2I-1 General Information for Vegetated Swale Systems

A. Introduction

Vegetated swale (open channel) systems are practices explicitly designed to capture and treat the full water quality volume (WQv) within dry or wet cells formed by check dams or other means and include systems designed to convey and treat either shallow flow (swales) or sheet flow (filter strips) runoff. These BMPs are commonly referred to as biofilters, since the grasses and vegetation filter the stormwater runoff as it flows through and/or over the vegetated surface (U.S. EPA, 1999b). A degree of treatment, storage, and infiltration can be provided by conveying stormwater runoff in vegetated systems and can help to reduce the overall volume of stormwater runoff generated from a project drainage area. Open channel vegetated systems can be an effective alternative to traditional curb-and-gutter and storm sewer conveyance systems.

Vegetated swales (also known as bio-swales, enhanced swales, or water quality swales) are vegetated open channels that receive directed flow and convey stormwater. Swales intercept both sheet and concentrated flows and convey these flows in a concentrated, vegetation-lined channel.

Filter strips (also known as bio-filtration strips or vegetated filter strips (VFS) are vegetated sections of land over which stormwater flows as overland sheet flow. Grass filter strips intercept sheet runoff from the impervious network of streets, parking lots, and rooftops, and divert stormwater to a uniformly-graded meadow, buffer zone, or another downstream structural BMP.

Vegetated swales and vegetated filter strips can function as pre-treatment systems for water entering bioretention system or other BMPs. If these systems are to succeed in filtering pollutants from the water column, the planting design must consider the hydrology, soils, and maintenance requirements of the site. Removal of pollutants is accomplished through the process of filtration by vegetation, sedimentation, adsorption onto soil particles, infiltration into the soil surface, and deeper percolation into the soil strata. Vegetated strips and swales are primarily effective at removing debris and suspended solids. Dissolved materials are primarily removed by adsorption within the soil profile.

B. Types of vegetated practices

1. **Vegetated swales.** A vegetated swale is an infiltration and filtration method that is typically used to provide pre-treatment before stormwater runoff is discharged to treatment systems. There are three types of vegetated swales:

    a. **Grass swales.** A grass swale, frequently referred to as a grassed waterway, is a broad and shallow earthen channel vegetated with erosion-resistant and flood-tolerant grasses. Grass swales have traditionally been used as a low-cost stormwater conveyance practice in low-to-medium density residential developments (e.g., ¼ to ½ -acre lots) to safely move concentrated flow and as a pre-treatment practice upstream of other BMPs. A number of Iowa jurisdictions have typical rural road section standards that allow the use of grass swales within the public right-of-way. Figure 1 provides a representative typical section, including both a cross section and plan view of a grass swale.

b. **Dry swale with filter media.** The dry swale (or bio-swale) consists of an open channel that has been modified to enhance its water quality treatment capability by adding a filtering medium consisting of a soil bed with an underdrain system (CRC, 1996). The dry swale system is sized to accept the entire WQv and allow it to be filtered through the treatment medium and/or infiltrate through the bottom of the swale. The dry swale system is designed to drain down between storm events within about one day. Since this system is dry most of the time, it is the preferred system for residential applications. The water quality treatment mechanisms are similar to bioretention practices, except that the pollutant uptake is likely to be more limited since only a grass cover crop is available for nutrient uptake. Figure 2 illustrates the design components of the dry swale with filter media (MDE, 2000).

c. **Wet swales.** The wet swale (or wetland channel) also consists of a broad open channel capable of temporarily storing the WQv, but does not have an underlying filtering bed (CRC, 1996). The wet swale is constructed directly within existing soils and may or may not intercept the water table. Like the dry swale, the WQv within the wet swale should be stored for approximately 24 hours. The wet swale has water quality treatment mechanisms similar to stormwater wetlands, which rely primarily on settling of suspended solids, adsorption, and uptake of pollutants by vegetative root systems. These systems are often called wetland channel systems since they are basically a linear shallow wetland system. Figure 3 illustrates the design components of the wet swale (MDE, 2000).

Vegetated grass swales have a number of desirable attributes with respect to total stormwater management (MDE, 2000, ASCE, 1998, CRC, 1996 and Yu, 1993). These attributes include:

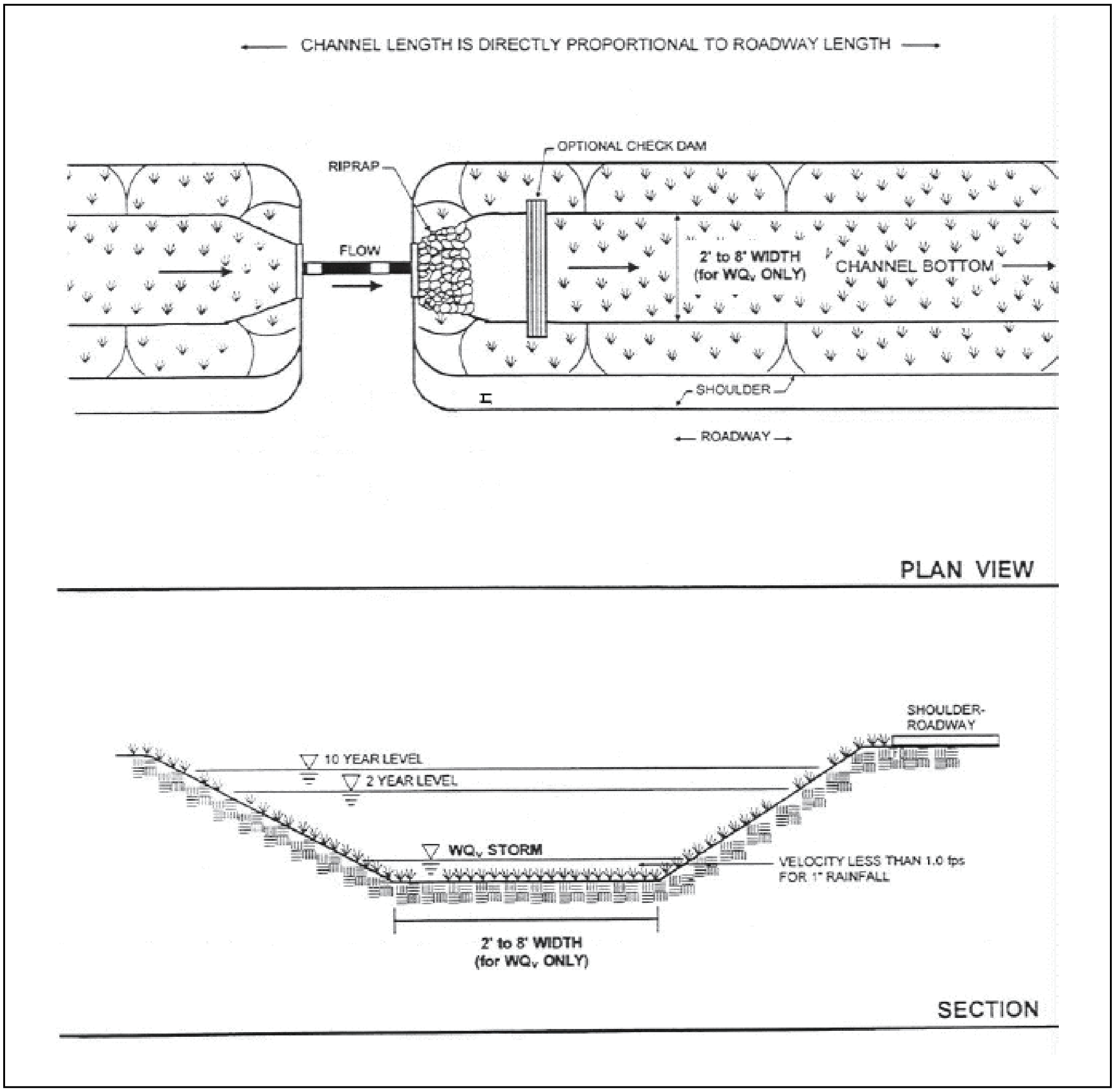
- Slower flow velocities than pipe systems, resulting in longer times of concentration and corresponding reduction of peak discharges.
- Ability to disconnect directly connected impervious surfaces such as driveways and roadways, thus reducing the computed runoff curve number (CN) and peak discharge (see Part 2C).
- Filtering of pollutants by grass media and infiltration of runoff into the soil profile, thus reducing peak discharges and providing additional pollutant removal.
- Uptake of pollutants by plant roots.

2. **Vegetative filter strips and buffers.** Vegetated filter strips (VFS) are areas of land with vegetative cover that are designed to accept runoff as overland sheet flow from upstream development. They can be constructed or existing vegetated buffer areas can be used. Dense vegetative cover facilitates sediment attenuation and pollutant removal. Unlike grass swales, VFS are effective only for overland sheet flow and provide little treatment for concentrated flows. Grading and level spreaders can be used to create a uniformly-sloping area that distributes the runoff evenly across the filter strip (Haan et al., 1984, Hayes et al., 1984, Barfield and Hayes, 1988 and Dillaha et al., 1989). Filter strips have been used to treat runoff from roads and highways, roof downspouts, very small parking lots, and pervious surfaces. Filter strips are often used as pre-treatment for other structural practices, such as infiltration basins and infiltration trenches. Figure 4 illustrates the primary design components of the filter strip (CRC, 1996).

3. **Bioretention.** The bioretention concept was originally developed as an alternative to traditional BMP structures (Clar et al., 1993 and 1994). Bioretention is a practice that manages and treats stormwater runoff using a conditioned planting soil bed and planting materials to filter runoff stored within a shallow depression. The method combines physical filtering (filtration process), adsorption with biological processes; and, on sites with moderately permeable soils, some portion of the WQv in these systems can be infiltrated into the soil profile. The system consists of a flow regulation structure, pre-treatment filter strip or grass swale, sand bed, pea gravel overflow

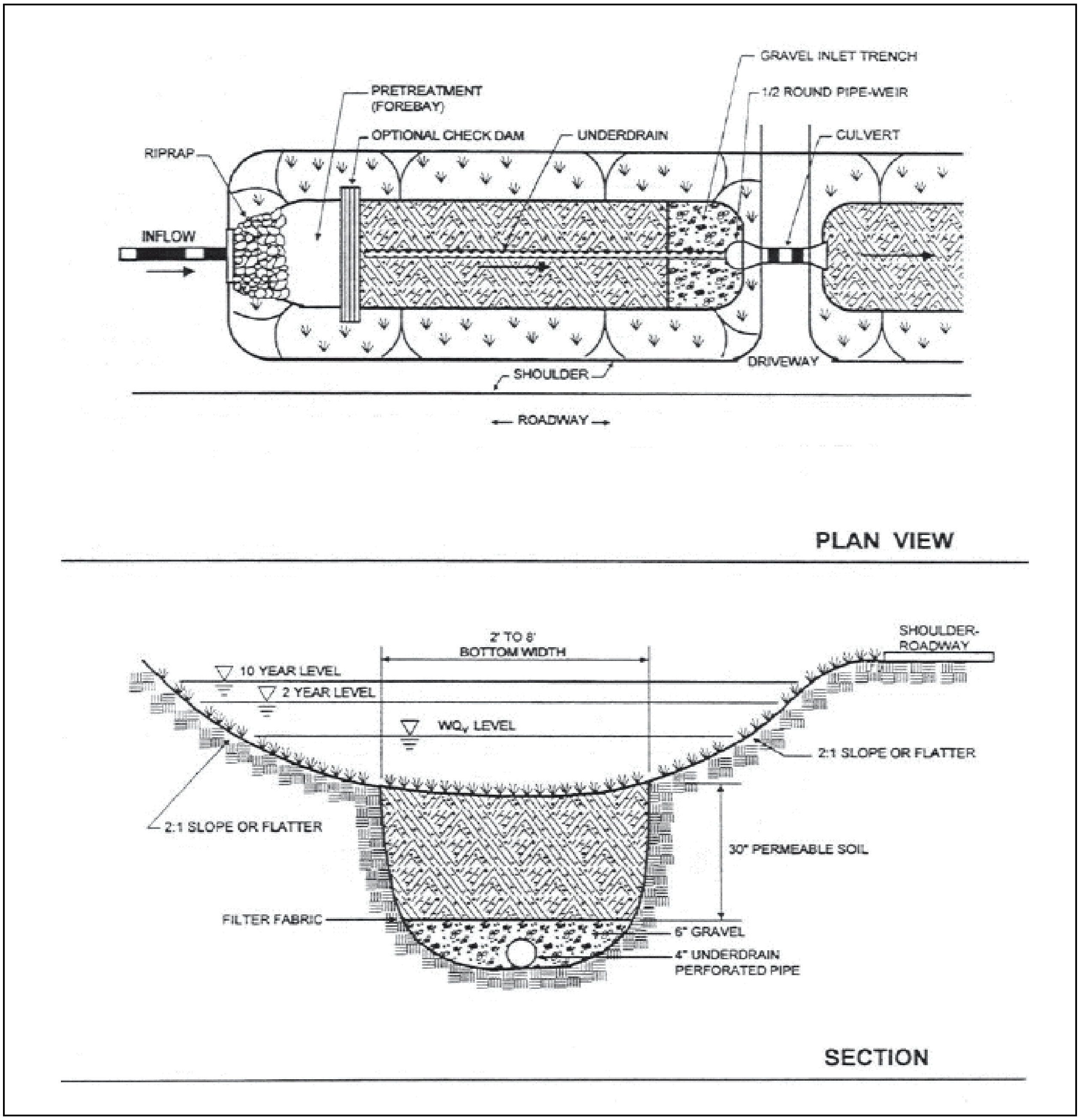
curtain drain, shallow ponding area, surface organic layer of mulch, planting soil bed, plant material, gravel underdrain system, and an overflow system. A more detailed description and design procedure for bioretention systems is included in Part 2E. The primary design components of the bioretention system are included in Figure 5 for comparison to the other vegetated systems (MDE, 2000).

Figure 1: Grass swale



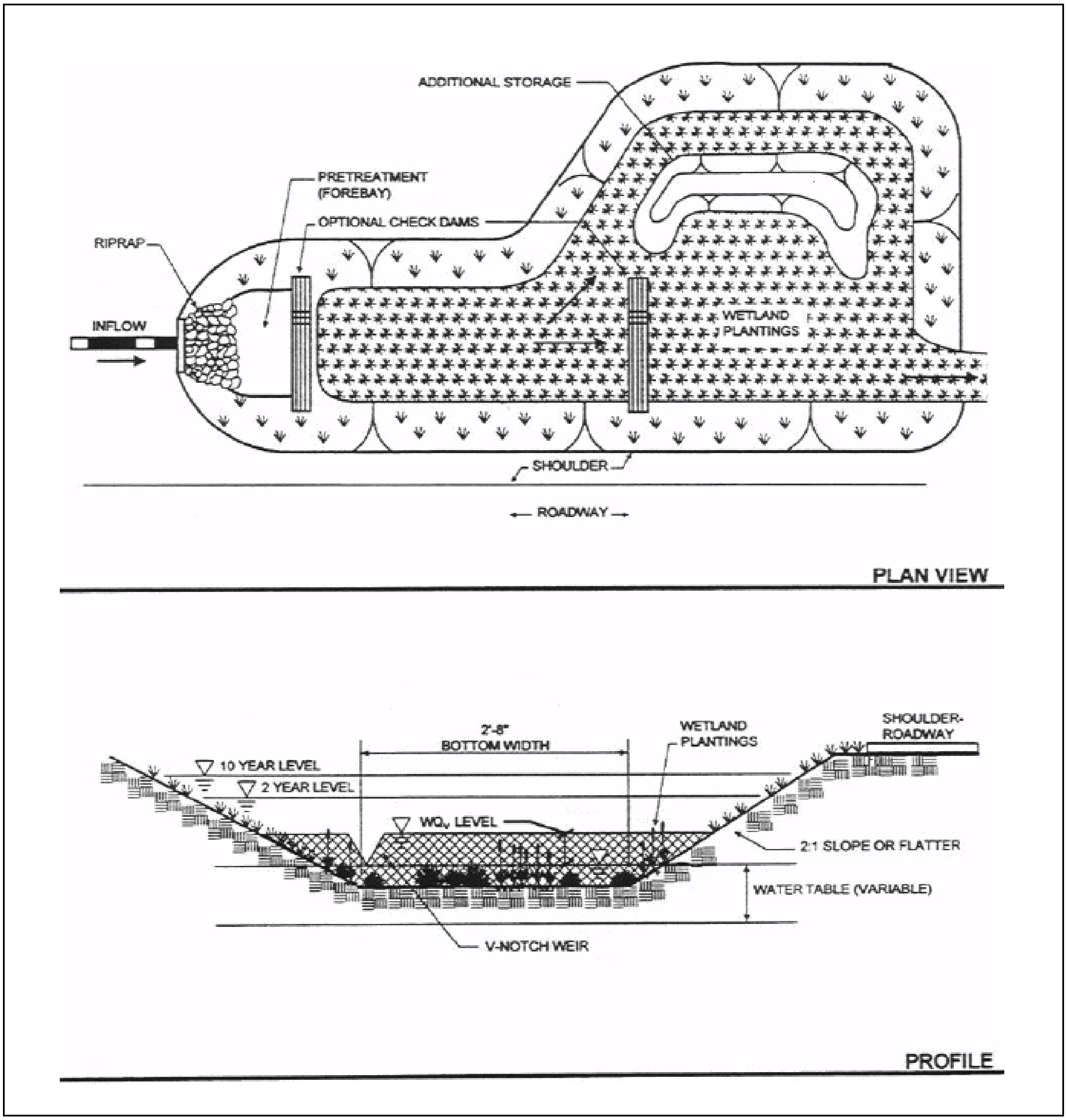
Source: MDE, 2000

Figure 2: Dry swale with filter media



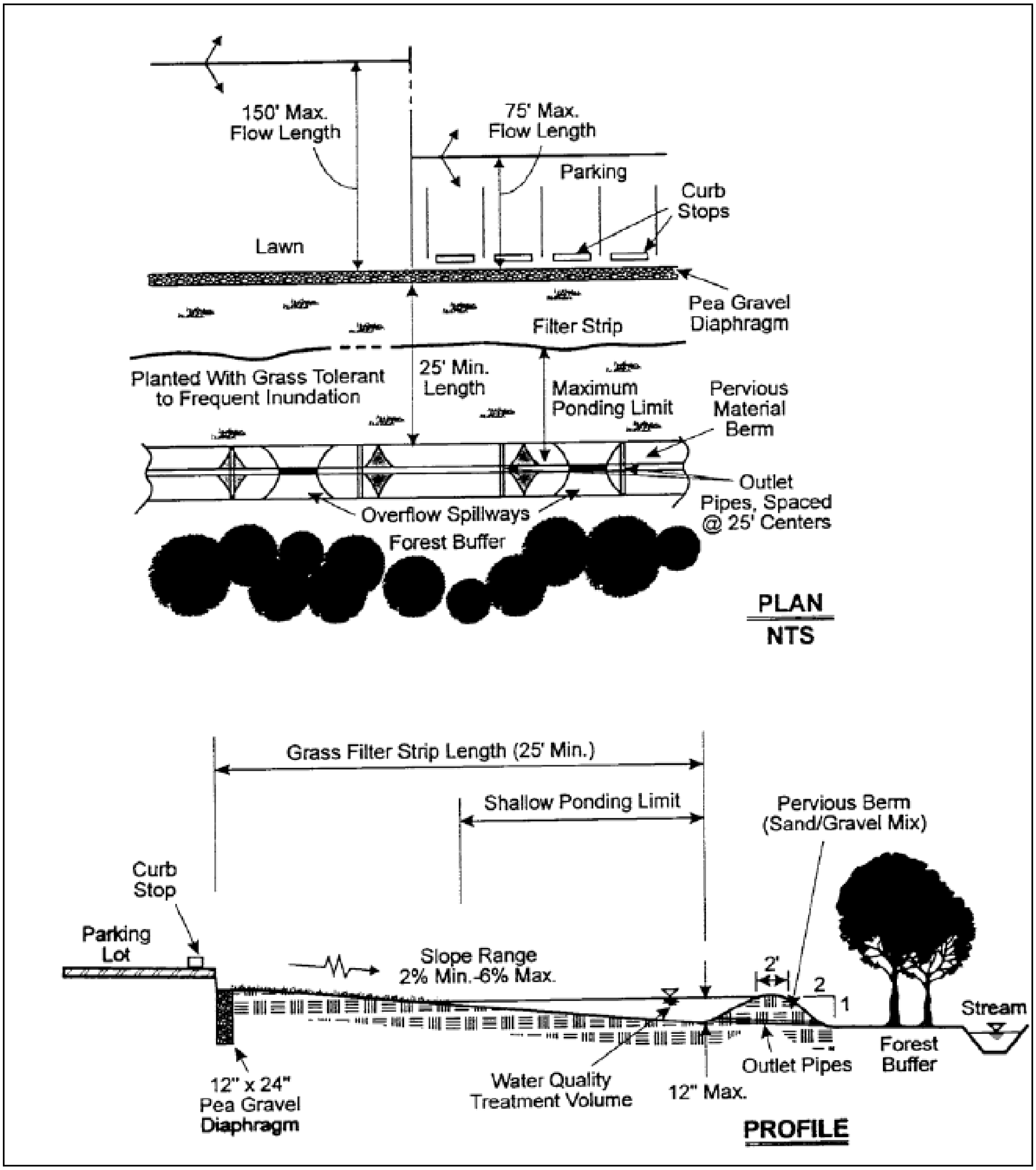
Source: MDE, 2000

Figure 3: Wet swale



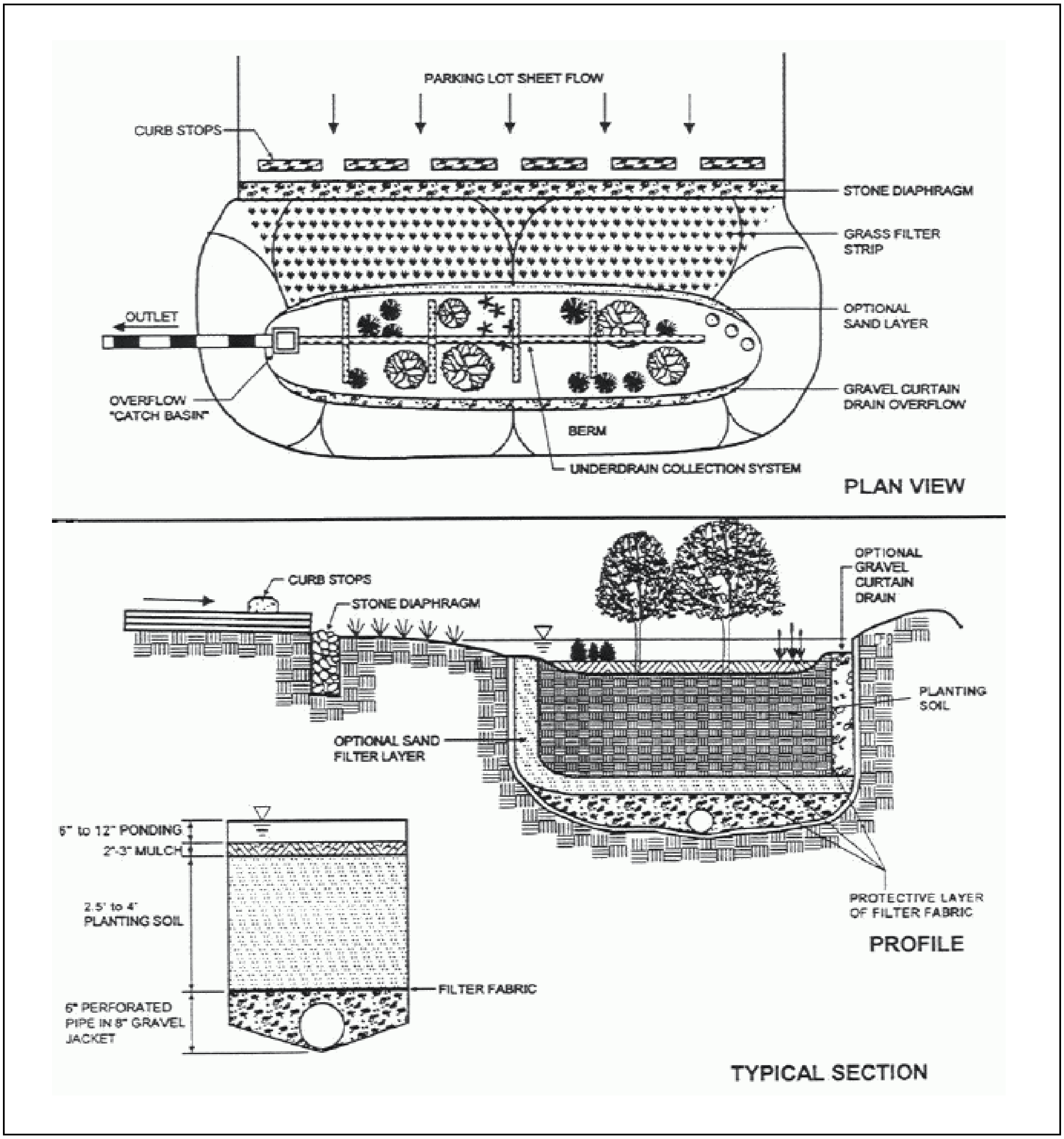
Source: MDE, 2000

Figure 4: Filter strip with berm



Source: Claytor and Schueler, CRC, 1996

Figure 5: Bioretention system



Source: MDE, 2000

C. Comparative pollutant removal capability

The pollutant removal capabilities for biofilter-type BMPs are summarized in Table 1. Biofilters are similar with respect to performance. For example, all typically report relatively high removal rates of suspended sediment, ranging from 68% for the grass swale to 90% or more for the dry swale and the bioretention cell.

Table 1: Estimated pollutant removal capability of biofilters (%)

Biofilter	Data	TSS	TN	TP	Bacteria	Metals	Hydrocarbons
Grass Swale	1	68	NA	29	Negative	Cu-42%; Zn -45%	*
Dry Swale	1	93	92	83	*	Cu-70%; Zn -86%	*
Wet Swale	1	74	40	28	*	Cu-11%; Zn -33%	*
Filter Strip	2	70	30	10	*	40-50%	*
Bioretention	3,4	86	43	71-90	*	Cu-93%; Zn-99%; Pb-99%	COD–97% Oil & Grease -67%

NA – Not applicable; * - no data available

Sources: (1) Winer, 2000 (2) CRC, 1996 (3) Yu, et al., 1999 and (4) Davis et al., 1998

D. Suitability and selection considerations

Three factors are considered in selecting the appropriate vegetated system for a particular development site:

- Compatibility of the vegetated system with the land use type
- Compatibility of the system with site conditions such as space consumption, available head, cost, or maintenance consideration
- Effectiveness of the system design in removing the key pollutants of concern

Usually by the time all three factors are considered, the options are narrowed down to one or two design options. The designer can then compare the criteria for the remaining options and select one based on cost and effectiveness.

E. Land use factors

As a group, vegetative biofilter systems can be applied to a diverse range of development conditions. However, individual designs are limited to a much narrower range. These common development situations include urban retrofit sites, parking lots, roads and streets, small residential subdivisions, and backyard/rooftop drainage. Table 2 provides a matrix illustrating the most economical and feasible biofilter designs for each of these five broad categories of development, as well as those that are not applicable. In urban retrofit settings where space is at a premium, the bioretention cell has proven to be one of the most versatile. In these types of urban retrofit cases, the space requirements of grass swales, swales and filter strips are so great that they are often eliminated from consideration.

Table 2: Land use and vegetated systems suitability

Land use	**Suitability of vegetated system**
Urban retrofit	Bioretention cell has proven very versatile for use in retrofit conditions. Swales are usually not well-suited
Parking lots	Bioretention cell is well-suited for use in parking lots. Swales may be suitable under certain conditions (space, soils, water table). Filter strips can be effective.
Roads	City streets in high-density urban areas generally do not provide enough space for most vegetated biofilter systems. Suburban areas, in particular large- to medium-lot size subdivisions, can accommodate all of the vegetated biofilter systems.
Highway	Highways may accommodate if sufficient space is available in median or side slopes. Grass swales and filter strips can most often be integrated into the roadway configuration and provide a logical treatment option.
Residential	Low-density residential provides opportunities for all vegetated biofilter types. High-density residential may provide limited opportunities based on space limitations.
Rooftops	Roof drain disconnections to filter strips or bioretention areas are recommended where feasible.

F. Site conditions

Table 3 compares how each vegetated biofilter design rates with respect to a number of site conditions, including media, water table, drainage area, slope, head, and required area.

Table 3: Physical site conditions and biofilter suitability

System type	Media	Water table Depth (ft)	Maximum drainage area (acres)	Maximum slope (%)	Head (ft)	Ratio size to drainage area (%)
Grass swale	Soil	2	5	6	2	6.5
Dry swale	Engineered soil mix	2	5	6	3-6	10-20
Wet swale	Soil	Below water table	5	6	1	10-20
Filter trip	Soil	2	N/A	6	N/A	10-20
Bioretention	Engineered soil mix	2	2	15	5	5-10

Notes:
N/A – not applicable
Media – key evaluation factors are based on initial determination the NRCS HSG at the site. A more detailed geotechnical investigation is usually required for infiltration feasibility and during design to confirm permeability and other soil factors.
Water table depth – the minimum depth to the seasonally high water table from the bottom or invert of the BMP.
Maximum drainage area – the recommended maximum allowable drainage area for a practice. When the drainage area exceeds the recommended maximum, some design judgment may be applied or multiple structures can be installed.
Head – an estimate of the elevation difference required at the site form the inlet to the outlet to allow for gravity flow.
Ratio size to drainage area – indicates percentage of the total drainage area required for the BMP.

Source: Adapted from MDE, 2000

G. Flow regulation

The four design variations presented in this section are primarily on-line stormwater treatment practices. The inherent nature of the practices and their applications for use do not fit with many off-line applications. Clearly, it is best to divert the WQv into the practice wherever possible, and bypass the larger storms around the facility. The grass swale and dry and wet swales can receive runoff from concentrated sources (pipe outfalls), as well as from lateral sheet flow along the length of the practice. An isolation/diversion structure within the drainage network is the preferred method for diverting concentrated flows prior to entering these treatment practices. The filter strip receives runoff through sheet flow from impervious or pervious surfaces and is commonly designed as an on-line practice. It may be possible, through site grading and other design techniques, to provide an overflow diversion that bypasses larger flows around the facility. However, since the filter strip drainage area is often limited by the flow path, the volume of high-flow runoff will not generally be excessive, and there should be little need to design the system as an off-line practice.

H. Pre-treatment

As with all other filtering practices, pre-treatment is necessary to extend the operational life of the practice, as well as increasing the pollutant removal capability. All four design variations have incorporated nominal pre-treatment as a component of the system design. The difference between these practices and other filtering practices is that the pre-treatment component is more qualitative in nature and is an integral part of the practice itself (e.g., the side slopes of the grass swale). The design components for pre-treatment which are specific to the four design variations are presented below (from Clayor and Schueler, CRC, 1996). With the exception of sizing a forebay at the initial inflow point, there are no specific, quantitative sizing criteria for these pre-treatment components.

1. **Grass swale, dry swale, and wet swale.**
   - A shallow forebay is provided at the initial inflow point of the channel. The volume of this forebay should equal approximately 0.05 inches per impervious acre of drainage.
   - A pea gravel diaphragm is recommended along the top of the channel to provide pre-treatment for lateral flows entering the practice.
   - Mild side slopes ($\leq$ 3:1) provide additional pre-treatment for lateral flows.

2. **Filter strip.**
   - A pea gravel diaphragm is recommended along the top of the slope.
   - The uphill area, above the shallow ponding limit provides additional pre-treatment.

A summary of the design criteria for vegetated open channel practices is provided in Table 4.

Table 4: Design criteria summary for vegetated open channel practices

Type of practice	Design Criteria by System Component			
	Flow regulation quantity/ method	**Pre-treatment quantity/method**	**Filter bed and media**	**Overflow**
Grass swale	On-line, rate based on peak Q_{wq} for WQv, velocity <1.5 fpsec.	Pea gravel diaphragm and vegetated filter strip; forebay at inflow, no minimum volume.	Rate-based design, minimum residence time =10 min. Depending on slope, treatment area approx. = 6.5% of impervious drainage area. Grass surface/soil interface.	On-line flow, sized to treat WQv with velocity <1.5 fpsec, 2-year non-erosive velocities (< 4.0 to 5.0 fpsec), adequate capacity for 10-year storm with 6-inch freeboard.
Dry swale	On-line volume based on WQv.	Pea gravel diaphragm and vegetated filter strip; forebay at inflow, no minimum volume.	Volume-based design to retain WQv. Depending on slope and depth, treatment area approx. =16% of impervious drainage area. 30-inch thick planting soil bed, consisting of 50% soil/50% sand mix.	On-line flow, sized to treat WQv, 2-year non-erosive velocities (< 4.0 to 5.0 fps), adequate capacity for 10-year storm with 6-inch freeboard.
Wet swale	On-line volume based on WQv.	Pea gravel diaphragm and vegetated filter strip, forebay at inflow, no minimum volume.	Volume-based design to retain WQv. Depending on slope and depth, treatment area approx. =16% of impervious drainage area. Grass/wetland vegetation surface/soil interface.	On-line flow, sized to treat WQv, 2-year non-erosive velocities (< 4.0 to 5.0 fps), adequate capacity for 10-year storm with 6-inch freeboard.
Filter strip	On-line volume based on WQv.	Pea gravel diaphragm; no minimum volume.	Volume-based design to retain WQv. Depending on slope and depth, treatment area approx. =100% of impervious drainage area. Grass surface/soil interface.	On-line flow, sized to treat WQv, all other flows overflow berm.