4.7.9 **Benefits Vs Costs**

- can provide effective flood control, streambank erosion control, removal of particulate and soluble contaminants, and limited groundwater recharge (depends on soil conditions)
- one of the most aesthetically pleasing structural BMPs – can increase property value
- can include other uses – recreation, fish and wildlife habitat or wetland
- wet ponds are more expensive than extended detention dry basins - permanent pool volume two to seven times larger than extended detention dry basin (WEF, 1998).
- wet ponds accomplish removal of soluble contaminants such as nutrients (important if receiving waters are sensitive to nutrient inputs)
- wet ponds are most cost effective in larger catchments
- provides some infiltration unless lined.
- temperature increase is a concern on coldwater streams capable of supporting trout or salmon – minimize use of riprap and provide shading vegetation to reduce warming
- inadequate maintenance can lead to problems with floating debris and scum, algae, odours, and insects
- some safety concerns associated with side slopes, water pool
- see Section 4.21 for overview cost benefit analysis
FIGURE 4-6a EXAMPLE OF WET POND
(FROM CWP et al., 1997)
FIGURE 4-6b  EXAMPLE OF MULTIPLE POND SYSTEM  
(FROM CWP et al., 1997)
4.8  **BMP S7: Dry Detention Vault and Wet Vault**

4.8.1  **Description**

Detention vaults and tanks are underground storage/treatment facilities constructed of reinforced concrete (vaults) or corrugated pipe (tanks). They may be used to handle general site runoff, or they may be dedicated to the runoff from impervious surfaces such as roofs and parking lots. Detention vaults may be designed to empty completely between storms (dry vaults), or they may be designed to maintain a permanent water pool (wet vaults). A schematic drawing of a typical dry/wet vault is shown on Figure 4-7 at the end of Section 4.8.

Dry vaults are similar in nature to dry detention basins (BMP S5). Conventional dry detention vaults are on-line facilities designed to control the frequency of flooding downstream by limiting the peak runoff flow. Extended detention dry vaults are also on-line facilities, but they employ lower release rates to control the frequency of bankfull flows for streambank protection in addition to flood control. Unlike extended detention dry basins, extended detention dry vaults do not accomplish significant removal of contaminants.

Wet vaults are similar in nature to wet ponds (BMP S6), except that, being underground, wet vaults lack at least some of the biological contaminant removal mechanisms that are present in wet ponds (e.g., uptake and conversion by algae and aquatic plants, filtering through root mats). A live storage volume can be added above the permanent pool for flow control as well as water quality enhancement. If water quality is the only objective, the wet vault is designed off-line, and larger flows are bypassed.

4.8.2  **Applications**

- conventional dry detention vaults are suitable for peak flow control only
- extended detention dry vaults are suitable for flood control and streambank erosion protection
- wet vaults provide contaminant removal through sedimentation in the permanent pool – live storage can also be provided for streambank protection and flood control
- vaults and tanks can be retrofitted to developed and redeveloping areas as well as new developments
- typically used in areas where space limitations preclude the use of surface detention basins and ponds – e.g., municipal repair and maintenance yards, heavily urbanized areas
- typically serve small collection areas
- suitable for ultra urban areas
4.8.3 Performance

- contaminant removal of wet vaults is poorly documented – they are assumed to remove particulate contaminants only, since the potential for biological action is limited
- assume similar contaminant removal efficiencies to extended detention dry basin (BMP S5)
- assume negligible contaminant removal for dry vaults

4.8.4 Pretreatment and/or Post-Treatment Requirements

- dry vaults should include other BMPs upstream or downstream if water quality improvement is desired

4.8.5 General Design Criteria


Sizing

- conventional dry vaults (on-line) – size for peak flow control - see conventional dry detention basins for geometry etc.
- extended detention dry vaults (on-line) – size for streambank protection - see extended detention dry basins for geometry etc.
- water quality wet vaults (off-line) – see wet ponds for sizing criteria and geometry etc.

Design Features

- dry vaults and wet vaults should be divided into 2 cells using a baffle, with the first cell (forebay) occupying 25% of the total volume (WSDOE, 1992)
- access manholes required
- locate to ensure ease of access by maintenance vehicles
- site at least 6 m from structures, property lines, septic tank fields
- site at least 15 m from steep slopes
- provide anti-floatation in areas with high groundwater table

4.8.6 Limitations

- for dry vaults limit contributing impervious area to 1.2 ha (WWC, 1995)
- for wet vaults limit contributing impervious area to 4 ha (KC, 1998)
4.8.7 **Capital Costs and Implementation Requirements**

- typical construction cost $550 to $600 per cubic meter of vault (UVC, 1998)
- for total capital cost add 35% to construction cost (engineering, contingencies, erosion and sediment control during construction, landscaping, etc.) – does not include the cost of land
- minimal staff training requirements

4.8.8 **Operation and Maintenance Requirements and Costs**

- typical maintenance cost for cleaning by vactor truck $210 + $26.50 V where $V = \text{m}^3$ vault volume (Spencer, 1998)
- follow confined entry procedures when entering vaults
- inspect annually at a minimum, remove floating debris and oil, maintain more frequently if wet vault is used as oil-water separator (KC, 1998)
- remove sediments when depth reaches 150 mm
- requires maintenance plan including scope, schedule, record keeping, and responsibilities

4.8.9 **Benefits Vs Costs**

- both dry vaults and wet vaults can provide flood control, streambank erosion protection and help to prevent water level fluctuations.
- wet vaults provide removal of particulate contaminants (sediments, particulate metals and organics), but performance is poorly documented – dry vaults provide negligible water quality enhancement
- wet vaults help to prevent sedimentation and obstruction of the drainage system
- wet vaults help to prevent sedimentation of fish spawning beds
- wet vaults may be more prone to odours then dry vaults
- high capital cost compared to surface BMPs
- not normally cost effective unless space limitations preclude the use of equivalent surface BMPs (basins, ponds, wetlands)
- few aesthetic concerns since vaults are normally underground
- some safety concerns associated with confined spaces
- see Section 4.21 for overview cost benefit analysis
FIGURE 4-7  TYPICAL DETENTION VAULT (DRY/WET)  
(FROM WSDOE, 1992)
4.9 BMP S8: Constructed Wetlands

4.9.1 Description

Constructed wetlands, also referred to as engineered wetlands, are similar in nature and purpose to wet ponds (BMP S6). That is, constructed wetlands normally maintain a permanent pool of water for contaminant removal, and they can be designed to include live storage for flood control and streambank erosion protection as well. Alternatively, wetlands designed to handle the water quality storm only can be constructed off-line, with some other flow control device constructed on-line. The off-line approach has two potential advantages over the on-line method. First, the inclusion of live storage in the wetland can lead to large fluctuations in water level, which can damage the wetland. Second, the shallow nature of wetlands can be inconsistent with large storage volumes. These potential advantages will be less significant in wetlands with relatively large surface areas.

An alternative design is the subsurface flow wetland (reed bed) system, where water is directed to flow horizontally below the ground surface through a porous soil or gravel matrix planted with aquatic vegetation. Subsurface flow wetlands have seen limited application in stormwater management, although they have been extensively investigated for wastewater treatment.

Contaminant removal mechanisms in wetlands include gravity settling of particulates, filtration of solids by root mats and soils, adsorption to soil particles, chemical transformations, and uptake or conversion to less harmful forms by plants and bacteria.

Constructed wetland variants for stormwater management that maintain a free water surface include the shallow wetland (water depth 0.30 m to 0.45 m with emergent plants), the pond/wetland system (wet pond followed by a shallow wetland), the extended detention shallow wetland (shallow marsh with extended detention live storage above the wetland), and the pocket wetland (small wetland where the permanent water pool intersects the groundwater table). A schematic drawing of a typical constructed shallow wetland is shown on Figure 4-8a, and a pond-wetland system is shown on Figure 4-8b at the end of Section 4.9.

4.9.2 Applications

- can be used for peak flow control and streambank erosion protection, water quality enhancement, community enhancement (recreation, aesthetic value)
- suitable for new developments
- unsuitable for existing developments unless they can be retrofitted to existing parks and greenspace
• suitable for residential areas, municipal office complexes and municipal repair/maintenance yards
• suitable for small on-site facilities and large regional facilities
• not practical for ultra urban areas

4.9.3 Performance

• contaminant removal varies widely – treatment volume appears to be an important variable but the relationship is not clearly evident (Schueler, 1994a)
• the best overall contaminant removal appears to be associated with combination techniques such as the pond/marsh system – poor internal design geometry significantly reduces performance (Schueler, 1994a)
• median contaminant removal efficiencies for wetlands based on 35 performance monitoring studies as follows (Schueler, 1997b):
  - total suspended solids 78%
  - organic carbon 28%
  - total phosphorus 51%
  - soluble phosphorus 39%
  - total nitrogen 21%
  - nitrate nitrogen 67%
  - lead 63%
  - copper 39%
  - zinc 54%
  - cadmium 69%
  - hydrocarbon 90%
  - bacteria 77%

4.9.4 Pretreatment and/or Post-Treatment Requirements

• provide sedimentation forebay with stabilized inlet – volume 10% of permanent pool storage, 1.2 m to 1.8 m deep with fixed sediment depth marker to monitor sediment accumulation (Figure 4-8a)
• maintenance access to forebay 4.5 m wide, maximum slope 5:1
• forebay should have stabilized access and bottom to prevent sinking of mechanical equipment
• may require pretreatment to reduce toxic contaminants if used for runoff from industrial areas (WWC et al., 1995)
• provide energy dissipation at the outlet structure to minimize erosion

4.9.5 General Design Criteria

• design team should include engineer, wetlands specialist, landscape architect, groundwater hydrologist, and construction contractor

_Sizing_

• sizing decisions include pool volume, live storage volume, surface area, and depth contouring
• one design approach is to size the wetland permanent water pool volume according to the procedures for wet ponds (e.g., Horner et al., 1994) – this will result in a larger surface area than an equivalent wet pond, since wetlands are generally shallower than wet ponds
• others recommend that the surface area of the wetland should not exceed that of the equivalent wet pond, since wetlands have potential advantages over wet ponds for contaminant removal (e.g., CDM et al., 1993 and KC, 1998)
• recommended minimum wetland surface area 1% of contributing drainage area – 2% preferred (e.g., WWC, 1993) – total land consumption including buffers 3% to 5% of watershed area (CWP, 1998)

_Dimensions_

• minimum 25% of total permanent pool volume should have depth greater than 1.2 m (this may be met by the forebay and micropool), minimum 35% of total surface area should have depth of 150 mm or less, minimum 65% of total surface area should have depth of 450 mm or less (CWP, 1997)
• minimum freeboard 300 mm
• minimum length to width ratio 3:1, 5:1 preferred (Horner et al., 1994)
• longitudinal slope parallel to flow path less than 1%, no lateral slope (Horner et al., 1994)
• recommended side slopes 5:1 to 12:1, maximum 3:1 (Horner et al., 1994)

_Design Features_

• adopt structural complexities modeled on natural wetlands (varying depths, high marsh peninsulas and islands
• make wetland relatively wide at inlet to distribute flow - avoid dead (stagnant) spots
• provide shallow safety bench 5 m wide where toe of side slope meets any deep pool
• create sheet flow where possible
• multiple meandering channels rather than single straight channel recommended, minimum flow path for single channel 2:1 (Horner et al., 1994)
• baffle islands may be included to help prevent short-circuiting
• minimize flow velocity to limit erosion
• intersperse open water areas with marsh
• provide buffer zone minimum width 8 m from maximum water surface (CWP et al., 1997)

**Inlet and Outlet**

• provide micropool at outlet 1.2 m to 1.8 m deep to protect low flow pipe and limit sediment resuspension (see Figure 4-8a and 4-8b)
• place anti-seep collar around outlet pipe (CWP et al., 1997)
• provide drain capable of dewatering wetland for maintenance if possible
• protect low-flow orifice from clogging – use submerged reverse-slope pipe (Figure 4-8a and 4-8b), trash rack, or, if perforated pipe is used for the outlet, protect with wire cloth and stone jacket (geotextile not recommended)
• provide emergency spillway if wetland is on-line

**Vegetation and Soils**

• use forested buffer where possible to discourage waterfowl
• use hydric soils that contain native vegetative plant material as mulch where possible
• base plant selection on the potential for survival rather than potential contaminant uptake (contaminant removal depends more on chemical and bacterial processes than on plant uptake)
• select native plant species that are tolerant to wide ranges in water elevation, pH, and temperature
• use a minimum of species adapted to each elevation zone (diversification will occur naturally)
• select mainly perennial species that establish rapidly and can tolerate inundation
• match environmental requirements of plants to site conditions
• give priority to species used successfully in constructed wetlands and commercially available species
• include species not foraged by wildlife expected to use the site
• establish woody species to follow herbaceous species
• plant to achieve objectives other than contaminant removal

4.9.6 **Limitations**

**Construction**

• construction management is critical – elevations and contouring, intersection with groundwater, etc. (WEF, 1998)
• ensure designers are in the field during construction
Site Restrictions

- requires a site with adequate water supply to maintain permanent water pool - perform water balance to ensure that wetland will not dry up for extended periods during summer (precipitation, evapotranspiration, groundwater inflow/outflow, surface inflow/outflow, and storage) - standing water may not be necessary for the entire year, as long as soils remain wet – do not allow dry period to extend beyond 2 months (Horner et al., 1994)
- may require liner to sustain permanent pool in permeable soils
- maximum site slope 8% (CWP, 1998)
- minimum contributing drainage area 4 ha, 10 ha preferred, unless groundwater confirmed as primary water source (FHWA, 1996) - pocket wetland may serve smaller areas since permanent pool is maintained by groundwater (CWP, 1997)

Vegetation

- limit extended detention live storage depth to 1 m or less to help protect plants - consult aquatic biologist (OMEE, 1994)
- requires suitable soils to establish vegetation
- may require replanting of vegetation
- wet season coincident with minimal plant growth in GVS&DD
- nutrient release may occur during winter (however, this is the period of minimal impact on receiving waters for nutrients)
- overgrowth can reduce hydraulic capacity

Other Limitations

- temperature increase is a concern on coldwater streams capable of supporting trout or salmon – minimize use of riprap and provide shading vegetation to reduce warming, align north south if possible
- inadequate maintenance can lead to problems with floating debris and scum, algae, odours, and insects
- wetlands constructed primarily for the purpose of stormwater management may come to be regarded as natural systems – this may ultimately interfere with the stormwater management function of the wetland

4.9.7 Capital Costs and Implementation Requirements

- construction cost budget $34.70 x (35.31V)\(^{0.70}\), where V = m\(^3\) storage volume (adapted from Brown and Schueler, 1997 and CWP, 1998)
- typical construction cost $33 to $66 per m\(^3\) (adapted from Brown and Schueler, 1997)
- minimal staff training requirements
• for total capital cost add 35% to construction cost (engineering, contingencies, erosion and sediment control during construction, landscaping, etc) – does not include the cost of land

4.9.8 Operation and Maintenance Requirements and Costs

Costs

• budget 3% to 6% of construction cost per year (Wiegand et al., 1986; Schueler et al., 1987; and SWRPC, 1991)

Inspection and Cleaning Frequency

• inspect at least twice per year during first 3 years after construction during both growing and non-growing season - inspect at least annually thereafter and after each major storm event
• inspect periodically during wet weather to observe function
• at outset of rainy season and after each significant storm - remove trash and floatables, correct erosion problems, unlog outlet structures
• inspect hydraulic and structural facilities annually – expected life of outlet structures 25 yr for corrugated metal and 50-75 yr for structural concrete (FHWA, 1996)
• note whether design water elevation is being maintained and whether original contours have been maintained
• clean sediment forebay every 5-7 years or when 50% of capacity has been lost (CWP, 1997)
• assuming that the sediment forebay is routinely cleaned as required, the main wetland cell(s) should last up to 50 years before a major sediment cleanout is required (WWC, 1995)

Vegetation

• monitor plant growth and distribution (planted and volunteers) – plants may require watering, mulching, weed removal, replanting etc. during first 3 years
• annual harvesting of vegetation may be practiced to reduce seasonal exports of nutrients – the effectiveness of this practice is not well documented – if harvesting is practiced, it should be done in the early summer when the nutrient content of the plants is at its peak, and again in the fall before plant dormancy (CDM et al., 1993)

Other Requirements

• develop maintenance plan that outlines schedule, scope, record keeping and responsibilities
• keep maintenance records of outlet structure, spillway, forebay, embankments, harvesting of vegetation, etc.
• schedule maintenance around sensitive wildlife and vegetation seasons
• consider reserving an area on-site for temporary storage and testing of sediments
• provide direct maintenance access to forebay and outlet structure capable of supporting heavy equipment, minimum width 5 m, maximum slope 4:1
• provide maintenance access or easement, minimum width 3.7 m (Figure 4-8a and 4-8b)
• control nuisance insects, remove nuisance plant species and replant with desirable species as required

4.9.9 Benefits Vs Costs

• wide range of benefits including flood control, streambank erosion protection, fish and wildlife habitat protection/enhancement, aesthetic and recreational benefits
• greater diversity in structure than most other BMPs, with a resulting greater potential for removal of particulate, colloidal and dissolved contaminants
• more potential for filtering through root mats and soils and adsorption of contaminants to soil particles than wet ponds
• wider application and more reliable service than infiltration
• relatively high construction cost – more complex to construct than most other surface BMPs
• delayed efficiency until plants are well established
• public concern about nuisances (mosquitoes, odours)
• relatively large space requirement
• some safety concerns associated with open water pools
• see Section 4.21 for overview cost benefit analysis
FIGURE 4-8a  EXAMPLE OF SHALLOW WETLAND  
(FROM CWP et al.. 1997)
FIGURE 4-8b EXAMPLE OF POND-WETLAND SYSTEM
(FROM CWP et al., 1997)
4.10 BMP S9: Grassed Channel/Wet Swale

4.10.1 Description

Swales are natural depressions or wide shallow, channels used to convey and treat stormwater. There are two basic design variations described in this section, grassed channels and wet swales. Both are commonly referred to as biofiltration swales. A third design, the dry swale with underdrains, is a variant of bioretention, and is described under BMP S15.

Grassed channels are gently sloped, open ditches lined with turf grass or native vegetation that can take the place of conventional stormwater conveyance and piping systems. Grassed channels are designed to convey stormwater during runoff events, and are normally dry between storms. The vegetation helps to decrease stormwater flow velocities; the resulting increase in the time of concentration helps to reduce peak flow rates, which in turn helps to reduce flooding and streambank erosion. Some of the flow may also infiltrate into the ground, reducing the overall runoff volume. In addition, removal of contaminants can be accomplished through filtration by plant stems, adsorption to soil particles, and biological processes. Grassed channels are normally designed to convey the runoff from relatively large, infrequent storms (e.g., the 10-year event), while providing filtration and water quality treatment for smaller, more frequent events (e.g., the 6-month event). For the water quality storm, the flow depth does not normally exceed the height of the bottom vegetation. A schematic drawing of a grassed channel is shown on Figure 4-9a at the end of Section 4.10.

Wet swales are similar to grassed channels, except that the channel contains standing water between storms. Standing water may be due to a high groundwater table or high baseflow, in which case the swale will be wet for extended periods. Alternatively, check dams with or without low flow openings may be added, to store the water quality storm in shallow ponding areas within the swale. Check dams help to reduce flow velocity, promote infiltration, enhance settling of particulates, and can result in increased infiltration and evapotranspiration for the water quality storm. Enhanced contaminant removal through mechanisms similar to those described for wetlands (BMP S8) occurs in the standing water pools within the swale. Sections of the swale that will contain standing water for extended periods are planted with water-tolerant or wetland vegetation, while the side slopes are normally planted with turf. A schematic drawing of a wet swale is shown on Figure 4-9b at the end of Section 4.10.

4.10.2 Applications

- on-line BMP for stormwater conveyance and treatment
- particularly suited alongside roadways and parking lots
- some attenuation of peak flows for flood control and streambank erosion protection
- water quality enhancement
- some groundwater recharge possible
- can be used as pretreatment for other BMPs
- suitable for new developments – may be retro-fitted to existing developments and redeveloping areas or to existing ditches if space is available
- suitable for residential areas, municipal office complexes, municipal repair/maintenance yards, and roadways
- suitable for removing oil and grease from general urban runoff
- not practical for ultra urban areas

4.10.3 Performance

- relatively effective for capturing suspended solids, oils, and particulate metals
- less effective for soluble metals and nutrients
- contaminant removal is a function of length
- average contaminant removal efficiency of a swale in the Puget Sound area over 6 storms as follows (Horner et al., 1994; MMS, 1992; and Reeves, 1994):

<table>
<thead>
<tr>
<th></th>
<th>30 m length</th>
<th>60 m length</th>
</tr>
</thead>
<tbody>
<tr>
<td>total suspended solids</td>
<td>60%</td>
<td>83%</td>
</tr>
<tr>
<td>turbidity</td>
<td>65%</td>
<td>65%</td>
</tr>
<tr>
<td>oil &amp; grease/TPH</td>
<td>49%</td>
<td>75%</td>
</tr>
<tr>
<td>total zinc</td>
<td>16%</td>
<td>63%</td>
</tr>
<tr>
<td>total lead</td>
<td>15%</td>
<td>67%</td>
</tr>
<tr>
<td>total phosphorus</td>
<td>45%</td>
<td>29%</td>
</tr>
<tr>
<td>nitrate+nitrate nitrogen</td>
<td>negative</td>
<td>negative</td>
</tr>
<tr>
<td>fecal coliforms</td>
<td>negative</td>
<td>negative</td>
</tr>
</tbody>
</table>

- FHWA (1996) proposes the following contaminant removal efficiencies for swales:
  - total suspended solids 70%
  - total phosphorus 30%
  - total nitrogen 25%
  - heavy metals 50% to 90%
  - oxygen demand 25%
  - oil and grease 75%

4.10.4 Pretreatment and/or Post-Treatment Requirements

- reduce flow velocity, trap sediments and distribute flow evenly at entrance (weir, riprap pad, level spreader, stilling basin, etc.)
- remove excess sediments upstream where possible
• remove high concentrations of oil and grease upstream of swale

4.10.5 General Design Criteria and Considerations


Sizing

• use Manning formula for open channels to design swale width for given flow, channel slope and water depth – then check flow velocity and hydraulic residence time
• the appropriate Mannings n varies with the type of vegetation and the flow depth
• for the water quality (biofiltration) storm where the flow depth is less than the vegetation height, use n = 0.20 for grass swales to be mowed regularly and n = 0.24 for infrequently mowed swales (Horner et al., 1994)
• for large conveyance flows, use typical n for open channels, e.g., n = 0.03 for grassed channels where flow depth exceeds 300 mm (Claytor and Schueler, 1996)
• minimum residence time for the water quality storm 5 min – at least 9 min recommended (Horner et al., 1994)
• maximum flow velocity for water quality storm 0.3 m/s (KC, 1998), maximum flow velocity for larger storms should be non-erosive - in the absence of specific information on the erosivity of the channel, limit velocity to 1 m/s (Horner et al., 1994) – alternatively, bypass large storms

Design Features

• design flow depth for water quality storm not more than 1/3 the height of emergent wetland vegetation (up to a maximum of 50 mm below the normal height of the shortest wetland species) or ½ the grass height in regularly mowed swales up to a maximum depth of 75 mm (WEF, 1998)
• WSDOE (1992) recommends a maximum grass height of 150 mm with a maximum flow depth of 125 mm

Dimensions

• minimum length 30 m (Horner et al., 1994)
• maximum bottom width 2.4 m, unless structural measures (e.g., dividing berms) are used to ensure sheet flow (Reeves, 1994)
• minimum bottom width 0.6 m (WEF, 1998)
• parabolic or trapezoidal cross section (Reeves, 1994)
• maximum side slope without terracing 3:1 – 4:1 recommended for ease of maintenance (WEF, 1998)
• minimum freeboard 150 mm (Horner et al., 1994)
longitudinal slope 2% to 4%, install checkdams if slope exceeds 4%, install underdrains (see BMP S16) if slope less than 2% (Horner et al. 1994)

Soils and Vegetation

• sandy loam topsoil layer with organic matter content of 10% to 20% and no more than 20% clay
• do not use manure mulching or high fertilizer hydroteering to establish groundcover as this may cause nutrient export
• minimize compaction during construction
• divert runoff if possible during establishment of vegetation

4.10.6 Limitations

• maximum contributing area 2 ha at 35% imperviousness, 1.5 ha at 75% imperviousness, 1 ha at 90% imperviousness, assuming max. flow velocity 5 m/s and swale bottom width 0.75 m (OMEE, 1994)
• maximum longitudinal slope without check dams 4%, with check dams 6% (may traverse slope if necessary)
• susceptible to erosion
• may be difficult to sustain even sheet flow
• susceptible to sediment accumulation – provide pretreatment if high sediment load expected
• requires the use of wetland species in areas of high water table or if drainage is poor
• may require irrigation during dry season
• prevent leaf fall into swale
• shading may inhibit plant growth, particularly in deep swales

4.10.7 Capital Costs and Implementation Requirements

• construction cost depends on swale depth, land slope, soil conditions, etc.
• budget construction cost for grassed channel $5.40/m² surface area plus $2.25/m² surface area for stabilization (DDNREC, 1997)
• typical construction cost for grassed channel $24 to $74 per linear m (FHWA, 1996)
• simple check dams $75 to $100 each (adapted from DDNREC, 1997)
• for total capital cost add 35% to construction cost (engineering, contingencies, erosion and sediment control during construction, landscaping, etc) – does not include the cost of land
• minimal staff training requirements
4.10.8 Operation and Maintenance Requirements and Costs

*Costs*

- budget 5% to 7% of construction cost per year (SWRPC, 1991)

*Inspection and Maintenance Frequency*

- inspect routinely (preferably monthly), especially after large storms (WEF, 1998)
- correct erosion problems as necessary
- routine mowing to keep grass in the active growth phase and maintain dense cover - as frequently as bi-weekly during the peak growing season (Claytor and Schueler, 1996)
- remove clippings to prevent clogging of outlets and prevent nutrient release
- keep inlet flow spreaders free of debris
- remove trash and debris for aesthetic reasons
- remove sediments by hand using flat shovel if sediment covers vegetation or begins to reduce capacity
- reseed damaged areas immediately

*Other Requirements*

- do not mow below design water quality flow depth
- wheel strips constructed of modular pavers may be used in the swale bottom for vehicle access (KC, 1998)
- requires maintenance plan including scope, schedule, record keeping, and responsibilities

4.10.9 Benefits Vs Costs

- some attenuation of peak flows for flood control and streambank erosion protection
- contaminant removal is less than wet ponds, constructed wetlands, and infiltration but still significant.
- can significantly reduce the sediment and contaminant load on downstream facilities
- wet swales may provide fish habitat
- can be aesthetically pleasing if maintained properly – aesthetic concerns include accumulation of trash and debris, insect nuisance in wet swales.
- technically simple
- more appropriate for removing low concentrations of oil and grease (< 10 mg/L) than coalescing plate separators (BMP S1)
- relatively inexpensive – more costly where swale channel is deep
- can last for 10 to 20 years with proper design and maintenance (FHWA, 1996)
• can reduce development costs by combining conveyance and treatment in one system
• lower construction cost than conventional conveyance systems that include curbing, inlets, and pipes (DDNREC, 1997)
• see Section 4.21 for overview cost benefit analysis.
FIGURE 4-9a  EXAMPLE OF BIOFILTER (GRASS CHANNEL)  
(FROM CWP et al., 1997)

BMP S9: Grassed Channel/Wet Swale

FIGURE 4-9b  EXAMPLE OF WET SWALE
(FROM CWP et al., 1997)
4.11 BMP S10: Vegetated Filter Strip

4.11.1 Description

Vegetated filter strips, commonly referred to as biofilters, are similar in some respects to vegetated swales (BMP S9), in that the runoff from the water quality storm is directed to flow over a vegetated surface. However, filter strips are broad areas that promote even sheet flow over a sloped vegetated ground surface, where swales are flow conveyance channels. The vegetated surface of filter strips can range from turf to forest. A schematic drawing of a typical grassed filter strip is shown on Figure 4-10 at the end of Section 4.11.

In filter strip design, stormwater flows are intercepted and directed over the vegetated surface before the flows have become substantially concentrated. Some infiltration may occur, and the time of concentration is increased; this may result in some attenuation of peak runoff rates for flood control and streambank erosion protection, although other detention BMPs are typically required as well for these purposes. Contaminant removal mechanisms are similar to those described for grassed channels (filtering of suspended solids, adsorption to soil particles and plants, infiltration, some biological action).

4.11.2 Applications

- stormwater conveyance and treatment
- suitable for small storms only – bypass larger flows to prevent erosion
- particularly suited alongside roadways and parking lots, paved sites without underground collection and conveyance systems
- some attenuation of peak flows for flood control and streambank erosion protection
- suitable for water quality enhancement
- some groundwater recharge possible
- can be used as pretreatment for other BMPs, particularly for sediment removal
- suitable for new developments – may be retro-fitted to existing developments and redeveloping areas if space is available
- suitable for residential areas, municipal office complexes and municipal repair/maintenance yards
- suitable for removing oil and grease from general urban runoff
- not practical for ultra urban areas

4.11.3 Performance

- best contaminant removal performance for small storms and low-density developments
- most effective for removing larger particles
- removal of soluble contaminants depends on degree of infiltration
- contaminant removal is a function of filter strip length, slope, soil permeability, size of contributing area, and runoff velocity – the most significant improvement in performance occurs as longitudinal length increases from 6 m to 18 m (FHWA, 1996)
- removal of suspended solids as follows (from DDNREC, 1997):

<table>
<thead>
<tr>
<th>filter longitudinal slope</th>
<th>filter length for particulate trapping efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>70%</td>
</tr>
<tr>
<td>1%</td>
<td>3 m</td>
</tr>
<tr>
<td>2%</td>
<td>9 m</td>
</tr>
<tr>
<td>3%</td>
<td>12 m</td>
</tr>
<tr>
<td>4%</td>
<td>18 m</td>
</tr>
<tr>
<td>5%</td>
<td>23 m</td>
</tr>
</tbody>
</table>

- FHWA (1996) proposes the following contaminant removal efficiencies for vegetated filter strips:
  - total suspended solids 70%
  - total phosphorus 40%
  - total nitrogen 20% to 40%
  - heavy metals 40% to 80%
  - oxygen demand 0% to 20%

4.11.4 Pretreatment and/or Post-Treatment Requirements
- flow spreader required along upper edge of strip (see Figure 4-10)
- may be used as pretreatment for other downstream BMPs

4.11.5 General Design Criteria

Sizing
- size for water quality flow
- use the Manning equation to calculate design flow depth for a given width of strip (e.g., FHWA, 1996 and KC, 1998)
- if design flow depth exceeds 25 mm, reduce design flow rate, widen strip or use alternate BMP (WEF, 1998 and KC, 1998)
- use Mannings n = 0.2 for grass strips, n = 0.24 if strip is infrequently mowed, selected higher value for forested strip (FHWA, 1996 and WEF, 1998)
**Dimensions**

- use hydraulic radius = design flow depth (FHWA, 1996 and WEF, 1998)
- required length of strip = hydraulic residence time (HRT) x design flow velocity, where minimum HRT = 9 min (KC, 1998)
- recommended filter strip length 20 m to 30 m, recommended minimum width 2.4 m or 20% of the path of contributing sheet flow over the upstream impervious area, whichever is greater (FHWA, 1996)
- grade to a uniform, even slope
- recommended width (m) to longitudinal slope (%) ratio 1.2:1 (i.e., for a 5% longitudinal slope, strip should be 6 m wide – DDNREC, 1997)
- maximum longitudinal slope of drainage area connected to strip (i.e., parallel to flow path) 5% (KC, 1998)

**Vegetation and Soils**

- use salt and metal tolerant vegetation near roadways
- promote humic layer in forested strips to maximize performance
- provide 50 mm minimum compost over entire area unless native soil has at least 10% organic content – till compost into soil to minimum depth 150 mm (KC, 1998)
- do not use manure mulching or high fertilizer hydroseeding to establish groundcover as this may cause nutrient export
- plant erosion resistant grasses
- if located next to a roadway, evaluate shrink/swell capacity of soils (FHWA, 1996)
- minimize compaction during construction
- divert runoff around strip until vegetation established

**Design Features**

- integrate into overall site design
- avoid concentration of flows
- control flow velocity to limit erosion
- avoid use of curbs at downslope edge or provide through-curb ports

**4.11.6 Limitations**

**Land Use**

- high-density development may generate flows that are too intense for filter strips
- can accomplish significant attenuation of runoff flow rates only in low-density situations with low to moderate impervious cover, where there are small fluctuations in peak flows (FHWA, 1996)
Site Restrictions

- maximum contributing drainage area 2 ha (FHWA, 1996)
- ratio of total contributing area to filter strip area should not exceed 50:1 (DDNREC, 1997)
- maximum flow path draining to filter strip 50 m (KC, 1998)
- maximum lateral slope of drainage area connected to strip (i.e., parallel to edge of pavement) 2% - use stepped spreaders for slightly steeper slopes (KC, 1998)
- minimum longitudinal slope 1%, recommended maximum longitudinal slope 5%, never exceed 10% (DDNREC, 1997) – note that KC (1998) allows up to 20% longitudinal slope, but, according to WSDOE (1992) effective contaminant removal will not occur on slopes exceeding 10%
- desirable permeability of underlying soils 0.15 to 4.3 mm/hr (FHWA, 1996)

Other Limitations

- susceptible to short circuiting and erosion via flow channelization
- must be protected from activities that will tend to channelize flows – provide appropriate signs
- may be difficult to sustain even sheet flow
- shading may inhibit plant growth
- may require irrigation during dry season
- foreasted strips should have flatter slopes than grassed strips due to greater erosion potential

4.11.7 Capital Costs and Implementation Requirements

- for grassed strips - seeding $5/m² vegetated area, sod $11/m² vegetated area (adapted from SWRPC, 1991)
- for forested strips - $4,000 to $20,000 per hectare for nursery stock planting, depending on species and size – $400 to $2,000 per hectare for seedling planting (FHWA, 1996)
- for total capital cost add 35% to construction cost (engineering, contingencies, erosion and sediment control during construction, landscaping, etc) – does not include the cost of land
- minimal staff training requirements
4.11.8 Operation and Maintenance Requirements and Costs

Costs

- if natural succession allowed to occur budget $370/ha/yr, if natural secession not allowed to occur budget $3,000/ha/yr (adapted from USEPA, 1995)
- typical for grassed strips $1,200/ha/yr (adapted from SWRPC, 1991)
- periodic aeration of soils and/or reseeding may be required

Inspection and Maintenance Frequency

- inspect routinely (preferably monthly), especially after large storms (WEF, 1998)
- correct erosion problems as necessary
- routine mowing to keep grass in the active growth phase and maintain dense cover - as frequently as biweekly during the peak growing season (Claytor and Schueler, 1996) - minimum height for turf grass 75 mm, maximum 300 mm (DDNREC, 1997)
- remove clippings to prevent clogging of outlets and prevent nutrient release
- do not fertilize grassed strips unless required for healthy growth
- keep inlet flow spreaders free of debris
- remove trash and debris for aesthetic reasons
- remove sediments by hand using flat shovel if sediment covers vegetation or begins to reduce capacity
- reseed damaged areas immediately

Other Requirements

- provide access along upper edge of strip to allow maintenance of inflow spreader and allow access for mowing equipment
- forested strips require little maintenance but are more subject to channelization and erosion (FHWA, 1996)
- important to maintain dense vegetation on grassed strips
- requires maintenance plan including scope, schedule, record keeping, and responsibilities

4.11.9 Benefits Vs Costs

- helps to promote groundwater recharge.
- effective removal of particulates but less effective for dissolved contaminants than wet ponds and constructed wetlands
- more appropriate for removing low concentrations of oil and grease (< 10 mg/L) than coalescing plate separators (BMP S1)
- relatively inexpensive
• can reduce development costs by combining conveyance and treatment in one system
• lower construction cost than conventional conveyance systems that include curbing, inlets, and pipes (DDNREC, 1997)
• helps to reduce watershed imperviousness
• forested strips help to preserve the character of riparian zones and provide wildlife habitat
• forested strips provide better contaminant removal and infiltration than grassed strips
• can last for 10 to 20 years with proper design maintenance (FHWA, 1996)
• requires more land area than biofiltration swale due to shallower flow depth (KC, 1998)
• provides limited attenuation of peak flows
• see Section 4.21 for overview cost benefit analysis
FIGURE 4-10  TYPICAL FILTER STRIP DETAILS
(FROM KC. 1998)
4.12 BMP S11: Off-Line Infiltration Basin

4.12.1 Description

Infiltration basins are designed to capture and temporarily store runoff in a surface pond until it gradually infiltrates into the ground. Infiltration reduces both peak runoff rates and runoff volumes. Infiltration also recharges groundwater and removes contaminants through filtration, adsorption to soil particles, chemical reactions, and the actions of soil bacteria. Structural infiltration practices have the highest failure rate among structural BMPs, mainly due to clogging by sediments, high water table, poorly drained soils, and oil in runoff (Horner et al., 1994). Infiltration basins in general may be on-line or off-line; however, for the climatic and geological conditions in the GVS&DD, only off-line infiltration basins designed to handle the water quality storm and bypass larger flows are considered practical (Schueler, 1998). A schematic drawing of an infiltration basin is shown on Figure 4-11 at the end of Section 4.12.

4.12.2 Applications

- primarily for stormwater treatment and groundwater recharge
- minimal attenuation of peak flows for flood control and streambank erosion protection
- suitable for new developments – may be retro-fitted to existing developments and redeveloping areas if space is available (parks and greenspace)
- suitable for residential areas, municipal office complexes and municipal repair/maintenance yards
- not practical for ultra urban areas

4.12.3 Performance

- infiltration facilities are the only BMPs that can provide complete or nearly complete control of runoff peak flow rate, runoff volume, and water quality (only in cases where all or most of the captured runoff can be infiltrated).
- however, infiltration facilities have the worst track record of any Structural BMP due to failures associated with clogging and poor drainage
- FHWA (1996) proposes the following contaminant removal efficiencies:
  - total suspended solids 75% to 99%
  - total phosphorus 50% to 70%
  - total nitrogen 45% to 70%
  - heavy metals 50% to 90%
  - oxygen demand 70% to 90%
Schueler (1987) estimates the following long-term contaminant removal efficiencies for infiltration basins:

<table>
<thead>
<tr>
<th></th>
<th>Rule 1</th>
<th>Rule 2</th>
<th>Rule 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>sediment</td>
<td>75%</td>
<td>90%</td>
<td>99%</td>
</tr>
<tr>
<td>total phosphorus</td>
<td>50%-55%</td>
<td>60%-70%</td>
<td>65%-75%</td>
</tr>
<tr>
<td>total nitrogen</td>
<td>45%-55%</td>
<td>55%-60%</td>
<td>60%-70%</td>
</tr>
<tr>
<td>trace metals</td>
<td>75%-80%</td>
<td>85%-90%</td>
<td>95%-99%</td>
</tr>
<tr>
<td>oxygen demand</td>
<td>70%</td>
<td>80%</td>
<td>90%</td>
</tr>
<tr>
<td>bacteria</td>
<td>75%</td>
<td>90%</td>
<td>98%</td>
</tr>
</tbody>
</table>

where:
- Rule 1: the basin is sized to store and infiltrate 32 mm of rain per impervious ha in the contributing watershed
- Rule 2: the basin is sized to store and infiltrate 26 mm of rain over the entire contributing watershed
- Rule 3: the basin is sized to store and infiltrate the 2-year runoff volume from the contributing watershed

4.12.4 Pretreatment and/or Post-Treatment Requirements

- pretreatment to remove at least 80% of sediments is essential to prevent clogging
- pretreatment may be required to remove contaminants (Horner et al., 1994)
- downward migration of metals is not typically observed in the Puget Sound area – the exception is for coarse gravelly soils (Hilding, 1994)

4.12.5 General Design Criteria


**Sizing**

- size for water quality runoff volume only – bypass larger flows
- a simple sizing method is to set estimated basin area = water quality volume/design water depth, where design water depth = design draining time/average infiltration rate (WEF, 1998)
- recommended maximum water depth 0.3 m (WEF, 1998)

**Infiltration Rate**

- maximum draining time 48 hours (WSDOE, 1992)
- reduce measured infiltration rate by a factor of 2 for design (WSDOE, 1992)
- recommended minimum infiltration capacity 13 mm/hr (WSDOE, 1992)
- maximum infiltration capacity 61 mm/hr unless contaminant removal is accomplished by pretreatment (Horner et al., 1994)
- minimum 600 mm freeboard (FHWA, 1996)

**Infiltration Media**

- for runoff treatment, underlying soils should contain sufficient organic matter and/or clay to accomplish contaminant removal, minimum 450 mm soil layer with minimum cation exchange capacity (CEC) of 5 milliequivalents per 100 g dry soil (WSDOE, 1992)
- layered infiltration media recommended – 3 layers, each 0.3 m to 0.6 m deep, separated by filter fabric — upper layers commonly sand or peat-sand or crushed limestone for phosphorus reduction and pH adjustment (Horner et al., 1994)

**Design Features**

- basin floor should be as flat as possible
- avoid compaction of soils during construction
- divert construction runoff
- stabilize banks
- bed should be deeply tilled after final grading
- similar criteria to wet ponds for introduction of inflow at low velocity and uniform distribution, side slopes, emergency overflow, and safety (Horner et al., 1994)

**4.12.6 Limitations**

**Site Restrictions**

- contributing area 2 ha to 20 ha (FHWA, 1996) – Schueler (1987) recommends 0.8 ha to 6 ha
- unsuitable for construction on fill material or on slopes exceeding 15%, locate at least 15 m from any slope greater than 15% and at least 30 m upslope and 6 m downslope of any building (Horner et al., 1994)
- minimum depth to bedrock, high water table or impermeable layer 1 m to 1.5 m (Horner et al., 1994)
- minimum setback from septic drain fields 30 m (KC, 1998)
Soils

- unsuitable for clay soils due to restricted percolation, unsuitable for gravel and coarse sands unless pretreatment provided due to risk of groundwater contamination (Horner et al., 1994)
- maximum clay content 30%, maximum silt-clay content 40% (WSDOE, 1992)
- limited by soil infiltration capacity and depth the groundwater/impermeable layer (see design criteria)
- the various methods for measuring infiltration rate give inconsistent results in the Puget Sound area (Hilding, 1994)

Other Restrictions

- do not infiltrate contaminated runoff without prior treatment
- evaluate potential risk for groundwater contamination
- high potential for failure due to clogging
- do not use for sediment control during construction
- difficult to maintain grass on basin floor due to frequent inundation, poor soils, or standing water (Hilding, 1994)
- infiltration basins often evolve into small (pocket) wetlands (Schueler, 1994)
- may be difficult to mow basin floor if it becomes boggy

4.12.7 Capital Costs and Implementation Requirements

- budget construction cost $71/m³ storage volume for 1,000 m² basin (425 m³ storage volume) – adapted from SWRPC (1991)
- budget construction cost $44/m³ storage volume for 4,000 m² basin (2,160 m³ storage volume) – adapted from SWRPC (1991)
- for total capital cost add 35% to construction cost (engineering, contingencies, erosion and sediment control during construction, landscaping, etc) – does not include the cost of land
- minimal staff training requirements

4.12.8 Operation and Maintenance Requirements and Costs

Costs

- budget 1% to 3% of construction cost per year (Livingston et al., 1997 and SWRPC, 1991)
- average maintenance cost in Puget Sound area $750 to $1,500 per basin per year (adapted from Hilding, 1994)
Inspection and Maintenance Frequency

- inspect monthly and after every major storm for the first few months and semi-annually after it is determined that the basin is functioning properly (WSDOE, 1992)
- inspect hydraulic and structural facilities annually – expected life of outlet structures 25 yr for corrugated metal and 50-75 yr for structural concrete (FHWA, 1996)
- inspect periodically during wet weather to observe function
- watch for differential settlement, cracking erosion, leakage, tree growth, sediment accumulation, remove debris and litter
- maintain grass for performance and appearance – mow at least twice per year to discourage woody growth

Other Requirements

- requires maintenance plan including scope, schedule, record keeping, and responsibilities
- keep maintenance records of outlet structure, spillway, forebay, embankments, harvesting of vegetation, etc.
- provide direct maintenance access to inlet and outlet structures capable of supporting heavy equipment, minimum width 5 m, maximum slope 4:1
- same requirements for maintenance access as for wet ponds (BMP S6)
- control nuisance insects, remove nuisance plant species and replant with desirable species as required

4.12.9 Benefits Vs Costs

- attenuates both peak flows and runoff volumes
- can reduce the size of downstream conveyance and detention facilities
- can provide more effective contaminant removal than most other structural BMPs
- promotes groundwater recharge
- aesthetic concerns include lack of grass cover, presence of trash and debris may generate complaints from residents (Hilding, 1994)
- may have a short life span
- relatively expensive to construct and maintain
- potential risk of groundwater contamination
- may cause groundwater mounding
- see Section 4.21 for overview cost benefit analysis
FIGURE 4-11 EXAMPLE OF INFILTRATION BASIN
(FROM CWP et al., 1997)
4.13 BMP S12: Roof Downspout System

4.13.1 Description

Roof downspout systems are a type of infiltration system intended only for infiltrating the runoff from roof downspout drains; they are not designed to handle general site runoff (e.g., from paved areas, lawns, etc.). The means of infiltration in roof downspout systems may be via sub-surface infiltration trenches filled with drain rock, sub-surface sand filters, dry wells (sub-surface reservoirs made from large diameter pipes set on end over a base of washed rock), sub-surface perforated infiltration tanks, dispersion (open-top) trenches (including rock pockets and French drains), or surface dispersion (Konrad et al., 1995). Sub-surface sand filters are discussed under BMP S16. The other variations of roof downspout systems are discussed in this section.

Recommended sizing for each of the above design variants for various roof areas and soil infiltration rates are provided in the tables contained in Appendix D. These dimensions are based on a design storm of 50 mm over 24 hours (2-year storm). It has been determined that a system designed to these standards will overflow on average every other year in the area near the Seattle airport. These values can be scaled up or down directly for larger or smaller design vents. For example, for a design storm of 75 mm over 24 hours (10-year storm), multiply the values in the tables by a factor of 1.5, and for 90 mm over 24 hours (50-year storm) multiply by a factor of 1.75. Note that the dimensions given in the tables can be configured differently (e.g., wider than suggested) if necessary (Konrad et al., 1995).

Rooftop runoff is commonly described as “relatively clean” in design manuals, and is consequently considered safe for infiltration without prior treatment (WSDOE, 1992). However, it should be noted that Field and Pitt (1990) reported a sample of residential rooftop runoff to be toxic; the toxicity was attributed to leaching of metals from galvanized eaves and downspouts. Other potential sources of contamination in rooftop runoff include atmospheric deposition, asphalt shingles, bird droppings, and decaying organic matter. In cases where groundwater is sensitive to contamination, the use of a sand filter for contaminant removal should be considered (see BMP S16).

Subsurface systems (infiltration trenches, tanks, and dry wells) provide temporary storage of runoff and provide an opportunity for it to infiltrate into the surrounding soil. Surface dispersion systems rely on vegetated surfaces to infiltrate stormwater. Roof downspout systems can accomplish runoff peak flow, volume reduction, and groundwater recharge. Some removal of contaminants is possible as the water infiltrates into the surrounding soil. A schematic drawing of a typical roof downspout system containing washed drain rock in a subsurface infiltration trench is shown on Figure 4-12 at the end of Section 4.13.
4.13.2 Applications

- designed to infiltrate relatively clean rooftop runoff only (see BMP S16 if contaminant removal required)
- not designed to handle site runoff (lawns, parking lots, etc.)
- suitable for flood control, streambank erosion protection and groundwater recharge
- suitable for retro-fitting to existing developments and redeveloping areas as well as new developments
- mainly for residential areas – can also be used for municipal buildings

4.13.3 Performance

- can significantly reduce peak runoff flow rates and runoff volumes and recharge groundwater if extensively used in residential areas
- assume negligible contaminant removal

4.13.4 Pretreatment and/or Post-Treatment Requirements

- provide catchbasin sump with fine mesh screen or other pretreatment to remove leaves and debris (see Figure 4-12)

4.13.5 General Design Criteria

- see WSDOE (1992), Konrad et al. (1995), and Olympia (1994) for detailed design guidance
- design to handle the flood control volume, streambank protection volume, or groundwater recharge volume, depending on objectives – alternatively, design to infiltrate as much water as possible given site constraints
- use PVC or similar material rather than galvanized metal for eaves and downspouts
- use setback requirements (see Limitations) to determine area available for infiltration – use several small systems at individual downspouts if necessary (Konrad et al., 1995)
- avoid compaction of soils during construction
- divert construction runoff
- provide high flow bypass with overflow route
- perform seepage analysis to determine impact on building foundations and basements
- maximum draining time 72 hours (Konrad et al., 1995) – WSDOE (1992) recommends 48 hours
- infiltration trenches – 0.6 m wide and 0.5 m deep filled with drain rock, 150 mm diameter perforated PVC pipe running length of trench, top of trench approximately 1 m to 2 m below final grade, primary design variable is length of trench (Konrad et al., 1995), fill material should be clean aggregate with diameter 38 mm to 76 mm
surrounded by filter fabric except for the top 300 mm, void space assumed 30% to 40% (WSDOE, 1992), provide one observation well for every 15 m of trench/tank constructed of 100 mm to 150 mm diameter PVC pipe with cap (WSDOE, 1992), wrap aggregate rock in filter fabric prior to backfilling – see Appendix D for sizing criteria.

- **dry wells** – cylindrical, open bottom containers containing no fill material and placed on a bed of drain rock, top of tank approximately 1 m to 2 m below final grade, primary design variable is diameter (Konrad et al., 1995), provide one observation well for every 15 m of trench/tank constructed of 100 mm to 150 mm diameter PVC pipe with cap (WSDOE, 1992) – see Appendix D for sizing criteria.

- **infiltration tanks** – rectangular, perforated tanks surrounded by drain rock and soil, 1.5 m wide by 1.5 m deep containing no fill material, top of tank 1 m to 2 m below final grade, primary design variable is length (Konrad et al., 1995) – see Appendix D for sizing criteria.

- **surface dispersion trench** – shallow trench excavated and backfilled with drain rock, 1 m wide by 0.3 m deep, may have perforated PVC pipe running length of trench (optional), no soil cap, primary design variable is length (Konrad et al., 1995), fill material should be clean aggregate with diameter 38 mm to 76 mm surrounded by filter fabric except for the top 300 mm, void space assumed 30% to 40% (WSDOE, 1992), provide one observation well for every 15 m of trench/tank constructed of 100 mm to 150 mm diameter PVC pipe with cap (WSDOE, 1992) – see Appendix D for sizing criteria.

- **surface dispersion systems** – splash blocks draining away from building to gardens or other vegetated areas with permeable soil, approximately 0.5 m wide flow path (tailor to site), maximum ponding depth 10 mm, primary design variable is vegetated length of flow path (Konrad et al., 1995), wrap aggregate rock in filter fabric prior to backfilling – see Appendix D for sizing criteria.

### 4.13.6 Limitations

**Site Restrictions**

- locate minimum 3 m from any structure and minimum 15 m from any steep slope (WSDOE, 1992)
- minimum height of base of infiltration system above seasonal high water table 0.3 m (Konrad et al. 1995)
- maximum site slope 40% (Konrad et al. 1995)
- locate infiltration facility at least 3 m upslope of any structure, at least 3 m from property lines, at least 10 m from water supply wells, and at least 6 m from environmentally sensitive areas (Konrad et al. 1995)
- do not use for sediment control during construction
Soils and Infiltration Media

- unsuitable for clay soils due to restricted percolation (Horner et al., 1994)
- unsuitable for construction on fill material
- maximum clay content 30%, maximum silt-clay content 40% (WSDOE, 1992)
- limited by soil infiltration capacity and depth the groundwater/impermeable layer (see design criteria)
- the various methods for measuring infiltration rate give inconsistent results in the Puget Sound area (Hilding, 1994)

Other Restrictions

- should not be used if rooftop runoff is contaminated (e.g., in areas of significant depositional air pollution – WSDOE, 1992)
- evaluate potential risk for groundwater contamination

4.13.7 Capital Costs and other Implementation Requirements

- subsurface infiltration trenches budget construction cost $110 V where $V =$ trench volume in m$^3$ (adapted from Brown and Scheuler, 1997 and CWP, 1998)
- for total capital cost add 35% to construction cost (engineering, contingencies, erosion and sediment control during construction, landscaping, etc) – does not include the cost of land
- minimal staff training requirement

4.13.8 Operation and Maintenance Requirements and Costs

- these systems can perform well with a minimum of maintenance
- responsibilities for maintenance must be clearly established for use on single family lots
- maintain maintenance log
- monitor observation well quarterly and after large storms during first year, annually thereafter (during operation), depending on observations (WSDOE, 1992)
- clean catchbasins and screens regularly as required
- surface dispersion trenches and surface dispersion systems may require periodic weeding, replacement of rock, or loosening of soil
- watch for standing water, saturation and settling of surrounding area, blocking of overflow path with debris, saturation downslope
4.13.9 Benefits Vs Costs

- relatively simple to install
- can reduce the need for downstream conveyance and detention facilities
- promotes groundwater recharge
- infiltration trench variant requires large area
- dry well requires less area but requires relatively permeable soil
- infiltration trenches, dry wells, and infiltration tanks are buried and the surface can be used for other purposes (turf, garden, etc.)
- dispersion trenches and surface dispersion are easy to construct but top area is exposed and cannot be used for other purposes – incorporate drainrock into landscaping features
- the relative advantages and disadvantages of the various systems are summarized below (from Konrad et al., 1995):

<table>
<thead>
<tr>
<th>Infiltration System</th>
<th>Minimum length of available land</th>
<th>Minimum area of available land</th>
<th>Minimum infiltration capacity</th>
<th>Cost: material/labour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface Dispersion</td>
<td>Long</td>
<td>Large</td>
<td>High</td>
<td>Low/Low</td>
</tr>
<tr>
<td>Infiltration Trench</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Medium/High</td>
</tr>
<tr>
<td>Dispersion Trench</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low/Medium</td>
</tr>
<tr>
<td>Infiltration Tank</td>
<td>Short</td>
<td>Small</td>
<td>Medium</td>
<td>High/High</td>
</tr>
<tr>
<td>Dry Well</td>
<td>Short</td>
<td>Small</td>
<td>Medium</td>
<td>High/High</td>
</tr>
</tbody>
</table>

- see Section 4.21 for overview cost benefit analysis
FIGURE 4-12  TYPICAL ROOF DOWNSPOUT SYSTEM
(FROM WSDOE, 1992)
4.14 BMP S13: Porous Pavement

4.14.1 Description

Porous pavement is a permeable paving material that allows stormwater to percolate through the pavement to a gravel base. The pavement consists of a uniform, open graded coarse aggregate, cemented together with either concrete or asphalt. Water reaching the gravel base either infiltrates into the soil or is routed to the conveyance system via underdrains. Porous pavements provide similar water quality benefits to infiltration basins (BMP S11). In addition, temporary storage in the gravel base with subsequent infiltration can provide significant reductions in runoff peak flows and volumes (FHWA, 1996). A schematic drawing of a porous pavement system is shown on Figure 4-13 at the end of Section 4.14.

4.14.2 Applications

- only practical for low traffic volumes (parking lots, access roads, driveways, parking lanes)
- can receive runoff from other areas, provided sediment loads are small (see Limitations)
- suitable for flood control, streambank erosion protection, groundwater recharge, and water quality improvement
- suitable for retro-fitting to existing developments and redeveloping areas as well as new developments
- residential areas, municipal office complexes
- suitable for ultra urban areas

4.14.3 Performance

- higher contaminant removals for particulate contaminants than for soluble.
- long term contaminant removal efficiencies as follows (from Schueler, 1987):
  - sediment 82% to 95%
  - total phosphorus 65%
  - total nitrogen 80% to 85%
  - chemical oxygen demand 82%
  - zinc 99%
  - lead 98%

4.14.4 Pretreatment and/or Post-Treatment Requirements

- protect from sediment loads – provide berms, filter strips, or other diversionary structures to inhibit unintended runoff from other areas
4.14.5 General Design Criteria

- see FHWA (1996), WSDOE (1992), Horner (1998), Konrad et al. (1995), and Schueler (1987) for detailed design guidance
- recommended draining time of subsurface gravel reservoir 24 hr to 72 hr (FHWA, 1996)
- stabilize surrounding areas
- avoid excessive compaction of subsoil during construction
- may be designed to infiltrate all or part of the water passing through the pavement layer to the surrounding soil as follows:
  - full exfiltration systems – retain 100% of capture water for exfiltration to surrounding soil, if reservoir becomes full, excess water will runoff pavement surface and must be handled in a conventional system
  - partial exfiltration systems – have underdrain piping systems designed to route flows in excess of the design exfiltration volume to conventional conveyance system
  - water quality exfiltration systems – designed to receive and exfiltrate only the design water quality volume with excess flows bypassed to a conventional conveyance system

4.14.6 Limitations

**Site Restrictions**

- maximum contributing area 0.1 ha to 4 ha (FHWA, 1996)
- minimum infiltration rate of underlying soil 6.9 mm/hr, at least 12.7 mm/hr preferred, adequate soil permeability should extend for a depth of at least 1.2 m (FHWA, 1996)
- minimum depth to high groundwater table 1.2 m (FHWA, 1996)
- minimum distance to drinking water well 30 m, 30 m upgradient and 3 m downgradient from building foundations (FHWA, 1996)
- maximum slope of pavement and contributing area 5% (FHWA, 1996)

**Other Restrictions**

- not intended to remove sediments
- do not use in applications with high potential for groundwater contamination (e.g., gas stations)
- requires high level of construction workmanship
- winter sanding will reduce effectiveness
4.14.7 Capital Costs and other Implementation Requirements

- budget $20 to $30 per m² pavement for construction (adapted from SWRPC, 1991 and Schueler, 1987)
- additional costs above conventional pavements are the underlying gravel reservoir layer, extra cost for open graded pavement (10% to 15% higher than conventional asphalt), filter fabric, sediment and erosion control, and underdrain system (if used)
- for total capital cost add 35% to construction cost (engineering, contingencies, erosion and sediment control during construction, landscaping, etc) – does not include the cost of land

4.14.8 Operation and Maintenance Requirements and Costs

- estimated effective life 5 to 10 years (FHWA, 1996)
- difficult to rehabilitate clogged pavement – drill 13 mm holes in clogged pavement at regular intervals if necessary
- clean at least quarterly with vacuum street sweeper followed by high pressure wash (see BMP OM4)
- do not use abrasives, avoid ploughing if possible
- requires maintenance plan including scope, schedule, record keeping, and responsibilities

4.14.9 Benefits Vs Costs

- provides effective runoff quantity and quality control, and groundwater recharge
- can be cost effective for areas smaller than 4 ha with no off-site contribution – otherwise other BMPs are more cost effective (FHWA, 1996)
- can reduce or eliminate the need for conventional curb and gutter systems and downstream detention
- greater potential to reduce runoff peak flow rates, runoff volumes, and contaminants than gravel or conventional asphalt shoulders (St. John and Horner, 1997)
- high failure rate due to poor construction and maintenance practices, may become sealed after 1-3 years (WEF, 1998) - subject to wheel rut deformation
- requires extensive site evaluation
- see Section 4.21 for overview cost benefit analysis
FIGURE 4-13  SCHEMATIC OF POROUS PAVEMENT SYSTEM
(FROM FHWA, 1996)
4.15 **BMP S14: Concrete Grid And Modular Pavers**

4.15.1 **Description**

Concrete grid and modular pavers consist of strong structural materials with regularly interspersed void areas filled with pervious material (normally soil). The structural materials provide a load bearing surface for vehicles, and the interspersed void areas allow infiltration of stormwater to the underlying soil. The structural material may be poured-in-place concrete, precast concrete grids, or modular unit pavers. The pervious material may support grass or other vegetation. Schematic drawings of example concrete grid and modular pavers are shown on Figure 4-14 at the end of Section 4.15.

4.15.2 **Applications**

- limited to low traffic areas (driveways, parking areas, storage yards, bike paths, walkways, recreational vehicle pads, service roads, fire lanes, etc.)
- can receive runoff from other areas, provided sediment loads are small
- suitable for reduction in peak flows and runoff volumes, contaminant removal, groundwater recharge
- suitable for retro-fitting to existing developments and redeveloping areas as well as new developments
- residential areas, municipal office complexes, municipal vehicle storage yards (spill control required)
- limited application in ultra urban areas

4.15.3 **Performance**

- assume contaminant removal similar to infiltration basins (BMP S11)

4.15.4 **Pretreatment and/or Post-Treatment Requirements**

- protect from sediment loads – provide berms, filter strips, or other diversionary structures to inhibit unintended runon

4.15.5 **General Design Criteria**

- see WSDOE (1992), WEF (1998), FHWA (1996), (WCC et al., 1995), and Konrad et al. (1995) for detailed design guidance
Sizing and Dimensions

- water storage/infiltration volume according to design objectives (quantity, quality, groundwater recharge) – 50 mm is typical for the Puget Sound area (Konrad et al., 1995)
- excavation depth approximately 3 times water storage volume to account for porosity of fill material (Konrad et al., 1995)

Soils

- soils investigation required
- for runoff treatment, underlying soils should contain sufficient organic matter and/or clay
- avoid compaction of soils during construction
- reduce measured infiltration rate by a factor of 2 for design (WSDOE, 1992)

Design Features

- maximum drawdown time 24 hours (WSDOE, 1992)
- divert construction runoff
- stabilize surrounding areas
- include signs to warn against excessive loads, sediment inputs, or servicing of vehicles where spills may result (WCC et al., 1995)

4.15.6 Limitations

Soils

- to accomplish contaminant removal, minimum 450 mm soil layer with minimum cation exchange capacity (CEC) of 5 milliequivalents per 100 g dry soil (WSDOE, 1992)
- recommended minimum infiltration capacity 13 mm/hr (WSDOE, 1992)
- maximum infiltration capacity 61 mm/hr unless contaminant removal is accomplished by pretreatment (Horner et al., 1994)
- maximum clay content 30%, maximum silt-clay content 40% (WSDOE, 1992)
- unsuitable for clay soils due to restricted percolation, unsuitable for gravel and coarse sands unless pretreatment provided due to risk of groundwater contamination (Horner et al., 1994)
- unsuitable for construction on fill material or on slopes exceeding 15%, locate at least 15 m from any slope greater than 15% and at least 30 m upslope and 6 m downslope of any building (Horner et al., 1994)
- the various methods for measuring infiltration rate give inconsistent results in the Puget Sound area (Hilding, 1994)
• for runoff quantity control, soils should be coarse and well drained but contaminated runoff cannot be infiltrated

**Site Restrictions**

• minimum depth to bedrock, high water table or impermeable layer 1 m to 1.5 m (Horner et al., 1994)
• do not use in applications with high potential for groundwater contamination (e.g., gas stations, vehicle repair facilities where spills may occur)
• evaluate potential risk for groundwater contamination
• minimum setback from septic drain fields 30 m (KC, 1998)
• not intended to remove sediments

**4.15.7 Capital Costs and Implementation Requirements**

• budget construction cost $80 to $115 per m$^2$ for system using porous interlocking concrete pavers (WG, 1998) – poured in place slabs and simple lattice units should be less expensive
• for total capital cost add 35% to construction cost (engineering, contingencies, erosion and sediment control during construction, landscaping, etc) – does not include the cost of land
• minimal staff training requirements

**4.15.8 Operation and Maintenance Requirements and Costs**

• turf requires maintenance if used – watering, fertilizing, mowing
• avoid the use of pesticides and fertilizers that have adverse effects on concrete products

**4.15.9 Benefits Vs Costs**

• can provide effective runoff quantity control, groundwater recharge
• potential for very effective contaminant removal depending on subsoil
• can reduce or eliminate the need for conventional curb and gutter systems and downstream detention
• requires extensive site evaluation
• higher capital cost but lower maintenance requirements and easier to renovate than porous asphalt pavement
• see Section 4.21 for overview cost benefit analysis
FIGURE 4-14 TYPES OF GRIDS AND MODULAR PAVEMENTS (FROM WSDOE, 1992)
4.16 BMP S15: Bioretention And Dry Swale With Underdrains

4.16.1 Description

Bioretention is a type of stormwater filtering system where runoff is temporarily stored in a shallow depression and then allowed to gradually infiltrate through a constructed filter bed of soil and plants to an underlying drain system. This BMP is relatively new, having been developed in Maryland in the early 1990s (Claytor and Schueler, 1996). The bioretention system consists of a flow regulation structure/level spreader with a vegetated filter strip or grass channel leading to a shallow ponding area. The ponding area contains a surface layer of organic mulch, underlain by a planting soil bed that supports turf, shrubs, and trees, underlain in turn by a sand bed and then an underdrain system. Bioretention systems are normally designed to handle the water quality volume only; larger flows are bypassed via an overflow gravel curtain and a high flow overflow structure. Contaminant removal mechanisms include filtration, adsorption, volatilization, ion exchange, microbial action, and plant uptake. A schematic drawing of a bioretention system is shown on Figure 4-15a at the end of Section 4.16.

The dry swale with underdrains is essentially a design variant of bioretention. The dry swale is similar in many respects to grassed channels and wet swales (BMP S9). The dry swale is designed to temporarily store the design water quality volume behind a weir, and then allow it to infiltrate through a soil bed to an underdrain system. Flows greater than the water quality volume pass over the weir and out of the swale. Contaminant removal mechanisms are similar to bioretention. A schematic drawing of a dry swale with underdrains is shown on Figure 4-15b at the end of Section 4.16.

4.16.2 Applications

- bioretention normally located off-line for treatment only
- dry swale with underdrains is designed to treat the water quality volume and convey larger flows
- suitable for new developments – can also be retro-fitted to existing parks and greenspace if space is available
- suitable for most development situations - residential areas, municipal office complexes, rooftop runoff, parking lot and roadway runoff, parks and greenspace, golf courses, etc.
- dry swales with underdrains are mainly applied to moderate to large lot residential land uses, and they can also accommodate runoff from small impervious areas such as roofs and small parking lots
- not practical for ultra urban areas
4.16.3 Performance

- both bioretention and dry swales with underdrains are relatively new and little performance data exists
- Schueler (1997b) suggests the following contaminant removal efficiencies for bioretention and dry swales based on limited data:
  - total suspended solids 81%
  - oxygen demand 67%
  - total phosphorus 9%
  - nitrate nitrogen 38%
  - lead 67%
  - zinc 71%
  - hydrocarbons 62%

4.16.4 Pretreatment and/or Post-Treatment Requirements

- for bioretention areas - normally use vegetated filter strips or grassed channels for pretreatment to reduce flow velocities and capture coarse sediments, a grass filter strip with a pea gravel diaphragm is preferred for applications that receive sheet flow (e.g., from parking lots – see Figure 4-15a), a grassed channel (minimum length 6.1 m) with a pea gravel diaphragm is preferred for applications that receive channelized flow diverted from the drainage system - the purpose of the pea gravel diaphragm is to distribute flow, slow velocity, and capture sediments - may use parking area sweeping if space is limited
- for dry swales with underdrains – provide forebay at initial inflow point for channelized flows (volume 3 mm of runoff per impervious hectare of contributing area), grass filters with pea gravel diaphragms for sheet flows (see Figure 4-15b)

4.16.5 General Design Criteria

Bioretention Areas

- see FHWA (1996) and Claytor and Schueler (1996) for detailed design guidance
- off-line design recommended to prevent erosion damage from larger storms but on-line design may be used for small drainage areas if necessary (Claytor and Schueler, 1996)
- size for water quality storm only – note that this may also provide significant attenuation of peak runoff flow rates if bioretention is extensively used
- Claytor and Schueler (1996) recommend minimum width 3 m, minimum length 5 m, length to width ratio 2:1 for widths greater than 3 m, maximum ponding depth 0.15 m, minimum soil bed depth 1.2 m, and a maximum drawdown time of 72 hours
• underdrain system minimum 150 mm diameter perforated pipe on maximum 3 m centres and minimum grade 0.5% within an 800 mm gravel bed – provide at least one cleanout per bed (Claytor and Schueler, 1996)

• runoff may be diverted from an enclosed storm drain system, from curbed pavements via slotted deflector grooves, or from open conveyance channels via diversion structures

• estimate planting bed space requirement as shown in Section 4.17 for BMP S16-Sand Filters (from Claytor and Schueler):

  • pea gravel overflow curtain drain recommended to promote infiltration into the soil bed (see Figure 4-15a)

  • planting soils should be sandy loam or a sand/loam mix with 35% to 60% sand and no more than 25% clay by volume – minimum permeability 0.3 m/d, use conservative value of 0.15 m/d for design (Claytor and Schueler, 1996)

  • develop planting plan to simulate a terrestrial forest community of native species, use water-tolerant species in zone of inundation

**Dry Swale with Underdrains**

• see Claytor and Schueler (1996) for detailed design guidance

• normally on-line, water quality volume is treated and larger flows are routed over a weir to downstream facilities

• can receive both sheet flow and channelized flow

• size to filter water quality volume and check erosive potential for larger storms

• see grassed channels/wet swales (BMP S9) for swale shape and configuration, maximum flow velocities, etc.

• bottom width 0.6 m to 2.4 m, maximum side slopes 2:1, recommended longitudinal slope 1% to 2% (Claytor and Schueler, 1996)

• size outlet structures to pass any flows greater than the water quality storm

• depth of soil bed 750 mm – see bioretention for soil characteristics

• maximum ponding depth for water quality storm 450 mm, maximum drawdown time 24 hours (Claytor and Schueler, 1996)

• see bioretention for underdrain requirements

### 4.16.6 Limitations

• maximum contributing area for bioretention areas and dry swales 2 ha, (CWP, 1998)

• bioretention is mainly suited to smaller areas (FHWA, 1996)

• minimum depth to water table 610 mm

• maximum site slope for bioretention 6% for dry solids 4% (CWP, 1998)

• hydraulic headloss for bioretention 1.5 m, for dry swales 1 m to 1.5 m (CWP, 1998)
4.16.7 Capital Costs and Implementation Requirements

- budget construction cost for bioretention $850 x (35.31V)^{0.99}$ where $V = m^3$ water quality treatment volume (adapted from CWP, 1998)
- typical construction cost $280/m^3$ water quality treatment (adapted from CWP, 1998)
- assume dry swale with underdrains is 80% of the cost of bioretention (CWP, 1998)
- for total capital cost add 35% to construction cost (engineering, contingencies, erosion and sediment control during construction, landscaping, etc) – does not include the cost of land
- minimal staff training requirements

4.16.8 Operation and Maintenance Requirements and Costs

Costs

- budget 5% to 7% of construction cost per year (assumed the same as grassed channels and wet swales (CWP 1998))

Inspection and Maintenance Frequency

- remove leaves each fall
- inspect overflow structures annually
- inspect periodically during wet weather to observe function
- inspect hydraulic and structural facilities annually – expected life of outlet structures 25 yr for corrugated metal and 50-75 yr for structural concrete (FHWA, 1996)
- at outset of rainy season and after each significant storm - remove trash and floatables, correct erosion problems, unlog outlet structures
- test pH of planting bed annually – adjust if pH $< 5.2$ or pH $> 8.0$
- correct erosion problems immediately
- pea gravel diaphragm may require periodic flushing and/or replacement (possibly every 3-4 years) – inspect annually for clogging
- may require aeration of turf areas
- similar landscaping maintenance to vegetated filter strips and swales

Other Requirements

- schedule maintenance around sensitive wildlife and vegetation seasons for forested bioretention areas
- develop maintenance plan that outlines schedule, scope and responsibilities, keep maintenance records
- monitor plant growth and distribution (planted and volunteers) – plants may periodically require watering, mulching, weed removal, replanting etc.
• provide maintenance access or easement, minimum width 3.7 m
• control nuisance insects, remove nuisance plant species and replant with desirable species as required

4.16.9 Benefits Vs Costs

• both bioretention and dry swales provide some attenuation of peak flows, water quality improvement, and aesthetic benefits
• bioretention areas provide wildlife habitat if forested
• dry swales can reduce development costs by combining conveyance and treatment in one system
• both bioretention and dry swales are relatively new practices – little performance data available – however, both have a high potential for removal of particulate, colloidal and dissolved contaminants
• bioretention has greater diversity in structure than most other BMPs, and it is designed to mimic the natural hydrologic cycle
• more potential for filtering through roots and soils and adsorption of contaminants to soil particles than wet ponds
• wider potential application than infiltration
• relatively high construction cost – more complex to construct than most other BMPs
• delayed efficiency until plants are well established
• see Section 4.21 for overview cost benefit analysis
FIGURE 4-15A  EXAMPLE OF BIORETENTION
(FROM CWP et al., 1997)
FIGURE 4-15b  EXAMPLE OF DRY SWALE  
(FROM CWP, 1997)
4.17 BMP S16: Sand Filter

4.17.1 Description

Stormwater sand filters are similar in some respects to bioretention (BMP S15), in that they are designed to infiltrate the runoff from the water quality storm through a bed of sand underlain by a piped drainage system. Stormwater sand filters, which are essentially slow sand filters, are a relatively recent development in stormwater management. The use of slow sand filters for water supply and wastewater treatment is well established. Contaminant removal mechanisms for stormwater sand filters include filtration, adsorption, chemical reactions, and bacterial action in the sand bed. Flows larger than the treatment volume are bypassed. There are several design variants of the sand filter, both surface and subsurface. The most common surface types are the Austin filter and the Delaware filter (also called the perimeter filter).

A schematic drawing of a subsurface sand filter is shown on Figure 4-16 at the end of Section 4.17. The Austin type surface sand filter is essentially the same as the organic filter shown on Figure 4-18 (BMP S18), except that the media is sand rather than an organic mixture.

4.17.2 Applications

- designed for contaminant removal only – no significant attenuation of peak flows or runoff volumes
- can be used in areas where site conditions prevent the use of other BMPs such as infiltration, wet ponds and wetlands – not generally limited by site characteristics or climate
- suitable for residential areas, municipal complexes, municipal repair and maintenance yards
- suitable for developed and redeveloping areas as well as new developments
- suitable for space-limited areas

4.17.3 Performance

- the following median contaminant removal efficiencies are based on monitoring of eleven sand filters (Schueler, 1997b)
  - total suspended solids 87%
  - organic carbon 66%
  - total phosphorus 51%
  - soluble phosphorus (-31%)
  - total nitrogen 44%
  - nitrate nitrogen (-13%)
  - lead 71%
- zinc 80%
- copper 34%
- hydrocarbons 81%
- bacteria 55%

4.17.4 Pretreatment and/or Post-Treatment Requirements

- pretreatment for sediment removal is essential to prevent clogging of sand media
- for any sand filter, Claytor and Schueler (1996) recommend that the sedimentation basin should ideally be capable of storing the entire water quality volume (WQV), minimum should be 75% of the WQV, recommended drawdown time 24 hours, sedimentation basin surface area in m² (Aₜ) for 90% trap efficiency should be Aₜ = 0.0062 x WQV for I < 75% and Aₜ = 0.00075 x WQV for I > 75%, where I = % impervious area
- Austin Filter and Delaware Filter - WEF recommends volume of sedimentation chamber 38 m³ per ha contributing area, surface area 25 m² per ha contributing area (WEF, 1998)
- Austin Filter - dry sedimentation chamber with energy dissipater at inlet, for full sedimentation, size sedimentation basin as extended detention dry basin – capture entire water quality volume with 40 hr drawdown time, for partial sedimentation (removes heavy sediments and trash only), minimum volume of sedimentation basin 20% of water quality volume (WEF, 1998) - partial sedimentation requires more frequent maintenance and a larger filter surface area (Virginia, 1992)
- Underground Filter - normally has a wet micropool for sedimentation

4.17.5 General Design Criteria and Considerations

- size for water quality treatment volume only
- filter bed surface areas in general can be sized as follows based on Darcy’s Law (from Claytor and Schueler, 1996):

\[
A_f = \frac{WQV \cdot d_f}{k(h+d_f)(t_f)}
\]

Where:

- \(A_f\) = Surface area of the bioretention planting bed (m²)
- \(WQV\) = Water quality treatment volume (m³), see Section 4.1
- \(d_f\) = Planting soil bed depth (m), typical 1.2 m
- \(k\) = Coefficient of permeability for planting soil bed (m/d), typical 0.15 m/d
h = Average height of water above the bioretention bed (m); \( h_{avg} = \frac{1}{2} h_{max} \), typical 0.075 m

t_f = Time required for the Water Quality Treatment Volume (WQV) to filter through the planting soil bed

- recommended drawdown time 40 hours (Claytor and Schueler, 1996)
- design k value 1.1 m/d for sand if pretreatment is designed for full sedimentation (Claytor and Schueler, 1996)

**Surface Sand Filter (see Figure 4-18 in Section 4.19)**

- recommended filter bed area 23 m² per impervious ha contributing area (FHWA, 1996)
- 460 mm to 610 mm sand layer - sod overlay optional (FHWA, 1996)
- sand underlain by perforated PVC pipe(s) in gravel jacket, pipe recommended diameter
- 100 mm (FHWA, 1996) to 150 mm (CWP, 1997)
- sand grain size no larger than concrete sand (FHWA, 1996)
- minimum length to width ratio 3:1, preferably 5:1 (CDM et al. 1993)

**Delaware (Perimeter) Filter**

- WEF recommends volume of filtration chamber 38 m³ per ha contributing area, surface area 25 m² per ha contributing area - sedimentation and filtration chambers are the same size (WEF, 1998)
- 460 mm to 610 mm sand layer – gravel or debris screen overlay optional (Claytor and Schueler, 1996)
- sand underlain by perforated PVC pipe(s) in gravel jacket, pipe recommended diameter
- 100 mm (FHWA, 1996) to 150 mm (CWP, 1997)

**Underground Sand Filter (see Figure 4-16)**

- depth of permanent pool 1 m
- Schueler and Claytor (1996) recommend sizing sand bed as shown above for surface filters
- minimum 460 mm sand layer (Virginia, 1992)
- sand underlain by perforated PVC pipe(s) in gravel jacket – filter fabric between gravel layer and sand media
- pipe recommended diameter 100 mm (FHWA, 1996) to 150 mm (CWP, 1997)
- recommended length to width ratio 2:1 (FHWA, 1996)
- sand grain size no larger than 2 mm (Virginia, 1992)
• note WEF (1998) recommends overflow weir of the Washington DC type be blocked and that the manholes be replaced with grates to allow monitoring of the filter for plugging

4.17.6 Limitations

• must be protected from excessive sediment loading
• typically requires a head drop of about 1.2 m between inlet and outlet (KC, 1998)
• do not use in areas where heavy sediment loads expected unless adequate pretreatment is used
• surface filter maximum contributing area 12 ha, underground filter maximum contributing area 4 ha, perimeter filter maximum contributing area 2 ha (FHWA, 1996)
• little operating experience in climatic conditions typical of the GVRD
• underground filter minimum depth to high groundwater table 0.6 m to 1.2 m (Virginia (1992)

4.17.7 Capital Costs and other Implementation Requirements

• unit costs vary with size - budget construction costs $37,500 to $75,000 per impervious ha contributing area (adapted from FHWA, 1996):
• alternatively, budget construction cost $160/m⁢³ to $320/m⁢³ of water quality storage (Brown, 1997)

4.17.8 Operation and Maintenance Requirements and Costs

Costs

• budget 11% to 13% of construction cost per year (Livingston et al., 1997 and Brown and Schueler, 1997)

Inspection and Maintenance Frequency

• if surface sand filters are designed with only partial sedimentation for pretreatment, more intensive maintenance will be required
• inspect semiannually and after major storms (WEF, 1998)
• remove all floatables and sediment from the sedimentation basin when 100 mm depth accumulates (WEF, 1998) – KC (1998) recommends 300 mm depth
• remove sediments from filter when 2.5 mm or more accumulates or when standing water persists past the design drawdown time (WEF, 1998) – KC (1998) recommends 13 mm
• typical cleaning frequency for surface filters in Austin, TX twice per year by raking off dried sediment
• if water level over filter drops at a rate less than 13 mm/hr, corrective maintenance is needed – if rate is greater than 300 mm/hr, short circuiting is likely (KC, 1998)
• sand typically replaced after 4-10 years, based on experience in Austin, TX (KC, 1998)
• surface vegetation may require watering
• requires maintenance plan including scope, schedule, record keeping, and responsibilities

4.17.9 Benefits Vs Costs

• can provide water quality enhancement only
• requires more frequent maintenance than most other BMPs (WWC, 1993)
• more expensive to construct than most other BMPs
• underground filters are more expensive but require less space than surface filters
• cost may decline as technology becomes more widely used
• can be used where site constraints and/or space limitations prevent the use of other BMPs
• limited experience in the climatic conditions typical of the GVRD
• can present safety and aesthetic concerns in residential areas (open beds, concrete walls, odours, visual)
• see Section 4.21 for overview cost benefit analysis
FIGURE 4-16   EXAMPLE OF UNDERGROUND SAND FILTER  
(FROM CWP, 1997)
4.18 BMP S17: Catch Basin Filter

4.18.1 Description

Catch basin filters (also called catch basin inserts) are devices installed underneath catch basin inlets to treat stormwater that enters the catch basin. Configurations vary, but the essential element is some type of filtration media (fiberglass, activated carbon, oil absorbent material, etc.) to remove contaminants as the stormwater passes through the filter. Contaminant removal mechanisms include settling, filtration, adsorption, and absorption. A schematic drawing of a catch basin filter is shown on Figure 4-17 at the end of Section 4.18.

4.18.2 Applications

- water quality improvements only – no attenuation of peak runoff flows or volumes
- suitable for developed and redeveloping areas as well as new developments
- special purpose BMP for high traffic sites and municipal repair and maintenance yards, industrial sites, etc.
- can be used to reduce O&M costs of other downstream Structural BMPs
- not suitable for residential areas
- not suitable for spill protection unless catch basin is configured for spill containment
- typically designed to remove particulate contaminants, oil and grease, trash and debris
- can be used for sediment control during construction
- suitable for unpaved areas where load of coarse sediment is expected to be high (CBIC, 1995)
- not recommended for removal of fine particulates or dissolved pollutants (CBIC, 1995)

4.18.3 Performance

- the filtration media can be specified to remove specific contaminants, including sediments
- little independent performance data
- effective for removing medium sand (>90% removal) – not recommended for silt or clay sized particles (Leif, 1998)
- similar sediment trapping efficiency to catch basin sumps (BMP S4)
- can approach the performance of CPI oil water separators (i.e., 10 mg/L oil and grease – see BMP S1), CBIC (1995)
- effective at removing trash and debris (CBIC, 1995)
- little removal of dissolved metals or metals associated with fine particulates (CBIC, 1995)
4.18.4 Pretreatment and/or Post Treatment Requirements

- none – source control recommended

4.18.5 General Design Criteria

- requires little design analysis beyond selection of filter medium for specific applications
- estimate design flows using Rational Method, identify site-specific contaminants of concern, and compare to manufacturer’s specs (CBIC, 1995)
- washout of trapped material may be reduced by inclusion of energy dissipator and high flow bypass (CBIC, 1995)
- effective media for oil include wood fiber products such as fibrous moss (e.g., sphagnum) – use media made from recycled products where possible (KC, 1998)
- filter media are proprietary
- should be designed to fit with standard catch basin grate
- locate for maintenance access

4.18.6 Limitations

- may be limited by drainage area – recommended maximum contributing area 465 m² per unit - this represents a design flow of 72 L/min in the Seattle area (KC, 1998)
- dependant on availability of space in existing catchbasins
- previously trapped materials may be washed out during subsequent storms (CBIC, 1995)
- not recommended for removing fine particulates or soluble contaminants (CBIC, 1995)

4.18.7 Capital Costs and other Implementation Requirements

- catchbasin inserts $500 to $800 each plus installation (ATSI, 1998)
- costs of filter media vary with media type – see O&M cost

4.18.8 Operation and Maintenance Requirements and Costs

- budget $50 per unit per month (varies with type of filter media), assuming monthly media replacement – does not include disposal of used media (adapted from KC, 1998 and ATSI, 1998)
- minimum inspection frequency monthly – replace media and remove sediments from catch basin sump as required
- maintenance log and schedule required
• some inserts are heavy enough to require a forklift for removal (KC, 1998)

4.18.9 Benefits Vs Costs

• water quality enhancement only
• minimal space requirements
• minimal planning and engineering requirements
• low initial cost compared to other oil removal BMPs
• more frequent maintenance than other oil removal BMPs
• can extend the maintenance cycle of catch basin sumps designed to trap sediments (BMP S4)
• can reduce the maintenance costs of downstream BMPs
• poor removal of fine particulates and associated contaminants compared to other BMPs such as wet ponds and grass swales (CBIC, 1995)
• greater maintenance frequency than oil-water separators and less containment of large spills
• see Section 4.21 for overview cost benefit analysis
FIGURE 4-17  SCHEMATIC OF CATCH BASIN INSERT
(FROM KC, 1998)
4.19 BMP S18: Organic Filter

4.19.1 Description

Organic filters are essentially the same as sand filters (BMP S16), except that the media is composed of an organic material such as compost or a peat-sand mixture, rather than sand. Stormwater percolates downward through a bed of organic media to an underdrain system of perforated pipe surrounded by gravel. Contaminant removal mechanisms are similar to those described for sand filters. The use of organic material is designed to increase the removal of contaminants (particularly nutrients) compared to sand media. Similar to sand filters, organic filters can be configured as surface units or underground vaults. A schematic drawing of a surface peat-sand stormwater filter is shown on Figure 4-18. An underground organic filter would be configured in a similar way to the sand filter shown on Figure 4-16 (BMP S16) at the end of Section 4.19. Organic filters using a proprietary system of canisters containing the organic filter media are also available.

4.19.2 Applications

- designed for contaminant removal only – no significant attenuation of peak flows or runoff volumes
- can be used in areas where site conditions prevent the use of other BMPs such as infiltration, wet ponds and wetlands – not generally limited by site characteristics or climate
- suitable for residential areas, municipal complexes, municipal repair and maintenance yards
- suitable for developed and redeveloping areas as well as new developments
- suitable for space-limited areas
- suitable for removal of metals

4.19.3 Performance

- monitoring of a leaf compost filter in Portland, OR over 13 storms showed the following average contaminant removal efficiencies (no independent testing data available at the time of preparing this manual):
  - total suspended solids 95%
  - turbidity 84%
  - chemical oxygen demand 67%
  - total phosphorus 41%
  - total kjeldahl nitrogen 56%
  - nitrate nitrogen 34%
  - ammonia nitrogen 42%
  - zinc 88%
  - copper 67%
- total petroleum hydrocarbons 87%

4.19.4 Pretreatment and/or Post-Treatment Requirements

- should be used as the second or third component in a treatment train
- see pretreatment requirements for sand filters (BMP S16)

4.19.5 General Design Criteria

- see Claytor and Schueler (1996), CWP (1997) and KC (1998) for detailed design guidance

Sizing

- filter bed surface areas in general can be sized based on Darcy’s Law as shown for sand filters – see BMP S16 (from Claytor and Schueler, 1996)

Design Features

- recommended drawdown time 40 hours (Claytor and Schueler, 1996)
- for peat/sand mixture - design k value 0.6 m/d, average k for profile including peat/sand layer and sand layer 0.84 m/d (Claytor and Schueler, 1996)
- (Claytor and Schueler, 1996) recommend design k value of 2.7 m/d for the Chesapeake Bay area to account for clogging and local conditions
- bed depth 460 mm (Claytor and Schueler, 1996)
- peat-sand filter – 460 mm bed of 50/50 peat/sand mix underlain by 150 mm bed of concrete sand and then 150 mm diameter perforated PVC drain pipes in 200 mm gravel layer – see sand filters for other design criteria (BMP S16)

4.19.6 Limitations

- must be protected from excessive sediment loading
- typically requires a head drop of about 1.2 m between inlet and outlet (KC, 1998)
- do not use in areas where heavy sediment loads expected unless adequate pretreatment is used
- little operating experience in climatic conditions typical of the GVRD
- can present safety and aesthetic concerns in residential areas (open beds, concrete walls, odours, visual)
- underground filter minimum depth to high groundwater table 0.6 m to 1.2 m (Virginia (1992)
4.19.7 Capital Costs and Implementation Requirements

- assume similar to underground sand filters (BMP S16), unless proprietary filtration media used

4.19.8 Operation and Maintenance Requirements and Costs

- assume similar to sand filters – i.e., 11% to 13% of construction cost per year
- replace media annually or when infiltration capacity drops below design rate (KC, 1998)
- inspect semiannually and after major storms (WEF, 1998)
- remove all floatables and sediment from the sedimentation basin when 100 mm depth accumulates (WEF, 1998) – KC (1998) recommends 300 mm depth
- remove sediments from filter when 2.5 mm or more accumulates or when standing water persists past the design drawdown time (WEF, 1998) – KC (1998) recommends 13 mm
- typical cleaning frequency for surface filters in Austin, TX twice per year by raking off dried sediment

4.19.9 Benefits Vs Costs

- requires more frequent maintenance than most other BMPs (WWC, 1993)
- more expensive to construct than most other BMPs
- underground filters are the most expensive but require less space than surface filters
- cost may decline as technology becomes more widely used
- can be used where site constraints and/or space limitations prevent the use of other BMPs
- limited experience in the climatic conditions typical of the GVRD
- no independent testing for stormwater applications - however, the process is theoretically sound, and is accepted for stormwater treatment in the King County manual (KC, 1998)
- see Section 4.21 for overview cost benefit analysis
FIGURE 4-18  EXAMPLE OF ORGANIC FILTER  
(FROM CWP, 1997)
4.20 BMP S19: Multi-Chambered Treatment Train

4.20.1 Description

The multi-chambered treatment train (MCTT) was developed as a special purpose device to treat heavily contaminated runoff from sites where space restrictions prevent the use of other BMPs. The MCTT is divided into three main chambers. The first (inlet) chamber employs screening to remove large particulates, and flash aeration to remove volatile compounds. The second chamber is designed for enhanced settling of fine particulates using inclined plate or tube settlers; floating oil is removed by absorbent pads, and volatile compounds are further removed by bubble aeration. The third chamber contains a sand or peat filter for removal of dissolved compounds. A schematic drawing of the MCTT is shown on Figure 4-19 at the end of Section 4.20.

4.20.2 Applications

- designed for contaminant removal only – no significant attenuation of peak flows or runoff volumes
- can be used in areas where site conditions prevent the use of other BMPs such as infiltration, wet ponds and wetlands – not generally limited by site characteristics or climate
- suitable for areas where runoff is expected to carry a relatively heavy contaminant load – e.g., municipal repair and maintenance yards
- suitable for developed and redeveloping areas as well as new developments
- suitable for space-limited areas
- designed for underground use

4.20.3 Performance

- initial results from two full-scale units in Wisconsin show the following contaminant removal efficiencies (Pitt, 1997) and (Pitt et al., 1997):
  - total suspended solids 83% to 98%
  - turbidity 40% to 94%
  - chemical oxygen demand 60% to 86%
  - total phosphorus 80% to 88%
  - nitrate 14%
  - toxicity (suspended) 96%
  - toxicity (dissolved) 98%
  - lead 93% to 96%
  - zinc 90% to 91%
  - cadmium 91%
  - copper 65% to 90%
  - n-Nitro-di-n-propylamine 100%
- pyrene 100%
- bis (2-ethylhexy) phthalate 99%

4.20.4 Pretreatment and/or Post-Treatment Requirements

- pretreatment (screening in first chamber and settling of particulates in the second chamber) is integral to the MCTT

4.20.5 General Design Criteria

- see Pitt et al. (1997) for detailed design guidance
- design sizing depends on site-specific factors including design storm, time between storms, sediment load, and desired maintenance regime (Pitt, 1997)
- a computer model has been developed to determine the treatment volume and toxicity reduction (Pitt, 1997)

Inlet Chamber

- contains conventional catch basin sump to trap grit and sand, minimum sump depth 1 m
- includes flash aerator composed of a small column of packing balls with counter current air flow to remove volatile pollutants and trap trash (see Figure 4-19)

Settling Chamber

- contains floating absorbent pads to trap oil and grease
- includes fine bubble aerator (generator powered fish farm aeration stone) to remove additional volatile compounds
- includes inclined plate or tube settlers inclined at 30° and 45° in rows of opposing direction to enhance sedimentation and prevent scour (see Figure 4-19)
- required treatment volume is relatively low for areas with numerous low intensity storms (e.g. Seattle)
- most effective holding time 2 days for 90% toxicant control – design treatment volume for Seattle, 1.5 m deep sized to contain runoff from 10 mm of rainfall
- settling chamber designed to drain completely between storms

Final Filtration/Sorption/Ion Exchange Chamber

- Gunderboom™ filter fabric covers filter media to reduce channelization, slow infiltration, and sorb oils
- filter media composed of peat/sand mixture at least 300 mm deep removes small particulates and dissolved contaminants through filtration, sorption, and/or ion exchange
• filter fabric under media separates filter media from underlying gravel layer and prevents gravel from clogging
• gravel layer packed around perforated PVC pipes provides additional filtration and outlet (see Figure 4-19)

4.20.6 Limitations

• the MCTT is still in the development stage, but is based on proven processes
• space requirement typically 0.5% to 1.5% of paved drainage area

4.20.7 Capital Costs and Implementation Requirements

• budget construction cost $15,000 to $30,000 per 0.1 ha drainage area, assuming the use of prefabricated units (adapted from Pitt, 1997)

4.20.8 Operation and Maintenance Requirements and Costs

• new technology – no O&M cost data yet available – assume similar to sand filters, ie., 11% to 13% of construction cost per year.

4.20.9 Benefits Vs Costs

• water quality enhancement only
• few aesthetic or safety concerns
• may only be required when a very high level of treatment is needed – can remove volatile compounds, metals, hydrocarbons, etc.
• initial data shows performance is superior to sand filters
• relatively expensive
• still in development stage
• see Section 4.21 for overview cost benefit analysis
FIGURE 4-19 MULTI-CHAMBER TREATMENT TRAIN (MCTT) (FROM PITT, 1997)
4.21 Overview Cost Benefit Comparison of Structural BMPs

This section contains an overview comparison of BMP costs and benefits, to assist in determining the relative advantages and disadvantages of each BMP in light of the watershed goals and objectives. For comparative purposes, three example sites were developed, a 15 ha residential area, a 2 ha municipal office complex, and a 0.5 ha municipal repair and maintenance yard. Appropriate BMPs for each type of development were selected according to the design criteria and limitations described in the preceding sections. Capital and O&M costs for the BMPs considered applicable to the residential area, the office complex, and the repair yard are summarized in Tables 4-1, 4-2 and 4-3, respectively.

The degree to which each example BMP meets the overall watershed objectives described in Section 2 is include in Tables 4-1 through 4-3. For a more detailed summary of the benefits of each BMP, see the preceding sections of this chapter and the selection matrices included in Section 2.

For all of the examples, a water quality storm of 30 mm of precipitation was assumed (this approximates the 6-month, 24-hour storm in the Seattle area). The water quality runoff volume was estimated according to the method described by CWP (1998). The detention storage requirements for quantity control were estimated for the 10-year, 24-hour event using OTTHYMO, assuming that the post development peak flow could not exceed the predevelopment peak flow. Forested land cover was assumed for the undeveloped condition.

Residential Area

For the residential area, it was assumed that the entire development would be single family dwellings, resulting in an estimated total impervious area of approximately 45%. The total length of roadway (average width 20 m) was estimated at 1,000 linear m. BMPs judged to be applicable to the collected runoff from the entire residential development were extended detention dry basins, wet ponds, constructed wetlands, and off-line infiltration basins. BMPs judged to be applicable to the stormwater collection system in the residential area were grassed swales, trapped catchbasins, and sediment trapping manholes. A summary of costs for each of these BMPs based on the equations included in the preceding sections of this chapter is shown in Table 4-1.

As shown in Table 4-1, the BMPs that best meet the goal of protecting life and property (mainly through flood control and streambank erosion protection) are extended detention dry basins, wet ponds, and constructed wetlands. All three of these BMPs protect fish habitat (e.g., flow rate control, reduced erosion and sedimentation, contaminant removal). Wet ponds and constructed wetlands have the potential to remove some dissolved and colloidal contaminants, while dry basins can only remove particulates effectively. Constructed wetlands have the greatest potential for creation of fish and wildlife habitat, due to the greater diversity of structure, although wet ponds can also meet these objectives. Both wet ponds and constructed wetlands are more aesthetically pleasing than dry basins. Capital costs are similar between dry basins and wet
ponds, although O&M costs are significantly higher for wet ponds. Capital and O&M costs are slightly higher for constructed wetlands than for wet ponds (Table 4-1).

Controls on the stormwater collection system for residential areas include grassed swales in lieu of curb and gutter systems, and sediment trapping manholes or trapped catchbasins for piped systems (Table 4-1). Grassed swales provide limited runoff quantity control if there is some infiltration, as well as removal of particulate contaminants. Swales have significant capital and O&M costs; however, it should be noted that the costs of turf maintenance will be similar whether the space is occupied by lawns or grassed swales. Manhole sediment traps and trapped catch basins provide limited benefits, but they can reduce the sediment load on downstream facilities by about 20%, if they are maintained properly. Conventional manholes and catchbasins would have to be installed in any case, at an estimated construction cost of $20,000 for manholes and $40,000 for catchbasins. The additional capital cost for the sediment trapping variety is estimated at about $10,000 for both manholes and catchbasins. Manhole sediment traps have lower capital costs and O&M costs than trapped catch basins, due to the much lower number of units required (10 manholes compared to 66 catchbasins).

**Municipal Office Complex**

For the municipal office complex (similar in nature to a commercial site), it was assumed that 65% of the total site area of 2 ha would be impervious surface; this was further assumed to be divided approximately equally between roof surface and paved surface. BMPs judged to be applicable to the municipal office complex were a roof downspout system, bioretention, a surface sand filter, and a small wet pond. All but the roof downspout system were sized for the entire water quality runoff volume; the roof downspout system was sized for the roof runoff volume only (estimated at 50% of the total water quality volume). A summary of costs for each of these BMPs based on the equations included in the preceding sections of this chapter is shown in Table 4-2.

As shown in Table 4-2, the roof downspout system and the wet pond have the lowest capital costs, with the wet pond having the lower O&M costs of the two. Bioretention and surface sand filters have much higher capital and O&M costs than roof downspout systems or wet ponds. Both wet ponds and roof downspout systems provide runoff quantity control (flood protection, streambank erosion protection, fish habitat protection) while bioretention and sand filters are restricted mainly to contaminant removal. Roof downspout systems are the only BMP in this group that can significantly reduce the total volume of runoff, although wet ponds may provide limited infiltration as well. Roof downspout systems are not designed for contaminant removal, but they are the most effective for recharging groundwater (contaminant removal may occur in underlying soils). Wet ponds, bioretention, and sand filters can remove dissolved as well as particulate contaminants. Bioretention and sand filters should be superior to wet ponds in this respect, since they provide a filtration barrier. Bioretention includes a biological component, and should therefore provide more effective nutrient removal than sand filters. Wet ponds are the only BMP in this group that potentially create fish habitat, and they are also the most
aesthetically pleasing. Bioretention can include creation of wildlife habitat, and it can also provide significant aesthetic enhancement.

**Municipal Maintenance/Repair Yard**

For the municipal maintenance/repair yard (similar in nature to an industrial site), it was assumed that 100% of the site area would be covered with impervious surface. BMPs considered applicable to the repair yard are the coalescing plate separator (CPS), the water quality inlet, grassed filter strips, porous pavement, concrete modular pavers, underground organic filters, catch basin filters, and the multi-chambered treatment train (MCTT). A summary of costs for each of these BMPs based on the equations included in the preceding sections of this chapter is shown in Table 4-3.

The example BMPs applicable to the repair yard vary widely in costs and benefits. The coalescing plate separator has a relatively low capital cost, but high O&M costs. Only oil and grease can be removed from site runoff using this BMP. The water quality inlet (WQI) has lower capital and O&M costs than the CPS, but the WQI is useful for pretreatment only. The grassed filter strip has much lower capital costs and comparable O&M costs to the WQI, and it provides effective removal of a range of contaminants if properly designed and maintained. Porous and modular pavers and the multi-chambered treatment train (MCTT) are at the high end for capital and O&M costs, but these BMPs also provide the most effective contaminant removal. The MCTT is the only BMP that provides air stripping of volatile compounds. Porous and modular pavers also provide additional benefits (runoff volume reduction, groundwater recharge). The organic filter (with pretreatment for sediment removal) provides a similar level of contaminant removal to the MCTT (except for air stripping of volatile compounds) at a much lower capital and O&M cost. Catch basin filters can provide effective contaminant removal at relatively low capital and O&M costs, provided that the filtration media is selected for the contaminants of concern. The grass filter strip has the highest aesthetic value of any BMP in this group, followed by modular pavers.
Table 4-1: Structural BMP Cost Benefit Overview for a 15 ha Residential Development

<table>
<thead>
<tr>
<th>BMP</th>
<th>Construction Cost Equation(^1)</th>
<th>Construction Cost(^1)</th>
<th>Total Capital Cost(^2)</th>
<th>Annual Maintenance Costs(^2)</th>
<th>Benefits</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Protect Life and Property</td>
<td>Protect Fish Habitat</td>
</tr>
<tr>
<td>Extended Detention Dry Basin</td>
<td>$11.65 \times (35.31V_t)^{0.35}</td>
<td>$112,000</td>
<td>$151,000</td>
<td>$1,100</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Wet Pond</td>
<td>$28.90 \times (35.31V_t)^{0.35}</td>
<td>$108,000</td>
<td>$146,000</td>
<td>$4,900</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Constructed Wetland</td>
<td>$34.70 \times (35.31V_t)^{0.35}</td>
<td>$130,000</td>
<td>$176,000</td>
<td>$5,900</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Off-line Infiltration Basin</td>
<td>$44 V_{wq}</td>
<td>$90,200</td>
<td>$122,000</td>
<td>$4,500</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Grassed Swales</td>
<td>$100,000</td>
<td>$135,000</td>
<td>$6,000</td>
<td></td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Manhole Sediment Trap</td>
<td>$30,000</td>
<td>$40,500</td>
<td>$2,000</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Trapped Catch Basins</td>
<td>$52,800</td>
<td>$71,300</td>
<td>$6,600</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

1 see individual sections in this chapter for cost equation sources
2 construction cost plus 35% for engineering, contingencies, sediment control, etc.
3 \(V_{wq}\) = water quality volume = 2,050 m\(^3\)
4 \(V_t\) = total volume (\(V_{wq}\) + storage for flood control) = 3,610 m\(^3\)
5 assume quarterly cleanout schedule

\(\text{High Positive Impact}\) \(\text{Moderate Positive Impact}\) \(\text{Minimal Impact}\)
### Table 4-2: Structural BMP Cost Benefit Overview for a 2 ha Municipal Office Complex

<table>
<thead>
<tr>
<th>BMP</th>
<th>Construction Cost Equation(^1)</th>
<th>Construction Cost(^1)</th>
<th>Total Capital Cost(^2)</th>
<th>Annual Maintenance Costs(^3)</th>
<th>Benefits</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof Downspout System</td>
<td>$132 V_{wq} \times 0.5</td>
<td>$27,000</td>
<td>$36,500</td>
<td>$3,200</td>
<td>3 3 2 2</td>
<td>effective quality control and groundwater recharge</td>
</tr>
<tr>
<td>Bioretention</td>
<td>$8.80(35.31 V_{wq})^{0.99}</td>
<td>$115,800</td>
<td>$156,300</td>
<td>$7,000</td>
<td>2 3 3 3</td>
<td>no quantity control effective removal of particulate and some dissolved contaminants</td>
</tr>
<tr>
<td>Surface Sand Filter</td>
<td>$280 V_{wq}</td>
<td>$114,800</td>
<td>$155,000</td>
<td>$13,800</td>
<td>2 3 3 2</td>
<td>no quantity control effective removal of particulate and some dissolved contaminants</td>
</tr>
<tr>
<td>Wet Pond</td>
<td>$28.90(35.31 V_{t})^{0.70}</td>
<td>$34,400</td>
<td>$46,400</td>
<td>$1,500</td>
<td>3 3 3 3</td>
<td>effective quantity control effective removal of particulate and some dissolved contaminants</td>
</tr>
</tbody>
</table>

\(^1\) see individual sections in this chapter for cost equation sources

\(^2\) construction cost plus 35% for engineering, contingencies, sediment control, etc.

\(^3\) \(V_{wq}\) = water quality volume = 410 m\(^3\)

\(^4\) \(V_{t}\) = total volume \((V_{wq} + \text{storage}) = 700 m^3\)
<table>
<thead>
<tr>
<th>BMP</th>
<th>Construction Cost Equation</th>
<th>Construction Cost $</th>
<th>Total Capital Cost $</th>
<th>Annual Maintenance Costs $</th>
<th>Protect Life and Property</th>
<th>Protect Fish Habitat</th>
<th>Protect Water Quality</th>
<th>Community Acceptance</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coalescing Plate Separator</td>
<td>N/A</td>
<td>$15,000</td>
<td>$20,300</td>
<td>$12,000</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>effective removal of oil and grease only</td>
</tr>
<tr>
<td>Water Quality Inlet</td>
<td>N/A</td>
<td>$10,000</td>
<td>$13,500</td>
<td>$1,200</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>pretreatment to reduce load on downstream BMPs no quantity control</td>
</tr>
<tr>
<td>Grassed Filter Strip</td>
<td>425 m² @ $5 / m²</td>
<td>$2,125</td>
<td>$2,900</td>
<td>$1,000</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>effective removal of particulate contaminants limited quantity control</td>
</tr>
<tr>
<td>Porous Pavement</td>
<td>5,000 m² @ $25 / m²</td>
<td>$125,000</td>
<td>$170,000</td>
<td>$35,000</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>effective quantity and quality control effective removal of particulate and dissolved contamines</td>
</tr>
<tr>
<td>Concrete Modular Pavers</td>
<td>5,000 m² @ $95 / m²</td>
<td>$475,000</td>
<td>$641,200</td>
<td>$1,000</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>effective quantity and quality control effective removal of particulate and dissolved contamines</td>
</tr>
<tr>
<td>Organic Filter</td>
<td>$60,000 impervious ha</td>
<td>$30,000</td>
<td>$40,500</td>
<td>$3,600</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>effective removal of particulate and dissolved contamines no quantity control</td>
</tr>
<tr>
<td>Catch Basin Filter</td>
<td>15 units @ $650 / unit</td>
<td>$9,800</td>
<td>$13,200</td>
<td>$800</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>effective removal of particulate and dissolved contamines no quantity control</td>
</tr>
<tr>
<td>Multi-Chambered Treatment Train</td>
<td>$22,500 per 0.1 impervious ha</td>
<td>$112,500</td>
<td>$151,900</td>
<td>$18,200</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>effective removal of particulate and dissolved contamines no quantity control</td>
</tr>
</tbody>
</table>

1. see individual sections in this chapter for cost equation sources
2. construction cost plus 35% for engineering, contingencies, sediment control, etc.
3. $V_{wq} = \text{water quality volume} = 150 \text{ m}^3$

Notes:
1. Minimal Impact
2. Moderate Positive Impact
3. High Positive Impact
5.0 OPERATIONAL AND MAINTENANCE BMPS

This section contains detailed discussion of the Operational and Maintenance BMPs selected for this manual. General descriptions, applications, implementation requirements, performance capabilities and limitations, costs and benefits are included.

Operational and Maintenance activities are often funded by various agency departments, making cost tracking and estimation difficult. Cost estimates for Operational and Maintenance BMPs were estimated from values reported in the literature, contacts with jurisdictions in the states of Washington and Oregon, local information, and the experience of the project team.

Various agencies responsible for operation and maintenance and stormwater program activities in the states of Oregon and Washington were contacted. The agencies were asked to provide detailed cost information regarding Non-Structural and Operational and Maintenance BMPs. A primary source of information was the Unified Sewerage Agency (USA) of Washington County, Oregon. USA is responsible for regulating, managing, and maintaining surface water, sewage, and stormwater for over 155,000 homes and businesses in the urban area west of Portland, Oregon. Approximately 20% of USA’s efforts are devoted to managing stormwater and surface water for quality and quantity concerns. USA currently maintains about 200 stormwater BMPs, including a mixture of detention ponds, water quality ponds, swales, stormwater filters, and constructed wetlands. The agency imposes an average monthly stormwater fee of Cdn $6.00 on the service population in addition to system connection charges.

USA provided annual operating budgets (1999) for some of the O&M and program BMPs detailed in this study. The costs are presented on a per capita basis (program unit cost/population) and a unit service area basis (program unit cost/services area). In some cases, the USA budget included both sanitary and stormwater activities. In these instances, the assumption of a 20% stormwater and 80% sanitary allocation of costs was made. The values from USA include all operation and maintenance or program costs except for office space. Educational BMP costs are funded equally from sanitary and stormwater funds. Typical USA costs include salaries and benefits, materials, supplies, rental equipment, office supplies, administrative costs, and miscellaneous expenses.
5.1 BMP: OM1 Maintenance Of Structural BMPs

5.1.1 Description

Stormwater management often includes the use of structural facilities for controlling runoff flow rates and volumes, removing contaminants, and recharging groundwater. Proper operation and maintenance of structural facilities is essential if these facilities are to function as designed. Depending on the facility, maintenance activities can include removal of captured trash, sediments and other contaminants, control of vegetation, and corrective maintenance as required. A comprehensive operation and maintenance program is essential if Structural BMPs are to function as designed. Failure of Structural BMPs is often attributed to lack of proper maintenance. Operation and maintenance requirements and costs for individual Structural BMPs are included in Section 4 of this manual. Section 5.1 contains an overview description of a comprehensive operation and maintenance plan for Structural BMPs.

5.1.2 Application

- quantity and quality control
- protects/enhances habitat and aesthetic values
- applies to all Structural BMPs for all types of land use and all levels of development

5.1.3 Performance

- the performance of individual Structural BMPs is described in Section 4 – this is based on the assumption that Structural BMPs are maintained as recommended
- a comprehensive operation and maintenance program is required to achieve the levels of performance described in Section 4

5.1.4 General Criteria

- facility owners, maintenance personnel and the public should understand the relationships between proper maintenance and BMP performance (see BMPs NS4 and NS5, Education and Training)
- detailed guidance on developing maintenance programs, including checklists for specific Structural BMPs, training needs, and desired results are available in Horner (1994), FHWA (1996), and Livingston et al. (1997)
- equipment needs for specific maintenance activities are listed in Livingston et al. (1997)
- routine maintenance requirements for individual BMPs are described in Section 4 and in the design manuals referenced there
• elements that should be included in any operation and maintenance program are described below

**Inspection**

• develop and implement aggressive field inspection programs to identify maintenance needs
• place priority on maintenance of Structural BMPs in areas that have the greatest risk of flooding and erosion, habitat value, and contaminant loadings
• keep accurate records of the frequency and nature of maintenance activities and adjust inspection and maintenance frequency as required

**Repairs and Maintenance**

• preventative measures are preferred over corrective measures
• perform immediate repairs if structural integrity is at risk
• inspect culvert inlets and outlets for scour and perform repairs as required
• stencil storm drains, catch basins and inlets to inform the public of their discharge to surface waters
• maintain vegetation on rights of way, biofiltration BMPs, buffers, ponds, etc. – minimize the use of pesticides and chemical fertilizers

**Contaminant Removal**

• clean sediment traps before they are 40% full
• if collected sediments have the appearance of oil or other hazardous contamination, have the material analyzed to determine appropriate disposal requirements – take steps to identify the source of high contaminant loadings
• identify locations where sediments, trash and debris collect in the stormwater conveyance system and concentrate efforts at these locations
• undertake proper storage and disposal of vactor truck wastes

5.1.5 **Limitations**

• each type of BMP facility has its own unique O&M requirements
• the operation and maintenance program may be limited by municipal staff and financial resources
• maintenance activities can be limited by access restrictions
• collected contaminants, sediments and trash must be disposed of properly – there may be restrictions on the disposal of heavily contaminated materials
• requires support from regulations and bylaws (see D&K et al., 1998)
5.1.6 Capital Costs and Implementation Requirements

- stable long term funding is essential
- clear delineation of responsibilities is essential
- capital costs and implementation requirements depend on the number and nature of Structural BMPs and the size of the drainage area – equipment may be shared among smaller jurisdictions
- may require purchase of additional capital equipment (e.g., vactor trucks, excavators, mowing equipment, trucks, hand tools, etc.) – see Livingston et al. (1997) for detailed equipment requirements
- may require additional staff
- requires staff training

5.1.7 Operation and Maintenance Requirements and Costs

- ongoing operation and maintenance program for all Structural BMPs including quantity and quality control facilities $1,800/yr/km² drainage area or $1.50/capita/yr (USA, 1998)
- see Section 5.1.4 for ongoing requirements

5.1.8 Benefits Vs Costs

- significant annual cost but is an essential element of stormwater management
- Structural BMPs should not be installed unless comprehensive long-term operation and maintenance is assured
- the benefit of a comprehensive operation and maintenance program is proper long-term functioning of Structural BMPs for quantity and quality control, habitat protection, and aesthetic value
- the cost of not developing such a program over the long-term is failure of Structural BMPs to perform as designed, with possible consequences ranging from catastrophic flooding to severe degradation of fish and wildlife habitat to aesthetic nuisances
- the cost to perform regular maintenance can be several times less than the cost of restoring long-neglected facilities (Livingston et al., 1997)
- see Table 5-1 at the end of this chapter for overview cost benefit comparison.
5.2 **BMP: OM2 Detection, Removal, And Prevention Of Illicit Connections**

5.2.1 **Description**

The detection, removal and prevention of illicit connections (sanitary sewage and industrial discharges) to the storm drain system can remove a significant source of contamination from storm runoff discharges. Control can be undertaken through prevention of illicit connections in new developments and redeveloping areas and detection and removal of illicit connections in existing developments. This BMP is supported by the GVRD source control bylaw discussed in Appendix F.

5.2.2 **Applications**

- protects/enhances water quality, habitat, and aesthetic values
- suitable for all types and levels of development

5.2.3 **Performance**

- the performance of this BMP has not been quantified
- helps to reduce contaminants, particularly suspended solids, oxygen demand, and bacteria

5.2.4 **General Criteria**

- see WWC and CDM (1997) and CDM et al. (1993) for detailed guidance

*Inspection and Maintenance Program*

- require visual inspection of new developments and redevelopment
- develop documentation and protocols to track inspections and catalog the storm drain system
- maintain storm drain maps that include the locations of all storm drainage facilities and documented connections to the system, as well as surrounding land use
- field crews can use the storm drain maps to ensure that connections and discharges are legal and appropriate
- use land use designations to identify probable areas of illicit connections
Field Inspections

- conduct visual inspections of storm drains and channels for evidence of deposits, stains, vegetation, odours, colour, turbidity and floating mater that may indicate the presence of illicit connections
- undertake storm drain inspection program through dye and smoke testing and TV inspection to identify illicit connections
- sampling and analysis of accumulated sediments and dry weather flows in the storm conveyance system and at outfalls can be used to help identify problem areas – see USEPA (1993) for guidance on field screening procedures for identifying illicit connections
- correct illicit connections by plugging, disconnecting, or otherwise removing
- do not allow slurry from pavement saw cutting to enter storm drains

5.2.5 Limitations

- requires support from municipal plumbing and building codes and bylaws (see D&K et al., 1998 and discussion of GVRD source control bylaw contained in Appendix F)
- may require right of access to private property
- proper connections may be verified on date of inspection but could be altered later

5.2.6 Capital Costs and Implementation Requirements

- this BMP has negligible capital costs, assuming that TV inspections, dye and smoke testing are carried out by a private contractor
- some staff training required for program coordination and record keeping

5.2.7 Operation and Maintenance Costs and Requirements

- $600/yr/km storm drain, incl. TV inspection (GVRD, 1998)
- $185/yr/ha served, incl. TV inspection (APWA, 1992)

5.2.8 Benefits Vs Costs

- can provide significant water quality benefits
- protects fish habitat by reducing oxygen demand
- protects recreational resources by reducing bacterial contamination
- relatively expensive but can be undertaken in phases targeting worst problem areas first
- see Table 5-1 at the end of this chapter for overview cost benefit comparison
5.3 BMP OM3: Spill And Complaint Reporting And Response

5.3.1 Description

Spill reporting and response is designed to prevent contaminants resulting from spills from reaching the stormwater conveyance system. The elements of spill response include reporting of the spill to the proper authority, a response aimed at stopping the source of the spill, containment, cleanup, and disposal of the spilled material. For the purposes of this manual, it was assumed that emergency spill response teams trained to deal with hazardous materials would already be in place (e.g., local fire departments), and that the municipality would coordinate spill response with these authorities and assist where possible. It was further assumed that municipalities would take the lead in containment and cleanup of non-hazardous spills.

Complaint reporting and response other than for spills can include illegal outfall discharges, dumping of yard wastes, household garbage, and junk (cars appliances, etc.). For the purposes of this manual, it was assumed that municipalities would respond to illegal (non-hazardous) dumping complaints and conduct cleanup and disposal operations. Removal of illegally dumped materials from open drainage channels is described in Section 5.5 (BMP OM5). Illegal dumping or discharge of hazardous materials would be coordinated with the appropriate authority (e.g., see discussion of GVRD source control bylaw contained in Appendix F).

5.3.2 Applications

- spill response - water quality and habitat protection
- other complaints – helps to maintain hydraulic capacity of drainage channels, protects/enhances habitat and aesthetic values
- suitable for all types and levels of development
- spill response is particularly suited to public roadways, maintenance/repair yards and loading/unloading areas.

5.3.3 Performance

- the performance of this BMP has not been quantified
- prevents spilled toxic and hazardous materials from reaching sensitive surface and ground waters
- prevents spilled and dumped non-hazardous materials from contributing to loading of sediments and trash to drainage conveyance system
5.3.4 General Criteria

Complaints

- municipalities can publicize a 24-hour hotline or help line number for public use in reporting hazardous spills and/or illegal dumping and discharges – response responsibilities and procedures for different types of spills and illegal dumping should be clearly delineated – LA County has developed various forms for different types of complaints so that the proper information can be solicited from callers and the appropriate authorities are notified – overall coordination on the part of the municipality should be undertaken to ensure that the needed investigative and enforcement support are provided (WWC and CDM, 1998)
- maintain a database of all complaints/reports and the follow up response – track all complaints of illegal discharges until problems have been resolved

Spill Response Plan

- a suggested procedure for developing a spill control plan is summarized below (adapted from USEPA, 1992)
- identify areas of high spill potential on a map of the watershed (e.g., loading and unloading areas, storage areas, waste handling and disposal areas, fueling areas, public roadways etc.)
- overlay spill potential map with a drainage area map that shows conveyance systems and outfalls
- develop spill response scenarios to prevent spilled material from reaching the stormwater conveyance system for areas with high spill potential
- absorbent and containment booms can be stored at key locations and anchors may be installed into channel walls for quick deployment of booms (WCC and CDM, 1998)
- spill response plans must be clear, concise step-by-step instructions for responding to specific types and/or locations of spills
- organize the plan to facilitate rapid identification of the appropriate spill response procedures
- consider the potential magnitude and frequency of spills
- requires clear identification of the members of the spill response team and delineation of authority and responsibility (including the lead agency) for specific types of spills
- include clear descriptions of safety measures and procedures for notifying appropriate authorities for providing assistance (police, fire department, hospital, sewage treatment plant if toxic materials reach the sewer collection system)
5.3.5 Limitations

- response may not be undertaken unless the spill is reported
- hazardous spills require specialized training and equipment
- success in containing hazardous spills depends on quick and efficient response
- may expose municipal employees to hazardous materials

5.3.6 Capital Costs and Implementation Requirements

- develop and enact spill response plan $30,000 (adapted from AWWA, 1992)
- requires outfitting of spill containment vehicle (containment booms and barriers, sweeps, absorbents and pads, containers, safety equipment etc.)
- costs for containment materials as follows (adapted from Ferguson et al., 1997)
  - medium pads $100 to $150 per 200
  - large pads $200 to $250 per 100
  - mini booms $15 to $25 each
  - large single booms $60 to $90 each
  - large double booms $75 to $110 each
- may require vactor truck for cleanup (capital cost $260,000 to $300,000), dump trucks, loaders, hand tools, etc. – see costs for BMP OM5 Section 5.5
- requires staff training for spill containment, cleanup and disposal as well as worker safety and protection

5.3.7 Operation and Maintenance Requirements and Costs

- maintenance and repair of spill control vehicle
- replacement of used spill control materials
- ongoing staff training
- typical cost $500/yr/km² drainage area (USA, 1998)
- typical cost $0.20/capita/yr (GVRD, 1998) to $0.40/capita/yr (USA, 1998)

5.3.8 Benefits Vs Costs

- costs are moderate for a BMP that is rarely used, but spill containment and response is regarded as essential considering the potential consequences of taking no action (fish kills, traffic hazards, legal liability, public outcry)
- see Table 5-1 at the end of this chapter for overview cost benefit analysis.
5.4 BMP OM4: Street Cleaning

5.4.1 Description

Street sweeping was at one time thought to be ineffective for removing significant quantities of contaminants from urban runoff, mainly due to the inability of traditional mechanical sweepers to remove the finer particulates that often constitute the bulk of the sediment load in road runoff (e.g., Ellis, 1989 and Bender and Rice, 1982). However, with the advent of more efficient sweeping equipment, street cleaning is now an accepted BMP for stormwater management (e.g., CDM et al., 1993 and FHWA, 1996). Traditional mechanical sweepers use a rotating broom or brush to propel particles onto a moving conveyor and then to a storage hopper; a water spray may be used to control dust. Innovations designed to improve sweeping efficiency include vacuum assisted particle pickup/transport systems, and regenerative (recycled) air to blast particles from the road surface into a hopper, followed by filtering of particles from the air stream. These innovations have been shown to significantly improve the performance of street sweepers by picking up finer particles than traditional sweepers. Sweeping may also be done in tandem, with a high-efficiency sweeper following a traditional mechanical sweeper.

5.4.2 Applications

- water quality and habitat protection
- helps to protect drainage conveyance systems from obstruction by sediments
- suitable for residential areas, municipal parking areas, municipal maintenance and repair facilities
- suitable for new developments, existing developments, and redeveloping areas
- most suitable for ultra urban and other intensely developed and heavy traffic areas
- particularly appropriate where surface waters are nearby and little land is available for Structural BMPs
- vacuum assisted sweeper and regenerative air sweeper are both effective for single family residential areas, while the vacuum assisted sweeper is the more effective of the two for major arterial roads (Schueler, 1998b)

5.4.3 Performance

- removes particulate contaminants
- also reduces dissolved contaminants in runoff by picking up solid contaminants that would otherwise become dissolved during runoff events
- reduction in contaminant load using traditional street sweeping with mechanical broom sweeper in Oregon as follows for monthly to twice weekly sweeping frequency (from Sutherland):
  - total suspended solids 5% to 30%
- heavy metals 5% to 25%
- nutrients 0% to 15%
- oxygen demand 5% to 20%

• reduction in contaminant load using high efficiency street sweeping (vacuum or regenerative air) in Oregon as follows for monthly to twice weekly sweeping frequency (from Sutherland):
  - total suspended solids 40% to 80%
  - heavy metals 35% to 70%
  - nutrients 15% to 40%
  - oxygen demand 20% to 50%

5.4.4 General Criteria

• the following elements must be addressed in a street sweeping program (FHWA, 1996):
  - identify and focus on priority areas where debris is known to accumulate and produce the highest contaminant loads on the most frequent basis
  - determine sweeping frequency based on rate of debris accumulation and time interval between rain events – increase frequency just prior to rainy season
  - determine type (size) of particles to be removed and select mechanical sweepers or vacuum assisted sweepers (see Limitations)
• most effective sweeper operating speeds 10 to 13 km/hr (FHWA, 1996)
• most effective sweeping frequency bi-weekly or weekly

5.4.5 Limitations

• effectiveness depends on contaminant accumulation, sweeping frequency, type of equipment, brush adjustment, rotation rate, brush weight, sweeping pattern, road surface and curb condition, particle size distribution of sediments, rainfall frequency (FHWA, 1996)
• parked cars impede sweeping – requires support from parking regulations and bylaws
• sweepers do not remove oil and grease
• mechanical sweepers (brush or broom) effective removal of particles > 400 microns, but cannot remove fines (Horner et al., 1994)
• vacuum assisted sweepers and regenerative air sweeper can remove particles less than 63 microns (Schueler, 1998b)
• street sweeping is most effective during dry weather (FHWA, 1996)
• sediments washed onto pavements during storms and atmospheric wetfall may be washed off pavements during the same storm with no opportunity for removal by sweepers (Schueler, 1998b)
5.4.6 Capital Costs and Implementation Requirements

- mechanical sweeper $115,000 (adapted from Finley, 1996)
- vacuum assisted sweeper $225,000 (adapted from Satterfield, 1996)
- typical useful sweeper life about 4 years (CDM et al., 1993)
- requires trained operators, maintenance personnel and facilities, and possibly parking enforcement officers
- requires careful design of cleaning routes, disposal of collected wastes

5.4.7 Operation and Maintenance Requirements and Costs

- average O&M cost within the GVS&DD $35/km (GVRD, 1998)
- mechanical sweeper O&M cost $27/curb km/pass, average total cost including annualized capital cost $29/curb km/pass (adapted from Finley, 1996 and SWRPC, 1991)
- vacuum assisted sweeper $14/curb km/pass, average total cost including annualized capital cost $16/curb km/pass (adapted from Satterfield, 1996 and SWRPC, 1991)
- requires proper storage and disposal of collected waste
- $2,300/km²/yr or $1.85/capital/yr for 6 sweepings per year of all curbed streets (USA, 1998)
- requires maintenance program including schedule and record keeping

5.4.8 Benefits Vs Costs

- helps to prevent sedimentation and blocking of conveyance systems and fish spawning beds
- protects/enhances water quality
- potential noise and dust nuisance
- vacuum assisted sweepers have a higher capital cost but a lower O&M cost than mechanical sweepers, resulting in a lower life cycle cost for vacuum assisted sweepers
- vacuum assisted sweepers have a much greater contaminant removal efficiency than mechanical sweepers (CWP, 1998)
- a recent study for the Port of Seattle showed that a weekly street sweeping program for a marine cargo container yard would have a life cycle cost of approximately Cdn $3 million, compared to Cdn $27 million for constructing wet vaults (see BMP S7) – contaminant removal was concluded to be comparable between the two alternatives, based on modeling only and not accounting for wetfall (Schueler, 1998b)
- sweepers that are effective at removing smaller particles may generate respirable dust and particulates (< 10 microns) that are a safety concern
- vacuum sweepers are noisier than mechanical sweepers
- see Table 5-1 at the end of this chapter for overview cost benefit comparison
5.5 BMP OM5: Maintenance Of Runoff Conveyance Systems, Streambanks And Hill Slopes

5.5.1 Description

Maintenance of runoff conveyance systems includes removal of accumulated sediments and illegally dumped materials from open watercourses and piped systems, and protection of streambanks and channels from erosion. These activities prevent a loss of hydraulic capacity in the runoff conveyance system and reduce contaminant loads by removing particulates that would otherwise be resuspended during subsequent runoff events.

Maintenance of stream and conveyance channels includes erosion protection/remediation, modification of channel characteristics to improve hydraulic capacity or contaminant removal, and removal of accumulated sediments and illegally dumped materials. These activities are useful from the standpoint of hydraulic capacity, habitat protection, water quality, and aesthetics.

Storm drain flushing is normally undertaken only on an as-needed basis, when flat-graded pipes become clogged with sediments. This activity could also be undertaken on a routine basis, to regularly remove sediments from the storm drainage system; however, this would require a method for routine containment and treatment of the flushed effluent, and/or routing of the flush water to the sanitary sewer system. For the purposes of this manual, it was assumed that storm drain flushing would be undertaken only as required to maintain the necessary hydraulic capacity in drainage pipes, and not as a water quality protection procedure. Other methods of sediment removal that prevent particulates from entering storm drains such as detention ponds (BMPs S5 and S6), sediment trapping catch basins and manholes (BMPs S3 and S4), and street cleaning (BMP OM4) are judged to be more cost effective than storm drain flushing from a water quality standpoint.

Inspection of hill slopes on municipal property can be undertaken by field crews during routine maintenance activities. Identification and correction of hill slope stability problems can help to prevent erosion/sedimentation and slumping, which can lead to obstruction of the drainage system, habitat destruction, and safety hazards.

5.5.2 Applications

- water quality and habitat protection
- reduces flooding by helping to protect downstream drainage conveyance system from obstruction by sediments
• hill slope stabilization protects storm conveyance system from blockage by slumping and sedimentation, also protects public and worker safety by preventing landslip.
• applies to all types and levels of development

5.5.3 Performance

• the performance of this BMP has not been quantified

5.5.4 General Criteria

Conveyance Systems and Stream Channels

• identify illegal dumping hotspots, inspect and cleanup regularly, post “No Dumping” signs at these locations
• remove trash and debris including car bodies and automotive scrap, car batteries, tires, shopping carts, furniture, appliances, animal waste, plant cuttings, etc
• the two major objectives of modifications to channel characteristics are to improve channel hydraulics and to enhance habitat value – these may be mutually exclusive to some extent, and one objective or the other may have to be compromised, depending on the nature of the channel and the watershed objectives
• to reduce velocity and control erosion use grade control structures to reduce gradient, or increase channel roughness with boulders, dense vegetation, and complex bank forms – note that decreasing velocity will increase flood height – this may require flooding of designated low lying areas
• channel form and stability may be altered and preserved by bank armoring, vegetative cover, and flow deflection
• avoid concrete channel linings where habitat is an issue – riprap and gabions are preferred where armoring is necessary
• install sills to prevent down cutting of streambeds
• retain natural meanders wherever possible
• retain trees for habitat, shading, and aesthetic value
• select vegetation that will maintain channel hydraulics and improve fisheries habitat
• schedule maintenance activities around sensitive periods for plants, animals and fish

Hill Slopes

• identify potential hill slope stability and erosion problems during routine field activities-check for sediment accumulation at foot of slopes.
• repair erosion damage as required

5.5.5 Limitations

• “No Dumping” and “No Littering” signs require support from bylaws and regulations (see D&K et al., 1998)
• access to channels may be limited

5.5.6 Capital Costs and Implementation Requirements

• stabilize streambanks $350/m, daylight channels $170/m, remove fish barriers average $12,000/barrier (GVRD, 1998)
• improve natural channels to improve capacity, prevent erosion and enhance habitat $15,000/ha (APWA, 1992)

5.5.7 Operation and Maintenance Requirements and Costs

• maintenance and repair of runoff conveyance systems $100/ha/yr, $8.40/capita/yr (USA, 1998)
• clean open ditches $80/yr/km (GVRD, 1998)
• clean and maintain channels annually, including trash removal $80/yr/ha (APWA, 1992)
• clean and maintain storm drains every 3 to 6 years $80/yr/ha served (APWA, 1992)
• sewer/drain cleaning $2 to $3 per m (Ferguson et al., 1997)
• inspect open channels after large storm events – check for debris, sediment accumulation, obstructions, and erosion problems
• keep maintenance log of materials removed and locations

5.5.8 Benefits Vs Costs

• costly but essential service-assumed already in place in most municipalities.
• maintains and/or enhances hydraulic capacity to prevent flooding.
• prevents and mitigates streambank erosion
• creates/enhances fish and wildlife habitat
• significantly enhances aesthetic values
• see Table 5-1 at the end of this chapter for overview cost benefit comparison
5.6 BMP OM6: Catch Basin Cleaning

5.6.1 Description

Cleaning of stormwater catchbasins on a regular basis prevents resuspension of accumulated sediments during the first flush of storms, prevents sediment accumulation in the downstream conveyance system, and restores the catchbasin sediment trapping capacity. It was assumed for this analysis that catchbasins would have significant sediment trapping capacity (see BMP S4), as opposed to a simple inlet.

5.6.2 Applications

- maintains hydraulic capacity for flood control
- protects/enhances water quality
- protect aesthetic values
- suitable for all land use types and levels of developments

5.6.3 Performance

- regular cleaning reduces the loading of sediment and debris to downstream facilities
- performance has not been quantified – assume similar contaminant removal efficiencies to sediment trapping manholes (BMP S3) if cleaned regularly – i.e., 15% to 30% removal of sediments, 10% to 25% removal of heavy metals

5.6.4 General Criteria

- see BMP S4 design criteria
- 5 to 20 catchbasins can be cleaned per hour depending on type and amount of debris (Ferguson et al., 1997)
- requires an inventory of catchbasins with a maintenance plan and schedule
- requires accurate record keeping
- review maintenance log to determine problem areas where trash and sediments accumulate faster than normal and take steps to identify the source

5.6.5 Limitations

- collected sediments should be tested for metals, etc. to determine whether they are classified as hazardous wastes
5.6.6 Capital Costs and Implementation Requirements

- capital cost for vactor truck $260,000 to $300,000 (adapted from Ferguson et al., 1997)
- requires trained two person team
- requires disposal of sediments

5.6.7 Operation and Maintenance Requirements and Costs

- typical cost in the GVS&DD for cleaning conventional catchbasins $15/unit (GVRD, 1998)
- typical cost for cleaning and inspecting storm inlets and catchbasins annually $80/yr/ha served (APWA, 1992)
- estimated cost for cleaning sediment trapping catch basins by private contractor $30 to $50/unit/cleanout cycle, not including disposal (Spencer, 1998)
- clean catchbasin sumps before the onset of the rainy season and as required throughout the year – clean when sumps are 40% full (Ferguson et al., 1997)

5.6.8 Benefits Vs Costs

- relatively costly program - may be more economical to trap sediments in dedicated facilities (see Section 4, Structural BMPs)
- maintains and/or enhances hydraulic capacity to prevent flooding,
- prevents and mitigates streambank erosion
- creates/enhances fish and wildlife habitat
- significantly enhances aesthetic values
- see Table 5-1 for overview cost benefit comparison
5.7  BMP OM7: Roadway And Bridge Maintenance

5.7.1 Description

Roadway and bridge maintenance activities generate contaminants that may be washed into streams by storm runoff. The main contaminant sources associated with roadway maintenance are salting and sanding of roadways and paving activities. Maintenance and cleaning of bridges and roadways generates oil and grease, heavy metals, sediments, bird guano, pavement particles, deicing chemicals, paints, cleaners, and abrasives.

5.7.2 Applications

- water quality and habitat protection
- public roadways and bridges in all types and levels of development

5.7.3 Performance

- the performance of this BMP has not been quantified

5.7.4 General Criteria


Roadways

- minimize paved areas as much as possible (see BMP NS2)
- repair potholes and worn pavement to reduce sediment loading
- avoid paving in the rain
- collect maintenance waste and prevent from entering storm drains
- shovel or vacuum saw-out slurry and broken asphalt
- keep drip pans or absorbents below leaking or dripping paving equipment
- use non-toxic cleaning solutions
- minimize the impacts of salt use – see Warrington and Phelan (1998) for detailed guidance.
- salt stockpiles should be covered
- maintain vegetation along rights of way
- minimize pesticide and fertilizer use on rights of way, implement integrated pest management where possible, consider alternate products

Bridges

- site new bridges to minimize impact on sensitive areas
- use tarps, screens, sheets or panels to contain construction and maintenance debris from bridge maintenance - alternatively, use vacuum recovery.
- new bridge designs should minimize stormwater runon from roadways and avoid direct discharge of bridge drainage to streams – drains should be routed to vegetated surfaces or other BMPs
- do not mix paints or clean equipment on bridges or near water
- follow safe chemical storage procedures
- use booms in underlying surface waters to trap debris.

5.7.5 Limitations

- minimization of paved areas may be limited by required widths for roadways, shoulders, etc.
- siting of new bridges limited by available sites, as well as socioeconomic, financial and political issues

5.7.6 Capital Costs and Implementation Requirements

- covered salt storage $50/tonne salt (USEPA, 1993)
- salt spread control on truck $9,000 (USEPA, 1993)
- training of workers required
- establish vegetation on rights of way – seed $5/m², sod $11/m² (adapted from SWRPC, 1991)

5.7.7 Operation and Maintenance Requirements and Costs

- proper containment of dust and abrasives can increase bridge painting costs by 10% to 15%, with an additional 10% to 15% for disposal (FHWA, 1996)
- use of alternative deicing chemicals $1,100/tonne compared to $50/tonne for salt (FHWA, 1996)
- maintain rights of way – if natural secession allowed to occur $370/ha/yr, if natural secession not allowed to occur $3,000/ha/yr (USEPA, 1993)

5.7.8 Benefits Vs Costs

- helps to protect fish habitat and water quality
- helps to prevent sedimentation
- significant (20% to 30%) increase in overall bridge maintenance costs.
5.8 Overview Cost Benefit Comparison of O&M BMPs

This section contains an overview of Operational and Maintenance BMP costs and benefits, to assist in determining the relative advantages and disadvantages of each BMP in light of watershed goals and objectives. For comparative purposes, an urban municipality 10,000 hectares in area with a population of 150,000 was assumed. The costs of each Operational and Maintenance BMP when applied to this municipality using the costing data contained in the previous sections of this chapter are summarized in Table 5-1. The degree to which each BMP meets the overall watershed goals is included in Table 5-1.

As shown in Table 5-1, the greatest cost is for maintenance of stormwater conveyance systems ($1 to $1.25 million per year). This BMP is regarded as essential to any municipality with a stormwater conveyance system. Protection of life and property is assumed to be a priority objective in any watershed, and maintenance of the conveyance system is essential to meet this goal.

Catch basin cleaning is the second most expensive BMP at $800,000 per year. Based on this estimate, it may be more cost effective to undertake sediment control on a more centralized basis using Structural BMPs if space is available. Catch basin cleaning may find applications in existing developments where space is not available for Structural BMPs.

Street cleaning is the third most expensive BMP at $230,000 to $280,000 per year. This BMP has added complications, including enforcement of parking restrictions, noise, and dust nuisance. This BMP will have a minimal impact on the protection of life and property, but it has the potential to achieve significant water quality improvement at a lower cost than Structural BMPs. Street cleaning is particularly suited to existing developments where space is not available for Structural BMPs. However, street cleaning cannot meet the objective of water quantity control.

Maintenance of Structural BMPs is similar in cost to street cleaning ($180,000 to $250,000 per year). This BMP is regarded as essential if Structural BMPs are used. Otherwise, Structural BMPs will fail to perform as designed and may become liabilities.
### Table 5-1: Operational and Maintenance BMP Cost Benefit Overview for a 10,000 ha Municipality with a Population of 150,000

<table>
<thead>
<tr>
<th>BMP</th>
<th>Annual Program Cost</th>
<th>Benefits</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance of Structural BMP's</td>
<td>$180,000 to $250,000</td>
<td>3 3 3 3</td>
<td>essential if structural BMPs are used</td>
</tr>
<tr>
<td>Detection, Removal and Prevention of Illicit Connections</td>
<td>$100,000$(^2)</td>
<td>1 2 3 2</td>
<td>phased program targets priority areas and receiving waters</td>
</tr>
<tr>
<td>Spill and Complaint Reporting and Response</td>
<td>$50,000</td>
<td>2 2 3 3</td>
<td>moderate cost compared to the consequences of taking no action in responding to spills</td>
</tr>
<tr>
<td>Street Cleaning</td>
<td>$230,000 to $280,000</td>
<td>1 2 3 2</td>
<td>effectiveness limited by parking pattern</td>
</tr>
<tr>
<td>Maintenance of Runoff Conveyance Systems</td>
<td>$1,000,000 to 1,250,000</td>
<td>2 2 2 3</td>
<td>essential program normally in place already</td>
</tr>
<tr>
<td>Catch Basin Cleaning</td>
<td>$800,000</td>
<td>2 2 2 2</td>
<td>relatively costly but some catch basin cleaning normally required in any case</td>
</tr>
</tbody>
</table>

$^1$ see individual sections in this chapter for cost equations

$^2$ assumes 5% of drainage area inspected annually

High Positive Impact

Moderate Positive Impact

Minimal or Unknown Impact
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