



Design Considerations

- Accumulation of Metals
- Clogged Soil Outlet Structures
- Vegetation/Landscape Maintenance

Description

An infiltration trench is a long, narrow, rock-filled trench with no outlet that receives stormwater runoff. Runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix. Infiltration trenches perform well for removal of fine sediment and associated pollutants. Pretreatment using buffer strips, swales, or detention basins is important for limiting amounts of coarse sediment entering the trench which can clog and render the trench ineffective.

California Experience

Caltrans constructed two infiltration trenches at highway maintenance stations in Southern California. Of these, one failed to operate to the design standard because of average soil infiltration rates lower than that measured in the single infiltration test. This highlights the critical need for appropriate evaluation of the site. Once in operation, little maintenance was required at either site.

Advantages

- Provides 100% reduction in the load discharged to surface waters.
- An important benefit of infiltration trenches is the approximation of pre-development hydrology during which a significant portion of the average annual rainfall runoff is infiltrated rather than flushed directly to creeks.
- If the water quality volume is adequately sized, infiltration trenches can be useful for providing control of channel forming (erosion) and high frequency (generally less than the 2-year) flood events.

Targeted Constituents

- | | |
|------------------|---|
| ✓ Sediment | ■ |
| ✓ Nutrients | ■ |
| ✓ Trash | ■ |
| ✓ Metals | ■ |
| ✓ Bacteria | ■ |
| ✓ Oil and Grease | ■ |
| ✓ Organics | ■ |

Legend (Removal Effectiveness)

- | | |
|----------|--------|
| ● Low | ■ High |
| ▲ Medium | |



- As an underground BMP, trenches are unobtrusive and have little impact of site aesthetics.

Limitations

- Have a high failure rate if soil and subsurface conditions are not suitable.
- May not be appropriate for industrial sites or locations where spills may occur.
- The maximum contributing area to an individual infiltration practice should generally be less than 5 acres.
- Infiltration basins require a minimum soil infiltration rate of 0.5 inches/hour, not appropriate at sites with Hydrologic Soil Types C and D.
- If infiltration rates exceed 2.4 inches/hour, then the runoff should be fully treated prior to infiltration to protect groundwater quality.
- Not suitable on fill sites or steep slopes.
- Risk of groundwater contamination in very coarse soils.
- Upstream drainage area must be completely stabilized before construction.
- Difficult to restore functioning of infiltration trenches once clogged.

Design and Sizing Guidelines

- Provide pretreatment for infiltration trenches in order to reduce the sediment load. Pretreatment refers to design features that provide settling of large particles before runoff reaches a management practice, easing the long-term maintenance burden. Pretreatment is important for all structural stormwater management practices, but it is particularly important for infiltration practices. To ensure that pretreatment mechanisms are effective, designers should incorporate practices such as grassed swales, vegetated filter strips, detention, or a plunge pool in series.
- Specify locally available trench rock that is 1.5 to 2.5 inches in diameter.
- Determine the trench volume by assuming the WQV will fill the void space based on the computed porosity of the rock matrix (normally about 35%).
- Determine the bottom surface area needed to drain the trench within 72 hr by dividing the WQV by the infiltration rate.

$$d = \frac{WQV + RFV}{SA}$$

- Calculate trench depth using the following equation:

where:

D = Trench depth

WQV	=	Water quality volume
RFV	=	Rock fill volume
SA	=	Surface area of the trench bottom

- The use of vertical piping, either for distribution or infiltration enhancement shall not be allowed to avoid device classification as a Class V injection well per 40 CFR146.5(e)(4).
- Provide observation well to allow observation of drain time.
- May include a horizontal layer of filter fabric just below the surface of the trench to retain sediment and reduce the potential for clogging.

Construction/Inspection Considerations

Stabilize the entire area draining to the facility before construction begins. If impossible, place a diversion berm around the perimeter of the infiltration site to prevent sediment entrance during construction. Stabilize the entire contributing drainage area before allowing any runoff to enter once construction is complete.

Performance

Infiltration trenches eliminate the discharge of the water quality volume to surface receiving waters and consequently can be considered to have 100% removal of all pollutants within this volume. Transport of some of these constituents to groundwater is likely, although the attenuation in the soil and subsurface layers will be substantial for many constituents.

Infiltration trenches can be expected to remove up to 90 percent of sediments, metals, coliform bacteria and organic matter, and up to 60 percent of phosphorus and nitrogen in the infiltrated runoff (Schueler, 1992). Biochemical oxygen demand (BOD) removal is estimated to be between 70 to 80 percent. Lower removal rates for nitrate, chlorides and soluble metals should be expected, especially in sandy soils (Schueler, 1992). Pollutant removal efficiencies may be improved by using washed aggregate and adding organic matter and loam to the subsoil. The stone aggregate should be washed to remove dirt and fines before placement in the trench. The addition of organic material and loam to the trench subsoil may enhance metals removal through adsorption.

Siting Criteria

The use of infiltration trenches may be limited by a number of factors, including type of native soils, climate, and location of groundwater table. Site characteristics, such as excessive slope of the drainage area, fine-grained soil types, and proximate location of the water table and bedrock, may preclude the use of infiltration trenches. Generally, infiltration trenches are not suitable for areas with relatively impermeable soils containing clay and silt or in areas with fill.

As with any infiltration BMP, the potential for groundwater contamination must be carefully considered, especially if the groundwater is used for human consumption or agricultural purposes. The infiltration trench is not suitable for sites that use or store chemicals or hazardous materials unless hazardous and toxic materials are prevented from entering the trench. In these areas, other BMPs that do not allow interaction with the groundwater should be considered.

The potential for spills can be minimized by aggressive pollution prevention measures. Many municipalities and industries have developed comprehensive spill prevention control and countermeasure (SPCC) plans. These plans should be modified to include the infiltration trench and the contributing drainage area. For example, diversion structures can be used to prevent spills from entering the infiltration trench. Because of the potential to contaminate groundwater, extensive site investigation must be undertaken early in the site planning process to establish site suitability for the installation of an infiltration trench.

Longevity can be increased by careful geotechnical evaluation prior to construction and by designing and implementing an inspection and maintenance plan. Soil infiltration rates and the water table depth should be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration trench. Pretreatment structures, such as a vegetated buffer strip or water quality inlet, can increase longevity by removing sediments, hydrocarbons, and other materials that may clog the trench. Regular maintenance, including the replacement of clogged aggregate, will also increase the effectiveness and life of the trench.

Evaluation of the viability of a particular site is the same as for infiltration basins and includes:

- Determine soil type (consider RCS soil type 'A, B or C' only) from mapping and consult USDA soil survey tables to review other parameters such as the amount of silt and clay, presence of a restrictive layer or seasonal high water table, and estimated permeability. The soil should not have more than 30 percent clay or more than 40 percent of clay and silt combined. Eliminate sites that are clearly unsuitable for infiltration.
- Groundwater separation should be at least 3 m from the basin invert to the measured ground water elevation. There is concern at the state and regional levels of the impact on groundwater quality from infiltrated runoff, especially when the separation between groundwater and the surface is small.
- Location away from buildings, slopes and highway pavement (greater than 6 m) and wells and bridge structures (greater than 30 m). Sites constructed of fill, having a base flow or with a slope greater than 15 percent should not be considered.
- Ensure that adequate head is available to operate flow splitter structures (to allow the basin to be offline) without ponding in the splitter structure or creating backwater upstream of the splitter.
- Base flow should not be present in the tributary watershed.

Secondary Screening Based on Site Geotechnical Investigation

- At least three in-hole conductivity tests shall be performed using USBR 7300-89 or Bouwer-Rice procedures (the latter if groundwater is encountered within the boring), two tests at different locations within the proposed basin and the third down gradient by no more than approximately 10 m. The tests shall measure permeability in the side slopes and the bed within a depth of 3 m of the invert.
- The minimum acceptable hydraulic conductivity as measured in any of the three required test holes is 13 mm/hr. If any test hole shows less than the minimum value, the site should be disqualified from further consideration.

- Exclude from consideration sites constructed in fill or partially in fill unless no silts or clays are present in the soil boring. Fill tends to be compacted, with clays in a dispersed rather than flocculated state, greatly reducing permeability.
- The geotechnical investigation should be such that a good understanding is gained as to how the stormwater runoff will move in the soil (horizontally or vertically) and if there are any geological conditions that could inhibit the movement of water.

Maintenance

Infiltration trenches required the least maintenance of any of the BMPs evaluated in the Caltrans study, with approximately 17 field hours spent on the operation and maintenance of each site. Inspection of the infiltration trench was the largest field activity, requiring approximately 8 hr/yr.

In addition to reduced water quality performance, clogged infiltration trenches with surface standing water can become a nuisance due to mosquito breeding. If the trench takes more than 72 hours to drain, then the rock fill should be removed and all dimensions of the trench should be increased by 2 inches to provide a fresh surface for infiltration.

Cost

Construction Cost

Infiltration trenches are somewhat expensive, when compared to other stormwater practices, in terms of cost per area treated. Typical construction costs, including contingency and design costs, are about \$5 per ft³ of stormwater treated (SWRPC, 1991; Brown and Schueler, 1997). Actual construction costs may be much higher. The average construction cost of two infiltration trenches installed by Caltrans in southern California was about \$50/ft³; however, these were constructed as retrofit installations.

Infiltration trenches typically consume about 2 to 3 percent of the site draining to them, which is relatively small. In addition, infiltration trenches can fit into thin, linear areas. Thus, they can generally fit into relatively unusable portions of a site.

Maintenance Cost

One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly sited or maintained, infiltration trenches have a high failure rate. In general, maintenance costs for infiltration trenches are estimated at between 5 percent and 20 percent of the construction cost. More realistic values are probably closer to the 20-percent range, to ensure long-term functionality of the practice.

References and Sources of Additional Information

Caltrans, 2002, BMP Retrofit Pilot Program Proposed Final Report, Rpt. CTSW-RT-01-050, California Dept. of Transportation, Sacramento, CA.

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection, Ellicott City, MD.

Galli, J. 1992. *Analysis of Urban BMP Performance and Longevity in Prince George's County, Maryland*. Metropolitan Washington Council of Governments, Washington, DC.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual*. <http://www.mde.state.md.us/environment/wma/stormwatermanual>. Accessed May 22, 2001.

Metzger, M. E., D. F. Messer, C. L. Beitia, C. M. Myers, and V. L. Kramer. 2002. The Dark Side Of Stormwater Runoff Management: Disease Vectors Associated With Structural BMPs. *Stormwater* 3(2): 24-39.

Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments, Washington, DC.

Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. *Costs of Urban Nonpoint Source Water Pollution Control Measures*. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency, Office of Water, Washington, DC.

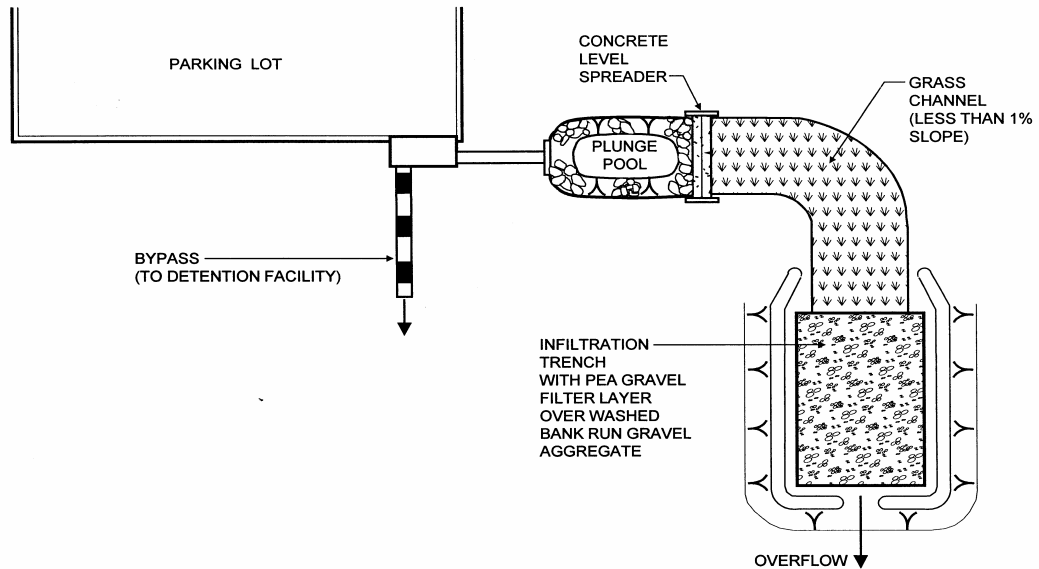
Information Resources

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for the U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC, by the Center for Watershed Protection, Ellicott City, MD.

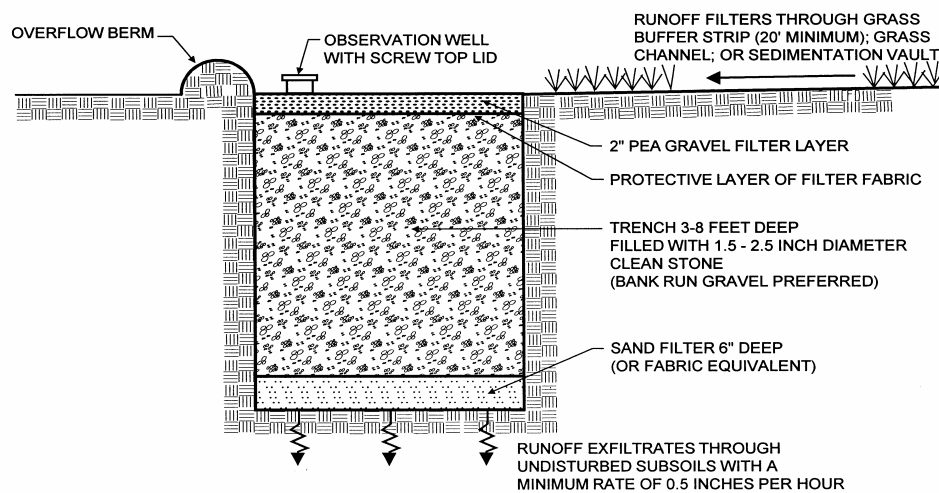
Ferguson, B.K. 1994. *Stormwater Infiltration*. CRC Press, Ann Arbor, MI.

Minnesota Pollution Control Agency. 1989. *Protecting Water Quality in Urban Areas: Best Management Practices*. Minnesota Pollution Control Agency, Minneapolis, MN.

USEPA. 1993. *Guidance to Specify Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.



PLAN VIEW



SECTION



Description

An infiltration basin is a shallow impoundment that is designed to infiltrate stormwater. Infiltration basins use the natural filtering ability of the soil to remove pollutants in stormwater runoff. Infiltration facilities store runoff until it gradually exfiltrates through the soil and eventually into the water table. This practice has high pollutant removal efficiency and can also help recharge groundwater, thus helping to maintain low flows in stream systems. Infiltration basins can be challenging to apply on many sites, however, because of soils requirements. In addition, some studies have shown relatively high failure rates compared with other management practices.

California Experience

Infiltration basins have a long history of use in California, especially in the Central Valley. Basins located in Fresno were among those initially evaluated in the National Urban Runoff Program and were found to be effective at reducing the volume of runoff, while posing little long-term threat to groundwater quality (EPA, 1983; Schroeder, 1995). Proper siting of these devices is crucial as underscored by the experience of Caltrans in siting two basins in Southern California. The basin with marginal separation from groundwater and soil permeability failed immediately and could never be rehabilitated.

Advantages

- Provides 100% reduction in the load discharged to surface waters.
- The principal benefit of infiltration basins is the approximation of pre-development hydrology during which a

Design Considerations

- Soil for Infiltration
- Slope
- Aesthetics

Targeted Constituents

- ✓ Sediment ■
- ✓ Nutrients ■
- ✓ Trash ■
- ✓ Metals ■
- ✓ Bacteria ■
- ✓ Oil and Grease ■
- ✓ Organics ■

Legend (Removal Effectiveness)

- Low
- High
- ▲ Medium



significant portion of the average annual rainfall runoff is infiltrated and evaporated rather than flushed directly to creeks.

- If the water quality volume is adequately sized, infiltration basins can be useful for providing control of channel forming (erosion) and high frequency (generally less than the 2-year) flood events.

Limitations

- May not be appropriate for industrial sites or locations where spills may occur.
- Infiltration basins require a minimum soil infiltration rate of 0.5 inches/hour, not appropriate at sites with Hydrologic Soil Types C and D.
- If infiltration rates exceed 2.4 inches/hour, then the runoff should be fully treated prior to infiltration to protect groundwater quality.
- Not suitable on fill sites or steep slopes.
- Risk of groundwater contamination in very coarse soils.
- Upstream drainage area must be completely stabilized before construction.
- Difficult to restore functioning of infiltration basins once clogged.

Design and Sizing Guidelines

- Water quality volume determined by local requirements or sized so that 85% of the annual runoff volume is captured.
- Basin sized so that the entire water quality volume is infiltrated within 48 hours.
- Vegetation establishment on the basin floor may help reduce the clogging rate.

Construction/Inspection Considerations

- Before construction begins, stabilize the entire area draining to the facility. If impossible, place a diversion berm around the perimeter of the infiltration site to prevent sediment entrance during construction or remove the top 2 inches of soil after the site is stabilized. Stabilize the entire contributing drainage area, including the side slopes, before allowing any runoff to enter once construction is complete.
- Place excavated material such that it can not be washed back into the basin if a storm occurs during construction of the facility.
- Build the basin without driving heavy equipment over the infiltration surface. Any equipment driven on the surface should have extra-wide (“low pressure”) tires. Prior to any construction, rope off the infiltration area to stop entrance by unwanted equipment.
- After final grading, till the infiltration surface deeply.
- Use appropriate erosion control seed mix for the specific project and location.

Performance

As water migrates through porous soil and rock, pollutant attenuation mechanisms include precipitation, sorption, physical filtration, and bacterial degradation. If functioning properly, this approach is presumed to have high removal efficiencies for particulate pollutants and moderate removal of soluble pollutants. Actual pollutant removal in the subsurface would be expected to vary depending upon site-specific soil types. This technology eliminates discharge to surface waters except for the very largest storms; consequently, complete removal of all stormwater constituents can be assumed.

There remain some concerns about the potential for groundwater contamination despite the findings of the NURP and Nightingale (1975; 1987a,b,c; 1989). For instance, a report by Pitt et al. (1994) highlighted the potential for groundwater contamination from intentional and unintentional stormwater infiltration. That report recommends that infiltration facilities not be sited in areas where high concentrations are present or where there is a potential for spills of toxic material. Conversely, Schroeder (1995) reported that there was no evidence of groundwater impacts from an infiltration basin serving a large industrial catchment in Fresno, CA.

Siting Criteria

The key element in siting infiltration basins is identifying sites with appropriate soil and hydrogeologic properties, which is critical for long term performance. In one study conducted in Prince George's County, Maryland (Galli, 1992), all of the infiltration basins investigated clogged within 2 years. It is believed that these failures were for the most part due to allowing infiltration at sites with rates of less than 0.5 in/hr, basing siting on soil type rather than field infiltration tests, and poor construction practices that resulted in soil compaction of the basin invert.

A study of 23 infiltration basins in the Pacific Northwest showed better long-term performance in an area with highly permeable soils (Hilding, 1996). In this study, few of the infiltration basins had failed after 10 years. Consequently, the following guidelines for identifying appropriate soil and subsurface conditions should be rigorously adhered to.

- Determine soil type (consider RCS soil type 'A, B or C' only) from mapping and consult USDA soil survey tables to review other parameters such as the amount of silt and clay, presence of a restrictive layer or seasonal high water table, and estimated permeability. The soil should not have more than 30% clay or more than 40% of clay and silt combined. Eliminate sites that are clearly unsuitable for infiltration.
- Groundwater separation should be at least 3 m from the basin invert to the measured ground water elevation. There is concern at the state and regional levels of the impact on groundwater quality from infiltrated runoff, especially when the separation between groundwater and the surface is small.
- Location away from buildings, slopes and highway pavement (greater than 6 m) and wells and bridge structures (greater than 30 m). Sites constructed of fill, having a base flow or with a slope greater than 15% should not be considered.
- Ensure that adequate head is available to operate flow splitter structures (to allow the basin to be offline) without ponding in the splitter structure or creating backwater upstream of the splitter.

- Base flow should not be present in the tributary watershed.

Secondary Screening Based on Site Geotechnical Investigation

- At least three in-hole conductivity tests shall be performed using USBR 7300-89 or Bouwer-Rice procedures (the latter if groundwater is encountered within the boring), two tests at different locations within the proposed basin and the third down gradient by no more than approximately 10 m. The tests shall measure permeability in the side slopes and the bed within a depth of 3 m of the invert.
- The minimum acceptable hydraulic conductivity as measured in any of the three required test holes is 13 mm/hr. If any test hole shows less than the minimum value, the site should be disqualified from further consideration.
- Exclude from consideration sites constructed in fill or partially in fill unless no silts or clays are present in the soil boring. Fill tends to be compacted, with clays in a dispersed rather than flocculated state, greatly reducing permeability.
- The geotechnical investigation should be such that a good understanding is gained as to how the stormwater runoff will move in the soil (horizontally or vertically) and if there are any geological conditions that could inhibit the movement of water.

Additional Design Guidelines

- (1) Basin Sizing - The required water quality volume is determined by local regulations or sufficient to capture 85% of the annual runoff.
- (2) Provide pretreatment if sediment loading is a maintenance concern for the basin.
- (3) Include energy dissipation in the inlet design for the basins. Avoid designs that include a permanent pool to reduce opportunity for standing water and associated vector problems.
- (4) Basin invert area should be determined by the equation:

$$A = \frac{WQV}{kt}$$

where A = Basin invert area (m²)

WQV = water quality volume (m³)

k = 0.5 times the lowest field-measured hydraulic conductivity (m/hr)

t = drawdown time (48 hr)

- (5) The use of vertical piping, either for distribution or infiltration enhancement shall not be allowed to avoid device classification as a Class V injection well per 40 CFR146.5(e)(4).

Maintenance

Regular maintenance is critical to the successful operation of infiltration basins. Recommended operation and maintenance guidelines include:

- Inspections and maintenance to ensure.
- Observe drain time for the design storm after completion or modification of the facility to confirm that the desired drain time has been obtained.
- Schedule semiannual inspections for beginning and end of the wet season to identify potential problems such as erosion of the basin side slopes and invert, standing water, trash and debris, and sediment accumulation.
- Remove accumulated trash and debris in the basin at the start and end of the wet season.
- Inspect for standing water at the end of the wet season.
- Trim vegetation at the beginning and end of the wet season to prevent establishment of woody vegetation and for aesthetic and vector reasons.
- Remove accumulated sediment and regrade when the accumulated sediment volume exceeds 10% of the basin.
- If erosion is occurring within the basin, revegetate immediately and stabilize with an erosion control mulch or mat until vegetation cover is established.
- To avoid reversing soil development, scarification or other disturbance should only be performed when there are actual signs of clogging, rather than on a routine basis. Always remove deposited sediments before scarification, and use a hand-guided rotary tiller, if possible, or a disc harrow pulled by a very light tractor.

Cost

Infiltration basins are relatively cost-effective practices because little infrastructure is needed when constructing them. One study estimated the total construction cost at about \$2 per ft (adjusted for inflation) of storage for a 0.25-acre basin (SWRPC, 1991). As with other BMPs, these published cost estimates may deviate greatly from what might be incurred at a specific site. For instance, Caltrans spent about \$18/ft³ for the two infiltration basins constructed in southern California, each of which had a water quality volume of about 0.34 ac.-ft. Much of the higher cost can be attributed to changes in the storm drain system necessary to route the runoff to the basin locations.

Infiltration basins typically consume about 2 to 3% of the site draining to them, which is relatively small. Additional space may be required for buffer, landscaping, access road, and fencing. Maintenance costs are estimated at 5 to 10% of construction costs.

One cost concern associated with infiltration practices is the maintenance burden and longevity. If improperly maintained, infiltration basins have a high failure rate. Thus, it may be necessary to replace the basin with a different technology after a relatively short period of time.

References and Sources of Additional Information

- Caltrans, 2002, BMP Retrofit Pilot Program Proposed Final Report, Rpt. CTSW-RT-01-050, California Dept. of Transportation, Sacramento, CA.
- Galli, J. 1992. *Analysis of Urban BMP Performance and Longevity in Prince George's County, Maryland*. Metropolitan Washington Council of Governments, Washington, DC.
- Hilding, K. 1996. Longevity of infiltration basins assessed in Puget Sound. *Watershed Protection Techniques* 1(3):124–125.
- Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual*. <http://www.mde.state.md.us/environment/wma/stormwatermanual>. Accessed May 22, 2002.
- Nightingale, H.I., 1975, "Lead, Zinc, and Copper in Soils of Urban Storm-Runoff Retention Basins," *American Water Works Assoc. Journal*. Vol. 67, p. 443-446.
- Nightingale, H.I., 1987a, "Water Quality beneath Urban Runoff Water Management Basins," *Water Resources Bulletin*, Vol. 23, p. 197-205.
- Nightingale, H.I., 1987b, "Accumulation of As, Ni, Cu, and Pb in Retention and Recharge Basin Soils from Urban Runoff," *Water Resources Bulletin*, Vol. 23, p. 663-672.
- Nightingale, H.I., 1987c, "Organic Pollutants in Soils of Retention/Recharge Basins Receiving Urban Runoff Water," *Soil Science* Vol. 148, pp. 39-45.
- Nightingale, H.I., Harrison, D., and Salo, J.E., 1985, "An Evaluation Technique for Groundwater Quality Beneath Urban Runoff Retention and Percolation Basins," *Ground Water Monitoring Review*, Vol. 5, No. 1, pp. 43-50.
- Oberts, G. 1994. Performance of Stormwater Ponds and Wetlands in Winter. *Watershed Protection Techniques* 1(2): 64–68.
- Pitt, R., et al. 1994, *Potential Groundwater Contamination from Intentional and Nonintentional Stormwater Infiltration*, EPA/600/R-94/051, Risk Reduction Engineering Laboratory, U.S. EPA, Cincinnati, OH.
- Schueler, T. 1987. *Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs*. Metropolitan Washington Council of Governments, Washington, DC.
- Schroeder, R.A., 1995, *Potential For Chemical Transport Beneath a Storm-Runoff Recharge (Retention) Basin for an Industrial Catchment in Fresno, CA*, USGS Water-Resource Investigations Report 93-4140.
- Southeastern Wisconsin Regional Planning Commission (SWRPC). 1991. *Costs of Urban Nonpoint Source Water Pollution Control Measures*. Southeastern Wisconsin Regional Planning Commission, Waukesha, WI.
- U.S. EPA, 1983, *Results of the Nationwide Urban Runoff Program: Volume 1 – Final Report*, WH-554, Water Planning Division, Washington, DC.

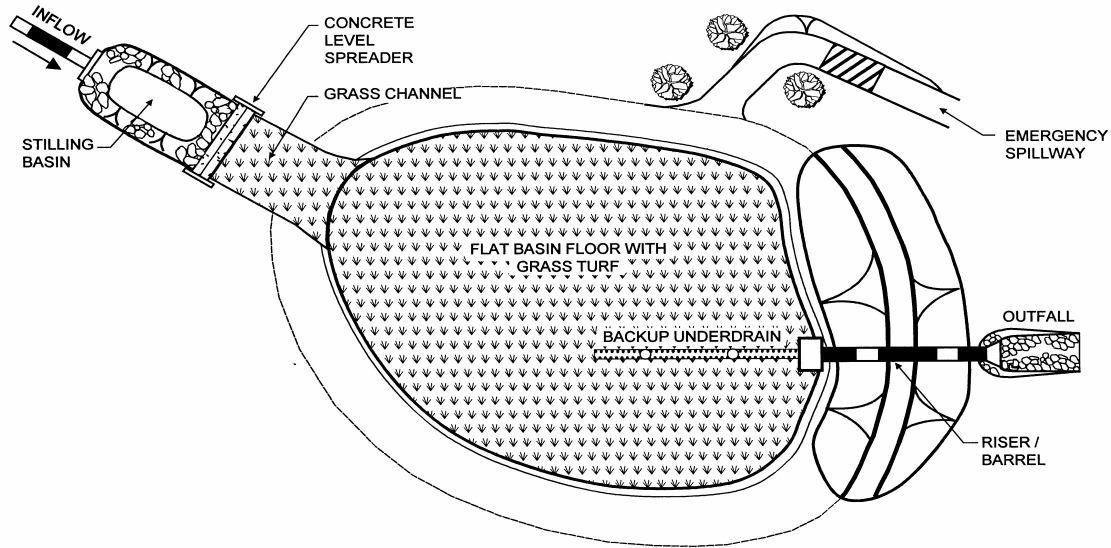
Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency Office of Water, Washington, DC.

Information Resources

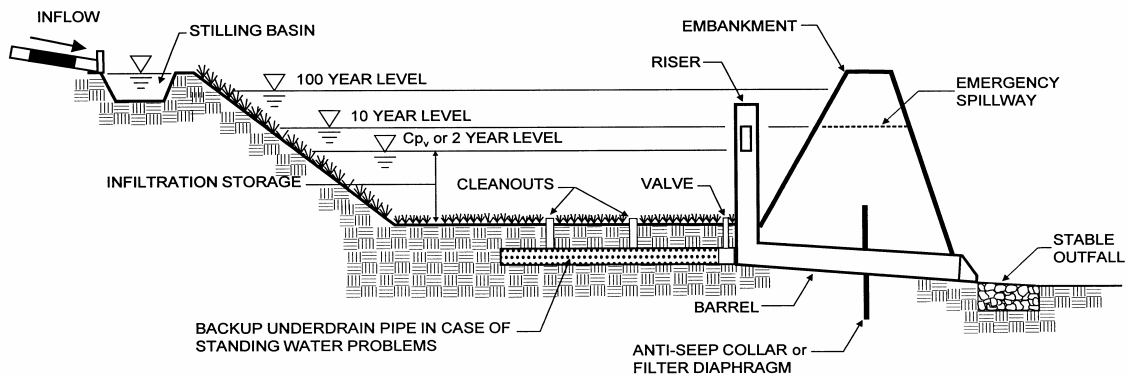
Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for U.S. Environmental Protection Agency Office of Wetlands, Oceans and Watersheds. Washington, DC.

Ferguson, B.K., 1994. *Stormwater Infiltration*. CRC Press, Ann Arbor, MI.

USEPA. 1993. *Guidance to Specify Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.



PLAN VIEW



PROFILE

Description

Retention/irrigation refers to the capture of stormwater runoff in a holding pond and subsequent use of the captured volume for irrigation of landscape or natural pervious areas. This technology is very effective as a stormwater quality practice in that, for the captured water quality volume, it provides virtually no discharge to receiving waters and high stormwater constituent removal efficiencies. This technology mimics natural undeveloped watershed conditions wherein the vast majority of the rainfall volume during smaller rainfall events is infiltrated through the soil profile. Their main advantage over other infiltration technologies is the use of an irrigation system to spread the runoff over a larger area for infiltration. This allows them to be used in areas with low permeability soils.

Capture of stormwater can be accomplished in almost any kind of runoff storage facility, ranging from dry, concrete-lined ponds to those with vegetated basins and permanent pools. The pump and wet well should be automated with a rainfall sensor to provide irrigation only during periods when required infiltration rates can be realized. Generally, a spray irrigation system is required to provide an adequate flow rate for distributing the water quality volume (LCRA, 1998). Collection of roof runoff for subsequent use (rainwater harvesting) also qualifies as a retention/irrigation practice.

This technology is still in its infancy and there are no published reports on its effectiveness, cost, or operational requirements. The guidelines presented below should be considered tentative until additional data are available.

California Experience

This BMP has never been implemented in California, only in the Austin, Texas area. The use there is limited to watersheds where no increase in pollutant load is allowed because of the sensitive nature of the watersheds.

Advantages

- Pollutant removal effectiveness is high, accomplished primarily by: (1) sedimentation in the primary storage facility; (2) physical filtration of particulates through the soil profile; (3) dissolved constituents uptake in the vegetative root zone by the soil-resident microbial community.
- The hydrologic characteristics of this technique are effective for simulating pre-developed watershed conditions through: (1) containment of higher frequency flood volumes (less than about a 2-year event); and (2) reduction of flow rates and velocities

Design Considerations

- Soil for Infiltration
- Area Required
- Slope
- Environmental Side-effects

Targeted Constituents

✓ Sediment	■
✓ Nutrients	■
✓ Trash	■
✓ Metals	■
✓ Bacteria	■
✓ Oil and Grease	■
✓ Organics	■

Legend (Removal Effectiveness)

- Low
- High
- ▲ Medium



for erosive flow events.

- Pollutant removal rates are estimated to be nearly 100% for all pollutants in the captured and irrigated stormwater volume. However, relatively frequent inspection and maintenance is necessary to assure proper operation of these facilities.
- This technology is particularly appropriate for areas with infrequent rainfall because the system is not required to operate often and the ability to provide stormwater for irrigation can reduce demand on surface and groundwater supplies.

Limitations

- Retention-irrigation is a relatively expensive technology due primarily to mechanical systems, power requirements, and high maintenance needs.
- Due to the relative complexity of irrigation systems, they must be inspected and maintained at regular intervals to ensure reliable system function.
- Retention-irrigation systems use pumps requiring electrical energy inputs (which cost money, create pollution, and can be interrupted). Mechanical systems are also more complex, requiring skilled maintenance, and they are more vulnerable to vandalism than simpler, passive systems.
- Retention-irrigation systems require open space for irrigation and thus may be difficult to retrofit in urban areas.
- Effective use of retention irrigation requires some form of pre-treatment of runoff flows (i.e., sediment forebay or vegetated filter) to remove coarse sediment and to protect the long-term operating capacity of the irrigation equipment.
- Retention/irrigation BMPs capture and store water that, depending on design may be accessible to mosquitoes and other vectors for breeding.

Design and Sizing Guidelines

- Runoff Storage Facility Configuration and Sizing - Design of the runoff storage facility is flexible as long as the water quality volume and an appropriate pump and wet well system can be accommodated.
- Pump and Wet Well System - A reliable pump, wet well, and rainfall or soil moisture sensor system should be used to distribute the water quality volume. These systems should be similar to those used for wastewater effluent irrigation, which are commonly used in areas where “no discharge” wastewater treatment plant permits are issued.
- Detention Time - The irrigation schedule should allow for complete drawdown of the water quality volume within 72 hours. Irrigation should not begin within 12 hours of the end of rainfall so that direct storm runoff has ceased and soils are not saturated. Consequently, the length of the active irrigation period is 60 hours. The irrigation should include a cycling factor of $\frac{1}{2}$, so that each portion of the area will be irrigated for only 30 hours during the total of 60 hours allowed for disposal of the water quality volume. Irrigation also should not occur during subsequent rainfall events.

- Irrigation System - Generally a spray irrigation system is required to provide an adequate flow rate for timely distribution of the water quality volume.
- Designs that utilize covered water storage should be accessible to vector control personnel via access doors to facilitate vector surveillance and control if needed.
- Irrigation Site Criteria – The area selected for irrigation must be pervious, on slopes of less than 10%. A geological assessment is required for proposed irrigation areas to assure that there is a minimum of 12 inches of soil cover. Rocky soils are acceptable for irrigation; however, the coarse material (diameter greater than 0.5 inches) should not account for more than 30% of the soil volume. Optimum sites for irrigation include recreational and greenbelt areas as well as landscaping in commercial developments. The stormwater irrigation area should be distinct and different from any areas used for wastewater effluent irrigation. Finally, the area designated for irrigation should have at least a 100-foot buffer from wells, septic systems, and natural wetlands.
- Irrigation Area – The irrigation rate must be low enough so that the irrigation does not produce any surface runoff; consequently, the irrigation rate may not exceed the permeability of the soil. The minimum required irrigation area should be calculated using the following formula:

$$A = \frac{12 \times V}{T \times r}$$

where:

A = area required for irrigation (ft²)

V = water quality volume (ft³)

T = period of active irrigation (30 hr)

r = Permeability (in/hr)

- The permeability of the soils in the area proposed for irrigation should be determined using a double ring infiltrometer (ASTM D 3385-94) or from county soil surveys prepared by the Natural Resource Conservation Service. If a range of permeabilities is reported, the average value should be used in the calculation. If no permeability data is available, a value of 0.1 inches/hour should be assumed.
- It should be noted that the minimum area requires intermittent irrigation over a period of 60 hours at low rates to use the entire water quality volume. This intensive irrigation may be harmful to vegetation that is not adapted to long periods of wet conditions. In practice, a much larger irrigation area will provide better use of the retained water and promote a healthy landscape.

Performance

This technology is still in its infancy and there are no published reports on its effectiveness, cost, or operational requirements.

Siting Criteria

Capture of stormwater can be accomplished in almost any kind of runoff storage facility, ranging from dry, concrete-lined ponds to those with vegetated basins and permanent pools. Siting is contingent upon the type of facility used.

Additional Design Guidelines

This technology is still in its infancy and there are no published reports on its effectiveness, cost, or operational requirements.

Maintenance

Relatively frequent inspection and maintenance is necessary to verify proper operation of these facilities. Some maintenance concerns are specific to the type or irrigation system practice used.

BMPs that store water can become a nuisance due to mosquito and other vector breeding. Preventing mosquito access to standing water sources in BMPs (particularly below-ground) is the best prevention plan, but can prove challenging due to multiple entrances and the need to maintain the hydraulic integrity of the system. Reliance on electrical pumps is prone to failure and in some designs (e.g., sumps, vaults) may not provide complete dewatering, both which increase the chances of water standing for over 72 hours and becoming a breeding place for vectors. BMPs that hold water for over 72 hours and/or rely on electrical or mechanical devices to dewater may require routine inspections and treatments by local mosquito and vector control agencies to suppress mosquito production. Open storage designs such as ponds and basins (see appropriate fact sheets) will require routine preventative maintenance plans and may also require routine inspections and treatments by local mosquito and vector control agencies.

Cost

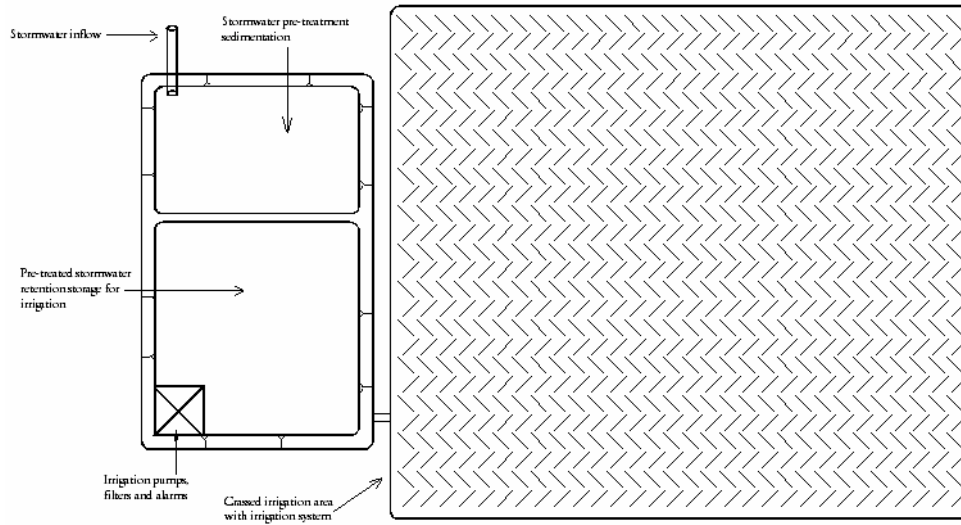
This technology is still in its infancy and there are no published reports on its effectiveness, cost, or operational requirements. However, O&M costs for retention-irrigation systems are high compared to virtually all other stormwater quality control practices because of the need for: (1) frequent inspections; (2) the reliance on mechanical equipment; and (3) power costs.

References and Sources of Additional Information

Barrett, M., 1999, *Complying with the Edwards Aquifer Rules: Technical Guidance on Best Management Practices*, Texas Natural Resource Conservation Commission Report RG-348. <http://www.tnrcc.state.tx.us/admin/topdoc/rg/348/index.html>

Lower-Colorado River Authority (LCRA), 1998, *Nonpoint Source Pollution Control Technical Manual*, Austin, TX.

Metzger, M. E., D. F. Messer, C. L. Beitia, C. M. Myers, and V. L. Kramer. 2002. The dark side of stormwater runoff management: disease vectors associated with structural BMPs. *Stormwater* 3(2): 24-39.





Design Considerations

- Area Required
- Slope
- Water Availability
- Aesthetics
- Environmental Side-effects

Description

Wet ponds (a.k.a. stormwater ponds, retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season) and differ from constructed wetlands primarily in having a greater average depth. Ponds treat incoming stormwater runoff by settling and biological uptake. The primary removal mechanism is settling as stormwater runoff resides in this pool, but pollutant uptake, particularly of nutrients, also occurs to some degree through biological activity in the pond. Wet ponds are among the most widely used stormwater practices. While there are several different versions of the wet pond design, the most common modification is the extended detention wet pond, where storage is provided above the permanent pool in order to detain stormwater runoff and promote settling. The schematic diagram is of an on-line pond that includes detention for larger events, but this is not required in all areas of the state.

California Experience

Caltrans constructed a wet pond in northern San Diego County (I-5 and La Costa Blvd.). Largest issues at this site were related to vector control, vegetation management, and concern that endangered species would become resident and hinder maintenance activities.

Advantages

- If properly designed, constructed and maintained, wet basins can provide substantial aesthetic/recreational value and wildlife and wetlands habitat.
- Ponds are often viewed as a public amenity when integrated into a park setting.

Targeted Constituents

✓	Sediment	■
✓	Nutrients	▲
✓	Trash	■
✓	Metals	■
✓	Bacteria	■
✓	Oil and Grease	■
✓	Organics	■

Legend (Removal Effectiveness)

- Low
- High
- ▲ Medium



- Due to the presence of the permanent wet pool, properly designed and maintained wet basins can provide significant water quality improvement across a relatively broad spectrum of constituents including dissolved nutrients.
- Widespread application with sufficient capture volume can provide significant control of channel erosion and enlargement caused by changes to flow frequency relationships resulting from the increase of impervious cover in a watershed.

Limitations

- Some concern about safety when constructed where there is public access.
- Mosquito and midge breeding is likely to occur in ponds.
- Cannot be placed on steep unstable slopes.
- Need for base flow or supplemental water if water level is to be maintained.
- Require a relatively large footprint
- Depending on volume and depth, pond designs may require approval from the State Division of Safety of Dams

Design and Sizing Guidelines

- Capture volume determined by local requirements or sized to treat 85% of the annual runoff volume.
- Use a draw down time of 48 hours in most areas of California. Draw down times in excess of 48 hours may result in vector breeding, and should be used only after coordination with local vector control authorities. Draw down times of less than 48 hours should be limited to BMP drainage areas with coarse soils that readily settle and to watersheds where warming may be detrimental to downstream fisheries.
- Permanent pool volume equal to twice the water quality volume.
- Water depth not to exceed about 8 feet.
- Wetland vegetation occupying no more than 25% of surface area.
- Include energy dissipation in the inlet design and a sediment forebay to reduce resuspension of accumulated sediment and facilitate maintenance.
- A maintenance ramp should be included in the design to facilitate access to the forebay for maintenance activities and for vector surveillance and control.
- To facilitate vector surveillance and control activities, road access should be provided along at least one side of BMPs that are seven meters or less in width. Those BMPs that have shoreline-to-shoreline distances in excess of seven meters should have perimeter road access on both sides or be designed such that no parcel of water is greater than seven meters from the road.

Construction/Inspection Considerations

- In areas with porous soils an impermeable liner may be required to maintain an adequate permanent pool level.
- Outlet structures and piping should be installed with collars to prevent water from seeping through the fill and causing structural failure.
- Inspect facility after first large storm to determine whether the desired residence time has been achieved.

Performance

The observed pollutant removal of a wet pond is highly dependent on two factors: the volume of the permanent pool relative to the amount of runoff from the typical event in the area and the quality of the base flow that sustains the permanent pool. A recent study (Caltrans, 2002) has documented that if the permanent pool is much larger than the volume of runoff from an average event, then displacement of the permanent pool by the wet weather flow is the primary process. A statistical comparison of the wet pond discharge quality during dry and wet weather shows that they are not significantly different. Consequently, there is a relatively constant discharge quality during storms that is the same as the concentrations observed in the pond during ambient (dry weather) conditions. Consequently, for most constituents the performance of the pond is better characterized by the average effluent concentration, rather than the “percent reduction,” which has been the conventional measure of performance. Since the effluent quality is essentially constant, the percent reduction observed is mainly a function of the influent concentrations observed at a particular site.

The dry and wet weather discharge quality is, therefore, related to the quality of the base flow that sustains the permanent pool and of the transformations that occur to those constituents during their residence in the basin. One could potentially expect a wide range of effluent concentrations at different locations even if the wet ponds were designed according to the same guidelines, if the quality of the base flow differed significantly. This may explain the wide range of concentration reductions reported in various studies.

Concentrations of nutrients in base flow may be substantially higher than in urban stormwater runoff. Even though these concentrations may be substantially reduced during the residence time of the base flow in the pond, when this water is displaced by wet weather flows, concentrations may still be quite elevated compared to the levels that promote eutrophication in surface water systems. Consequently comparing influent and effluent nutrient concentrations during wet weather can make the performance seem highly variable.

Relatively small perennial flows may often substantially exceed the wet weather flow treated. Consequently, one should also consider the load reduction observed under ambient conditions when assessing the potential benefit to the receiving water.

Siting Criteria

Wet ponds are a widely applicable stormwater management practice and can be used over a broad range of storm frequencies and sizes, drainage areas and land use types. Although they have limited applicability in highly urbanized settings and in arid climates, they have few other restrictions. Wet basins may be constructed on- or off-line and can be sited at feasible locations along established drainage ways with consistent base flow. An off-line design is preferred. Wet basins are often utilized in smaller sub-watersheds and are particularly appropriate in areas with residential land

uses or other areas where high nutrient loads are considered to be potential problems (e.g., golf courses).

Ponds do not consume a large area (typically 2–3 percent of the contributing drainage area); however, these facilities are generally large. Other practices, such as filters or swales, may be "squeezed" into relatively unusable land, but ponds need a relatively large continuous area. Wet basins are typically used in drainage basins of more than ten acres and less than one square mile (Schueler et al., 1992). Emphasis can be placed in siting wet basins in areas where the pond can also function as an aesthetic amenity or in conjunction with other stormwater management functions.

Wet basin application is appropriate in the following settings: (1) where there is a need to achieve a reasonably high level of dissolved contaminant removal and/or sediment capture; (2) in small to medium-sized regional tributary areas with available open space and drainage areas greater than about 10 ha (25 ac.); (3) where base flow rates or other channel flow sources are relatively consistent year-round; (4) in residential settings where aesthetic and wildlife habitat benefits can be appreciated and maintenance activities are likely to be consistently undertaken.

Traditional wet extended detention ponds can be applied in most regions of the United States, with the exception of arid climates. In arid regions, it is difficult to justify the supplemental water needed to maintain a permanent pool because of the scarcity of water. Even in semi-arid Austin, Texas, one study found that 2.6 acre-feet per year of supplemental water was needed to maintain a permanent pool of only 0.29 acre-feet (Saunders and Gilroy, 1997). Seasonal wet ponds (i.e., ponds that maintain a permanent pool only during the wet season) may prove effective in areas with distinct wet and dry seasons; however, this configuration has not been extensively evaluated.

Wet ponds may pose a risk to cold water systems because of their potential for stream warming. When water remains in the permanent pool, it is heated by the sun. A study in Prince George's County, Maryland, found that stormwater wet ponds heat stormwater by about 9°F from the inlet to the outlet (Galli, 1990).

Additional Design Guidelines

Specific designs may vary considerably, depending on site constraints or preferences of the designer or community. There are several variations of the wet pond design, including constructed wetlands, and wet extended detention ponds. Some of these design alternatives are intended to make the practice adaptable to various sites and to account for regional constraints and opportunities. In conventional wet ponds, the open water area comprises 50% or more of the total surface area of the pond. The permanent pool should be no deeper than 2.5 m (8 feet) and should average 1.2 – 2 m (4-6 feet) deep. The greater depth of this configuration helps limit the extent of the vegetation to an aquatic bench around the perimeter of the pond with a nominal depth of about 1 foot and variable width. This shallow bench also protects the banks from erosion, enhances habitat and aesthetic values, and reduces the drowning hazard.

The wet extended detention pond combines the treatment concepts of the dry extended detention pond and the wet pond. In this design, the water quality volume is detained above the permanent pool and released over 24 hours. In addition to increasing the residence time, which improves pollutant removal, this design also attenuates peak runoff rates. Consequently, this design alternative is recommended.

Pretreatment incorporates design features that help to settle out coarse sediment particles. By removing these particles from runoff before they reach the large permanent pool, the maintenance burden of the pond is reduced. In ponds, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10 percent of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge the entire pond.

There are a variety of sizing criteria for determining the volume of the permanent pool, mostly related to the water quality volume (i.e., the volume of water treated for pollutant removal) or the average storm size in a particular area. In addition, several theoretical approaches to determination of permanent pool volume have been developed. However, there is little empirical evidence to support these designs. Consequently, a simplified method (i.e., permanent pool volume equal to twice the water quality volume) is recommended.

Other design features do not increase the volume of a pond, but can increase the amount of time stormwater remains in the device and eliminate short-circuiting. Ponds should always be designed with a length-to-width ratio of at least 1.5:1, where feasible. In addition, the design should incorporate features to lengthen the flow path through the pond, such as underwater berms designed to create a longer route through the pond. Combining these two measures helps ensure that the entire pond volume is used to treat stormwater. Wet ponds with greater amounts of vegetation often have channels through the vegetated areas and contain dead areas where stormwater is restricted from mixing with the entire permanent pool, which can lead to less pollutant removal. Consequently, a pond with open water comprising about 75% of the surface area is preferred.

Design features are also incorporated to ease maintenance of both the forebay and the main pool of ponds. Ponds should be designed with a maintenance access to the forebay to ease this relatively routine (every 5–7 year) maintenance activity. In addition, ponds should generally have a drain to draw down the pond for vegetation harvesting or the more infrequent dredging of the main cell of the pond.

Cold climates present many challenges to designers of wet ponds. The spring snowmelt may have a high pollutant load and a large volume to be treated. In addition, cold winters may cause freezing of the permanent pool or freezing at inlets and outlets. Finally, high salt concentrations in runoff resulting from road salting, and sediment loads from road sanding, may impact pond vegetation as well as reduce the storage and treatment capacity of the pond.

One option to deal with high pollutant loads and runoff volumes during the spring snowmelt is the use of a seasonally operated pond to capture snowmelt during the winter and retain the permanent pool during warmer seasons. In this option, proposed by Oberts (1994), the pond has two water quality outlets, both equipped with gate valves. In the summer, the lower outlet is closed. During the fall and throughout the winter, the lower outlet is opened to draw down the permanent pool. As the spring melt begins, the lower outlet is closed to provide detention for the melt event. The manipulation of this system requires some labor and vigilance; a careful maintenance agreement should be confirmed.

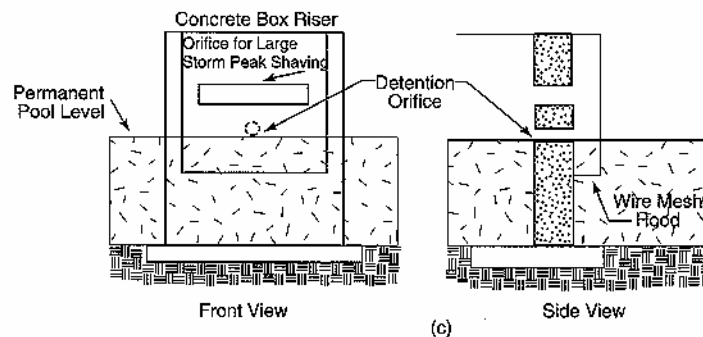
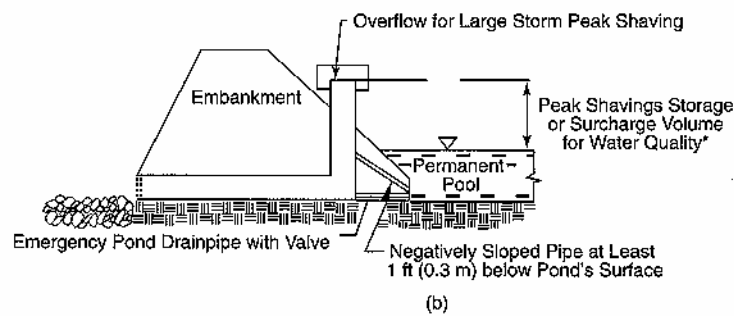
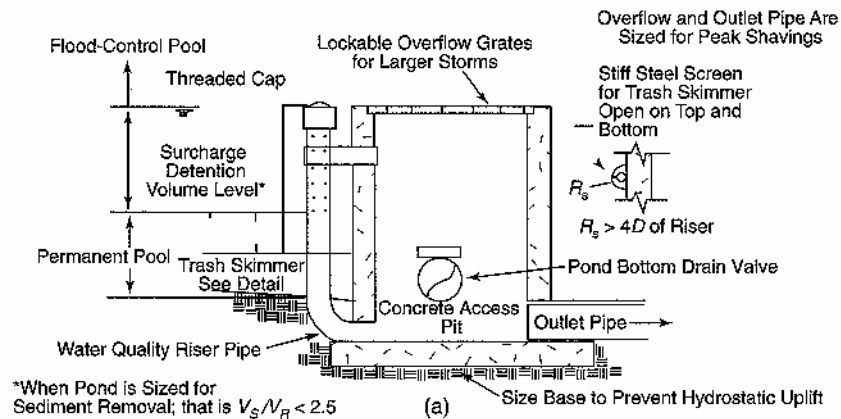
Several other modifications may help to improve the performance of ponds in cold climates. Designers should consider planting the pond with salt-tolerant vegetation if the facility receives road runoff. In order to counteract the effects of freezing on inlet and outlet structures, the use of inlet and outlet structures that are resistant to frost, including weirs and larger diameter pipes, may be

useful. Designing structures on-line, with a continuous flow of water through the pond, will also help prevent freezing of these structures. Finally, since freezing of the permanent pool can reduce the effectiveness of pond systems, it is important to incorporate extended detention into the design to retain usable treatment area above the permanent pool when it is frozen.

Summary of Design Recommendations

- (1) Facility Sizing – The basin should be sized to hold the permanent pool as well as the required water quality volume. The volume of the permanent pool should equal twice the water quality volume.
- (2) Pond Configuration - The wet basin should be configured as a two stage facility with a sediment forebay and a main pool. The basins should be wedge-shaped, narrowest at the inlet and widest at the outlet. The minimum length to width ratio should be 1.5 where feasible. The perimeter of all permanent pool areas with depths of 4.0 feet or greater should be surrounded by an aquatic bench. This bench should extend inward 5-10 feet from the perimeter of the permanent pool and should be no more than 18 inches below normal depth. The area of the bench should not exceed about 25% of pond surface. The depth in the center of the basin should be 4 – 8 feet deep to prevent vegetation from encroaching on the pond open water surface.
- (3) Pond Side Slopes - Side slopes of the basin should be 3:1 (H:V) or flatter for grass stabilized slopes. Slopes steeper than 3:1 should be stabilized with an appropriate slope stabilization practice.
- (4) Sediment Forebay - A sediment forebay should be used to isolate gross sediments as they enter the facility and to simplify sediment removal. The sediment forebay should consist of a separate cell formed by an earthen berm, gabion, or loose riprap wall. The forebay should be sized to contain 15 to 25% of the permanent pool volume and should be at least 3 feet deep. Exit velocities from the forebay should not be erosive. Direct maintenance access should be provided to the forebay. The bottom of the forebay may be hardened (concrete) to make sediment removal easier. A fixed vertical sediment depth marker should be installed in the forebay to measure sediment accumulation.
- (5) Outflow Structure - Figure 2 presents a schematic representation of suggested outflow structures. The outlet structure should be designed to drain the water quality volume over 24 hours with the orifice sized according to the equation presented in the Extended Detention Basin fact sheet. The facility should have a separate drain pipe with a manual valve that can completely or partially drain the pond for maintenance purposes. To allow for possible sediment accumulation, the submerged end of the pipe should be protected, and the drain pipe should be sized to drain the pond within 24 hours. The valve should be located at a point where it can be operated in a safe and convenient manner.

For on-line facilities, the principal and emergency spillways must be sized to provide 1.0 foot of freeboard during the 25-year event and to safely pass the 100-year flood. The embankment should be designed in accordance with all relevant specifications for small dams.



- (6) Splitter Box - When the pond is designed as an off-line facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the 25-year event while providing at least 1.0 foot of freeboard along pond side slopes.
- (7) Vegetation - A plan should be prepared that indicates how aquatic and terrestrial areas will be vegetatively stabilized. Wetland vegetation elements should be placed along the aquatic bench or in the shallow portions of the permanent pool. The optimal elevation for planting of wetland vegetation is within 6 inches vertically of the normal pool elevation. A list of some wetland vegetation native to California is presented in Table 1.

Botanical Name	Common Name
BACCHARIS SALICIFOLIA	MULE FAT
FRANKENIA GRANDIFOLIA	HEATH
SALIX GOODINGII	BLACK WILLOW
SALIX LASIOLEPIS	ARROYO WILLOW
SAMUCUS MEXICANUS	MEXICAN ELDERBERRY
HAPLOPAPPUS VENETUS	COAST GOLDENBRUSH
DISTICHIS SPICATA	SALT GRASS
LIMONIUM CALIFORNICUM	COASTAL STATICE
ATRIPLEX LENTIFORMIS	COASTAL QUAIL BUSH
BACCHARIS PILULARIS	CHAPARRAL BROOM
MIMULUS LONGIFLORUS	MONKEY FLOWER
SCIRPUS CALIFORNICUS	BULRUSH
SCIRPUS ROBUSTUS	BULRUSH
TYPHA LATIFOLIA	BROADLEAF CATTAIL
JUNCUS ACUTUS	RUSH

Maintenance

The amount of maintenance required for a wet pond is highly dependent on local regulatory agencies, particular health and vector control agencies. These agencies are often extremely concerned about the potential for mosquito breeding that may occur in the permanent pool. Even though mosquito fish (*Gambusia affinis*) were introduced into a wet pond constructed by Caltrans in the San Diego area, mosquito breeding was routinely observed during inspections. In addition, the vegetation at this site became sufficiently dense on the bench around the edge of the pool that mosquito fish were unable to enter this area to feed upon the mosquito larvae. The vegetation at this site was particularly vigorous because of the high nutrient concentrations in the perennial base flow (15.5 mg/L NO₃-N) and the mild climate, which permitted growth year round. Consequently, the vector control agency required an annual harvest of vegetation to address this situation. This harvest can be very expensive.

On the other hand, routine harvesting may increase nutrient removal and prevent the export of these constituents from dead and dying plants falling in the water. A previous study (Faulkner and Richardson, 1991) documented dramatic reductions in nutrient removal after the first several years of operation and related it to the vegetation achieving a maximum density. That content then decreases through the growth season, as the total biomass increases. In effect, the total amount of

nutrients/m² of wetland remains essentially the same from June through September, when the plants start to put the P back into the rhizomes. Therefore harvesting should occur between June and September. Research also suggests that harvesting only the foliage is less effective, since a very small percentage of the removed nutrients is taken out with harvesting.

Since wet ponds are often selected for their aesthetic considerations as well as pollutant removal, they are often sited in areas of high visibility. Consequently, floating litter and debris are removed more frequently than would be required simply to support proper functioning of the pond and outlet. This is one of the primary maintenance activities performed at the Central Market Pond located in Austin, Texas. In this type of setting, vegetation management in the area surrounding the pond can also contribute substantially to the overall maintenance requirements.

One normally thinks of sediment removal as one of the typical activities performed at stormwater BMPs. This activity does not normally constitute one of the major activities on an annual basis. At the concentrations of TSS observed in urban runoff from stable watersheds, sediment removal may only be required every 20 years or so. Because this activity is performed so infrequently, accurate costs for this activity are lacking.

In addition to regular maintenance activities needed to maintain the function of wet ponds, some design features can be incorporated to ease the maintenance burden. In wet ponds, maintenance reduction features include techniques to reduce the amount of maintenance needed, as well as techniques to make regular maintenance activities easier.

One potential maintenance concern in wet ponds is clogging of the outlet. Ponds should be designed with a non-clogging outlet such as a reverse-slope pipe, or a weir outlet with a trash rack. A reverse-slope pipe draws from below the permanent pool extending in a reverse angle up to the riser and establishes the water elevation of the permanent pool. Because these outlets draw water from below the level of the permanent pool, they are less likely to be clogged by floating debris.

Typical maintenance activities and frequencies include:

- Schedule semiannual inspections for burrows, sediment accumulation, structural integrity of the outlet, and litter accumulation.
- Remove accumulated trash and debris in the basin at the middle and end of the wet season. The frequency of this activity may be altered to meet specific site conditions and aesthetic considerations.
- Where permitted by the Department of Fish and Game or other agency regulations, stock wet ponds/constructed wetlands regularly with mosquito fish (*Gambusia spp.*) to enhance natural mosquito and midge control.
- Introduce mosquito fish and maintain vegetation to assist their movements to control mosquitoes, as well as to provide access for vector inspectors. An annual vegetation harvest in summer appears to be optimum, in that it is after the bird breeding season, mosquito fish can provide the needed control until vegetation reaches late summer density, and there is time for re-growth for runoff treatment purposes before the wet season. In certain cases, more frequent plant harvesting may be required by local vector control agencies.

- Maintain emergent and perimeter shoreline vegetation as well as site and road access to facilitate vector surveillance and control activities.
- Remove accumulated sediment in the forebay and regrade about every 5-7 years or when the accumulated sediment volume exceeds 10 percent of the basin volume. Sediment removal may not be required in the main pool area for as long as 20 years.

Cost

Construction Cost

Wet ponds can be relatively inexpensive stormwater practices; however, the construction costs associated with these facilities vary considerably. Much of this variability can be attributed to the degree to which the existing topography will support a wet pond, the complexity and amount of concrete required for the outlet structure, and whether it is installed as part of new construction or implemented as a retrofit of existing storm drain system.

A recent study (Brown and Schueler, 1997) estimated the cost of a variety of stormwater management practices. The study resulted in the following cost equation, adjusting for inflation:

$$C = 24.5V^{0.705}$$

where:

C = Construction, design and permitting cost;

V = Volume in the pond to include the 10-year storm (ft³).

Using this equation, typical construction costs are:

\$45,700 for a 1 acre-foot facility

\$232,000 for a 10 acre-foot facility

\$1,170,000 for a 100 acre-foot facility

In contrast, Caltrans (2002) reported spending over \$448,000 for a pond with a total permanent pool plus water quality volume of only 1036 m³ (0.8 ac.-ft.), while the City of Austin spent \$584,000 (including design) for a pond with a permanent pool volume of 3,100 m³ (2.5 ac.-ft.). The large discrepancies between the costs of these actual facilities and the model developed by Brown and Schueler indicate that construction costs are highly site specific, depending on topography, soils, subsurface conditions, the local labor, rate and other considerations.

Maintenance Cost

For ponds, the annual cost of routine maintenance has typically been estimated at about 3 to 5 percent of the construction cost; however, the published literature is almost totally devoid of actual maintenance costs. Since ponds are long-lived facilities (typically longer than 20 years), major maintenance activities are unlikely to occur during a relatively short study.

Caltrans (2002) estimated annual maintenance costs of \$17,000 based on three years of monitoring of a pond treating runoff from 1.7 ha. Almost all the activities are associated with the annual vegetation harvest for vector control. Total cost at this site falls within the 3-5% range reported

above; however, the construction costs were much higher than those estimated by Brown and Schueler (1997). The City of Austin has been reimbursing a developer about \$25,000/yr for wet pond maintenance at a site located at a very visible location. Maintenance costs are mainly the result of vegetation management and litter removal. On the other hand, King County estimates annual maintenance costs at about \$3,000 per pond; however, this cost likely does not include annual extensive vegetation removal. Consequently, maintenance costs may vary considerably at sites in California depending on the aggressiveness of the vegetation management in that area and the frequency of litter removal.

References and Sources of Additional Information

Amalfi, F.A., R. Kadlec, R.L. Knight, G. O'Meara, W.K. Reisen, W.E. Walton, and R. Wass. 1999. A Mosquito Control Strategy For The Tres Rios Demonstration Constructed Wetlands. CH2M Hill, Tempe, AZ, 140 pp.

Bannerman, R., and R. Dodds. 1992. Unpublished data. Bureau of Water Resources Management, Wisconsin Department of Natural Resources, Madison, WI.

Borden, R. C., J.L. Dorn, J.B. Stillman, and S.K. Liehr; 1996. *Evaluation of Ponds and Wetlands for Protection of Public Water Supplies*. Draft Report. Water Resources Research Institute of the University of North Carolina, Department of Civil Engineering, North Carolina State University, Raleigh, NC.

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection; Ellicott City, MD.

Caltrans, 2002, *Proposed Final Report: BMP Retrofit Pilot Program*, California Dept. of Transportation Report CTSW-RT-01-050, and Sacramento, CA.

City of Austin, TX. 1991. *Design Guidelines for Water Quality Control Basins*. Public Works Department, Austin, TX.

City of Austin, TX. 1996. Evaluation of Non-Point Source Controls: A 319 Grant Project. Draft Water Quality Report Series, Public Works Department, Austin, TX.

Cullum, M. 1985. Stormwater Runoff Analysis at a Single Family Residential Site. Publication 85-1. University of Central Florida, Orlando, FL. pp. 247–256.

Dorman, M.E., J. Hartigan, R.F. Steg, and T. Quasebarth. 1989. *Retention, Detention and Overland Flow for Pollutant Removal From Highway Stormwater Runoff*. Vol. 1 Research Report. FHWA/RD 89/202. Federal Highway Administration, Washington, DC.

Dorothy, J.M., and K. Staker. 1990. A preliminary Survey For Mosquito Breeding In Stormwater Retention Ponds In Three Maryland Counties. Mosquito Control, Maryland Department of Agriculture, College Park, MD. 5 pp.

Driscoll, E.D. 1983. *Performance of Detention Basins for Control of Urban Runoff Quality*. Presented at the 1983 International Symposium on Urban Hydrology, Hydraulics and Sedimentation Control, University of Kentucky, Lexington, KY.

- Emmerling-Dinovo, C. 1995. Stormwater detention basins and residential locational decisions. *Water Resources Bulletin*, 31(3):515–52.
- Faulkner, S. and Richardson, C., 1991, Physical and chemical characteristics of freshwater wetland soils, in *Constructed Wetlands for Wastewater Treatment*, ed. D. Hammer, Lewis Publishers, 831 pp.
- Gain, W.S. 1996. *The Effects of Flow Path Modification on Water Quality Constituent Retention in an Urban Stormwater Detention Pond and Wetland System*. Water Resources Investigations Report 95-4297. U.S. Geological Survey, Tallahassee, FL.
- Galli, F. 1990. *Thermal Impacts Associated with Urbanization and Stormwater Best Management Practices*. Prepared for the Maryland Department of the Environment, Baltimore, MD, by the Metropolitan Council of Governments, Washington, DC.
- Glick, Roger, 2001, personal communication, City of Austin Watershed Protection Dept., Austin, TX.
- Holler, J.D. 1989. Water Quality Efficiency Of An Urban Commercial Wet Detention Stormwater Management System At Boynton Beach Mall in South Palm Beach County, FL. *Florida Scientist* 52(1):48–57.
- Holler, J.D. 1990. Nonpoint Source Phosphorous Control By A Combination Wet Detention/ Filtration Facility In Kissimmee, FL. *Florida Scientist* 53(1):28–37.
- Horner, R.R., J. Guedry, and M.H. Kortenhoff. 1990. *Improving the Cost Effectiveness of Highway Construction Site Erosion and Pollution Control*. Final Report. Washington State Transportation Commission, Olympia, WA.
- Kantrowitz .I. and W. Woodham 1995. *Efficiency of a Stormwater Detention Pond in Reducing Loads of Chemical and Physical Constituents in Urban Stream flow, Pinellas County, Florida*. Water Resources Investigations Report 94-4217. U.S. Geological Survey, Tallahassee, FL.
- Martin, E. 1988. Effectiveness of an urban runoff detention pond/wetland system. *Journal of Environmental Engineering* 114(4):810–827.
- Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual*. <http://www.mde.state.md.us/environment/wma/stormwatermanual>.
- McLean, J. 2000. Mosquitoes In Constructed Wetlands: A Management Bugaboo? In T.R. Schueler and H.K. Holland [eds.], *The Practice of Watershed Protection*. pp. 29-33. Center for Watershed Protection, Ellicott City, MD.
- Metzger, M. E., D. F. Messer, C. L. Beitia, C. M. Myers, and V. L. Kramer. 2002. The Dark Side Of Stormwater Runoff Management: Disease Vectors Associated With Structural BMPs. *Stormwater* 3(2): 24-39.
- Oberts, G.L. 1994. Performance of stormwater ponds and wetlands in winter. *Watershed Protection Techniques* 1(2):64–68.

Oberts, G.L., P.J. Wotzka, and J.A. Hartsoe. 1989. *The Water Quality Performance of Select Urban Runoff Treatment Systems*. Publication No. 590-89-062a. Prepared for the Legislative Commission on Minnesota Resources, Metropolitan Council, St. Paul, MN.

Oberts, G.L., and L. Wotzka. 1988. The water quality performance of a detention basin wetland treatment system in an urban area. In *Nonpoint Source Pollution: Economy, Policy, Management and Appropriate Technology*. American Water Resources Association, Middleburg, VA.

Occoquan Watershed Monitoring Laboratory. 1983. Metropolitan Washington Urban Runoff Project. Final Report. Prepared for the Metropolitan Washington Council of Governments, Washington, DC, by the Occoquan Watershed Monitoring Laboratory, Manassas, VA.

Ontario Ministry of the Environment. 1991. *Stormwater Quality Best Management Practices*. Marshall Macklin Monaghan Limited, Toronto, Ontario.

Protection Agency, Office of Water, Washington, DC, by the Watershed Management Institute, Ingleside, MD.

Santana, F.J., J.R. Wood, R.E. Parsons, and S.K. Chamberlain. 1994. Control Of Mosquito Breeding In Permitted Stormwater Systems. Sarasota County Mosquito Control and Southwest Florida Water Management District, Brooksville, FL., 46 pp.

Saunders, G. and M. Gilroy, 1997. *Treatment of Nonpoint Source Pollution with Wetland/Aquatic Ecosystem Best Management Practices*. Texas Water Development Board, Lower Colorado River Authority, Austin, TX.

Schueler, T. 1997a. Comparative pollutant removal capability of urban BMPs: A reanalysis. *Watershed Protection Techniques* 2(4):515–520.

Schueler, T. 1997b. Influence of groundwater on performance of stormwater ponds in Florida. *Watershed Protection Techniques* 2(4):525–528.

Urbonas, B., J. Carlson, and B. Vang. 1994. Joint Pond-Wetland System in Colorado. Denver Urban Drainage and Flood Control District, Denver, CO.

U.S. Environmental Protection Agency (USEPA). 1995. *Economic Benefits of Runoff Controls*. U.S. Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC.

Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. Environmental Protection Agency, Office of Water, Washington, DC, by the Watershed Management Institute, Ingleside, MD.
Water Environment Federation and ASCE, 1998, *Urban Runoff Quality Management*, WEF Manual of Practice No. 23 and ASCE Manual and Report on Engineering Practice No. 87.

Wu, J. 1989. Evaluation of Detention Basin Performance in the Piedmont Region of North Carolina. Report No. 89-248. North Carolina Water Resources Research Institute, Raleigh, NC.

Yousef, Y., M. Wanielista, and H. Harper. 1986. Design and Effectiveness of Urban Retention Basins. In *Urban Runoff Quality—Impact and Quality Enhancement Technology*. B. Urbonas and L.A. Roesner (Eds.). American Society of Civil Engineering, New York, New York. pp. 338–350.

Information Resources

Center for Watershed Protection (CWP). 1995. *Stormwater Management Pond Design Example for Extended Detention Wet Pond*. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1997. *Stormwater BMP Design Supplement for Cold Climates*. Prepared for U.S. Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds, Washington, DC, by the Center for Watershed Protection, Ellicott City, MD.

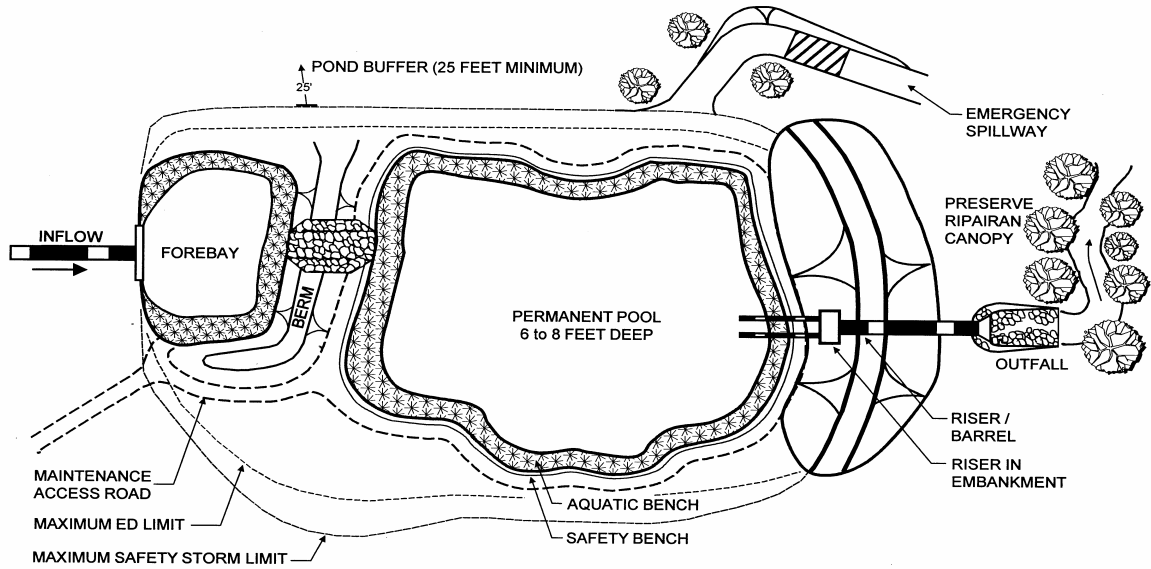
Denver Urban Drainage and Flood Control District. 1992. *Urban Storm Drainage Criteria Manual—Volume 3: Best Management Practices*. Denver Urban Drainage and Flood Control District, Denver, CO.

Galli, J. 1992. *Preliminary Analysis of the Performance and Longevity of Urban BMPs Installed in Prince George's County, Maryland*. Prince George's County, Maryland, Department of Natural Resources, Largo, MD.

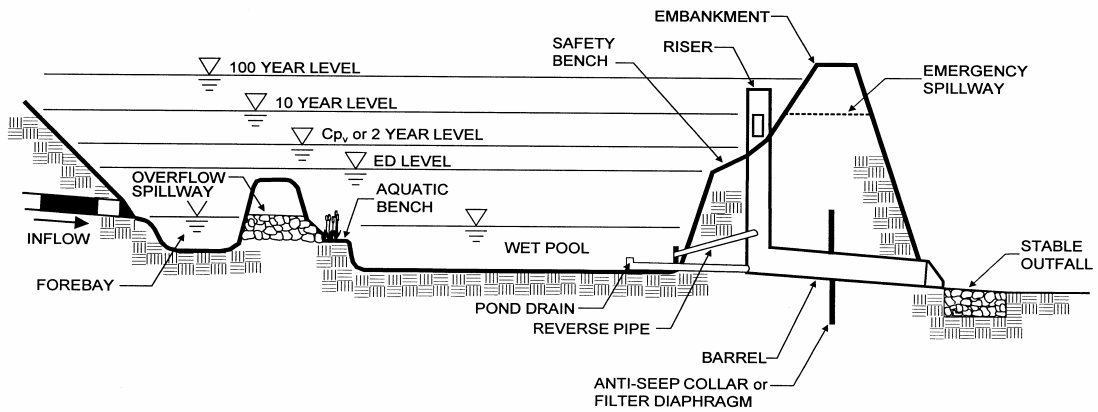
MacRae, C. 1996. Experience from Morphological Research on Canadian Streams: Is Control of the Two-Year Frequency Runoff Event the Best Basis for Stream Channel Protection? In *Effects of Watershed Development and Management on Aquatic Ecosystems*. American Society of Civil Engineers. Snowbird, UT. pp. 144–162.

Minnesota Pollution Control Agency. 1989. *Protecting Water Quality in Urban Areas: Best Management Practices*. Minnesota Pollution Control Agency, Minneapolis, MN.

U.S. Environmental Protection Agency (USEPA). 1993. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. EPA-840-B-92-002. U.S. Environmental Protection Agency, Office of Water, Washington, DC.



PLAN VIEW



PROFILE



Description

Constructed wetlands are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season) and differ from wet ponds primarily in being shallower and having greater vegetation coverage. The schematic diagram is of an on-line pond that includes detention for larger events, but this is not required in all areas of the state.

A distinction should be made between using a constructed wetland for storm water management and diverting storm water into a natural wetland. The latter practice is not recommended and in all circumstances, natural wetlands should be protected from the adverse effects of development, including impacts from increased storm water runoff. This is especially important because natural wetlands provide storm water and flood control benefits on a regional scale.

Wetlands are among the most effective stormwater practices in terms of pollutant removal and they also offer aesthetic value. As stormwater runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake within the wetland. Flow through the root systems forces the vegetation to remove nutrients and dissolved pollutants from the stormwater.

California Experience

The City of Laguna Niguel in Orange County has constructed several wetlands, primarily to reduce bacteria concentrations in dry weather flows. The wetlands have been very successful in this regard. Even though there is not enough perennial flow to maintain the permanent pool at a constant elevation, the wetland vegetation has thrived.

Design Considerations

- Area Required
- Slope
- Water Availability
- Aesthetics
- Environmental Side-effects

Targeted Constituents

- | | | |
|---|----------------|---|
| ✓ | Sediment | ■ |
| ✓ | Nutrients | ▲ |
| ✓ | Trash | ■ |
| ✓ | Metals | ■ |
| ✓ | Bacteria | ■ |
| ✓ | Oil and Grease | ■ |
| ✓ | Organics | ■ |

Legend (Removal Effectiveness)

- | | | | |
|---|--------|---|------|
| ● | Low | ■ | High |
| ▲ | Medium | | |



Advantages

- If properly designed, constructed and maintained, wet basins can provide substantial wildlife and wetlands habitat.
- Due to the presence of the permanent wet pool, properly designed and maintained wet basins can provide significant water quality improvement across a relatively broad spectrum of constituents including dissolved nutrients.
- Widespread application with sufficient capture volume can provide significant control of channel erosion and enlargement caused by changes to flow frequency relationships resulting from the increase of impervious cover in a watershed.

Limitations

- There may be some aesthetic concerns about a facility that looks swampy.
- Some concern about safety when constructed where there is public access.
- Mosquito and midge breeding is likely to occur in wetlands.
- Cannot be placed on steep unstable slopes.
- Need for base flow or supplemental water if water level is to be maintained.
- Require a relatively large footprint
- Depending on volume and depth, pond designs may require approval from the State Division of Safety of Dams

Design and Sizing Guidelines

- Capture volume determined by local requirements or sized to treat 85% of the annual runoff volume.
- Outlet designed to discharge the capture volume over a period of 24 hours.
- Permanent pool volume equal to twice the water quality volume.
- Water depth not to exceed about 4 feet.
- Wetland vegetation occupying no more than 50% of surface area.
- Include energy dissipation in the inlet design and a sediment forebay to reduce resuspension of accumulated sediment and facilitate maintenance.
- A maintenance ramp should be included in the design to facilitate access to the forebay for maintenance activities and for vector surveillance and control.
- To facilitate vector surveillance and control activities, road access should be provided along at least one side of BMPs that are seven meters or less in width. Those BMPs that have shoreline-to-shoreline distances in excess of seven meters should have perimeter road access on both sides or be designed such that no parcel of water is greater than seven meters from the road.

Construction/Inspection Considerations

- In areas with porous soils an impermeable liner may be required to maintain an adequate permanent pool level.
- Outlet structures and piping should be installed with collars to prevent water from seeping through the fill and causing structural failure.
- Inspect facility after first large storm to determine whether the desired residence time has been achieved.

Performance

The processes that impact the performance of constructed wetlands are essentially the same as those operating in wet ponds and similar pollutant reduction would be expected. One concern about the long-term performance of wetlands is associated with the vegetation density. If vegetation covers the majority of the facility, open water is confined to a few well defined channels. This can limit mixing of the stormwater runoff with the permanent pool and reduce the effectiveness as compared to a wet pond where a majority of the area is open water.

Siting Criteria

Wet ponds are a widely applicable stormwater management practice and can be used over a broad range of storm frequencies and sizes, drainage areas and land use types. Although they have limited applicability in highly urbanized settings and in arid climates, they have few other restrictions. Constructed wetlands may be constructed on- or off-line and can be sited at feasible locations along established drainage ways with consistent base flow. An off-line design is preferred. Constructed wetlands are often utilized in smaller sub-watersheds and are particularly appropriate in areas with residential land uses or other areas where high nutrient loads are considered to be potential problems (e.g., golf courses).

Wetlands generally consume a fairly large area (typically 4-6 percent of the contributing drainage area), and these facilities are generally larger than wet ponds because the average depth is less.

Wet basin application is appropriate in the following settings: (1) where there is a need to achieve a reasonably high level of dissolved contaminant removal and/or sediment capture; (2) in small to medium-sized regional tributary areas with available open space and drainage areas greater than about 10 ha (25 ac.); (3) where base flow rates or other channel flow sources are relatively consistent year-round; (4) in settings where wildlife habitat benefits can be appreciated.

Additional Design Guidelines

Constructed wetlands generally feature relatively uniformly vegetated areas with depths of one foot or less and open water areas (25-50% of the total area) no more than about 1.2 m (4 feet) deep, although design configuration options are relatively flexible. Wetland vegetation is comprised generally of a diverse, local aquatic plant species. Constructed wetlands can be designed on-line or off-line and generally serve relatively smaller drainage areas than wet ponds, although because of the shallow depths, the footprint of the facility will be larger than a wet pond serving the same tributary area.

The extended detention shallow wetland combines the treatment concepts of the dry extended detention pond and the constructed wetland. In this design, the water quality volume is detained above the permanent pool and released over 24 hours. In addition to increasing the residence time, which improves pollutant removal, this design also attenuates peak runoff rates. Consequently, this design alternative is recommended.

Pretreatment incorporates design features that help to settle out coarse sediment particles. By removing these particles from runoff before they reach the large permanent pool, the maintenance burden of the pond is reduced. In ponds, pretreatment is achieved with a sediment forebay. A sediment forebay is a small pool (typically about 10 percent of the volume of the permanent pool). Coarse particles remain trapped in the forebay, and maintenance is performed on this smaller pool, eliminating the need to dredge the entire pond.

Effective wetland design displays "complex microtopography." In other words, wetlands should have zones of both very shallow (<6 inches) and moderately shallow (<18 inches) wetlands incorporated, using underwater earth berms to create the zones. This design will provide a longer flow path through the wetland to encourage settling, and it provides two depth zones to encourage plant diversity.

There are a variety of sizing criteria for determining the volume of the permanent pool, mostly related to the water quality volume (i.e., the volume of water treated for pollutant removal) or the average storm size in a particular area. In addition, several theoretical approaches to determination of permanent pool volume have been developed. However, there is little empirical evidence to support these designs. Consequently, a simplified method (i.e., permanent pool volume equal to twice the water quality volume) is recommended.

Design features are also incorporated to ease maintenance of both the forebay and the main pool of ponds. Ponds should be designed with a maintenance access to the forebay to ease this relatively routine (every 5–7 year) maintenance activity. In addition, ponds should generally have a drain to draw down the pond for vegetation harvesting or the more infrequent dredging of the main cell of the pond.

Summary of Design Recommendations

- (1) Facility Sizing – The basin should be sized to hold the permanent pool as well as the required water quality volume. The volume of the permanent pool should equal twice the water quality volume.
- (2) Pond Configuration - The wet basin should be configured as a two stage facility with a sediment forebay and a main pool. The basins should be wedge-shaped, narrowest at the inlet and widest at the outlet. The minimum length to width ratio should be 1.5 where feasible. The depth in the center of the basin should be about 4 feet deep to prevent vegetation from encroaching on the pond open water surface.
- (3) Pond Side Slopes - Side slopes of the basin should be 3:1 (H:V) or flatter for grass stabilized slopes. Slopes steeper than 3:1 should be stabilized with an appropriate slope stabilization practice.
- (4) Sediment Forebay - A sediment forebay should be used to isolate gross sediments as they enter the facility and to simplify sediment removal. The sediment forebay

should consist of a separate cell formed by an earthen berm, gabion, or loose riprap wall. The forebay should be sized to contain 15 to 25% of the permanent pool volume and should be at least 3 feet deep. Exit velocities from the forebay should not be erosive. Direct maintenance access should be provided to the forebay. The bottom of the forebay may be hardened (concrete) to make sediment removal easier. A fixed vertical sediment depth marker should be installed in the forebay to measure sediment accumulation.

- (5) Splitter Box - When the pond is designed as an off-line facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the 25-year event while providing at least 1.0 foot of freeboard along pond side slopes.
- (6) Vegetation - A plan should be prepared that indicates how aquatic and terrestrial areas will be vegetatively stabilized. Wetland vegetation elements should be placed along the aquatic bench or in the shallow portions of the permanent pool. The optimal elevation for planting of wetland vegetation is within 6 inches vertically of the normal pool elevation. A list of some wetland vegetation native to California is presented in the wet pond fact sheet.

Maintenance

The amount of maintenance required for a constructed wetland is highly dependent on local regulatory agencies, particular health and vector control agencies. These agencies are often extremely concerned about the potential for mosquito breeding that may occur in the permanent pool.

Routine harvesting of vegetation may increase nutrient removal and prevent the export of these constituents from dead and dying plants falling in the water. A previous study (Faulkner and Richardson, 1991) documented dramatic reductions in nutrient removal after the first several years of operation and related it to the vegetation achieving a maximum density. Vegetation harvesting in the summer is recommended.

Typical maintenance activities and frequencies include:

- Schedule semiannual inspections for burrows, sediment accumulation, structural integrity of the outlet, and litter accumulation.
- Remove accumulated trash and debris in the basin at the middle and end of the wet season. The frequency of this activity may be altered to meet specific site conditions and aesthetic considerations.
- Where permitted by the Department of Fish and Game or other agency regulations, stock wet ponds/constructed wetlands regularly with mosquito fish (*Gambusia spp.*) to enhance natural mosquito and midge control.
- Introduce mosquito fish and maintain vegetation to assist their movements to control mosquitoes, as well as to provide access for vector inspectors. An annual vegetation harvest in summer appears to be optimum, in that it is after the bird breeding season, mosquito fish can provide the needed control until vegetation reaches late summer density, and there is

time for re-growth for runoff treatment purposes before the wet season. In certain cases, more frequent plant harvesting may be required by local vector control agencies.

- Maintain emergent and perimeter shoreline vegetation as well as site and road access to facilitate vector surveillance and control activities.
- Remove accumulated sediment in the forebay and regrade about every 5-7 years or when the accumulated sediment volume exceeds 10 percent of the basin volume. Sediment removal may not be required in the main pool area for as long as 20 years.

Cost

Construction Cost

Wetlands are relatively inexpensive storm water practices. Construction cost data for wetlands are rare, but one simplifying assumption is that they are typically about 25 percent more expensive than storm water ponds of an equivalent volume. Using this assumption, an equation developed by Brown and Schueler (1997) to estimate the cost of wet ponds can be modified to estimate the cost of storm water wetlands using the equation:

$$C = 30.6V^{0.705}$$

where:

C = Construction, design, and permitting cost;

V = Wetland volume needed to control the 10-year storm (ft³).

Using this equation, typical construction costs are the following:

\$ 57,100 for a 1 acre-foot facility

\$ 289,000 for a 10 acre-foot facility

\$ 1,470,000 for a 100 acre-foot facility

Wetlands consume about 3 to 5 percent of the land that drains to them, which is relatively high compared with other storm water management practices. In areas where land value is high, this may make wetlands an infeasible option.

Maintenance Cost

For ponds, the annual cost of routine maintenance has typically been estimated at about 3 to 5 percent of the construction cost; however, the published literature is almost totally devoid of actual maintenance costs. Since ponds are long-lived facilities (typically longer than 20 years), major maintenance activities are unlikely to occur during a relatively short study.

References and Sources of Additional Information

Amalfi, F.A., R. Kadlec, R.L. Knight, G. O'Meara, W.K. Reisen, W.E. Walton, and R. Wass. 1999. A mosquito control strategy for the Tres Rios Demonstration Constructed Wetlands. CH2M Hill, Tempe, AZ, 140 pp.

Borden, R. C., J.L. Dorn, J.B. Stillman, and S.K. Liehr; 1996. *Evaluation of Ponds and Wetlands for Protection of Public Water Supplies*. Draft Report. Water Resources Research Institute of the University of North Carolina, Department of Civil Engineering, North Carolina State University, Raleigh, NC.

City of Austin, TX. 1991. *Design Guidelines for Water Quality Control Basins*. Public Works Department, Austin, TX.

Cullum, M. 1985. Stormwater Runoff Analysis at a Single Family Residential Site. Publication 85-1. University of Central Florida, Orlando, FL. pp. 247–256.

Dorothy, J.M., and K. Staker. 1990. A Preliminary Survey for Mosquito Breeding in Stormwater Retention Ponds in Three Maryland Counties. Mosquito Control, Maryland Department of Agriculture, College Park, MD. 5 pp.

Faulkner, S. and Richardson, C., 1991, Physical And Chemical Characteristics of Freshwater Wetland Soils, in *Constructed Wetlands for Wastewater Treatment*, ed. D. Hammer, Lewis Publishers, 831 pp.

Gain, W.S. 1996. *The Effects of Flow Path Modification on Water Quality Constituent Retention in an Urban Stormwater Detention Pond and Wetland System*. Water Resources Investigations Report 95-4297. U.S. Geological Survey, Tallahassee, FL.

Martin, E. 1988. Effectiveness Of An Urban Runoff Detention Pond/Wetland System. *Journal of Environmental Engineering* 114(4):810–827.

Maryland Department of the Environment (MDE). 2000. Maryland Stormwater Design Manual. <http://www.mde.state.md.us/environment/wma/stormwatermanual>.

McLean, J. 2000. Mosquitoes In Constructed Wetlands: A Management Bugaboo? In T.R. Schueler and H.K. Holland [eds.], *The Practice of Watershed Protection*. pp. 29-33. Center for Watershed Protection, Ellicott City, MD

Metzger, M. E., D. F. Messer, C. L. Beitia, C. M. Myers, and V. L. Kramer. 2002. The Dark Side of Stormwater Runoff Management: Disease Vectors Associated with Structural BMPs. *Stormwater* 3(2): 24-39.

Oberts, G.L. 1994. Performance Of Stormwater Ponds And Wetlands In Winter. *Watershed Protection Techniques* 1(2):64–68.

Oberts, G.L., and L. Wotzka. 1988. The Water Quality Performance Of A Detention Basin Wetland Treatment System In An Urban Area. In *Nonpoint Source Pollution: Economy, Policy, Management and Appropriate Technology*. American Water Resources Association, Middleburg, VA.

Santana, F.J., J.R. Wood, R.E. Parsons, and S.K. Chamberlain. 1994. Control Of Mosquito Breeding In Permitted Stormwater Systems. Sarasota County Mosquito Control and Southwest Florida Water Management District, Brooksville, FL., 46 pp.

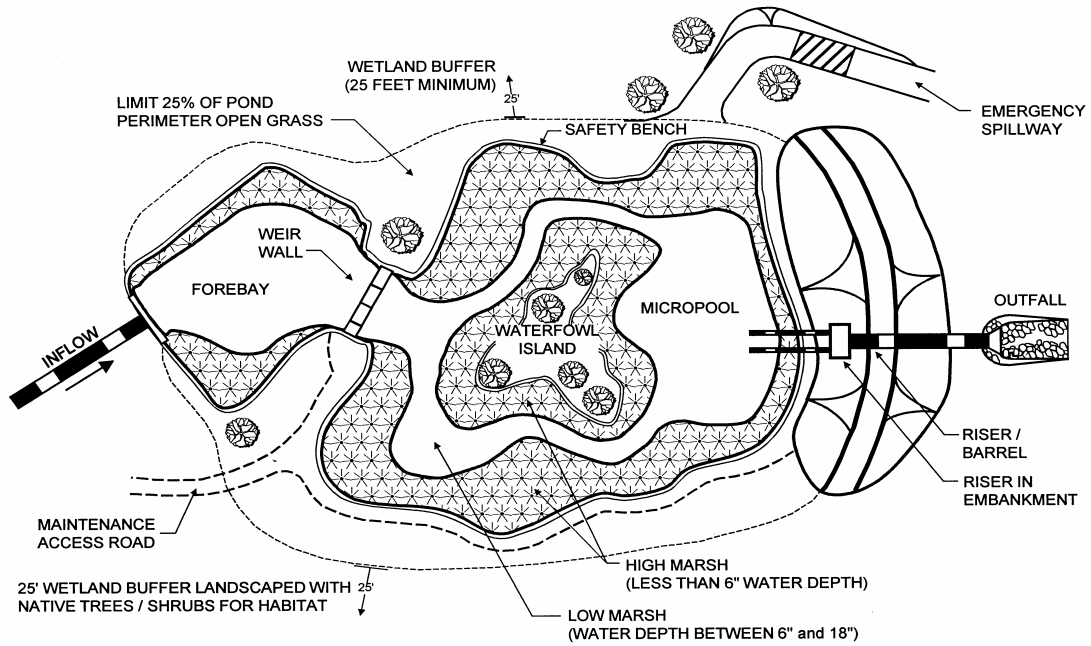
Saunders, G. and M. Gilroy, 1997. Treatment of Nonpoint Source Pollution with Wetland/Aquatic Ecosystem Best Management Practices. Texas Water Development Board, Lower Colorado River Authority, Austin, TX.

Schueler, T. 1997a. Comparative Pollutant Removal Capability Of Urban BMPs: A Reanalysis. Watershed Protection Techniques 2(4):515–520.

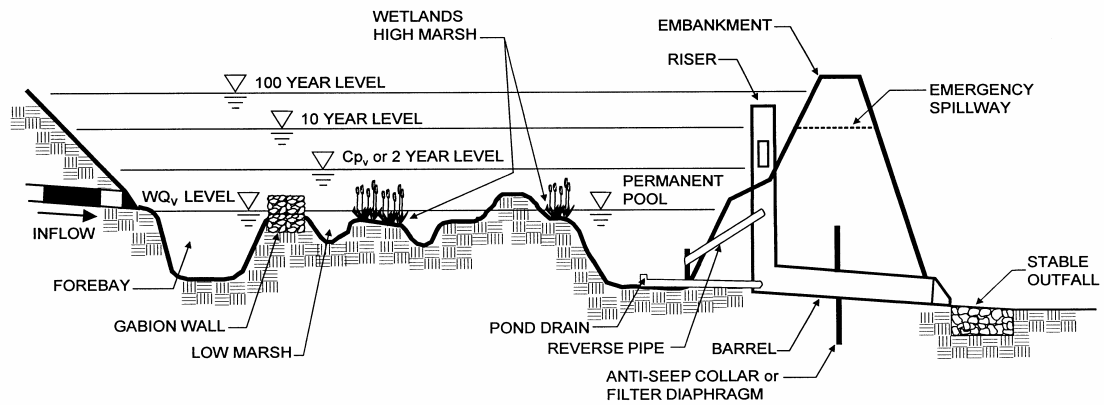
Urbonas, B., J. Carlson, and B. Vang. 1994. Joint Pond-Wetland System in Colorado. Denver Urban Drainage and Flood Control District, Denver, CO.

Water Environment Federation and ASCE, 1998, Urban Runoff Quality Management, WEF Manual of Practice No. 23 and ASCE Manual and Report on Engineering Practice No. 87.

Wu, J. 1989. Evaluation of Detention Basin Performance in the Piedmont Region of North Carolina. Report No. 89-248. North Carolina Water Resources Research Institute, Raleigh, NC.



PLAN VIEW



PROFILE



Design Considerations

- Soil for Infiltration
- Tributary Area
- Slope
- Aesthetics
- Environmental Side-effects

Description

The bioretention best management practice (BMP) functions as a soil and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. These facilities normally consist of a grass buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. The runoff's velocity is reduced by passing over or through buffer strip and subsequently distributed evenly along a ponding area. Exfiltration of the stored water in the bioretention area planting soil into the underlying soils occurs over a period of days.

California Experience

None documented. Bioretention has been used as a stormwater BMP since 1992. In addition to Prince George's County, MD and Alexandria, VA, bioretention has been used successfully at urban and suburban areas in Montgomery County, MD; Baltimore County, MD; Chesterfield County, VA; Prince William County, VA; Smith Mountain Lake State Park, VA; and Cary, NC.

Advantages

- Bioretention provides stormwater treatment that enhances the quality of downstream water bodies by temporarily storing runoff in the BMP and releasing it over a period of four days to the receiving water (EPA, 1999).
- The vegetation provides shade and wind breaks, absorbs noise, and improves an area's landscape.

Limitations

- The bioretention BMP is not recommended for areas with slopes greater than 20% or where mature tree removal would

Targeted Constituents

✓	Sediment	■
✓	Nutrients	▲
✓	Trash	■
✓	Metals	■
✓	Bacteria	■
✓	Oil and Grease	■
✓	Organics	■

Legend (Removal Effectiveness)

- Low
- High
- ▲ Medium



be required since clogging may result, particularly if the BMP receives runoff with high sediment loads (EPA, 1999).

- Bioretention is not a suitable BMP at locations where the water table is within 6 feet of the ground surface and where the surrounding soil stratum is unstable.
- By design, bioretention BMPs have the potential to create very attractive habitats for mosquitoes and other vectors because of highly organic, often heavily vegetated areas mixed with shallow water.
- In cold climates the soil may freeze, preventing runoff from infiltrating into the planting soil.

Design and Sizing Guidelines

- The bioretention area should be sized to capture the design storm runoff.
- In areas where the native soil permeability is less than 0.5 in/hr an underdrain should be provided.
- Recommended minimum dimensions are 15 feet by 40 feet, although the preferred width is 25 feet. Excavated depth should be 4 feet.
- Area should drain completely within 72 hours.
- Approximately 1 tree or shrub per 50 ft² of bioretention area should be included.
- Cover area with about 3 inches of mulch.

Construction/Inspection Considerations

Bioretention area should not be established until contributing watershed is stabilized.

Performance

Bioretention removes stormwater pollutants through physical and biological processes, including adsorption, filtration, plant uptake, microbial activity, decomposition, sedimentation and volatilization (EPA, 1999). Adsorption is the process whereby particulate pollutants attach to soil (e.g., clay) or vegetation surfaces. Adequate contact time between the surface and pollutant must be provided for in the design of the system for this removal process to occur. Thus, the infiltration rate of the soils must not exceed those specified in the design criteria or pollutant removal may decrease. Pollutants removed by adsorption include metals, phosphorus, and hydrocarbons. Filtration occurs as runoff passes through the bioretention area media, such as the sand bed, ground cover, and planting soil.

Common particulates removed from stormwater include particulate organic matter, phosphorus, and suspended solids. Biological processes that occur in wetlands result in pollutant uptake by plants and microorganisms in the soil. Plant growth is sustained by the uptake of nutrients from the soils, with woody plants locking up these nutrients through the seasons. Microbial activity within the soil also contributes to the removal of nitrogen and organic matter. Nitrogen is removed by nitrifying and denitrifying bacteria, while aerobic bacteria are responsible for the decomposition of the organic matter. Microbial processes require oxygen and can result in depleted oxygen levels if the bioretention area is not adequately

aerated. Sedimentation occurs in the swale or ponding area as the velocity slows and solids fall out of suspension.

The removal effectiveness of bioretention has been studied during field and laboratory studies conducted by the University of Maryland (Davis et al, 1998). During these experiments, synthetic stormwater runoff was pumped through several laboratory and field bioretention areas to simulate typical storm events in Prince George's County, MD. Removal rates for heavy metals and nutrients are shown in Table 1.

Pollutant	Removal Rate
Total Phosphorus	70-83%
Metals (Cu, Zn, Pb)	93-98%
TKN	68-80%
Total Suspended Solids	90%
Organics	90%
Bacteria	90%

Results for both the laboratory and field experiments were similar for each of the pollutants analyzed. Doubling or halving the influent pollutant levels had little effect on the effluent pollutants concentrations (Davis et al, 1998).

The microbial activity and plant uptake occurring in the bioretention area will likely result in higher removal rates than those determined for infiltration BMPs.

Siting Criteria

Bioretention BMPs are generally used to treat stormwater from impervious surfaces at commercial, residential, and industrial areas (EPA, 1999). Implementation of bioretention for stormwater management is ideal for median strips, parking lot islands, and swales. Moreover, the runoff in these areas can be designed to either divert directly into the bioretention area or convey into the bioretention area by a curb and gutter collection system.

The best location for bioretention areas is upland from inlets that receive sheet flow from graded areas and at areas that will be excavated (EPA, 1999). In order to maximize treatment effectiveness, the site must be graded in such a way that minimizes erosive conditions as sheet flow is conveyed to the treatment area. Locations where a bioretention area can be readily incorporated into the site plan without further environmental damage are preferred. Furthermore, to effectively minimize sediment loading in the treatment area, bioretention only should be used in stabilized drainage areas.

Additional Design Guidelines

The layout of the bioretention area is determined after site constraints such as location of utilities, underlying soils, existing vegetation, and drainage are considered (EPA, 1999). Sites with loamy sand soils are especially appropriate for bioretention because the excavated soil can be backfilled and used as the planting soil, thus eliminating the cost of importing planting soil.

The use of bioretention may not be feasible given an unstable surrounding soil stratum, soils with clay content greater than 25 percent, a site with slopes greater than 20 percent, and/or a site with mature trees that would be removed during construction of the BMP.

Bioretention can be designed to be off-line or on-line of the existing drainage system (EPA, 1999). The drainage area for a bioretention area should be between 0.1 and 0.4 hectares (0.25 and 1.0 acres). Larger drainage areas may require multiple bioretention areas. Furthermore, the maximum drainage area for a bioretention area is determined by the expected rainfall intensity and runoff rate. Stabilized areas may erode when velocities are greater than 5 feet per second (1.5 meter per second). The designer should determine the potential for erosive conditions at the site.

The size of the bioretention area, which is a function of the drainage area and the runoff generated from the area is sized to capture the water quality volume.

The recommended minimum dimensions of the bioretention area are 15 feet (4.6 meters) wide by 40 feet (12.2 meters) long, where the minimum width allows enough space for a dense, randomly-distributed area of trees and shrubs to become established. Thus replicating a natural forest and creating a microclimate, thereby enabling the bioretention area to tolerate the effects of heat stress, acid rain, runoff pollutants, and insect and disease infestations which landscaped areas in urban settings typically are unable to tolerate. The preferred width is 25 feet (7.6 meters), with a length of twice the width. Essentially, any facilities wider than 20 feet (6.1 meters) should be twice as long as they are wide, which promotes the distribution of flow and decreases the chances of concentrated flow.

In order to provide adequate storage and prevent water from standing for excessive periods of time the ponding depth of the bioretention area should not exceed 6 inches (15 centimeters). Water should not be left to stand for more than 72 hours. A restriction on the type of plants that can be used may be necessary due to some plants' water intolerance. Furthermore, if water is left standing for longer than 72 hours mosquitoes and other insects may start to breed.

The appropriate planting soil should be backfilled into the excavated bioretention area. Planting soils should be sandy loam, loamy sand, or loam texture with a clay content ranging from 10 to 25 percent.

Generally the soil should have infiltration rates greater than 0.5 inches (1.25 centimeters) per hour, which is typical of sandy loams, loamy sands, or loams. The pH of the soil should range between 5.5 and 6.5, where pollutants such as organic nitrogen and phosphorus can be adsorbed by the soil and microbial activity can flourish. Additional requirements for the planting soil include a 1.5 to 3 percent organic content and a maximum 500 ppm concentration of soluble salts.

Soil tests should be performed for every 500 cubic yards (382 cubic meters) of planting soil, with the exception of pH and organic content tests, which are required only once per bioretention area (EPA, 1999). Planting soil should be 4 inches (10.1 centimeters) deeper than the bottom of the largest root ball and 4 feet (1.2 meters) altogether. This depth will provide adequate soil for the plants' root systems to become established, prevent plant damage due to severe wind, and provide adequate moisture capacity. Most sites will require excavation in order to obtain the recommended depth.

Planting soil depths of greater than 4 feet (1.2 meters) may require additional construction practices such as shoring measures (EPA, 1999). Planting soil should be placed in 18 inches or greater lifts and lightly compacted until the desired depth is reached. Since high canopy trees may be destroyed during maintenance the bioretention area should be vegetated to resemble a terrestrial forest community ecosystem that is dominated by understory trees. Three species each of both trees and shrubs are recommended to be planted at a rate of 2500 trees and shrubs per hectare (1000 per acre). For instance, a 15 foot (4.6 meter) by 40 foot (12.2 meter) bioretention area (600 square feet or 55.75 square meters) would require 14 trees and shrubs. The shrub-to-tree ratio should be 2:1 to 3:1.

Trees and shrubs should be planted when conditions are favorable. Vegetation should be watered at the end of each day for fourteen days following its planting. Plant species tolerant of pollutant loads and varying wet and dry conditions should be used in the bioretention area.

The designer should assess aesthetics, site layout, and maintenance requirements when selecting plant species. Adjacent non-native invasive species should be identified and the designer should take measures, such as providing a soil breach to eliminate the threat of these species invading the bioretention area. Regional landscaping manuals should be consulted to ensure that the planting of the bioretention area meets the landscaping requirements established by the local authorities. The designers should evaluate the best placement of vegetation within the bioretention area. Plants should be placed at irregular intervals to replicate a natural forest. Trees should be placed on the perimeter of the area to provide shade and shelter from the wind. Trees and shrubs can be sheltered from damaging flows if they are placed away from the path of the incoming runoff. In cold climates, species that are more tolerant to cold winds, such as evergreens, should be placed in windier areas of the site.

Following placement of the trees and shrubs, the ground cover and/or mulch should be established. Ground cover such as grasses or legumes can be planted at the beginning of the growing season. Mulch should be placed immediately after trees and shrubs are planted. Two to 3 inches (5 to 7.6 cm) of commercially-available fine shredded hardwood mulch or shredded hardwood chips should be applied to the bioretention area to protect from erosion.

Maintenance

The primary maintenance requirement for bioretention areas is that of inspection and repair or replacement of the treatment area's components. Generally, this involves nothing more than the routine periodic maintenance that is required of any landscaped area. Plants that are appropriate for the site, climatic, and watering conditions should be selected for use in the bioretention cell. Appropriately selected plants will aide in reducing fertilizer, pesticide, water, and overall maintenance requirements. Bioretention system components should blend over time through plant and root growth, organic decomposition, and the development of a natural

soil horizon. These biologic and physical processes over time will lengthen the facility's life span and reduce the need for extensive maintenance.

Routine maintenance should include a biannual health evaluation of the trees and shrubs and subsequent removal of any dead or diseased vegetation (EPA, 1999). Diseased vegetation should be treated as needed using preventative and low-toxic measures to the extent possible. BMPs have the potential to create very attractive habitats for mosquitoes and other vectors because of highly organic, often heavily vegetated areas mixed with shallow water. Routine inspections for areas of standing water within the BMP and corrective measures to restore proper infiltration rates are necessary to prevent creating mosquito and other vector habitat. In addition, bioretention BMPs are susceptible to invasion by aggressive plant species such as cattails, which increase the chances of water standing and subsequent vector production if not routinely maintained.

In order to maintain the treatment area's appearance it may be necessary to prune and weed. Furthermore, mulch replacement is suggested when erosion is evident or when the site begins to look unattractive. Specifically, the entire area may require mulch replacement every two to three years, although spot mulching may be sufficient when there are random void areas. Mulch replacement should be done prior to the start of the wet season.

New Jersey's Department of Environmental Protection states in their bioretention systems standards that accumulated sediment and debris removal (especially at the inflow point) will normally be the primary maintenance function. Other potential tasks include replacement of dead vegetation, soil pH regulation, erosion repair at inflow points, mulch replenishment, unclogging the underdrain, and repairing overflow structures. There is also the possibility that the cation exchange capacity of the soils in the cell will be significantly reduced over time. Depending on pollutant loads, soils may need to be replaced within 5-10 years of construction (LID, 2000).

Cost

Construction Cost

Construction cost estimates for a bioretention area are slightly greater than those for the required landscaping for a new development (EPA, 1999). A general rule of thumb (Coffman, 1999) is that residential bioretention areas average about \$3 to \$4 per square foot, depending on soil conditions and the density and types of plants used. Commercial, industrial and institutional site costs can range between \$10 to \$40 per square foot, based on the need for control structures, curbing, storm drains and underdrains.

Retrofitting a site typically costs more, averaging \$6,500 per bioretention area. The higher costs are attributed to the demolition of existing concrete, asphalt, and existing structures and the replacement of fill material with planting soil. The costs of retrofitting a commercial site in Maryland, Kettering Development, with 15 bioretention areas were estimated at \$111,600.

In any bioretention area design, the cost of plants varies substantially and can account for a significant portion of the expenditures. While these cost estimates are slightly greater than those of typical landscaping treatment (due to the increased number of plantings, additional soil excavation, backfill material, use of underdrains etc.), those landscaping expenses that would be required regardless of the bioretention installation should be subtracted when determining the net cost.

Perhaps of most importance, however, the cost savings compared to the use of traditional structural stormwater conveyance systems makes bioretention areas quite attractive financially. For example, the use of bioretention can decrease the cost required for constructing stormwater conveyance systems at a site. A medical office building in Maryland was able to reduce the amount of storm drain pipe that was needed from 800 to 230 feet - a cost savings of \$24,000 (PGDER, 1993). And a new residential development spent a total of approximately \$100,000 using bioretention cells on each lot instead of nearly \$400,000 for the traditional stormwater ponds that were originally planned (Rappahanock,). Also, in residential areas, stormwater management controls become a part of each property owner's landscape, reducing the public burden to maintain large centralized facilities.

Maintenance Cost

The operation and maintenance costs for a bioretention facility will be comparable to those of typical landscaping required for a site. Costs beyond the normal landscaping fees will include the cost for testing the soils and may include costs for a sand bed and planting soil.

References and Sources of Additional Information

Coffman, L.S., R. Goo and R. Frederick, 1999: Low impact development: an innovative alternative approach to stormwater management. Proceedings of the 26th Annual Water Resources Planning and Management Conference ASCE, June 6-9, Tempe, Arizona.

Davis, A.P., Shokouhian, M., Sharma, H. and Minami, C., "Laboratory Study of Biological Retention (Bioretention) for Urban Stormwater Management," *Water Environ. Res.*, 73(1), 5-14 (2001).

Davis, A.P., Shokouhian, M., Sharma, H., Minami, C., and Winogradoff, D. "Water Quality Improvement through Bioretention: Lead, Copper, and Zinc," *Water Environ. Res.*, accepted for publication, August 2002.

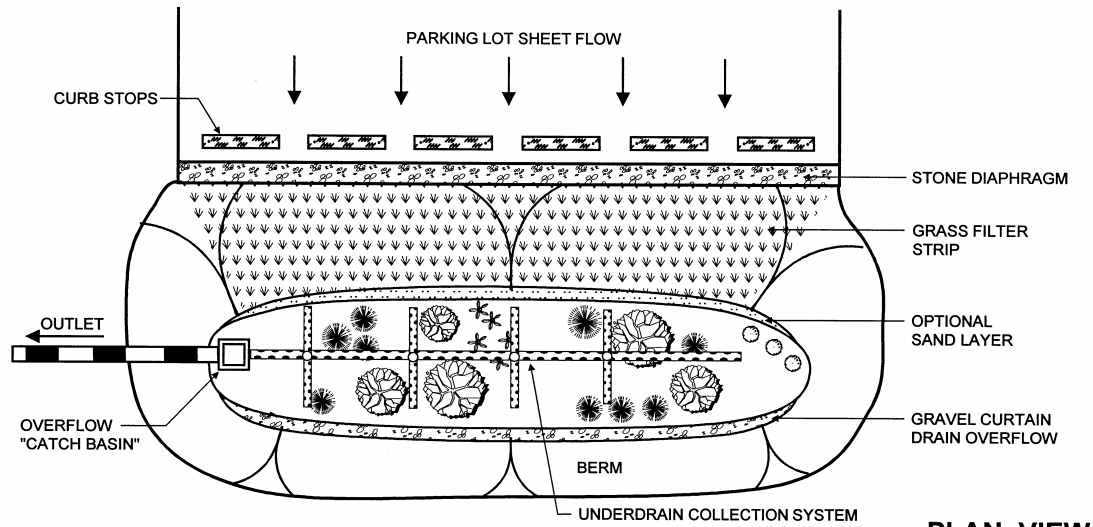
Kim, H., Seagren, E.A., and Davis, A.P., "Engineered Bioretention for Removal of Nitrate from Stormwater Runoff," *WEFTEC 2000 Conference Proceedings on CDROM Research Symposium, Nitrogen Removal*, Session 19, Anaheim CA, October 2000.

Hsieh, C.-h. and Davis, A.P. "Engineering Bioretention for Treatment of Urban Stormwater Runoff," *Watersheds 2002, Proceedings on CDROM Research Symposium*, Session 15, Ft. Lauderdale, FL, Feb. 2002.

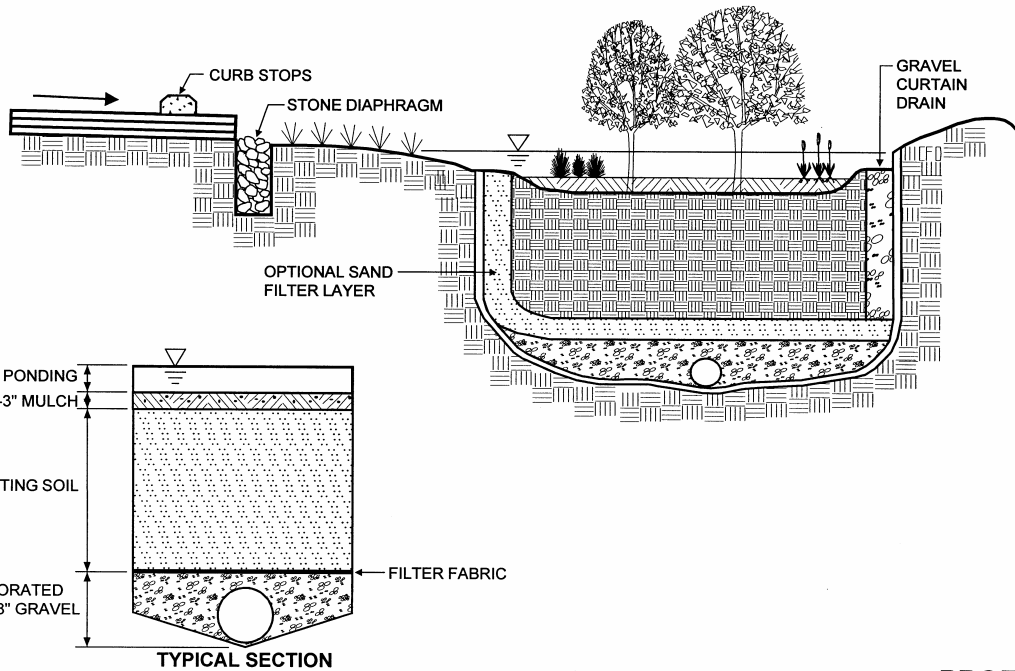
Prince George's County Department of Environmental Resources (PGDER), 1993. Design Manual for Use of *Bioretention in Stormwater Management*. Division of Environmental Management, Watershed Protection Branch. Landover, MD.

U.S. EPA Office of Water, 1999. Stormwater Technology Fact Sheet: Bioretention. EPA 832-F-99-012.

Weinstein, N. Davis, A.P. and Veeramachaneni, R. "Low Impact Development (LID) Stormwater Management Approach for the Control of Diffuse Pollution from Urban Roadways," *5th International Conference Diffuse/Nonpoint Pollution and Watershed Management Proceedings*, C.S. Melching and Emre Alp, Eds. 2001 International Water Association



PLAN VIEW



PROFILE

Schematic of a Bioretention Facility (MDE, 2000)



Design Considerations

- Aesthetics
- Hydraulic Head

Description

Stormwater media filters are usually two-chambered including a pretreatment settling basin and a filter bed filled with sand or other absorptive filtering media. As stormwater flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as stormwater flows through the filtering media in the second chamber. There are a number of design variations including the Austin sand filter, Delaware sand filter, and multi-chambered treatment train (MCTT).

California Experience

Caltrans constructed and monitored five Austin sand filters, two MCTTs, and one Delaware design in southern California. Pollutant removal was very similar for each of the designs; however operational and maintenance aspects were quite different. The Delaware filter and MCTT maintain permanent pools and consequently mosquito management was a critical issue, while the Austin style which is designed to empty completely between storms was less affected. Removal of the top few inches of sand was required at 3 of the Austin filters and the Delaware filter during the third year of operation; consequently, sizing of the filter bed is a critical design factor for establishing maintenance frequency.

Advantages

- Relatively high pollutant removal, especially for sediment and associated pollutants.
- Widespread application with sufficient capture volume can provide significant control of channel erosion and enlargement caused by changes to flow frequency relationships resulting from the increase of impervious cover in a watershed.

Limitations

Targeted Constituents

- | | | |
|---|----------------|---|
| ✓ | Sediment | ■ |
| ✓ | Nutrients | ● |
| ✓ | Trash | ■ |
| ✓ | Metals | ■ |
| ✓ | Bacteria | ▲ |
| ✓ | Oil and Grease | ■ |
| ✓ | Organics | ■ |

Legend (Removal Effectiveness)

- | | | | |
|---|--------|---|------|
| ● | Low | ■ | High |
| ▲ | Medium | | |



- More expensive to construct than many other BMPs.
- May require more maintenance than some other BMPs depending upon the sizing of the filter bed.
- Generally require more hydraulic head to operate properly (minimum 4 feet).
- High solids loads will cause the filter to clog.
- Work best for relatively small, impervious watersheds.
- Filters in residential areas can present aesthetic and safety problems if constructed with vertical concrete walls.
- Certain designs (e.g., MCTT and Delaware filter) maintain permanent sources of standing water where mosquito and midge breeding is likely to occur.

Design and Sizing Guidelines

- Capture volume determined by local requirements or sized to treat 85% of the annual runoff volume.
- Filter bed sized to discharge the capture volume over a period of 48 hours.
- Filter bed 18 inches thick above underdrain system.
- Include energy dissipation in the inlet design to reduce resuspension of accumulated sediment.
- A maintenance ramp should be included in the design to facilitate access to the sedimentation and filter basins for maintenance activities (particularly for the Austin design).
- Designs that utilize covered sedimentation and filtration basins should be accessible to vector control personnel via access doors to facilitate vector surveillance and controlling the basins if needed.

Construction/Inspection Considerations

- Tributary area should be completely stabilized before media is installed to prevent premature clogging.

Performance

The pollutant removal performance of media filters and other stormwater BMPs is generally characterized by the percent reduction in the influent load. This method implies a relationship between influent and effluent concentrations. For instance, it would be expected that a device that is reported to achieve a 75% reduction would have an effluent concentration equal to 25% of the influent concentrations. Recent work in California (Caltrans, 2002) on various sand filter designs indicates that this model for characterizing performance is inadequate. Figure 4 presents a graph relating influent and effluent TSS concentrations for the Austin full sedimentation design.

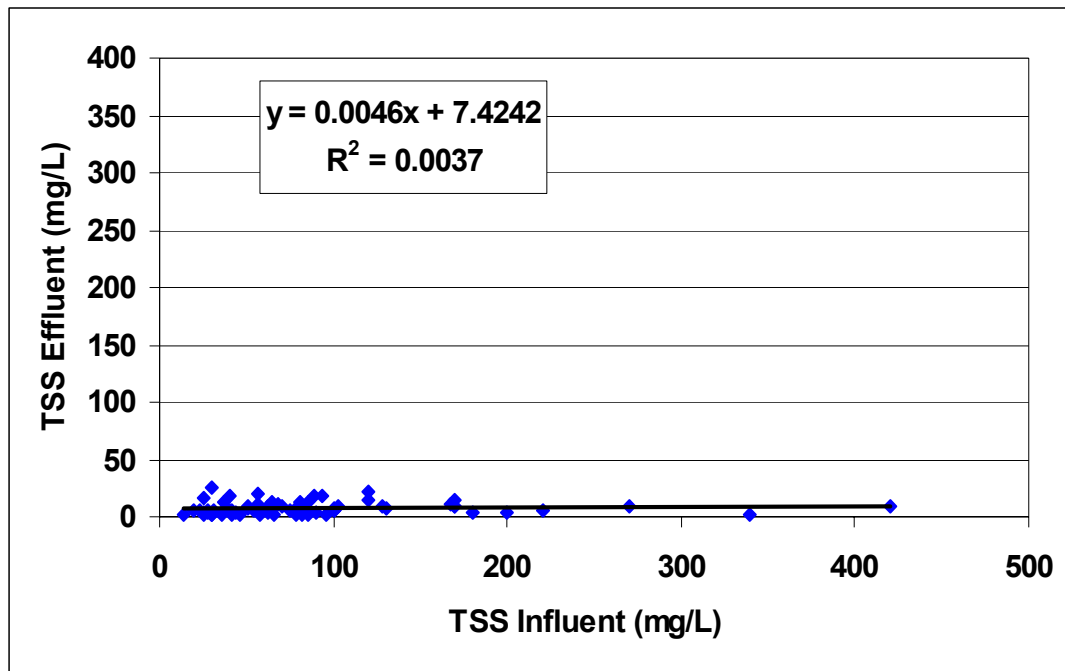


Figure 4
Comparison of Influent and Effluent Concentrations for TSS

It is clearly evident that the effluent concentration is relative constant and independent of influent concentration. Consequently, the performance is more accurately characterized by the effluent concentration, which is about 7.5 mg/L. Constant effluent concentrations also are observed for all other particle related constituents such as particulate metals (total - dissolved) and particulate phosphorus.

The small uncertainty in the estimate of the mean effluent concentration highlights the very consistent effluent quality for TSS produced by sand filters. In addition, it demonstrates that a calculated percent reduction for TSS and other constituents with similar behavior for Austin sand filters is a secondary characteristic of the device and depends primarily on the specific influent concentrations observed. The distinction between a constant effluent quality and a percent reduction is extremely important to recognize if the results are to be used to estimate effluent quality from sand filters installed at other sites with different influent concentrations or for estimating compliance with water quality standards for storms with high concentrations of particulate constituents.

If the conventionally derived removal efficiency (90%) were used to estimate the TSS concentrations in the treated runoff from storms with high influent concentrations, the estimated effluent concentration would be too high. For instance, the storm with the highest observed influent concentration (420 mg/L) would be expected to have a concentration in the treated runoff of 42 mg/L, rather than the 10 mg/L that was measured. In fact, the TSS effluent concentrations for all events with influent concentrations greater than 200 mg/L were 10 mg/L or less.

The stable effluent concentration of a sand filter under very different influent TSS concentrations implies something about the properties of the influent particle size distribution. If one assumes that

only the smallest size fraction can pass through the filter, then the similarity in effluent concentrations suggests that there is little difference in the total mass of the smallest sized particles even when the total TSS concentration varies greatly. Further, the difference in TSS concentration must then be caused by changes in the relative amount of the larger size fractions. Further research is necessary to determine the range of particle size that is effectively removed in the filter and the portion of the size fraction of suspended solids that it represents in urban stormwater.

Sand filters are effective stormwater management practices for pollutant removal. Conventional removal rates for all sand filters and organic filters are presented in Table 1. With the exception of nitrates, which are always exported from filtering systems because of the conversion of ammonia and organic nitrogen to nitrate, they perform relatively well at removing pollutants.

Table 1 Sand filter removal efficiencies (percent)

	Sand Filter (Glick et al, 1998)	Compost Filter System		Multi-Chamber Treatment Train		
		Stewart, 1992	Leif, 1999	Pitt et al., 1997	Pitt, 1996	Greb et al., 1998
TSS	89	95	85	85	83	98
TP	59	41	4	80	-	84
TN	17	-	-	-	-	-
Nitrate	-76	-34	-95	-	14	-
Metals	72-86	61-88	44-75	65-90	91-100	83-89
Bacteria	65	-	-	-	-	-

From the few studies available, it is difficult to determine if organic filters necessarily have higher removal efficiencies than sand filters. The MCTT may have high pollutant removal for some constituents, although an evaluation of these devices by the California Department of Transportation indicated no significant difference for most conventional pollutants.

In addition to the relatively high pollutant removal in media filters, these devices, when sized to capture the channel forming storm volume, are highly effective at attenuating peak flow rates and reducing channel erosion.

Siting Criteria

In general, sand filters are preferred over infiltration practices, such as infiltration trenches, when contamination of groundwater with conventional pollutants is of concern. This usually occurs in areas where underlying soils alone cannot treat runoff adequately - or ground water tables are high. In most cases, sand filters can be constructed with impermeable basin or chamber bottoms, which help to collect, treat, and release runoff to a storm drainage system or directly to surface water with no contact between contaminated runoff and groundwater. In regions where evaporation exceeds rainfall and a wet pond would be unlikely to maintain the required permanent pool, a sand filtration system can be used.

The selection of a sand filter design depends largely on the drainage area's characteristics. For example, the Washington, D.C. and Delaware sand filter systems are well suited for highly impervious areas where land available for structural controls is limited, since both are installed underground. They have been used to treat runoff from parking lots, driveways, loading docks, service stations, garages, airport runways/taxiways, and storage yards. The Austin sand filtration system is more suited for large drainage areas that have both impervious and pervious surfaces. This system is located at grade and is used to treat runoff from any urban land use.

It is challenging to use most sand filters in very flat terrain because they require a significant amount of hydraulic head (about 4 feet), to allow flow through the system. One exception is the perimeter sand filter, which can be applied with as little as 2 feet of head.

Sand filters are best applied on relatively small sites (up to 25 acres for surface sand filters and closer to 2 acres for perimeter or underground filters). Filters have been used on larger drainage areas, of up to 100 acres, but these systems can clog when they treat larger drainage areas unless adequate measures are provided to prevent clogging, such as a larger sedimentation chamber or more intensive regular maintenance.

When sand filters are designed as a stand-alone practice, they can be used on almost any soil because they can be designed so that stormwater never infiltrates into the soil or interacts with the ground water. Alternatively, sand filters can be designed as pretreatment for an infiltration practice, where soils do play a role.

Additional Design Guidelines

Pretreatment is a critical component of any stormwater management practice. In sand filters, pretreatment is achieved in the sedimentation chamber that precedes the filter bed. In this chamber, the coarsest particles settle out and thus do not reach the filter bed. Pretreatment reduces the maintenance burden of sand filters by reducing the potential for these sediments to clog the filter. When pretreatment is not provided designers should increase the size of the filter area to reduce the clogging potential. In sand filters, designers should select a medium sand as the filtering medium. A fine aggregate (ASTM C-33) that is intended for use in concrete is commonly specified.

Many guidelines recommend sizing the filter bed using Darcy's Law, which relates the velocity of fluids to the hydraulic head and the coefficient of permeability of a medium. The resulting equation, as derived by the city of Austin, Texas, (1996), is

$$A_f = WQV d / [k t (h+d)]$$

Where:

A_f = area of the filter bed (ft²);

d = depth of the filter bed (ft; usually about 1.5 feet, depending on the design);

k = coefficient of permeability of the filtering medium (ft/day);

t = time for the water quality volume to filter through the system (days; usually assumed to be 1.67 days); and

h = average water height above the sand bed (ft; assumed to be one-half of the maximum head).

Typical values for k, as assembled by CWP (1996), are shown in Table 2.

Filter Medium	Coefficient of Permeability (ft/day)
Sand	3.5
Peat/Sand	2.75
Compost	8.7

The permeability of sand shown in Table 2 is extremely conservative, but is widely used since it is incorporated in the design guidelines of the City of Austin. When the sand is initially installed, the permeability is so high (over 100 ft/d) that generally only a portion of the filter area is required to infiltrate the entire volume, especially in a “full sedimentation” Austin design where the capture volume is released to the filter basin over 24 hours.

The preceding methodology results in a filter bed area that is oversized when new and the entire water quality volume is filtered in less than a day with no significant height of water on top of the sand bed. Consequently, the following simple rule of thumb is adequate for sizing the filter area. If the filter is preceded by a sedimentation basin that releases the water quality volume (WQV) to the filter over 24 hours, then

$$A_f = WQV/18$$

If no pretreatment is provided then the filter area is calculated more conservatively as:

$$A_f = WQV/10$$

Typically, filtering practices are designed as “off-line” systems, meaning that during larger storms all runoff greater than the water quality volume is bypassed untreated using a flow splitter, which is a structure that directs larger flows to the storm drain system or to a stabilized channel. One exception is the perimeter filter; in this design, all flows enter the system, but larger flows overflow to an outlet chamber and are not treated by the practice.

The Austin design variations are preferred where there is sufficient space, because they lack a permanent pool, which eliminates vector concerns. Design details of this variation are summarized below.

Summary of Design Recommendations

- (1) Capture Volume - The facility should be sized to capture the required water quality volume, preferably in a separate pretreatment sedimentation basin.

- (2) Basin Geometry – The water depth in the sedimentation basin when full should be at least 2 feet and no greater than 10 feet. A fixed vertical sediment depth marker should be installed in the sedimentation basin to indicate when 20% of the basin volume has been lost because of sediment accumulation. When a pretreatment sedimentation basin is provided the minimum average surface area for the sand filter (A_f) is calculated from the following equation:

$$A_f = WQV/18$$

If no pretreatment is provided then the filter area is calculated as:

$$A_f = WQV/10$$

- (3) Sand and Gravel Configuration - The sand filter is constructed with 18 inches of sand overlying 6 inches of gravel. The sand and gravel media are separated by permeable geotextile fabric and the gravel layer is situated on geotextile fabric. Four-inch perforated PVC pipe is used to drain captured flows from the gravel layer. A minimum of 2 inches of gravel must cover the top surface of the PVC pipe. Figure 5 presents a schematic representation of a standard sand bed profile.
- (4) Sand Properties – The sand grain size distribution should be comparable to that of “washed concrete sand,” as specified for fine aggregate in ASTM C-33.
- (5) Underdrain Pipe Configuration – In an Austin filter, the underdrain piping should consist of a main collector pipe and two or more lateral branch pipes, each with a minimum diameter of 4 inches. The pipes should have a minimum slope of 1% (1/8 inch per foot) and the laterals should be spaced at intervals of no more than 10 feet. There should be no fewer than two lateral branch pipes. Each individual underdrain pipe should have a cleanout access location. All piping is to be Schedule 40 PVC. The maximum spacing between rows of perforations should not exceed 6 inches.
- (6) Flow Splitter - The inflow structure to the sedimentation chamber should incorporate a flow-splitting device capable of isolating the capture volume and bypassing the 25-year peak flow around the facility with the sedimentation/filtration pond full.

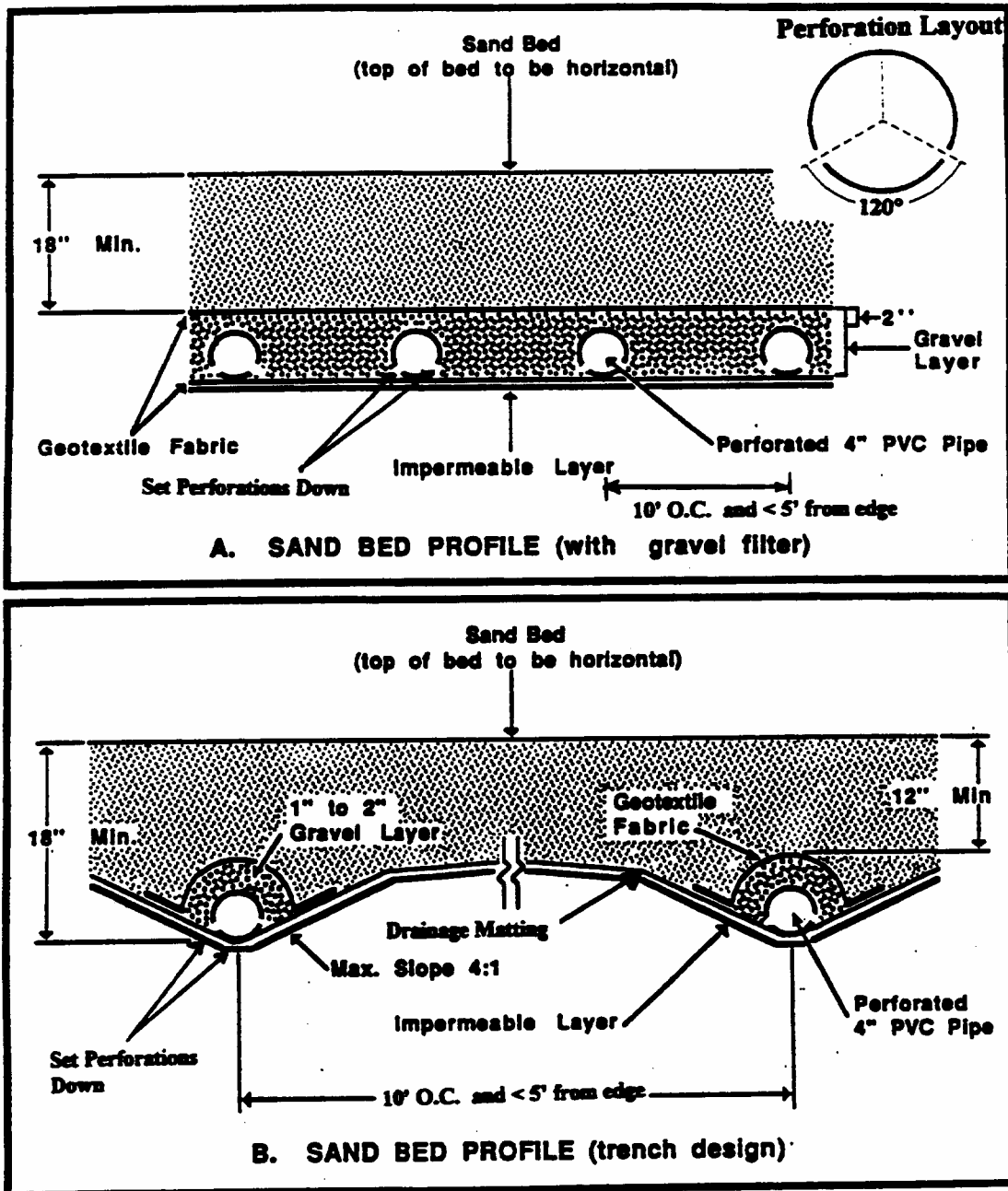


Figure 5
Schematic of Sand Bed Profile

- (7) Basin Inlet – Energy dissipation is required at the sedimentation basin inlet so that flows entering the basin should be distributed uniformly and at low velocity in order to prevent resuspension and encourage quiescent conditions necessary for deposition of solids.
- (8) Sedimentation Pond Outlet Structure - The outflow structure from the sedimentation chamber should be (1) an earthen berm; (2) a concrete wall; or (3) a rock gabion. Gabion outflow structures should extend across the full width of the facility such that no short-circuiting of flows can occur. The gabion rock should be 4 inches in diameter. The

receiving end of the sand filter should be protected (splash pad, riprap, etc.) such that erosion of the sand media does not occur. When a riser pipe is used to connect the sedimentation and filtration basins (example in Figure 6), a valve should be included to isolate the sedimentation basin in case of a hazardous material spill in the watershed. The control for the valve must be accessible at all times, including when the basin is full. The riser pipe should have a minimum diameter of 6 inches with four 1-inch perforations per row. The vertical spacing between rows should be 4 inches (on centers).

- (9) Sand Filter Discharge – If a gabion structure is used to separate the sedimentation and filtration basins, a valve must be installed so that discharge from the BMP can be stopped in case runoff from a spill of hazardous material enters the sand filter. The control for the valve must be accessible at all times, including when the basin is full.

Maintenance

Even though sand filters are generally thought of as one of the higher maintenance BMPs, in a recent California study an average of only about 49 hours a year were required for field activities. This was less maintenance than was required by extended detention basins serving comparable sized catchments. Most maintenance consists of routine removal of trash and debris, especially in Austin sand filters where the outlet riser from the sedimentation basin can become clogged.

Most data (i.e. Clark, 2001) indicate that hydraulic failure from clogging of the sand media occurs before pollutant breakthrough. Typically, only the very top of the sand becomes clogged while the rest remains in relative pristine condition as shown in Figure 7. The rate of clogging has been related to the TSS loading on the filter bed (Urbonas, 1999); however, the data are quite variable. Empirical observation of sites treating urban and highway runoff indicates that clogging of the filter occurs after 2 – 10 years of service. Presumably, this is related to differences in the type and amount of sediment in the catchment areas of the various installations. Once clogging occurs the top 2 – 3 inches of filter media is removed, which restores much, but not all, of the lost permeability. This removal of the surface layer can occur several times before the entire filter bed must be replaced. The cost of the removal of the surface layer is not prohibitive, generally ranging between \$2,000 (EPA Fact Sheet) and \$4,000 (Caltrans, 2002) depending on the size of the filter.

Media filters can become a nuisance due to mosquito and midge breeding in certain designs or if not regularly maintained. "Wet" designs (e.g., MCTT and Delaware filter) are more conducive to vectors than others (e.g., Austin filters) because they maintain permanent sources of standing water where breeding is likely to occur. Caltrans successfully excluded mosquitoes and midges from accessing the permanent water in the sedimentation basin of MCTT installations through use of a tight-fitting aluminum cover to seal vectors out. However, typical wet designs may require routine inspections and treatments by local mosquito and vector control agencies to suppress mosquito production. Vector habitats may also be created in "dry" designs when media filters clog, and/or when features such as level spreaders that hold water over 72 hours are included in the installation. Dry designs such as Austin filters should dewater completely (recommended 72 hour residence time or less) to prevent creating mosquito and other vector habitats. Maintenance efforts to prevent vector breeding in dry designs will need to focus on basic housekeeping practices such as removal of debris accumulations and vegetation management (in filter media) to prevent clogs and/or pools of standing water.

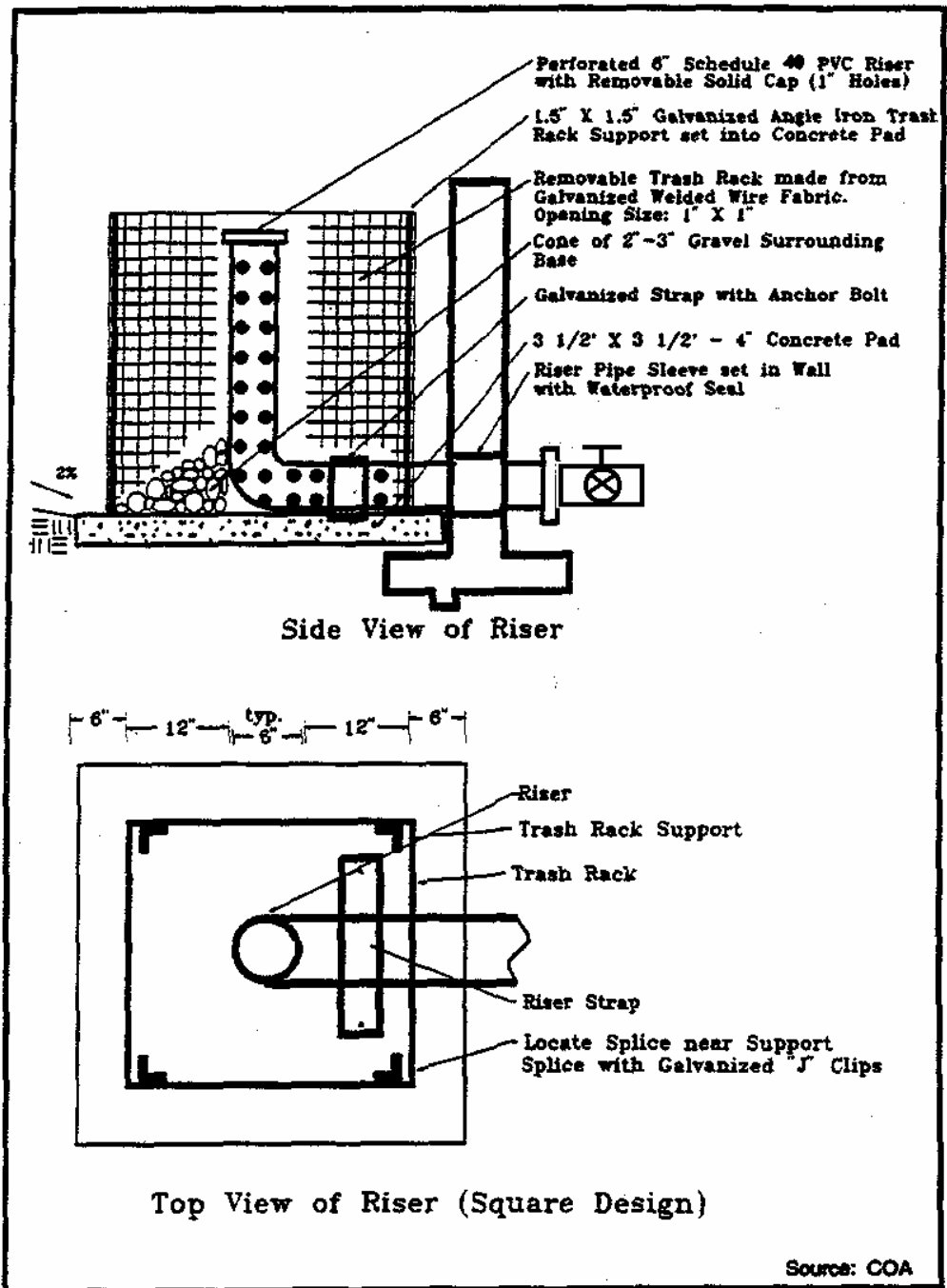


Figure 6
Detail of Sedimentation Riser Pipe



Figure 7
Formation of Clogging Crust on Filter Bed

Recommended maintenance activities and frequencies include:

- Inspections semi-annually for standing water, sediment, trash and debris, and to identify potential problems.
- Remove accumulated trash and debris in the sedimentation basin, from the riser pipe, and the filter bed during routine inspections.
- Inspect the facility once during the wet season after a large rain event to determine whether the facility is draining completely within 72 hr.
- Remove top 50 mm (2 in.) of sand and dispose of sediment if facility drain time exceeds 72 hr. Restore media depth to 450 mm (18 in.) when overall media depth drops to 300 mm (12 in.).
- Remove accumulated sediment in the sedimentation basin every 10 yr or when the sediment occupies 10 percent of the basin volume, whichever is less.

Cost

Construction Cost

There are few consistent published data on the cost of sand filters, largely because, with the exception of Austin, Texas, Alexandria, Virginia, and Washington, D.C., they have not been widely used. Furthermore, filters have such varied designs that it is difficult to assign a cost to filters in general. A study by Brown and Schueler (1997) was unable to find a statistically valid relationship between the volume of water treated in a filter and the cost of the practice. The EPA filter fact sheet indicates a cost for an Austin sand filter at \$18,500 (1997 dollars) for a 0.4 hectare- (1 acre-)

drainage area. However, the same design implemented at a 1.1 ha site by the California Department of Transportation, cost \$240,000. Consequently, there is a tremendous uncertainty about what the average construction cost might be.

It is important to note that, although underground and perimeter sand filters can be more expensive than surface sand filters, they consume no surface space, making them a relatively cost-effective practice in ultra-urban areas where land is at a premium.

Given the number of facilities installed in the areas that promote their use it should be possible to develop fairly accurate construction cost numbers through a more comprehensive survey of municipalities and developers that have implemented these filters.

Maintenance Cost

Annual costs for maintaining sand filter systems average about 5 percent of the initial construction cost (Schueler, 1992). Media is replaced as needed, with the frequency correlated with the solids loading on the filter bed. Currently the sand is being replaced in the D.C. filter systems about every 2 years, while an Austin design might last 3-10 years depending on the watershed characteristics. The cost to replace the gravel layer, filter fabric and top portion of the sand for D.C. sand filters is approximately \$1,700 (1997 dollars).

Caltrans estimated future maintenance costs for the Austin design, assuming a device sized to treat runoff from approximately 4 acres. These estimates are presented in Table 3 and assume a fully burdened hourly rate of \$44 for labor. This estimate is somewhat uncertain, since complete replacement of the filter bed was not required during the period that maintenance costs were recorded.

Activity	Labor Hours	Equipment and Materials (\$)	Cost
Inspections	4	0	176
Maintenance	36	125	1,706
Vector Control	0	0	0
Administration	3	0	132
Direct Costs	-	888	888
Total	43	\$1,013	\$2,902

References and Sources of Additional Information

Barton Springs/Edwards Aquifer Conservation District. 1996. *Final Report: Enhanced Roadway Runoff Best Management Practices*. City of Austin, Drainage Utility, LCRA, TDOT. Austin, TX. 200 pp.

Bell, W., L. Stokes, L.J. Gavan, and T.N. Nguyen. 1995. *Assessment of the Pollutant Removal Efficiencies of Delaware Sand Filter BMPs*. Final Report. Department of Transportation and

Environmental Services. Alexandria, VA. 140 pp. Also in Performance of Delaware Sand Filter Assessed. *Watershed Protection Techniques*. Center for Watershed Protection. Fall 1995. Vol. 2(1): 291–293.

Brown, W., and T. Schueler. 1997. *The Economics of Stormwater BMPs in the Mid-Atlantic Region*. Prepared for the Chesapeake Research Consortium, Edgewater, MD, by the Center for Watershed Protection, Ellicott City, MD.

Caltrans, 2002, *Proposed Final Report: BMP Retrofit Pilot Program*, California Dept. of Transportation Report CTSW-RT-01-050, Sacramento, CA.

Center for Watershed Protection (CWP). 1996. *Design of Stormwater Filtering Systems*. Prepared for the Chesapeake Research Consortium, Solomons, MD, and U.S. EPA Region 5, Chicago, IL, by the Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1997. Multi-Chamber Treatment Train developed for stormwater hot spots. *Watershed Protection Techniques* 2(3):445–449.

City of Austin, TX. 1990. *Removal Efficiencies of Stormwater Control Structures*. Final Report. Environmental Resource Management Division. 36 p. Also in: *Developments in Sand Filter Technology to Improve Stormwater Runoff Quality*. *Watershed Protection Techniques*. Center for Watershed Protection. Summer 1994. Vol. 1(2): 47–54.

City of Austin, TX. 1996. *Design of Water Quality Controls*. City of Austin, TX.

Clark, S.E., 2000, *Urban Stormwater Filtration: Optimization of Design Parameters and a Pilot-Scale Evaluation*, Ph.D. Dissertation, University of Alabama at Birmingham.

CSF Treatment Systems, Inc. (CSF). 1996. *Stormwater management promotional brochure*. CSF Treatment Systems, Inc., Portland, OR.

Curran, T. 1996. Peat Sand Efficiency Calculations for McGregor Park. Unpublished data. Lower Colorado River Authority. Austin, TX.

Galli, F. 1990. *Peat-Sand Filters: A Proposed Stormwater Management Practice for Urban Areas*. Metropolitan Washington Council of Governments, Washington, DC.

Glick, Roger, Chang, George C., and Barrett, Michael E., 1998, Monitoring and evaluation of stormwater quality control basins, in *Watershed Management: Moving from Theory to Implementation*, Denver, CO, May 3-6, 1998, pp. 369 – 376.

Greb, S., S. Corsi, and R. Waschbush. 1998. Evaluation of Stormceptor© and Multi-Chamber Treatment Train as Urban Retrofit Strategies. Presented at Retrofit Opportunities for Water Resource Protection in Urban Environments, A National Conference. The Westin Hotel, Chicago, IL, February 10–12, 1998.

Harper, H., and J. Herr. 1993. *Treatment Efficiency of Detention With Filtration Systems*. Environmental Research and Design, Inc. Final Report Submitted to Florida Department of Environmental Regulation. Orlando, FL. 164 pp.

Horner, R.R. and Horner, C.R., 1999, Performance of a Perimeter (“Delaware”) Sand Filter in Treating Stormwater Runoff from a Barge Loading Terminal. *Proc. of the Comprehensive Stormwater and Aquatic Ecosystem Management Conf.*, Auckland, N.Z., Feb. 1999, pp. 183-192.

Horner, R.R., and C.R. Horner. 1995. *Design, Construction and Evaluation of a Sand Filter Stormwater Treatment System*. Part II. Performance Monitoring. Report to Alaska Marine Lines, Seattle, WA. 38 p. Also in Performance of Delaware Sand Filter Assessed. *Watershed Protection Techniques*. Center for Watershed Protection. Fall 1995. Vol. 2(1): 291–293.

Keblin, Michael V., Barrett, Michael E., Malina, Joseph F., Jr., Charbeneau, Randall J, 1998, *The Effectiveness of Permanent Highway Runoff Controls: Sedimentation/Filtration Systems*, Research Report 2954-1, Center for Transportation Research, University of Texas at Austin.

King County, Washington, Department of Natural Resources. 2000. *King County Surface Water Design Manual*. <http://splash.metrokc.gov/wlr/dss/manual.htm>. Last updated March 6, 2000. Accessed January 5, 2001.

Leif, T. 1999. *Compost Stormwater Filter Evaluation*. Snohomish County, Washington, Department of Public Works, Everett, WA.

Maryland Department of the Environment (MDE). 2000. *Maryland Stormwater Design Manual*. <http://www.mde.state.md.us/environment/wma/stormwatermanual>. Accessed May 22, 2001.

Metzger, M. E., D. F. Messer, C. L. Beitia, C. M. Myers, and V. L. Kramer. 2002. The fvBMPs. *Stormwater* 3(2): 24-39.

Pitt, R. 1996. The Control of Toxicants at Critical Source Areas. Presented at the ASCE/Engineering Foundation Conference, Snowbird, UT, August 1996.

Pitt, R., M. Lilburn, and S. Burian. 1997. *Storm Drainage Design for the Future: Summary of Current U.S. EPA Research*. American Society of Civil Engineers Technical Conference, Gulf Shores, AL, July 1997.

Robertson, B., R. Pitt, A. Ayyoubi, and R. Field. 1995. A Multi-Chambered Stormwater Treatment Train. In *Proceedings of the Engineering Foundation Conference: Stormwater NPDES-Related Monitoring Needs, Mt. Crested Butte, Colorado, August 7–12, 1994*, American Society of Civil Engineers, New York, New York.

Schueler, T. 1994. Developments in sand filter technology to improve stormwater runoff quality. *Watershed Protection Techniques* 1(2):47–54.

Schueler, T. 1997. Comparative Pollutant Removal Capability of Urban BMPs: A Reanalysis. *Watershed Protection Techniques* 2(4):515–520.

Stewart, W. 1992. *Compost Stormwater Treatment System*. W&H Pacific Consultants. Draft Report. Portland, OR. Also in Innovative Leaf Compost System Used to Filter Runoff at Small Sites in the Northwest. *Watershed Protection Techniques*. Center for Watershed Protection. February 1994. Vol. 1(1): 13–14.

Urbonas, B.R, 1999, Design of a sand filter for stormwater quality enhancement, Water Environment Research, V. 71, No. 1, pp. 102-113.

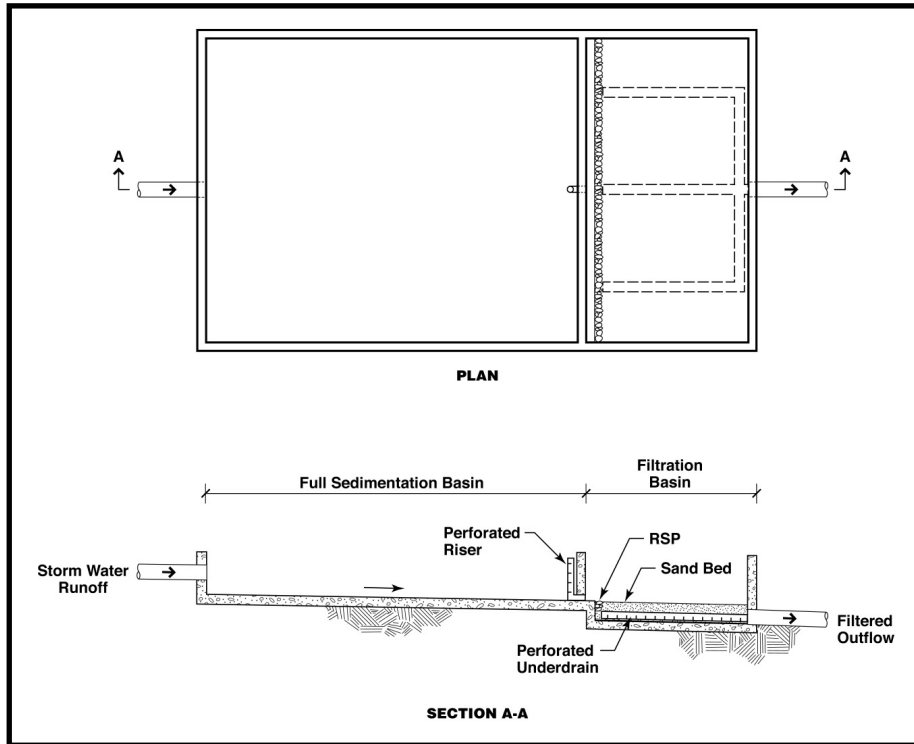
U.S. EPA, 1999, Stormwater Technology Fact Sheet: Sand Filters, Report EPA 832-F-99-007 <http://www.epa.gov/owm/mtb/sandfltr.pdf>, Office of Water, Washington, DC

Washington State Department of Ecology (DOE). 1992. *Stormwater Management Manual for the Puget Sound Basin*, Washington State Department of Ecology, Olympia, WA.

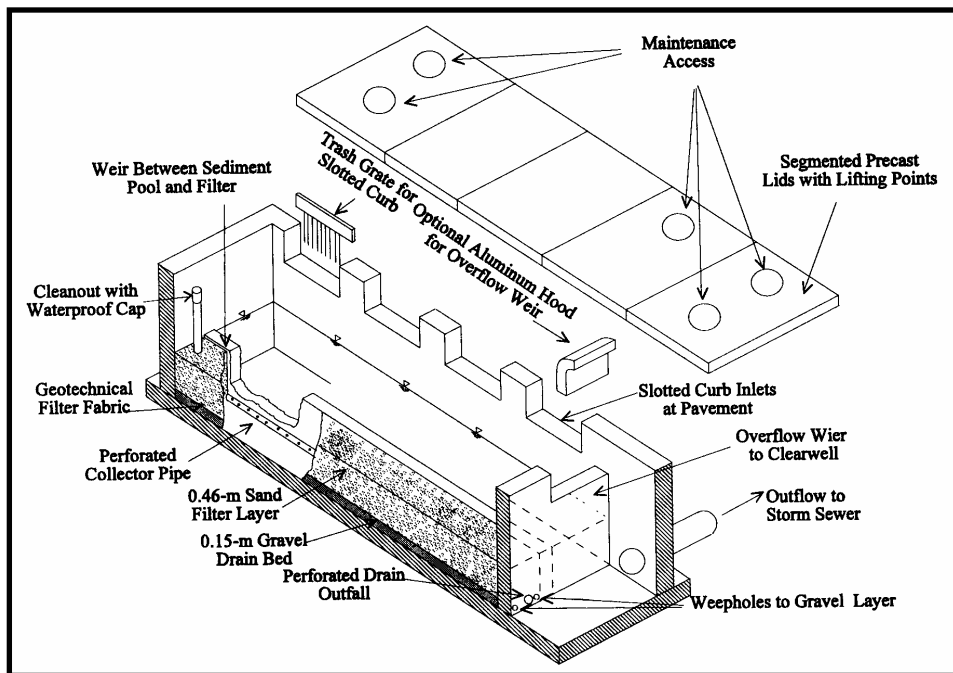
Watershed Management Institute (WMI). 1997. *Operation, Maintenance, and Management of Stormwater Management Systems*. Prepared for U.S. EPA Office of Water, Washington, DC, by Watershed Management Institute.

Welborn, C., and J. Veenhuis. 1987. *Effects of Runoff Controls on the Quantity and Quality of Urban Runoff in Two Locations in Austin, TX*. USGS Water Resources Investigations Report. 87-4004. 88 pp.

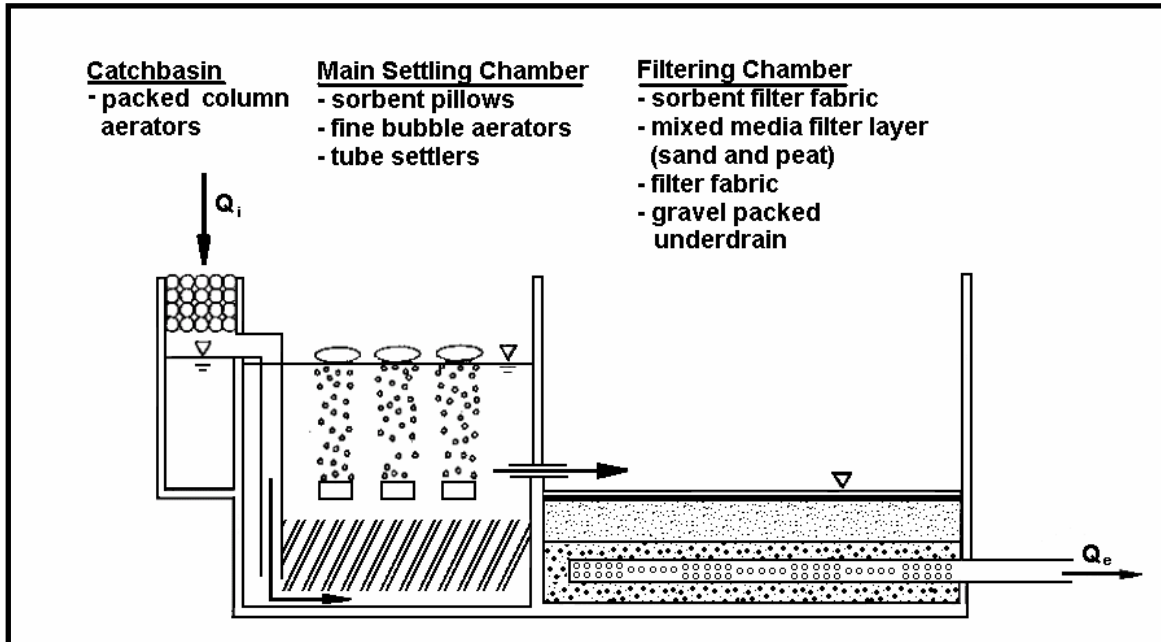
Young, G.K., et al., 1996, *Evaluation and Management of Highway Runoff Water Quality*, Publication No. FHWA-PD-96-032, U.S. Department of Transportation, Federal Highway Administration, Office of Environment and Planning.



Schematic of the "Full Sedimentation" Austin Sand Filter



Schematic of a Delaware Sand Filter (Young et al., 1996)



Schematic of a MCTT (Robertson et al., 1995)

Description

Water quality inlets (WQIs), also commonly called trapping catch basins, oil/grit separators or oil/water separators, consist of one or more chambers that promote sedimentation of coarse materials and separation of free oil (as opposed to emulsified or dissolved oil) from stormwater. Some WQIs also contain screens to help retain larger or floating debris, and many of the newer designs also include a coalescing unit that helps promote oil/water separation. A typical WQI, as shown in the schematic, consists of a sedimentation chamber, an oil separation chamber, and a discharge chamber.

These devices are appropriate for capturing hydrocarbon spills, but provide very marginal sediment removal and are not very effective for treatment of stormwater runoff. WQIs typically capture only the first portion of runoff for treatment and are generally used for pretreatment before discharging to other best management practices (BMPs).

California Experience

Caltrans investigated the use of coalescing plate oil/water separators at maintenance stations in Southern California. Twenty-two maintenance stations were originally considered for implementation of this technology; however, only one site appeared to have concentrations that were sufficiently high to warrant installation of an oil-water separator. Concentrations of free oil in stormwater runoff observed during the course of the study even from this site were too low for effective operation of this technology, and no free oil was ever captured by the device.

Advantages

- Can provide spill control.

Limitations

- WQIs generally provide limited hydraulic and residuals storage. Due to the limited storage, WQIs do not provide substantial stormwater improvement.
- Standing water in the devices can provide a breeding ground for mosquitoes.
- Certain designs maintain permanent sources of standing water where mosquito and other vector breeding may occur.

Design and Sizing Guidelines

- Water quality inlets are most effective for spill control and should be sized accordingly.

Design Considerations

- Area Required

Targeted Constituents

✓ Sediment	●
✓ Nutrients	●
✓ Trash	▲
✓ Metals	●
✓ Bacteria	●
✓ Oil and Grease	▲
✓ Organics	●

Legend (Removal Effectiveness)

- Low
- High
- ▲ Medium



- Designs that utilize covered sedimentation and filtration basins should be accessible to vector control personnel via access doors to facilitate vector surveillance and controlling the basins if needed.

Performance

WQIs are primarily utilized to remove sediment from stormwater runoff. Grit and sediment are partially removed by gravity settling within the first two chambers. A WQI with a detention time of 1 hour may expect to have 20 to 40 percent removal of sediments. Hydrocarbons associated with the accumulated sediments are also often removed from the runoff through this process. The WQI achieves slight, if any, removal of nutrients, metals and organic pollutants other than free petroleum products (Schueler, 1992).

A 1993 MWCOG study found that an average of less than 5 centimeters (2 inches) of sediments (mostly coarse-grained grit and organic matter) were trapped in the WQIs. Hydrocarbon and total organic carbon (TOC) concentrations of the sediments averaged 8,150 and 53,900 milligrams per kilogram, respectively. The mean hydrocarbon concentration in the WQI water column was 10 milligrams per liter. The study also indicated that sediment accumulation did not increase over time, suggesting that the sediments become re-suspended during storm events. The authors concluded that although the WQI effectively separates oil and grease from water, re-suspension of the settled matter appears to limit removal efficiencies. Actual removal only occurs when the residuals are removed from the WQI (Schueler 1992).

A 1990 report by API found that the efficiency of oil and water separation in a WQI is inversely proportional to the ratio of the discharge rate to the unit's surface area. Due to the small capacity of the WQI, the discharge rate is typically very high and the detention time is very short. For example, the MWCOG study found that the average detention time in a WQI is less than 0.5 hour. This can result in minimal pollutant settling (API, 1990). However, the addition of coalescing units in many current WQI units may increase oil/water separation efficiency. Most coalescing units are designed to achieve a specific outlet concentration of oil and grease (for example, 10-15 mg/L oil and grease).

Pollutant removal in stormwater inlets can be somewhat improved using inserts, which are promoted for removal of oil and grease, trash, debris, and sediment. Some inserts are designed to drop directly into existing catch basins, while others may require extensive retrofit construction.

Siting Criteria

Oil/water separation units are often utilized in specific industrial areas, such as airport aprons, equipment washdown areas, or vehicle storage areas. In these instances, runoff from the area of concern will usually be diverted directly into the unit, while all other runoff is sent to the storm drain downstream from the oil/water separator. Oil/water separation tanks are often fitted with diffusion baffles at the inlets to prevent turbulent flow from entering the unit and resuspending settled pollutants.

Additional Design Guidelines

Prior to WQI design, the site should be evaluated to determine if another BMP would be more cost-effective in removing the pollutants of concern. WQIs should be used when no other BMP is feasible. The WQI should be constructed near a storm drain network so that flow can be easily diverted to the WQI for treatment (NVPDC, 1992). Any construction activities within the

drainage area should be completed before installation of the WQI, and the drainage area should be revegetated so that the sediment loading to the WQI is minimized.

WQIs are most effective for small drainage areas. Drainage areas of 0.4 hectares (1 acre) or less are often recommended. WQIs are typically used in an off-line configuration (i.e., portions of runoff are diverted to the WQI), but they can be used as on-line units (i.e., receive all runoff). Generally, off-line units are designed to handle the first 1.3 centimeters (0.5 inches) of runoff from the drainage areas. Upstream isolation/diversion structures can be used to divert the water to the off-line structure (Schueler, 1992). On-line units receive higher flows that will likely cause increased turbulence and resuspension of settled material, thereby reducing WQI performance.

Oil/water separation tanks are often fitted with diffusion baffles at the inlets to prevent turbulent flow from entering the unit and resuspending settled pollutants. WQIs are available as pre-manufactured units or can be cast in place. Reinforced concrete should be used to construct below-grade WQIs. The WQIs should be water tight to prevent possible ground water contamination.

Maintenance

Typical maintenance of WQIs includes trash removal if a screen or other debris capturing device is used, and removal of sediment using a vacuum truck. Operators need to be properly trained in WQI maintenance. Maintenance should include keeping a log of the amount of sediment collected and the date of removal. Some cities have incorporated the use of GIS systems to track sediment collection and to optimize future catch basin cleaning efforts.

One study (Pitt, 1985) concluded that WQIs can capture sediments up to approximately 60 percent of the sump volume. When sediment fills greater than 60 percent of their volume, catch basins reach steady state. Storm flows can then resuspend sediments trapped in the catch basin, and will bypass treatment. Frequent clean-out can retain the volume in the catch basin sump available for treatment of stormwater flows.

At a minimum, these inlets should be cleaned at least twice during the wet season. Two studies suggest that increasing the frequency of maintenance can improve the performance of catch basins, particularly in industrial or commercial areas. One study of 60 catch basins in Alameda County, California, found that increasing the maintenance frequency from once per year to twice per year could increase the total sediment removed by catch basins on an annual basis (Mineart and Singh, 1994). Annual sediment removed per inlet was 54 pounds for annual cleaning, 70 pounds for semi-annual and quarterly cleaning, and 160 pounds for monthly cleaning. For catch basins draining industrial uses, monthly cleaning increased total annual sediment collected to six times the amount collected by annual cleaning (180 pounds versus 30 pounds). These results suggest that, at least for industrial uses, more frequent cleaning of catch basins may improve efficiency.

BMPs designed with permanent water sumps, vaults, and/or catch basins (frequently installed below-ground) can become a nuisance due to mosquito and other vector breeding. Preventing mosquito access to standing water sources in BMPs (particularly below-ground) is the best prevention plan, but can prove challenging due to multiple entrances and the need to maintain the hydraulic integrity of the system. BMPs that maintain permanent standing water may require routine inspections and treatments by local mosquito and vector control agencies to

suppress mosquito production. Standing water in oil/water separators may contain sufficient floating hydrocarbons to prevent mosquito breeding, but this is not a reliable control alternative to vector exclusion or chemical treatment.

Cost

A typical pre-cast catch basin costs between \$2,000 and \$3,000; however, oil/water separators can be much more expensive. The true pollutant removal cost associated with catch basins, however, is the long-term maintenance cost. A vactor truck, the most common method of catch basin cleaning, costs between \$125,000 and \$150,000. This initial cost may be high for smaller Phase II communities. However, it may be possible to share a vactor truck with another community. Typical vactor trucks can store between 10 and 15 cubic yards of material, which is enough storage for three to five catch basins. Assuming semi-annual cleaning, and that the vactor truck could be filled and material disposed of twice in one day, one truck would be sufficient to clean between 750 and 1,000 catch basins. Another maintenance cost is the staff time needed to operate the truck. Depending on the regulations within a community, disposal costs of the sediment captured in catch basins may be significant.

References and Sources of Additional Information

American Petroleum Institute (API), 1990. *Monographs on Refinery Environmental Control - Management of Water Discharges (Design and Operation of Oil-Water Separators)*. Publication 421, First Edition.

Aronson, G., D. Watson, and W. Pisaro. *Evaluation of Catch Basin Performance for Urban Stormwater Pollution Control*. U.S. Environmental Protection Agency, Washington, DC.

Berg, V.H., 1991. *Water Quality Inlets (Oil/Grit Separators)*. Maryland Department of the Environment, Sediment and Stormwater Administration.

Lager, J., W. Smith, R. Finn, and E. Finnemore. 1977. *Urban Stormwater Management and Technology: Update and Users' Guide*. Prepared for U.S. Environmental Protection Agency. EPA-600/8-77-014. 313 pp.

Metropolitan Washington Council of Governments (MWCOC), 1993. *The Quality of Trapped Sediments and Pool Water Within Oil Grit Separators in Suburban Maryland*. Interim Report.

Metzger, M. E., D. F. Messer, C. L. Beitia, C. M. Myers, and V. L. Kramer. 2002. The Dark Side Of Stormwater Runoff Management: Disease Vectors Associated With Structural Bmps. *Stormwater* 3(2): 24-39.

Metzger, M. E., and S. Kluh. 2003. Surface Hydrocarbons Vs. Mosquito Breeding. *Stormwater* 4(1): 10.

Mineart, P., and S. Singh. 1994. *Storm Inlet Pilot Study*. Alameda County Urban Runoff Clean Water Program, Oakland, CA.

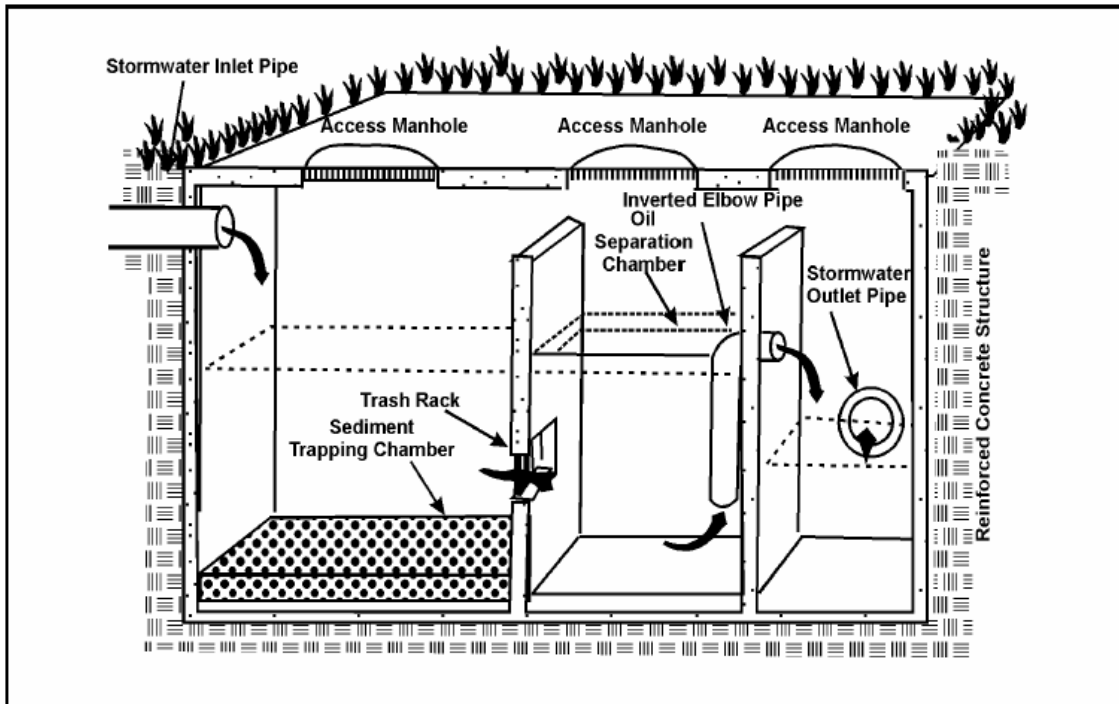
Northern Virginia Planning District Commission (NVPDC) and Engineers and Surveyors Institute, 1992. *Northern Virginia BMP Handbook*.

Pitt, R., and P. Bissonnette. 1984. *Bellevue Urban Runoff Program Summary Report*. U.S. Environmental Protection Agency, Water Planning Division, Washington, DC.

Pitt, R., M. Lilburn, S. Nix, S.R. Durrans, S. Burian, J. Voorhees, and J. Martinson. 2000. *Guidance Manual for Integrated Wet Weather Flow (WWF) Collection and Treatment Systems for Newly Urbanized Areas (New WWF Systems)*. U.S. Environmental Protection Agency, Office of Research and Development, Cincinnati, OH.

Schueler, T.R., 1992. *A Current Assessment of Urban Best Management Practices*. Metropolitan Washington Council of Governments.

U.S. EPA, 1999, Stormwater Technology Fact Sheet: Water Quality Inlets, EPA 832-F-99-029, Office of Water, Washington DC.



Description

A multiple treatment system uses two or more BMPs in series. Some examples of multiple systems include: settling basin combined with a sand filter; settling basin or biofilter combined with an infiltration basin or trench; extended detention zone on a wet pond.

California Experience

The research wetlands at Fremont, California are a combination of wet ponds, wetlands, and vegetated controls.

Advantages

- BMPs that are less sensitive to high pollutant loadings, especially solids, can be used to pretreat runoff for sand filters and infiltration devices where the potential for clogging exists.
- BMPs which target different constituents can be combined to provide treatment for all constituents of concern.
- BMPs which use different removal processes (sedimentation, filtration, biological uptake) can be combined to improve the overall removal efficiency for a given constituent.
- BMPs in series can provide redundancy and reduce the likelihood of total system failure.

Limitations

- Capital costs of multiple systems are higher than for single devices.
- Space requirements are greater than that required for a single technology.

Design and Sizing Guidelines

Refer to individual treatment control BMP fact sheets.

Performance

- Be aware that placing multiple BMPs in series does not necessarily result in combined cumulative increased performance. This is because the first BMP may already achieve part of the gain normally achieved by the second BMP. On the other hand, picking the right combination can often help optimize performance of the second BMP since the influent to the second BMP is of more consistent water quality, and thus more consistent performance, thereby allowing the BMP to achieve its highest performance.
- When addressing multiple constituents through multiple BMPs, one BMP may optimize removal of a particular constituent, while another BMP optimizes removal of a different

Design Considerations

- Area Required
- Slope
- Water Availability
- Hydraulic Head
- Environmental Side-effects

Targeted Constituents

✓ Sediment	■
✓ Nutrients	●
✓ Trash	■
✓ Metals	■
✓ Bacteria	▲
✓ Oil and Grease	■
✓ Organics	■

Legend (Removal Effectiveness)

- Low
- High
- ▲ Medium

constituent or set of constituents. Therefore, selecting the right combination of BMPs can be very constructive in collectively removing multiple constituents.

Siting Criteria

Refer to individual treatment control BMP fact sheets.

Additional Design Guidelines

- When using two or more BMPs in series, it may be possible to reduce the size of BMPs.
- Existing pretreatment requirements may be able to be avoided when using some BMP combinations.

Maintenance

Refer to individual treatment control BMP fact sheets.

Cost

Refer to individual treatment control BMP fact sheets.

Resources and Sources of Additional Information

Refer to individual treatment control BMP fact sheets.

Description

A manufactured wetland is similar to public domain stormwater wetlands. In a manufactured wetland, gravel substrate and subsurface flow of the stormwater through the root systems force the vegetation to remove nutrients and dissolved pollutants from the stormwater.

Only one company currently manufactures a pre-engineered wetland: It consists of a standard module, about 9.5 feet in diameter and 4 feet in height. The module is constructed of recycled polyethylene. The number of units is varied to meet the design volume of the site.

California Experience

There are currently only a few installations in California.

Advantages

- Constructed wetlands remove dissolved pollutants unlike many of the other treatment technologies, whether manufactured or in the public domain.
- Gravel substrate and subsurface flow of the stormwater through the root systems forces the vegetation to remove nutrients and dissolved pollutants from the stormwater.
- Unlike standard constructed wetlands (TC-21), there is no standing water in the manufactured wetland between storms (after emptying with each storm). This minimizes but does not entirely eliminate the opportunity for mosquito breeding.
- Can be incorporated into the landscaping of the development.
- The gravel substrate likely provides a good environment for bacteria, facilitating the removal of nitrogen and the degradation of oil and greases, and other organic compounds.
- The gravel substrate can be augmented with media that is specifically effective at removing dissolved pollutants, increasing further the performance of the system.
- Vegetation is more easily harvested in comparison to a wet pond or standard constructed wetland (TC-21).
- Provides modest habitat for insects and other small invertebrates which in turn provide food for birds and other small animals.

Design Considerations

- Drainage Area Size
- Potential Pretreatment Requirements

Targeted Constituents

- ✓ Sediment
- ✓ Nutrients
- ✓ Trash
- ✓ Metals
- ✓ Bacteria
- ✓ Oil and Grease
- ✓ Organics

Removal Effectiveness

See New Development and Redevelopment Handbook-Section 5.



Limitations

- Not likely suitable for drainage areas greater than an acre due to the number of units that is required for larger sites.
- May attract invasive wetland species
- May require irrigation during the dry season
- With an emptying time as much as 5 days, a breeding ground for mosquitoes may occur during and immediately following each storm
- If site development requirements of local government also includes detention for flow control, the drawdown characteristics of the system must be compatible with the detention system.
- Where many units are required, the pattern of circular plastic covers of the center wells may not be appealing.

Design and Sizing Guidelines

The unit consists of two concentric chambers, analogous to a doughnut. The inner chamber is open whereas the outer chamber is filled with gravel in which the wetland plants reside. The water enters a center well, moving in a circular motion around nearly the entire circumference of the well. Via floating surface skimmers the water then enters the outer chamber. The flow rate is controlled at the outlet with a valve. The substrate for the vegetation is small gravel. Gravel substrate encourages the wetland vegetation to use nutrients and metals in the stormwater. The concept of subsurface flow through gravel has its parentage with subsurface flow constructed wetlands used to treat wastewater.

The unit includes a burlap bag over the inlet to remove debris, and screens within the center well for the same purpose. However, the upstream drainage system is considered the primary remover of coarse solids and debris. If the drainage system lacks drain inlets with sumps where coarse sediments and floatables are removed, it is desirable to include a pretreatment unit for this purpose such as a manhole or wet vault of suitable size.

Targeted Pollutant	Alternative Media	References
Complex organics (e.g., pesticides)	Activated carbon	Metcalf and Eddy (2002), Minton (2002)
Petroleum hydrocarbons	Activated carbon, organoclay, granular polymer	Minton (2002)
Dissolved metals	Zeolite, activated carbon	Minton (2002), Groffman, et al. (1997), Netzer and Hughes (1984), Stormwater Management Inc. technical memos
Dissolved phosphorus	Blast furnace slag, iron-ore, iron wool, limestone, aluminum oxide, dolomite, iron-infused resin	James, et al. (1992), Minton (2002), Shapiro (1999), Ayoub, et al. (2001), Storm-water Management Inc memos

The design water quality volume is determined by local governments or sized so that 85% of the annual runoff volume is treated.

Construction/Inspection Considerations

Refer to manufacturer guidelines.

Performance

There is little operating data for the manufactured wetland, although these data indicate very high removal efficiencies, similar to created stormwater wetlands. An advantage of wet ponds and standard constructed wetlands over most other treatment technologies is the removal of dissolved pollutants. However, this occurs only to the extent that the stormwater pollutants are able to diffuse into the soil where they are removed by the soil or the plants. Except for non-rooted plants, pollutant uptake by vegetation does not occur in the overlying wet pool (Minton, 2002). Placement of wetland plants in gravel with the stormwater flowing directly through the root system forces uptake by the vegetation. To maintain performance therefore requires annual or harvesting of the vegetation (See Maintenance). However, the removal of dissolved phosphorus, metals, and complex organics like pesticides in earthen-lined ponds and wetlands is primarily by chemical sorption or precipitation with the soil, not uptake by plants (Minton, 2002). Gravel substrate does not provide ideal conditions for these chemical processes. There are currently no operating data for the manufactured wetland with respect to the removal of dissolved pollutants and therefore whether uptake solely by plants is sufficient is unknown. It may be desirable to augment the gravel with media capable of removing dissolved pollutants. The supplemental media can be specific for the pollutant that is to be removed. Table 1 lists media that have been evaluated in either stormwater or wastewater constructed wetlands or filtration systems.

The gravel substrate likely provides a good environment for bacteria, facilitating the removal of nitrogen (its primary mechanism of removal) and the degradation of petroleum and other organic compounds. While this has been confirmed to occur in the manufactured product discussed here, experience with constructed wetlands used for wastewater treatment (Minton, 2002) suggests that it likely occurs

Siting Criteria

While not stated by the manufacturer, the system is likely most appropriate for small drainage areas of an approximately an acre or less, given the number of units required per acre.

Additional Design Guidelines

As noted previously, the number of units installed is the function of the volume of water to be treated: multiple units are installed in parallel with incoming stormwater split via a manifold. The storage volume of one unit is approximately 185 ft³. The recommended emptying rate is 0.25 gallons per minute (average). To illustrate sizing, assume a development site of one acre and the design event is 0.75 inches. The total volume of the design event is 2,722 cubic feet. Thus, a minimum of 15 units is required, ignoring throughput during the storm. At this rate, a unit drains in approximately 3.8 days.

However, the emptying time must be considered with respect to the inter-event time between storms. If the emptying time is too great there is a statistical probability of some water being present in the units when the next storm occurs. If so, the full volume of the design event is not treated over the long term. The manufacturer currently does not provide a design method that

considers this factor. The recommended approach is to use the method presented in TC-22 for Extended Detention systems inasmuch as the Storm Treat is a “fill-and-draw” system that functions like Extended Detention and should be expected to capture and treat the same stormwater volume over time.

Fewer units are possible if the upstream drainage system is able to store water, although this extends the emptying time. If a detention facility is required for flow control, it can provide the necessary storage and the number of wetland units is reduced, but not substantially given the need to drain the system in a timely fashion. Furthermore, if a detention facility is included it must control the release rate, not the manufactured wetland. This may require a more rapid release rate than recommended by the manufacturer. However, there are no data relating emptying rate with performance. Since the system also functions in effect as a horizontal filter, throughput rates higher than what is recommended by the manufacturer may be possible without a significant reduction in performance.

Maintenance

To maximize the benefits of wetland vegetation in its removal of pollutants, the vegetation must be harvested each growth season. Harvesting is particularly important with respect to the removal of phosphorus and metals, less so nitrogen. Harvesting should occur by mid-summer before the plants begin to transfer phosphorus from the aboveground foliage to subsurface roots, or begin to lose metals that desorb during plant die-off. While not stated by the manufacturer, it is also desirable that every few years the entire plant mass including roots is harvested. This is because the belowground biomass constitutes a significant reservoir (possibly half) of the nutrients and metals that are removed from the stormwater by plants (Minton, 2002). Annual maintenance is typical.

If debris and floatable material is not effectively removed in the pretreatment unit, premature clogging of the debris bag may occur.

- Crop vegetation near end of each growth season to capture the nutrients and pollutants removed by the wetland vegetation.
- Inspect periodically to ensure that invasive species of wetland plants is not occurring
- Conduct inspection during the dry season to determine if irrigation of plants is necessary
- Clean center well periodically.

Cost

Manufacturers provide costs for the units including delivery. Installation costs are generally on the order of 50 to 100 % of the manufacturer’s cost.

Cost Considerations

- If the drainage system lacks drain inlets with sumps where coarse sediments and floatables are removed, it is desirable to include a pretreatment unit for this purpose such as a manhole or wet vault of suitable size. This should be factored in the cost-analysis when comparing to other treatment BMPs. If already a requirement of the local government, a detention facility for flow control can serve this purpose.

- In comparison to public domain wet ponds (TC-20) and constructed wetlands (TC-21), vegetation harvesting is simpler, and therefore less costly.

References and Sources of Additional Information

Ayoub, G.M., B. Koopman, and N. Pandya, 2001, Iron and aluminum hydroxy (oxide) coated filter media for low-concentration phosphorus removal, *Water Environ. Res.*, 73, 7, 478

Groffman, A., S. Peterson, D. Brookins, 1997, The removal of lead and other heavy metals from wastewater streams using zeolites, zeocarb, and other natural materials as a sorption media, presented to the 70th Annual Conference, Water Environment Federation, Alexandria, Virginia

James, B.R., M.C. Rabvenhorst, and G.A. Frigon, 1992, Phosphorus sorption by peat and sand amended with iron oxides or steel wool, *Water Environ. Res.*, 64, 699. Manufacturer's literature Metcalf and Eddy, Inc., 2002, *Wastewater Engineering: Treatment, Disposal, Reuse*, McGraw-Hill, New York, New York. Minton, G.R., 2002, *Stormwater Treatment: Biological, Chemical, and Engineering Principles*, RPA Press, Seattle, Washington, 416 pages. Netzer, A., and D.E. Hughes, 1984, Adsorption of copper, lead, and cobalt by activated carbon, *Water Res.*, 18, 927. Shapiro and Associates and the Bellevue Utilities Department, 1999, Lakemont stormwater treatment facility monitoring report, Bellevue, Washington.

Description

Stormwater media filters are usually two-chambered including a pretreatment settling basin and a filter bed filled with sand or other absorptive filtering media. As stormwater flows into the first chamber, large particles settle out, and then finer particles and other pollutants are removed as stormwater flows through the filtering media in the second chamber.

There are currently three manufacturers of stormwater filter systems. Two are similar in that they use cartridges of a standard size. The cartridges are placed in vaults; the number of cartridges a function of the design flow rate. The water flows laterally (horizontally) into the cartridge to a centerwell, then downward to an underdrain system. The third product is a flatbed filter, similar in appearance to sand filters.

California Experience

There are currently about 75 facilities in California that use manufactured filters.

Advantages

- Requires a smaller area than standard flatbed sand filters, wet ponds, and constructed wetlands.
- There is no standing water in the units between storms, minimizing but does not entirely eliminate the opportunity for mosquito breeding.
- Media capable of removing dissolved pollutants can be selected.
- One system utilizes media in layers, allowing for selective removal of pollutants.
- The modular concept allows the design engineer to more closely match the size of the facility to the design storm.

Limitations

- As some of the manufactured filter systems function at higher flow rates and/or have larger media than found in flatbed filters, the former may not provide the same level of performance as standard sand filters. However, the level of treatment may still be satisfactory.
- As with all filtration systems, use in catchments that have significant areas of non-stabilized soils can lead to premature clogging.

Design Considerations

- Design Storm
- Media Type
- Maintenance Requirement

Targeted Constituents

- ✓ Sediment
- ✓ Nutrients
- ✓ Trash
- ✓ Metals
- ✓ Bacteria
- ✓ Oil and Grease
- ✓ Organics

Removal Effectiveness

See New Development and Redevelopment Handbook-Section 5.



Design and Sizing Guidelines

There are currently three manufacturers of stormwater filter systems.

Filter System A: This system is similar in appearance to a slow-rate sand filter. However, the media is cellulose material treated to enhance its ability to remove hydrocarbons and other organic compounds. The media depth is 12 inches (30 cm). It operates at a very high rate, 20 gpm/ft² at peak flows. Normal operating rates are much lower assuming that the stormwater covers the entire bed at flows less than the peak rate. The system uses vortex separation for pretreatment. As the media is intended to remove sediments (with attached pollutants) and organic compounds, it would not be expected to remove dissolved pollutants such as nutrients and metals unless they are complexed with the organic compounds that are removed.

Filter System B: It uses a simple vertical filter consisting of 3 inch diameter, 30 inch high slotted plastic pipe wrapped with fabric. The standard fabric has nominal openings of 10 microns. The stormwater flows into the vertical filter pipes and out through an underdrain system. Several units are placed vertically at 1 foot intervals to give the desired capacity. Pretreatment is typically a dry extended detention basin, with a detention time of about 30 hours. Stormwater is retained in the basin by a bladder that is automatically inflated when rainfall begins. This action starts a timer which opens the bladder 30 hours later. The filter bay has an emptying time of 12 to 24 hours, or about 1 to 2 gpm/ft² of filter area. This provides a total elapsed time of 42 to 54 hours. Given that the media is fabric, the system does not remove dissolved pollutants. It does remove pollutants attached to the sediment that is removed.

Filter System C: The system use vertical cartridges in which stormwater enters radially to a center well within the filter unit, flowing downward to an underdrain system. Flow is controlled by a passive float valve system, which prevents water from passing through the cartridge until the water level in the vault rises to the top of the cartridge. Full use of the entire filter surface area and the volume of the cartridge is assured by a passive siphon mechanism as the water surface recedes below the top of the cartridge. A balance between hydrostatic forces assures a more or less equal flow potential across the vertical face of the filter surface. Hence, the filter surface receives suspended solids evenly. Absent the float valve and siphon systems, the amount of water treated over time per unit area in a vertical filter is not constant, decreasing with the filter height; furthermore, a filter would clog unevenly. Restriction of the flow using orifices ensures consistent hydraulic conductivity of the cartridge as a whole by allowing the orifice, rather than the media, whose hydraulic conductivity decreases over time, to control flow.

The manufacturer offers several media used singly or in combination (dual- or multi-media). Total media thickness is about 7 inches. Some media, such as fabric and perlite, remove only suspended solids (with attached pollutants). Media that also remove dissolved include compost, zeolite, and iron-infused polymer. Pretreatment occurs in an upstream unit and/or the vault within which the cartridges are located.

Water quality volume or flow rate (depending on the particular product) is determined by local governments or sized so that 85% of the annual runoff volume is treated.

Construction/Inspection Considerations

- Inspect one or more times as necessary during the first wet season of operation to be certain that it is draining properly.

Performance

The mechanisms of pollutant removal are essentially the same as with public domain filters (TC-40) if of a similar design. Whether removal of dissolved pollutants occurs depends on the media. Perlite and fabric do not remove dissolved pollutants, whereas for examples, zeolites, compost, activated carbon, and peat have this capability.

As most manufactured filter systems function at higher flow rates and have larger media than found in flatbed filters, they may not provide the same level of performance as standard sand filters. However, the level of treatment may still be satisfactory.

Siting Criteria

There are no unique siting criteria.

Additional Design Guidelines

Follow guidelines provided by the manufacturer.

Maintenance

- Maintenance activities and frequencies are specific to each product. Annual maintenance is typical.
- Manufactured filters, like standard filters (TC-40), require more frequent maintenance than most standard treatment systems like wet ponds and constructed wetlands, typically annually for most sites.
- Pretreatment systems that may precede the filter unit should be maintained at a frequency specified for the particular process.

Cost

Manufacturers provide costs for the units including delivery. Installation costs are generally on the order of 50 to 100 % of the manufacturer's costs.

Cost Considerations

- Filters are generally more expensive to maintain than swales, ponds, and basins.
- The modularity of the manufactured systems allows the design engineer to closely match the capacity of the facility to the design storm, more so than with most other manufactured products.

References and Sources of Additional Information

Minton, G.R., 2002, Stormwater Treatment: Biological, Chemical, and Engineering Principles, RPA Press, 416 pages.

Description

A wet vault is a vault with a permanent water pool, generally 3 to 5 feet deep. The vault may also have a constricted outlet that causes a temporary rise of the water level (i.e., extended detention) during each storm. This live volume generally drains within 12 to 48 hours after the end of each storm.

California Experience

There are currently several hundred stormwater treatment facilities in California that use manufactured wet vaults currently in operation in California.

Advantages

- Internal baffling and other design features such as bypasses may increase performance over traditional wet vaults and/or reduce the likelihood of resuspension and loss of sediments or floatables during high flows.
- Head loss is modest.

Limitations

- Concern about mosquito breeding in standing water
- The area served is limited by the capacity of the largest models.
- As the products come in standard sizes, the facilities will be oversized in many cases relative to the design treatment storm, increasing the cost.
- Do not remove dissolved pollutants.
- A loss of dissolved pollutants may occur as accumulated organic matter (e.g., leaves) decomposes in the units.

Design and Sizing Guidelines

Water quality volume or flow rate (depending on the particular product) is determined by local governments or sized so that 85% of the annual runoff volume is treated. There are three general configurations of wet vaults currently available, differing with the particular manufacturer.

Vault System A: This system consists of two standard precast manholes, the size varying to achieve the desired capacity. Stormwater enters the first (primary) manhole where coarse solids are removed. The stormwater flows from the first to the second (storage) manhole, carrying floatables where they are captured and retained. Further sedimentation occurs in this second manhole. The off-line serves as a storage reservoir for

Design Considerations

- Hydraulic Capacity
- Sediment Accumulation

Targeted Constituents

- ✓ Sediment
- ✓ Nutrients
- ✓ Trash
- ✓ Metals
- Bacteria
- ✓ Oil and Grease
- ✓ Organics

Removal Effectiveness

See New Development and Redevelopment Handbook-Section 5.



floatables as stormwater flows through at flow rates less than the design flow. A patented device controls the flow into the storage manhole. All flows above the stated treatment flow rate bypass through the device. The bypass prevents resuspension or loss of sediment and floatables that have accumulated in the second manhole. It is important to recognize that has storage of accumulated sediment occurs directly in the operating area of the manholes; treatment efficiency will decline over time given the reduction in treatment volume

The manufacturer currently provides 4 models, with treatment capacities (flow rate above which bypass occurs) from 2.4 to 21.8 cfs. The hydraulic capacities range from 10 to 100 cfs. As such, all stormwater achieves at least partial treatment through essentially all but the most extreme storm flows since some settling occurs in the first manhole. The manufacturer provides information on the total system (water) volume, sediment capacity, and floatable capacities. The size of the storage manhole can be varied with each of the four models to increase storage capacity as desired, following recommendations of the manufacturer. The footprint of this system ranges from about 200 to 350 ft², with heights of about 11.5 to 13.5 feet (excluding minimum soil cover and access port extenders), depending on the model. Head loss ranges from 5 to 12 inches, depending on the model. Sediment and floatable capacities range up to 201 cf and 150 gallons, respectively. The recommended point of maintenance is when about 25% of the wet pool volume is supplanted by sediment. The affect of the accumulation of sediment on performance is not given

Vault System B: This wet vault has outward appearance of a standard, rectangular wet vault, but with its own unique design for internal baffles. Included is an entrance baffle, presumably to reduce the energy of the flow entering the unit. Baffles are also affixed to the floor, purportedly to reduce resuspension of settled sediments improve performance. A floating sorbent pad may be placed near the outlet to remove free oil floating on the surface. The vault includes both a permanent wet pool, 3 feet in depth, and live storage volume that is filled during each storm. The live storage volume is accomplished by restricting the outlet. The system is modular: that is, it consists of standard units that are added to increase the length, thereby providing the desired volume. Presumably for very large sites there is a practical total length. Further capacity could be accomplished by having two or more vaults in parallel. The capacity of the system is therefore essentially unlimited, Being modular may allow the design engineer to more closely match facility size to the design event.

Vault System C: This system is like System A, but differs in two primary respects. The Stormceptor module consists of only one circular structure. Hence, standard precast manholes can be used for the smaller models but larger models are non-standard sizes. Like System A, System C has an internal bypass, involving a unique design. The purpose of the bypass is to prevent resuspension of previously suspended material. All stormwater up to the bypass rate is diverted downward into the center well where removal occurs. Flows in excess of the treatment capacity are diverted directly across the top of the device to the outlet. According to the manufacturer there is also some storage capacity for floatables immediately beneath the bypass structure.

Twelve models are available. The treatment capacity of each is not indicated for the Stormceptor as it is a function of the removal efficiency specified by the designer. The manufacturer provides a methodology for the calculation of efficiency as a function of flow rate (see Design Guidelines). Hydraulic capacities range up to approximately 63 cfs. The head requirement is a function of the model and desired hydraulic flow rate, ranging up to 21 inches.

Diameters range from 4 to 12 feet, and minimum heights up to about 13 feet plus the diameter of the incoming pipe. Sediment and floatable capacities range up to 1,470 cf and 3,055 gallons, respectively. The recommended point of maintenance is when about 15% of the wet pool volume is supplanted by sediment. The affect of the accumulation of sediment on performance is not given but can be estimated using the manufacturer's sizing methodology.

Construction/Inspection Considerations

Refer to guidelines provided by the manufacturer.

Performance

A manufactured wet vault can be expected to perform similarly to large catch basins in that its wet volume (dead storage) is similar to that determined by methodology provided in TC-20 for wet ponds. Hence, the engineer should compare the volume of the model s/he intends to select to what the volume of a constructed wet vault would be for the site. Conceivably, manufactured vaults may give better performance than standard catch basins, given the inclusion of design elements that are intended to minimize resuspension. Given this benefit, it could be argued that manufactured wet vaults can be smaller than traditional catch basins, to achieve similar performance. However, there are no data indicating the incremental benefit of the particular design elements of each manufactured product.

Siting Criteria

There are no unique siting criteria. The size of the drainage area that can be served by a manufactured wet vault is directly related to the capacities of the largest models.

Additional Design Guidelines

Refer to guidelines of the manufacturers.

Maintenance

Maintenance consists of the removal of accumulated material with an eductor truck. It may be necessary to remove and dispose the floatables separately due to the presence of petroleum product. Annual maintenance is typical.

It is important to recognize that as storage of accumulated sediment occurs directly in the operating area of the wet vault, treatment efficiency will decline over time given the reduction in treatment volume. Whether this is significant depends on the design capacity. If the total volume of the wet pool is similar to that determined by the method on TC-20, the effect on performance is minor.

Maintenance Requirements

- Each manufacturer provides storage capacities with respect to sediments and floatables, with recommendations on the frequency of cleaning as a function of the percentage of the volume in the unit that has been filled by these materials.
- The recommended frequency of cleaning differs with the manufacturer, ranging from one to two years. It is prudent to inspect the unit twice during the first wet season of operation, setting the cleaning frequency accordingly.

Cost

Manufacturers provide costs for the units including delivery. Installation costs are generally on the order of 50 to 100 % of the manufacturer's cost.

Cost Considerations

- The different geometries of the several manufactured separators suggest that when comparing the costs of these systems to each other, that local conditions (e.g., groundwater levels) may affect the relative cost-effectiveness.
- Subsurface facilities are more expensive to construct than surface facilities of similar size. However, the added cost of construction is in many developments offset by the value of continued use of the land.
- Some of the manufactured vaults may be less expensive to maintain than public domain vaults as the former may be cleaned without the need for confined space entry.
- Subsurface facilities do not require landscaping, reducing maintenance costs accordingly.

References and Sources of Additional Information

Manufacturers literature.

Description

Vortex separators: (alternatively, swirl concentrators) are gravity separators, and in principle are essentially wet vaults. The difference from wet vaults, however, is that the vortex separator is round, rather than rectangular, and the water moves in a centrifugal fashion before exiting. By having the water move in a circular fashion, rather than a straight line as is the case with a standard wet vault, it is possible to obtain significant removal of suspended sediments and attached pollutants with less space. Vortex separators were originally developed for combined sewer overflows (CSOs), where it is used primarily to remove coarse inorganic solids. Vortex separation has been adapted to stormwater treatment by several manufacturers.

California Experience

There are currently about 100 installations in California.

Advantages

- May provide the desired performance in less space and therefore less cost.
- May be more cost-effective pre-treatment devices than traditional wet or dry basins.
- Mosquito control may be less of an issue than with traditional wet basins.

Limitations

- As some of the systems have standing water that remains between storms, there is concern about mosquito breeding.
- It is likely that vortex separators are not as effective as wet vaults at removing fine sediments, on the order 50 to 100 microns in diameter and less.
- The area served is limited by the capacity of the largest models.
- As the products come in standard sizes, the facilities will be oversized in many cases relative to the design treatment storm, increasing the cost.
- The non-steady flows of stormwater decreases the efficiency of vortex separators from what may be estimated or determined from testing under constant flow.
- Do not remove dissolved pollutants.
- A loss of dissolved pollutants may occur as accumulated organic

Design Considerations

- Service Area
- Settling Velocity
- Appropriate Sizing
- Inlet Pipe Diameter

Targeted Constituents

✓ Sediment	▲
✓ Nutrients	●
✓ Trash	
✓ Metals	●
Bacteria	
✓ Oil and Grease	
✓ Organics	

Legend (Removal Effectiveness)

- Low
- High
- ▲ Medium



matter (e.g., leaves) decomposes in the units.

Design and Sizing Guidelines

The stormwater enters, typically below the effluent line, tangentially into the basin, thereby imparting a circular motion in the system. Due to centrifugal forces created by the circular motion, the suspended particles move to the center of the device where they settle to the bottom. There are two general types of vortex separation: free vortex and dampened (or impeded) vortex. Free vortex separation becomes dampened vortex separation by the placement of radial baffles on the weir-plate that impede the free vortex-flow pattern

It has been stated with respect to CSOs that the practical lower limit of vortex separation is a particle with a settling velocity of 12 to 16.5 feet per hour (0.10 to 0.14 cm/s). As such, the focus for vortex separation in CSOs has been with settleable solids generally 200 microns and larger, given the presence of the lighter organic solids. For inorganic sediment, the above settling velocity range represents a particle diameter of 50 to 100 microns. Head loss is a function of the size of the target particle. At 200 microns it is normally minor but increases significantly if the goal is to remove smaller particles.

The commercial separators applied to stormwater treatment vary considerably with respect to geometry, and the inclusion of radial baffles and internal circular chambers. At one extreme is the inclusion of a chamber within the round concentrator. Water flows initially around the perimeter between the inner and outer chambers, and then into the inner chamber, giving rise to a sudden change in velocity that purportedly enhances removal efficiency. The opposite extreme is to introduce the water tangentially into a round manhole with no internal parts of any kind except for an outlet hood. Whether the inclusion of chambers and baffles gives better performance is unknown. Some contend that free vortex, also identified as swirl concentration, creates less turbulence thereby increasing removal efficiency. One product is unique in that it includes a static separator screen.

- Sizing is based on the peak flow of the design treatment event as specified by local government.
- If an in-line facility, the design peak flow is four times the peak of the design treatment event.
- If an off-line facility, the design peak flow is equal to the peak of the design treatment event.
- Headloss differs with the product and the model but is generally on the order of one foot or less in most cases.

Construction/Inspection Considerations

No special considerations.

Performance

Manufacturer's differ with respect to performance claims, but a general statement is that the manufacturer's design and rated capacity (cfs) for each model is based on and believed to achieve an aggregate reduction of 90% of all particles with a specific gravity of 2.65 (glacial sand) down to 150 microns, and to capture the floatables, and oil and grease. Laboratory tests of two products support this claim. The stated performance expectation therefore implies that a

lesser removal efficiency is obtained with particles less than 150 microns, and the lighter, organic settleables. Laboratory tests of one of the products found about 60% removal of 50 micron sand at the expected average operating flow rate

Experience with the use of vortex separators for treating combined sewer overflows (CSOs), the original application of this technology, suggests that the lower practical limit for particle removal are particles with a settling velocity of 12 feet per hour (Sullivan, 1982), which represents a particle diameter of 100 to 200 microns, depending on the specific gravity of the particle. The CSO experience therefore seems consistent with the limited experience with treating stormwater, summarized above

Traditional treatment technologies such as wet ponds and extended detention basins are generally believed to be more effective at removing very small particles, down to the range of 10 to 20 microns. Hence, it is intuitively expected that vortex separators do not perform as well as the traditional wet and dry basins, and filters. Whether this matters depends on the particle size distribution of the sediments in stormwater. If the distribution leans towards small material, there should be a marked difference between vortex separators and, say, traditional wet vaults. There are little data to support this conjecture

In comparison to other treatment technologies, such as wet ponds and grass swales, there are few studies of vortex separators. Only two of manufactured products currently available have been field tested. Two field studies have been conducted. Both achieved in excess of 80% removal of TSS. However, the test was conducted in the Northeast (New York state and Maine) where it is possible the stormwater contained significant quantities of deicing sand. Consequently, the influent TSS concentrations and particle size are both likely considerably higher than is found in California stormwater. These data suggest that if the stormwater particles are for the most part fine (i.e., less than 50 microns), vortex separators will not be as efficient as traditional treatment BMPs such as wet ponds and swales, if the latter are sized according to the recommendations of this handbook.

There are no equations that provide a straightforward determination of efficiency as a function of unit configuration and size. Design specifications of commercial separators are derived from empirical equations that are unique and proprietary to each manufacturer. However, some general relationships between performance and the geometry of a separator have been developed. CSO studies have found that the primary determinants of performance of vortex separators are the diameters of the inlet pipe and chamber with all other geometry proportional to these two.

Sullivan et al. (1982) found that performance is related to the ratios of chamber to inlet diameters, D_2/D_1 , and height between the inlet and outlet and the inlet diameter, H_1/D_1 , shown in Figure 3. The relationships are: as D_2/D_1 approaches one, the efficiency decreases; and, as the H_1/D_1 ratio decreases, the efficiency decreases. These relationships may allow qualitative comparisons of the alternative designs of manufacturers. Engineers who wish to apply these concepts should review relevant publications presented in the References.

Siting Criteria

There are no particularly unique siting criteria. The size of the drainage area that can be served by vortex separators is directly related to the capacities of the largest models.

Additional Design Guidelines

Vortex separators have two capacities if positioned as in-line facilities, a treatment capacity and a hydraulic capacity. Failure to recognize the difference between the two may lead to significant under sizing; i.e., too small a model is selected. This observation is relevant to three of the five products. These three technologies all are designed to experience a unit flow rate of about 24 gallons/square foot of separator footprint at the peak of the design treatment event. This is the horizontal area of the separator zone within the container, not the total footprint of the unit. At this unit flow rate, laboratory tests by these manufacturers have established that the performance will meet the general claims previously described. However, the units are sized to handle 100 gallons/square foot at the peak of the hydraulic event. Hence, in selecting a particular model the design engineer must be certain to match the peak flow of the design event to the stated treatment capacity, not the hydraulic capacity. The former is one-fourth the latter. If the unit is positioned as an off-line facility, the model selected is based on the capacity equal to the peak of the design treatment event.

Maintenance

Maintenance consists of the removal of accumulated material with an eductor truck. It may be necessary to remove and dispose the floatables separately due to the presence of petroleum product.

Maintenance Requirements

Remove all accumulated sediment, and litter and other floatables, annually, unless experience indicates the need for more or less frequent maintenance.

Cost

Manufacturers provide costs for the units including delivery. Installation costs are generally on the order of 50 to 100 % of the manufacturer's cost. For most sites the units are cleaned annually.

Cost Considerations

The different geometry of the several manufactured separators suggests that when comparing the costs of these systems to each other, that local conditions (e.g., groundwater levels) may affect the relative cost-effectiveness.

References and Sources of Additional Information

Field, R., 1972, The swirl concentrator as a combined sewer overflow regulator facility, EPA/R2-72-008, U.S. Environmental Protection Agency, Washington, D.C.

Field, R., D. Averill, T.P. O'Connor, and P. Steel, 1997, Vortex separation technology, Water Qual. Res. J. Canada, 32, 1, 185

Manufacturers technical materials

Sullivan, R.H., et al., 1982, Design manual – swirl and helical bend pollution control devices, EPA-600/8-82/013, U.S. Environmental Protection Agency, Washington, D.C.

Sullivan, R.H., M.M. Cohn, J.E. Ure, F.F. Parkinson, and G. Caliana, 1974, Relationship between diameter and height for the design of a swirl concentrator as a combined sewer overflow regulator, EPA 670/2-74-039, U.S. Environmental Protection Agency, Washington, D.C.

Sullivan, R.H., M.M. Cohn, J.E. Ure, F.F. Parkinson, and G. Caliana, 1974, The swirl concentrator as a grit separator device, EPA670/2-74-026, U.S. Environmental Protection Agency, Washington, D.C.

Sullivan, R.H., M.M. Cohn, J.E. Ure, F.F. Parkinson, and G. Caliana, 1978, Swirl primary separator device and pilot demonstration, EPA600/2-78-126, U.S. Environmental Protection Agency, Washington, D.C.

Description

Drain inserts are manufactured filters or fabric placed in a drop inlet to remove sediment and debris. There are a multitude of inserts of various shapes and configurations, typically falling into one of three different groups: socks, boxes, and trays. The sock consists of a fabric, usually constructed of polypropylene. The fabric may be attached to a frame or the grate of the inlet holds the sock. Socks are meant for vertical (drop) inlets. Boxes are constructed of plastic or wire mesh. Typically a polypropylene “bag” is placed in the wire mesh box. The bag takes the form of the box. Most box products are one box; that is, the setting area and filtration through media occur in the same box. Some products consist of one or more trays or mesh grates. The trays may hold different types of media. Filtration media vary by manufacturer. Types include polypropylene, porous polymer, treated cellulose, and activated carbon.

California Experience

The number of installations is unknown but likely exceeds a thousand. Some users have reported that these systems require considerable maintenance to prevent plugging and bypass.

Advantages

- Does not require additional space as inserts as the drain inlets are already a component of the standard drainage systems.
- Easy access for inspection and maintenance.
- As there is no standing water, there is little concern for mosquito breeding.
- A relatively inexpensive retrofit option.

Limitations

Performance is likely significantly less than treatment systems that are located at the end of the drainage system such as ponds and vaults. Usually not suitable for large areas or areas with trash or leaves than can plug the insert.

Design and Sizing Guidelines

Refer to manufacturer’s guidelines. Drain inserts come any many configurations but can be placed into three general groups: socks, boxes, and trays. The sock consists of a fabric, usually constructed of polypropylene. The fabric may be attached to a frame or the grate of the inlet holds the sock. Socks are meant for vertical (drop) inlets. Boxes are constructed of plastic or wire mesh. Typically a polypropylene “bag” is placed in the wire mesh box. The bag takes the form of the box. Most box products are

Design Considerations

- Use with other BMPs
- Fit and Seal Capacity within Inlet

Targeted Constituents

- ✓ Sediment
- ✓ Nutrients
- ✓ Trash
- ✓ Metals
- ✓ Bacteria
- ✓ Oil and Grease
- ✓ Organics

Removal Effectiveness

See New Development and Redevelopment Handbook-Section 5.



one box; that is, the setting area and filtration through media occurs in the same box. One manufacturer has a double-box. Stormwater enters the first box where setting occurs. The stormwater flows into the second box where the filter media is located. Some products consist of one or more trays or mesh grates. The trays can hold different types of media. Filtration media vary with the manufacturer: types include polypropylene, porous polymer, treated cellulose, and activated carbon.

Construction/Inspection Considerations

Be certain that installation is done in a manner that makes certain that the stormwater enters the unit and does not leak around the perimeter. Leakage between the frame of the insert and the frame of the drain inlet can easily occur with vertical (drop) inlets.

Performance

Few products have performance data collected under field conditions.

Siting Criteria

It is recommended that inserts be used only for retrofit situations or as pretreatment where other treatment BMPs presented in this section area used.

Additional Design Guidelines

Follow guidelines provided by individual manufacturers.

Maintenance

Likely require frequent maintenance, on the order of several times per year.

Cost

- The initial cost of individual inserts ranges from less than \$100 to about \$2,000. The cost of using multiple units in curb inlet drains varies with the size of the inlet.
- The low cost of inserts may tend to favor the use of these systems over other, more effective treatment BMPs. However, the low cost of each unit may be offset by the number of units that are required, more frequent maintenance, and the shorter structural life (and therefore replacement).

References and Sources of Additional Information

Hrachovec, R., and G. Minton, 2001, Field testing of a sock-type catch basin insert, Planet CPR, Seattle, Washington

Interagency Catch Basin Insert Committee, Evaluation of Commercially-Available Catch Basin Inserts for the Treatment of Stormwater Runoff from Developed Sites, 1995

Larry Walker Associates, June 1998, NDMP Inlet/In-Line Control Measure Study Report

Manufacturers literature

Santa Monica (City), Santa Monica Bay Municipal Stormwater/Urban Runoff Project - Evaluation of Potential Catch basin Retrofits, Woodward Clyde, September 24, 1998

Woodward Clyde, June 11, 1996, Parking Lot Monitoring Report, Santa Clara Valley Nonpoint Source Pollution Control Program.

