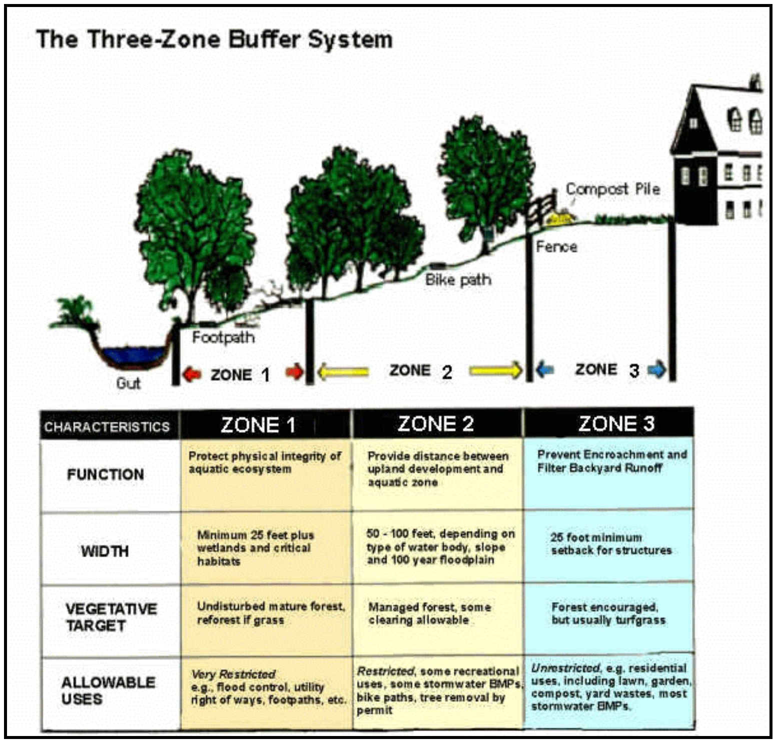
APPENDIX C: STORMWATER PRACTICE SPECIFICATIONS

Buffer Zones C-1
Grassed Swales C-3
Sand Filters C-5
Water Quality Inlets C-7
Extended Detention Ponds C-9
Constructed Wetlands C-13
Porous Pavers C-17
Infiltration Trenches C-21
Bio-Retention C-25
References C-27

Buffer Zones

Buffer zones are areas of vegetated land along a shoreline, wetland or gut where development is prohibited, or are vegetated areas located at the downstream (or hill) edge of disturbed, developed or impervious areas. There are three types of buffer zones: setbacks, vegetated buffers and engineered buffers (CWP, 2001b).



CHARACTERISTICS	ZONE 1	ZONE 2	ZONE 3
FUNCTION	Protect physical integrity of aquatic ecosystem	Provide distance between upland development and aquatic zone	Prevent Encroachment and Filter Backyard Runoff
WIDTH	Minimum 25 feet plus wetlands and critical habitats	50 - 100 feet, depending on type of water body, slope and 100 year floodplain	25 foot minimum setback for structures
VEGETATIVE TARGET	Undisturbed mature forest, reforest if grass	Managed forest, some clearing allowable	Forest encouraged, but usually turfgrass
ALLOWABLE USES	*Very Restricted* e.g., flood control, utility right of ways, footpaths, etc.	*Restricted*, some recreational uses, some stormwater BMPs, bike paths, tree removal by permit	*Unrestricted*, e.g. residential uses, including lawn, garden, compost, yard wastes, most stormwater BMPs.

Figure C.1. Three-zone aquatic buffer system (modified from *CWP, 2001b* and *CH2M Hill, 1998*).

Setbacks are areas that separate waterways from potential pollution hazards (typically development sites). Vegetated buffers are natural areas that exist to divide land uses or provide landscaping. Engineered buffers are areas specifically designed to treat stormwater before it enters a gut, wetland or coastal area (CWP, 2001b). They may closely resemble natural ecosystems, such as grassy pastures or forests. Buffer zones are designed specifically to protect waterbodies, slow stormwater runoff and remove pollutants from stormwater, and in this way differ from ***Filter Strips*** (see Chapter 3), which are designed specifically to filter sediment from runoff.

Siting and Design Criteria

Effective buffer zone design is based on criteria that determine how a buffer will be sized, delineated, managed and crossed, including: minimum total buffer width, three-zone buffer system, mature forest as target vegetation/habitat, conditions for buffer expansion or contraction, physical delineation requirements, conditions where buffer can be crossed, integrating stormwater and stormwater management within the buffer, buffer limit review, buffer education, inspection and enforcement, and buffer flexibility (CWP, 2001b).

Setbacks should have a minimum width of 100 feet to provide adequate protection of waterbodies from development activities (especially on steeper slopes i.e., > 15%). However, in urban and suburban areas where open space is limited, narrower buffers adjacent to guts and wetlands can still be beneficial. The three-zone buffer system is an effective way to establish a buffer (Figure C.1). This method consists of inner, middle and outer buffers zones that have different functions, width, target vegetation, and allowable uses.

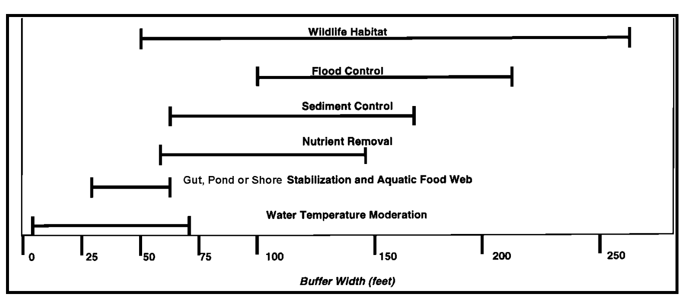


Figure C.2. Range of minimum width for meeting specific buffer objectives (*CH2M Hill, 1998*).

The optimum width for a buffer depends on the function of the buffer (Figure C.2). For a three-zone buffer system (Figure C.1), the width of the zone depends on the size of the gut, pond, or bay and the topographic setting (slope, etc.). Zone 1 starts from the top of the gut bank, shoreline or cliff and is usually 15 to 25 feet or wider. It consist of woody trees and shrubs (preferably native) that provide shade and nutrients to the water body and stabilize banks or shorelines. Minimal disturbance is recommended for this area, and vegetation must be maintained (CH2M Hill, 1998).

Zone 2 is usually 50 to 100 feet wide, depending on slopes and category of gut, pond or bay. Zone 2 provides stormwater filtering, buffering and infiltration. Only sheet or subsurface flow should reach this area, concentrated flows (from swales or channels) entering or crossing the area will cause erosion and decrease the effectiveness of the buffer. This zone also consists of trees and shrubs (preferably native, either set aside or planted).

Zone 3 is usually 20 to 25 feet or wider. This zone converts concentrated flows to sheet flow and also functions as a filter strip, removing sediment and nutrients from runoff (see ***Filter Strips*** in Chapter 3 and Appendix B).

In developed areas where wide buffers may not be available, a minimum buffer width of 35 feet can be used if following the following design principles:

- Encourage sheet flow into the edge of the buffer and use practices such as Filter Strips to create sheet flow before runoff enters the buffer.
- Width should be proportional to the watershed area and slope.
- Forest vegetation should include both understory (shrubs, forbs, grasses) and canopy species (trees). Tree species are particularly important to stabilize gut and pond banks and shorelines.
- Use native plants wherever possible. In suburban and urban areas, forested buffers do not have to resemble natural ecosystems to improve water quality and habitat. However, planting designs must be dense enough to filter sediment, provide stabilization and attenuate nutrients (CH2M Hill, 1998).

Buffers can be implemented on steep slopes along with soil bioengineering (see ***Soil Bioengineering***, Chapter 3 and Appendix B) practices to stabilize banks, shores and buffer zones. Areas susceptible to intense flooding may also need additional stabilization practices.

Maintenance

Corrective maintenance is needed around the edge of the buffer to prevent concentrated flows from forming. Accumulated sediments near the top of the buffer may need to be manually removed over time to keep the original grade and prevent channels from forming. Vegetation within the buffers should also be maintained, including selective pruning, weeding, and replanting. Fertilization is not recommended. Eradication of invasive, non-native (exotic) plants such as tan-tan, cashia and guinea grass may be necessary to ensure forest health and diversity. Some weeds can be suppressed by planting vigorous native species that can out-compete exotic species.

Inspect buffers annually and examine for damage by foot or vehicle traffic, livestock, encroachment, gully erosion and evidence of concentrated flows through or around strip.

GRASSED SWALES

Grassed swales can be used in most development situations with few restrictions, and are particularly well-suited to treat highway or residential road runoff because of their linear design. Grassed swales are commonly used to replace existing drainage ditches that are traditionally designed only to convey stormwater away from roads. It may also be possible to incorporate features to enhance swales' pollutant removal or infiltration by using check dams (small dams along the ditch that trap sediment, slow runoff, and reduce the swale slope) (CWP, 2001d).

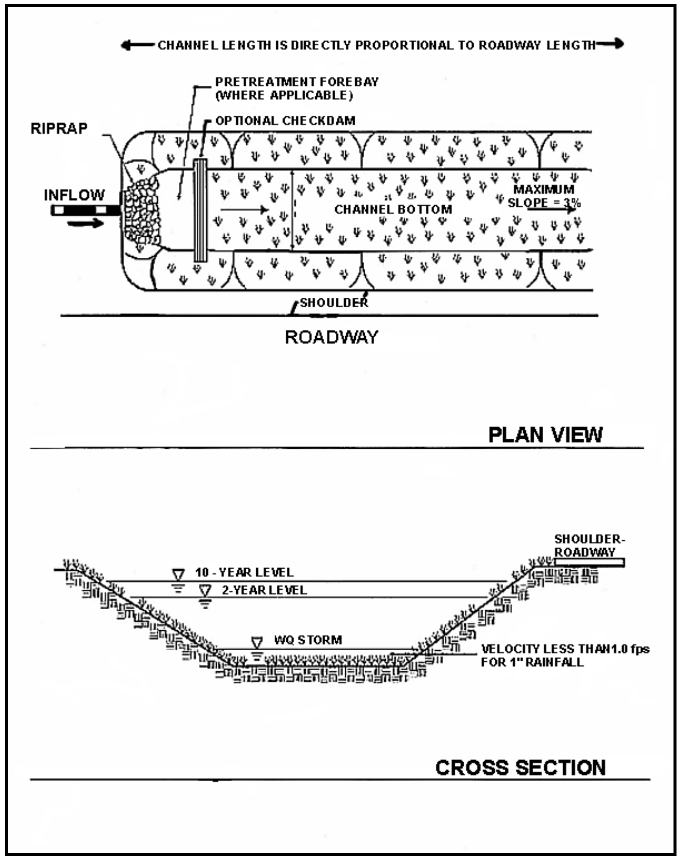


Figure C.3. Schematic design of a grassed swale (Schueler, 1987).

Siting and Design Criteria

1. Individual grassed swales or channels should only be used to treat small drainage areas (less than 5 acres). Otherwise, stormwater velocity is too great to treat runoff and prevent channel erosion.

2. Swales should only be used on sites with fairly flat slopes ($<$ 5%). Swale side slopes should be no greater than 3:1 (horizontal:vertical).

3. A dense cover of water and drought-tolerant, erosion-resistant grass must be established. Swale grasses should never be cut closer than 2" from the ground surface; ideally, mower blades should be set to 3" - 4" above the ground surface.

3. Grassed swales can be used on most soils, except for highly impermeable soils. The swale may need to be tilled before grass cover can be established to restore infiltration capacity lost as a result of prior construction activities.

4. Check dams can be installed in swales to promote additional stormwater infiltration. The best method is to sink a log or large rip-rap halfway into the swale, and place large stone on the downstream site of the log (or rip-rap) to prevent a scour hole from forming. Earthen check dams are **NOT** recommended because they tend to erode on the downstream side of the dam. If a check dam is used, the maximum ponding time of runoff backed up behind the check dam is less than 24 hours.

Construction Specifications

See specifications for ***Drainage Swale*** in Appendix B.

Maintenance

Swale maintenance is aimed towards keeping the grass cover dense and vigorous. This involves periodic mowing, spot re-seeding, and weed control. Table C.1 provides an overview of typical maintenance activities for grassed swales.

Table C.1. Typical Maintenance Activities for Grassed Swales (adapted from: CWP, 1996).

Activity	Schedule
C Inspect pea gravel diaphragm for clogging and correct problem. C Inspect grass along side slopes for erosion and formation of rills or gullies and correct. C Remove accumulated trash and debris. C Inspect and correct erosion problems. C Based on inspection, plant an alternative grass species if the original grass cover has not been successfully established.	Annual (Semi-annual the first year)
C Roto-till or cultivate the surface of the swale if it does not draw down (evaporate and/or infiltrate) within 48 hours. C Remove sediment build-up from bottom of swale once it has accumulated to 25% of original design volume.	As needed (Infrequent)
C Mow grass to maintain a height of 3 to 4 inches.	As needed (frequent seasonally)

Sand Filters

Design & Construction Criteria

Numerous design variations on the original sand filter have been developed. Those most applicable to Virgin Islands conditions are shown in Figure C.4. The required surface area of the filter is a direct function of the impervious acreage treated and varies according to local rainfall volumes. The Austin sand filter full sedimentation design (top left of Figure C.4) requires a basin liner, a 2:1 length to width ratio, and the sand must have a grain size smaller than sand used to make concrete. The Austin sand filter partial sedimentation design (top middle of Figure C.4) requires more frequent sand replacement than the full sedimentation design and requires a basin liner. The Delaware sand filter sand chamber design (bottom middle of Figure C.4) requires very little head. Grates cover each chamber for easy access, however, traffic load needs to be considered in designing the structure (Schueler, 1994).

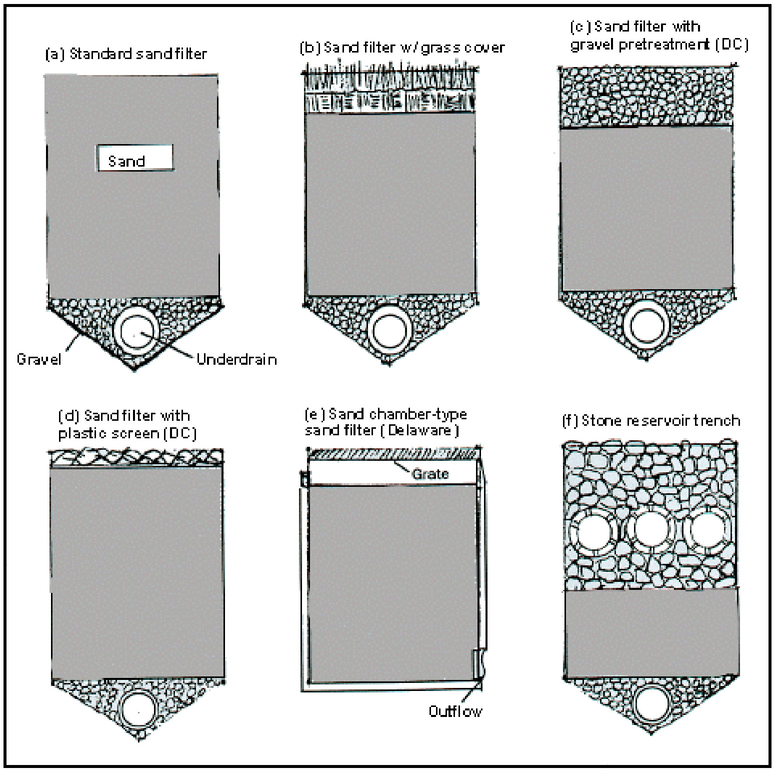


Figure C.4. Cross-section of sand filter design variations (Schueler, 1994).

Table C.2. Comparison of sand filter designs (Schueler, 1994).

DESIGN VARIABLES	Austin Sand Filter *(full sedimentation)*	Austin Sand Filter *(partial sedimentation)*	Delaware Sand Filter
Applicable Situations & Drainage Area	Most can serve 1 to 30 acres	Most can serve 1 to 30 acres	No more than 5 acres of impervious parking lot
Filter Bed Profile	18" sand, 4-6 inches gravel, optional sod layer on surface of bed	18" sand, 4-6 inches gravel, optional sod layer on surface of bed	18" of sand
Filter Bed Area (sf/la)*	100	180	360
Total Treatment Volume	First ½" of runoff with 24 hr. drawdown sediment chamber	First ½" of runoff, S.C. = 20% of Water Quality Volume	First 1" of runoff
Pretreatment Method	Dry sediment chamber	Dry sediment chamber	Shallow wet pool
Pretreatment Volume	sc >> fb**	sc ~= fb	sc = fb

* sf/la = square foot of filter bed area per impervious acre.
** sc = sedimentation chamber; fb = filter bed.

Maintenance

Sand filters must be maintained frequently, by hand. Maintenance includes removing surface sediment, trash, debris and leaf litter from the filters as it accumulates in order to prevent clogging. In areas that have heavy oil and grease loadings, replacing the top 2 to 3 inches of sand or overlying layers of geotextile is necessary every 3 to 5 years (CH2M Hill, 1998).

Water Quality Inlets

Siting and Design Criteria

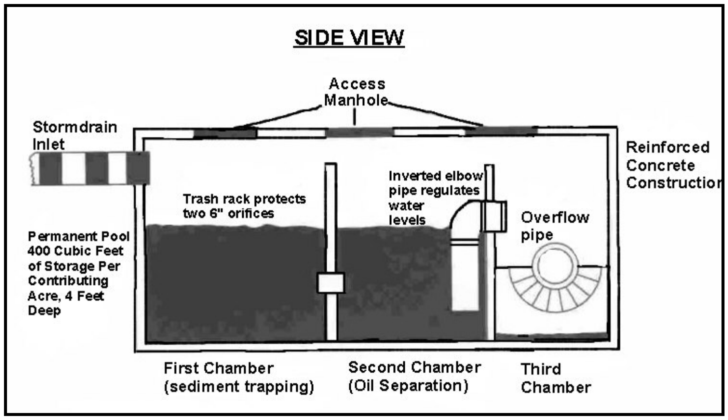


Figure C.5. Schematic design of a water quality inlet/oil-grit separator (Schueler, et al., 1992).

A common design of the water quality inlet has three chambers that pool stormwater, settle particulates (sediment), and remove oil (Figure C.5). As stormwater flows through the system, oil and grease separate either to the surface and are skimmed off, or attach to sediment and are held in the inlet. The quantity of pollutants removed by water quality inlet depends on the volume of the device, flow velocity and the depth of the baffles and elbows in the chambers. Because water quality inlets are relatively small, they can be placed throughout a drainage system to capture coarse sediment, floating wastes, and spills (CH2M Hill, 1998).

A second type of design removes higher levels of pollutants using simple skimmer and control structures in the first chamber of the inlet. This requires using an open water quality inlet with a skimmer plate extending below the ponding control elevation at the outlet. Runoff speed is reduced in the first chamber, dropping out course sediment and separating oil, grease and floatables that are held in the inlet by the skimmer.

Water quality inlets should be designed to provide wet storage for the first one-tenth of the water quality volume (the total runoff that will flow to the device during the water quality design storm, CH2M Hill, 1998). The storage requirement is calculated from the volume of the first two chambers to the top of the weirs only. If the length of the system exceeds 12 feet, the first two chambers should be proportioned so that the first chamber is ⅔ of the length and the second chamber is ⅓ of the length. The weir dividing the first and second chambers should be designed to pass the specified spillway design flood (usually the 10-year storm). The submerged opening between the first and second chambers should be rectangular and appropriately sized to pass the design storm. The opening should be protected by a trash rack bolted to the dividing wall. The second and third chambers should be connected by an inverted elbow pipe to trap petroleum hydrocarbons in the second chamber. A 90° elbow with a sealable access port in the top of the elbow should be used to permit cleaning.

Many types of commercial prefabricated water quality inlets, such as Stormceptor® (see Chapter 4), are available. Each manufacturer has design and installation guidelines for their products that can be used to identify the appropriate inlet for each site.

Maintenance

Water quality inlets should be inspected regularly and cleaned at least twice a year to remove accumulated sediment, oil and grease, floatables, and other pollutants. Sediment should be removed from skimmer structures less frequently, but the skimmers should still be inspected periodically. Wastes removed from the systems my be hazardous, and should be tested to determine proper disposal methods.

Extended Detention Ponds

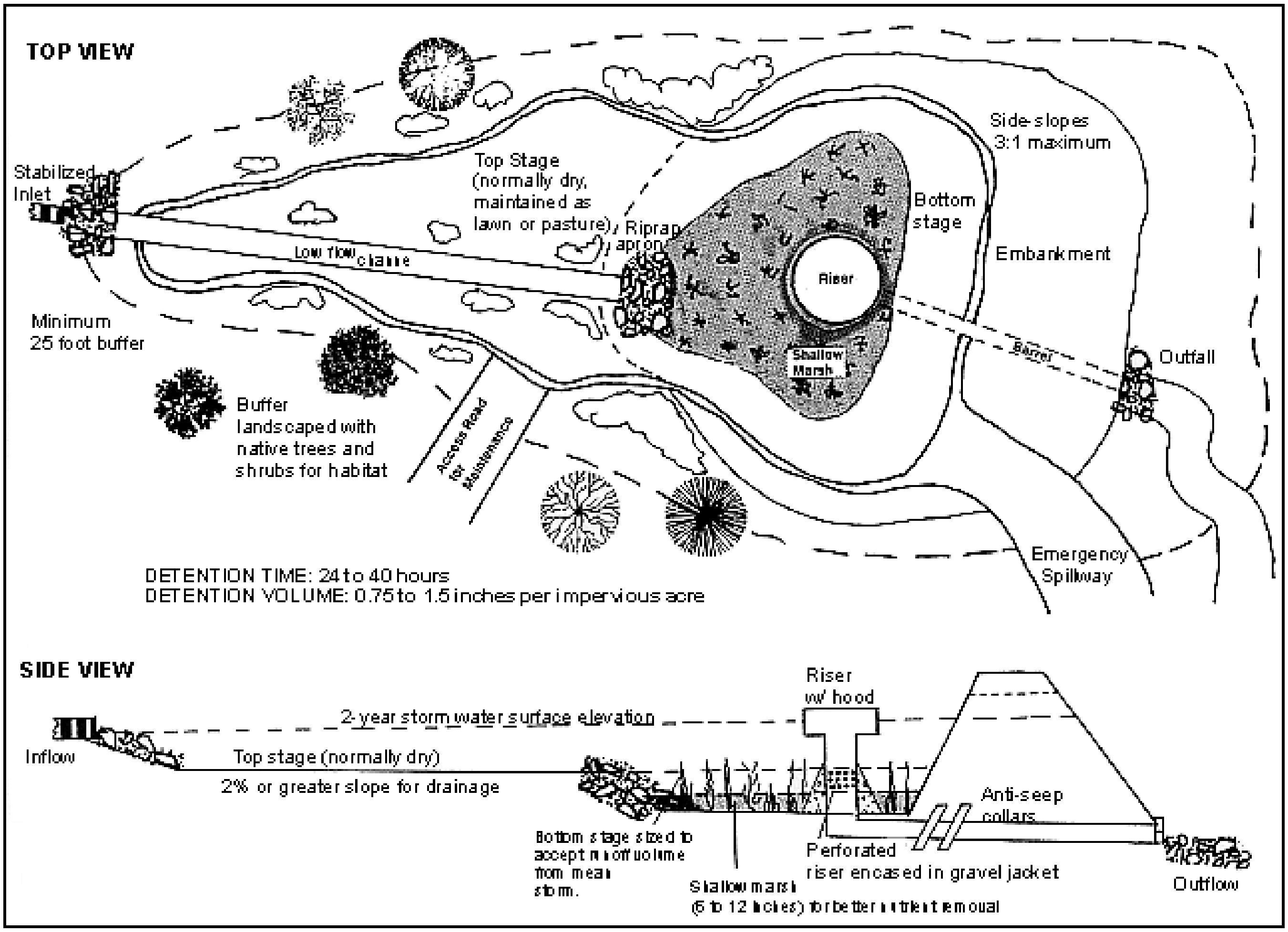


Figure C.6. Drawing of extended detention (ED) pond design features (Schueler, 1987).

Design & Construction Criteria

Quantity Detained: At a minimum, the extended detention pond (Figure C.6) should detain the volume of runoff produced by a one inch storm (see Chapter 6). This will ensure both removal of a large percentage of particulate pollutants and downstream channel erosion protection for most storms. Higher levels of control can be achieved when the runoff volume from the one or two-year storm is detained.

Duration: Twenty-four (24) hours of extra detention are needed for optimum pollutant removal. The outlet control device should be adjusted so that smaller runoff events (0.1 to 0.2 inches) are detained for at least six (6) hours. For larger watersheds, up to 40 hours of extended detention time may be needed to prevent erosion of the downstream channel. The runoff velocity exiting the extended detention pond to the downstream channel should be computed as follows to make sure that it is not erosive:

1. Determine average discharge (cfs) for extended detention release (Q_{ex}):

$$Q_{ex} = S / T \qquad \text{[EQ. C-1]}$$

where S = detention storage volume (cubic feet, ft^3)
T = detention time (hours x 3600 seconds/hour)

2. Determine discharge for natural channel segment (Q_c):

$$Q_c = 0.25\ X_c\ V_a \qquad \text{[EQ. C-2]}$$

where X_c = channel cross-sectional area (square feet, ft^2)
V_a = permissible velocity (3 - 5 feet per second, ft/sec)

3. If Q_{ex} is greater than Q_c, then repeat steps 1 and 2 using either a longer detention time (t) or a smaller detention storage volume (S) until Q_{ex} becomes less than Q_c.

Two-Stage Design: A two-stage pond design is recommended for dry ponds. The upper stage of the pond is sized and graded (2% minimum) to remain dry except during infrequent, large storms, while the bottom stage should be designed to be regularly flooded. The volume of the bottom stage should be set to store the runoff produced by the mean storm:

$$Volb = \frac{R_m\ R_v}{12} * A \qquad \text{[EQ. C-3]}$$

where Volb = volume of bottom stage (acre-feet)
R_m = volume of mean storm (0.4 to 0.5 inches)
R_v = rainfall/runoff coefficient (approximated by eq. C-4)
A = area of contributing watershed (acres).

$$R_v = 0.05 + 0.009\ I \qquad \text{[EQ. C-4]}$$

where I = the percent of site imperviousness

The bottom stage of the pond will usually be too wet to mow and so should be managed as a wetland or as a shallow pool. These management methods will prevent resuspension of deposited pollutants. Extra storage (in addition to stormwater and ED requirements) should be provided in the bottom stage or at the inlet to account for accumulation of sediment for up to 20 years.

Wetland Creation: Whenever possible, a wetland should be created in the bottom stage to help remove soluble pollutants from stormwater. Wetlands will also hide unsightly debris and sediment deposits that accumulate near the riser and provide wildlife habitat. Water depths of 6 - 12 inches are needed for optimum plant growth. The wetland should be planted with native species suited to its environment (see next section).

Extended Detention Control Device: A vertical, internally-controlled extension of the low flow orifice is the most trouble-free design; it can withstand partial clogging and gradual sediment accumulation, and can also be used to set water levels. Control devices installed below the ground surface should be protected with filter fabric and/or wire mesh and encased in a stone or gravel trench of diameter greater than the orifice. It should also have an above-ground extension with a tight-fitting cap to make clean-out easier.

Pilot Channels: A riprap, concrete or paved low flow channel is needed to route water through the upper stage of the pond. This channel should end at the lip of the lower stage and riprap or gabion baskets should be placed to reduce flow velocity and spread out the flow path of the runoff reaching the lower stage.

Slopes: Slopes leading to the pond should be shallow so that gully erosion of the pond banks does not occur during larger storms. Side slopes should not be steeper than 3:1 (horizontal:vertical) or flatter than 20:1. Banks that are steeper than 2:1 should be stabilized with riprap to prevent erosion. The slope of the upper stage of an extended detention pond should be between 2 and 5% to promote rapid drainage. The stream channel below the pond outlet should also be lined with large stone riprap and graded to a 0.5% slope to prevent scouring during larger events. A layer of filter cloth should be laid down that conforms to the natural dimensions of the channel, and then anchored with 18-30 inch stone riprap. Smaller riprap (9 - 12 inches) can be used if the diameter of the pipe outfall is less than 24 inches. The outfall pipe should discharge at the bottom of the embankment directly to the outflow channel.

Pond Buffer: A minimum 25 foot wide buffer strip should be maintained around the pond and landscaped using low-maintenance grasses, shrubs and trees.

Embankment: At least 10-15% extra fill should be allowed on the embankment to account for possible subsidence. The embankment should have at least one foot of freeboard above the emergency spillway. Anti-seep collars should be used to prevent seepage around the barrel. The embankment should be graded to allow access for heavy equipment and needs to be mowed twice a year to prevent tree/bush growth.

Site Access: Access from public or private rights-of-way to the pond should be at least 10 feet wide on a slope of 5:1 or less and stabilized to withstand heavy equipment traffic.

Dry ponds can be easily adapted to extend stormwater detention times. A two-stage design is recommended for dry ponds where the top portion of the pond remains dry most of the time, and a smaller part near the riser is regularly flooded (Figure C.6). The devices used to extend detention are usually attached to the low flow orifice or the riser. Some common methods used to extend detention are shown in Figure C.7, and include (from Schueler, 1987) the following:

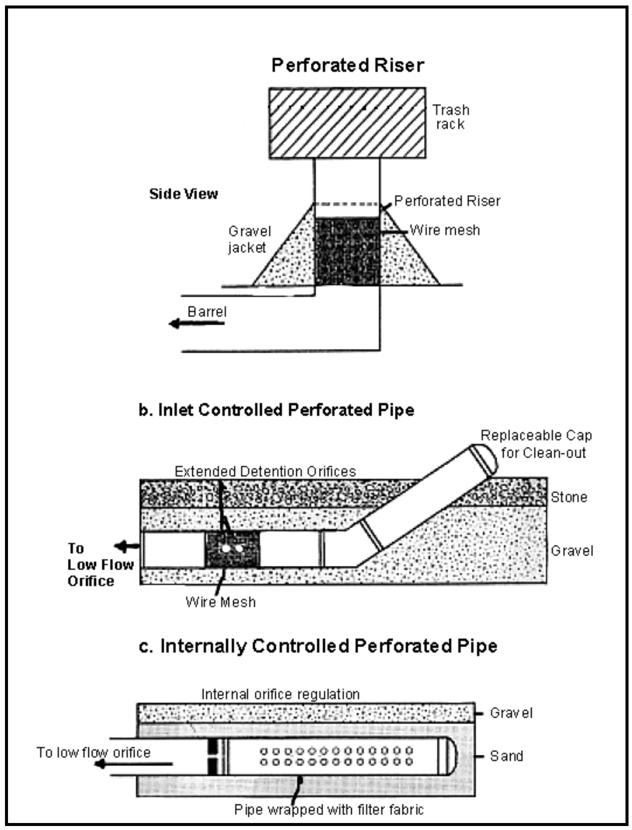


Figure C.7. Common approaches to extended detention times in ponds (Maryland Department of the Environment, 1987).

Perforated Riser Enclosed in a Gravel Jacket (Figure C.7.a). A standard corrugated metal pipe riser is perforated with small holes and the normal low flow orifice is closed. The total diameter of all the holes regulates the outflow from the pond to achieve the design detention time for all storms smaller than the two-year design storm. A gravel jacket and wire mesh screen filter stormwater to prevent clogging. However, perforated risers have some drawbacks, including difficulty in achieving target detention time because of uncertainty of flow rates through the vertical riser and clogging of the bottom of the gravel jacket by deposited sediment.

Perforated Extension of Low Flow Orifice, Inlet Controlled (Figure C.7.b). This design entails extending and capping the low flow orifice. Small diameter holes are drilled into the extended PVC pipe, these holes are protected by a 1/4" wire mesh and a layer of gravel and stone. An elbow joint is used to extend the pipe above the pond surface to facilitate cleaning with high velocity jet hoses. This design should only be used in areas where regular maintenance and cleaning is performed, because it is prone to clogging.

Perforated Extension of Low Flow Orifice, Outlet Controlled (Figure C.7.c). This method also uses a perforated pipe extended from the low flow orifice. The major difference between this method and the previous one is that the release rate of the pipe is regulated by an internal flange within the pipe, instead of holes drilled in the pipe. This provides additional protection from clogging. If sediment does partially clog the gravel/geotextile filters or the outside of the perforated pipe, enough water can flow through the remaining holes to release stormwater according to design.

Maintenance

Wet-weather inspections should be conducted annually. Inspectors should check condition of the extended detention control device and low flow channel. ED facilities should be maintained as a meadow to reduce mowing frequency and maintenance costs.

Sediment Removal: A five to ten year sediment removal cycle is recommended. Extra storage in the lower stage may be provided to accommodate sediment deposition.

Constructed Wetlands

Constructed wetlands are used in stormwater management to provide detention time during which stormwater quality can be enhanced. Artificial wetlands can be built as either **surface water systems** or **subsurface flow systems.**

Surface water systems are made up of basins or channels that can be constructed using an impoundment in a low-lying area (Figure C.8). They can also be constructed in the lower stage of a detention basin. These systems can provide a dense stand of aquatic vegetation that acts as a biological filter to remove pollutants from stormwater flowing through the wetland. In these systems, only 25% of the total surface area is open water. The rest of the wetland consists of submergent and emergent vegetation. Most surface water systems do not have a long retention period.

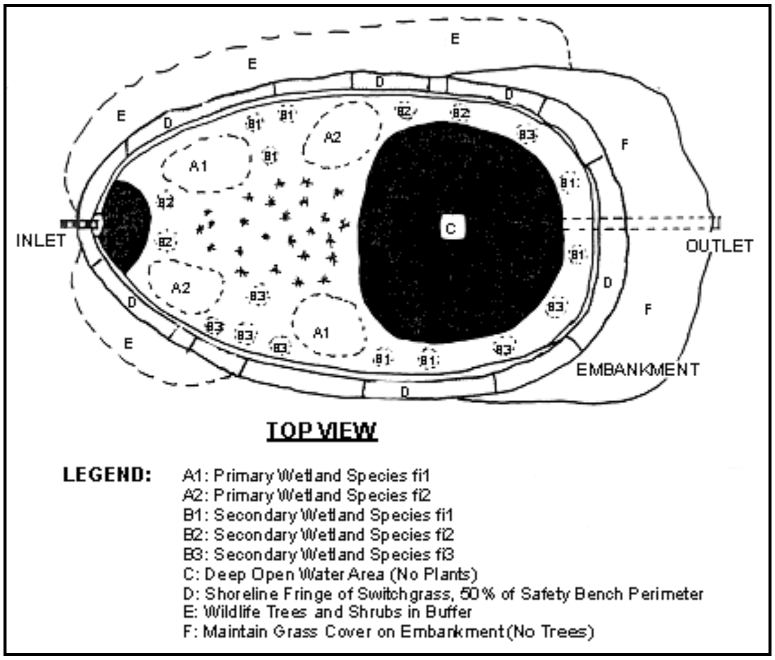


Figure C.8. Surface water wetland design — note the diversity of recommended plant species (Schueler, 1987).

Subsurface flow systems are built of trenches or beds on impermeable soils or underlain with a constructed impermeable subsurface barrier (Figure C.9). Pea-size gravel or coarse sand is placed into the trench or bed to a depth of six inches to support submergent vegetation. The wetland is built on a slight inclination between the inlet and outlet. Pollutants present in stormwater runoff are removed by the vegetation's root system as the runoff infiltrates through the gravel or sand. This type of system is generally recommended for the predominately clayey soils of the Virgin Islands.

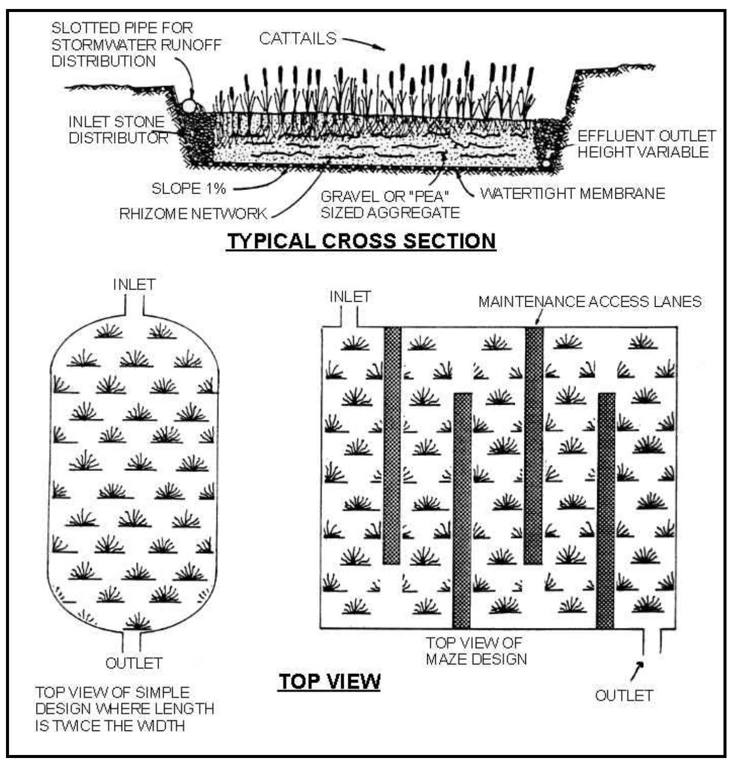


Figure C.9. Subsurface flow system design (New York State Department of Environmental Conservation, 1992).

Design & Construction Criteria

Surface Water Wetlands

1. Water inflow to the wetland must be maintained at a level greater than water outflow from the wetland through infiltration or evaporation in order to maintain a shallow pool of water in the wetland at all times. This requires sufficient stormwater runoff and/or baseflow inputs to the wetland and an infiltration/evaporation rate less than the sum of inflows.

2. Preferred locations for surface water wetlands are: low-lying areas adjacent to, but separated from, existing guts and wetlands by buffer strips; extended detention ponds; or a forebay to a detention pond or basin.

3. The wetland basin should be sized to have an extended detention time of 24 hours for the one-year storm.

4. Wetland basins will perform best when the wetland surface area is maximized. The surface area of the wetland should account for at least 3% of the area of the sub-watershed draining into it.

5. Extended detention wetlands are designed to have areas that are not entirely wetland and not entirely upland. This border area will be flooded whenever stormwater runoff enters the basin, but will not have standing water in it after the extended detention period is over. Diverse vegetation will be established in this area that thrive on damp soil and can tolerate brief flooding. This border area is the zone that is within 10 to 20 feet from the edge of the permanent pool.

6. The wetland basin design should incorporate water depths within the wetland that are conducive to the growth of emergent vegetation.

   a. The water level in 75% of the wetland should be less than or equal to 12 inches deep. Half of this area should also be less than 6 inches deep. The remainder (25%) of the wetland surface area should be open water with depths ranging 2 to 3 feet deep.
   b. This deep area of the wetland should include the outlet structure so that sediment build-up does not interfere with basin outflow.
   c. Stormwater inflow to the wetland should be maintained as sheet flow as much as possible to prevent scouring of the basin. As much vegetation and distance as possible should separate the basin inlet from outlet. The length to width ration should be at least 2:1.
   d. It is not necessary to have a smoothly graded substrate and precise depths, however, it is better to have a shallower wetland than a deeper one. Figure C.10 depicts different wetland layouts.

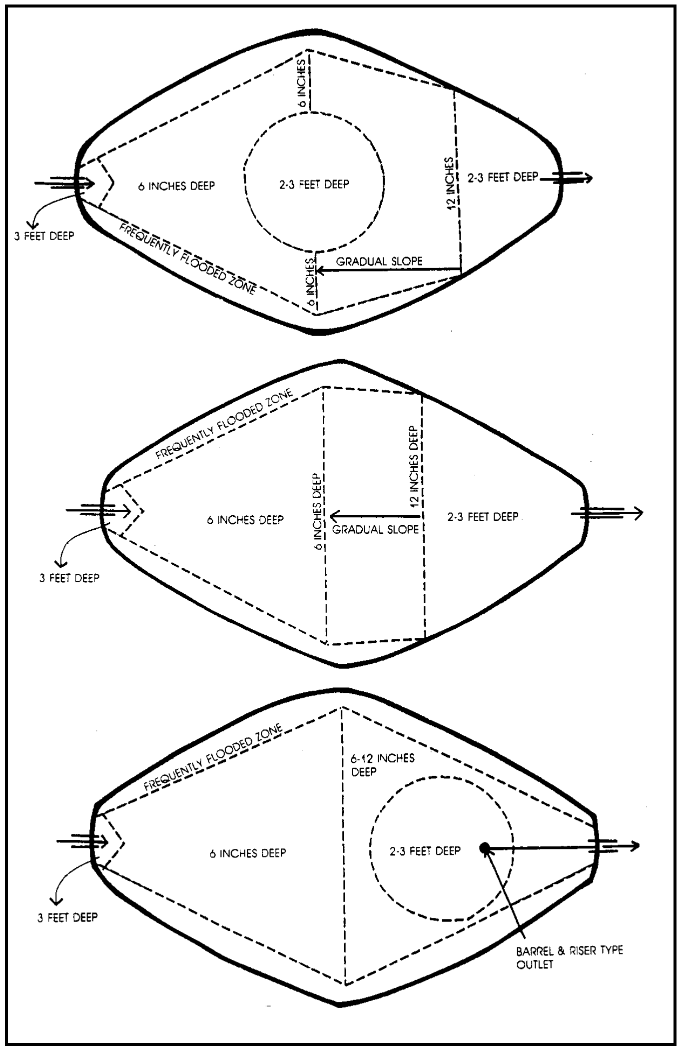


Figure C.10. Potential Surface Water Wetland Designs (Maryland Department of the Environment, 1987).

7. The wetland outlet structure must be capable of damming enough water to create the wetland and detain sufficient water to support wetland plants for extended time periods. The outlet also must be designed to permit water to flow out of the wetland without becoming blocked by debris (such as a barrel and riser). Orifices used for extended detention must be protected from blockage by plant material with wire mesh extending below the orifice and suspended at least one foot away from the riser.

8. Preserve topsoil at the wetland site when constructing the basin and then spread the topsoil over the excavated site to aid in the establishment of wetland vegetation.

9. The most reliable method of establishing a wetland is to transplant live plants or dormant rhizomes from nursery stock. Most plant species have very specific water depth requirements. Most species thrive in shallow water conditions (less than one foot deep). Sites for wetland creation must have a steady water flow in order to maintain plant species. Plant species that can be used in the Virgin Islands for surface water systems are listed in Table C.2. For further information on appropriate plant species for construction wetlands, contact the UVI Cooperative Extension Service or the USDA Natural Resources Conservation Service.

Subsurface Flow Wetlands

1. Construct the system on soils that are impermeable or on an impermeable synthetic liner. The most desirable soil permeability ranges from 0.14 to 0.014 inches per hour. Sandy clays and silty clay loams may be suitable when compacted.

2. Slope the floor of the subsurface flow system 1 percent from inlet to outlet.

3. Place approximately 12" of pea-sized or coarse gravel into the bed of the system to provide a medium to support the growth of emergent vegetation and for stormwater to flow through.

4. Construct a sediment basin, grit/oil separator or forebay at the inlet to capture sediment and prevent clogging of the aggregate medium.

5. Table C.3 provides suggestions of plant species suitable to the Virgin Islands. For more information on appropriate wetland plant species, contact the UVI Cooperative Extension Service or the USDA Natural Resources Conservation Service.

Table C.3. Plant species for surface and subsurface wetlands (USDA-SCS Caribbean Area, 1992 & 1993).

	Maximum Depth of Water Tolerated	**Available Commercially**
Species Acceptable for Surface Water Systems		
Primary Species *Scirpus californicus* (bulrush)		
Scirpus validus (softstem bulrush)	12 inches	Yes
Typha spp. (cattail)		
Panicum hemitomon (maidencane)		
Secondary Species *Dieffenbachia* spp.		
Cyperus spp.		
Colocasia spp. (malangas)		
Canna flacida (canna lily)		
Colocasia esculenta (elephant ear)		
Zizaneopsis miliacea (giant cutgrass)		
Species Acceptable for Subsurface Flow Systems		
Phragmites communis (common reed grass)	3 inches	Yes
Typha spp. (cattail)	12 inches	Yes
Brachiaria mutica (paragrass)		
Eriochloa polystachya (caribgrass)		
Brachiaria arrecta (taner grass)		
Echinochloa polystachya (aleman grass)		

6. Refer to the U.S. EPA *Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment Systems* for procedures on sizing subsurface flow systems.

Porous Pavers

Concrete grid and modular pavement involves the use of special pervious paving materials in low-traffic areas (such as low-use parking lots, emergency areas, driveways, walkways). The paving consists of concrete grids, high-strength plastic grids, or other materials placed on a pervious base such as gravel or sand (Figure C.12). (The gravel or sand base may also be lined with filter fabric to prevent the rock material from becoming imbedded.) The grids or paving material is then filled with sand, gravel or soil. Grids filled with soil are typically seeded to attain a grassed or lawn surface. The resulting system provides an adequate bearing surface while allowing a significant amount of infiltration, thus reducing runoff volume and discharge rate and improving water quality. Concrete tire-tracks with grassed interiors can also be used for steeper driveways (Figure C.11).

Figure C.11. Concrete tire-track driveway example.

There are many different types of porous pavers commercially available. A few brands are listed below, however, endorsement of any of these manufacturers is not intended. Design and construction guidelines for porous paving systems are specific to the paving type. See manufacturers technical specifications and design details instructions (provided at their websites) for details.

Figure C.12. Geoblock pavement installed at UVI-CES St. Thomas office, prior to filling with soil and seeding (*photo by Dale Morton, 1999*).

Geoblock® (produced by Presto Products Company, www.prestogeo.com) is a series of inter-locking, high-strength blocks made from a minimum of 50% post-consumer recycled plastic, using tongue-and-groove interlock forms to create a flexible, structural bridge that spreads concentrated loads. This system is designed to flex under loads that would break concrete (see Figures C.12 and C.13). This paving presents over 80% open area to the surface for infiltration. It supports heavy or concentrated loads by creating a flexible structural bridge over a prepared subbase. Geoblock® can be filled with soil and seeded with grass, or filled with gravel. For parking lots with frequent use, a grass surface is not recommended; gravel-filling is more appropriate. Daily vehicle use tends to kill grass and increase erosion potential. Grassed surfaces are more appropriate for overflow parking areas or emergency fire lanes or parking areas. Geoblock® is only recommended for use on level surfaces. Parking areas, driveways or walkways with slopes should use Geoweb®, GrassPave2®, or another more flexible system.

Figure C.13. Geoblock installation close-up, note j-bars used to anchor blocks in place (*photo by Dale Morton, 1999*).

Figure C.14. Close-up of Geoweb® cells being filled with soil (left). Installation of Geoweb® at the UVI-CES St. Thomas driveway (*photos by Dale Morton, 1999*).

Geoweb®, ***TerraCell®*** (manufactured by Webtec, Inc., www.webtecgeos.com) and ***EnviroGrid®*** (manufactured by AGH Industries, Inc., www.aghindustries.com) are cellular confinement systems that use web-shaped, heavy-duty plastic containment material filled with native granular soil and covered with grass, or filled with gravel or crushed rock. These systems have over 98% open area and can be used for low-volume parking areas, driveways and emergency vehicle access lanes (see Figure C.14).

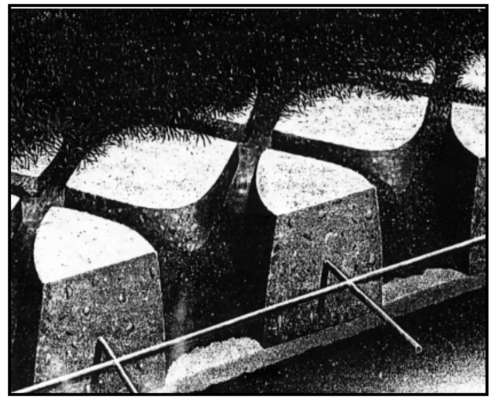


Figure C.15. Grasscrete paving system *(Bomanite Corp, 1988)*.

Grasscrete® (manufactured by Bomanite Corporation, www.bomanite.com/products/grasscrete.htm) - concrete block reinforced with steel bars that are formed so that spaces are left between for stormwater to infiltrate through. Reusable forms and steel reinforcing mesh are positioned first. Concrete is then poured and after initial setting, the forms are removed. After concrete has hardened sufficiently, openings in the slab are filled with soil and planted with grass seed or sod (Figure C.15).

GrassPave2® (manufactured by Invisible Structures, Inc., www.invisiblestructures.com/GP2/grasspave.htm) is a similar system to GeoBlock®, but with more flexibility. It provides load bearing strength while protecting vegetation root systems from compaction. High void spaces within the entire cross-section enable root development and storage capacity for rainfall from storm events. Stormwater runoff is slowed through and across Grasspave2 surfaces, depositing suspended sediment and increasing discharge time. Suspended pollutants and moderate amounts of engine oil are broken down by active soil bacteria, which are aided by the system's oxygen exchange capacity.

Design & Construction Criteria

(These instructions are for educational purposes only. Please refer to manufacturer's specifications for information on installing other types of porous pavers.)

Webbed Cellular Confinement Materials:

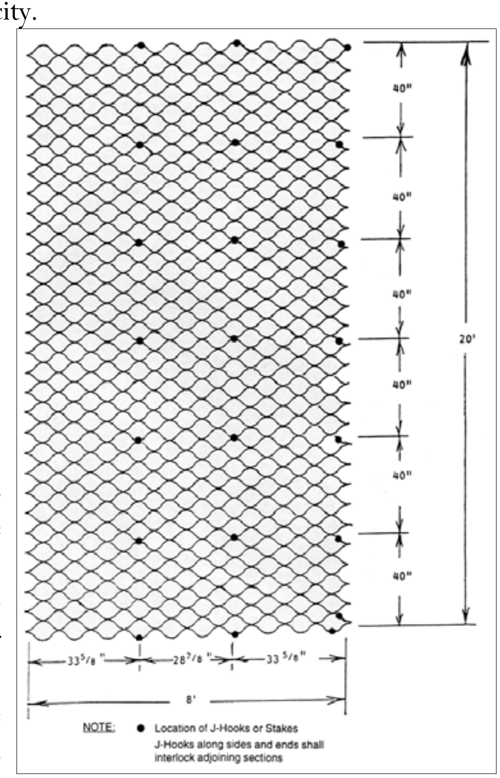


Figure C.16. EnviroGrid® light density staking diagram (AGH Industries, Inc., 1999).

1. Prepare the site by removing vegetative cover and debris from the area to be stabilized. Complete other earth change, excavation and/or fills. Ensure that foundation soils meet minimum strength requirements (through proof rolling or other method). Remove in-situ soils that are unacceptable for load support and replace with suitable materials.
2. Place a suitable geotextile between the subgrade and infill materials to be stabilized (if needed). Install drainage materials, if needed or specified.
3. Expand web sections to proper dimension (20') and position (Figure C.16). Anchor web sections into position using j-bars (Figure C.17), a stretcher frame, straight stakes, or ATRA™ clips along the sides and ends of the section. (J-hooks shall be made from construction rebar, ¾" or ½" diameter and 18" long).
4. Check each section to ensure that it is fully expanded. Full expansion will result in a better fitting and looking stabilization area.
5. Correctly align and interleaf edges of adjoining web sections and ensure that the upper surfaces of adjoining sections are flush.
6. Join web sections with industrial staples.
7. Filled expanded web cells with soil, sand, crushed stone or gravel with a backhoe, or front-end loader, or by hand. Overfill web sections to at least 2" above the cell walls.
8. Compact fill material to specified density.

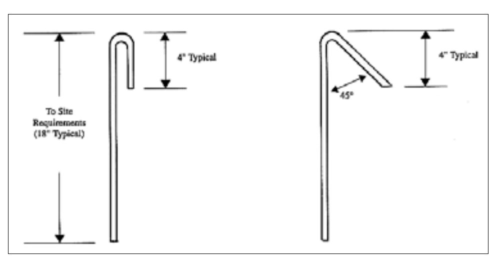


Figure C.17. Standard j-hook details (AGH Industries, Inc. 1999).

GeoBlock®:

1. Prepare the subgrade by excavating the area, allowing for unit thickness less ~ ¼" for settlement. If working with soils that have poor permeability (clayey soils) in an area that has potential to collect water, provide adequate drainage from the excavated area. Uniformly grade the base. Level and clear it of large objects such as rocks, wood, stumps, etc. this enables the block units to interlock properly and remain stationary after installation.
2. Prepare the base by installing a recommended "engineered base" consisting of coarse sand, clear-stone or crushed rock blended with topsoil to promote vegetative growth and provide required structural support (Figure C.18). The aggregate portion of the base should be free from fines and have a known percentage void-space when compacted.
3. Install the blocks with the round hole to the ground. For best performance under traffic loading, stagger the blocks so that the long direction of the block is perpendicular to the direction of traffic, as shown in Figure C.19. The staggered pattern is made by using half-blocks, cut from a full block. Cut the blocks with a hand or power saw to custom fit contours and around obstructions. The final seam pattern should have straight seams perpendicular to traffic flow and staggered seams parallel to traffic flow.
4. Place the blocks against a stationary edge, if available. Slide the blocks together so that they interlock tightly, as shown in Figure C.19.
5. Anchor the blocks in place to prevent them from shifting during installation. Blocks can be anchored with wood, metal stakes or j-bars.
6. Fill the blocks with a suitable topsoil, sand, gravel, or crushed rock immediately after block installation. This will minimize block separation. Spread or rake the material level by hand. If using topsoil for a grassed surface, remove any stones present. The surface of the fill should be level with the top of the blocks.
7. If a grassed surface is desired, seed or sod the area, using seeding rates, fertilizers and irrigation as is necessary for the area (see ***Temporary Seeding*** or ***Permanent Seeding and Planting***, Chapter 3 and Appendix B). Grass should be maintained by mowing and re-seeding of bare patches.

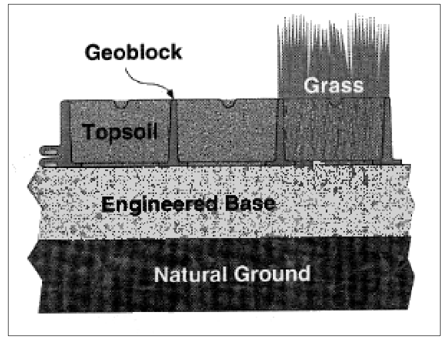


Figure C.18. Geoblock® porous pavement system (*Presto Products Company, 1997*).

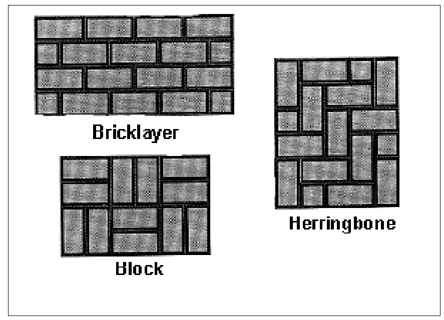


Figure C.19. Geoblock® installation - various laying patterns (*Presto Products Company, 1997*).

Infiltration Trenches

Siting & Design Criteria

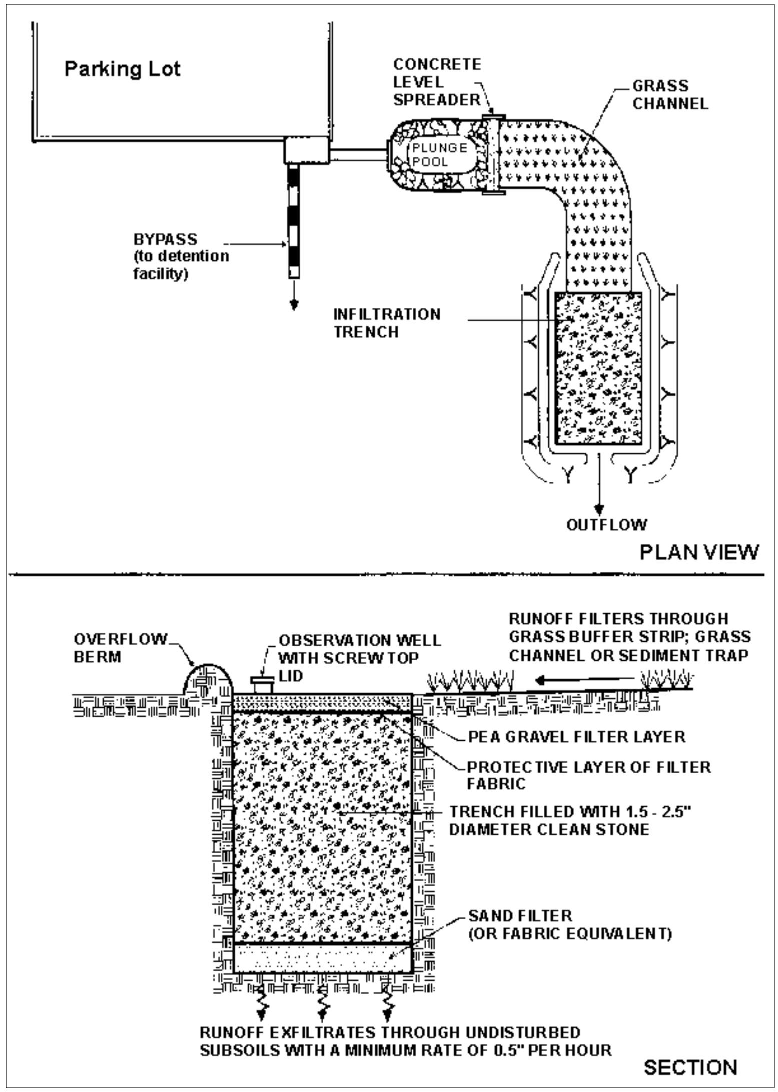


Figure C.20. Schematic design of an infiltration trench (CWP, 2001c).

Infiltration trenches should be sited to ensure that soils at the site are appropriate for infiltration and designed to minimize potential groundwater contamination. Infiltration trenches are typically used on smaller sites (less than 5 acres) that have relatively high impervious cover (Figure C.20, CWP, 2001c).

Surface Area of Trench Bottom: Pollutant removal can be enhanced by increasing the surface area of the trench bottom, i.e., making the trench more shallow and broad rather than deep and narrow.

Draining Time: Design the trench to completely drain within three days after the maximum design storm event. If a trench is constructed over soils with a marginal infiltration capacity (clayey soils), adjust the depth of the trench so that it drains in two days or less, as a safety margin. However, design the trench to retain stormwater for at least six hours in order to provide adequate pollutant removal.

Maintenance: Install a test well in the trench to monitor drain times after installation. If the trench does not completely drain within 3 days after a storm, it is likely that the bottom of the trench has clogged and corrective measures are needed. On the other hand, if a partial infiltration trench empties completely within a day, either the collection efficiency of the underdrain is too great, or the bottom of the trench has clogged, or both. Correct these problems.

Soils: Trenches are not a feasible option for sites with soils in Hydrologic Soil Group "D" (soils with infiltration rates less than 0.27 inches per hour. See Chapter 5 for a listing of V.I. soils and their hydrologic soil groups). Silt loams and sandy clay loams ("C" soils) provide marginal infiltration rates, and should only be considered for partial exfiltration systems (see Table C.4). Trenches are not suitable over fill soils that form an unstable subgrade, and are prone to slope failure.

In soils that meet the above criteria, take soil cores or trenches to a depth of at least five feet below the anticipated level of the stone reservoir bottom. Examine these cores for evidence of any impermeable soil layers that may impede infiltration, such as clay lenses, hardpans, or fragipans. The presence of such layers do not necessarily preclude a trench, as long as the stone reservoir completely penetrates the layer.

Slope: An underground trench is not feasible on sites with slopes greater than 20%. Surface trenches are not recommended for sites whose contributing slopes are greater than 15% (CWP, 2001c). Keep the slope of the bottom of the trench as close to zero as possible in order to evenly distribute exfiltration, unless the design includes a positive outlet.

Depth to Bedrock: Keep the bottom of the stone reservoir at least four feet above the bedrock level. Depth to rock can be estimated from soil maps, but should be confirmed by soil test borings.

Depth to Seasonally High Water Table: Keep the bottom of the stone reservoir a minimum of two to four feet from the seasonally high water table.

Proximity to Wells/Foundations: Locate trenches in commercial and industrial areas at least 100 feet away from a drinking water well to minimize the possibility of groundwater contamination, and at least 10 feet down-gradient and 100 feet up-gradient from building foundations.

Maximum Reservoir Depth: It may be necessary to limit the depth of the stone reservoir when underlying soils have relatively low exfiltration rates in order to insure that the stone reservoir will completely drain in 72 hours. These limits are shown for various soil textures in Table C.4. Dimensions of the infiltration trench may need to be modified in order to accommodate the necessary volume without exceeding maximum depth limits.

Table C.4. Soil limitations for infiltration trenches (Schueler, 1987).

Soil Texture	Minimum Infiltration Rate (fc, in/hr)	SCS Soil Group	Maximum Trench Depth (in.)	
			48 hours	72 hours
Sand	8.27	A	992	1489
Loamy Sand	2.41	A	290	434
Sandy Loam	1.02	B	122	183
Loam	0.52	B	62	93
Silt Loam	0.27	C	32	49
Sandy Clay Loam	0.17	C	20	31
Clay Loam	0.09	D	11	16
Silty Clay Loam	0.06	D	7	11
Sandy Clay	0.05	D	6	9
Silty Clay	0.04	D	6	7
Clay	0.02	D	2	4

Watershed Size: Trenches should **NOT** serve drainage areas greater than 5 acres in size.

Space Limitations: The application of surface trenches may be space-limited on some “tight” sites because of the 20 foot buffer strip requirement.

Construction Specifications

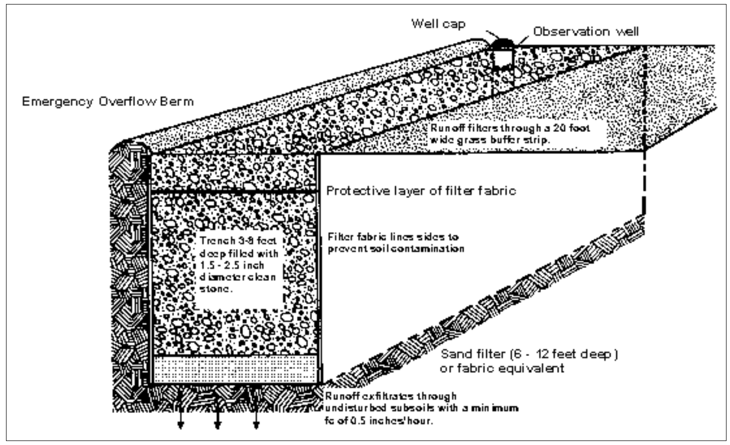


Figure C.21. Infiltration trench cross-section (Schueler, 1987).

Infiltration trench installation considerations include system location, depth and width, aggregate gradation, geotextile requirements, and installation, inspection and maintenance schedule.

The runoff storage capacity of an infiltration trench filled with drainage materials (Figure C.21) should be equal to the volume of the trench multiplied by the porosity of the media. Preferable drainage material types include uniform sand, gravel, or crushed stone. Uniform materials have high porosity and large storage capacities, therefore, less material is required for facility. Drainage materials should be hard, durable, inert particles free from slate, shale, clay, silt and plants. To increase the runoff storage capacity of trenches, plastic or concrete gallery frames can be inserted (CH2M Hill, 1998).

Drainage materials should be enclosed in geotextile. Use of an appropriate type of geotextile is necessary to prevent soil from penetrating the sides of the trench or clogging at the soil interface. Geotextiles should be carefully installed to minimize smearing of soil on the bottom and sides of trenches (this will reduce permeability through the trench). To minimize accumulation of sediment inside the trench, insert a geotextile 6 to 12 inches below the top of the drainage materials. The geotextile will intercept sediment, leaves and other debris before it can penetrate the gravel (or other material) and clog the trench (CH2M Hill, 1998).

Maintenance

Infiltration trenches need regular inspection and maintenance to perform properly. Table C.5 outlines required maintenance practices.

Table C.5. Typical maintenance activities for infiltration trenches (CWP, 2001c).

Activity	Schedule
C Check observation wells following 3 days of dry weather. Failure to percolate within this time period indicates clogging. C Inspect pretreatment devices and diversion structures for sediment build-up and structural damage.	Semi-annual inspection
C Remove sediment and oil/grease from pretreatment practices, as well as overflow structures	standard maintenance
C if bypass capability is available, infiltration rate may be regained in the short term by using practices such as an extended dry period.	5-year maintenance
C Total rehabilitation of the trench to maintain storage capacity within 2/3 of the design treatment volume and 72-hour exfiltration rate limit. C Excavate trench walls to expose clean soil.	Upon failure

BioRetention

Siting & Design Criteria

Bioretention systems can be used in median strips, parking lot islands, and other small (less than 5 acres) drainage areas. Bioretention systems work best on shallow (~5%) slopes, but with proper design can be used on steeper slopes (up to 15-20%).

Planting soil ranging from 10 to 25% clay along with sandy loam, loamy sand or loam texture is recommended for offline bioretention systems (see Chapter 4, CH2M Hill, 1998). The soil pH should range between 5.5 and 6.5. A desirable planting soil is permeable to allow runoff to infiltrate and adsorbs organic nitrogen and phosphorus.

In areas with high clay contents (the soils are not conducive to infiltration), the bioretention practice can be modified with a collector pipe system installed beneath the basin to form a bioretention filter.

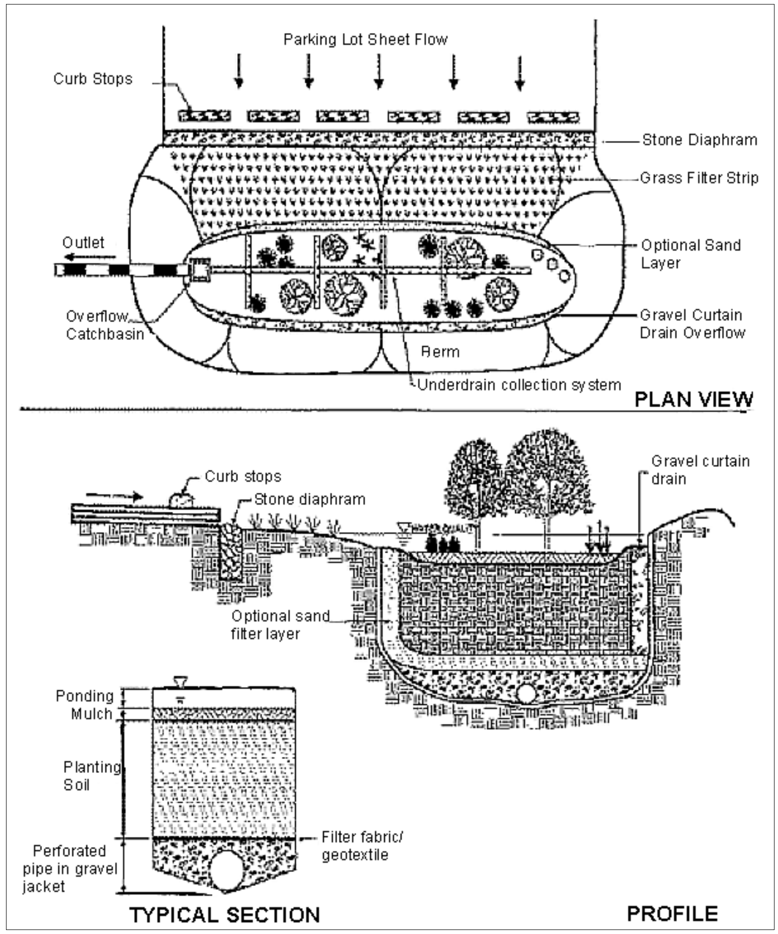


Figure C.22. Schematic design of a bioretention practice (CWP, 2001f).

Check dams can be used to reduce stormwater runoff speeds within grass swales, forming "on-line" bioretention areas that promote sedimentation behind the dam (Figure C.22). Properly anchored gabions, rock filter berms or large logs can be used as check dams on moderate slopes. Silt fences **must not** be used as check dams, because concentrated flows quickly wash out these materials (CH2M Hill, 1998).

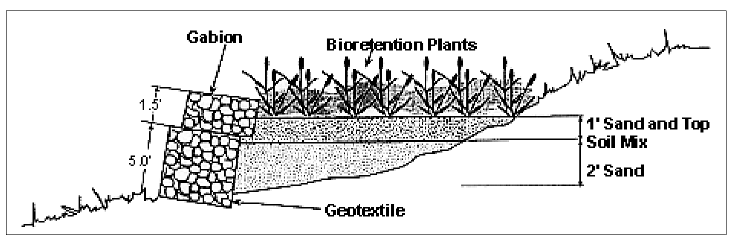


Figure C.23. Cross section of an on-line bioretention system formed by damming a grass swale with a mild to moderate slope with gabion baskets *(CH2M Hill, 1998)*.

On-line bioretention areas using check dams must be sized, built and maintained properly or they will either be washed out or contribute to flooding. The relationship between ponding depth behind the check dam and discharge rate can be computed by using the following critical-depth formula, which accounts for a generalized weir profile:

$$Q = ((A^3 \times g) / T)^{1/2}$$

Where Q = Discharge rate
A = area subtended by top of check dam and ponding elevation
T = width of check dam
g = gravitational constant

Off-Line Bioretention Systems – these systems have six components: a grass filter strip or energy dissipation area, a ponding or treatment area, planting soil, sand bed (optional), mulch layer, and plant material (Figures C.24 and C.25). The grass filter strip (or energy dissipation area) filters sediment from runoff and reduces stormwater speed. The sand bed further slows runoff, spreads it over the basin, filters part of the water, provides drainage in the planting soil, and enhances seepage from the system (CH2M Hill, 1998).

The ponding area stores runoff waiting for treatment and also functions as a presettling basin for particulates not removed by the grass filter strip. The mulch layer filters pollutants, minimizes erosion, and provides a habitat for microorganisms to break-down hydrocarbons and other pollutants. The soil layer supports the plants and clay particles in the soil adsorb heavy metals, nutrients, hydrocarbons and other pollutants. The minimum depth of the soil layer should be 3 to 4 feet.

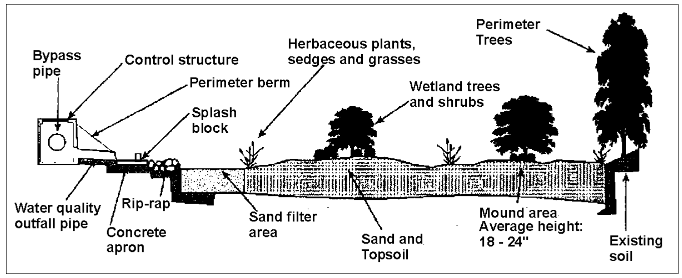


Figure C.24. Bioretention cross-section. Runoff from storms greater than 1-year storm is bypassed through main drainage system. Runoff from small storms is diverted at the control structure (manhole). Stormwater energy is dissipated by the splash block or rip-rap. Stormwater is filtered through an open sand filter. Excess stormwater is treated in the bioretention area (CH2M Hill, 1998).

The number of tree and shrubs planted will vary based on site conditions, but a minimum of three different species each of shrubs and trees should be planted. The site conditions (slope, volume and velocity of runoff, climate, etc.) will also determine the size of the system, however, average recommendations are:

C Minimum width of 10 to 15 feet
C Minimum length of 30 to 40 feet
C The ponded are should have a maximum dept of 6 inches. If collector pipes are used, the maximum ponded depth can increase to 12 inches.
C The planting soil should have a minimum depth of 3 to 4 feet.

On-Line Bioretention Systems – a bioretention area in a swale upstream from a check dam is built with similar specifications as the off-line system. The planting soil depth can be reduced (1 to 2 feet) if the drainage area is small (less than 2 acres, CH2M Hill, 1998). Rock check dams should be build of 8" to 12" rock, placed by hand or mechanically. The dam must completely span the swale or channel to prevent it from being washed out. Log check dams should be built of 4" to 6" diameter logs and embedded at least 18" into the soil.

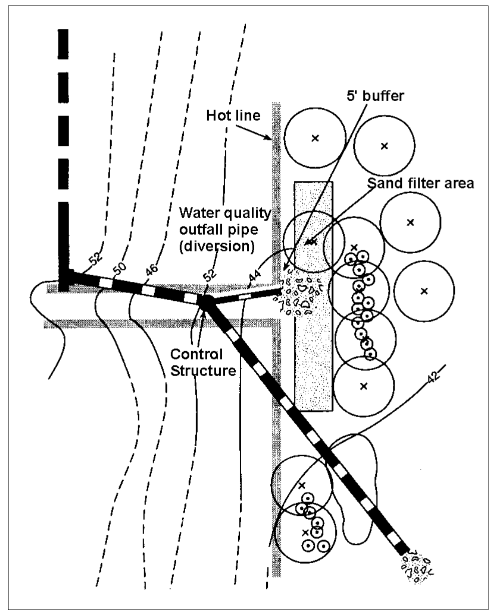


Figure C.25. Bioretention plan view (CH2M Hill, 1998).

Maintenance

Bioretention systems should be inspected on a monthly basis until plants are established. Inspections could then be conducted annually. Sediment should be removed from behind check dams when accumulations reach one-half the sump depth. See Table C.6 for maintenance details.

Table C.6. Typical maintenance activities for bioretention areas (CWP, 2001f).

Activity	Schedule
C Remulch void areas C Treat diseased trees and shrubs	as needed
C Water plants daily for two weeks	at project completion
C Inspect soil and repair eroded areas C Remove litter and debris	monthly
C Remove and replace dead and diseased plants	twice per year
C Add additional mulch C Replace tree stakes and wire	once per year

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