3 Permanent Structural Best Management Practices

3.1 Introduction

The Edwards Aquifer Rules (30 TAC Chapter 213) regulate activities having the potential for polluting the Edwards Aquifer and associated surface waters. The goals of the rules are the protection of existing and potential uses of groundwater and the maintenance of Texas Surface Water Quality Standards. The activities addressed are those that pose a threat to water quality. The rules apply in the Edwards Aquifer recharge, transition, and contributing zones, which include portions of Medina, Bexar, Comal, Kinney, Uvalde, Hays, Travis and Williamson Counties.

This chapter provides technical guidance to engineers and planners on how to meet the pollutant reduction requirements for stormwater runoff contained in the rules. In general, compliance will require the use of Best Management Practices (BMPs). BMPs include structural runoff controls, schedules of activities, prohibitions of practices, maintenance procedures, and other management practices to prevent or reduce the pollution of water in the State. BMPs not included in this document may be used with the permission of the Executive Director of the TCEQ based on objective performance monitoring studies.

Permanent BMPs are those measures that are used to control pollution from regulated activities after construction is complete. Under 30 TAC Chapter 213, permanent BMPs are implemented to reduce pollution of surface water or stormwater that originates on site or upgradient from the site and flows across the site. They must prevent pollution of surface water downgradient of the site, including pollution caused by contaminated stormwater runoff from the site. To the extent practical, BMPs must maintain flow to naturally occurring sensitive features identified in the geologic assessment, executive director review, or during excavation, blasting, or construction.

This manual identifies BMPs that are appropriate for the Edwards Aquifer region and their TSS removal efficiencies. The selected BMP or combination of BMPs must reduce the increase in total suspended solids (TSS) load associated with development by at least 80%. The manual also includes the BMP design criteria and a methodology for calculating runoff capture volume that will result in the specified removal. Finally, maintenance guidelines are included to help engineers develop plans that will ensure the long-term performance of these devices.

Single-family residential developments with less than 20% impervious cover are not required to treat stormwater discharges. Other types of development with less than 20% impervious cover, including multifamily, schools, and small businesses, may be allowed to discharge stormwater without treatment on a case by case basis as approved by the Executive Director of the TCEQ. This exemption will allow many rural residential developments (large lot) to avoid the expense of installing and maintaining structural runoff controls. Careful attention during site design, as described in Section 2.2 of this manual, can help achieve this low level of impervious cover.

Even where the impervious cover of a proposed development exceeds 20%, the use of conventional stormwater controls, such as sand filters, can be avoided by judicious use of vegetated controls (grassy swales and vegetative filter strips). For instance, stormwater runoff from roads in many rural areas are conveyed across vegetated areas and through grass lined ditches. When designed as described in this manual, these vegetated areas will provide the required reduction in TSS loads without additional treatment.

In addition to other applications, natural vegetated filter strips (buffers) can be provided around individual houses or other buildings on sites where the impervious cover is less than 20%. These areas also can provide sufficient treatment, which can eliminate or greatly reduce the need for other structural runoff treatment systems. When vegetated areas around individual houses or buildings are claimed as buffer strips to help meet the required TSS reduction, they must be shown on plats or other recorded documents that show their precise configuration along with a restriction on the use of herbicides or insecticides in these areas.

Occasionally there is a need or desire to locate stormwater treatment systems within the floodplain. Where feasible the system should be located outside of the floodplain. Structural BMPs located in the floodplain should be constructed with the wall elevation of any basins or ponds higher than the elevation of the 100 year flood at that location. The walls should be constructed of materials that will withstand expected flood velocities at that location.

Where an undeveloped tract within or associated with a preexisting development will be developed, it may be difficult to implement a BMP within the constraints of the existing drainage system. In the situation where the new development is part of a larger preexisting common plan of development, one may comply with the TSS removal requirements at these sites by treating another portion of the tract. Treatment of parking areas on the adjacent tract, rather than roof or landscape runoff is preferred. It is also necessary to have a binding agreement that lays out the responsibility for maintenance of the BMP when the site is not located on the tract being developed. Check with the appropriate TCEQ Regional Office to discuss options when this situation occurs.

The material in this chapter is derived primarily from stormwater guidance documents developed and adopted by other regulatory bodies. Primary sources include the Lower Colorado River Authority (1998), North Central Texas Council of Governments (NCTCOG, 1993), the City of Austin (1997), the California Stormwater Quality Association (2004), and Young et al. (1996).

3.2 BMP Applicability

3.2.1 Introduction

The applicability of a BMP for water quality control is dependent upon the TSS reduction required at the site and the nature of the site itself. Such factors as slope, soil type and depth, and availability of a constant supply of water, determine which BMPs may be appropriate at a site. Descriptions of BMPs with verified performance and their siting requirements are summarized in Table 3-1 and discussed in detail below. Detailed descriptions and operational requirements for proprietary BMPs should be obtained from the manufacturer. A few general statements about applicability and performance may help in the BMP selection process.

Many of the approved BMPs include basins for capturing stormwater runoff. Care should be taken to avoid siting these facilities on potential recharge features or in major drainage ways. Placement in drainage ways may require sizing of the facility to treat runoff from upgradient of the site and may require a permit from the Corps of Engineers. Information about when a permit is required is available at www.swf.usace.army.mil.

Retention/irrigation offers many advantages for achieving the required reduction in TSS load. One of the main advantages includes water conservation in an area where water demand is increasing. In addition, this practice has the highest TSS removal efficiency, which means that it requires the smallest capture volume to achieve the required reduction in TSS load.

Vegetated filter strips also perform well in certain settings such as along roads, streets and highways. Filter strips can also be used around individual buildings and other pervious areas on a site to disconnect impervious cover. The TSS removal is high enough to achieve the required 80% TSS reduction without the use of other controls. When vegetated areas around individual houses or buildings are claimed as buffer strips to help meet the required TSS reduction, they must be shown on plats or other recorded documents that show their precise configuration along with a restriction on the use of herbicides or insecticides in these areas. Effective implementation requires sufficient soil and rainfall to support the vegetation.

Extended detention basins offer some advantages for stormwater treatment. The maintenance requirements should be less than those of sand filter systems and they can be sized to provide protection of water quality leaving the site and address downstream erosion. The TSS removal efficiency of extended detention basins used alone may not be sufficient to achieve the required reduction depending on pre- and post-development land uses. When grassy swales are used to convey runoff to detention basins, the required reduction can normally be achieved.

Table 3-1 Summary of Permanent Structural BMPs with Verified Performance

Permanent Structural BMP	TSS removal efficiency (%)	Drainage Area Limit		Slope Range/Limitation		Amount of land required	Maintenance requirements
		Small (less than 10 ac)	Large (10+ acres)	2 – 6 %	20 % or less		
Retention/Irrigation	100		✡	✡		Large (irrigation)	High
Extended Detention Basin	75		1 ✡	✡		Moderate	Low to Medium
Grassy Swales	70	✡		✡		Large	Low to Medium
Vegetative Filter Strips	85	✡			✡	Large	Low
Sand Filter Systems	89	✡				Moderate	Medium
AquaLogic Cartridge System	95	✡				Moderate	High
Wet Basins	93		2 ✡	✡		Large	Medium to High
Constructed Wetlands	93		✡	✡		Large	Medium to High
Bioretention	89	✡				Small	Medium to High
Permeable Concrete	89-100	✡		✡		Small	Medium

Note: 1. Maximum drainage area for this BMP is 100 acres
2. Maximum drainage area is 1 mi^2

Sand filters have been the primary stormwater treatment system in the Austin and San Antonio areas for a number of years. The TSS removal is high enough that they can be used as stand alone systems. Maintenance requirements may be higher than some other controls; however, they may be the best choice in areas with high impervious cover and space constraints.

Wet basins and constructed wetlands should be used with caution in this area. They offer the potential for aesthetic benefits and provide habitat for wildlife; however, supplemental water may be required at most sites to sustain the permanent pool and wetland vegetation. These systems have better nutrient removal than some other BMPs, but this often translates into increased growth of algae. Consequently, frequent algae removal may be required to maintain the aesthetic qualities. Wet basins are generally preferred because their greater water depth helps control vegetation and reduce eutrophication.

Permeable concrete is a technology new to this manual that is allowed only in the contributing zone at this time. This technology refers to poured in place concrete that meets the specifications in Section 3.4.13. Pavers are still being evaluated for long-term performance and are currently not included as an approved technology.

Infiltration basins and trenches have not been included in this guidance document because of potential contamination of groundwater when used on the recharge zone and lack of appropriate site conditions in the majority of the contributing zone. Criteria that generally preclude the use of these controls in this area include the predominance of SCS type "C" and "D" soils, infiltration rates of less than 0.5 inch/hour, less than four feet of separation from bedrock, and clay content of the soil greater than 20%. In the few areas where conditions permit, these devices may be used on the contributing zone with the approval of the Executive Director of the TCEQ. Water quality capture volume and TSS removal efficiency would the same as for retention/irrigation systems.

A wide variety of proprietary stormwater treatment controls are available from a number of vendors. This manual will deal with most of them only on a generic basis and any mention of specific model names will be for illustration only and not constitute an endorsement. These types of devices are often selected (in other areas) based on their relatively small footprint compared to conventional public domain BMPs, but they may have trouble achieving a TSS reduction of 80%, when sized according to the manufacturer's normal recommendations. Guidelines are provided on appropriate sizing to achieve the TCEQ requirements when installed as a standalone BMP.

3.2.2 Retention/Irrigation

Stormwater retention practices are characterized by the capture and disposal of runoff without direct release of captured flow to receiving streams. Retention practices exhibit excellent pollutant removal but can be design and maintenance intensive. Retention/irrigation refers to the capture of stormwater runoff in a holding pond, then use of the captured water quality volume for irrigation of appropriate landscape areas. Collection of roof runoff for subsequent use (rainwater harvesting) also qualifies as a retention/irrigation practice, but should be operated and sized to provide adequate capture volume. This technology, which emphasizes beneficial use of stormwater runoff, is particularly appropriate for the Edwards Aquifer area, because of increasing demands on groundwater supplies for agricultural irrigation, urban water supply, and spring flow maintenance.

Retention/irrigation systems represent an aggressive, highly effective approach to stormwater quality control. The goal of this technology is to roughly simulate the natural (undeveloped) hydrologic regime in which the large majority of rainfall is ultimately infiltrated and/or lost to evapotranspiration. Pollutant removal effectiveness is high, accomplished through physical filtration of solids in the soil profile and uptake of nutrients by vegetation. The primary drawback of this approach is the potentially high maintenance requirements for the irrigation system, which must remain operational if this BMP is to function effectively.

Selection Criteria

- Appropriate for dryer areas where stormwater reuse can reduce demand on groundwater supplies
- Mimics natural systems by only producing discharge to surface water during large events or wet periods
- Removes 100% of the pollutants for the water quality capture volume when properly designed, constructed, operated, and maintained.

Limitations

- Requires sufficient land for irrigation
- Irrigated areas must have sufficient soil coverage to prevent groundwater contamination
- Includes mechanical components that might increase maintenance requirements

Cost

Cost of the retention facility is comparable to that of an extended detention basin. Additional costs include pumps, irrigation system, and electrical power. Many areas that are appropriate for irrigation such as golf courses would require an irrigation system anyway.

3.2.3 Extended Detention Basins

Extended detention basins are normally used to remove particulate pollutants and to reduce maximum runoff rates associated with development to their pre-development levels. The water quality benefits are the removal of sediment and buoyant materials. Furthermore, nutrients, heavy metals, toxic materials, and oxygen-demanding materials associated with the particles also are removed. The control of the maximum runoff rates serves to protect drainage channels below the device from erosion and to reduce downstream flooding. Although detention facilities designed for flood control have different design requirements than those used for water quality enhancement, it is possible to achieve these two objectives in a single facility. For example, the City of Austin has a dual-purpose facility on Great Northern Blvd.

These devices require sufficient area and hydraulic head to function properly. Detention facilities may be berm-encased areas, excavated basins, or buried tanks although the latter are not preferred in most situations (Young et al., 1996). A schematic of an extended detention basin is shown in Figure 3-1.

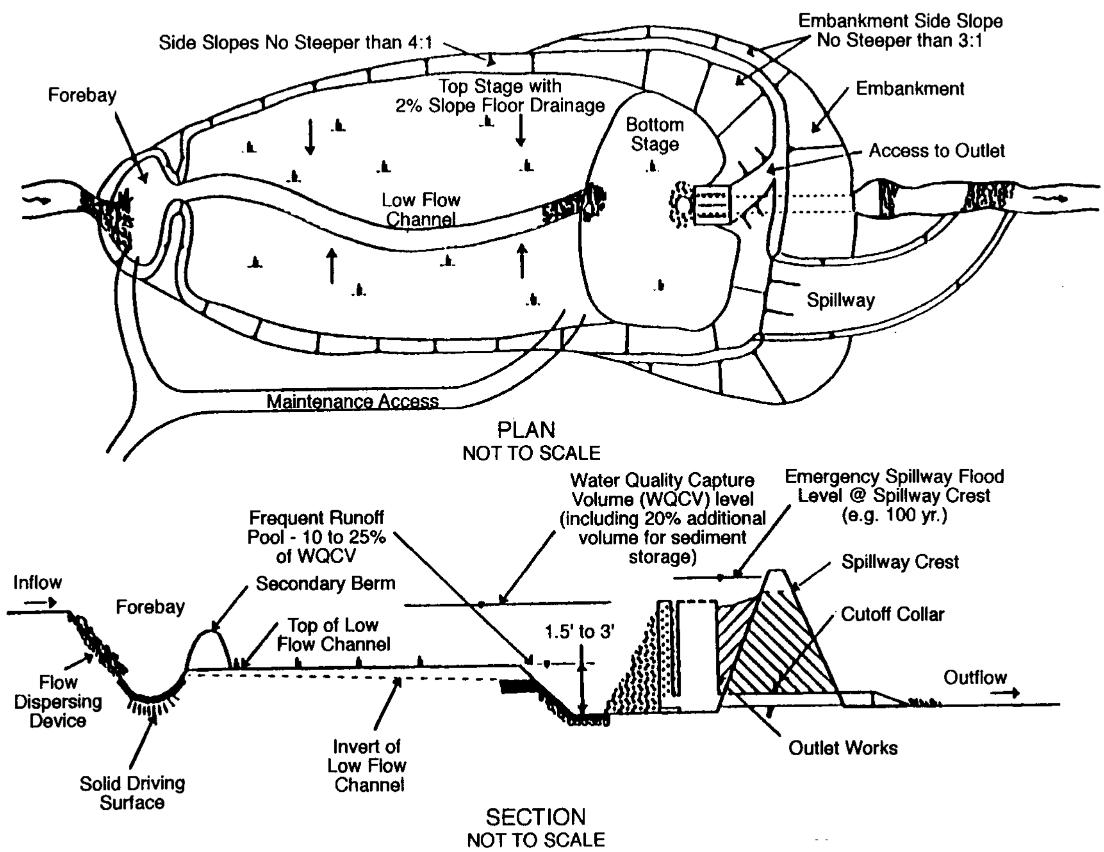


Figure 3-1 Schematic of an Extended Detention Basin (NCTCOG, 1993)

Basically, extended detention facilities are depressed basins that temporarily store a portion of stormwater runoff following a storm event. Water is controlled by means of a hydraulic control structure to restrict outlet discharge. The water quality benefits of a detention dry pond increase by extending the detention time. Substantial removal of TSS is possible if stormwater is retained for more than 24 hours. Extended detention basins normally do not have a permanent water pool between storm events. Detention facilities frequently are employed for temporary sediment control during construction, and it may be possible to retain some of these installations permanently (Young et al., 1996).

Selection Criteria (NCTCOG, 1993)

- Objective is to remove particles and associated pollutants
- Use where water availability prevents use of wet basins or where land for irrigation is not available
- Use in combination with other controls such as grassy swales and vegetated filter strips to achieve required TSS removal

Limitations (NCTCOG, 1993)

- Limitation of the diameter of the orifice may not allow use of extended detention on small watersheds (may require very small orifice that would be prone to clogging)
- Requires differential elevation between inlet and outlet
- Improper design or construction may result in a mud hole
- Drainage area less than 100 acres

Cost Considerations (Young et al., 1996)

This BMP is less expensive than sand filters, wet ponds, and created wetlands but more expensive than grassy swales and vegetated buffer strips. There are items to consider when designing an extended detention basin that can reduce the cost of construction. The largest single cost for the installation of an extended detention dry pond is the cost of excavation. Limiting the volume of excavation can therefore reduce costs substantially. This can be accomplished by utilizing natural depressions and topography as much as possible. In cases where a flood control facility already exists at the site, it may be possible to convert the existing BMP structure to provide extended detention by increasing the storage volume and modifying the outlet structure. If feasible, the conversion can be made for a fraction of the cost of constructing a new pond.

In addition to construction costs, maintenance costs also must be included when considering an extended detention dry pond. Routine maintenance costs can include money for such items as mowing, inspections, trash removal, erosion control, and nuisance control. Non-routine maintenance costs to consider include structural repairs, sediment removal, and eventual replacement of the outlet structure. The frequency of sediment removal varies from pond to pond depending on the amount of sediment in the runoff. It is estimated, however, that extended detention dry ponds would require sediment removal about every 5 to 10 years. The estimated life of outlet structures is 25 years for corrugated metal and 50 to 75 years for reinforced concrete. The total annual cost for the above maintenance requirements, for both routine and non-routine maintenance has been estimated at three to five percent of the base construction cost.

Grassy Swales

Grassy swales are vegetated channels that convey stormwater and remove pollutants by sedimentation and infiltration through soil. They require shallow slopes and soils that drain well. Pollutant removal capability is related to channel dimensions, longitudinal slope, and amount of vegetation. Optimum design of these components will increase contact time of runoff through the swale and improve pollutant removal rates.

Grassy swales are primarily stormwater conveyance systems. They can provide sufficient control under light to moderate runoff conditions, but their ability to control large storms is limited. Therefore, they are most applicable in low to moderate sloped areas or along highway medians as an alternative to ditches and curb and gutter drainage. Their performance diminishes sharply in highly urbanized settings, and they are generally not effective enough to receive construction stage runoff where high sediment loads can overwhelm the system (Schueler et al., 1992). Grassy swales can be used as a pretreatment measure for other downstream BMPs, such as extended detention basins. Enhanced grassy swales utilize check dams and wide depressions to increase runoff storage and promote greater settling of pollutants (Young et al., 1996). A cross-section of a grassy swale is presented in Figure 3-2.

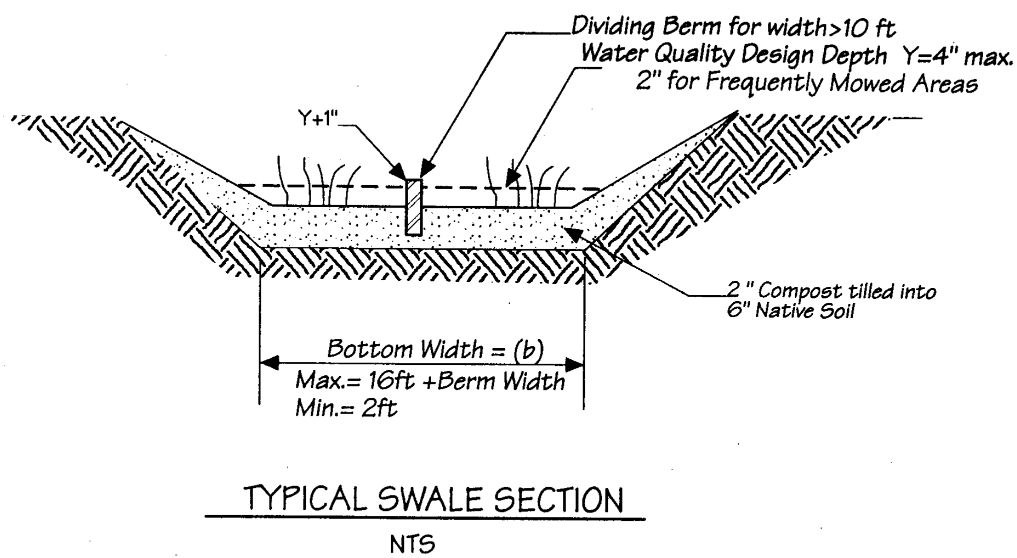


Figure 3-2 Section of a Typical Swale (King County, 1996)

Grassy swales can be more aesthetically pleasing than concrete or rock-lined drainage systems and are generally less expensive to construct and maintain. Swales can slightly reduce impervious area and reduce the pollutant accumulation and delivery associated with curbs and gutters. The disadvantages of this technique include the possibility of erosion and channelization over time, and the need for more right-of-way as compared to a storm drain system. When properly constructed, inspected, and maintained, the life expectancy of a swale is estimated to be 20 years (Young et al., 1996).

Selection Criteria (NCTCOG, 1993)

- Pretreatment for other BMPs
- Limited to treating a few acres
- Availability of water during dry periods to maintain vegetation
- Sufficient available land area

The suitability of a swale at a site will depend on land use, size of the area serviced, soil type, slope, imperviousness of the contributing watershed, and dimensions and slope of the swale system (Schueler et al., 1992). In general, swales can be used to serve areas of less than 10 acres, with slopes no greater than 5 %. The seasonal high water table should be at least 4 feet below the surface. Use of natural topographic lows is encouraged, and natural drainage courses should be regarded as significant local resources to be kept in use (Young et al., 1996).

Research in the Austin area indicates that vegetated controls are effective at removing pollutants even when dormant. Therefore, irrigation is not required to maintain growth during dry periods, but may be necessary only to prevent the vegetation from dying.

Limitations (NCTCOG, 1993)

- Can be difficult to avoid channelization
- Cannot be placed on steep slopes
- Area required may make infeasible on intensely developed areas

The topography of the site should permit the design of a channel with appropriate slope and cross-sectional area. Site topography may also dictate a need for additional structural controls since the maximum recommended longitudinal slope is about 2.5%. Flatter slopes can be used, if sufficient to provide adequate conveyance. Steep slopes increase flow velocity, decrease detention time, and may require energy dissipating and grade check. Steep slopes also can be managed using a series of check dams to terrace the swale and reduce the slope to within acceptable limits. The use of check dams with swales also promotes infiltration.

Cost Considerations

Swales are one of the least expensive stormwater treatment options and cost less to construct than curb and gutter drainage systems.

3.2.4 Vegetative Filter Strips

Filter strips, also known as vegetated buffer strips, are vegetated sections of land similar to grassy swales, except they are essentially flat with low slopes, and are designed only to accept runoff as overland sheet flow. A photograph of a vegetated buffer strip is shown in Figure 3-3. The dense vegetative cover facilitates conventional pollutant removal through detention, filtration by vegetation, and infiltration (Young et al., 1996).

Figure 3-3 Filter Strip

Filter strips cannot treat high velocity flows, and do not provide enough storage or infiltration to effectively reduce peak discharges to predevelopment levels for design storms (Schueler et al., 1992). This lack of quantity control restricts their use to relatively small tributary areas.

There are three primary applications for vegetative filter strips. One application is as an interim measure on a phased development. Another is along roadways where runoff that would otherwise discharge directly to a receiving water, passes through the filter strip before entering a conveyance system. Properly designed roadway medians and shoulders make effective vegetated filter strips. The third application is land in the natural condition adjacent to perimeter lots in subdivisions that will not drain via gravity to other BMPs.

Vegetative filter strips can be implemented as an interim BMP on a phased project where the initial level of development results in less than 20% impervious cover in a sub-watershed on the tract. The requirements for this type of installation are less stringent than those implemented as a permanent BMP and level spreaders are acceptable for distributing the flow over the strip. Once the impervious cover in a sub-watershed exceeds 20%, a permanent BMP such as a sand filter or pond must be constructed to treat the runoff.

In vegetative filter strips implemented as a permanent and final BMP, the catchment area must have sheet flow to the filter strips without the use of a level spreader. Although an inexpensive control measure, they are most useful in contributing watershed areas where peak runoff velocities are low, as they are unable to treat the high flow velocities typically associated with high impervious cover.

Successful performance of filter strips relies heavily on maintaining shallow unconcentrated flow. To avoid flow channelization and maintain performance, a filter strip should:

- Contain dense vegetation with a mix of erosion resistant, soil binding species
- Engineered vegetated filter strips should be graded to a uniform, even and a slope of less than 20%
- Natural vegetated filter strip slopes should not exceed 10%, providing that there are no flow concentrating areas on the strip.
- Laterally traverse the contributing runoff area (Schueler, 1987)

Filter strips can be used upgradient from watercourses, wetlands, or other water bodies, along toes and tops of slopes, and at outlets of other stormwater management structures. They should be incorporated into street drainage and master drainage planning (Urbonas et al., 1992). The most important criteria for selection and use of this BMP are soils, space, and slope.

Selection Criteria

- Soils and moisture are adequate to grow relatively dense vegetative stands
- Sufficient space is available
- Slope is less than 20%
- Comparable performance to more expensive structural controls

Limitations (NCTCOG, 1993)

- Can be difficult to maintain sheet flow
- Cannot be placed on steep slopes
- Area required may make infeasible on some sites

Cost Considerations

Filter strips are one of the least expensive stormwater treatment options and cost less to construct than curb and gutter drainage systems.

3.2.5 Sand Filter Systems

Sand filters consist of basins that capture stormwater runoff and then filter the runoff through a bed of sand in the floor of the facility. These BMPs can be configured as either a single basin or as separate sedimentation and filtration basins. These facilities should be installed at grade to facilitate drying out of the sand between storm events.

The objective of sand filters is to remove sediment and the pollutants from the first flush of pavement and impervious area runoff. The filtration of nutrients, organics, and coliform bacteria is enhanced by a mat of bacterial slime that develops during normal operations. One of the main advantages of sand filters is their adaptability; they can be used on areas with thin soils, high evaporation rates, low-soil infiltration rates, in limited-space areas, and where groundwater is to be protected (Young et al., 1996). A diagram of a sand filter system with separate sedimentation and filtration basins is presented in Figure 3-4.

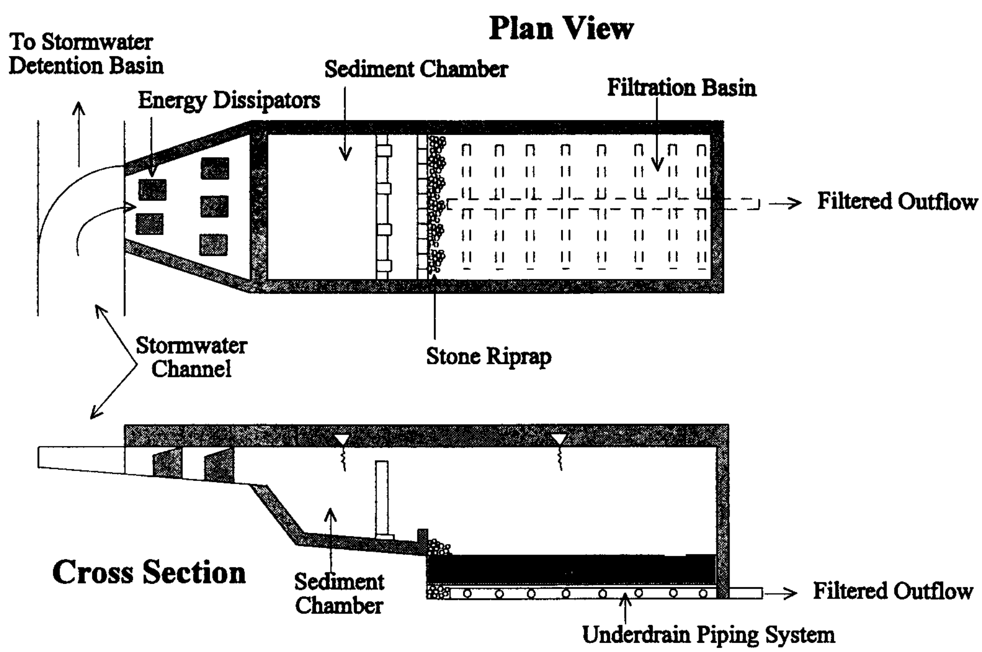


Figure 3-4 Schematic of a Sand Filter System (Young et al., 1996)

Since their original inception in Austin, Texas, thousands of intermittent sand filters have been implemented to treat stormwater runoff. There have been numerous alterations or variations in the original design as engineers in other jurisdictions have improved and adapted the technology to meet their specific requirements. Major types include the Austin Sand Filter, the District of Columbia Underground Sand Filter, the Alexandria Dry Vault Sand Filter, the Delaware Sand Filter, and peat-sand filters which are adapted to provide a sorption layer and vegetative cover to various sand filter designs (Young et al., 1996).

Selection Criteria

- Appropriate for space-limited areas
- Applicable in arid climates where wet basins and constructed wetlands are not appropriate
- High TSS removal efficiency

Limitations

- Require more maintenance than some other BMPs
- Generally require more hydraulic head to operate properly (minimum 4 feet)
- High solids loads will cause the filter to clog
- Work best for relatively small, impervious watersheds
- Filters in residential areas can present aesthetic and safety problems

Cost Considerations

Filtration systems may require less land than some other BMPs, reducing the land acquisition cost; however, the structure itself is one of the more expensive BMPs. In addition, maintenance costs can be substantial.

3.2.6 Bioretention

The bioretention best management practice (BMP) functions as a soil and plant-based filtration device that removes pollutants through a variety of physical, biological, and chemical treatment processes. These facilities normally consist of a grass buffer strip, sand bed, ponding area, organic or mulch layer, planting soil, and plants. The runoff velocity is reduced by passing over the grass buffer strip and subsequently distributed evenly along a ponding area. Exfiltration of the stored water in the bioretention area planting soil into the underlying soils occurs over a period of days. A schematic of a bioretention system is presented in Figure 3-5.

Selection Criteria

- Good choice of an onsite system serving a relatively small drainage area, since it can be incorporated into the site landscaping.

- Bioretention provides storm water treatment that enhances the quality of downstream water bodies by temporarily storing runoff in the BMP and releasing it over a period of four days to the receiving water (EPA, 1999).

- The vegetation provides shade and wind breaks, absorbs noise, and improves an area's landscape.

Limitations

- The bioretention BMP is not recommended for areas with slopes greater than 20% or where mature tree removal would be required since clogging may result, particularly if the BMP receives runoff with high sediment loads (EPA, 1999).

- Bioretention is not a suitable BMP at locations where the water table is within 6 feet of the ground surface and where the surrounding soil stratum is unstable.

- Water filtered by the soil and organic layer will normally have higher nutrient concentrations than untreated runoff.

Cost Considerations

The major costs associated with bioretention systems are the soil mixture and plants. The costs are greater than those for landscaping alone; however, the water quality benefits can be substantial. Many systems include only a few plants since pollutant uptake by the vegetation is not considered to be substantial.

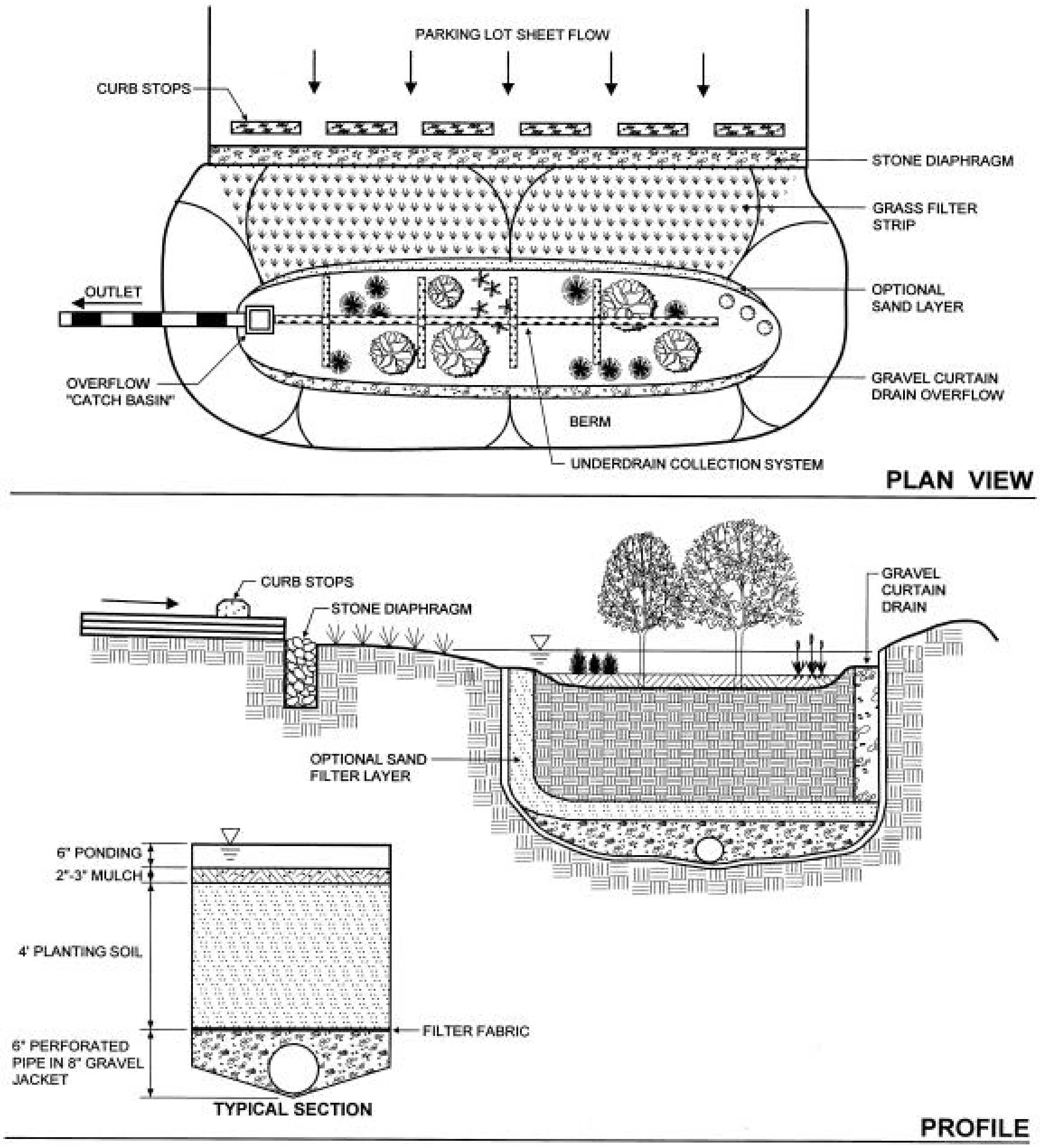


Figure 3-5 Schematic of a Bioretention Facility (MDE, 2000)

3.2.7 Wet Basins

The wet basin (pond) is a facility that removes sediment, organic nutrients, and trace metals from stormwater runoff. This is accomplished by detaining stormwater using an in-line permanent pool or pond resulting in settling of pollutants. The wet basin is similar to an extended detention basin, except that a permanent volume of water is incorporated into the design (Figure 3-6). Biological processes occurring in the permanent pool aid in reducing the amount of soluble nutrients present in the water (Schueler, 1987). Wet basins also offer flood-control benefits. Because they are designed with permanent pools, wet basins can also have recreational and aesthetic benefits (Young et al., 1996).

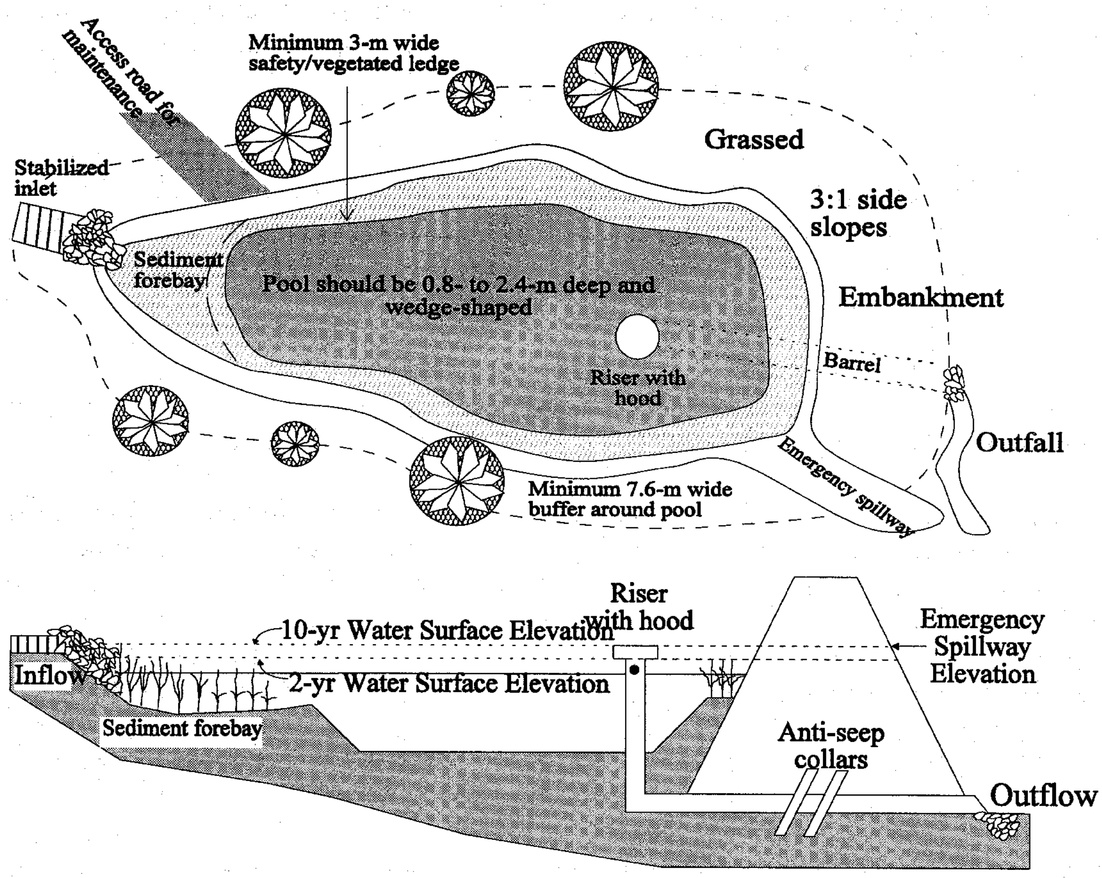


Figure 3-6 Schematic of a Wet Basin (Young et al., 1996)

Wet basins may be feasible for watershed areas greater than 10 acres and possessing a dependable water source. A drainage area of one square mile is usually the maximum drainage area where a wet pond can be installed (Schueler et al., 1992). It is most cost effective to use retention ponds in larger and more densely developed areas. An adequate source of water must be available to ensure a permanent pool throughout the entire year. If the wet pond is not properly maintained or the pond becomes stagnant, floating debris, scum, algal blooms, unpleasant odors, and insects may appear. Sediment removal from the main portion of the pond is usually necessary after the pond has been functional for about 20 years.

Soil conditions are important for the proper functioning of the wet pond. The pond is a permanent pool, and thus must be constructed such that the water must not be allowed to exfiltrate from the permanent portion of the pool. A geomembrane or clay liner will be necessary to prevent contamination of groundwater.

Selection Criteria (NCTCOG, 1993)

- Desire to achieve high level of particulate and some dissolved contaminant removal
- Ideal for large, regional tributary areas
- Multiple benefits of passive recreation (e.g., bird watching, wildlife habitat)
- Site area greater than 10 acres

Limitations (NCTCOG, 1993)

- There is concern about mosquitoes; however, stocking the pond with gambusia may eliminate this problem
- Cannot be placed on steep slopes
- Not normally used in arid regions where evapotranspiration greatly exceeds precipitation (which is most of the Edwards region)
- May be infeasible to site or retrofit in dense urban areas

Cost Considerations

Aquatic weed control (especially algae) is often required and the cost can be substantial to maintain aesthetic qualities when baseflow is low. The land requirements to achieve the necessary storage volume can also be significant. Wet basin costs are 25% to 40% greater than those reported for conventional stormwater detention. The cost of periodic sediment removal can be higher, since much of the wetland vegetation may be destroyed in the process and should be replaced.

3.2.8 Constructed Wetlands

Constructed wetlands provide physical, chemical, and biological water quality treatment of stormwater runoff. Physical treatment occurs as a result of decreasing flow velocities in the wetland, and is present in the form of evaporation, sedimentation, adsorption, and/or filtration. Chemical processes include chelation, precipitation, and chemical adsorption. Biological processes include decomposition, plant uptake and removal of nutrients, plus biological transformation and degradation. Hydrology is one of the most influential factors in pollutant removal due to its effects on sedimentation, aeration, biological transformation, and adsorption onto bottom sediments (Dorman et al., 1996). The large surface area of the bottom of the wetland encourages higher levels of adsorption, absorption, filtration, microbial transformation, and biological utilization than might normally occur in more channelized watercourses (Young, et al., 1996). A schematic diagram of a constructed wetland is shown in Figure 3-7.

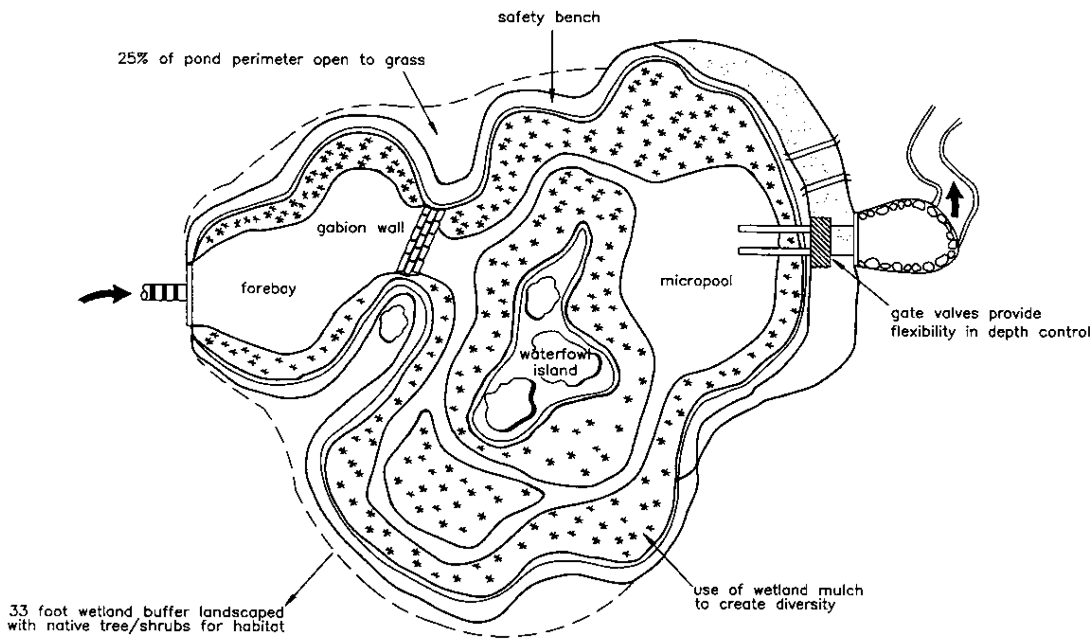


Figure 3-7 Schematic of a Constructed Wetland (Schueler et al., 1992)

Constructed wetlands offer natural aesthetic qualities, wildlife habitat, erosion control, and pollutant removal. Wetlands do have some disadvantages in that a continuous base flow is required. If not properly maintained, wetlands can accumulate salts and scum that can be flushed out by large storm flows. Sediment removal is also required to maintain the proper functioning of the wetland (Young et al., 1996).

The success of a wetland will be much more likely if some general guidelines are followed. The wetland should be designed such that a minimum amount of maintenance is required. This will be affected by the plants, animals, microbes, and hydrology. The natural surroundings, including such things as the potential energy of a stream or a flooding river, should be utilized as much as possible. It is necessary to recognize that a fully functional wetland cannot be established spontaneously. Time is required for vegetation to establish and for nutrient retention and wildlife enhancement to function efficiently. Also, the wetland should approximate a natural situation as much as possible, and unnatural attributes, such as a rectangular shape or a rigid channel, should be avoided (Young et al., 1996).

Site considerations should include the water table depth, soil/substrate, and space requirements. Because the wetland must have a source of flow, it is desirable that the water table is at or near the surface. This is not always possible. If runoff is the only source of inflow for the wetland, the water level often fluctuates and establishment of vegetation may be difficult. The soil or substrate of an artificial wetland should be loose loam to clay. A perennial baseflow must be present to sustain the artificial wetland. The presence of organic material is often helpful in increasing pollutant removal and retention. A greater amount of space is required for a wetland system than is required for a detention facility treating the same amount of area (Dorman et al., 1996).

Natural wetlands should not be used for stormwater treatment. A natural wetland is defined by examination of the soils, hydrology, and vegetation that are dominant in the area. Wetlands are characterized by the substrate being predominantly undrained hydric soil. A wetland may also be characterized by a substrate, which is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year. Wetlands also usually support hydrophytes, or plants that are adapted to aquatic and semi-aquatic environments (Young et al., 1996).

<u>Selection Criteria (NCTCOG, 1993)</u>

- Desire to achieve high level of particulate and some dissolved contaminant removal
- Ideal for large, regional tributary areas
- Multiple benefits of passive recreation (e.g., bird watching, wildlife habitat)
- Never use natural or mitigated wetlands as a treatment device

<u>Limitations (NCTCOG, 1993)</u>

- There is concern about mosquitoes; however, stocking the pond with gambusia may eliminate this problem
- Cannot be placed on steep slopes
- Will need base flow or supplemental water to maintain wetland vegetation
- May be infeasible to site or retrofit in dense urban areas
- Nutrient release may occur during winter
- Overgrowth may lead to reduced hydraulic capacity
- Agencies may claim as wetlands and restrict maintenance

There is justified concern that stormwater BMPs that create ‘wetland’ areas may become jurisdictional and subject to control the U.S. Army Corps of Engineers by way of Section

404 of the Clean Water Act. This is normally only a problem when the wetlands are not maintained according to an established maintenance program. The Corp is beginning to establish procedures whereby structural BMPs may be differentiated from jurisdictional wetlands.

Cost Considerations

The land requirements to achieve the required storage volume are generally greater than for wet basins, because of the required shallow water depths.

3.2.9 AquaLogic™ Cartridge Filter System

The desire for an alternative to sand filtration resulted in the development and implementation of the Computer Controlled Cartridge Filter System by AquaLogic™. Although cartridge filtration has been around for many years, its use in the treatment of stormwater runoff is a fairly recent innovation. Instead of sand, a permeable media in cartridge form is utilized to separate particles from the stormwater passing through it. Cartridges are designed with a specific pore size such that all particles equal to or greater than the pore size selected are removed from the stormwater stream. A schematic diagram of the Computer Controlled Cartridge Filter is presented in Figure 3-8.

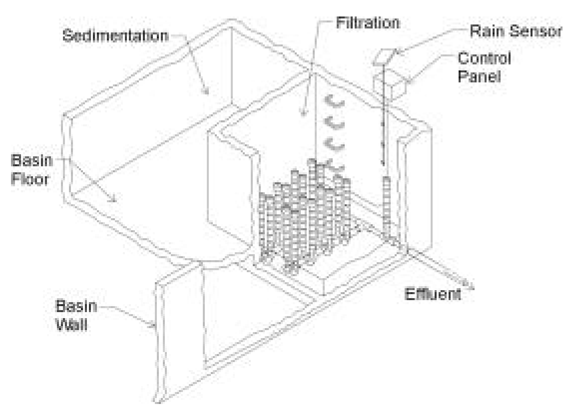


Figure 3-8 Diagram of a Cartridge Filter System

Because the media in this type of filter is in the form of a lightweight cartridge, the effort required for installation, operation and maintenance is much less than for sand based filters. Cartridge filters can be removed, replaced and discarded in a matter of minutes resulting in a new media set that is ready for another rainfall event. In addition, the space required for the Cartridge Filter is less than that required for horizontal surface loaded filters for the same contributing area.

Selection Criteria

- Appropriate for space-limited areas
- Appropriate for arid climate areas
- High TSS removal efficiency
- Appropriate for retrofits as well as new installations
- Appropriate where heavy equipment is not available for maintenance
- Appropriate for covered or buried installations

Limitations

- High solids load can cause filter to clog
- Requires primary sedimentation

Cost Considerations

Computer controlled cartridge filtration systems require less land and structure and are less costly than sand filtration systems to construct; however, frequent replacement of cartridges may be necessary.

3.2.10 Wet Vaults

Description

A wet vault is a vault with a permanent water pool, generally 3 to 10 feet deep. The vault may also have a constricted outlet that causes a temporary rise of the water level (i.e., extended detention) during each storm; however, most of these devices treat stormwater runoff as flow-through type devices. These devices are normally marketed as proprietary devices and sold as Stormceptor, Baysaver, CDS, Vortechnics and many other similar systems.

Selection Criteria

- Generally selected for space constrained installations and for retrofit of existing facilities
- Internal baffling and other design features such as bypasses may increase performance over traditional wet vaults and/or reduce the likelihood of resuspension and loss of sediments or floatables during high flows.
- Head loss is modest.

Limitations

- Concern about mosquito breeding in standing water
- The area served is limited by the capacity of the largest models.

- As the products come in standard sizes, the facilities will be oversized in many cases relative to the design treatment storm, increasing the cost.
- Do not remove dissolved pollutants.
- Discharge of dissolved pollutants may occur as accumulated organic matter (e.g., leaves) decomposes in the units.

Cost Considerations

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

- The different geometries of the several manufactured separators suggest that when comparing the costs of these systems to each other, that local conditions (e.g., groundwater levels) may affect the relative cost-effectiveness.
- Subsurface facilities are more expensive to construct than surface facilities of similar size. However, the added cost of construction is in many developments offset by the value of continued use of the land.
- Removal of sediment, trash, and other debris may be required much more frequently than in larger conventional BMPs such as ponds or sand filters.
- Subsurface facilities do not require landscaping, eliminating some types of maintenance activities.

3.2.11 Permeable Concrete

Permeable concrete may be used for light vehicle loads in parking lots or for sidewalks in the contributing zone only. Its use in the recharge zone is not approved at this time. The term describes a system comprising a load-bearing, durable concrete surface together with an underlying layered structure that temporarily stores water prior to infiltration or drainage to a controlled outlet. Attenuation of flow is provided by the storage within the underlying structure or sub base, together with appropriate flow controls. An underlying geotextile layer may permit groundwater recharge where sufficient soil depth exists, thus contributing to the restoration of the natural water cycle. Alternatively, where infiltration is inappropriate (e.g. if the groundwater vulnerability is high, or the soil type is unsuitable), the installation can be constructed with an underdrain.

Figure 3-9 Permeable Concrete in Parking Lot at a Recreational Center

Advantages

- Reduces runoff volume
- Provides stormwater treatment.
- Unobtrusive, resulting in high level of acceptability.

Limitations

There are some specific disadvantages associated with permeable pavement, which are as follows:

- Permeable concrete has serious potential workability issues when installed, because it sets rapidly and it can be difficult to achieve a uniform pour.
- Spills of hazardous materials can be difficult to clean up and may require removal of the pavement to access contaminated soils below.
- Permeable concrete can become clogged if improperly installed or maintained.
- The application should be limited to roadways with low traffic volumes, axle loads and speeds (less than 30 mph limit), car parking areas and other areas with little or no traffic. Permeable surfaces are currently not considered suitable for roads with heavy traffic, due to the risks associated with failure on

high speed roads, the safety implications of ponding, and disruption arising from reconstruction.

- ♦ Unacceptable applications include highways, airport runways, industrial waste, manufacturing or storage facilities, gas stations, car washes, and vehicle maintenance facilities.
- ♦ When using unlined, infiltration systems, there is some risk of contaminating groundwater, so a sand layer is incorporated in the base material to treat the runoff prior to discharge.
- ♦ The use of permeable pavement is restricted to gentle slopes, so car parking tends to be terraced.

3.3 TSS Removal and BMP Sizing Calculations

3.3.1 Introduction

These BMP sizing calculations have been substantially revised from the version included in the 1999 edition of the guidance document. The objectives of these revisions are to:

- Simplify the calculations
- Resolve discrepancies in the TSS load calculations
- Provide similar sized facilities as recommended in the previous manual

A major issue with the previous procedure was that the TSS load calculated based on the post development conditions often did not match the sum of the TSS loads calculated from the individual watersheds on the tract. This has now been resolved.

Under 30 TAC Chapter 213, 80% of the increase in TSS load resulting from development (over background) must be removed. This chapter sets out the methodology to be used to calculate the increase in load. The following steps explain the process used for calculating load reduction and sizing BMPs.

(1) Calculate the required TSS removal, which is based on the net increase in impervious acres.

(2) Select a BMP or combination of BMPs that are appropriate for the site.

(3) Calculate the TSS load removed by each BMP for each catchment.

(4) Calculate the percentage of runoff that must be treated to achieve the 80% removal of the increase in TSS.

(5) Calculate the capture volume or minimum flow rate required to obtain the 80% removal. This volume will be a function of the type of BMP and its TSS removal efficiency.

(6) If the selected BMP cannot achieve the required reduction, select another BMP with higher removal efficiency and repeat from Step (2), implement a second BMP in a treatment train approach, or reduce the increase in impervious cover.

3.3.2 Sizing Calculations

The annual pollutant load is the product of the annual runoff volume and the average TSS concentration associated with a particular land use. In the following calculations, it will be assumed that the TSS load of landscaped areas within the development will be the same as those areas in the undeveloped condition. **Consequently, the increase in TSS load will be solely a function of the net increase in impervious cover at the site**.

All impervious areas will be assumed to have a runoff coefficient of 0.90, while landscaped or natural areas will be assumed to have a runoff coefficient of 0.03. In the following steps, the TSS contribution will be calculated separately for each of these areas.

Impervious cover includes but is not limited to:

- Pavement including streets, driveways, parking lots, etc.
- Rooftops if not part of a rainwater harvesting system
- Compacted road base, such as that used for parking areas
- Other surfaces that prevent the infiltration of water into the soil.

Permeable concrete and pavers should considered impervious area for the purpose of TSS load reduction and BMP sizing. Roof areas connected to a rainfall harvesting system do not need to be included, but the volume of the rainfall collection system must be sufficient to retain the runoff from a 1.5 inch rainfall and the system should be managed so that it is emptied at least weekly to provide storage for subsequent storms.

When the development project includes residential tracts that will be developed subsequently, and whose future impervious level is unknown, the assumptions presented in Table 3-2 should be used. The values in this table do not include the area of the streets in the development. An amended WPAP must be submitted for TCEQ approval if the impervious cover assumptions prove to be lower than actually built on the site.

Table 3-2 Impervious Cover Assumptions for Residential Tracts

Lot Size	Assumed Impervious Cover (ft^2)
> 3 acres	10,000
Between 1 and 3 acres	7,000
Between 15,000 ft^2 and 1 acre	5,000
Between 10,000 and 15,000 ft^2	4,000
<10,000 ft^2	3,500

All the load calculations are based on Equation 3.1

Equation 3.1 $$L = A \times P \times Rv \times C \times 0.226$$

where:

L = annual pollutant load (pounds)
A = Contributing drainage area (acres)
P = Average annual precipitation (inches)
Rv = Appropriate runoff coefficient
C = Average TSS concentration (mg/L)
0.226 = units conversion factor

The average precipitation for the each county was estimated from maps prepared by Larkin and Bomar (1983) and is shown in Table 3-3. Projects that are located in two adjacent counties should use of the average of the two counties' rainfall.

Table 3-3 Average Annual Rainfall by County

County	Average Annual Precipitation (inches)
Bexar	30
Comal	33
Hays	33
Kinney	22
Medina	28
Travis	32
Uvalde	25
Williamson	32

Imperviousness is the percent, or decimal fraction, of the total site area covered by the sum of roads, parking lots, sidewalks, rooftops (unless part of a rainwater harvesting system) and other impermeable surfaces. Although runoff from roofs is often considered to be benign, monitoring in Texas indicates that roof runoff often contains constituent concentrations that exceed water quality standards (Chang and Crowley, 1993; Van

Metre and Mahler, 2003). In addition, TSS concentrations assigned to developed areas were based on stormwater monitoring of watersheds that included roofs and sidewalk areas. Consequently, roof runoff should be included in the calculations and must be captured and treated to the extent required to obtain 80% removal of the TSS load from the entire site.

Step 1: Required TSS Removal

The Edwards Rules require a reduction of 80% of the increase in TSS load resulting from the development. **The increase is assumed to occur only on the new impervious areas, with the landscaped portions of the tract contributing the same TSS load as those areas in the undeveloped condition**.

Monitoring data from the City of Austin indicates that the TSS concentration from undeveloped (or landscaped) areas is 80 mg/L, which increases to 170 mg/L when an area is paved. Consequently, the required load reduction is calculated as:

Equation 3.2 $$L_M = (0.8 \times 0.226)(A_N \times P \times 0.9 \times 170 - A_N \times P \times 0.03 \times 80)$$

Where:

L_M = Required TSS removal (pounds)
A_N = Net increase in impervious area (acres)
P = Average annual precipitation (inches)

This equation simplifies to:

Equation 3.3 $$L_M = 27.2(A_N \times P)$$

Step 2: Select an Appropriate BMP

Select a BMP or series of BMPs that will achieve at least an 80% reduction in TSS. The higher the efficiency of the BMP, the less runoff that will need to be treated to achieve the required reduction. The TSS removal efficiency for each approved BMP is shown in Table 3-4. Increasing the size of a BMP above that which is recommended in this guidance does not produce an increase in performance. This is especially true for extended detention basins, whose performance decreases when they are oversized.

Table 3-4 TSS Reduction of Selected BMPs

BMP	TSS Reduction (%)
Retention/Irrigation	100
Ext. Detention Basin	75
Grassy Swales	70
Vegetated Filter Strips	85
Sand Filters	89
AquaLogic™ Cartridge Filter System	95
Wet Basins	93
Constructed Wetlands	93
Bioretention	89
Permeable Concrete with underdrain	93
Permeable Concrete without underdrain	100
Wet Vault	Sizing Dependent

Wet Vaults

The TSS removal performance for wet vaults has been estimated on the basis of the conventional criteria used in estimating the performance of clarifiers commonly used in water and wastewater treatment facilities. The expected performance in this case is a function of the treatment flow rate and the size of the device. To get pollutant removal credit for a device of this type, it should be sized to treat, without bypass, the runoff from the tributary area for a storm having an intensity of 1.1 inches/hour. Analysis of local rainfall data indicates that 90 percent of the annual rainfall occurs at intensities below this level.

The runoff rate from the tributary area is calculated using the rational method as shown in Equation 3.4.

Equation 3.4 $$Q = CiA$$

Where: Q = flow rate in cubic feet per second
C = runoff coefficient for the tributary area
i = design rainfall intensity
A = tributary area (ac)

A runoff coefficient is calculated as the weighted average of the impervious and pervious areas. Runoff coefficient of impermeable areas is assumed to be 0.90, while that of pervious areas is assumed to be 0.03.

Calculate the overflow rate (hydraulic loading rate) for the system proposed for implementation using Equation 3.5.

Equation 3.5 $V_{OR} = Q/A$

Where:

V_{OR} = Overflow Rate (ft/s)
Q = Runoff rate calculated with Equation 3.4 (ft^3/s)
A = Water surface area in the wet vault (ft^2)

Once the overflow rate is calculated, refer to Figure 3-10 to determine the annual TSS removal for the proposed wet vault.

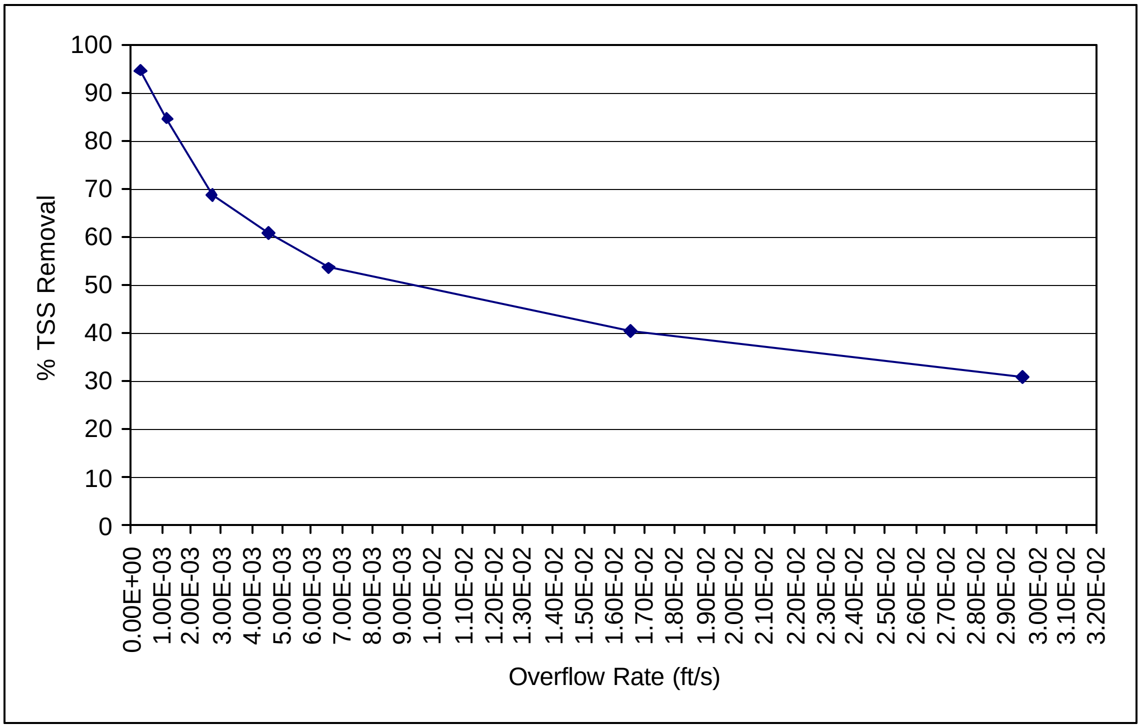


Figure 3-10 Annual TSS Removal as a Function of Overflow Rate

If the wet vault proposed for installations bypasses runoff at a rainfall intensity of less than 1.1 in/hour, then the efficiency calculated below must be reduced to account for less of the runoff being treated. This reduction in efficiency can be determined from Figure 3-11. For instance, if a device is installed that begins to bypass runoff at an intensity of 0.5 inches an hour, then only about 0.75 of the annual runoff will be treated, so the efficiency based on overflow rate must be reduced by 0.75/0.9, where 0.9 equals the fraction of runoff that would be treated if the device was sized for a 1.1 in/hour storm.

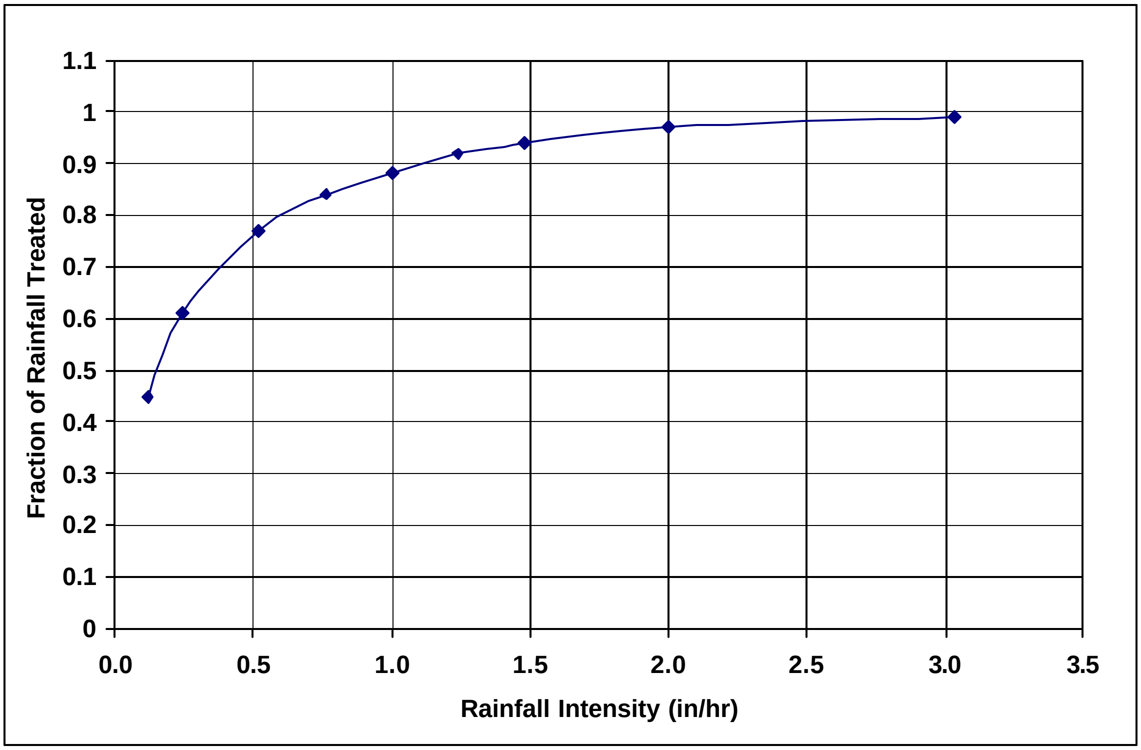


Figure 3-11 Relationship between Rainfall Intensity and Fraction Treated

BMPs in Series

BMPs can be located in series to achieve the total TSS reduction required. In general, BMPs located in series are those that individually have less than the required TSS removal efficiency. Since BMPs tend to have a minimum concentration that they produce, placing two of the same type of BMPs in series produces no additional benefits. Consequently, BMPs placed in series must be of different types to achieve the overall efficiency shown below.

The efficiency of each subsequent control would be expected to be less since the sediment that is most easily removed is captured in the first control; consequently, Equation 3.6 will be used to calculate total efficiency of BMPs in series:

Equation 3.6 $$E_{Tot} = [1 - ((1 - E_1) \times (1 - 0.5E_2) \times (1 - 0.25E_3))] \times 100$$

Where:

E_{Tot} = Total TSS removal efficiency of BMPs in series (%)
E_1 = Removal efficiency of first BMP (decimal fraction)
E_2 = Removal efficiency of second BMP (decimal fraction)
E_3 = Removal efficiency of third BMP (decimal fraction)

Step 3: Calculate TSS Load Removed by BMPs

The following section describes how to determine the load removed by a proposed BMP(s). The load removed depends on the amount of TSS entering the BMP(s) and its effectiveness.

The load entering each BMP is calculated from the sum of the contribution of the impervious and pervious areas with their respective stormwater concentrations for the BMP catchment area. This calculation assumes that no runoff bypasses the treatment facility.

Equation 3.7 $L_R =$ (BMP efficiency) x 0.226 x P x (A_I x 0.9 x 170 mg/L + A_P x 0.03 x 80 mg/L)

Which simplifies to:

Equation 3.8 L_R = (BMP efficiency) x P x (A_I x 34.6 + A_P x 0.54)

Where:

L_R = Load removed by BMP
BMP efficiency = TSS removal efficiency (expressed as a decimal fraction from Table 3-4)
A_I = impervious tributary area to the BMP (ac)
A_P = pervious tributary area to the BMP (ac)
P = average annual precipitation (in., Table 3-3)

Step 4: Calculate Fraction of Annual Runoff to be Treated

Based on the load reduction calculated above for each of the BMPs installed at the site and the required load reduction, calculate the fraction of annual runoff to be treated using Equation 3.9. This calculation assumes a constant concentration of TSS in the runoff.

Equation 3.9

$$F = \frac{L_M}{\sum L_R}$$

Where:

F = Fraction of the annual rainfall treated by the BMP
L_R = Load removed for each BMP from Step 3 calculation (pounds)
L_M = Required load reduction from Step 1 (pounds)

The value for *F* must be less than 1.0, since a value greater than that indicates that more runoff than would occur in an average year must be treated and that is infeasible. If a value for *F* of more than 1.0 is calculated a more efficient BMP must be selected for the site.

Step 5: Calculate Capture Volume or Minimum Flow Rate

This step relates the statistical properties of storm size and flow rate in the regulated area to the total volume of runoff. These calculations depend on whether the BMP is a capture and treat device, such as a sand filter system, or a flow through BMP such as a swale or wet vault.

For flow through type devices (swales and wet vaults), the size is calculated using a rainfall intensity of 1.1 inches/hour. Facilities not able to treat the runoff rate corresponding to this intensity must reduce the assumed removal efficiency using Figure 3-11.

Capture volume for capture and treat devices is developed from Table 3-5, which relates rainfall depth to the percentage of annual rainfall that occurs in storms less than or equal to this depth (i.e., 100% of the annual rainfall occurs in storms of 4 inches or less on average, while 78% of the annual runoff occurs in storms of an inch or less). For BMPs designed to capture and treat the runoff, the value, F, calculated in Step 4 is used to enter Table 3-5 and find the rainfall depth associated with this fraction.

Table 3-5 Relationship between Fraction of Annual Rainfall and Rainfall Depth (in)

F	Rainfall Depth	F	Rainfall Depth	F	Rainfall Depth	F	Rainfall Depth
1.00	4.00	0.80	1.08	0.60	0.58	0.40	0.29
0.99	3.66	0.79	1.04	0.59	0.56	0.39	0.28
0.98	3.33	0.78	1.00	0.58	0.54	0.38	0.27
0.97	3.00	0.77	0.97	0.57	0.52	0.37	0.25
0.96	2.80	0.76	0.94	0.56	0.50	0.36	0.24
0.95	2.60	0.75	0.92	0.55	0.49	0.35	0.23
0.94	2.40	0.74	0.89	0.54	0.47	0.34	0.23
0.93	2.20	0.73	0.86	0.53	0.46	0.33	0.22
0.92	2.00	0.72	0.83	0.52	0.45	0.32	0.21
0.91	1.80	0.71	0.80	0.51	0.44	0.31	0.20
0.90	1.70	0.70	0.78	0.50	0.42	0.30	0.19
0.89	1.60	0.69	0.75	0.49	0.41	0.29	0.18
0.88	1.50	0.68	0.73	0.48	0.40	0.28	0.18
0.87	1.44	0.67	0.71	0.47	0.38	0.27	0.17
0.86	1.38	0.66	0.69	0.46	0.37	0.26	0.16
0.85	1.32	0.65	0.67	0.45	0.36	0.25	0.15
0.84	1.26	0.64	0.66	0.44	0.34		
0.83	1.20	0.63	0.64	0.43	0.33		
0.82	1.16	0.62	0.62	0.42	0.32		
0.81	1.12	0.61	0.60	0.41	0.31		
0.80	1.08	0.60	0.58	0.40	0.29		

Once the appropriate rainfall depth has been determined from Table 3-5, the water quality volume for each BMP can be calculated from:

Equation 3.10 **WQV = Rainfall depth x Runoff Coefficient x Area**

Where the rainfall depth is determined from Table 3-5, the runoff coefficient for the tributary area from Figure 3-12 or calculated using Equation 3.11, and the area is the portion of site contributing runoff to the BMP.

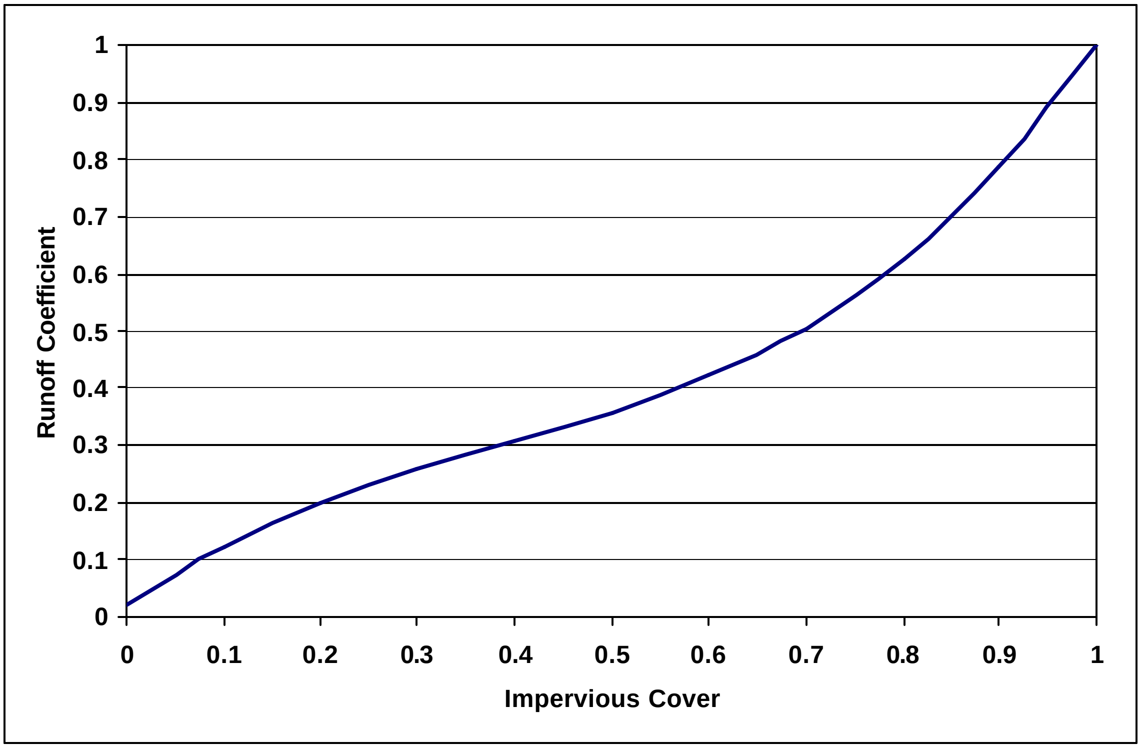


Figure 3-12 Relationship between Runoff Coefficient and Impervious Cover

Equation 3.11 Runoff Coefficient = $1.72(IC)^3 - 1.97(IC)^2 + 1.23(IC) + 0.02$

Where: IC = fraction of impervious cover

3.3.3 Offsite Drainage

Offsite drainage should be conveyed around or through the site without entering a BMP. Occasionally, it is not feasible to prevent off-site runoff from entering a BMP on the tract. When this occurs the size of the BMP should be increased to account for the additional runoff generated by this area.

To properly size the BMP to account for this volume, all the calculations are performed based on the site characteristics alone until Equation 3.9 is reached. At that point the runoff coefficient is determined based only on the impervious cover of the site, but then it is multiplied times the entire tributary area (including offsite areas) to determine capture volume. In this manner adding offsite drainage always results in a larger pond than if runoff from the site alone were treated.

When the offsite contributing area is substantial, it is worth seeking approval from TCEQ for achieving the required TSS reduction by including solids removed from offsite drainage. Approval may be granted on a case by case basis, depending on the status of the adjacent tract (is it developed, was it built under current TCEQ rules, etc.).

3.4 BMP Design Criteria

The following sections lay out the general design requirements for each of the approved BMPs. It is imperative that the contractor selected to construct these facilities is aware of these requirements and understands the importance of all elements included in the original design. All too often, the engineer responsible for developing the BMP design is not involved with the construction phase of the project and the facility as built does not function as designed. It is in the best interest of the facility owner and operator to ensure that these facilities are properly constructed to improve performance, minimize maintenance, and avoid having to remove and replace the facility.

The primary purpose of BMP implementation in this area is to prevent degradation of groundwater, so the stormwater conveyance system to BMPs should be designed with this as a major objective. Consequently, stormwater conveyance should not occur in channels where fractures or other openings would allow runoff to enter the aquifer without treatment. Appropriate conveyance structures include reinforced concrete pipe, concrete lined channels, and vegetated channels or swales. If vegetated channels are incorporated in the design, they must have at least 6 inches of topsoil stabilized with appropriate vegetation.

All pond bottoms, side slopes, and earthen embankments should be compacted to 95% of maximum density. Side slopes for earthen embankments should not exceed three to one (3H:1V). Rock slopes may exceed these limits if a geotechnical report warrants a deviation. Actual field conditions may override the geotechnical report. Expansion joints on freestanding walls should have watertight seals as needed. Earthen pond bottoms should have slopes of at least 0.5% toward the outlet.

3.4.1 General Requirements for Maintenance Access

(10) If fences, such as chain link, solid wood, masonry, stone or wrought iron, are used to control access to water quality facilities, gates, a minimum of 12 feet wide, should be provided to allow access of maintenance equipment.

(11) Water quality facilities should have a permanent maintenance equipment access ramp whose slope should not exceed four to one (4H:1V). The minimum width is 12 feet for a ramp into each basin of the facilities if the basin area is greater than 5000 ft^2. For smaller facilities, the ramp should be at least 6 feet wide.

(12) Drainage or drainage access easements on side lot lines should be located adjacent to a property line where feasible and not centered on a property line.

(13) Access/drainage easements and access drives should be provided for detention, retention, and water quality facilities. Access drives should be a minimum of 12 feet wide and not exceed 15% grade. Grade changes and alignment should be considered in the design of the access drive. A turning radius not less than 50 feet should be included for horizontal alignments. Grade changes should not exceed 12% for vertical alignments. The access drive should include a means for equipment to turn around when located more than 200 feet from a paved roadway. Access drives should be cleared, graded and stabilized.

(14) Access drives should be provided for area inlets and headwalls when access is proposed between single family lots or when access from any other location exceeds 20% grade. Access drives should be a minimum of 12 feet wide and not exceed 20% grade. Access drives should be cleared, graded, stabilized, and have sufficient load bearing capacity to support heavy equipment.

(15) Detention, retention, and water quality facilities should have a staging area for maintenance activities of not less than 800 square feet if the storage volume of the pond exceeds 2,000 cubic feet. The staging area should be located adjacent to the water quality facility and access drive, and be within an access easement. The staging area should be cleared, graded and revegetated, with slopes not exceeding 10% in any direction.

3.4.2 Basin Lining Requirements

Impermeable liners should be used for water quality basins (retention, extended detention, sand filters, wet ponds and constructed wetlands) located over the recharge zone and in areas with the potential for groundwater contamination. Impermeable liners may be clay, concrete or geomembrane. If geomembrane is used, suitable geotextile fabric should be placed on the top and bottom of the membrane for puncture protection and the liners covered with a minimum of 6 inches of compacted topsoil. The topsoil should be stabilized with appropriate vegetation. Clay liners should meet the specifications in Table 3-6 and have a minimum thickness of 12 inches.

Table 3-6 Clay Liner Specifications (COA, 2004)

Property	Test Method	Unit	Specification
Permeability	ASTM D-2434	cm/sec	1×10^{-6}
Plasticity Index of Clay	ASTM D-423 & D-424	%	Not less than 15
Liquid Limit of Clay	ASTM D-2216	%	Not less than 30
Clay Particles Passing	ASTM D-422	%	Not less than 30
Clay Compaction	ASTM D-2216	%	95% of Standard Proctor Density

If a geomembrane liner is used it should have a minimum thickness of 30 mils and be ultraviolet resistant. The geotextile fabric (for protection of geomembrane) should be nonwoven geotextile fabric and meet the specifications in Table 3-7.

Table 3-7 Geotextile Fabric Specifications (COA, 2004)

Property	**Test Method**	**Unit**	**Specification (min)**
Unit Weight		oz/yd^2	8
Filtration Rate		in/sec	0.08
Puncture Strength	ASTM D-751*	lb	125
Mullen Burst Strength	ASTM D-751	psi	400
Tensile Strength	ASTM D-1682	lb	200
Equiv. Opening Size	US Standard Sieve	No.	80

*modified

Installation methods for geomembrane liners vary according to the site requirements. Figure 3-13 shows a typical installation on an earthen slope with the top of the liner keyed in above the maximum water level of the basin. Figure 3-14 presents an example of geomembrane liner attached to the exterior of a concrete or rock wall. The "liquid membrane" shown in the figure is a hot fluid-applied, rubberized asphalt typically used for waterproofing and roofing applications, such as Hydrotech 6125 or equivalent.

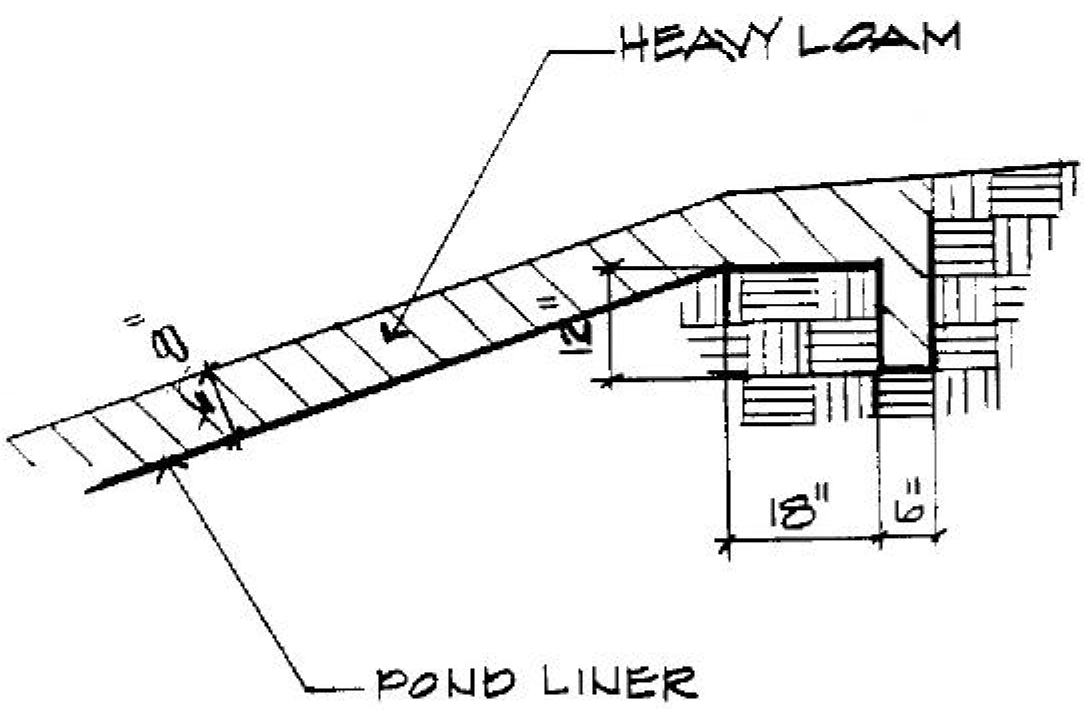


Figure 3-13 Example of Liner Installation on Earthen Slope (Courtesy COA)

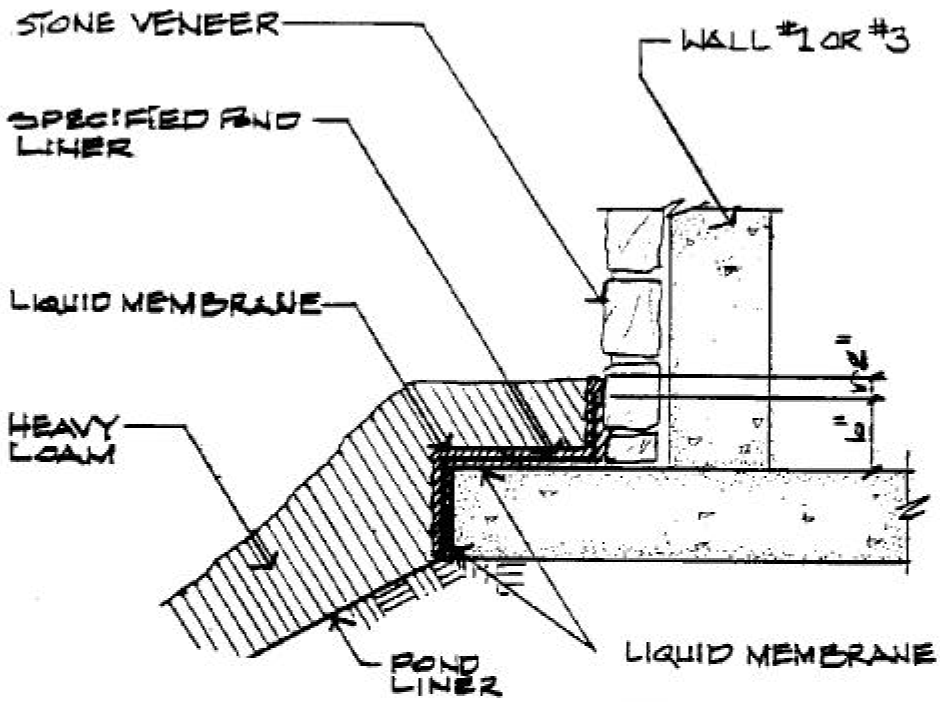


Figure 3-14 Pond Liner Attached to Exterior of Rock Wall (Courtesy COA)

Figure 3-15 presents an installation where the liner is installed prior to concrete forming. The liner is installed and keyed in above the maximum water level. The excavation is backfilled before forming and pouring the concrete.

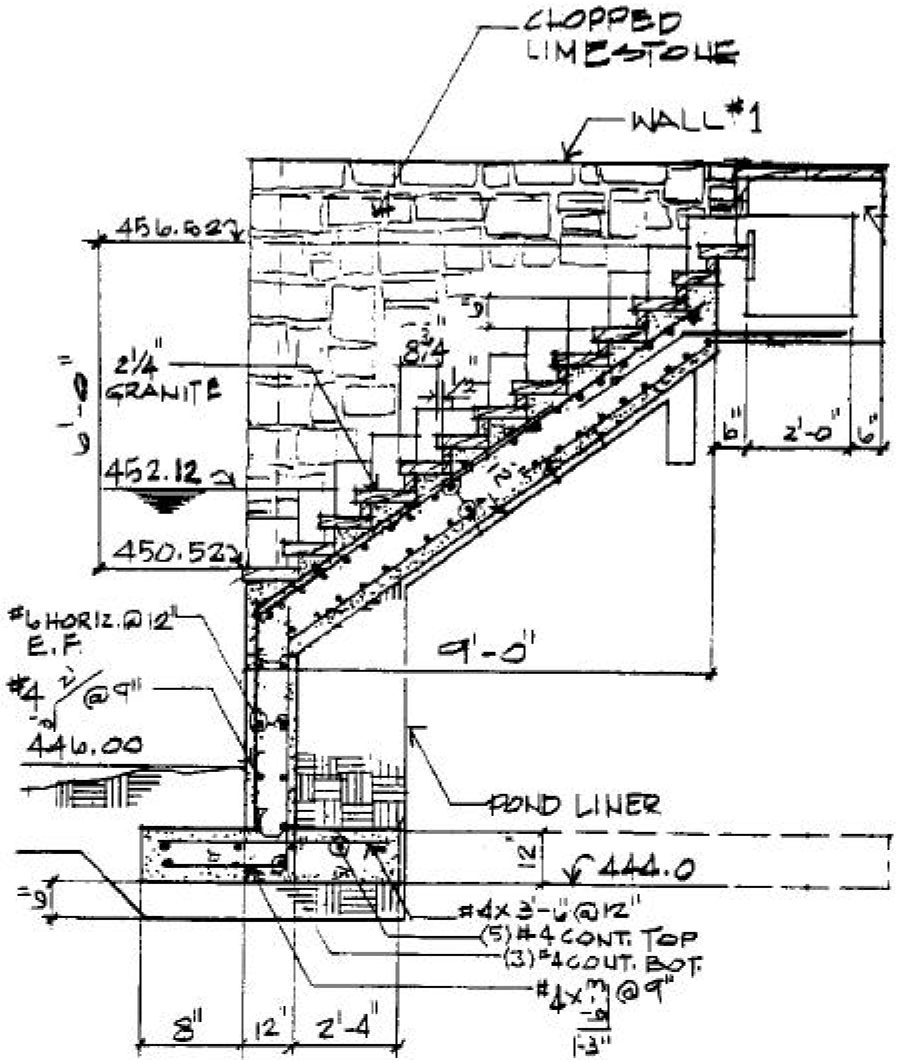


Figure 3-15 Example of Liner Installed Prior to Concrete Pour (Courtesy COA)

Water quality basins constructed on the contributing zone need not have impermeable liners, but should be built with appropriate materials to achieve desired residence times and to maintain structural integrity.

3.4.3 Retention/Irrigation

Capture of stormwater in retention/irrigation systems can be accomplished in virtually any kind of runoff storage facility ranging from fully dry, concrete-lined to vegetated with a permanent pool; thus, design of the storage system can be quite flexible and allows for excellent aesthetic appeal. The pump and wet well system should be automated with a rainfall or soil moisture sensor to allow for irrigation only during periods when required infiltration rates can be realized.

Design Criteria

(1) *Runoff Storage Facility Configuration and Sizing* – Design of the runoff storage facility is flexible as long as an appropriate pump and wet well system can be accommodated. The required water quality volume should be calculated as discussed in Section 3.3. The water quality volume should be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities. A fixed vertical sediment depth marker should be installed in the retention basin to indicate when sediment accumulation equals 20% of the water quality volume and sediment removal is required.

(2) *Pump and Wet Well System* – A reliable pump, wet well, and rainfall or soil moisture sensor system should be used to distribute the water quality volume. System specifications must be approved by the TCEQ. These systems should be similar to those used for wastewater effluent irrigation, which are commonly used in areas where "no discharge" wastewater treatment plant permits are issued.

(3) *Basin Lining* – The basin lining should conform to the specifications described in Section 3.4.2.

(4) *Basin Inlet* – The inlets to the retention basin should be designed to prevent erosion of the soil and liner. Rock riprap or other erosion prevention systems must be placed at the basin inlet to reduce velocities to less than 3 feet per second.

(5) *Pumps* – A pump capable of delivering 100% of the design capacity should be provided. Valves should be located outside the wet well on the discharge side of each pump to isolate the pumps for maintenance and for throttling if necessary. Pumps should be selected to operate within 20% of their best operating efficiency. A high/low-pressure pump shut off system (in case of line clogging or breaking) should be installed in the pump discharge piping.

(6) *Alarms* – An alarm system should be provided consisting of a red light located at a height of at least 5 feet above the ground level at the wet well. The alarm should activate when: (1) the high water level has been maintained in excess of 72 hours, (2) the water level is below the shutoff point and the pump has not turned off, or (3) the high/low-pressure pump shut off switch has been activated. The alarm should be vandal and weather resistant. A sign should be placed at the wet well clearly displaying the name and phone number of a responsible party that may be contacted if the alarm is activated.

(7) *Wet Well* – A separate wet well outside of the basin should be provided for the pump. The wet well should be constructed of precast or cast in place concrete. Complete access to the pump and other internal components of the wet well for maintenance should be provided through a lockable cover. An isolation valve to prevent flow from the retention basin to the wet well during maintenance activities is recommended. The wet well and pump must be designed to be low enough to completely evacuate the retention pond.

(8) *Intake Riser* – Prior to entering the wet well, stormwater should pass through an appropriate intake riser with a screen to reduce the potential for clogging of distribution pipes and sprinklers by larger debris - e.g. cups, cans, sticks.

(9) *Splitter Box* – The basin should be designed as an offline facility, with a splitter structure used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the 25-year storm event while providing at least 1.0 foot of freeboard along basin side slopes.

(10) *Detention Time* – The irrigation schedule should allow for complete drawdown of the water quality volume within 72 hours. Irrigation should not begin within 12 hours of the end of rainfall so that direct storm runoff has ceased and soils are not saturated. Consequently, the length of the active irrigation period is 60 hours. The irrigation should include a cycling factor of ½, so that each portion of the area will be irrigated for only 30 hours during the total of 60 hours allowed for disposal of the water quality volume. Continuous application on any area should not exceed 2-hours. Division of the irrigation area into two or more sections such that irrigation occurs alternately in each section is an acceptable way to meet this recommendation. Irrigation also should not occur during subsequent rainfall events.

(11) *Irrigation System* – All irrigation system distribution and lateral piping (i.e. from the pumps to the spray heads) should be Schedule 80 PVC. All pipes and electrical bundles passing beneath driveways or paved areas should be sleeved with PVC Class 200 pipe with solvent welded joints. Sleeve diameter must equal twice that of the pipe or electrical bundle. All pipes and valves should be marked to indicate that they contain non-potable water. All piping must be buried to protect it from weather, vandalism, and vehicular traffic. Velocities in all pipelines should be sufficient to prevent settling of solids.

(12) *Valves* – All valves should be designed specifically for sediment bearing water, and be of appropriate design for the intended purpose. All remote control, gate, and quick coupling valves should be located in ten-inch or larger plastic valve boxes.

(13) *Sprinklers* – All sprinkler heads should have full or partial circle rotor pop-up heads and must be capable of delivering the required rate of irrigation over the designated area in a uniform manner. Irrigation must not occur beyond the limits of the designated irrigation area. Partial circle sprinkler heads can be used as necessary to prevent irrigation beyond the designated limits. Sprinkler heads should be capable of passing solids that may pass through the intake. Sprinkler heads should be flush mounted and encased within a 2' x 2' concrete housing capable of protecting the head from mowing and service equipment. An example is presented in Figure 3-16.

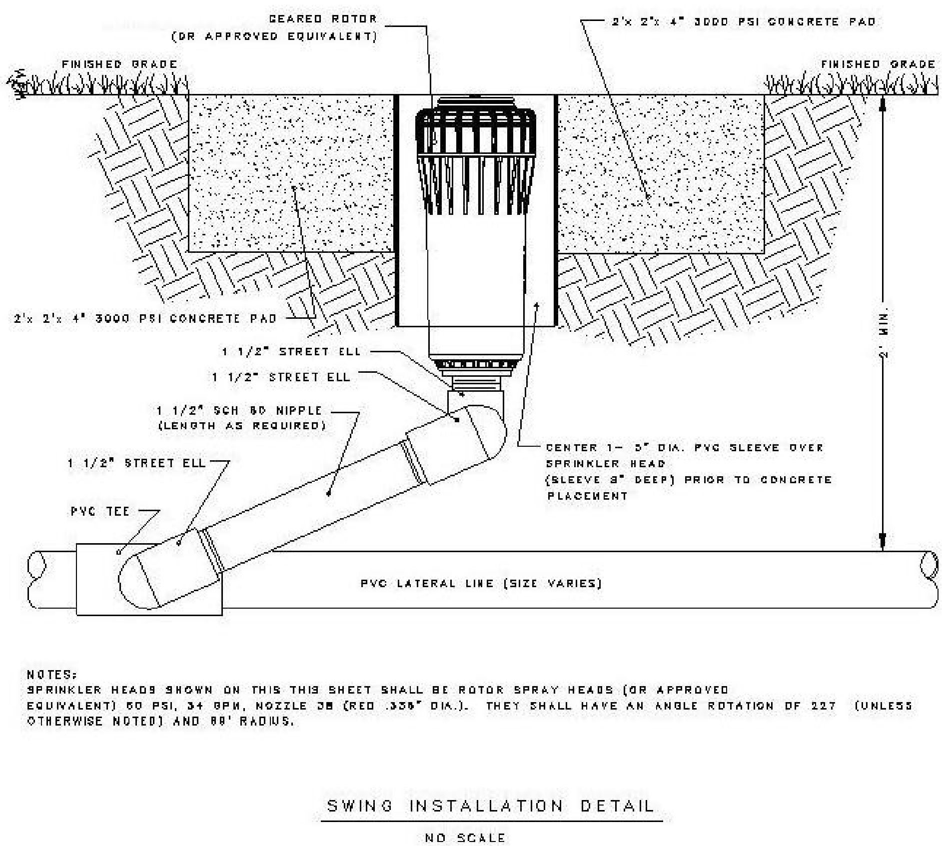


Figure 3-16 Sprinkler Head Detail

(14) *Irrigation Site Criteria* – The area selected for irrigation must be pervious, on slopes of less than 10%. A geological assessment is required for proposed irrigation areas to assure that there is a minimum of 12 inches of soil cover and no geologic/sensitive features that could allow the water to directly enter the aquifer. Rocky soils are acceptable for irrigation; however, the coarse material (diameter greater than 0.5 inches) should not account for more than 30% of the soil volume. Optimum sites for irrigation include recreational and greenbelt areas as well as landscaping in commercial developments. The stormwater irrigation area should be distinct and different from any areas used for wastewater effluent irrigation. Finally, the area designated for irrigation should have at least a 100-foot buffer from wells, septic systems, natural wetlands, and streams.

(15) *Irrigation Area* – The irrigation rate must be low enough so that the irrigation does not produce any surface runoff; consequently, the irrigation rate may not exceed the permeability of the soil. The minimum required irrigation area should be calculated using the following formula:

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

where:

A = area required for irrigation (ft^2)
V = water quality volume (ft^3)
T = period of active irrigation (30 hr)
r = Permeability (in/hr)

The permeability of the soils in the area proposed for irrigation should be determined using a double ring infiltrometer (ASTM D 3385-94) or from county soil surveys prepared by the Natural Resource Conservation Service (previously known as the Soil Conservation Service). If a range of permeabilities is reported, the average value should be used in the calculation. If no permeability data is available, a value of 0.1 inches/hour should be assumed.

It should be noted that the minimum area requires intermittent irrigation over a period of 60 hours at low rates to use the entire water quality volume. This intensive irrigation may be harmful to vegetation that is not adapted to long periods of wet conditions. In practice, a much larger irrigation area will provide better use of the retained water and promote a healthy landscape. Irrigation must not occur on land with slopes greater than 10 percent.

(16) *Safety Considerations* – Safety is provided either by fencing of the facility or by managing the contours of the pond to eliminate dropoffs and other hazards. Earthen side slopes should not exceed 3:1 (H:V) and should terminate on a flat safety bench area. Landscaping can be used to impede access to the facility. If the facility is fenced, gates should be provided to allow access for inspections and maintenance.

(17) *Vegetation* – The irrigation area should have native vegetation or be restored or re-established with native vegetation, unless approved by the Executive Director. These areas should not receive any fertilizers, pesticides, or herbicides. Vegetation on the pond embankments should be mowed as appropriate to prevent the establishment of woody vegetation.

3.4.4 Extended Detention Basins

Extended detention (ED) facilities capture and temporarily detain the water quality volume. They are intended to serve primarily as settling basins for the solids fraction and as a means of limiting downstream erosion by controlling peak flow rates during erosive events. Extended detention facilities may be constructed either online or offline.

Enhanced extended detention basins are designed to prevent clogging of the outflow structure and re-suspension of captured sediment; and to provide enhanced dissolved pollutant removal performance. The enhanced extended detention design typically incorporates a sediment forebay near the inlet, a micropool near the outlet, and a non-clogging outflow structure, such as a notched weir or orifice protected by a trash rack, or a perforated riser pipe protected by riprap.

Extended detention ponds are generally best suited to drainage areas greater than 5 acres, since the outlet orifice becomes prone to clogging for small water quality volumes. In addition, extended detention basins tend to accumulate debris deposits rapidly, making regular maintenance necessary to minimize aesthetic and performance problems. Extended detention facilities can readily be combined with flood and erosion control detention facilities by providing additional storage above the water quality volume (e.g., City of Austin facility on Great Northern Blvd).

Design Criteria

Estimating the appropriate dimensions of a BMP facility is largely based on a trial and error process in which the designer tries to fit the required BMP volume so that it works well with the site. Each site has its own unique limiting factors. Some constraints other than the existing topography include, but are not limited to, the location of existing and proposed utilities, depth to bedrock, and location and number of existing trees. The designer can analyze possible basin configurations by varying the surface area and depth and then determining the corresponding available storage (Young et al., 1996).

In order to enhance the effectiveness of BMP basins, the dimensions of the basin must be sized appropriately. Merely providing the required storage volume will not ensure maximum constituent removal. By effectively configuring the basin, the designer will create a long flow path, promote the establishment of low velocities, and avoid having stagnant areas of the basin. To promote settling and to attain an appealing environment, the design of BMP basin should consider the length to width ratio, cross-sectional areas, basin slopes and pond configuration, and aesthetics (Young et al., 1996).

(1) *Facility Sizing* – The required water quality volume is calculated as discussed in Section 3.3. This water quality volume should be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities. If a micropool is included in the design, it should be able to store 15 to 25% of the capture volume. The larger end of this range is generally preferred to prevent the micropool from drying out during drought periods. A fixed vertical sediment depth marker should be installed in the retention basin to indicate when sediment accumulation equals 20% of the water quality volume and sediment removal is required.

(2) *Basin Configuration* – A high aspect ratio improves the performance of detention basins; consequently, the outlets should be placed to maximize the flowpath through the facility. The ratio of flowpath length to width from the inlet to the outlet should be at least 2:1 (L:W). The flowpath length is defined as the distance from the inlet to the outlet as measured at the surface. The width is defined as the mean width of the basin. Basin depths optimally range from 2 to 5 feet. The basin should include a sediment forebay to provide the opportunity for larger particles to settle out. The forebay volume should be about 10% of the water quality volume and be provided with a fixed vertical sediment depth marker to measure sediment accumulation.

Both conventional and enhanced ED ponds should be designed with a dual stage configuration as shown in Figure 3-17 and Figure 3-18. Stage I is intended to serve primarily as a sediment forebay for gross particulates. Stage II is generally planted with vegetation adaptable to periodic inundation and may contain a permanent micropool for enhanced extended detention. Stage II is intended to provide additional sedimentation and some nutrient removal with the enhanced ED pond design. The design depth of Stage I should be 2.0 to 5.0 feet. A stabilized low flow channel is required to convey low flows through Stage I to Stage II. Rock riprap should be utilized to reduce velocities and spread the flow into the Stage II pond. The channel should maintain a longitudinal slope of 2 - 5%. The lateral slope across Stage I toward the low flow channel should be 1.0 - 1.5%. The bottom of Stage II should be 1.5 to 3.0 feet lower than the bottom of Stage I. The extended detention basin is optimally designed to have a gradual expansion from the inlet toward the middle of the facility and a gradual contraction toward the basin outfall.

(3) *Pond Side Slopes* – Side slopes of the pond should be 3:1 (H:V) or flatter for grass stabilized slopes. Slopes steeper than 3:1 (H:V) must be stabilized with an appropriate slope stabilization practice.

(4) *Basin Lining* – Basins must be constructed to prevent possible contamination of groundwater below the facility. Basin linings should conform to guidelines contained in Section 3.4.2.

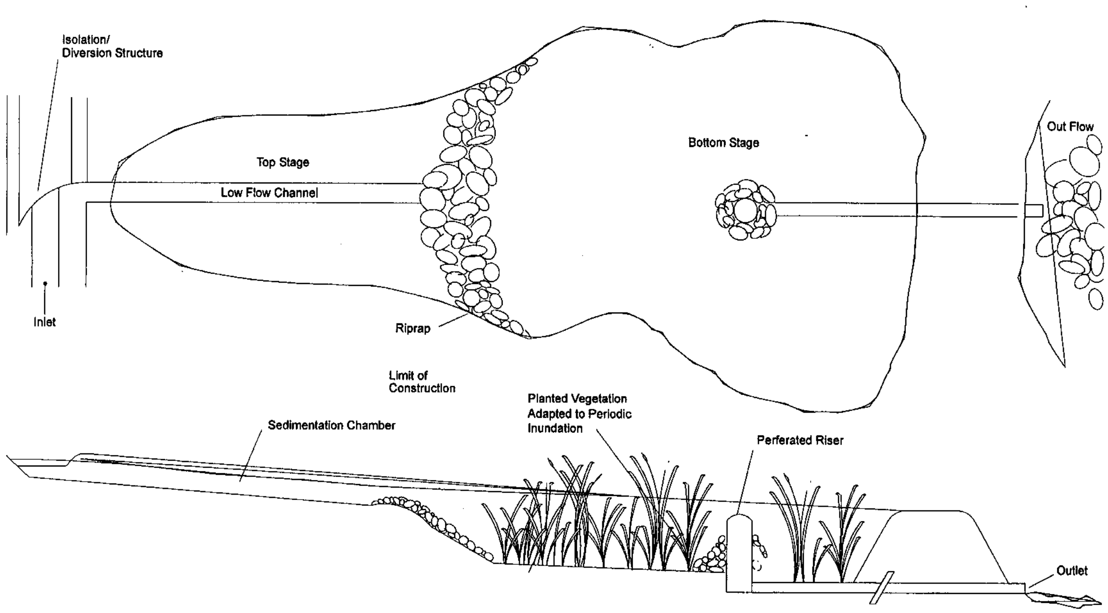


Figure 3-17 Schematic of a two stage Extended Detention Basin (LCRA, 1998)

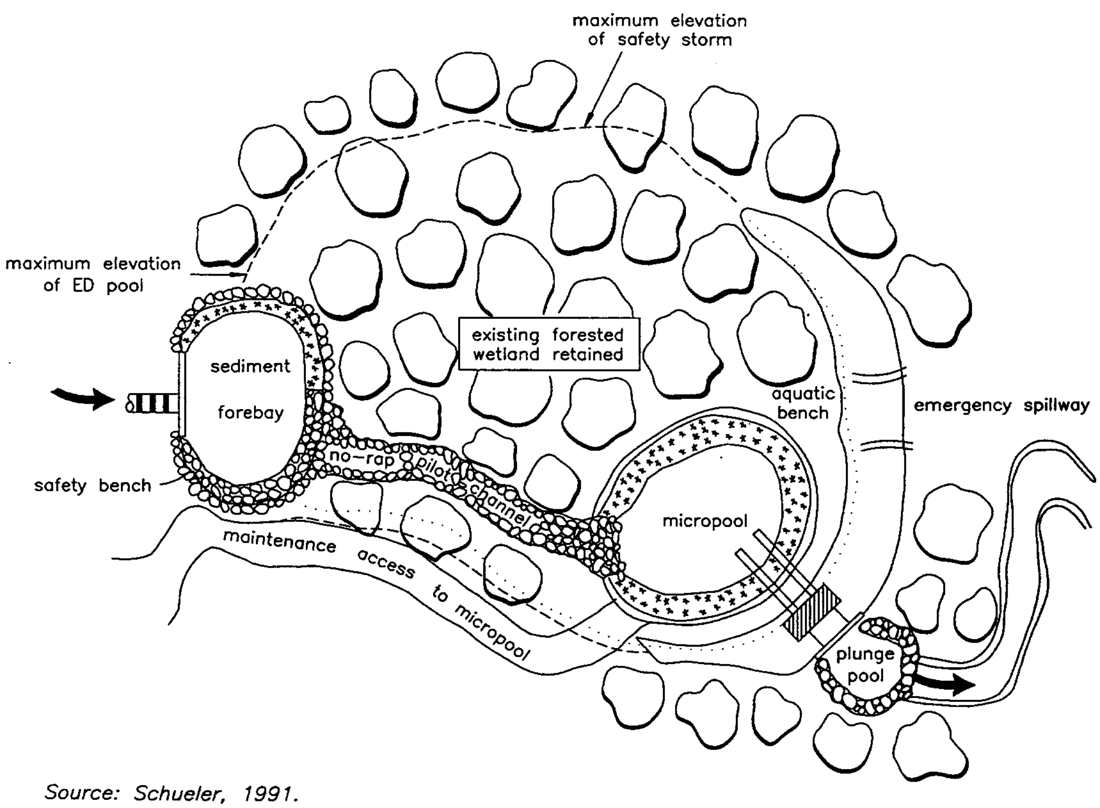


Figure 3-18 Schematic of an Enhanced Extended Detention Basin (Schueler, 1992)

(5) *Basin Inlet* – Energy dissipation is required at the basin inlet to reduce resuspension of accumulated sediment and to reduce the tendency for short-circuiting.

(6) *Outflow Structure* – Figure 3-19 presents a possible outflow structure configuration for extended detention facilities. A reverse slope outflow pipe design is preferred if a second stage micropool is provided in the facility. Otherwise, the facility's drawdown time should be regulated by a gate valve or orifice plate located downstream of the primary outflow opening. In general, the outflow structure should have a trash rack or other acceptable means of preventing clogging at the entrance to the outflow pipes.

The outflow structure should be sized to allow for complete drawdown of the water quality volume in 48 hours. No more than 50% of the water quality volume should drain from the facility within the first 24 hours. A valve or orifice can be used to regulate the rate of discharge from the basin.

The facility should have a separate drain pipe with a manual valve that can completely or partially drain the pond for maintenance purposes. To allow for possible sediment accumulation, the submerged end of the pipe should be protected, and the drain pipe should be sized one pipe schedule higher than the calculated diameter needed to drain the pond within 24 hours. The valves should be located at a point where they can be operated in a safe and convenient manner.

For online facilities, the principal and emergency spillways must be sized to provide 1.0 foot of freeboard during the 25-year event and to safely pass the flow from 100-year storm.

(7) *Vegetation* – The facility should be planted and maintained to provide for a full and robust vegetative cover. The following wet tolerant species are recommended for planting within the bottom stage (LCRA, 1998):

- Bushy Bluestem
- Sedges
- Cyperus
- Switch Grass
- Spike Rush
- Green Sprangletop
- Indian Grass
- Bullrush
- Scouring Rush
- Eastern Gamma
- Dropseed lris

A plan should be provided indicating how aquatic and terrestrial areas will be stabilized. A minimum 25-foot vegetative buffer area should extend away from the top slope of the pond in all directions. Vegetation on the pond embankments should be mowed as appropriate to prevent the establishment of woody vegetation.

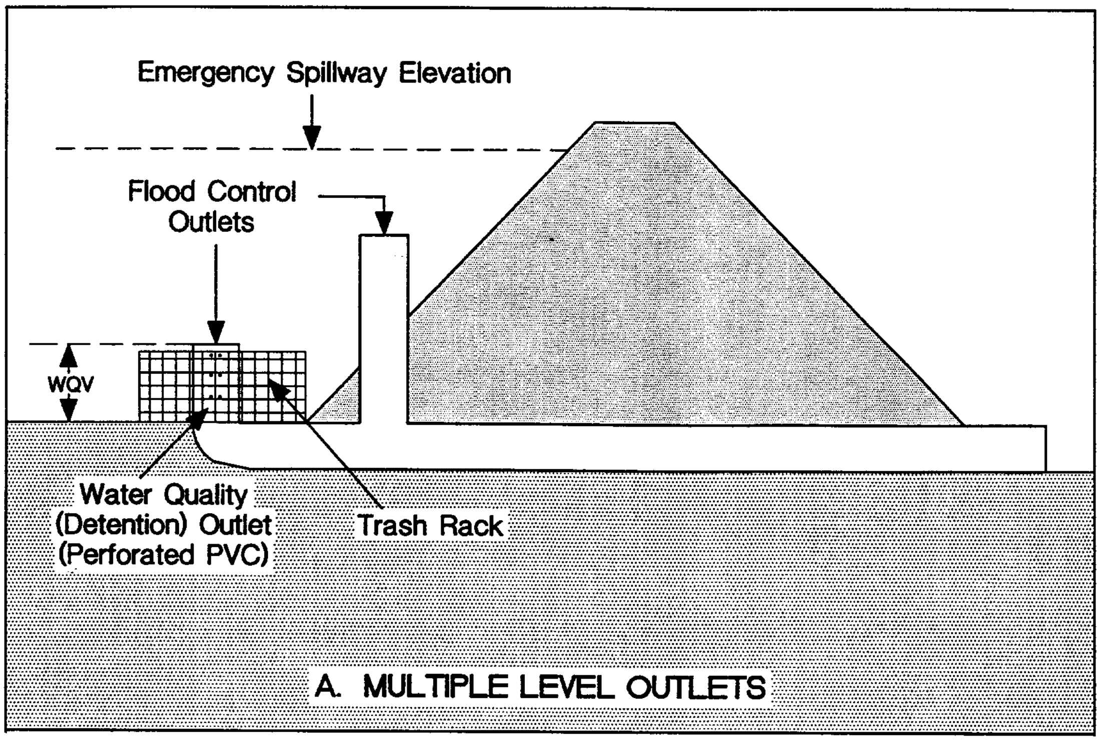


Figure 3-19 Schematic of Detention Basin Outlet Structure

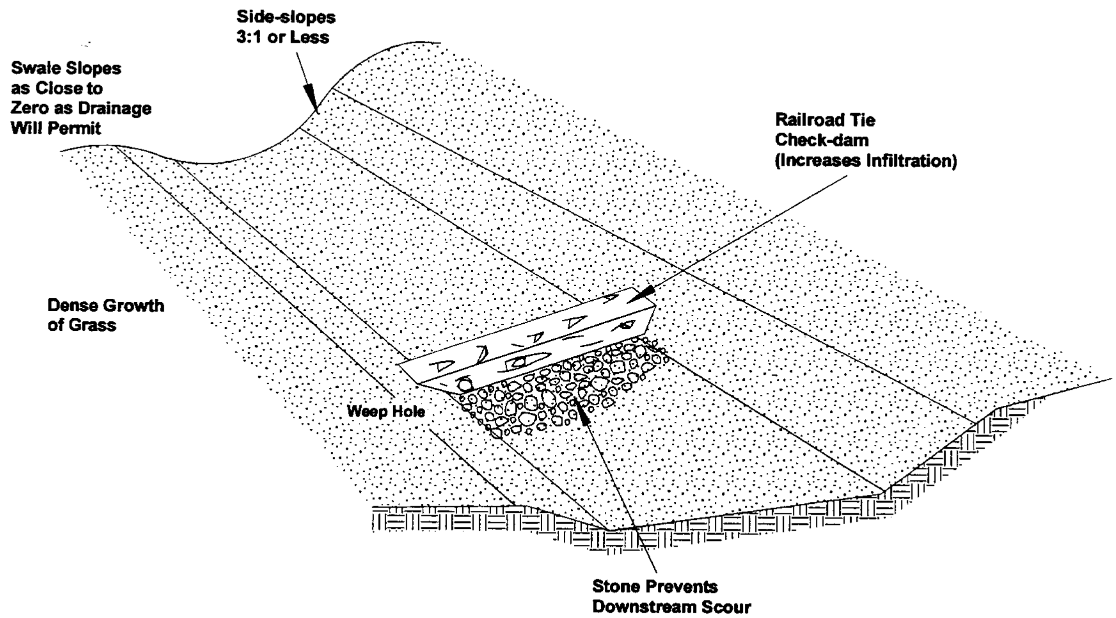
(8) *Splitter Box* – When the pond is designed as an offline facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the 25-year storm event while providing at least 1.0 foot of freeboard along pond side slopes.

(9) *Erosion Protection at the Outfall* – For online facilities, special consideration should be given to the facility's outfall location. Flared pipe end sections that discharge at or near the stream invert are preferred. The channel immediately below the pond outfall should be modified to conform to natural dimensions, and lined with large stone riprap placed over filter cloth. A stilling basin may be required to reduce flow velocities from the primary spillway to non-erosive velocities.

(10) *Safety Considerations* – Safety is provided either by fencing of the facility or by managing the contours of the pond to eliminate dropoffs and other hazards. Earthen side slopes should not exceed 3:1 (H:V) and should terminate on a flat safety bench area. Landscaping can be used to impede access to the facility. The primary spillway opening must not permit access by small children. Outfall pipes more than 48 inches in diameter should be fenced.

3.4.5 Grassy Swales

A grassy swale is a sloped, vegetated channel or ditch that provides both conveyance and water quality treatment of stormwater runoff (Figure 3-20). Pollutant removal occurs through the processes of particle settling, adsorption, and biological uptake that occur when runoff flows over and through vegetated areas.



Source: Schueler, 1987.

Figure 3-20 Diagram of Grassy Swale with Check Dam

General Criteria (WSDOT, 1995)

(1) The swale should have a length that provides a minimum hydraulic residence time of at least 5 minutes. The maximum bottom width is 10 feet unless a dividing berm is provided (Figure 3-2) and should not exceed 16 feet. If the flow is greater than that which can be handled by a single swale consider installing drop inlets to a storm drain system at intervals to reduce the volume of runoff or select a capture and treat type control. The depth of flow should not exceed 4 inches during a 1.1 inch/hour storm.

(2) The channel slope should be at least 0.5% and no greater than 2.5%.

(3) The swale can be sized as both a treatment facility for the design storm and as a conveyance system to pass the peak hydraulic flows of the 100-year storm if it is located "on-line."

(4) The geometry of the channel is not critical as long as a broad, relatively flat bottom is provided. The side slopes should be no steeper than 3:1 (H:V).

(5) Roadside ditches should be regarded as significant potential swale/buffer strip sites and should be utilized for this purpose whenever possible.

(6) If flow is to be introduced through curb cuts, place pavement slightly above the elevation of the vegetated areas. Curb cuts should be at least 12 inches wide to prevent clogging.

(7) Swales must have at least 80 percent vegetated cover in order to provide adequate treatment of runoff.

(8) It is important to maximize water contact with vegetation and the soil surface. For general purposes, select fine, close-growing, water-resistant grasses.

(9) Swales should generally not receive construction-stage runoff. If they do, presettling of sediments should be provided. Such swales should be evaluated for the need to remove sediments and restore vegetation following construction.

(10) If possible, divert runoff (other than necessary irrigation) during the period of vegetation establishment. Where runoff diversion is not possible, cover graded and seeded areas with suitable erosion control materials.

Design Procedure

(1) Determine the peak flow rate to the swale from a storm producing a constant rainfall rate of 1.1 inch/hour.

(2) Determine the slope of the swale. This will be somewhat dependent on where the swale is placed. The slope should be at least 1% and should be no steeper than 2.5%.

(3) Select a swale shape. Trapezoidal is the most common shape; however, rectangular and triangular shapes can be used. The remainder of the design process assumes that a trapezoidal shape has been selected.

(4) Use Manning's Equation to estimate the bottom width of the swale. Manning's Equation for English units is as follows:

$$Q = \frac{1.49}{n} AR^{2/3} S^{0.5}$$

Where:

Q = flow (cfs)
A = cross-sectional area of flow (ft^2)
R = hydraulic radius of flow cross-section (ft)
S = longitudinal slope of swales (ft/ft)
n = Manning's roughness coefficient (0.20 for typical swale)

For a trapezoid, this equation cannot be directly solved for bottom width. However, for trapezoidal channels that are flowing very shallow the hydraulic radius can be set equal to the depth of flow. Using this assumption, the equation can be altered to:

$$b = \frac{0.134Q}{y^{1.67} S^{0.5}} - zy$$

Where:
b = bottom width
y = depth of flow
z = the side slope of the swale in the form of z:1

Typically the depth of flow is selected to be 4 inches (100 mm). It can be set lower but doing so will increase the bottom width. Sometimes when the flow rate is very low the equation listed above will generate a negative value for b. Since it is not possible to have a negative bottom width, the bottom width should be set to 2 feet when this occurs. Swales are limited to a maximum bottom width of 10 feet. If the required bottom width is greater than 10 feet, parallel swales should be used in conjunction with a device that splits the flow and directs the proper amount to each swale.

(5) Calculate the cross-sectional area of flow for the given channel using the calculated bottom width and the selected side slopes and depth.

(6) Calculate the velocity of flow in the channel using:

$$V = Q / A$$

If V is less than or equal to 1.0 ft/s, the swale will function correctly with the selected bottom width. Proceed to design step 7. If V is greater than 1 ft/s, the swale will not function correctly. Increase the bottom width, recalculate the depth using Manning's Equation and return to design step 5.

(7) Calculate the minimum swale length (L) using:

$$L(ft) = V(ft/s) \times 300(s)$$

Where 300 seconds (5 minutes) is the minimum hydraulic residence time. Select a location where a swale with the calculated width and a length will fit. If the minimum length is not feasible within site constraints, the width of the swale should be increased so that the area of the swale is the same as if the calculated minimum length had been used.

(8) Select a vegetation cover suitable for the site.

(9) Determine the peak flow rate to the swale during the 100-year 24-hour storm. Using Manning's Equation, find the depth of flow (typically n = 0.04 during the 100-year flow). The depth of the channel should be 1 foot (300 mm) deeper than the depth of flow.

3.4.6 Vegetative Filter Strips

Filter strips may be natural or engineered. The use of natural filter strips is limited to perimeter lots and other areas that will not drain by gravity to other BMPs on the site.

Natural Filter Strips:

(1) The filter strip should extend along the entire length of the contributing area.

(2) The slope should not exceed 10%.

(3) The minimum dimension (in the direction of flow) should be 50 feet.

(4) All of the filter strip should lie above the elevation of the 2-yr, 3-hr storm of any adjacent drainage.

(5) There is no requirement for vegetation density or type.

Engineered Filter Strips

Many of the general criteria applied to swale design apply equally well to engineered vegetated filter strips. Vegetated roadside shoulders provide one of the best opportunities for incorporating filter strips into roadway and highway design as shown in Figure 3-21. The general design goal is to produce uniform, shallow overland flow across the entire filter strip. Landscaping on residential lots is not considered to function as a vegetated filter strip because fertilizers and pesticides are commonly applied in these areas. In addition, all areas designated as engineered filter strips should be described in a legally binding document that restricts modification of these areas through an easement, setback, or other enforceable mechanism.

(1) The filter strip should extend along the entire length of the contributing area and the slope should not exceed 20%. The minimum dimension of the filter strip (in the direction of flow) should be no less than 15 feet. The maximum width (in the direction of flow) of the contributing impervious area should not exceed 72 feet. For roadways with a vegetated strip along both sides the total width of the roadway should not exceed 144 feet (i.e., 72 feet draining to each side).

(2) The minimum vegetated cover for engineered strips is 80%.

(3) The area contributing runoff to a filter strip should be relatively flat so that the runoff is distributed evenly to the vegetated area without the use of a level spreader.

(4) The area to be used for the strip should be free of gullies or rills that can concentrate overland flow (Schueler, 1987).

(5) The top edge of the filter strip along the pavement will be designed to avoid the situation where runoff would travel along the top of the filter strip, rather than through it.

(6) Top edge of the filter strip should be level, otherwise runoff will tend to form a channel in the low spot. A level spreader should not be used to distribute runoff to an engineered filter strip.

(7) Filter strips should be landscaped after other portions of the project are completed.

Interim Filter Strips

Filter strips can be implemented as an interim BMP in a phased development when the initial level of development results in an impervious cover of less than 20% in a sub-watershed of the project.

(1) The filter strip area must be 50% of the size of the contributing impervious cover.

(2) Top edge of the filter strip should be level; otherwise, runoff will tend to form a channel in the low spot. If a level spreader is used (this is only allowed for interim use) to distribute runoff to the filter strip, it must be lined or be constructed of impermeable materials (concrete).

(3) The area to be used for the strip should be free of gullies or rills that can concentrate overland flow.

(4) Filter strips should be landscaped after other portions of the project are completed and vegetation coverage should be at least 80%.

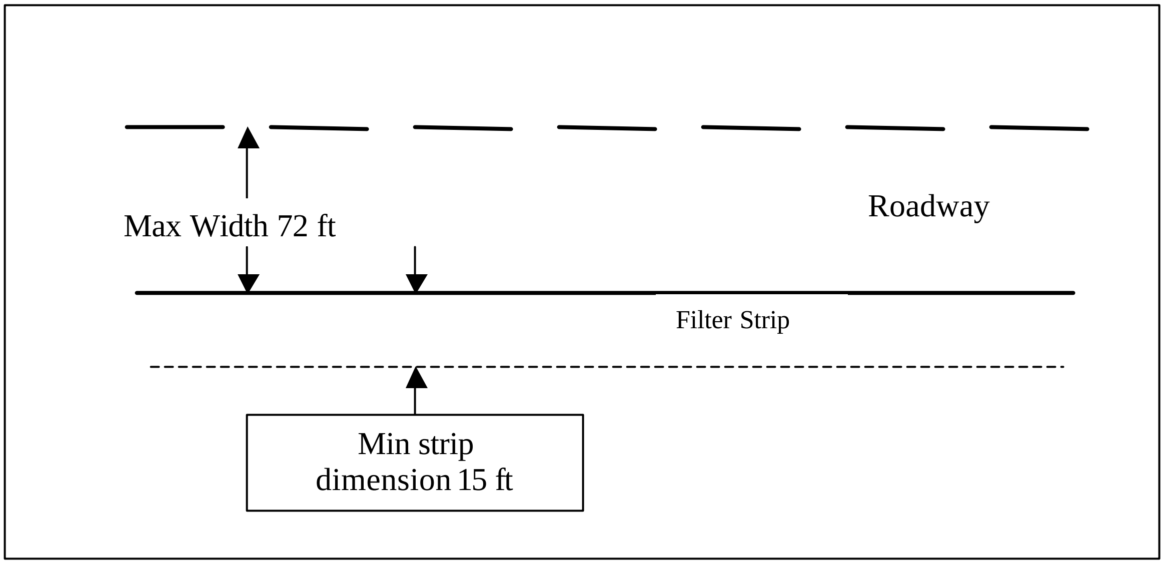


Figure 3-21 Example of Filter Strip along Roadway

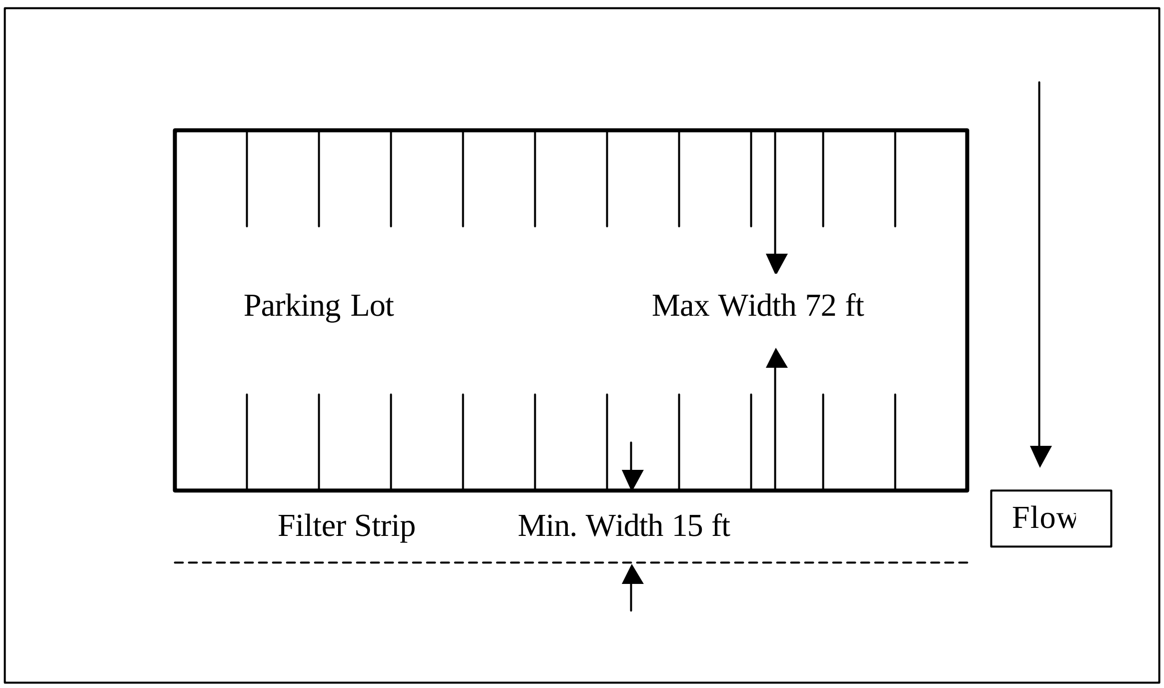


Figure 3-22 Example Configuration of Filter Strip adjacent to Parking Lot

3.4.7 Sand Filter Systems

Since the mid-1980's, sand filtration has been the predominant nonpoint source water quality management practice used in the Austin, Texas area. Sand filters tend to have good longevity due to their offline design and the high porosity of the sand media. However, without proper maintenance, sand filters are prone to clogging, which dramatically reduces performance and can lead to nuisances associated with standing water. Pollutant removal is achieved primarily by straining pollutants through the filtration media, settling of solids on the top of the sand bed, and, if the filter maintains a grass cover crop, through plant uptake. Sand filters often are perceived to have negative aesthetic appeal, especially when not maintained, thus landscaping and basin configuration design should be carefully considered.

Sand filters may be configured as either a single basin or separate basins for sedimentation and filtration. If the sand filter design includes a wall with a riser pipe between the sedimentation and filtration chambers (separate basins), then the sedimentation basin should be sized to contain the entire design capture volume (termed "full sedimentation" in the City of Austin design manual). If the two chambers are separated by gabion baskets or similar porous structures, then the sum of the volumes of the sedimentation and filtration chambers must equal the designed capture volume (also known as partial sedimentation).

Design Criteria

(1) *Facility Sizing* – The required water quality volume is dependent on the characteristics of the contributing drainage area. The method for calculation of required water quality volume is specified in Section 3.3 of this manual. This water quality volume should be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities. A fixed vertical sediment depth marker should be installed in the sedimentation basin to indicate when sediment accumulation equals 20% of the water quality volume and sediment removal is required.

(2) *Basin Geometry* – The water depth in the sedimentation basin when full should be at least 2 feet and no greater than 8 feet. A fixed vertical sediment depth marker should be installed in the sedimentation basin to indicate when the accumulated depth of sediment equals 6 inches and sediment removal is required. The minimum average surface area for the sand filter (Af) varies depending on whether the proposed facility includes a separate sedimentation basin.

The recommended filter area for sand filters with a separate sedimentation basin is:

$$A_f = \frac{WQV}{18}$$

A_f = minimum surface area for the filtration basin in square feet

WQV = water quality volume in cubic feet

The sand filter area for facilities that combine filtration and sedimentation in a single basin is calculated as:

$$A_f = \frac{WQV}{10}$$

The larger filter area compensates for the less effective pretreatment in the sedimentation basin and reduces maintenance requirements.

(3) *Sand and Gravel Configuration* – The sand filter is constructed with 18 inches of sand overlying 6 inches of gravel. The sand and gravel media are separated by permeable geotextile fabric. Four-inch perforated PVC pipe is used to drain captured flows from the gravel layer. A minimum of 2 inches of gravel must cover the top surface of the PVC pipe. Figure 3-23 presents a schematic representation of a standard sand bed profile.

(4) *Sand Properties* – The sand grain size distribution should be comparable to that of "washed concrete sand" (i.e., ASTM C-33 fine aggregate).

(5) *Underdrain Pipe Configuration* – The underdrain piping should consist of a main collector pipe and two or more lateral branch pipes, each with a minimum diameter of 4 inches. The pipes should have a minimum slope of 1% (1/8 inch per foot) and the laterals should be spaced at intervals of no more than 10 feet. There should be no fewer than two lateral branch pipes. Each individual underdrain pipe should have a screw-on cleanout access location. All piping is to be Schedule 40 PVC. The maximum spacing between rows of perforations should not exceed 6 inches.

(6) *Basin Lining* – The basin lining should conform to the specifications described in Section 3.4.2.

(7) *Flow Splitter* – The inflow structure to the sedimentation chamber should incorporate a flow-splitting device capable of isolating the capture volume and bypassing the 25-year peak flow around the sand filter system once the entire water quality volume has been captured.

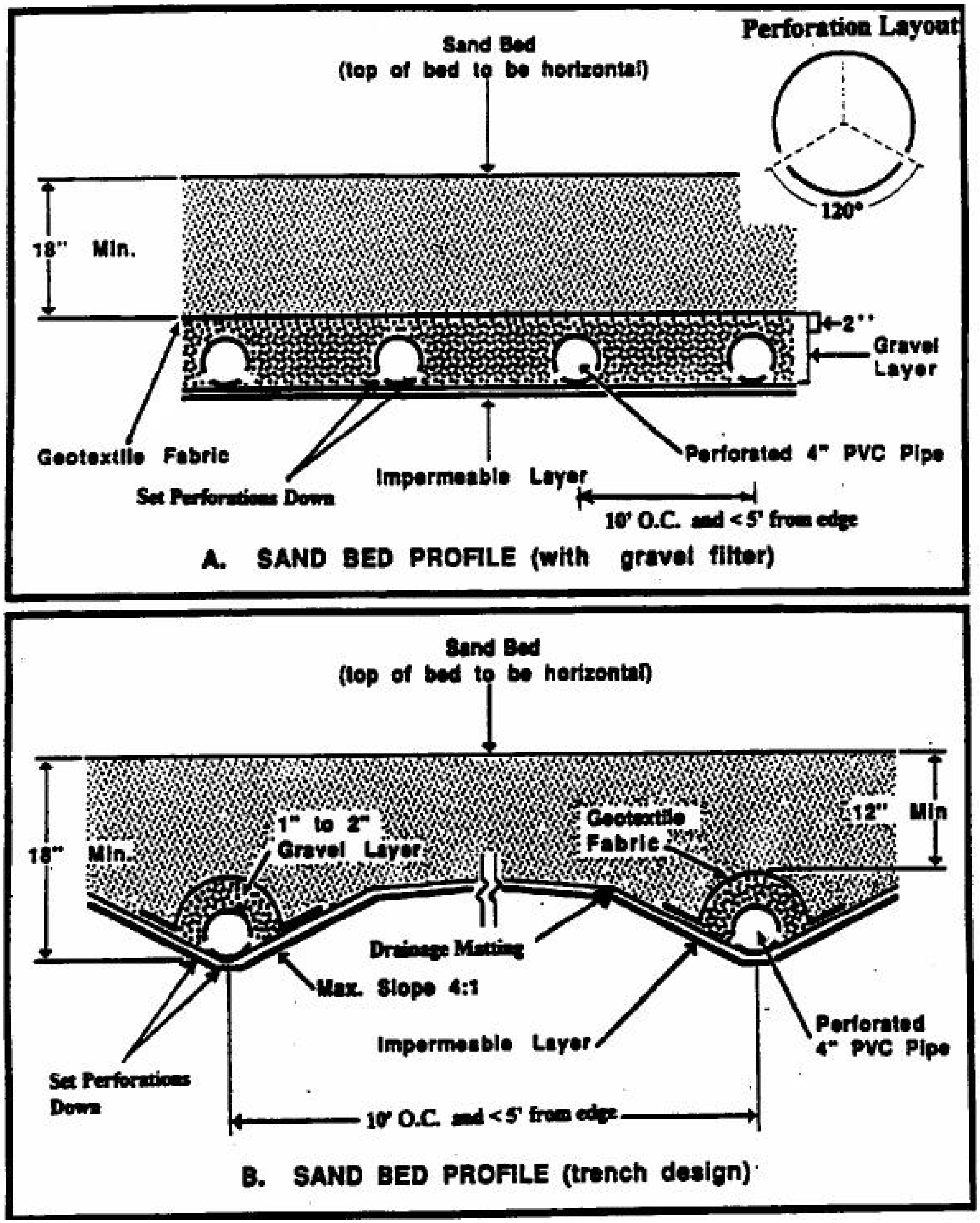


Figure 3-23 Schematic of Sand Bed Profile

(8) *Basin Inlet* – Energy dissipation is required at the sedimentation basin inlet so that flows entering the basin should be distributed uniformly and at low velocity in order to prevent resuspension and encourage conditions necessary for deposition of solids.

(9) *Sedimentation Pond Outlet Structure* – The outflow structure from the sedimentation chamber should be (1) an earthen berm; (2) a concrete wall; or (3) a rock gabion. When a concrete wall is used, rock riprap is not required upstream of the wall. Gabion outflow structures should extend across the full width of the facility such that no short-circuiting of flows can occur. The gabion rock should be 5 to 8 inches in diameter. The receiving end of the sand filter should be protected (splash pad, riprap, etc.) such that erosion of the sand media does not occur. The outlet of the sedimentation basin should have flow control so that the sedimentation basin drains from full in 24 hours. This can be accomplished with either an orifice or by adjusting a valve. The riser pipe should have a minimum diameter of 6 inches with four 1-inch perforations per row. The vertical spacing between rows should be 4 inches (on centers).

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

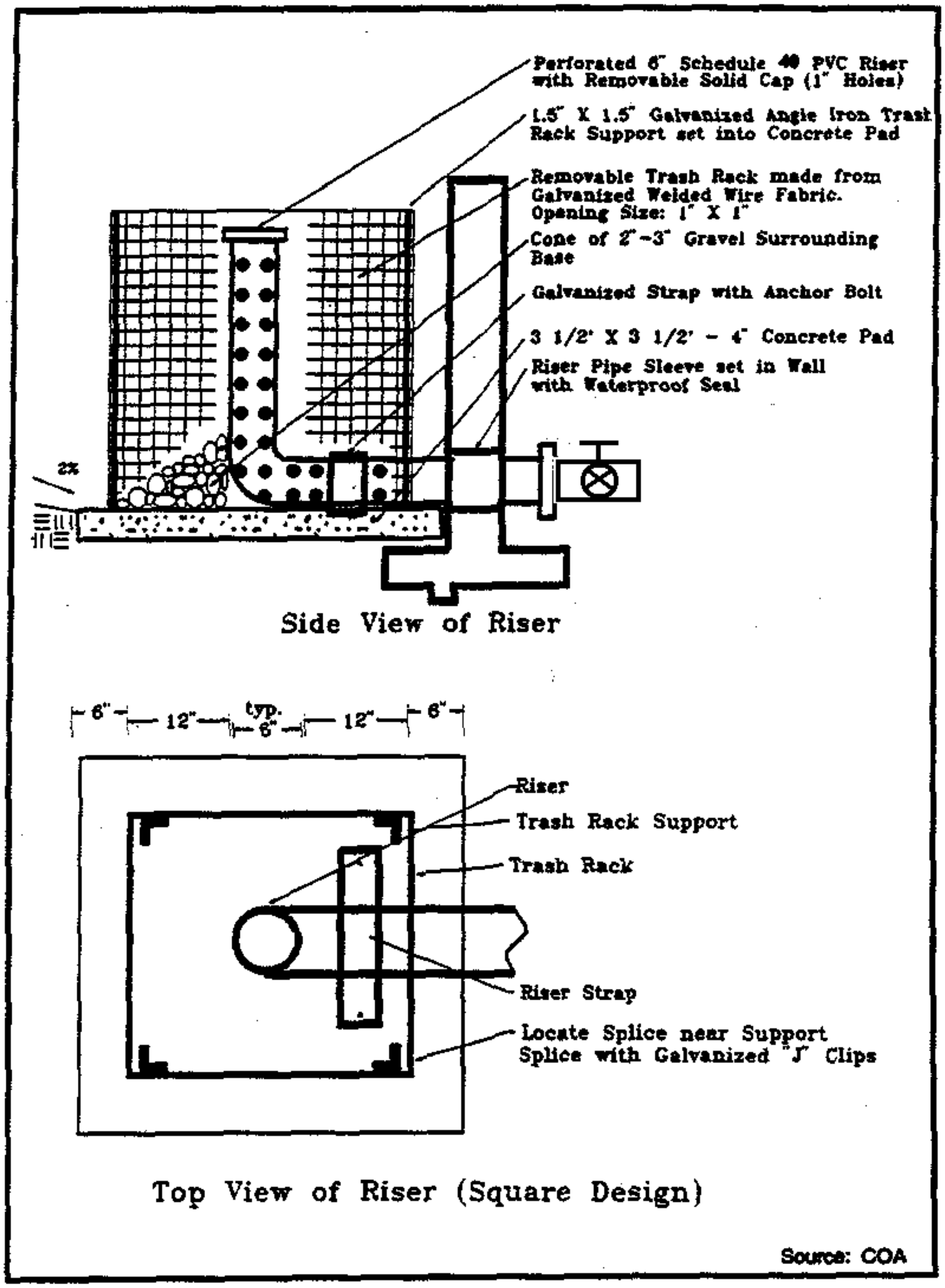


Figure 3-24 Detail of Sedimentation Riser Pipe

(11) *Safety Considerations* – Safety is provided either by fencing of the facility or by managing the contours of the pond to eliminate dropoffs and other hazards. Earthen side slopes should not exceed 3:1 (H:V) and should terminate on a flat safety bench area. Landscaping can be used to impede access to the facility. The primary spillway opening must not permit access by small children. Outfall pipes more than 48 inches in diameter should be fenced.

(12) *Stabilization Plan* – A plan should be provided indicating how adjacent terrestrial areas will be stabilized.

3.4.8 <u>Bioretention</u>

Bioretention facilities are effectively sand filters that include additional organic material in the filtration media to support vegetation. This allows these facilities to be integrated into the site landscaping where they can provide unobtrusive treatment of stormwater runoff.

1) *Water Quality Volume* – The water quality is calculated according to the guidelines in Section 3.3. This volume should be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities. A fixed vertical sediment depth marker should be installed in the facility to indicate when sediment accumulation equals 20% of the water quality volume and sediment removal is required.

2) *Inlet Design* – When siting bioretention facilities to intercept drainage, the designer should attempt to use the preferred "off-line" facility design. Off-line facilities are defined by the flow path through the facility. Any facility that utilizes the same entrance and exit flow path upon reaching pooling capacity is considered an off-line facility.

3) *Filtration Area* – The footprint of the media should be sufficiently large that it underlies the entire flooded area for the design water quality volume calculated according to the guidelines in Section 3.3. The water depth over the media for the design storm should not exceed 6 inches.

4) *Media Properties* – The filtration media should have a minimum thickness of 3 feet and should have a maximum clay content of less than 5%. The soil mixture should be 50-60% sand; 20-30% compost; and 20-30% topsoil. The soil should be a uniform mix, free of stones, stumps, roots, or other similar objects larger than two inches. No other materials or substances should be mixed or dumped within the bioretention that may be harmful to plant growth, or prove a hindrance to the planting or maintenance operations. Provide clean sand, free of deleterious materials. Sand should be ASTM C- 33 with grain size of 0.02- 0.04 inches (same as sand filter).

5) *Underdrains* – Underdrains should be incorporated in all designs. The underdrain piping should consist of a main collector pipe and two or more lateral branch pipes, each with a minimum diameter of 4 inches. Underdrains should be perforated with ¼ - ½ inch openings, 6 inches center to center. The pipes should have a minimum slope of 1% (1/8 inch per foot) and the laterals should be spaced at intervals of no more than 10 feet. Each individual underdrain pipe should have a cleanout access location. All piping is to be Schedule 40 PVC.

6) *Grading* – The designer/landscape architect can develop a landscaping plan for bioretention in similar fashion to conventional site landscaping design. The main difference is essentially the integrated stormwater management control-"functional landscaping" as well as the aesthetic appeal. Even though the facility is being designed to capture and treat stormwater, the designer is cautioned *not* to view bioretention as a wetland, pond, or other water feature. Rather, the designer should utilize plant species that are tolerant to wide fluctuations in soil moisture content.

7) *Setbacks* – When siting bioretention facilities, a 50 foot setback from septic fields should be provided. Setback from a foundation or slab should be 5 feet or greater.

8) *Liners* – There are two possible configurations of bioretention facilities, with and without liners. Liners must be used in facilities constructed in the recharge zone. A configuration like that shown in Figure 3-25 is preferred. In the contributing zone liners are not required and this will allow some portion of the runoff to infiltrate. In this configuration, the underdrain is installed above the invert of the excavation to promote infiltration as shown in Figure 3-26. When constructing a facility like that shown in Figure 3-26, the filter fabric does not need to extend to the side walls. The filter fabric may be installed horizontally above the gravel blanket- extending just 1-2 feet on either side of the underdrain pipe below. Do ***not*** wrap the underdrain with filter fabric.

9) *Vegetation* – Vegetation selected for the biorentention system should be tolerant of frequent inundation during extended periods of wet weather. In addition, large trees or other plants with root systems that might penetrate the liner should not be used.

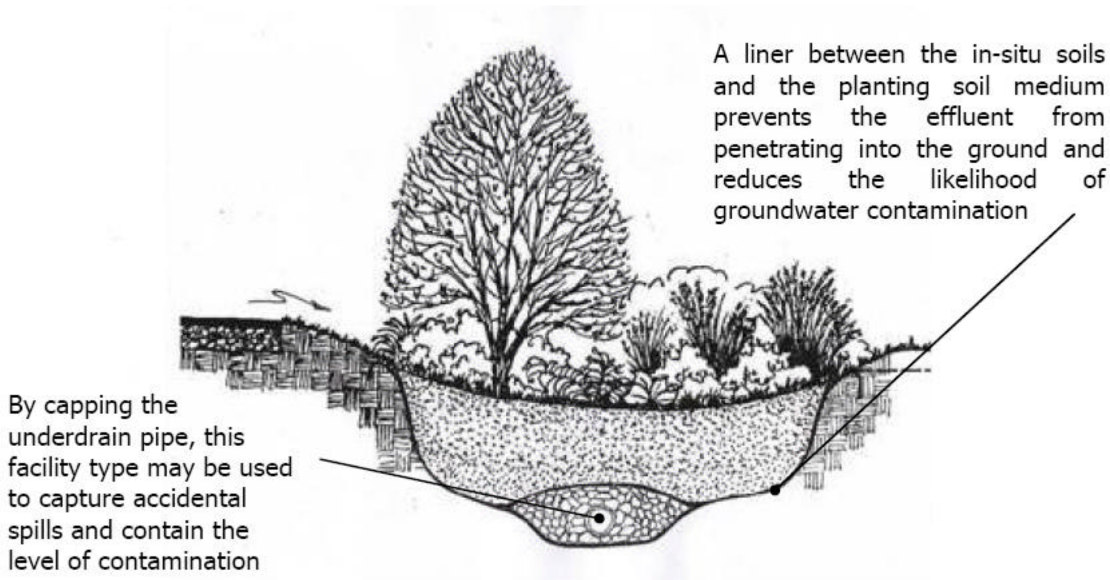


Figure 3-25 Bioretention with Underdrain and Liner

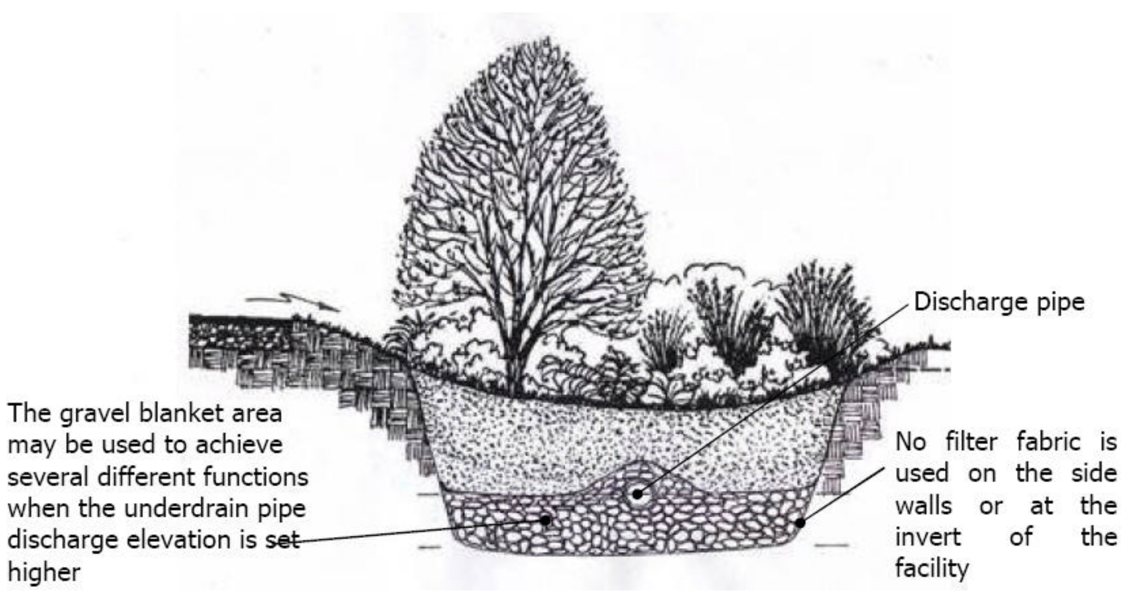


Figure 3-26 Bioretention System with Infiltration

Installation of soils must be done in a manner that will ensure adequate filtration. After scarifying the invert area of the proposed facility, place soil at 8"-12" lifts. Lifts are not to be compacted but are performed in order to reduce the possibility of excessive settlement. Lifts may be lightly watered to encourage natural compaction. Avoid over compaction by allowing time for natural compaction and settlement. No additional manual compaction of soil is necessary. Rake soil material as needed to level out. Overfill above the proposed surface invert to accommodate natural settlement to proper grade. Depending upon the soil material, up to 20% natural compaction may occur. For facilities designed with a liner, no scarification of the invert area is required.

3.4.9 Wet Basins

Wet basins are stormwater quality control facilities that maintain a permanent wet pool and a standing crop of emergent littoral vegetation. These facilities may vary in appearance from natural ponds to enlarged, bermed (manmade) sections of drainage systems and may function as online or offline facilities, although offline configuration is preferable. Offline designs can prevent scour and other damage to the wet pond and minimize costly outflow structure elements needed to accommodate extreme runoff events.

During storm events, runoff inflows displace part or all of the existing basin volume and are retained and treated in the facility until the next storm event. The pollutant removal mechanisms are settling of solids, wetland plant uptake, and microbial degradation. When the wet basin is adequately sized, pollutant removal performance can be excellent,. Wet basins also help provide erosion protection for the receiving channel by limiting peak flows during larger storm events.

Wet basins are often perceived as a positive aesthetic element in a community and offer significant opportunity for creative pond configuration and landscape design. Participation of an experienced wetland designer is suggested. A significant potential drawback for wet ponds in the central Texas area is that the contributing watershed for these facilities is often incapable of providing an adequate water supply to keep the pond full, especially during the summer months. Makeup water (i.e., well water or municipal drinking water) is sometimes used to supplement the rainfall/runoff process, especially for wet basin facilities treating watersheds that generate insufficient runoff (LCRA, 1998), but it is not required for stormwater treatment. The facility designer may want to develop a water balance for the proposed facility to determine the amount of supplemental water that may be required for aesthetic purposes.

Design Criteria

(1) *Facility Sizing* – The basin should be sized to hold the permanent pool as well as the required water quality volume. The water quality volume should be calculated as described in Section 3.3. This water quality volume should be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities. The volume of the permanent pool should equal the water quality volume (i.e., when full the facility holds twice the water quality volume).

(2) *Pond Configuration* – The wet basin should be configured as a two stage facility with a sediment forebay and a main pool. The basins should be wedge-shaped, narrowest at the inlet and widest at the outlet if possible. The minimum length to width ratio should be 1.0. Higher ratios are recommended.

(3) *Pond Side Slopes* – Side slopes of the basin should be 3:1 (H:V) or flatter for grass stabilized slopes. Slopes steeper than 3:1 should be stabilized with an appropriate slope stabilization practice.

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

(5) *Outflow Structure* – A low flow orifice should be provided that will drain the water quality volume in a minimum of 24 hours. Figure 3-27 presents a schematic representation of acceptable outflow structures. The facility should have a separate drain pipe with a manual valve that can completely or partially drain the pond for maintenance purposes. To allow for possible sediment accumulation, the submerged end of the pipe should be protected, and the drain pipe should be sized one pipe schedule higher than the calculated diameter needed to drain the pond within 24 hours. The valve should be located at a point where it can be operated in a safe and convenient manner.

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

(6) *Splitter Box* – When the pond is designed as an offline facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the 25-year event while providing at least 1.0 foot of freeboard along pond side slopes.

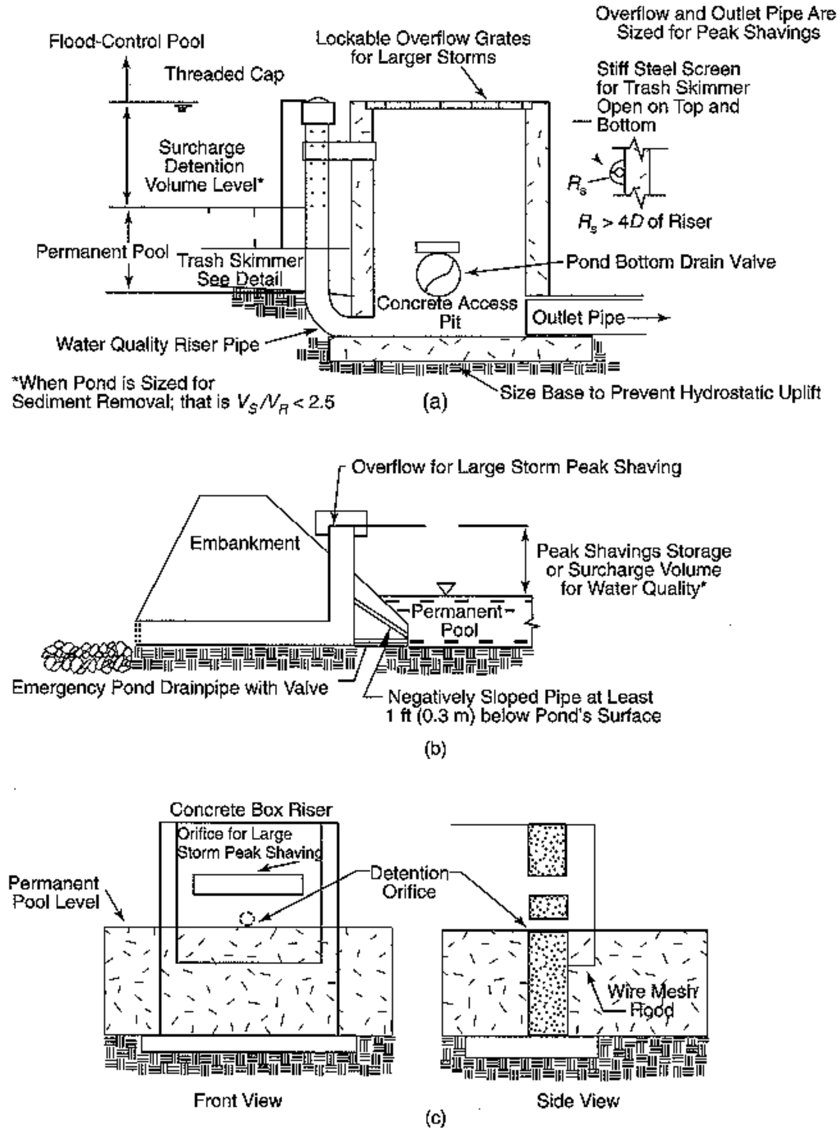


Figure 3-27 Schematic Diagrams of Wet Basin Outlets (WEF and ASCE, 1998)

(7) *Vegetation* – A plan should be prepared that indicates how aquatic and terrestrial areas will be vegetatively stabilized. Wetland vegetation elements may be placed along an aquatic bench around the perimeter, but is not required. The optimal elevation for planting of wetland vegetation is within 6 inches vertically of the normal pool elevation. Some of the wetland species appropriate for a warm weather climate and the planting guidelines are shown below (City of Austin, 1997).

Wetland Plant List

Install Bulrush in clumps, with individual plants spaced approximately three to four feet on center: At least two of the following species should be used:

BULRUSH	WATER DEPTH	NOTES
Scirpus validus, Bulrush	1' — 3'	8' tall evergreen, resists cattail encroachment
Scirpus californicus, Bulrush	1' — 3'	8' tall evergreen, resists cattail encroachment
Scirpus americanus, Three-square bulrush	2" — 6"	2' to 4' tall, w/ 3 distinct edges

At least two species of the following marsh plants should be used (additional species are encouraged). Install in clumps in shallow water, with individual plants spaced at approximately three feet on center:

MARSH DIVERSITY	WATER DEPTH	NOTES
1. Cyperus ochraeus, Flatsedge	2"—6"	1' to 2' tall, clump-forming, common to central Texas
2. Dichromena colorata, White-topped Sedge	2" —6"	1' to 2' tall, white bracts during warm season
3. Echinodorus rostratus, Burhead	3' - 1'	1' to 2' tall, annual, heart-shaped leaves, flower similar to arrowhead
4. Eleocharis quadrangulata, Four-square Spikerush	6" — 1'	1' to 2' tall, colonizes, inhabits deeper water than other Spikerushes
5. Iris Pseudacorus, Yellow Flag Iris	1' — 2'	3' to 4' tall. can be invasive, dense growth, yellow flowers
6. Junctus effusus, Soft Rush	6" — 1'	3' to 4' tall, forms a tight clump, evergreen, very attractive
7. Justicia americana, Water willow	2" — 6"	2' to 3' tall, common, white flowers, herbaceous, colonizes
8. Marsilea macropoda, Water Clover	2" — 6"	Looks like floating four-leaf clover, endemic to Texas
9. Najas guadalupensis, Water-Naiad	1' —4'	Submergent, valuable to fish and wildlife
10. Pontederia cordata, Pickerelweed	2" — 1'	3' tall, colonizes, cosmopolitan, purple flowers
11. Rhynchospora corniculata, Horned-rush	2" — 6"	2' to 3' tall, brass-colored flowers in May

Install spikerush at or near the water's edge, with individual plants spaced approximately three to six feet on center. At least two of the following species should be used:

SPIKERUSH	WATER DEPTH	NOTES
Eleocharis montevidensis, Spikerush	0” — 6”	1’ tall, rhizomatous, reduces erosion at the pond edge
Eleocharis macrostachys, Spikerush	0” — 6”	1’ tall, rhizomatous, reduces erosion at the pond edge
Eleocharis quadrangulata, Spikerush	3” — 1’	2’ to 2.5’ tall, rhizomatous, can accommodate deeper water, 4-angled

Install Arrowhead in clumps in shallow water, with individual plants spaced approximately three feet on center.

ARROWHEAD	WATER DEPTH	NOTES
Saggitaria latifolia, Arrowhead	2” — 1’	2’ height, wildlife value, white flowers, proven water quality performer

Floating-leafed aquatic plants are rooted in the sediment of the pond, and have leaves that float on the surface of the water. These leaves shade the water, which limits potential algae growth. At least two of the following species should be used and should be placed at random locations throughout the pond:

AQUATICS	WATER DEPTH	NOTES
1. Cabomba caroliniana, Fanwort	1’ — 4’	Approximately 6’ length underwater, submergent
2. Ceratophyllum spp., Coon-tail	1’ —4’	Maximum 8’ length, tolerant of turbidity and water fluctuation, wildlife food
3. Nymphaea odorata, Fanwort	6” —2’	A native, reliably hardy, floating- leaved aquatic, with white flowers
4. Potomageton pectinatus, Sago Pondweed	8” — 3’	Colonizes quickly, valuable to fish and wildlife; floating-leaved aquatic

(8) *Erosion Protection at the Outfall* – For online facilities, special consideration should be given to the facility’s outfall location. Flared pipe end sections that discharge at or near the stream invert are preferred. The channel immediately below the pond outfall should be modified to conform to natural dimensions, and lined with large riprap placed over filter cloth. Energy dissipation should be used to reduce flow velocities from the primary spillway to non-erosive velocities.

(9) *Safety Considerations* – Safety is provided either by fencing of the facility or by managing the contours of the pond to eliminate dropoffs and other hazards. Earthen side slopes should not exceed 3:1 (H:V). Landscaping can be used to impede access to the facility if desired. The primary spillway opening should not permit access by small children. Outfall pipes more than 48 inches in diameter should be fenced.

(10) *Depth of the Permanent Pool* – The permanent pool should be no deeper than 8 feet and should average 4-6 feet deep.

(11) *Fish* – To minimize problems with mosquitoes, *Gambusia affinis* (mosquito fish) or other similar native species should be stocked at a minimum initial density of 200 individuals per surface acre.

(12) *Aeration* – The performance and appearance of a constructed wetland may be improved by providing aeration of the permanent pool; however, this is not a requirement.

3.4.10 Constructed Wetland

Constructed wetlands are shallow pools with or without open water elements that create growing conditions suitable for marsh plants. Conventional stormwater wetlands are shallow manmade facilities supporting abundant vegetation and a robust microbial population. These facilities are generally designed as offline BMPs, but may be situated online if flows from extreme events can be accommodated without damage to the facility. Wetlands facilities are designed to maximize pollutant removal through plant uptake, microbial degradation, and settling of solids. As constructed water quality facilities, stormwater wetlands should never be located within delineated natural wetlands areas. In addition, they differ from manmade wetlands used to comply with mitigation requirements in that they do not replicate all of the ecological functions of a natural wetland (LCRA, 1998).

Like wet basins, constructed wetlands are capable of excellent pollutant removal if sized and designed properly. Performance is generally good with respect to settling of the solids fraction and for the dissolved constituents as well, due to active microbial action. Enhanced design elements include a sediment forebay, micropool areas, a complex microtopography, pondscaping, and multiple species of wetland trees, shrubs and plants. Significant potential exists for creative design and participation of an experienced wetland designer is highly recommended. As with wet basins, a consistent source of water is necessary to sustain the system; thus, in smaller watersheds and urban applications, makeup water (i.e., well water or municipal drinking water) may be required to supplement natural sources. Maintenance requirements are most intensive during the early stages when the wetland is being established (LCRA, 1998).

Design Criteria (LCRA, 1998)

(1) *Facility Sizing* – The water quality volume requirements are presented in Section 3.3 of this manual. This water quality volume should be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities. The wetland pool volume should equal the increased water quality volume.

(2) *Pond Configuration* – Stormwater constructed wetlands offer significant flexibility regarding pond configuration with the exception that short-circuiting of the facility must be avoided. Provision of irregular, multiple flow paths is desired. The use of open water elements (micropools) is recommended, especially near the facility outlet, both as a means of diversifying the biological community and as an aesthetic consideration. Islands may be placed in the facility to enhance waterfowl habitat and placement of trees. At least 25 percent of the basin should be an open water area at least 2-ft deep if the device is exclusively designed as a shallow marsh. The open-water area will make the marsh area more aesthetically pleasing, and the combined water/wetland area will create a good habitat for waterfowl (Schueler, 1987). The combination of forebay, outlet and free water surface should be 30 to 50 percent, and this area should be between 0.6- and 1.2-m (2- and 4-ft) deep. The wetland zone should be 50 to 70 percent of the area, and should be 150- to 300-mm (6- to 12-in) deep.

(3) *Sediment Forebay* – A sediment forebay is required to isolate gross sediments as they enter the facility and to simplify sediment removal. The sediment forebay should consist of a separate cell formed by an earthen berm, gabion wall, or loose riprap wall. The forebay should be sized to contain 0.25 inches per impervious acre of contributing drainage area and should be 2-4 feet deep. Direct maintenance access should be provided to the forebay. A fixed vertical sediment depth marker should be installed in the forebay to mark sediment accumulation.

(4) *Vegetation* – A diverse, locally appropriate selection of plant species is vital for all constructed wetlands. A planting plan should be prepared that indicates number of plants from each species to be used and how aquatic and terrestrial areas will be vegetatively stabilized. A plan should be prepared that indicates how aquatic and terrestrial areas will be vegetatively stabilized. Wetland vegetation elements should be placed along the aquatic bench or in the shallow portions of the permanent pool. The optimal elevation for planting of wetland vegetation is within 6 inches vertically of the normal pool elevation. Some of the wetland species appropriate for a warm weather climate and the planting guidelines are listed in Section 4.4.8. Participation of a wetland designer or landscape architect familiar with local plants is highly recommended.

(5) *Outflow Structure* – A flow control orifice should be provided that allows the water quality volume to drain from the facility in a minimum of 24 hours. The facility should have a separate drain pipe with a manual valve that can completely

or partially drain the pond for maintenance purposes. To allow for possible sediment accumulation, the submerged end of the pipe should be protected, and the drain pipe should be sized one pipe schedule higher than the calculated diameter needed to drain the pond within 24 hours. The valve should be located at a point where it can be operated in a safe and convenient manner. For online facilities, the principal and emergency spillways should be sized to provide 1.0 foot of freeboard during the 25-year event and to safely pass the 100-year flood. The embankment should be designed in accordance with all relevant state and federal specifications for small dams.

(6) *Depth of Inundation during Storm Events* – The depth of inundation of the facility above the normal pool elevation should not exceed 2.0 feet during the 25-year event.

(7) *Offline Configuration* – Offline configuration of the facility is required except where the designer can demonstrate that extreme events will not encourage scour or other damage to the wetlands. When the wetland is designed as an offline facility, a splitter structure is used to isolate the water quality volume. The splitter box, or other flow diverting approach, should be designed to convey the 25-year event while providing at least 0.5 foot of freeboard along the wetland side slopes.

(8) *Depth of Micropools* – The depth of micropools should not exceed 4 feet.

(9) *Fish* – To minimize problems with mosquitoes, *Gambusia affinis* (mosquito fish) or similar native species should be stocked at a minimum initial density of 200 individuals per surface acre.

3.4.11 AquaLogic™ Cartridge Filter System

In the San Antonio area, computer controlled cartridge filter systems emerged as a variation on the conventional sand filter design. The cartridge system consists of a series of above or below grade filter canisters containing replaceable/recyclable cartridges connected to a common underdrain. A small computer coupled to a rain sensor automatically controls the sedimentation and filtration process to maximize the resulting TSS removal efficiencies.

A cartridge filtration system must be completely separated from the sedimentation basin. The volume of the sedimentation basin should be equal to the design capture volume and the discharge from the sedimentation chamber should be isolated without releasing any flow to the filtration chamber for a minimum of 30 hours.

Design Criteria

(1) *Capture Volume* – The water quality volume requirements are presented in Section 3.3 of this manual. This water quality volume should be increased by a factor of 20% to accommodate reductions in the available storage volume due to deposition of solids in the time between full-scale maintenance activities. The sedimentation chamber should be designed to hold the total water quality volume and isolate it from the area where the filter canisters will be housed.

(2) *Basin Geometry* – The water depth in the sedimentation basin when full should be at least 2 feet and no greater than 10 feet. The floor of the sedimentation chamber should be sloped to collect and drain to a single through-wall pipe, which will direct inflow to the filtering area. The minimum horizontal area needed for the filtration chamber is dependent only on space requirements to accommodate the number of filter canisters required to treat the design capture volume. The sub-floor elevation of the filtration chamber should be a minimum of 14" below the lowest finished floor elevation of the sedimentation chamber. The minimum depth of the filtration chamber to accommodate vertical mounted filter canisters is 48". For a 30" standard filter cartridge and a minimum basin depth of 48" the required number of filter canisters (FCs) to treat the water quality volume and the corresponding filtration basin area (RIA_F) can be found from the following formulas:

$$FCs \quad = \quad WQV \times 7.48 \times 0.000293 \times 1.25$$

Where:

FCs = Number of Filter Canisters Including Reserves
WQV = Water Quality Volume in Cubic Feet

$$RIA_F = FC_S \times 2.00$$

Where:

RIA_F = Recommended Area of Filtration Basin in Square Feet
FCs = Number of Filter Canisters Including Reserves

(3) *Cartridge Configuration* – The filter cartridge is contained in a slotted PVC housing which keeps the cartridge sealed such that all flow must pass through the entry slots, then the media prior to discharge via the inner core tube of the cartridge. The complete length of the filter cartridge housing is wrapped in a geotextile fabric conforming to the specifications described in Section 3.4.2. Each filter canister shall be approximately equally spaced within the available filtration area and should be connected to a 4" schedule 40 PVC underdrain piping system. A diagram illustrating the standard filter cartridge configuration is presented in Figure 3-28.

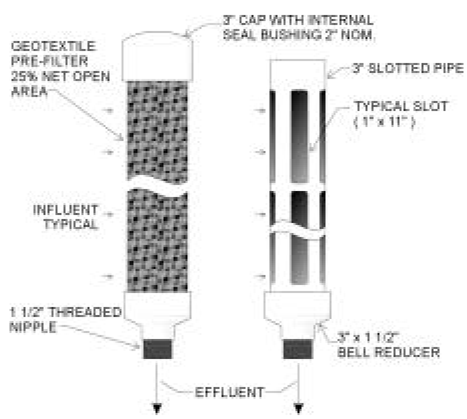


Figure 3-28 Diagram of a Standard Filter Cartridge (by AquaLogic™, 2000)

(4) *Media Properties* – The media used for filtration should have a mean filtration rating (average pore size) of 10 microns and also be rated to achieve 90% removal efficiency for TSS by the media manufacturer. The media should be wrapped around a central core and should be constructed from polypropylene, cotton or pleated paper materials. The nominal size of the finished filter cartridge should be 2.5”OD by 30”in length.

(5) *Underdrain Pipe Configuration* – The underdrain piping provides a point of connection for the required number of filter canisters and carries the filtered outflow to a single point of discharge (pond outfall). All underdrain piping shall be Schedule 40 PVC with solvent weld joints and shall be anchored in a minimum 9 inch sand blanket. The sand embedment shall be capped with a 3" layer of waterproof grout finished flush with bottom of the filter canisters and shaped to prevent ponding. The underdrain piping shall consist of a main collector pipe with minimum diameter of 4 inches and two or more lateral branch pipes. A method of cleanout shall be provided on all main collector pipes at an accessible location. The minimum spacing between filter canisters should not be less than 1.5 feet. Provide a standard female threaded adapter at each point of filter canister connection. Insure that the adapter at each point of connection is set so that the vertical mounted canister will be straight and plumb. Figure 3-29 presents a schematic representation of a standard underdrain piping profile.

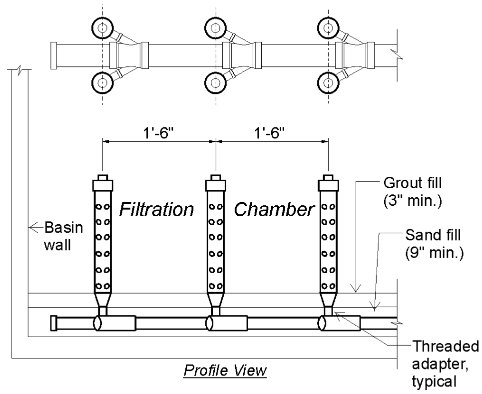


Figure 3-29 Schematic of Underdrain Piping

(6) *Flow Splitter* – The inflow structure to the sedimentation chamber should incorporate a flow-splitting device capable of isolating the capture volume and bypassing the 25-year peak flow around the pond with the sedimentation basin full. Excess runoff should be bypassed to a suitable outfall.

(7) *Sedimentation Basin Inlet* – Energy dissipation is required at the sedimentation basin inlet so that flows entering the basin are distributed uniformly and at low velocity in order to prevent resuspension and encourage quiescent conditions necessary for deposition of solids.

(8) *Sedimentation Pond Outlet* – The outflow structure from the sedimentation chamber shall be an earthen berm or concrete wall containing an in-pipe bladder valve for discrete control of the

sedimentation holding period and release time for the inflow to the filtration chamber to begin. The on/off operation of the bladder valve shall be rain sensor controlled such that the sedimentation period is not less than 30 hours after the rainfall event stops. The bladder valve shall be capable of manual closure in order to isolate a hazardous material spill to contain it in the sedimentation basin. The control for the valve must be accessible at all times, including when the basin is full. A schematic illustrating the in-pipe bladder valve is presented in Figure 3.18.

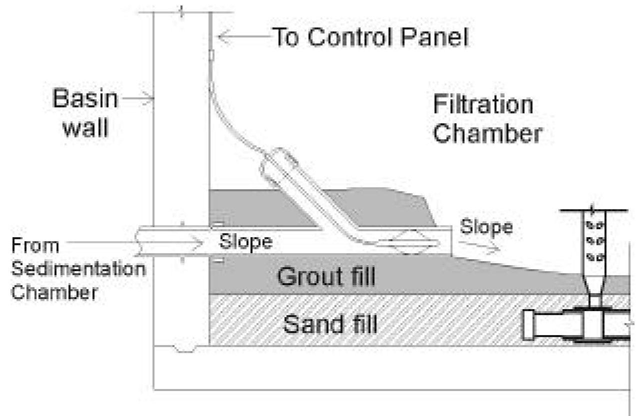


Figure 3-30 Schematic of In-Pipe Bladder Valve

(9) *Controls* – A rain sensor, air compressor and logic board controller should be provided to operate the filtration system automatically and all components shall be housed in a rainproof panel. An emergency override button to close the bladder valve in the event of a hazardous material spill shall also be included in the control panel. The sedimentation period control must be programmable to set the desired number of hours after the rainfall event stops that the capture volume will be held in the sedimentation basin prior to release into the filtration chamber. The panel shall be mounted on a pole embedded in concrete or attached to an accessible location on the filtration chamber sidewall. Figure 3-31 presents a schematic of the control panel/rain sensor assembly.

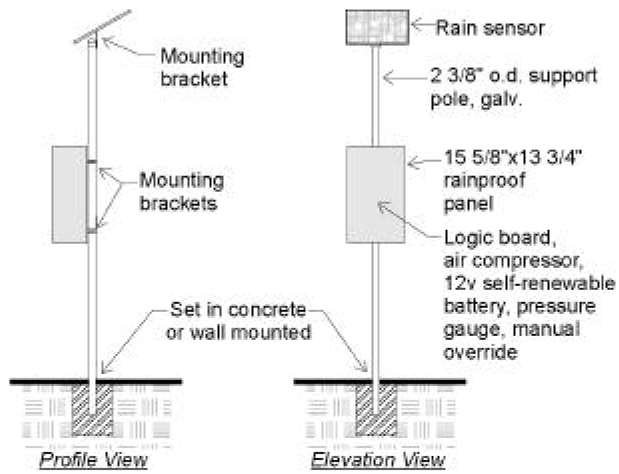


Figure 3-31 Schematic of Control Panel/Rain Sensor Assembly

(10) *Maximum Drawdown Time* – Computer Controlled Cartridge filtration BMPs should be designed to drawdown within 48 hours.

(11) *Safety Considerations* – Safety is provided either by fencing of the facility or by managing the contours of the pond to eliminate dropoffs and other hazards. Earthen sideslopes should not exceed 3:1 (H:V) and should terminate on a flat safety bench area. Landscaping can be used to impede access to the facility. The primary spillway opening must not permit access by small children and large outfall pipes should be fenced.

(12) *Landscaping and Stabilization* – The areas adjacent to the pond must be suitably stabilized using a combination of landscaping in addition to synthetic stabilization systems so that they will maintain themselves during the wetting and drying operations of the pond.

(13) *Filtration Chamber Discharge l* The filtration chamber discharge pipe (from underdrain piping) shall be extended and/or connected to a permitted discharge point for the treatment basin such that filtered effluent may flow by gravity at all times to discharge. For discharge conditions requiring pumping , provide a wet well to collect the effluent from the underdrain piping by gravity. A power company connection will be required for the sump pump. Insure that the discharge point from the sump pump is installed in a suitable location.

3.4.12 Wet Vaults

Wet vaults are normally proprietary systems designed by the various manufacturers. This guidance document has no specific suggestions on the internal configuration of these units. The only requirement in order to achieve the TSS removal calculated in Section 3.3.2 is that the device be able to accept without bypass the runoff from a 1.1 inch/hour rainfall from the tributary area.

When considering these devices for implementation, it should be noted that a broad, shallow device with a large surface area will achieve greater TSS removal than a facility with the same volume, but which is deeper. It is recommended, but not required, that the device implemented has an internal configuration that will promote uniform flow through the device and have baffles or other geometric features to trap litter and other floating material.

3.4.13 Permeable Concrete

Permeable concrete consists of concrete that is made without the fine (sand) fraction. Eliminating the sand increases the permeability, but greatly reduces the strength. Several manufacturers produce additives to increase the strength so that it is comparable to that achieved with a standard concrete mix. The lack of sand fraction also has the effect of substantially shortening the time for the concrete to setup and may make it difficult to get a consistent texture. Anyone considering this material should have highly detailed specifications and ensure that an experienced contractor is used for the work to minimize potential problems.

Permeable concrete areas must be constructed so that all runoff from adjacent areas such as landscaping, rooftops, etc. is directed away from the permeable pavement. This system may only treat the rainfall that falls directly on the surface of the concrete.

Permeable concrete may only be used in the contributing zone. Parking lots constructed with permeable concrete should be provided with curbs. These curbs must be configured in such a way as to store the required rainfall treatment depth (1.64 inches) on the surface of the parking lot in case the concrete becomes plugged. When permeable concrete is used for sidewalks or residential driveways no edging is required. In no case should runoff from other portions of the tract including roofs and landscaped areas be allowed to run onto the permeable concrete surface.

There are two possible configurations of permeable concrete: with and without an underdrain. Systems constructed with an underdrain should include a layer of sand to filter the stormwater prior to surface discharge. This type of system does not require an impermeable liner. Its TSS removal efficiency is assumed to be the same as a sand filter (89%).

Permeable concrete systems without an underdrain treat stormwater runoff via filtration with an appropriate soil layer located beneath the pavement as described in a subsequent section. TSS removal is assumed to be the same as a retention/irrigation system (100%).

MATERIALS:

Cement: Portland Cement Type I or II conforming to ASTM C 150 or Portland Cement Type IP or IS conforming to ASTM C 595.

Aggregate: Use Texas Department of Transportation (TxDOT) grade No. 8 coarse aggregate (3/8 to No. 16) per ASTM C 33; or No. 89 coarse aggregate (3/8 to No. 50) per ASTM D 448.

Admixtures: Optional

Water: Potable or should comply with TxDOT Standard Specifications

Base Material: The design of the water quality functions of the pavement system depends on adequate storage volume within the base material. The gravel layers should consist of clean, durable, uniformly graded rock meeting the ASTM C-33 specifications for No. 4 aggregate. The sand layer in systems with an underdrain should meet ASTM C-33 specifications for fine aggregate.

PROPORTIONS:

Cement Content: For pavements subject to vehicular traffic loading, the total cementitious material shall not be less than 564 lbs. per cubic yard

Aggregate Content: The volume of aggregate per cubic yard shall be equal to 27 cubic feet when calculated as a function of the unit weight determined in accordance with ASTM C 29 jigging procedure.

Admixture: Optional for strength.

Mix Water: Mix water quantity shall be such that the cement paste displays a wet metallic sheen without causing the paste to flow from the aggregate. (Mix water quantity yielding a cement paste with a dull-dry appearance has insufficient water for hydration.) Insufficient water results in inconsistency in the mix and poor aggregate bond strength. High water content results in the paste sealing the void system primarily at the bottom and poor aggregate surface bond.

Permeable Concrete with Underdrain and Surface Discharge

Base material should consist of the materials and configuration shown in Figure 3-32. The thickness of the concrete should be sufficient to bear expected loads.

Lateral Flow Barriers: Lateral flow barriers should be installed using a liner of PE or PVC that is at least 16 mils thick normal to the direction of flow to prevent flow of water downstream and then surfacing at the toe of the permeable pavement installation. The maximum distance (Lmax) between cutoff barriers should not exceed that shown in Figure 3-32.

Geotextile Fabric: The sand and gravel layers should be separated by a layer of geotextile fabric complying with the minimum specifications in Table 3-7. The purpose of the fabric is to prevent migration of fine material from the sand layer into the gravel. Geotextile fabric must overlap a minimum of 18 inches.

Underdrain Piping: The underdrain pipe should consist of 3 to 4 inch diameter Schedule 40 PVC. Perforations should be 3/8 inches in diameter and maximum spacing between perforations should not exceed six inches.

Impermeable Liner: An impermeable liner is provided only in the bottom of the underdrain trench when required to provide a flow barrier for installations that are not level.

Subsoil: The subsoil must be natural soil without waste, debris, or material that might leach chemicals into the subsurface. If fill material is required below the pavement, it must be clean and free of deleterious material. It must meet all geotechnical specifications for structural support.

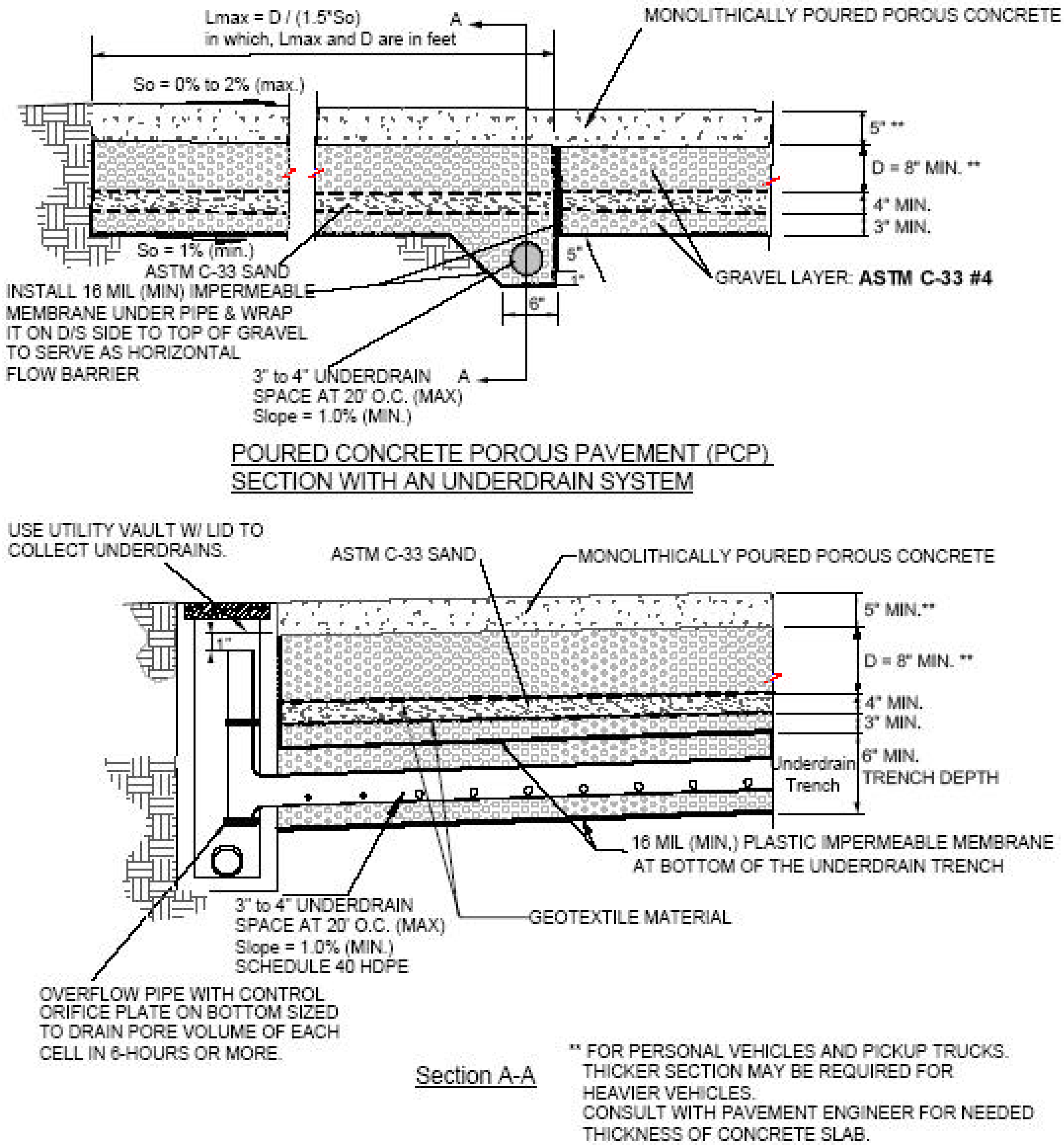


Figure 3-32 Schematic of Permeable Concrete Installation (after UCFCD, 2004)

Recommendations for Permeable Concrete without Underdrain

Base Material: Base material must consist of clean, durable, ASTM C-33 No. 4 aggregate 8 inches thick.

Geotextile Fabric: A layer of geotextile fabric complying with the minimum specifications in Table 3-7 is to be placed on top of the natural subsoil prior to placing base material. The fabric should extend up the natural earth sides and over the top of any adjacent berm. The purpose of the fabric is to prevent migration of fine material from the subsoil into the gravel.

Subsoil: Soil exploration must demonstrate a minimum of 12 inches of subsoil below the base material at every sample location. Soil tests must be conducted on the greater of 2 samples for each identified soil type, or 1 sample per 50,000 square feet of infiltration area. The subsoil must be natural soil without waste, debris, or material that might leach chemicals into the subsurface. If fill material is required below the pavement, it must be clean and free of deleterious material and have a texture comparable to natural soil at the site. Rocky soils are acceptable; however, the coarse material (diameter greater than 0.5 inches) should not account for more than 30% of the soil volume of either soil or fill material.

The subgrade must not be compacted or subjected to construction vehicle traffic prior to the placement of base. Subgrade work must be sequenced to minimize passes of construction vehicles in the beds themselves. If the excavated subgrade is exposed to rainfall runoff, it may accumulate fines. These must be removed prior to geotextile fabric and base placement. Grading should not occur during wet soil conditions to minimize smearing and sealing of the soil surface. If such sealing occurs, the surface must be scarified to restore natural texture and permeability.

3.5 Maintenance Guidelines

3.5.1 Maintenance Plan

A maintenance plan developed by the design engineer and acceptable to the TCEQ will be required prior to approval of the Water Pollution Abatement Plan (WPAP). The following information should be included in the proposed maintenance plan.

(1) Specification of routine and non-routine maintenance activities to be performed;

(2) A schedule for maintenance activities;

(3) Provision for access to the tract by TCEQ or other designated inspectors; and,

(4) Name, qualifications and contact information for the party(ies) responsible for maintaining the BMP(s).

(5) The plan should be signed and dated by the party responsible for maintenance.

3.5.2 General Guidelines

The ability and the commitment to maintain stormwater management facilities are necessary for the proper operation of these facilities. The designer must consider the maintenance needs and the type of maintenance that will take place, in order to provide for adequate access to and within the facility site.

To help stormwater management planners, designers, and reviewers include system maintenance, specific maintenance considerations were developed by Livingston et al (1997). These considerations, which were originally developed for the New Jersey Department of Environmental Protection's *Stormwater Management Facility Maintenance Manual*, should be considered whenever a stormwater management practice is pondered, planned, designed, or reviewed. The facility designer should pretend that they must do the maintenance to see if access and maintainability are provided.

Maintainability and facility access are particularly important issues if a proposed BMP will be installed below grade and covered. This type of configuration is becoming more common in space constrained areas and the maintenance plan should specify how these issues are addressed. In addition, these facilities may be considered as "confined space" requiring special equipment to enter and maintain according to OSHA and other regulatory agencies.

Maintainability

Maintainability can be expressed in three ways, all of which should be given equal importance by facility designers and reviewers:

- Every effort should be made to minimize the amount and frequency of regular maintenance at a stormwater management system.
- Performance of the remaining maintenance tasks should be as easy to perform as possible.
- All efforts should be made to eliminate the need for emergency or extraordinary maintenance at the facility.

Recommended techniques for accomplishing these goals, which can be used to both select the most appropriate type of BMP, as well as design and review it, are presented below.

Accessibility

According to many maintenance personnel, the biggest problem they encounter is not the amount or frequency of maintenance they must perform, but the difficulties they have in simply reaching the location of the required maintenance work. In order for proper maintenance to be performed, the various components of the stormwater system and, indeed, the facility itself, must be accessible to both maintenance personnel and their equipment and materials. Physical barriers such as fences, curbs, steep slopes, and lack of adequate and stable walking, standing, climbing, and staging areas can seriously hinder maintenance efforts and drastically increase maintenance difficulty, cost, time, and safety hazards. Amenities such as depressed curbs, hand and safety rails, gates, access roads, hatches, and manholes will expedite both inspection and maintenance efforts and help hold down costs and improve efficiency.

Important design considerations for components such as gates, hatches, manholes, trash racks, and other components that must be lifted or moved during inspection or maintenance operations, include both the item's weight and a secure place to put it when it's not in its normal location. When weight becomes excessive, mechanical aids such as hoists, lifts, and lifting hooks should be provided. When fastening removable items like trash racks, orifice and weir plates, and gratings, the use of noncorroding, removable, and readily accessible fasteners will also help greatly.

Sometimes design considerations may conflict. For example, in designing access roads, they must have the proper turning radius, slope, and wheel loading to allow cleaning of a pond by heavy construction equipment. The road's storm drain covers, designed for the desired wheel loading, may be too heavy to move easily. Perhaps a different access way may need to be provided.

Finally, legal barriers such as lack of access rights or inadequate maintenance easements can stop the best maintenance efforts before they can even get started. This is especially pertinent to project reviewers, who normally have the authority to require such legal aspects of the project.

Durability

The use of strong, durable, and non-corroding materials, components, and fasteners can greatly expedite facility maintenance efforts. These include strong, lightweight metals such as aluminum for trash racks, orifice and weir plates, and access hatches; reinforced concrete for outlet structures and inlet headwalls; hardy, disease resistant vegetation for bottoms, side slopes, and perimeters; and durable rock for gabions and riprap linings. In most instances, the extra investment normally required for more durable materials will pay off over time.

3.5.3 Basin Dewatering

A common sign of failure of some BMPs is standing water long after the rain event ends. This is especially true in sand filters, dry extended detention basins, and retention basins. In addition, wet ponds may also need to be drained for maintenance purposes. The water in each of these systems can be pumped into the storm drain conveyance system downstream of the BMP as long as it has been at least 48 hours since the last rain event. This delay usually provides sufficient time for most of the pollutants to settle out of the standing water; however, the discharge of sediment laden water is not allowed at any time.

3.5.4 Sediment Disposal

Stormwater pollutants include a variety of substances that are deposited on pervious and impervious surfaces and then transported by the next rainfall. In addition, there may be connections to the stormwater system that should go to the sanitary sewer system in older urbanized areas. Consequently, a variety of contaminants that may be classified as hazardous or toxic may enter stormwater management systems. These contaminants include heavy metals, petroleum hydrocarbons, pesticides, and a variety of organic chemicals. Consequently, several federal and state laws and regulations may apply to the disposal of sediments which accumulate in stormwater systems or which are captured by street sweepers (Livingston et al., 1997).

Maintenance of BMPs frequently requires disposal of accumulated sediment and other material. These materials are normally classified as special wastes when disposed of in municipal landfills.

A Type 1 Municipal Solid Waste (MSW) landfill can accept household waste--anything else is a special waste as defined in 30 TAC 330.2 (137). Special waste is a waste that requires special handling at a Type I MSW landfill. Labeling a filter media or sediment as a special waste is not a waste characterization.

The process to obtain authorization to dispose of a special waste begins with a request for approval called the "Request for Authorization for Disposal of Special Waste TCEQ Form 0152." The request is completed by the generator and submitted to the MSW permits section of the TCEQ for Executive Director review/approval. The MSW permits section performs the review described in.30 TAC 330.136 (reviews the request and either approves, disapproves, or requires additional information).

3.5.5 Retention/Irrigation

The following guidelines should be used to develop the maintenance plan for the retention/irrigation BMP.

- *Inspections*. The irrigation system, including pumps, should be inspected and tested (or observed while in operation) to assure proper operation at least 6 times annually. Two of these inspections should occur during or immediately following wet weather. Any leaks, broken spray heads, or other malfunctions with the irrigation system should be repaired immediately. In particular, sprinkler heads must be checked to determine if any are broken, clogged, or not spraying properly. All inspection and testing reports should be kept on site and accessible to inspectors.

- *Sediment Removal.* Remove sediment from splitter box, basin, and wet wells at least two times per year or when the depth reaches 3 inches.

- *Irrigation Areas.* To the greatest extent practicable, irrigation areas are to remain in their natural state. However, vegetation must be maintained in the irrigation area such that it does not impede the spray of water from the irrigation heads. Tree and shrub trimmings and other large debris should be removed from the irrigation area.

- *Mowing.* The upper stage, side slopes, and embankment of a retention basin must be mowed regularly to discourage woody growth and control weeds. Grass areas in and around basins must be mowed at least twice annually to limit vegetation height to 18 inches. More frequent mowing to maintain aesthetic appeal may be necessary in landscaped areas. When mowing is performed, a mulching mower should be used, or grass clippings should be caught and removed.

- *Debris and Litter Removal.* Debris and litter will accumulate near the basin pump and should be removed during regular mowing operations and inspections. Particular attention should be paid to floating debris that can eventually clog the irrigation system.

- *Erosion Control.* The pond side slopes and embankment may periodically suffer from slumping and erosion, although this should not occur often if the soils are properly compacted during construction. Regrading and revegetation may be required to correct the problems.

- *Nuisance Control.* Standing water or soggy conditions in the retention basin can create nuisance conditions for nearby residents. Odors, mosquitoes, weeds, and litter are all occasionally perceived to be problems. Most of these problems are generally a sign that regular inspections and maintenance are not being performed (e.g., mowing and debris removal).

3.5.6 Extended Detention Basins

Extended detention basins have moderate to high maintenance requirements, depending on the extent to which future maintenance needs are anticipated during the design stage. Responsibilities for both routine and nonroutine maintenance tasks need to be clearly understood and enforced. If regular maintenance and inspections are not undertaken, the basin will not achieve its intended purposes.

There are many factors that may affect the basin's operation and that should be periodically checked. These factors can include mowing, control of pond vegetation, removal of accumulated bottom sediments, removal of debris from all inflow and outflow structures, unclogging of orifice perforations, and the upkeep of all physical structures that are within the detention pond area. One should conduct periodic inspections and after each significant storm. Remove floatables and correct erosion problems in the pond slopes and bottom. Pay particular attention to the outlet control perforations for signs of clogging. If the orifices are clogged, remove sediment and other debris. The generic aspects that must be considered in the maintenance plan for a detention facility are as follows:

- *Inspections.* Basins should be inspected at least twice a year (once during or immediately following wet weather) to evaluate facility operation. When possible, inspections should be conducted during wet weather to determine if the pond is meeting the target detention times. In particular, the extended detention control device should be regularly inspected for evidence of clogging, or conversely, for too rapid a release. If the design drawdown times are exceeded by more than 24 hours, then repairs should be scheduled immediately. The upper stage pilot channel, if any, and its flow path to the lower stage should be checked for erosion problems. During each inspection, erosion areas inside and downstream of the BMP should be identified and repaired or revegetated immediately.

- *Mowing.* The upper stage, side slopes, embankment, and emergency spillway of an extended detention basin must be mowed regularly to discourage woody growth and control weeds. Grass areas in and around basins should be mowed at least twice annually to limit vegetation height to 18 inches. More frequent mowing to maintain aesthetic appeal may be necessary in landscaped areas. When mowing of grass is performed, a mulching mower should be used, or grass clippings should be caught and removed.

- *Debris and Litter Removal.* Debris and litter will accumulate near the extended detention control device and should be removed during regular mowing operations and inspections. Particular attention should be paid to floating debris that can eventually clog the control device or riser.

- *Erosion Control.* The pond side slopes, emergency spillway, and embankment all may periodically suffer from slumping and erosion, although this should not occur often if the soils are properly compacted during construction. Regrading and revegetation may be required to correct the problems. Similarly, the channel connecting an upper stage with a lower stage may periodically need to be replaced or repaired.

- *Structural Repairs and Replacement.* With each inspection, any damage to the structural elements of the system (pipes, concrete drainage structures, retaining walls, etc.) should be identified and repaired immediately. These repairs should include patching of cracked concrete, sealing of voids, and removal of vegetation from cracks and joints. The various inlet/outlet and riser works in a basin will eventually deteriorate and must be replaced. Public works experts have estimated that corrugated metal pipe (CMP) has a useful life of about 25 yr, whereas reinforced concrete barrels and risers may last from 50 to 75 yr.

- *Nuisance Control.* Standing water (not desired in a extended detention basin) or soggy conditions within the lower stage of the basin can create nuisance conditions for nearby residents. Odors, mosquitoes, weeds, and litter are all occasionally perceived to be problems. Most of these problems are generally a sign that regular inspections and maintenance are not being performed (e.g., mowing, debris removal, clearing the outlet control device).

- *Sediment Removal.* When properly designed, dry extended detention basins will accumulate quantities of sediment over time. Sediment accumulation is a serious maintenance concern in extended detention dry ponds for several reasons. First, the sediment gradually reduces available stormwater management storage capacity within the basin. Second, unlike wet extended detention basins (which have a permanent pool to conceal deposited sediments), sediment accumulation can make dry extended detention basins very unsightly. Third, and perhaps most importantly, sediment tends to accumulate around the control device. Sediment deposition increases the risk that the orifice will become clogged, and gradually reduces storage capacity reserved for pollutant removal. Sediment can also be resuspended if allowed to accumulate over time and escape through the hydraulic control to downstream channels and streams. For these reasons, accumulated sediment needs to be removed from the lower stage when sediment buildup fills 20% of the volume of the basin or at least every 10 years.

3.5.7 Grassy Swales

Maintenance for grassy swales is minimal and is largely aimed at keeping the grass cover dense and vigorous. Maintenance practices and schedules should be developed and included as part of the original plans to alleviate maintenance problems in the future. Recommended practices include (modified from Young et al., 1996):

- *Pest Management*. An Integrated Pest Management (IPM) Plan should be developed for vegetated areas. This plan should specify how problem insects and weeds will be controlled with minimal or no use of insecticides and herbicides.

- *Seasonal Mowing and Lawn Care*. Lawn mowing should be performed routinely, as needed, throughout the growing season. Grass height should not exceed 18 inches. Grass cuttings should be collected and disposed of offsite, or a mulching mower can be used. Regular mowing should also include weed control practices; however, herbicide use should be kept to a minimum (Urbonas et al., 1992). Healthy grass can be maintained without using fertilizers because runoff usually contains sufficient nutrients.

- *Inspection*. Inspect swales at least twice annually for erosion or damage to vegetation; however, additional inspection after periods of heavy runoff is most desirable. The swale should be checked for uniformity of grass cover, debris and litter, and areas of sediment accumulation. More frequent inspections of the grass cover during the first few years after establishment will help to determine if any problems are developing, and to plan for long-term restorative maintenance needs. Bare spots and areas of erosion identified during semi-annual inspections should be replanted and restored to meet specifications. Construction of a level spreader device may be necessary to reestablish shallow overland flow.

- *Debris and Litter Removal*. Trash tends to accumulate in swale areas, particularly along highways. Any swale structures (i.e. check dams) should be kept free of obstructions to reduce floatables being flushed downstream, and for aesthetic reasons. The need for this practice is determined through periodic inspection, but should be performed no less than two times per year (Urbonas et al., 1992).

- *Sediment Removal*. Sediment accumulating near culverts and in channels needs to be removed when they build up to 3 inches at any spot, or cover vegetation. Excess sediment should be removed by hand or with flat-bottomed shovels. If areas are eroded, they should be filled, compacted, and reseeded so that the final grade is level with the bottom of the swale. Sediment removal should be performed periodically, as determined through inspection.

- *Grass Reseeding and Mulching*. A healthy dense grass should be maintained in the channel and side slopes. Grass damaged during the sediment removal process should be promptly replaced using the same seed mix used during swale establishment. If possible, flow should be diverted from the damaged areas until the grass is firmly established.

- *Public Education*. Private homeowners are often responsible for roadside swale maintenance. Unfortunately, overzealous lawn care on the part of homeowners can present some problems. For example, mowing the swale too close to the ground, or excessive application of fertilizer and pesticides will all be detrimental to the performance of the swale. Pet waste can also be a problem in swales, and should be removed to avoid contamination from fecal coliform and other waste-associated bacteria. The delegation of maintenance responsibilities to individual landowners is a cost benefit to the locality. However, localities should provide an active educational program to encourage the recommended practices.

3.5.8 Vegetative Filter Strips

Once a vegetated area is well established, little additional maintenance is generally necessary. The key to establishing a viable vegetated feature is the care and maintenance it receives in the first few months after it is planted. Once established, all vegetated BMPs require some basic maintenance to insure the health of the plants including:

- *Pest Management*. An Integrated Pest Management (IPM) Plan should be developed for vegetated areas. This plan should specify how problem insects and weeds will be controlled with minimal or no use of insecticides and herbicides.

- *Seasonal Mowing and Lawn Care*. If the filter strip is made up of turf grass, it should be mowed as needed to limit vegetation height to 18 inches, using a mulching mower (or removal of clippings). If native grasses are used, the filter may require less frequent mowing, but a minimum of twice annually. Grass clippings and brush debris should not be deposited on vegetated filter strip areas. Regular mowing should also include weed control practices, however herbicide use should be kept to a minimum (Urbonas et al., 1992). Healthy grass can be maintained without using fertilizers because runoff usually contains sufficient nutrients. Irrigation of the site can help assure a dense and healthy vegetative cover.

- *Inspection*. Inspect filter strips at least twice annually for erosion or damage to vegetation; however, additional inspection after periods of heavy runoff is most desirable. The strip should be checked for uniformity of grass cover, debris and litter, and areas of sediment accumulation. More frequent inspections of the grass cover during the first few years after establishment will help to determine if any problems are developing, and to plan for long-term restorative maintenance needs. Bare spots and areas of erosion identified during semi-annual inspections must be replanted and restored to meet specifications. Construction of a level spreader device may be necessary to reestablish shallow overland flow.

- *Debris and Litter Removal*. Trash tends to accumulate in vegetated areas, particularly along highways. Any filter strip structures (i.e. level spreaders) should be kept free of obstructions to reduce floatables being flushed downstream, and for aesthetic reasons. The need for this practice is determined through periodic inspection, but should be performed no less than 4 times per year.

- *Sediment Removal*. Sediment removal is not normally required in filter strips, since the vegetation normally grows through it and binds it to the soil. However, sediment may accumulate along the upstream boundary of the strip preventing uniform overland flow. Excess sediment should be removed by hand or with flat-bottomed shovels.

- *Grass Reseeding and Mulching*. A healthy dense grass should be maintained on the filter strip. If areas are eroded, they should be filled, compacted, and reseeded so that the final grade is level. Grass damaged during the sediment removal process should be promptly replaced using the same seed mix used during filter strip establishment. If possible, flow should be diverted from the damaged areas until the grass is firmly established. Bare spots and areas of erosion identified during semi-annual inspections must be replanted and restored to meet specifications. Corrective maintenance, such as weeding or replanting should be done more frequently in the first two to three years after installation to ensure stabilization. Dense vegetation may require irrigation immediately after planting, and during particularly dry periods, particularly as the vegetation is initially established.

3.5.9 Sand Filter Systems

Regular, routine maintenance is essential to effective, long-lasting performance of sand filters. Neglect or failure to service the filters on a regular basis will lead to poor performance and eventual costly repairs. It is recommended that sand filter BMPs be inspected on a quarterly basis and after large storms for the first year of operation. This intensive monitoring is intended to ensure proper operation and provide maintenance personnel with a feel for the operational characteristics of the filter. Subsequent inspections can be limited to semi-annually or more often if deemed necessary (Young et al., 1996).

Certain construction and maintenance practices are essential to efficient operation of the filter. The biggest threat to any filtering system is exposure to heavy sediment loads that clog the filter media. Construction within the watershed should be complete prior to exposing the filter to stormwater runoff. All exposed areas should be stabilized to minimize sediment loads. Runoff from any unstabilized construction areas should be treated via a separate sediment system that bypasses the filter media.

Another important consideration in constructing the filter bed is to ensure that the top of the media is completely level. The filter design is based on the use of the entire filter media surface area; a sloped filter surface would result in disproportionate use of the filter media.

Other recommended maintenance guidelines include:

- *Inspections.* BMP facilities must be inspected at least twice a year (once during or immediately following wet weather) to evaluate facility operation. During each inspection, erosion areas inside and downstream of the BMP must be identified and repaired or revegetated immediately. With each inspection, any damage to the structural elements of the system (pipes, concrete drainage structures, retaining walls, etc.) must be identified and repaired immediately. Cracks, voids and undermining should be patched/filled to prevent additional structural damage. Trees and root systems should be removed to prevent growth in cracks and joints that can cause structural damage.

- *Sediment Removal*. Remove sediment from the inlet structure and sedimentation chamber when sediment buildup reaches a depth of 6 inches or when the proper functioning of inlet and outlet structures is impaired. Sediment should be cleared from the inlet structure at least every year and from the sedimentation basin at least every 5 years.

- *Media Replacement*. Maintenance of the filter media is necessary when the draw-down time exceeds 48 hours. When this occurs, the upper layer of sand should be removed and replaced with new material meeting the original specifications. Any discolored sand should also be removed and replaced. In filters that have been regularly maintained, this should be limited to the top 2 to 3 inches.

- *Debris and Litter Removal.* Debris and litter will accumulate near the sedimentation basin outlet device and should be removed during regular mowing operations and inspections. Particular attention should be paid to floating debris that can eventually clog the control device or riser.

- *Filter Underdrain.* Clean underdrain piping network to remove any sediment buildup as needed to maintain design drawdown time.

- *Mowing.* Grass areas in and around sand filters must be mowed at least twice annually to limit vegetation height to 18 inches. More frequent mowing to maintain aesthetic appeal may be necessary in landscaped areas. Vegetation on the pond embankments should be mowed as appropriate to prevent the establishment of woody vegetation.

3.5.10 Bioretention

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

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

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

New Jersey's Department of Environmental Protection states in their bioretention systems standards that accumulated sediment and debris removal (especially at the inflow point) will normally be the primary maintenance function. Other potential tasks include replacement of dead vegetation, soil pH regulation, erosion repair at inflow points, mulch replenishment, unclogging the underdrain, and repairing overflow structures.

Other recommended maintenance guidelines include:

- *Inspections.* BMP facilities should be inspected at least twice a year (once during or immediately following wet weather) to evaluate facility operation. During each inspection, erosion areas inside and downstream of the BMP must be identified and repaired or revegetated immediately.

- *Sediment Removal*. Remove sediment from the facility when sediment depth reaches 3 inches or when the sediment interferes with the health of vegetation or ability of the facility to meet required drawdown times. Sediment removal should be performed at least every 2 years.

- *Drain Time.* When the drain time exceeds 72 hours as observed in the observation well, the filter media should be removed and replaced with more permeable material.

- *Vegetation*. All dead and diseased vegetation considered beyond treatment shall be removed and replaced during semi-annual inspections. Diseased trees and shrubs should be treated during inspections. Remulch any bare areas by hand whenever needed. Replace mulch annually in the spring, or more frequently if needed, in landscaped areas of the basin where grass or groundcover is not planted. Grass areas in and around bioretention facilities must be mowed at least twice annually to limit vegetation height to 18 inches. More frequent mowing to maintain aesthetic appeal may be necessary in landscaped areas.

- *Debris and Litter Removal*. Debris and litter will accumulate in the facility and should be removed during regular mowing operations and inspections.

- *Filter Underdrain.* Clean underdrain piping network to remove any sediment buildup every 5 years, or as needed to maintain design drawdown time.

3.5.11 Wet Basins

A clear requirement for wet basins is that a firm commitment be made to carry out both routine and non-routine maintenance tasks. The nature of the maintenance requirements are outlined below, along with design tips that can help to reduce the maintenance burden (modified from Young et al., 1996).

Routine Maintenance.

- *Mowing.* The side-slopes, embankment, and emergency spillway of the basin should be mowed at least twice a year to prevent woody growth and control weeds.

- *Inspections.* Wet basins should be inspected at least twice a year (once during or immediately following wet weather) to evaluate facility operation. When possible, inspections should be conducted during wet weather to determine if the basin is functioning properly. There are many functions and characteristics of these BMPs that should be inspected. The embankment should be checked for subsidence, erosion, leakage, cracking, and tree growth. The condition of the emergency spillway should be checked. The inlet, barrel, and outlet should be inspected for clogging. The adequacy of upstream and downstream channel erosion protection measures should be checked. Stability of the side slopes should be checked. Modifications to the basin structure and contributing watershed should be evaluated. During semi-annual inspections, replace any dead or displaced vegetation. Replanting of various species of wetland vegetation may be required at first, until a viable mix of species is established. Cracks, voids and undermining should be patched/filled to prevent additional structural damage. Trees and root systems should be removed to prevent growth in cracks and joints that can cause structural damage. The inspections should be carried out with as-built pond plans in hand.

- *Debris and Litter Removal.* As part of periodic mowing operations and inspections, debris and litter should be removed from the surface of the basin. Particular attention should be paid to floatable debris around the riser, and the outlet should be checked for possible clogging.

- *Erosion Control.* The basin side slopes, emergency spillway, and embankment all may periodically suffer from slumping and erosion. Corrective measures such as regrading and revegetation may be necessary. Similarly, the riprap protecting the channel near the outlet may need to be repaired or replaced.

- *Nuisance Control.* Most public agencies surveyed indicate that control of insects, weeds, odors, and algae may be needed in some ponds. Nuisance control is probably the most frequent maintenance item demanded by local residents. If the ponds are properly sized and vegetated, these problems should be rare in wet ponds except under extremely dry weather conditions. Twice a year, the facility should be evaluated in terms of nuisance control (insects, weeds, odors, algae, etc.). Biological control of algae and mosquitoes using fish such as fathead minnows is preferable to chemical applications.

<u>Non-routine maintenance</u>.

- *Structural Repairs and Replacement.* Eventually, the various inlet/outlet and riser works in the wet basin will deteriorate and must be replaced. Some public works experts have estimated that corrugated metal pipe (CMP) has a useful life of about 25 yr, while concrete barrels and risers may last from 50 to 75 yr. The actual life depends on the type of soil, pH of runoff, and other factors. Polyvinyl chloride (PVC) pipe is a corrosion resistant alternative to metal and concrete pipes. Local experience typically determines which materials are best suited to the site conditions. Leakage or seepage of water through the embankment can be avoided if the embankment has been constructed of impermeable material, has been compacted, and if anti-seep collars are used around the barrel. Correction of any of these design flaws is difficult.

- *Sediment Removal.* Wet ponds will eventually accumulate enough sediment to significantly reduce storage capacity of the permanent pool. As might be expected, the accumulated sediment can reduce both the appearance and pollutant removal performance of the pond. Sediment accumulated in the sediment forebay area should be removed from the facility every two years to prevent accumulation in the permanent pool. Dredging of the permanent pool should occur at least every 20 years, or when accumulation of sediment impairs functioning of the outlet structure.

- *Harvesting.* If vegetation is present on the fringes or in the pond, it can be periodically harvested and the clippings removed to provide export of nutrients and to prevent the basin from filling with decaying organic matter.

3.5.12 Constructed Wetland

Constructed wetlands, like wet basins, require a firm commitment be made to carry out both routine and non-routine maintenance tasks. The nature of the maintenance requirements are outlined below (modified from Young et al., 1996).

Routine Maintenance.

- *Mowing.* The side slopes, embankment, and emergency spillway of a wetland must be mowed at least twice a year to control weeds.

- *Inspections.* Wetlands should be inspected at least twice a year (once during or immediately following wet weather) to evaluate facility operation. When possible, inspections should be conducted during wet weather to determine if the BMP is functioning properly. There are many functions and characteristics of wetlands that should be inspected. The embankment should be checked for subsidence, erosion, leakage, cracking, animal burrows, and tree growth. The condition of the emergency spillway should be checked. The inlet and outlet should be inspected for clogging. The adequacy of upstream and downstream channel erosion protection measures should be checked. Stability of the side slopes should be checked. During semi-annual inspections, replace any dead or displaced vegetation. Replanting of various species of wetland vegetation may be required at first, until a viable mix of species is established. During semi-annual inspections, the water level should be checked in the monitoring well. At least one of the inspections should occur during the summer. If insufficient water levels are found, supplemental water should be supplied, and the well rechecked monthly during the dry season. Concrete structures should be inspected and cracks, voids and undermining should be patched/filled to prevent additional structural damage.

- *Debris and Litter Removal.* As part of periodic mowing operations and inspections, debris and litter should be removed from the wetland to prevent clogging of any outlet. Also, the wetland will be more aesthetically pleasing if trash and debris are removed on a regular basis (Urbonas et al., 1992).

- *Erosion Control.* The wetland side slopes, emergency spillway, and embankment all may periodically suffer from slumping and erosion. Corrective measures such as regrading and revegetation may be necessary. Similarly, the riprap protecting the channel near the outlet may need to be repaired or replaced.

- *Nuisance Control.* Most public agencies surveyed indicate that control of insects, weeds, odors, and algae may be needed in some wetlands. Nuisance control is probably the most frequent maintenance item demanded by local residents. Twice a year, the facility should be evaluated in terms of nuisance control (insects, weeds, odors, algae, etc.). Biological control of algae and mosquitoes using fish such as fathead minnows is preferable to chemical applications. This is extremely important with wetlands, as pesticides are likely to adversely affect the microorganisms that are responsible for much of the pollutant removal.

Non-routine maintenance.

- *Structural Repairs and Replacement.* Eventually, the various inlet/outlet and riser works in a wetland will deteriorate and must be replaced. Some public works experts have estimated that corrugated metal pipe (CMP) has a useful life of about 25 yr, while concrete barrels and risers may last from 50 to 75 yr. The actual life depends on the type of soil, pH of runoff, and other factors. Polyvinyl chloride (PVC) pipe is a corrosion resistant alternative to metal and concrete pipes. Leakage or seepage of water through the embankment can be avoided if the embankment has been constructed of impermeable material, has been compacted, and if anti-seep collars are used around the barrel. Correction of any of these design flaws is difficult.

- *Sediment Removal.* During semi-annual inspections, sediment should be removed from the inlet structure/sediment forebay, or when sediment depth reaches 3 inches, or when sediment interferes with the health of the vegetative community. Accumulated sediment and muck in the remainder of the wetland should be removed every 10 to 15 yr, or as needed based on inspection. The growth zone depths and spatial distribution should be maintained (Urbonas et al., 1992).

- *Harvesting.* Harvesting of cattails, reeds and other plants will permanently remove some nutrients from the wetland area. Plants may be harvested manually or mechanically, depending on the wetland area.

3.5.13 AquaLogic Cartridge Filter System

Cartridge Filters require regular routine maintenance; however, the key element in the maintenance program is timely replacement of the filter cartridges. Each time a set of filter cartridges is removed and replaced, the sediment load is also removed. It is also important to check and verify that the other elements of the overall treatment system are functioning properly in order to extend the life of the filter cartridges. It is recommended that cartridge filter BMPs be inspected on a monthly basis and after each rainfall event for the first year of operation. After the first year, maintenance personnel will have a feel for the operational characteristics of the filter and subsequent inspections can be reduced if warranted.

The biggest threat to any filtering system is the exposure to heavy sediment loads that clog the filter media. In order to avoid premature exposure to a heavy sediment load, construction within the contributing watershed should be complete prior to exposing the filter to stormwater runoff. All exposed areas should be stabilized to minimize sediment loads and runoff from unstabilized construction areas should be routed around the filter and treated separately.

Other recommended maintenance guidelines include:

- *Inspections*. BMP facilities should be inspected at least twice a year (once during or immediately following wet weather) to evaluate facility operation. During each inspection, erosion areas inside and downstream of the BMP must be identified and repaired or revegetated immediately. With each inspection, any damage to the structural elements of the system (pipes, concrete drainage structures, retaining walls, etc.) must be identified and repaired immediately. Cracks, voids and undermining should be patched/filled to prevent growth in cracks and joints that can cause structural damage.

- *Sediment Removal*. Remove sediment from the inlet structure, sedimentation chamber and filtration chamber after each rainfall event. Sediment removal from the filtration basin is accomplished by removal and replacement of the filter cartridge set. Sediments found adhering to sidewall surfaces should be removed at least every quarter.

- *Media Replacement*. Filter cartridges should be replaced after 2 significant rainfall events or when the drawdown time exceeds 48 hours. The geotextile wrapping around the filter canisters should be inspected each time the filters are changed and should be replaced if damage or permanent clogging is observed.

- *Debris and Litter Removal*. Debris and litter will accumulate near the sedimentation basin outlet device and should be removed during regular clean-up operations and inspections. Particular attention should be paid to floating debris that can eventually clog the control valve.

- *Filter Underdrain*. Clean the underdrain piping network to remove any sediment buildup at least every two years, or as needed to maintain the design drawdown time.

- *Mowing*. Grass areas in and around cartridge filters must be mowed at least twice annually to limit vegetation height to 18 inches. More frequent mowing to maintain aesthetic appeal may be necessary in landscaped areas.

- *Bladder Control Valve.* The bladder control valve should be checked for proper operation in automatic and manual mode at least once per quarter. Should any operational problems be found repairs or replacement should be completed immediately.

- *Filtration Chamber Outfall*. The outfall point should be inspected at least once per quarter to insure that the discharge is leaving the filter by gravity.

- *Filter Canisters.* Clean the filter canisters at least once per quarter. Replace any damaged canisters immediately.

- *Controls*. Verify that all controls are functioning correctly at least once per month and after each rainfall event. Repair or replace any components that are inoperative.

- *Security Fencing.* Check and verify that the BMP facility site is secure at least once per month. Any site found to be insecure should be made secure immediately.

3.5.14 Wet Vaults

Wet vaults require regular inspection and must be cleaned when necessary to ensure optimum performance. The rate at which each system collects pollutants will often depend more on site activities that the size or type of unit. For example, watershed construction activities, or heavy winter sanding will cause sediments to accumulate at a more rapid rate.

Inspection is a vital component of an effective maintenance program. Visual inspection by maintenance crew must be performed to evaluate the volume of accumulated sediment. Such inspection must be performed on a quarterly basis. To avoid underestimating the volume of sediment in the chamber, a stadia rod or other measuring device must be lowered to the top of the sediment pile carefully. Fine, silty particles at the top of the sediment pile may offer less resistance to the end of the rod than larger particles toward the bottom of the pile. As an alternative, remote sensing or remote telemetry technology may be substituted for visual inspection, provided that an accurate assessment of the accumulated sediment depth is achieved.

Cleaning of structures should be performed when one third of the grit chamber or sedimentation chamber has been filled. It is preferable to clean structures when there is no flow passing through the system. Cleanout with a vacuum truck is the most effective and convenient method of excavating pollutants. A backhoe or clamshell grab may be used in cleaning some devices, but these are generally less effective than vacuuming. Sediments and other pollutants must be disposed of in accordance with Commission policy.

Motor oil and other hydrocarbons that accumulate on a routine basis should be removed when an appreciable layer has formed. It may be preferable to use adsorbent pads for collection of oil instead of vacuuming the oil-water emulsion.

- *Inspections.* Wet vaults should be inspected at least quarterly to evaluate facility operation. When possible, inspections should be conducted during wet weather to determine if the BMP is functioning properly. Concrete structures should be inspected and cracks, voids and undermining should be patched/filled to prevent additional structural damage.

- *Debris and Litter Removal.* Debris, litter, and sediment removal should occur when it accumulates to 1/3 of the sump volume to prevent resuspension.

- *Nuisance Control.* Standing water within wet vaults may become a location of mosquito breeding. The facility should be evaluated at least twice a year to determine if mosquito control is needed.

3.5.15 Permeable Concrete

The largest clogging threats to the system occur during construction and from landscaping. During initial or remodeling construction, contractors may use pavement areas to store materials such as sand, gravel with fines, soil or landscape materials containing fines. The owner or supervising contractor must require all contractors to protect the pavement using heavy Visqeen or plywood under such piles and to cover all piles to prevent blowing and or washing away of such materials.

The proximity of landscape ground covers such as mulch, dirt or other fine materials also present a risk of clogging. Buoyant fines may float during heavy rain showers or during watering. Heavier fines may be washed onto the pavement from storm runoff.

The pavement system must be protected from landscape clogging by either grading to prevent run-on to the pavement, or by adding a filtering area between any mulch or dirt surface and the pavement. The filter area may be any well-vegetated surface, including turf. A combination of grading to prevent run-on and a filter area provides the best assurance of long-term system permeability and functionality.

It is recommended that signs be posted in landscape areas and at entrances to the property as reminders of an ecologically sensitive pavement structure and that certain guidelines be adhered to including:

- No piling of dirt, sand, gravel or landscape material without covering the pavement first with a durable cover to protect the integrity of the pervious surface.
- All landscape cover must be graded to prevent washing and or floating of such materials onto or through the pervious surface.

- All chemical spills inclusive but not limited to petrochemicals, hydrocarbons, pesticides and herbicides should be reported to the owner so they can prevent uncontrolled migration. Chemical migration control may require flushing, and/or the introduction of microbiological organisms to neutralize any impacts to the soil or water.

The surface of parking lots should be swept at least twice per year with a vacuum type street sweeper to remove surface accumulations of sediment and other material. Pressure washing may also prove to be effective if the resulting water is immediately vacuumed from the surface.

Ponding of water on the surface of the permeable concrete indicates that more intensive maintenance is required to restore the system permeability. This may include removing and replacing the concrete or base material.

3.6 Erosion Prevention

The Edwards Aquifer rules require that a technical report must be submitted which, among other things, requires that measures taken to avoid or minimize the in-stream effects caused by the regulated activity be described. In-stream effects include increased stream flashing, stronger flows, and erosion. It is widely recognized that development increases the rate and volume of stormwater runoff. These changes increase the rate of channel erosion downstream of the development. For instance, channel erosion accounts for up to 90% of the TSS load in urban streams. Measures taken to reduce TSS loads in runoff from the site often mitigate these impacts to a large extent.

Studies of the morphology and hydrology of Austin area creeks (Raymond Chan & Associates, et al., 1997) indicate that the majority of erosion occurs during storms with return periods of less than one year. The study also indicates that relatively brief, intense storm events are responsible. Consequently, detention of the 1-year, 3-hour event with release of the captured water over a period of 24 hours will mitigate the most serious channel erosion problems. Table 3-8 lists the storm depth for each county for this size event.

Table 3-8 One-year, Three-hour Storm by County (TxDOT, 1998)

County	Precipitation (in)
Bexar	1.91
Comal	1.94
Hays	1.94
Kinney	1.68
Medina	1.84
Travis	1.93
Uvalde	1.72
Williamson	1.92

Grassy swales and vegetated filter strips do not provide significant protection against stream channel erosion resulting from development. Although stormwater infiltration in these BMPs can reduce to the total amount of runoff discharged, the volume reduction is generally not large because of the fined grained, low permeability soils in this area. Although not required in the rules, providing supplemental detention when using these types of BMPs would help prevent downstream erosion and flooding problems.

Channel and bank erosion can also occur where concentrated stormwater runoff discharged from a BMP or storm drain system enters a natural channel. At these sites, appropriate energy dissipation must be incorporated in the design.