STORMWATER TREATMENT WITH VEGETATED BUFFERS

Requested by:
American Association of State Highway and Transportation Officials

Standing Committee on Environment

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Under Subcontract to
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September 2009

The information contained in this report was prepared as part of NCHRP Project 25-25, Task 53, National Cooperative Highway Research Program, Transportation Research Board.

ACKNOWLEDGMENTS

This study was requested by the American Association of State Highway and Transportation Officials (AASHTO) and conducted as part of the National Cooperative Highway Research Program (NCHRP) Project 25-25. The NCHRP is supported by annual voluntary contributions from state departments of transportation. Project 25-25 is intended to fund quick response studies on behalf of the AASHTO Standing Committee on the Environment. The report was prepared by Beverly J. Storey, Ming-Han Li, Jett A. McFalls and Young-Jae Yi of the Texas Transportation Institute with contributions from John Suhrbier of Cambridge Systematics, Inc. The work was guided by a task group chaired by William Hauser, which included Mark Hemmerlein, Scott McGowen, Peter Newkirk, Matt Lauffer and Patricia Cazenas. The project was managed by Nanda Srinivasan, NCHRP Senior Program Officer.

INSTRUCTIONS TO PANEL MEMBERS

This project was conducted at the request of the AASHTO Standing Committee on the Environment as part of NCHRP Project 25-25. The report did not go through the usual rigorous review process established and monitored by the Transportation Research Board Executive Committee or the Governing Board of the National Research Council, and should not be described as a “TRB Report.” It should be described as a contractor’s report conducted for the AASHTO Standing Committee on the Environment with funding provided through the National Cooperative Highway Research Program Project 25-25.

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EXECUTIVE SUMMARY

The use of vegetated buffers, filter strips, and grass swales as primary water quality treatments for stormwater runoff is gaining momentum; however, to date, these vegetative stormwater treatments have not yet achieved the same level of acceptance by some state regulatory agencies as other post-construction water quality best management practices (BMP). This is due in part to a general misconception or lack of understanding of the performance capabilities of these applications. The focus of this project is to provide data demonstrating the proven performance capabilities of vegetated buffers, filter strips, and grass swales as post-construction, primary stormwater treatments. This information will be used to facilitate gaining acceptance of or credit for their use from regulatory agencies. Earlier studies reported varying ranges of pollutant removal capabilities for vegetative BMP applications. These earlier findings did not foster enough confidence in the reliability of their use. Recent research clearly shows that the effectiveness of filter strips and grass swales for removing pollutants from stormwater in roadside applications can have consistent, acceptable performance within a lesser treatment distance than most agencies' design criteria. The BMP performance data from the current research meets most state agency requirements for maintaining post-construction pollutant loads as nearly as possible the predevelopment characteristics and/or a "no net increase" in stormwater runoff.

Many state departments of transportation (DOT), regulatory, and environmental documents recommend vegetative BMPs for some level of stormwater treatment. Over 50 percent of the agencies reviewed encourage their use as primary stormwater treatments. The decisions for use of vegetative systems as primary stormwater treatments by most regulatory agencies were based upon:

- national and international research data that demonstrates effective performance,
- respective state agency research data,
- practical application or field demonstration,
- years of successful use, and
- the decision to adopt other state agency criteria from existing manuals, either environmental, regulatory or DOT (most occurring).

Design manuals and policies regarding the use of these BMPs may need updating to reflect current research findings. Due to the limited number of state agencies sponsoring current research regarding the water quality performance of vegetated roadsides, many state agencies adopt other agency's design and performance recommendations. This practice may perpetuate the traditional use perspective of vegetated buffers, filter strips, and grass swales as stormwater conveyance systems, and not as proven, viable post-construction primary stormwater treatment BMPs.

Key points within the majority of research conducted on roadsides regarding stormwater pollutant removal performance are the following:

- The research sites chosen for roadside data collection were not designed specifically for stormwater quality.

- Most of the data is from roadways with high average daily traffic (ADT).
- The sites had different dimensions from those BMPs intended for stormwater quality purposes.

The results of recent research indicate that the water quality performance of most standard roadside design (i.e., channels, ditches, grass swales, and slopes) is comparable to roadsides specifically designed to perform as vegetative stormwater treatments.

Data collection for this project involved a review of available information from current research, literature, and transportation, environmental, and regulatory agencies on their use of vegetated buffers, filter strips, and grass swales as identified in their documents and manuals. A survey of practice with follow-up interviews for a select group of survey respondents gathered additional information. Evaluation criteria for determining a “suggested practice” considered how well the physical characteristics of vegetated buffers, filter strips, and grass swales relate to the modeled removal efficiencies as found in current research, state agency manuals, and from the survey-of-practice results and documented practices.

The results of Task 53 demonstrate that most state transportation, environmental and regulatory agencies use vegetated practices for stormwater treatments, whether as a pretreatment for other water quality practices or as primary treatment. The focus of the project was on the BMPs use as primary treatment for rural post-construction applications; however, most state agencies either do not differentiate between urban and rural in their stormwater manuals or specify only for urban applications.

The majority of state agencies using vegetated buffers, filter strips, and grass swales as a primary stormwater treatment for post-construction rural roadside applications have specific design criteria that qualify their use as a primary water quality treatment. For filter strips, this usually includes filter strip length and slope. For grass swales, this may include design storm, longitudinal slope, soil type, the use of velocity controls, residence time, and vegetation type and density. Many states include the use of bioswales or swales designed specifically for water quality treatment. These swales are similar in design to a standard roadside grass swale but may utilize different soils, subsurface drain, or may be wider and flatter to maximize the hydraulic residence time and surface contact within the swale.

There were three key reasons given by transportation, regulatory, and environmental agencies for not specifying vegetated water quality treatment systems for use in post-construction rural roadside applications:

1. The state regulatory agency does not require post-construction treatments.
2. The state regulatory agency does not require post-construction treatments in rural applications or only regulates within urban areas.
3. Vegetated stormwater treatments are not used because the region cannot support the vegetation density levels required for effective pollutant removal due to minimal annual rainfall, high altitude, or extended winter seasons.

The majority of the regulatory agencies that do not require post-construction treatments in rural applications do not reject the use of vegetated stormwater treatment systems; they simply do not recommend specific practices, monitor, and/or require their use in these specific applications. Federal, state and local agencies consider the use of vegetated roadsides as a water quality treatment positively due, in part, to implementation and maintenance costs, and a growing public awareness and acceptance of “green” or low impact development (LID) techniques.

Uniform terminology and more consistent design criteria would facilitate better communication of data results between transportation and regulatory agencies. There are numerous terms used for similar applications within the research, federal, state and local agency manuals and documents that make direct performance comparisons challenging.

The results of this project will enable a sharing of suggested practices, provide a synthesis of recommended practice examples by transportation, environmental, and regulatory agencies regarding the utilization of vegetated buffers, filter strips, and grass swales as a primary stormwater treatment for post-construction rural roadside applications that will facilitate support for gaining more widespread acceptance by state regulatory agencies.

CHAPTER 1 BACKGROUND

The Clean Water Act, which was enacted in 1972 and amended in 1987 to include stormwater discharges, requires that states assess the condition of surface waters within their jurisdiction to determine whether they support their designated beneficial uses. There is a total maximum daily load (TMDL) requirement for each of the segments designated as impaired for the constituents that are contributing to the impairment. The TMDL specifies the maximum pollutant load (as a concentration or load) assimilated by the water body without impairing its beneficial uses. If a receiving water body is impaired for specific constituents, each of the dischargers to these impaired segments, including state DOTs, must agree to implement best management practices focused on removing the targeted constituents. Some state agencies require performance standards for post-construction BMPs regardless of the receiving water body. The BMPs used must meet state or local standards for maintaining post-construction pollutant loads as nearly as possible the predevelopment characteristics and/or a “no net increase” in peak discharge. Many agencies require evidence that the proposed action and implementation of water quality controls satisfy the specific state or local requirements to minimize pollution impacts caused by development within a watershed.

The interaction of highway infrastructure and the natural environment is of increasing concern. Construction, operation, and maintenance of infrastructure often generate changes in land surface permeability and introduce hydraulic structures that increase runoff rates or divert natural runoff flow. Furthermore, the roadway may collect compounds on the surfaces, which are easily transportable to the natural receiving waters during storm events, contributing to water pollution. Fine particles that collect on the roadway surface also can act as adsorbents that transport deleterious compounds, such as nutrients and metals, into the receiving water. The principal element of highway infrastructure that has the greatest potential to reduce contaminants entering into natural waters during storm events is the rural roadsides with established vegetation.

1.1 Problem Statement and Research Objectives

Many state regulatory agencies have not yet accepted vegetated buffers, filter strips, and grass swales for use as primary treatment of stormwater runoff as they have other water quality BMPs. This is due in part to a general misconception or lack of understanding of the performance capabilities of these applications. Earlier studies reported varying ranges of pollutant removal capabilities for vegetated BMP applications. These findings did not foster enough confidence in the reliability of their use. However, recent research clearly shows that there can be consistent, acceptable pollutant removal performance of vegetated buffers, filter strips, and grass swales.

Many state agency design manuals recommend some type of vegetated stormwater treatment with over 50 percent of the regulatory and/or environmental agencies identified encouraging their use as primary stormwater treatments. Some states’ use of these BMPs does not go beyond pretreatment to reduce sediment loading to filtration systems or other structural stormwater controls. Due to the limited number of state agencies sponsoring current research regarding the water quality performance of vegetated roadsides, many agencies adopt other state agency application, design and performance recommendations. This practice, in itself, is neither good nor bad; however, it does tend to perpetuate outdated research data simply because funding is limited for many states to conduct their own research. This practice may also be responsible for the traditional use perspective of vegetated buffers, filter strips, and grass swales as stormwater conveyance systems, and not as a proven, viable post-construction primary stormwater treatment BMPs.

Drainage infrastructure design incorporates vegetated roadsides for stormwater conveyance and does not typically design specifically for water quality treatment. Research has quantified the performance of vegetated roadsides and proven their substantial stormwater quality benefits. Vegetated stormwater treatment systems employ the same pollutant removal mechanisms as other water quality facilities that are:

- filtration of sediment by grass blades or other vegetation,
- sedimentation at the base of the biomass as runoff velocities are reduced,
- infiltration into the soil as hydraulic residence time increases, and
- biological and chemical activity in the vegetation/soil media.

The overall goal of this report is to provide a synthesis of best practice examples by transportation, environmental and regulatory agencies regarding the utilization of vegetated buffers, filter strips, and grass swales as a primary stormwater treatment for rural roadside applications that will facilitate support for gaining more widespread acceptance by state regulatory agencies. Evaluation criteria for determining a "suggested practice" will consider how well the physical characteristics of these BMPs relate to the modeled removal efficiencies as found in the literature and from documented practices.

1.2 Approach

The project used two basic approaches for assessing the successful implementation of vegetated stormwater systems by state transportation agencies and the coinciding acceptance of their use by the respective regulatory agencies. The first approach was to examine and synthesize the available information from the literature as well as state transportation, environmental and regulatory agency manuals and documents for best management practices regarding post-construction stormwater treatment in rural roadside applications. This approach included scanning materials for available engineered designs and practices currently accepted by respective state regulatory agencies for use as stormwater treatment and their relative physical and performance characteristics. The second approach to evaluating BMP use and acceptance by state regulatory agencies was a national survey of state agency use of vegetated buffers, filter strips, and grass swales. The survey had three main goals:

- to solicit information from state transportation, regulatory, and environmental agencies regarding the reasons for the acceptance or non-acceptance of their use as a primary stormwater treatment,
- to identify common physical characteristics such as width, length, percentage of vegetative cover, percent slope, etc., and
- to identify any supporting research or data used by the agency in their decisions.

Follow-up interviews confirmed agency rationale for acceptance/use or non-acceptance/use.

Chapter 2 Description of Vegetated Stormwater Treatment Systems

Many roadsides, especially rural roadsides, have some variation of a vegetated buffer located adjacent to the roadway. This may range in size and complexity from the typical roadside ditch, swale or channel to an extended slope with large, woody vegetation. Historically, the design of the roadside has been from a safety and drainage perspective. Designs for channels, ditches, swales and roadside slopes emphasize the conveyance of stormwater runoff. Stormwater treatment has not been a significant consideration when determining the design of the roadside vegetated area. AASHTO's *A Policy on Geometric Design of Highways and Streets* or Green Book (*1)* recommends slopes flatter than 25 percent to meet safety criteria; however, many rural roadsides can and do accommodate flatter slopes. Although a number of DOTs' design guidelines for roadside channels set the maximum of 33 percent or 50 percent for channel side slopes, AASHTO recommends channel side slopes of 33 percent or steeper only where site conditions do not permit use of flatter slopes. Figure 1 shows a typical rural roadway section. Roadside vegetated areas designed for water quality treatment must meet the safety clear zone and recoverable slope requirements of the specific roadway. The ***key point*** is that most standard roadside designs can accommodate the use of vegetated buffers, filter strips, and grass swales as stormwater quality BMPs.

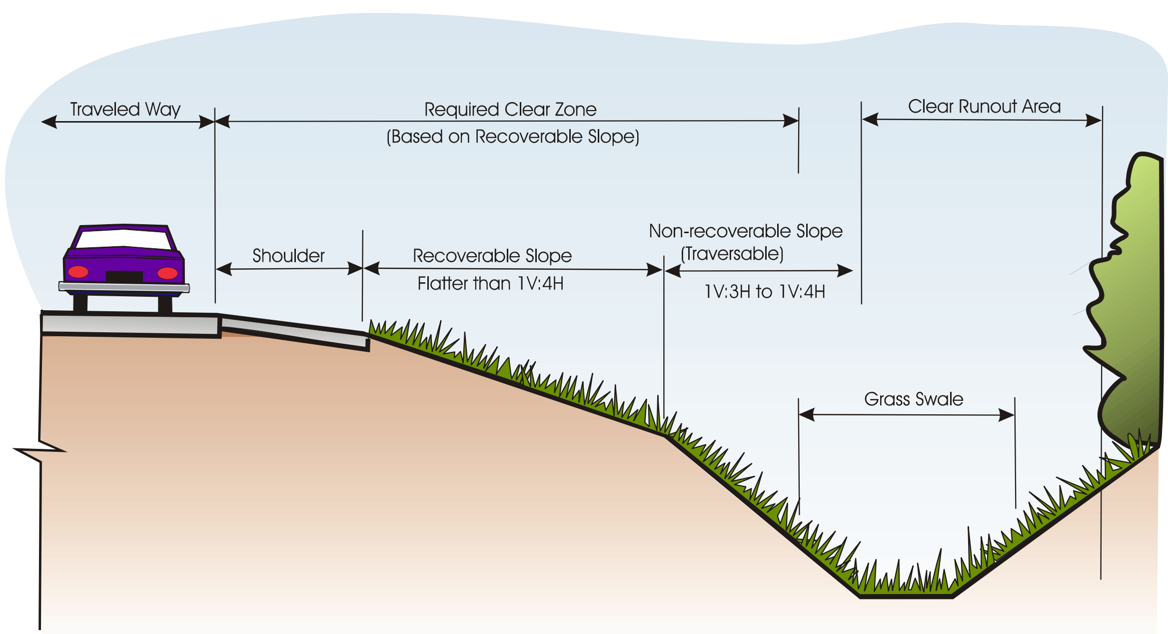


Figure 1: Roadside Safety Elements

2.1 Issues Related to Non-Standardized Terminology

One major hurdle found within the literature, research, and throughout the state agency documents is the variety of terms used to describe similar applications. The terms vegetated buffer, filter strip, and grass swale were neither consistently defined nor used. Reference as to how length and width of the BMPs were determined differed as well. In general, most documents do not define how width and length are determined, particularly for vegetated buffers and filter strips. How is the length of a filter strip measured? Is it parallel or perpendicular to the flow path? The body of research reviewed for this project contained numerous inconsistencies in definitions and dimensioning. Comparing "state to state" criteria was often not comparing "apples to apples." Employing common or more consistent definitions for similar vegetated stormwater treatments will enable a more direct comparison of pollutant removal performance, design parameters, and implementation techniques as well as facilitating communication among agencies and researchers.

The researchers conducted an on-line search of available manuals and documents from state transportation, environmental, and regulatory agencies regarding the use of vegetated buffers, filter strips, and grass swales used for post-construction rural stormwater quality treatment. The search confirmed the use of numerous terms for similar applications. These include but are not limited to:

- grass strip biofilter,
- grass swale biofilter,
- grass-lined swale,
- grass drainage swale,
- dry swale,
- wet swale,
- water quality swale,
- grass drainage channel,
- grass channel,
- vegetated channel,
- wetland channel,
- biofiltration swale,
- bioinfiltration swale,
- drainage swale,
- vegetated systems (biofilters),
- buffer zone,
- irrigated grass buffer strip,
- natural area conservation,
- overland flow filtration/infiltration zone, and
- vegetated filter strip.

According to the literature, a typical open channel design for stormwater management for rural roadsides is a depressed area adjacent to the road. A classic roadside channel design manual published by the Federal Highway Administration *(2)* called the area a roadway channel. AASHTO describes the roadside area as drainage channels and side slopes *(1).* Examples of the inconsistencies include stormwater BMP manuals of some state DOTs such as Colorado DOT's *CDOT MS4 Permit: New Development and Redevelopment Stormwater Management Program (3)* use of vegetated swale, grassed swale, and grass swale in the same document. The Nevada DOT *(4)* uses the terms biofiltration swales and biofiltration strips. A California study *(5)* and a Texas study (*6)* describe a grassy roadway embankment as a filter strip and a drainage ditch as a swale. It is common to find more than one term used for the same intended application, sometimes within the same paragraph or page.

Such inconsistent use of terms may limit the understanding of the performance of these BMPs and, as stated previously, their stormwater treatment value. Vegetated buffers, filter strips, and grass swales are different in their form and designated function; however, they are sometimes used interchangeably within the literature and state agency documents. A typical filter strip has a moderate slope that can treat low volume of sheet flows (i.e., 2-yr design storm) *(7)*. On the other hand, a grass swale can channel drainage with steep side slopes of 50 percent or less designed to treat a larger volume of concentrated flows (i.e., 10-yr design storm). Hence, performance test results of the sole-application of each measure are not comparable. This is due in part to research conducted using different design storms, and sites with different slope and length dimensions compared to prototypes used for sole-applications. Many state agencies provide similar design guidelines for roadside channels although they may use differing terminology.

This section attempts to document terms related to the scope of this project, provide researchers' understanding of these terms, and supporting research data. The information in this report uses the terms found within the respective documents and does not attempt to change terminology to a standard use. However, section 2.7 in this chapter has suggested terminology, definitions and uses.

2.2 Vegetated Buffers

The Environmental Protection Agency (EPA) *(8)* defines vegetated buffers as "areas of natural or established vegetation maintained to protect the water quality of neighboring areas… Vegetated buffers can be used in any area able to support vegetation. They are most effective and beneficial on floodplains, near wetlands, along stream banks, and on unstable slopes." EPA also classifies vegetated buffers as a sediment control method for construction sites. Based on the description above, a vegetated buffer performs as a broad low-sloped filter strip usually located between a construction site or transportation facility and a riparian area. Other terms found in the literature describing similar applications are vegetated systems (biofilters), buffer zone, buffer strip, natural area conservation, overland flow filtration/infiltration zone, and vegetated filter strip.

A vegetated buffer can consist of grasses, shrubs, and trees depending upon the location; however, it generally utilizes more and larger woody plant materials than other vegetated practices. This type of buffer is most often associated with adjoining water bodies as riparian buffers or zones, and because of this, is not generally found directly adjacent to a roadway. Filter strips and grass swales are also considered vegetated buffers and are most often associated with and used adjacent to rural roadsides. Filter strips and grass swales generally use lower growing and herbaceous plant materials that do not pose the safety issues associated with large trees and shrubs as fixed-objects on the roadside as shown in Figure 2. The determination of length and width measurements varies throughout the literature.

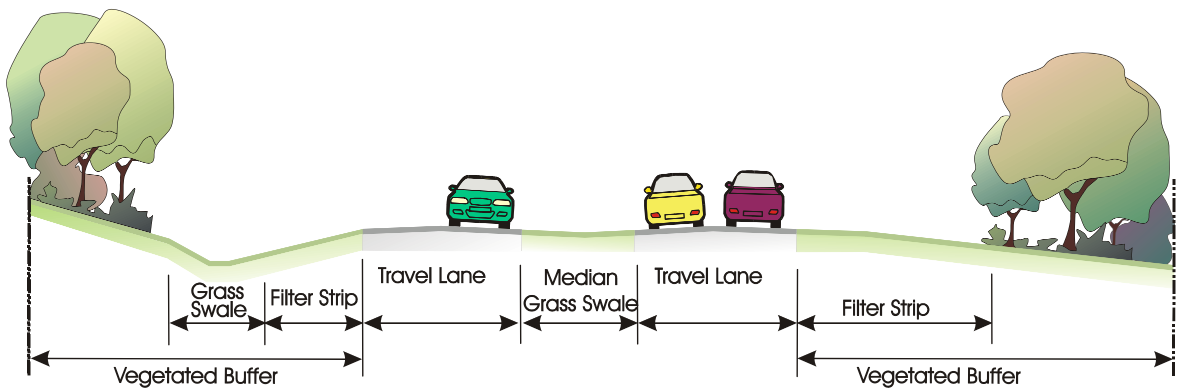


Figure 2: Roadside Vegetated Buffer

2.3 Filter Strips

Filter strips (i.e., buffer strips, vegetated filter strip, vegetated systems, biofilters, buffer zone, overland flow filtration/infiltration zone, and vegetated filter strip) are evenly sloped vegetated areas that treat sheet or overland flow from adjacent surfaces. Filter strips slow runoff velocities, filter out sediment and other pollutants, and provide some infiltration into underlying soils *(8)* (see Figure 3). The primary transportation facility application for vegetated filter strips is along rural roadways where runoff that would otherwise discharge directly to receiving waters first passes through a filter strip before entering a conveyance system *(9)*. A dense vegetative cover, long flow length, and low gradient provide the most efficient removal rates *(10)* as well as mitigating for thermal pollution created by impervious surfaces. The method of obtaining dimensions varies throughout the literature.

To be effective, filter strips require sheet flow across the entire strip. Once flow concentrates to form a rill or small, shallow channel, it reduces stormwater travel time and may become a source of erosion. Unfortunately, this usually occurs on filter strips where it is difficult to keep sheet flow over a long distance and a low slope. This may be due in part to the inability to obtain evenly compacted and flat soil surfaces using common construction methodology or using existing vegetation. A level spreader can be used to ensure even distribution of stormwater over the filter strip if sheet flow cannot be sustained.

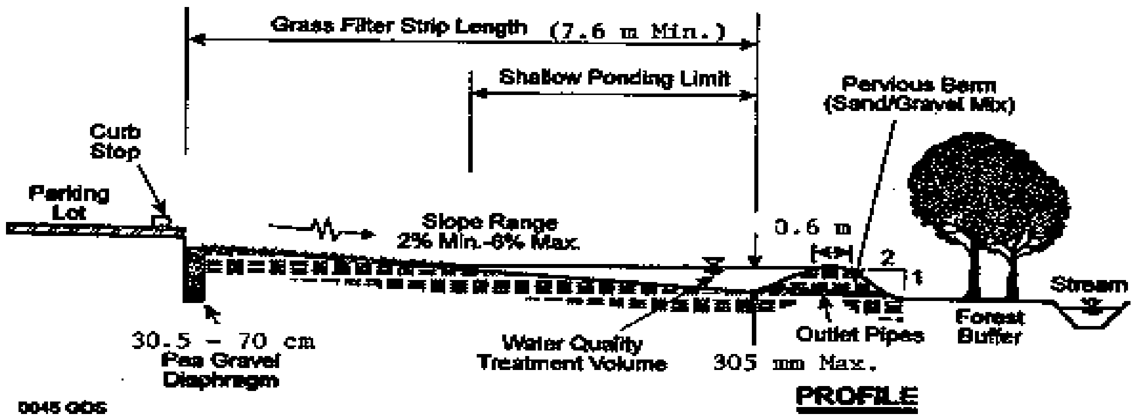


Figure 3: Typical Filter Strip *(10)*

EPA recommends that filter strips should have slopes between 2 and 6 percent, which is consistent with other studies *(11, 12)*. Slopes greater than 6 percent encourage the formation of concentrated flow; however, slopes flatter than 2 percent may result in ponding of runoff on the surface. This runoff ponding in moderation may be viewed as an increased hydraulic residence time within the filter strip and, therefore, beneficial.

With the slope constraint, filter strips can, at best, treat rainfall events with low to moderate input rates – which may be storms of low-intensity or high-intensity short duration. As a stand-alone BMP, filter strips cannot treat high-velocity flows and do not provide enough storage or infiltration to effectively reduce peak discharges to predevelopment levels *(13).* While providing water quality treatment for small frequent storms, filter strips must be able to convey high runoff flow from the roadway when high-intensity storms occur. Hence, designers have traditionally regarded filter strips as pretreatment or secondary BMPs located up stream of other treatments.

2.4 Swales

EPA defines swale (i.e., grass strip biofilter, grass swale biofilter, grass-lined swale, grass drainage swale, dry swale, wet swale, water quality swale, grass drainage channel, grass channel, vegetated channel, wetland channel, biofiltration swale, bioinfiltration swale, drainage swale, grassed channel, biofilter, or bioswale) as "a vegetated, open-channel management practice designed specifically to treat and attenuate stormwater runoff for a specified water quality volume" *(8)*. For low volumes of runoff, grass swales not only safely convey stormwater concentrated from a roadway, but they also improve water quality. "As stormwater runoff flows along these channels, it is treated through vegetation slowing the water to allow sedimentation, filtering through a subsoil matrix, and/or infiltration into the underlying soils" *(8).* Swales can also be sized to temporarily hold stormwater and address water volume management needs *(10)*.

The primary role of swales is historically regarded as a drainage channel with a filtration/sedimentation function and/or a temporary detention measure with soil infiltration capabilities; however, the *EPA Stormwater Menu of BMPs (8)* states, "grassed swales can be used to meet groundwater recharge and pollutant removal goals." EPA also recognizes that grass swales have some limitations, including:

- Swales can effectively treat a drainage area of limited size.
- If designed improperly (e.g., if proper slope is not achieved), swales will have limited pollutant removal capabilities.

Recommendations for longitudinal channel slopes vary within the existing research and literature. For instance, Schueler *(14)* recommends a vegetated swale slope as close to zero as drainage permits. The Minnesota Pollution Control Agency *(15)* recommends that the channel slope be less than 2 percent. The *Storm Water Management Manual for the Puget Sound Basin* specifies channel slopes between 2 and 4 percent *(16)*. The prototype of grass swale in Figure 4 is physically similar to "roadway channel" defined by Federal Highway Administration (FHWA) for rural roadsides. Variances in the definition of swale exist depending on whether the side slope is a channel sidewall to confine water or a filter strip to filter stormwater runoff. Thus, a critical distinction between grass swale and filter strip is whether the primary role is infiltration or filtration and whether it treats sheet flow or concentrated flow.

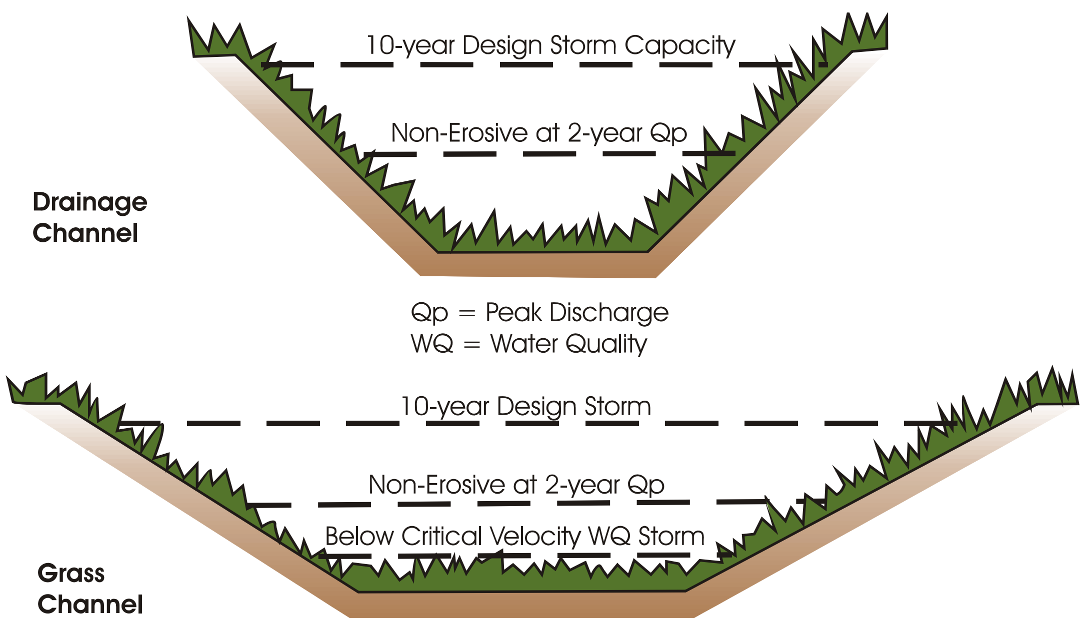


Figure 4: Types of Roadside Swales (*Adapted from 11*)

Swale classification (dry swale or grass swale) depends upon whether the swale has an infiltration system below the channel area or not. A dry swale is an infiltration device. A grass swale may or may not be an infiltration device, depending on the permeability of the underlying soils *(17)*. These are discussed further in the following section.

2.5 Water Quality Swales

Several state agencies include some type of engineered swale as a post-construction water quality treatment designed to meet their state and local performance requirements. These types of swales have numerous names. The most commonly used terms are dry swales and wet swales that are similar in construction to a typical roadside swale. Other similar but more complex applications include bioretention and wetland swales. The use of bioretention and wetland swales as post-construction vegetated treatments is rarely implemented along rural roadsides; however, their use at roadside rest areas is growing due in part to the small drainage area contribution limitations of these BMPs.

Dry swales generally consist of a subsurface or under-drain system and a specialized soil structure as shown in Figure 5. The Idaho Department of Environmental Quality's (IDDEQ) *Stormwater Best Management Practices Catalog (18)* uses design criteria similar to numerous other documents. It includes a hydraulic residence time of 9 minutes, a maximum flow velocity of 0.45 m/s [1.5 ft/s], and a minimum length of continuous swale of 61 m [200 ft] with a longitudinal slope of 2 to 4 percent. These parameters are similar to a typical roadside swale. IDDEQ recommends a wider, flatter swale to maximize surface contact with the dense vegetation for better performance.

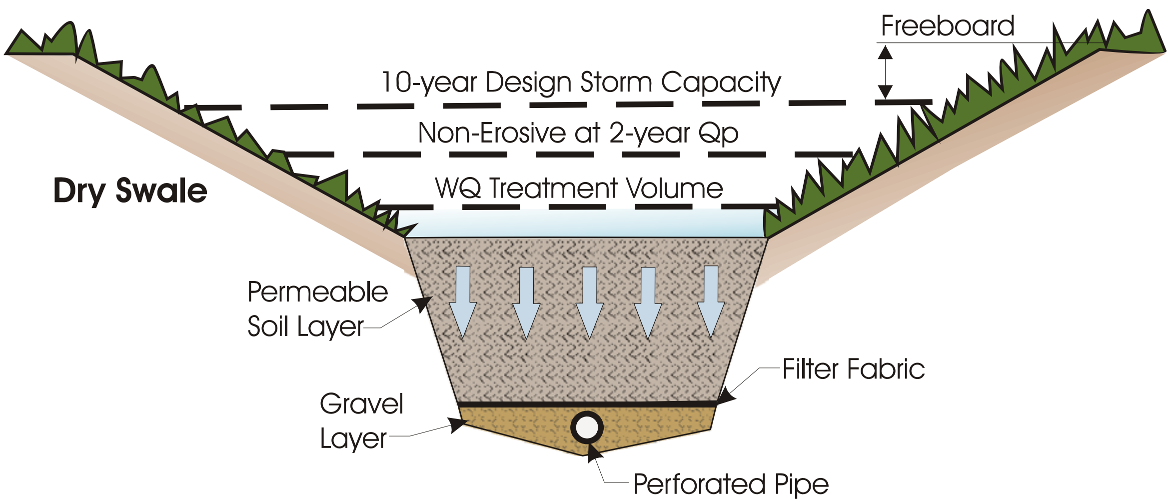


Figure 5: Dry Swale Components

The wet swale is generally a grass swale that uses a series of permanent velocity controls or check dams to create impoundments along the flow path of the swale (see Figure 6). Wet swales typically do not require any special construction techniques or soils; however, the addition of the permanent velocity controls increases the effective pollutant removal capabilities of the typical grass swale to make it a primary water quality treatment if the design of the swale will accommodate its use (i.e., slope, length, depth to water table).

2.5.1 Velocity Controls

The typical use of velocity controls, commonly referred to as check dams, in grass swales is to reduce flow velocities. This reduction in velocity allows sedimentation and infiltration by increasing the hydraulic residence time within the swale. Placement of these permanent check dams in the swale as shown in Figure 6 provides effective treatment. They create small, temporary impoundments upstream of the check dam. The literature confirms the associated water quality benefit with check dams in swales. Kaighn and Yu *(19)* particularly found that swales with check dams substantially outperformed the swales without. The difficulty of having check dams in swales is that check dams may interfere with maintenance. Implementation of velocity controls should address a balance between site-specific water quality, safety, and maintenance requirements.

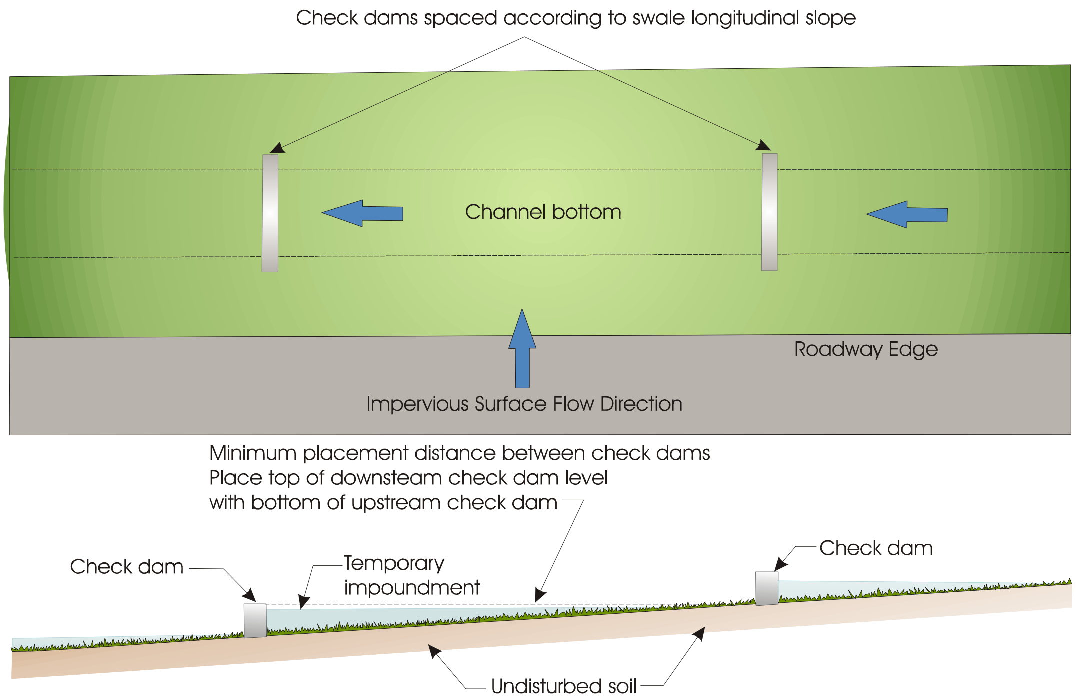


Figure 6: Velocity Control Use in Grass Swale

2.6 Filter Strip and Swale Combination

Many stormwater BMP manuals recommend the use of filter strips as an optional or secondary device to complement the function of swales. The application of the filter strip - swale combination is defined as a swale with a filter strip used as the sidewall. This is a typical roadside application. Another application is the use of a filter strip adjacent to the swale (see Figure 7). In this application, the filter strip can be used as primary treatment or pretreatment to reduce pollutant loading prior to entering a swale. The model below strictly follows EPA prototypes of a filter strip with slope less than 6 percent and a swale, but this strict application raises a concern. The reported performance of a sole-application of each measure in this model is limited. For example, Colorado Department of Transportation set the expected total suspended solids (TSS) removal range of filter strip and swale as 10 to 20 percent and 20 to 40 percent, respectively *(3)*. The limited performances tested from sole-applications of each measure may discourage not only the sole-applications, but also combined applications, without data to test their collective synergy. The Ohio DOT's *Location and Design Manual, Volume 2 Drainage Design (20)* has vegetated biofilter as a post-construction stormwater treatment BMP. "Vegetated Biofilter (VBF) is a BMP that filters storm water through vegetation. The vegetated biofilter consists of the vegetated portion of the graded shoulder, vegetated slope, and vegetated ditch." This reference to a complete roadside system was the only one found in the state agency documents.

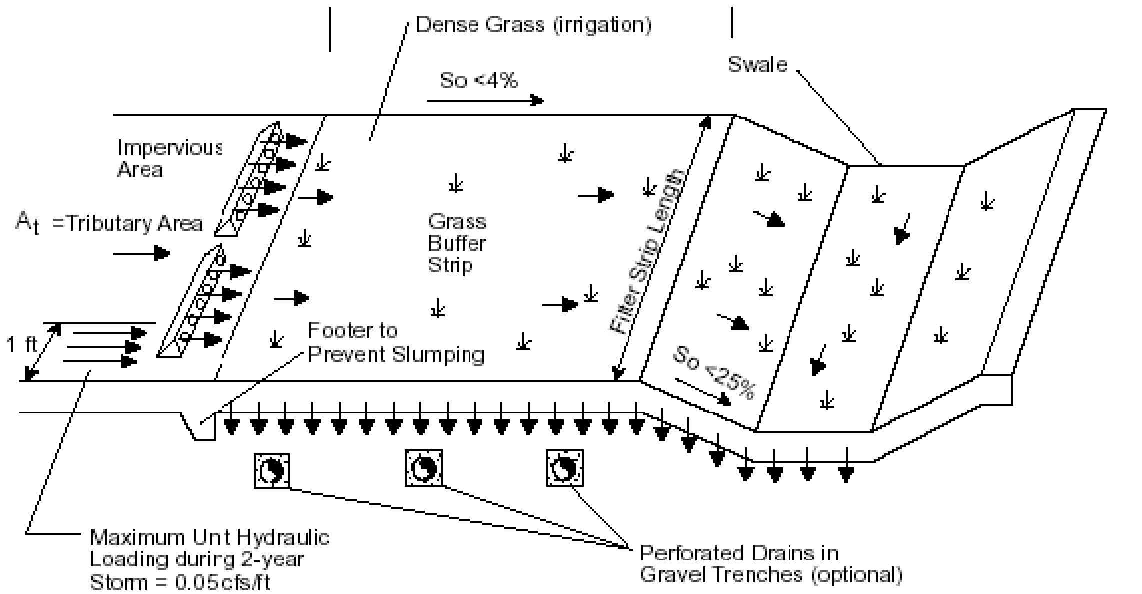


Figure 7: Example of Filter Strip-Swale Combination *(21)*

Rural roadsides generally use a pair of filter strips facing each other, thus naturally forming a vegetated swale. This combination of filter strips and swales creates a synergistic system by offsetting the major weakness of each separate component. Transportation agencies typically consider only the fore slope that creates the filter strip adjacent to the roadway edge as the target BMP. The existence of a swale enables filter strips to treat higher runoff volume. In addition, runoff filtration by filter strip walls, i.e., sediment deposition at the base of plants, may significantly improve the effectiveness of swales in pollutant removal. Recent studies concur that filter strips with slope of up to 10 to 20 percent perform efficiently and the filter strip usually accomplishes that primary removal in the filter strip-swale combination (*e.g., 6, 22, 23, 24*). The steeper slopes of 10 to 20 percent found in the research data (steeper than EPA's suggested 2 to 6 percent) make filter strips a much more practical application for rural roadsides.

2.7 Summary

The terms vegetated buffer, filter strip, and grass swale are inconsistently defined in roadside application. This may be due to the unique environment of vegetated roadsides (i.e., swales with moderately sloped filter strip walls). Such inconsistency must be resolved to ensure effective and reasonable applications of vegetative buffers, filter strips and grass swales and to further the acceptance of these BMPs as primary water quality treatments by state regulatory agencies. The following are the researchers' suggested terms and definitions:

- ***Vegetated buffer*** is the suggested term for a vegetated area that may consist of grasses, shrubs, and trees (planted or indigenous) with a consistently shallow slope that enables stormwater runoff to sheet flow across the surface. The length of a vegetated buffer is defined as the measurement parallel to the flow direction. Vegetated buffers provide pollutant removal by reducing runoff velocities as it filters through vegetation. Reduced velocity promotes sediment captured at the base of the vegetation and runoff infiltration into soil. They moderate the elevated temperature of runoff from impervious surfaces as it sheet flows across the surface to a receiving water body. Vegetated buffers may also reduce runoff quantity through infiltration and evapo-transpiration. Vegetated buffers may include filter strips; however, they generally consist of more and larger woody vegetation, are usually associated with riparian areas adjacent to water bodies, and therefore, in some cases, are not located directly adjacent to the roadway.

- ***Filter strip*** is the suggested term for a vegetated area (planted or indigenous) directly adjacent to the roadway and parallel to the pavement edge contour with a consistently shallow, even slope that enables stormwater runoff to sheet flow across the surface. Filter strips typically consist of grasses and low growing plant material. The length of a filter strip is measured parallel to the flow direction. Filter strips provide pollutant removal by reducing runoff velocities as it filters through vegetation. Reduced velocity promotes sediment captured by the vegetated mass and runoff infiltration into soil. They can also provide some relief from thermal pollution. Filter strips may reduce runoff quantity through infiltration and evapo-transpiration.
- ***Grass swale*** is the suggested term for a shallow-sloped, vegetated roadside drainage channel designed to convey stormwater runoff and provide enough residence time for some water quality treatment. Grass swales typically consist of grasses specified for their inundation tolerance, filtering capabilities, typical mowing height, and design flow velocities. Unlike vegetated buffers and filter strips, grass swales handle concentrated flows. The length and longitudinal slope of a grass swale is measured parallel to the flow direction. Grass swales provide some pollutant removal by sedimentation; however, the use of velocity controls increases the residence time thereby promoting greater filtration and infiltration into the soil and sediment capture upstream of the controls. The extended detention time will also allow for pollutant removal through adsorption, biological uptake, and microbial breakdown. Vegetated stormwater treatments may reduce runoff quantity through infiltration.

Steps toward standardizing terms, definitions, and usage will enable direct comparison of applications and effectiveness on a much broader scope. There was no attempt on the part of the researchers to change terminology to fit a standard use for the remainder of the report; therefore, terms are stated as found in the respective research, literature, and other documents.

CHAPTER 3 BMP PERFORMANCE OBJECTIVES AND FACTORS

3.1 Water Quality BMP Performance Objectives

The selection of post-construction BMPs relies upon their ability to meet specific state and local environmental and regulatory agency objectives. For some states, such as New Hampshire, the "no net increase" performance objective is a priority for implementation of post-construction, rural roadside water quality treatments. The report, *Development of Performance Measures Task 3.1 – Technical Memorandum Determining Urban Stormwater Best Management Practice (BMP) Removal Efficiencies (25),* compiled some basic BMP performance objectives that can apply to most stormwater treatments as shown below:

- Hydraulics
  - improve flow characteristics upstream and/or downstream of BMP
- Hydrology
  - flood mitigation, improve runoff characteristics (peak shaving)
- Water quality (efficiency)
  - reduce downstream pollutant loads and concentrations of pollutants
  - improve/minimize downstream thermal impact
  - achieve desired pollutant concentration in outflow
- Ability to reduce acute and/or chronic runoff toxicity
- Regulatory compliance with National Pollutant Discharge Elimination System (NPDES) permit
  - meet local, state, or federal water quality criteria
- Implementation feasibility,
- Capital, operation, and maintenance costs
- Aesthetics
- Maintenance
  - operate within maintenance, and repair schedule and requirements
  - ability of system to be retrofit, modified or expanded
- Longevity
- Resources
  - improve downstream aquatic and wildlife environment/habitat
  - multiple use functionality
- Function within safety parameter without significant risk and liability
- Ability to function with minimal environmental risk downstream
- Public perception and understanding of runoff quality, quantity and impacts on receiving waters

In addition to the above objectives, the Maine Department of Environmental Protection's *Stormwater Management for Maine (26)* lists cooling as one of their primary objectives. This objective is common to states that have cold-water streams and lakes with habitat subject to alteration by elevated water temperatures. Stormwater temperatures rise due to increased impervious surfaces. The removal of vegetation, which creates shade, and heating of stored water in stormwater management ponds exacerbates this condition. This elevated temperature has an adverse affect on many organisms native to the region.

Many variables affect the ability of the BMP to meet these performance objectives for runoff discharge quality including buffer length, highway width, vegetation cover, hydraulic residence time, soil infiltration rate, vegetation type, slope, traffic, precipitation, drainage, highway surface type, wind, and pollutant constituents. There have been inconsistent conclusions noted from the literature regarding how specific variables affect roadside runoff quality because flow rates and frequency, and pollutant concentration vary *(5, 24, 27, 28).* The complicated interactions among variables create inconsistencies as well as the fact that field studies are all different in terms of the test bed conditions *(6)*.

Despite such a limited understanding about performance factors of vegetated buffer, filter strips and grass swales, a number of studies agree that physical dimension (i.e., slope and length) and vegetation densities are important. Climate relates directly to establishing and sustaining vegetation densities. Section 3.5 discusses climate.

3.2 Slope and Length

Even though many studies on grass swales recognize swale longitudinal length (measured parallel to the flow path) as an important performance factor *(28, 29, 30),* the slope and length of adjacent filter strips (measured parallel to flow path) seem to have a greater impact on the efficiency of filter strip-swale combinations along highways. Filter strips play a primary role in the BMPs effective performance *(5, 6)*. For effective stormwater quality treatment, Barrett et al. *(23)* and Li et al. *(6)* recommend a minimum filter strip length 8 m [26 ft] under a moderate slope of 10 to 20 percent, and a vegetation density of over 80 percent. However, the study by Li et al. *(6)* showed some pollutant removal performance in as little as 4 m [13 ft]. Walsh et al. *(30)* reported that vegetated strips 7 to 9 m [23 to 30 ft] in length can be effective, but increased water depths and velocities have a negative effect on removal efficiencies. Gharabaghi et al. *(31)* also reported that vegetated filter strips removed about 50 to 98 percent of sediments as the flow path length increased from 2.44 to 19.52 m [8 to 64 ft].

The study by the California Department of Transportation (Caltrans) *Roadside Vegetated Treatment Sites (RVTS) Study (24)* gathered data over a 2-year period from various roadside locations to monitor filter strip performance. The "shortest length observed to produce a constant (best) effluent quality for all constituents that decrease in concentration" for seven of the eight sites are as follows:

- 4.2 m [14 ft] at Redding
- 4.6 m [15 ft] at Sacramento
- 8.3 m [27 ft] at San Rafael (shortest distance monitored)
- 9.2 m [30 ft] at Cottonwood (shortest distance monitored)
- 9.9 m [32 ft] at San Onofre
- 13 m [43 ft] at Irvine
- 13 m [43 ft] at Yorba Linda

There are numerous methods for designing grass swales such as Manning's equation to accommodate the peak discharge for the design rainfall frequency. However, the design of the filter strip's slope and length is less precise. Few guidelines are available for determining slope and length of filter strips, such as a peak flow velocity of 0.27 m/s [0.9 ft/s] and a desired hydraulic residence time of 9 minutes *(12)*. Research data is negligible regarding the optimal combination of slope and length for filter strips that provides the maximum efficiency of pollutant removal. Research conducted gathered data from existing roadsides designed using standard highway design criteria. As stated previously, the design of the roadside, hence vegetated buffers, filter strips, and grass swales, focuses on drainage and safety, and not stormwater treatment. Therefore, as shown by recent research, standard roadside design can meet stormwater treatment requirements.

3.3 Soils

Vegetated stormwater treatments have two main components that must work in concert to achieve optimum performance. These are vegetation and soil. Underlying soils must be adequate to sustain vegetation and allow for filtration and infiltration of runoff. Although within the body of current research there is minimal data addressing the specific relationship between roadside vegetated buffers, filter strips and grass swales and their respective soils, soil type and depth to bedrock and/or groundwater are criteria found in many stormwater BMP documents. The assumption is that agricultural and other soil research is very extensive and can relate directly to roadside applications. The most commonly recommended soil types are the Natural Resources Conservation Service (NRCS) hydrologic soil groups A, B, and C. A hydrologic group is composed of soils having similar runoff potential under similar storm and cover conditions. The same soil properties that influence runoff also affect the infiltration rate. They are the "depth to a seasonally high water table, saturated hydraulic conductivity after prolonged wetting, and depth to a layer with a very slow water transmission rate" *(32)*. The Arizona DOT's (AZDOT) *ADOT Post-Construction Best Management Practices Manual for Highway Design and Construction (33)* has compiled the information from the *New Jersey Stormwater Best Management Practices Manual (34)* into a graph that shows the relationship between filter strip length and slope, and NRCS soils. For each soil type, as the slope increases, so does the filter strips width as shown in Figure 8 *(adapted from 33)*.

AZDOT recommends characterizing subsurface soils and geology at least 1.2 m [4 ft] below the ground surface for infiltration practices, along with surface soil chemistry. Soil organic matter content is specifically mentioned not only for the ability to establish and sustain vegetation but also for its potential for high absorptive capacity for highway pollutants such as petroleum hydrocarbon compounds *(33, 35)*. Other soil considerations for use in a stormwater treatment include karst feature locations, cation exchange capacity (CEC) and soil pH (usually 6.5 or greater). Sandy soils have limited adsorption capacity and a CEC ranging from 1-10 milliequivalents (meq) per 100 g. Clay and organic soils have a CEC greater than 20 and have a high adsorption rate *(35)*. The *Stormwater Management Manual for Western Washington (36)* requires a CEC of greater than or equal to 5 meq/100 g dry soil, a minimum soil depth of 6 inches and an organic content of at least 1 percent.

The only hydrologic soil group consistently cautioned against or omitted was Group D. This soil group consists of soils that have a high runoff potential, very slow infiltration rates, high swelling potential, permanent high water table, and a claypan or clay layer at or near the surface and shallow soils over nearly impervious material *(32)*.

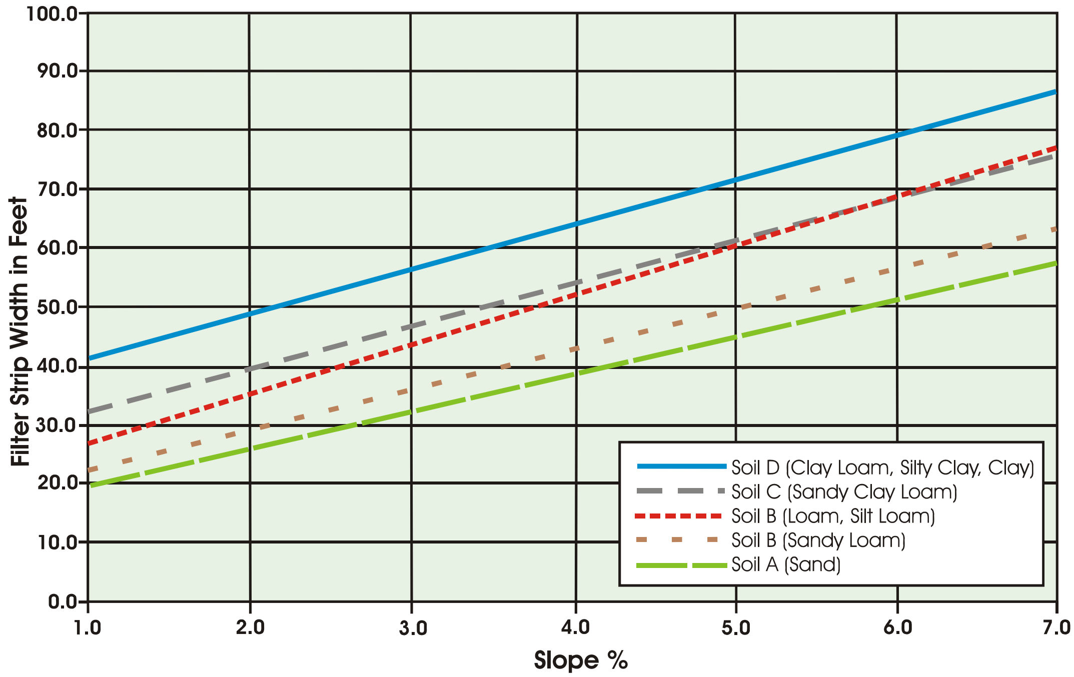


Figure 8: Relationship between Filter Strip Specifications and Soil *(33)*

3.4 Vegetation

A number of studies agree that vegetation density has a direct effect on the performance of vegetated roadsides *(6, 23, 24, 27)*. Specifically, areas with dense vegetative cover had better pollutant removal than other sites with less vegetative cover despite their flatter slopes *(22)*. Significant sediment removal occurs often within the first 4 m [13 ft] of the edge of pavement where grasses have a density level above 90 percent *(6)*. However, the minimum density requirement varies between 65 and 90 percent. The studies pointed out that performance falls rapidly as vegetative cover drops below 80 percent *(23, 24, 27)*.

Other research performed by Caltrans *(24)* examined standard roadway design requirements to determine if filter strips had the equivalent results as those vegetated areas specifically engineered for water quality performance. This two-year water quality study evaluated variables such as length, percent slope, and vegetative density at four different locations. The study compared the quantity and quality of the runoff from the filter strip to the runoff at the edge of the pavement. The study found that a minimum vegetative cover of approximately 65 percent is required for concentration reduction to occur although a rapid decline in performance occurs below about 80 percent. A consistent reduction occurred in the concentrations of total suspended solids (TSS), total metals, and dissolved metals while organic carbon and nutrient concentrations either increased or remained unchanged.

A key point comes from the comparisons of these results to those from another project completed by Caltrans, *BMP Retrofit Pilot Study (37)*, indicating that many existing vegetated areas along highways perform comparable to systems engineered specifically for water quality improvement. However, the California study only focused on the efficiency of the filter strip adjacent to the road and did not explore the complete performance of filter strip-swale combination. More pollutants could be concentrated at a swale bottom. In addition, the study did not adequately examine the degree of impact of some performance factors such as precipitation rate, soil type, and permeability due to similar test environment among samples and the lack of samples.

Results on the aforementioned studies indicate that vegetation density levels are important for performance but the species and height did not significantly influence the results. An important requirement for use of a vegetated BMP as a water quality treatment is the ability of the region to establish and sustain vegetation. Some states with a semi-arid to arid climate, extended winter, and/or high altitude, and/or inadequate soils often do not use vegetated water quality treatments simply because it requires multiple years to establish vegetation and annual rainfall may not be enough to sustain the required vegetation density level necessary for effective water quality treatment.

3.5 Climate

Regions of the country with harsh climate conditions may experience performance concerns with the use of vegetated stormwater treatments, in particular, issues surrounding prolonged rains and frozen ground. A higher precipitation rate (depth per hour) not only requires a larger capacity swale but also significantly reduces pollutant removal efficiency during peak flow discharges. Many governmental BMP manuals generally limit the use of grass swales and filter strips in high precipitation areas, as increased water velocities and depth (especially higher than vegetation height) are believed to have a negative effect on pollutant removal efficiencies *(23)*.

Performance issues are of concern in regions that have prolonged winter conditions and accumulations of plowed snow, ice, and snow packed roads. During spring snowmelt, there may be significant quantities of water draining into roadside swales and ditches. The problems associated with this condition are as follows:

- Vegetation is usually dormant and pollutant removal efficiencies are greatly reduced *(38)*.
- Frozen soils provide negligible infiltration.
- There may be accumulation of decomposed organic matter that adds to stormwater pollutants *(10)*.
- Snowmelts may contain accumulations of roadway pollutants such as oils, grease, sediment, and debris *(39)*.
- Underground infrastructure may be frozen, thereby making stormwater treatment BMPs ineffective and creating potential flooding conditions *(39)*.

The study conducted by the Alaska Department of Environmental Conservation's Water Quality Program, *BMP Effectiveness Report Fairbanks, Alaska (39*) listed proposed criteria for structural BMPs considered effective in the harsh regional conditions. The BMPs should:

- perform in freezing and/or snowy conditions,

- demonstrate effectiveness in controlling downstream transported silt-sized sediment (generally 0.05 to 0.002 mm in diameter) as well as sand and gravel,
- remain effective at low to medium flows (less than 0.084 m^3/s [3 cfs]),
- ensure that toxic compounds concentrations above regulatory limits are not released, and
- have an appropriate level of maintenance.

The preliminary list of suitable BMPs includes filter strips and grass swales; however, they acknowledged the likelihood of reduced performance efficiency during winter months. The choice of vegetation used in colder climates should consider tolerance for extended snow storage and runoff containing de-icing agents.

Altitude is another regional consideration related to vegetation performance for consideration. Vegetation at higher altitudes may not reach maturity for up to three years, similar to arid regions in the south and west. In addition, there are the following issues:

- Less availability of nutrients – Plant roots can take up food only when the soil is free of frost.
- Less soil microbial activity – Cold temperatures reduce activity of microorganisms that process organic debris thereby affecting soil structure.
- Less photosynthesis – The thinner atmosphere at high-elevation sites filters out less ultraviolet radiation from the sun. These rays can damage leaf surfaces, disrupting photosynthesis and even killing plants *(40)*.

3.6 Maintenance

Vegetation establishment may require the use of soil amendments such as fertilizer, compost, and other organic material, but these should be limited in maintenance activities. Vegetation species differ within each state and are a design factor to calculate permissible velocities for grass swales. A design flow velocity should not exceed the permissible velocity. Preferred vegetation height within swales is generally between 100 to 200 mm [4 to 8 in] or determined by flow depth not to exceed one-half to two-thirds of the grass height.

Most state DOTs recognize the minimal maintenance efforts and costs associated with vegetated buffers, filter strips, and grass swales. Periodic maintenance for grass swales should primarily focus on removing accumulated materials (e.g., sediment and trash or debris). Remove sediment build-up on the bottom of the swale when it has accumulated to the point where it occupies approximately 25 percent of the original design volume *(11)* or when the depth of sediment exceeds 100 mm [4 in] *(12)*.

Vegetation maintenance may include the use of herbicides to eradicate invasive or undesirable vegetation. Exercise caution when using herbicides in areas designated for water quality treatment. Vegetation density levels are a critical component of the BMPs optimal performance. Minimize the use of pesticides and quick-release fertilizers in stormwater quality treatment and conveyance areas to decrease the risks of transporting pollutants to receiving waters.

3.7 Summary

Rural roadsides often use a pair of filter strips facing each other, thus naturally forming a vegetated swale. Filter strips play a primary effectiveness role in the combination of filter strips and swale; therefore the slope and length of filter strips seem to have a greater impact on the performance of the combined BMPs. This combination of filter strips and swales may be used to increase the pollutant removal effectiveness and volume capacity. The factors most affecting the pollutant removal performance and the volume capacity include slope, length, infiltration rate, vegetation, and climate. Soils with high infiltration rates can significantly reduce the runoff volume thereby reducing the pollutant load to receiving waters. A common swale design process includes choosing cross-section type, adjoining filter strip slope, longitudinal swale slope and swale depth to contain the design storm frequency, and fitting the design flow velocity to the maximum permissible velocities.

Many studies agree that vegetation density is a major factor in determining the performance of vegetated roadsides. The minimum vegetation density for good performance is 80 percent. However, there is little agreement on the effects of vegetation species and height. Climate (e.g., temperature and precipitation rate) affects vegetation establishment, runoff infiltration rates, and the capacity of vegetated treatment BMPs and necessitates careful consideration.

CHAPTER 4 POLLUTANT REMOVAL PERFORMANCE

The major mechanisms for the removal of highway runoff pollutants using vegetated systems are filtration through vegetation, infiltration of runoff into the soil and sedimentation that occurs by flow velocity reduction as stormwater passing through the vegetation mass. Soil infiltration will reduce the amount of stormwater discharged to surface waters. The pollutants of most concern to state transportation, environmental, and regulating agencies include but are not limited to:

- total suspended solids (TSS),
- total Kjeldahl nitrogen (TKN),
- nitrate (N),
- total phosphorus (TP),
- copper (Cu),
- lead (Pb),
- zinc (Zn), and
- chemical oxygen demand (COD).

A comparison of the performance of vegetated systems to other post-construction BMPs is difficult due to the diverse terminology and the grouping of vegetated systems into one category such as biofilters. This does not allow for direct comparison. The EPA and FHWA are sponsors, in part, to the International Stormwater Best Management Practice Database, located at http://www.bmpdatabase.org/. This website has numerous resources for stormwater management. Among its available documents is *Analysis of Treatment System Performance (41)*, which compares the pollutant removal performance of detention basins, biofilters, hydrodynamic devices, media filters, retention ponds, wetland basins, and wetland channels. Their biofilter category combines filter strips and grass swales. For the biofilter category, results showed a significant difference between the average influent and effluent in TSS with an effluent range between 15 mg/L and 30 mg/L. “Although EPA does not provide a national recommended numeric water quality criterion for TSS, many NPDES construction dewatering and wastewater permits identify 30 mg/L as the average permissible TSS concentration. Median concentrations for all of the BMP categories are below 30 mg/L” *(41)*.

The *Water Quality Control Technologies Inventory: Data Collection Summary Report (42)* prepared for the City of Austin, Texas, summarizes the TSS removal efficiency of several BMPs. Table 1 shows some of the BMPs for comparison. Vegetated filter strips showed 85 percent removal efficiency, which is greater than the extended detention pond, vegetated grassy swales, and some proprietary systems reported.

Table 1: City of Austin, Texas BMP TSS Removal Efficiency Summary *(42)*

	TSS removal efficiency (%)	< 1ac	1–10 ac	10–25 ac	>25 ac
Non-Proprietary BMPs					
Baffle boxes	70		*	*	*
Vegetative filter strips	85		*		
Infiltration/exfiltration trenches	90		*		
Extended detention ponds	75			*	*
Wet detention ponds	93			*	*
Sedimentation/filtration systems	89		*		
Vegetated/grassy swales	70	*	*		
Constructed wetlands	93			*	*
Bioretention ponds	90	*			
Retention/irrigation systems	100			*	*
Proprietary BMPs					
Bio-Retention	90	*			
Inlet (constructed)	80		*	*	*
Inlet inserts	80-90		*	*	
Pipe inserts	debris		*	*	
Porous pavements	95		*		
Sedimentation/filtration chambers	60-92		*	*	

The New Jersey Department of Environmental Protection's (NJDEP) *New Jersey Stormwater Best Management Practices Manual (34)* has pollutant removal criteria for their specific stormwater treatments. The performance expectation of a vegetated filter strip for removing TSS (60 to 80 percent) is comparable to the other listed BMPs. These range from 40 to 60 percent for extended detention ponds to 90 percent for bioretention and constructed stormwater wetlands. The NJDEP Stormwater Management Rules state:

- An 80 percent TSS reduction in the post-construction runoff is necessary from a land development site that increases impervious surface by 0.1 ha [0.25] acres or more.
- NJDEP has adopted official TSS removal rates for each of the BMPs.
- Different removal rates and BMPs may be utilized if supporting information is provided and accepted by the applicable review agencies.
- TSS removal rates have been based upon several sources of BMP research and monitoring data as well as consultation with numerous stormwater management experts.
- Actual TSS removals at specific BMPs during specific storm events will depend upon a number of site factors and can be highly variable.

Other state agencies have adopted similar efficiency requirements. The rate for TSS removal is the simplest to implement, as it is generally the easiest to ascertain. The 80 percent removal rate is the most commonly found in state, municipal and local agency documents.

As previously stated, vegetated stormwater treatments can be as effective as other BMPs. The research conducted that may serve as the impetus behind many state agency decisions to allow the use of vegetated buffers, filter strips and grass swales as primary stormwater quality treatments is shown in Tables 2 and 3. The efficiency of pollutant removal for filter strips and grass swales as related to the highway environment is well documented. The body of research regarding vegetated buffers, i.e., woody vegetation, used in the highway environment is negligible. Vegetated roadsides are generally recognized as having positive pollutant removal performance (*5, 6, 19, 43*). The data suggest relatively high removal rates for some pollutants and fair phosphorus performance.

Table 2: Pollutant Removal Efficiency by Filter Strip (%)

Source	TSS	NO3	TP	Metal	Cu	Pb	Zn	COD	Type
Li et al. *(6)*	18	0	-121		41	29		2	strip
	68	-25	-218		67	48		35	strip
	21	39	-24		41	67		-22	strip
Kaighn and Yu *(19)*	87		91.5				83.8	84	swale
	23.3		11				17.8	29.8	swale
	63.9		-21.2				87.6	59.3	strip
Yu and Kaighn *(44)*	27	6	22				17		18 ft strip
	67	8	22				46		50 ft strip
	68	9	33				50		150 ft strip
Barrett et al. *(45)*	54	74	53		75	83		30	strip
Barrett et al. *(5)*	85~87	23~50	34~44		NA	17~41		61~63	strip
Barrett et al. *(27)*	77~97				76~98	83~99	87~99		strip
Yu et al. *(7)*	54	-27	-25			-16	47		75 ft strip
	84	20	40			50	55		150 ft strip

Adapted from Li et al. *(6)* and EPA *(8)*

Table 3: Pollutant Removal Efficiency by Grass Swale (%)

Source	TSS	NO3	TP	Metal	Cu	Pb	Zn	COD	Type
Kahn et al. *(46)*	83		29						200 ft swale
Dorman et al. *(43)*	98	45	18	37~81					dry swale
	65	11	41	14~55					swale
	-85	-100	12	14~88					swale
Goldberg *(47)*	67.8	31.4	4.5	42~62					grassed
Harper *(48)*	87	80	83	88~90					dry swale
Kercher et al.*(49)*	99	99	99	99					dry swale
Oakland *(50)*	33		-25	20~58					swale
Occoquan Watershed Monitoring Laboratory *(51)*	-100		-100	-100					swale
	-50		-9.1	-100					swale
	31		-23	100~33					swale
Pitt , McLean *(52)*	0			0					swale
Seattle Metro, Washington Department of Ecology *(53)*	60	-25	45	2~16					swale
	83	-25	29	46~73					swale
Wang et al.*(54)*	80			70~80					dry swale
Yousef et al.*(55)*		11	8	14~29					swale
		2	-19.5	41~90					swale

Adapted from Li et al. *(6)* and EPA *(8)*

4.1 Summary

Overall, vegetated roadsides have a positive pollutant removal performance. Encouraging studies conducted by Caltrans *(24, 37)* show that many existing vegetated areas along highways perform comparably to systems engineered specifically for water quality improvement. ***Key points*** regarding the majority of water quality research conducted on roadside vegetation that clearly demonstrates performance capabilities are:

- The research sites chosen for roadside data collection were not specifically designed for stormwater quality treatment.
- Most of the data is from roadways with high ADT.

- The sites had different dimensions from those BMPs specifically designed for stormwater quality treatment.

Many of the previous studies performed regarding the use of vegetated buffers, filter strips and grass swales as sole-applications have been associated with agricultural applications. Data from these studies may not translate directly to roadside environments because of the differences in runoff characteristics and user expectations, but the scale of these applications does coincide with rural roadsides.

Performance results of vegetated buffers, filter strips, and grass swales vary depending on test conditions; however, studies on vegetated roadsides suggest relatively high removal rates for TSS and heavy metals and fair performance for soluble nutrients such as phosphorous and nitrate. Recent research on the effectiveness of filter strips and grass swales for removing pollutants from stormwater clearly shows that there can be consistent performance within a lesser treatment distance than most agencies' design criteria. Uniform terminology and more consistent design criteria would facilitate broader use within transportation agencies and encourage greater support from environmental and regulatory agencies. All studies showed that existing routine maintenance activities for vegetated roadsides were adequate to establish conditions favorable for substantial pollutant removal.

CHAPTER 5 STATE OF THE PRACTICE

Data gathered regarding state agency use of post-construction, rural roadside water quality BMPs involved:

- a review of available state agency documents,
- a survey distributed to state transportation, environmental and regulatory agencies, and
- follow-up interviews with select respondents.

Researchers prepared a survey after the preliminary review of state stormwater documents. The web-based survey tried to keep the balance between being a comprehensive instrument and not requiring an excessive amount of time to complete. The results are in Appendix A.

5.1 State Agency Practice

A review of available manuals and documents from state DOTs, environmental and regulatory agencies was conducted. Almost 50 percent of the state transportation, environmental and regulatory agencies use some type of vegetated BMPs as primary stormwater treatment. Researchers conducted a thorough agency website search to locate manuals or other documents pertaining to vegetated post-construction BMPs. Stormwater management is a dynamic field with agencies continually updating and/or redesigning websites for ease of use and to disseminate new information. The Arizona Department of Transportation, Alaska Department of Environmental Management, California Department of Transportation, Delaware DOT, Kentucky Transportation Cabinet, New Hampshire Department of Environmental Services, to name a few, have updated or added new stormwater documents within the past two years. Many state agency websites were difficult to navigate and post-construction BMPs were not easily located. This raises some concerns with the researchers as to how an end user will find the required information. There was only one state, Wyoming, where the researchers could not find post-construction BMP guidance documents produced by the respective state agency. Surprisingly, some state agencies do not recognize any type of post-construction stormwater treatments in their available documents. These agencies referred the reader to other state or federal databases and documents for post-construction BMP guidance. The range of documentation of other state agencies varied greatly from “use grass swales” to the design criteria as shown in Appendix A.

Agencies generally designate the use of vegetated stormwater treatments in terms of primary or secondary (pretreatment) uses. Along with the use of vegetated buffers, filter strips and grass swales is the increasing use of biofiltration or bioinfiltration systems. These include bioswales, biofiltration, wetland swales, enhanced swales and other systems that incorporate other media, plant materials and/or subsurface drainage. Urban areas are usually associated with the majority of these applications due to smaller watersheds or drainage areas. Table 4 shows the state agencies using vegetated BMPs as primary stormwater treatments. Documentation is from manuals, websites, survey response, and/or follow-up interviews.

Table 4: State Agency Documentation of Vegetated Post-Construction BMPs

	Vegetated Buffer or Filter Strip	Grass Swale
Regulatory	CO, DE, IA, ID, MD, ME, MN, MO, NC, NE, NJ, NM, SC, TN, TX, UT, VA, VT, WA, WI, WV,	AK, CA, CO, CT, DE, FL, IA, ID, MA, MD, MI, MN, NC, NH, NY, OR, PA, UT, VA, VT, WA, WI
Transportation	AZ, CA, CO, CT, DE, IA, MD ME, MO, MT, NC, NH, NV, NY, OH, OK, OR, RI, TX, UT, VA, WA, WI	CA, CT, DE, FL, HI, IA, IL, KY, MA, MD, MI, MO, NC, NH, NV, NY, OH, OK, OR, UT, VA, WI

There are several notable practices, documents, and manuals for stormwater treatment from DOTs and regulatory agencies. Some are quite thorough in their design criteria and inclusion of specifications, details, photographs and drawings. The following section highlights seven states as examples: California, Connecticut, Idaho, New Hampshire, North Carolina, Washington and Wisconsin. Information from the remaining states is in Appendix A.

5.1.1 California

California has conducted research fundamental to many state agencies' use of vegetated BMPs. The California Department of Transportation (Caltrans) *Storm Water Quality Handbooks, Project Planning and Design Guide (56)* specifies the use of biostrips and bioswales as primary stormwater treatments. Each BMP must not only meet the criteria set forth in the *Caltrans Highway Design Manual (57)*, they must also meet specific design for water quality. For the biostrips, this means placing them in locations that are as flat and long as possible (per Caltrans length measured as perpendicular to flow). A maximum width (parallel to flow) is 30 m [100 ft] with minimum of 4.5 m to 9 m [15 to 30 ft]. For a swale to be designated as a Treatment BMP, criteria relating depth, velocity, and Hydraulic Residence Time (HRT) as presented in the formula below must be met:

$$(\text{HRT} \times 60)/(\text{depth} \times \text{velocity}) \geq C$$

where:

HRT = Hydraulic Residence Time during Water Quality Flow (WQF), minutes ($\geq$ 5 minutes)
60 = conversion factor from minutes to seconds
depth = depth of flow at WQF (varies with velocity selected, up to 0.5 ft)
velocity = velocity of flow at WQF (varies with depth selected, up to 1 feet per second [fps])
C = A constant: 1,300 (sec^2/ft^2)

Note that the hydraulic residence time is that time during which the WQF travels in the biofiltration swale, and is not related to the time of concentration term as used in hydrologic calculations.

The California EPA Central Coast Regional Water Quality Control Board has a *Structural Post-construction Storm Water Best Management Practice Selection Tool.* The tool lists various design criteria, pollutant removal capabilities, construction costs, annual maintenance, environmental impacts and social acceptance.
http://www.waterboards.ca.gov/centralcoast/water_issues/programs/stormwater/docs/special_projects/selection_tool_august_2007.pdf.

5.1.2 Connecticut

Connecticut state transportation, environmental, and regulatory agencies recognize the use of vegetated BMPs in post-construction water quality treatment. The 2004 *Connecticut Stormwater Quality Manual (58)* from the Connecticut Department of Environmental Protection (CTDEP) lists water quality treatment BMPs in terms of primary and secondary treatment applications, effectiveness, land use applications, physical feasibility criteria, downstream resource selection criteria, maintenance, and winter and cold weather operation criteria. As with the majority of states, most of the documents found pertaining to stormwater management target urban applications. Water quality swales are specified as a primary treatment for stormwater with grass drainage swales used as secondary or pretreatment. This is consistent with the CTDEP's response to the survey of practice. Water quality swales are vegetated open channels designed to provide significantly higher pollutant removal than traditional grass drainage channels. They treat and attenuate the water quality volume and convey excess stormwater runoff. Grass channels designs focus on stormwater conveyance rather than water quality treatment.

CTDEP further classifies their water quality swales as dry swales and wet swales. Dry swales designs incorporate a pool or series of containment pools created by permanent check dams at culverts or driveway crossings. These temporarily hold the stormwater volume. The soil bed consists of native soils or highly permeable fill material, underlain by a drainage system. Wet swales work in the same manner, but use existing soils and do not use a subsurface drain or soil filter bed. Wet swales may retain stormwater in a series of cells formed by permanent check dams with wetland type vegetation within the swale. Pollutants removal consists of sedimentation, adsorption, nutrient uptake, and infiltration in dry swales while wet swales use microbial activity similar to wetlands *(58)*.

The document states that:

> "Rural areas are typically characterized by low-density development (i.e., few neighbors) and relatively large amounts of available space. Stormwater treatment practices with larger area demands may be easier to locate with appropriate buffers in rural areas. Additionally, typical stormwater pollutants from rural areas include sediments and nutrients, which can be effectively managed by most stormwater treatment practices. As a result, most treatment practices are suitable for rural areas."

The Connecticut DOT's *Stormwater Management Plan (59)* lists their acceptable post-construction site runoff controls. Included in their vegetative practices are grassed swales and grassed filter strips. According to the *ConnDot Drainage Manual (60)*, “vegetative (grass) lined swales are preferred for storm water quality (treatment) purposes.” They should be sized to accommodate a 10-year discharge and have a grass with “Retardance Class C” as described in the FHWA *Design of Roadside Channels with Flexible Linings, Hydraulic Engineering Circular Number 15, Third Edition* (HEC-15) *(61)*.

5.1.3 Idaho

Idaho Department of Environmental Quality’s (IDDEQ) *Storm Water Best Management Practices Catalog for Idaho Cities and Counties (18)* lists biofiltration swale (vegetated swale), bioinfiltration swale, and vegetated filter strip as primary stormwater treatments. The document acknowledges that for these types of systems to provide the required hydraulic residence time, vegetation quality, water velocity, slope, and soil must meet specific criteria.

Biofiltration swales construction is similar to a standard storm drain channel, but they are wider and flatter to maximize residence time. See Table 5 for design criteria. The bioinfiltration swales (BI swale) differ in design but are similar in application. They use containment areas within the swale to promote greater infiltration. “An open basin BI swale at the ground surface can be used where sufficient open space is available. This takes advantage of existing natural surface depressions and swales on the site where a berm or a low dam could very simply create the needed area. Alternatively, the landscape can be designed to include a depressed area in which to place the bioinfiltration swale. Road ditch areas are suited to use for bioinfiltration swales given the proper soil conditions.”

Soil infiltration is an important part of the BI swale design. Soils used in this application should be at least loamy, with a clay content of less than 15 percent. The soil should contain 3 to 5 percent organic material and have a pH of 5.5 to 6.5. Planting soil should be a depth of 1.2 m [4 ft]. Adequate nutrient removal requires a minimum of 0.76 m [2.5 ft]. The IDDEQ document’s Appendix C discusses appropriate plant material choices for the various vegetated BMPs.

The vegetated filter strip criteria are similar to other state agency documents, with one exception. The IDDEQ has set a residence time for the vegetated filter strip of 20 minutes. The Washington DOT was the only other state agency found that defined a residence time for a filter strip application. The residence time is designed as a function of the vegetated filter strip length. The length (per IDDEQ parallel to flow) is calculated to produce residence time of at least 20 minutes with a velocity no greater than 0.15 m/s [0.5 fps] to maintain sheet flow conditions. Use level spreaders when necessary to maintain sheet flow. The vegetated filter strip design is the same as for a vegetated swale, which is BMP1 in their manual, using a water quality design storm (one-third the volume) and a hydraulic radius approximately equal to the design flow depth.

Although the Idaho state regulatory agency has a comprehensive document regarding post-construction BMP, the researchers did not find much information from the DOT. The majority of the DOT information found relates to construction site practices and temporary controls.

Table 5: Idaho DEQ Design Criteria

	Biofiltration Swale	Bioinfiltration Swale	Vegetated Swale
Contributing drainage area	≤6 ha [15 ac]	≤2 ha [5 ac] ≤0.4 ha [1 ac] for impervious surface	≤2 ha [5 ac] Impervious flow length ≤23 m [75 ft] Pervious ≤46 m [150 ft]
Slope	≤6% Use check dams for slopes > 4%	≤4%	≤10% for treatment maximum 14%
Side slope	≤3:1, 0.3 m [1 ft] freeboard		
Flow velocity	≤0.46 m/s [1.5 fps]		
Length	60 m [200 ft] continuous swale Total swale surface area = 1% of total drainage area		30 to 60 m [100 to 200 ft] Calculate the necessary length (parallel to flow) to produce residence time ≤20 minutes and a velocity of ≤0.14 m/s [0.5 fps]
Flow depth	75 mm [0.25 ft]		13 mm [0.5 in]
Design storm	2-yr, 24-hr		
Residence time	9 minutes preferred Minimum 5 minutes		20 minutes
Soils (NRCS)	B and C	A and B	B, C, and D
Infiltration		≥0.2 mm/s [0.5 in/hr] ≤1.2 mm/s [3.0 in/hr]	
Minimum depth to bedrock	0.9 m [3 ft]	1.8 m [6 ft]	1.5 m [5 ft]
Minimum depth to water table	0.6 m [2 ft]	0.9 m [3 ft]	0.9 [3 ft]
Bottom width	≥0.6 m [2 ft]		

The follow-up interviews from the survey received responses from some agencies that did not coincide with documentation. When interviewed, the IDDEQ stated that they do not review and approve stormwater BMPs, only 404 permits and that local and county ordinances have their own standards.

5.1.4 New Hampshire

Both the state regulatory agency and DOT document the use of vegetated buffer, filter strips and grass swales as stormwater treatments. The New Hampshire Department of Environmental Services' recently published document, *New Hampshire Stormwater Manual Volume 2 Post-Construction Best Management Practices Selection & Design (62)* contains very good and current information regarding several post-construction BMPs. Relevant to rural roadside applications are the treatment swales.

> "Treatment swales are designed to promote sedimentation by providing a minimum hydraulic residence time within the channel under design flow conditions (Water Quality Flow). This BMP may also provide some infiltration, vegetative filtration, and vegetative uptake. Conventional grass channels and ditches are primarily designed for conveyance. Treatment swales, in contrast, are designed for hydraulic residence time and shallow depths under water quality flow conditions. As a result, treatment swales provide higher pollutant removal efficiencies."

These treatment swales are primary water quality treatments using the design criteria provided (see Figure 9). The document also specifies Roadway Buffers as a primary treatment. Pretreatments are vegetated filter strips and "pretreatment" swales.

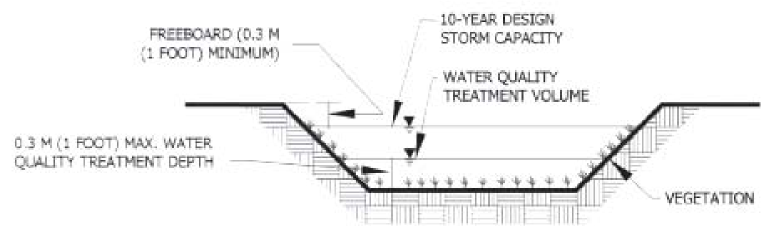
Design Criteria

Design Parameter	Criteria
Minimum Length	≥ 100 feet (not including portions in a roadside ditch)
Bottom Width	4 to 8 feet (widths up to 16 feet are allowable with dividing berm/structure such that neither channel width exceeds 8 feet)
Longitudinal Slope	0.5% to 2% without check dams 2% to 5% with check dams
Maximum Side Slopes	3:1
Flow Depth	4 inches maximum at the WQF
Hydraulic Residence Time	> 10 minutes during the WQF
Design Discharge Capacity	10-year, 24-hour storm without overtopping

• New Hampshire Stormwater Manual: Volume 2   Revision: 1.0

Example Design

Section



Adapted from MassHighway (2004)

Figure 9: New Hampshire Treatment Swale *(62)*

The New Hampshire DOT's *Highway Design Manual (64)* also list vegetated filter strips and vegetated treatment swales as primary BMPs. Specifications for their use as a water quality BMP are consistent with most other design manuals:

- vegetated filter strip,
  - gradual to moderate slopes to treat sheet flow by reducing velocity
  - natural vegetation if adequate and uniform
  - filter strips wide enough for thorough treatment
  - flow equally distributed to prevent concentration and rill formation

- vegetated treatment swale,
  - trapezoidal or parabolic shape
  - dense vegetation
  - ability to reduce flow depth to a maximum of 100 mm (4 in)
  - hydraulic residence time greater than 9 minutes at water quality flow (peak flow rate associated with the water quality volume)
  - appropriate Manning's roughness coefficient or a vegetal retardance factor related to the average length of vegetation to calculate the flow velocity and capacity of the swale.

5.1.5 North Carolina

North Carolina's Department of Environmental and Natural Resources (NCDENR), Division of Water Quality's *Stormwater Best Management Practices Manual (64)* has numerous post-construction BMPs with very detailed descriptions and specifications for use. This coincides with the survey of practice response from the DOT confirming vegetated BMP use for primary stormwater treatment. Included with each BMP is specific inspection and maintenance provisions with potential problems and solutions. This document also categorizes the design criteria for grassed swales as conveyance swales seeking pollutant credit or conveyance swales *not* seeking pollutant credit. For pollutant removal credit, design conveyance swales according to the Division of Water Quality's (DWQ) policy. "These are based on available research, and represent what DWQ considers necessary to achieve the stated removal efficiencies." These include:

- maximum velocity 0.3 m/s [1 fps] for the 10-year, 24-hour storm
- side slopes 5:1 or flatter
- maintenance agreement required
- length 46 m [150 ft] or greater
- minimum depth from swale bottom to seasonal high water table 0.3 m [1 ft]

The NCDENR lists filter strips as primary treatment for stormwater runoff from highways and as pretreatment for other BMPs. NCDENR requires the use of a level spreader for sites without permanent, sustained sheet flow. General design criteria are as follows:

- Slopes less than 5 percent are preferred. Maximum allowed is 15 percent.
- Top edge of filter strip should follow elevation contour.

The NCDENR measures filter strip length perpendicular to flow. The length must be between 4 and 40 m [13 and 130 ft] as determined by type of vegetative cover. They measure width parallel to flow. The width should be a minimum of 15 m [50 ft] for treatment credit as shown in Figure 10.

- For vegetation characterized as grass or thick ground cover, use a length of 4 m per 0.028 m^3/s [13 ft per 1 cfs] of flow for slopes that are 8 percent or flatter.
- For vegetation characterized as forested, use a length of 20 m per 0.028 m^3/s of flow [65 ft per 1 cfs] for slopes that are 6 percent or flatter.

- If the forest vegetation is 30 to 46 m [100 to150 ft] in width, reduce the length of filter strip to 15 m per 0.028 m^3/s of flow [50 ft per 1 cfs].
- If the forest vegetation is more than 46 m [150 ft] in width, reduce the length to 12 m [40 ft] of filter strip per 0.028 m^3/s [1 cfs] of flow.
- For filter strip with discrete sections of differing vegetation, use a weighted average calculation.

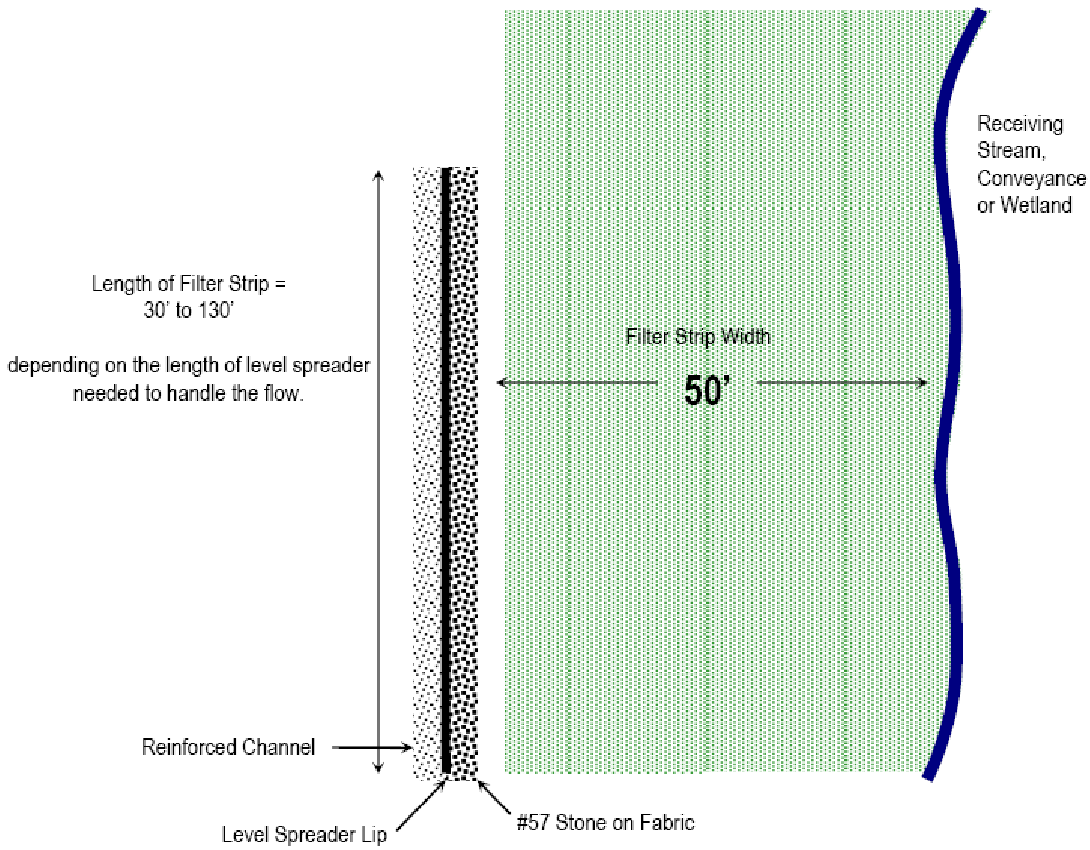


Figure 10: Filter Strip Schematic for Receiving Pollutant Removal Credits *(64)*

5.1.6 Washington

Washington State DOT (WSDOT) *Highway Runoff Manual (9)* designates several vegetation related BMPs for treating stormwater. Among the listed BMP types are dispersion and biofiltration. WSDOT describes the benefits of using natural dispersion techniques done by retaining and using existing natural area capacity to remove pollutants from non-urbanized highway runoff. The preserved, naturally vegetated dispersion area shown in Figure 11 requires sustained sheet flow from runoff and topographic, soil, and vegetation characteristics that provide for the removal of pollutants. Engineered dispersion BMPs are similar to natural dispersion areas; however, an engineered dispersion area is a constructed conveyance system accepting concentrated flow from storm sewer pipe, ditch, or other methods. The concentrated flow discharges into the dispersion area as sheet flow. Engineered dispersion areas use compost amended soils and additional vegetation to ensure required capacity and infiltration. "The most notable benefits associated with natural dispersion are that it maintains and preserves the natural functions; reduces the possibility of further impacts to the adjacent natural areas associated with the construction of physical treatment facilities; and can be very cost-effective. In most cases, this method not only meets the requirements for runoff treatment, but also provides flow attenuation."

Figure 11: Natural Dispersion Area SR 516, King County, WA *(9)*

There are three WSDOT biofiltration techniques using vegetated filter strips: basic vegetated filter strips, compost-amended vegetated filter strips (CAVFS), and narrow area vegetated filter strips (Figure 12). The narrow area vegetated filter strip is limited to use along areas with an impervious flow path of less than 9 m [30 ft]. The CAVFS is similar in design to a basic filter strip. It uses compost-amended soil to gain higher surface roughness; greater retention and infiltration capacity; improved removal of soluble cationic contaminants through sorption; improved overall vegetative health; and a reduction of invasive weeds. The CAVFS have a greater initial installation cost but require less land area for runoff treatment, which can reduce overall costs.

Figure 12: WSDOT Vegetated Filter Strip *(9)*

The Washington State Department of Ecology's *Stormwater Management for Eastern Washington (65)* and *Stormwater Management Manual for Western Washington (36)* use bio-infiltration swales and vegetated filter strips as primary treatments. Each document has very specific calculations for each BMP. For eastern Washington, these are some of the recommendations for filter strips.

- Place at least 0.3 m [1 ft], and preferably 0.9 to 1.2 m [3 to 4 ft] from the edge of pavement, to accommodate a vegetation free zone.
- Use for sheet flow only, not concentrated flow.
- A maximum flow path of each 9 m [30 ft] can contribute to a filter strip designed via this method.
- Use where the roadway ADT is less than 30,000.
- Limited use includes
  - roadways with longitudinal slopes greater than 5 percent, and
  - crowned roads with filter strips along both sides of the road.
- Do not use for banked roads that drain only to one side without additional analysis to account for the extended flow path length.

Typical use of the basic filter strip is on-line, and adjacent and parallel to a paved area such as parking lots, driveways, and roadways. Where a filter strip area is compost-amended to a minimum of 10 percent organic content, with hydroseeded grass maintained at 95 percent density, and a length of 100 mm [4 in] by mowing and periodic reseeding (possible landscaping with herbaceous shrubs), the filter strip serves as an enhanced treatment option *(36)*.

Biofiltration swales for eastern Washington, as with other BMPs in the document, are site-specific designs and adhere to numerous formulas to arrive at the desired design. “Roadside ditches should be regarded as significant potential biofiltration sites and should be utilized for this purpose whenever possible” *(65)*. The general design criteria are as follows:

- general length of 61 m [200 ft]
- maximum bottom width 3 m [10 ft]
- depth of flow maximum 100 mm [4 in] during the design storm
- flow velocity maximum 0.028 m/s [1 fps]
- channel slope between 1 percent and 5 percent
- trapezoid shape
- side slopes 3:1 or flatter

The swales can be sized as both a treatment facility for the 6-month storm and as a conveyance system to pass the peak hydraulic flows of the 25-year storm if it is located “on-line.” Maximize water contact with vegetation and the soil surface. Select fine, close-growing grasses (or other vegetation) that can withstand prolonged periods of wetting, as well as prolonged dry periods (to minimize the need for irrigation). While many of the criteria from the western Washington document are the same, a minimum swale length of 30 m [100 ft] and a hydraulic residence time of 9 minutes are required. It also recommends a 4:1 side slope.

A version of the biofiltration swale called the “continuous inflow biofiltration swale” in the western Washington document is specific to roadway stormwater treatment. Recommended use of this BMP is for roadsides, “where water enters a biofiltration swale continuously along the side slope rather than discretely at the head.” This requires a different design approach that uses an increased swale length to achieve the required hydraulic residence time of 18 minutes for this BMP. This residence time is an equivalent average because discharged runoff is not specific to one location in the swale. Application limitations for this BMP include situations where “significant lateral flows enter a swale at some point downstream from the head of the swale. In this situation, the swale width and length must be recalculated from the point of confluence to the discharge point in order to provide adequate treatment for the increased flows.” The design criteria are the same as specified for basic biofiltration swale except for the recommendation that these be on-line facilities due to side slope draining into the swale along the entire swale length. Chapter 9 in the western Washington document discusses the calculations for the increased residence time of 18 minutes.

5.1.7 Wisconsin

The Wisconsin Department of Natural Resources (WIDNR), Runoff Management Section’s *NR 151 Subchapter IV Transportation Facilities Performance Standards (66)* applies directly to DOT projects. The document sets performance standards for post-construction BMPs that include controlling 80 percent of the TSS in stormwater discharge. Vegetated swales meet these standards. The DOT 151 Transportation Section, Swale Treatment Exclusion has design criteria to meet the primary water quality requirements for rural roadsides:

- 61 m [200 ft] long
- Design for 2-yr storm
- Flow velocity of 0.46 m/s [1.5 fps]

From the survey of practice sent to state agencies, the response from WIDNR stated that if the BMP meets the technical standards then they are accepted for use. "These BMPs work." Other comments include:

- Swales perform better than curb and gutter sections.
- Existing swales need to meet TSS removal requirements – use WinSLAMM model.
- Roads in MS4 with rural cross-section need to use WinSLAMM model to meet infiltration technical standard and receive credit as a primary treatment.
- They are currently working on a model for filter strips.

5.2 Survey of Practice

A survey was developed and sent to stormwater professionals throughout the country. Recipients included state transportation, environmental and regulatory agency personnel. The purpose of the survey was to identify the various agency policies, practices and experience with vegetated buffers, filter strips and grass swales as stormwater treatment in rural roadside applications. The literature review noted that terms used in association with vegetated stormwater treatments differed around the country. Because of this, the researchers used common definitions for the survey. The term "grass swale" was used to describe any type of vegetated buffer used for concentrated flow. "Vegetated filter strip" was used to describe BMPs used for sheet flow. The survey used a web-based interface program. The survey recipients received an introductory e-mail that included a project description and a web link to the survey.

The survey requested information from the various state agencies regarding soil type, width, length, vegetation type, swale depth, and slopes. The survey response rate was 43 percent with 22 surveys completed by transportation agencies and 13 from environmental or regulatory agencies. The focus of this project is rural roadside applications. When asked if the respective state environmental and regulatory agency accepts grass swales as stormwater treatment structures in rural highway settings, 100 percent of the respondents replied yes. For vegetated filter strips, over 90 percent replied yes with Mississippi and Ohio DOTs indicating that vegetated filter strips are not accepted. Over 75 percent of the respondents use grass swales and filter strips as primary and secondary stormwater treatment (post-construction). The survey and results are in Appendix A.

5.3 Follow-up Interviews

Follow-up interviews conducted with a select group of survey respondents focused on regulatory agencies to ascertain their rationale for acceptance/use or non-acceptance/use of vegetated buffers, filter strips and grass swales as primary water quality treatments in rural roadside applications. The results are in Appendix A.

Chapter 6 Suggested Best Practices

The synthesized available knowledge base found in the current research and state transportation, environmental and regulatory agency recommendations produced the suggested best practices. These are preferred methods of using vegetated systems as post-construction, primary water quality treatments for rural roadside applications. The basis for design considerations and parameters are for their use as a water quality treatment on rural roadsides.

6.1 Vegetated Buffer

6.1.1 Description

Vegetated buffers are areas of natural or established vegetation that reduce runoff velocity, promote infiltration, filter sediment, and reduce the thermal impacts of roadway runoff as stormwater passes through it. Vegetated buffers may consist of grasses, shrubs and trees. Filter strips and grass swales may be included as part of a vegetated buffer (Figure 13). Suggested design criteria for use as a stormwater treatment are in Table 6.

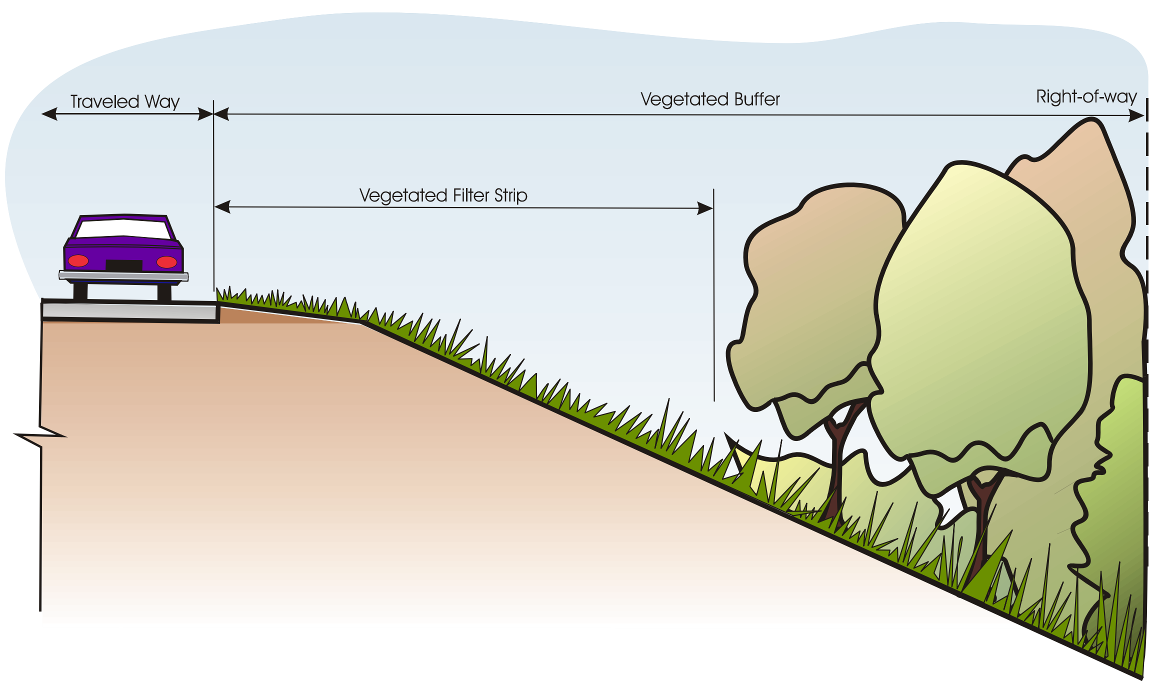


Figure 13: Vegetated Buffer and Filter Strip

6.1.2 Design Considerations

- The upslope edge of the vegetated buffer directly adjacent to a roadway must follow the elevation contour of the adjacent roadway so that stormwater runoff from the roadway will pass through the vegetated buffer as sheet flow.
- The slope should be free of areas that will concentrate the overland flow and create eroded conditions.

- Vegetated buffers are not suitable for steep terrain or in soils that cannot sustain vegetation.
- Contributing area must flow directly onto the vegetated buffer as sheet flow.
- Do not direct concentrated flow to the vegetated buffer unless a level spreader is used.
- Contributing roadway should follow the elevation contour and be parallel to the vegetated buffer.
- Measure vegetated buffer length parallel to the flow path.

Table 6: Suggested Design Criteria for Vegetated Buffers

Design Storm	N/A
Slope	Minimum 1 percent Maximum 20 percent Preferred 2 to 6 percent
Minimum Length (parallel to flow)	Minimum 8 m [26 ft]
Width (perpendicular to flow)	Usually equal to width of vegetated buffer
Contributing Drainage Area	Unlimited
Flow Type	Sheet flow only
Flow Velocity	Preferred 0.14 to 0.28 m/s [0.5 to 1 fps] Maximum of 0.84 m/s [3 fps]
Flow Depth	12 to 25 mm [0.5 in to 1 in] Must be able to convey stormwater from roadway
Vegetation Density	Minimum 80 percent Preferred 90 percent
Vegetation Type	Grasses, shrubs, and trees
Vegetation Height	Keep vegetation height within safety parameters for the roadway and to maintain density
Preferred NRCS Soil Types	All types however Types A and B are more effective due to greater infiltration rates
Hydraulic Residence Time	N/A
Depth to Water Table	Place to not interfere with seasonal high water
Depth to Bedrock	N/A

6.1.3 Maintenance Requirements

There is minimal to no maintenance required. An annual inspection of the buffer will determine areas of erosion, vegetation loss, and sedimentation. Depending upon location and vegetation used, periodic mowing may be necessary. Repair eroded areas to avoid further damage. Use a level spreader to maintain sheet flow when necessary.

6.2 Filter Strips

6.2.1 Description

Filter strips are areas of natural or established vegetation that require dense grasses that can sustain sheet flow to provide pollutant removal as stormwater passes through it. Filter strips can reduce runoff velocity, promote infiltration, filter sediment and reduce the thermal impacts of roadway runoff (see Figure 14). Filter strips can be used in conjunction with grass swales to increase the water quality performance. Suggested design criteria for use as a stormwater treatment are in Table 7.

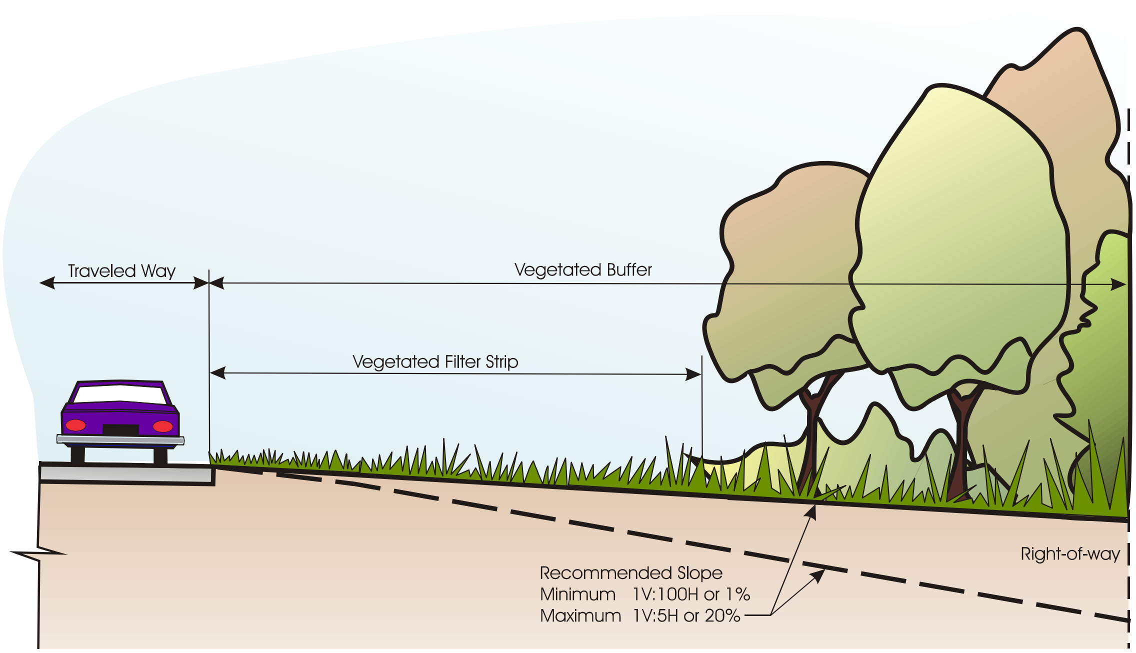


Figure 14: Filter Strip

6.2.2 Design Considerations

- The upslope edge of the filter strip directly adjacent to a roadway must follow the elevation contour of the adjacent roadway so that stormwater runoff from the roadway will pass through the filter strip as sheet flow.
- The slope should be free of areas that will concentrate the overland flow and create eroded conditions.
- Filter strips are not suitable for steep terrain or in soils that cannot sustain the required vegetation density levels.
- Contributing area must flow directly onto filter strip as sheet flow.
- Do not direct concentrated flow to the vegetated buffer unless a level spreader is used.
- Contributing roadway should follow the elevation contour and be parallel to the vegetated buffer.
- Measure vegetated buffer length parallel to the flow path.

Table 7: Suggested Design Criteria for Filter Strips

Design Storm	N/A
Slope – For use as Primary Stormwater Treatment	Minimum 1 percent Maximum 20 percent Preferred 2 to 6 percent
Minimum Length (parallel to flow)	Minimum 8 m [26 ft]
Width (perpendicular to flow)	Width of contributing area
Contributing Drainage Area	Contributing area is generally less than or equal to the width of the filter strip. An example is runoff from a rural 2-lane road 7.3 m [24 ft] flowing to an 8 m [26 ft] filter strip.
Flow Type	Sheet flow only
Flow Velocity	Preferred 0.14 to 0.28 m/s [0.5 to 1 fps] Maximum of 0.84 m/s [3 fps]
Flow Depth	12 to 25 mm [0.5 in to 1 in]
Vegetation Density	Minimum 80 percent Preferred 90 percent
Vegetation Type	Preferred – Grasses and other low growing permanent vegetation
Vegetation Height	Keep vegetation height within safety parameters for the roadway and to maintain density
Preferred NRCS Soil Types	All soil types however Types A and B are more effective due to greater infiltration rates
Hydraulic Residence Time	N/A
Depth to Water Table	Place to not interfere with seasonal high water
Depth to Bedrock	N/A

6.2.3 Maintenance Requirements

There is minimal to no maintenance required. An annual inspection of the filter strip will determine areas of erosion, vegetation loss, and sedimentation. Depending upon location and vegetation used, periodic mowing and vegetation maintenance may be necessary. Repair eroded areas to avoid further damage. Use a level spreader to maintain sheet flow when necessary.

6.3 Grass Swales

6.3.1 Description

A grass swale is a shallow open-channel conveyance system stabilized by grass or other low-growing herbaceous vegetation designed specifically to treat and attenuate stormwater runoff for a specified water quality volume (Figure 15). The water quality performance of grass swales can be enhanced by the use of velocity controls to increase residence time and provide for greater infiltration, sedimentation and adsorption.

Greater pollutant removal efficiency can be gained by extending the length and/or flattening the slope of the filter strip adjacent to the swale. This is suggested in locations where the primary stormwater treatment is the filter strip and the roadside can accommodate this configuration. The typical grass swales are trapezoid and parabolic. The design should maximize surface contact, such as a broad, flat grass swale. As with all roadsides, consider site-specific limitations to ensure that the grass swale configuration will meet the water quality treatment, safety and maintenance needs. Suggested design criteria for use as a stormwater treatment are in Table 8.

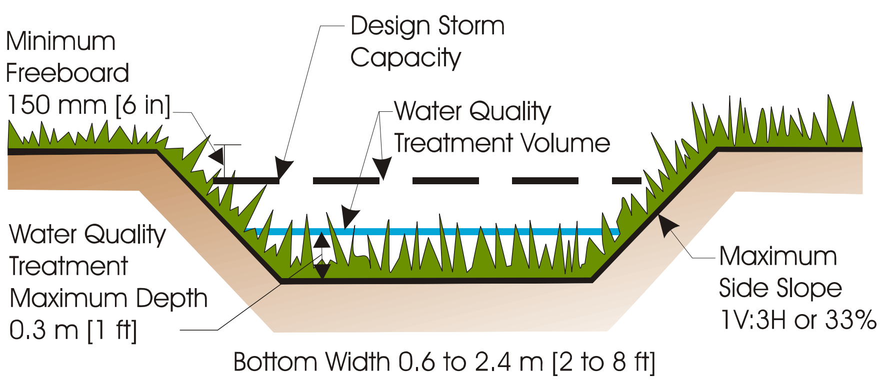


Figure 15: Grass Swale

6.3.2 Design Considerations

- The longitudinal slope of the grass swale should be as flat as possible to minimize velocities, increase infiltration and improve pollutant filtering.
- Use velocity control to reduce the velocity and increase residence time.
- At grade change locations within the grass swale, the designer should consider using turf reinforcement to reduce scour caused by hydraulic jumps.
- Design geometry must not allow the stormwater to exceed the maximum permissible velocity or flow depth for the design flow rate.
- Freeboard should be a minimum of 150 mm [6 in] freeboard.
- A dense grass cover is required to achieve the maximum water quality treatment.
- Soil type should have a moderate to high infiltration rate and be able to sustain healthy vegetation. Avoid compacted soils.

- Use a rolled erosion control product (RECP), turf-reinforcing mat (TRM), or other erosion control material (based upon site-specific design) during the vegetation establishment period as necessary.
- Measure the length of a grass swale parallel to the flow path.

Table 8: Suggested Design Criteria for Grass Swales

Design Storm	2-year with 10-year capacity
Longitudinal Slope	Minimum 1 percent Maximum 10 percent Preferred 2 to 6 percent
Side Slopes	Maximum 33 percent
Minimum Length (parallel to flow)	With check dams, length should be based upon longitudinal slope to accommodate hydraulic residence time of 9 minutes Without check dams, length should be minimum of 30 m [100 ft] of continuous swale before discharge
Width (perpendicular to flow)	Bottom between 0.6 to 2.4 m [2 to 8 ft]
Cross Section Configuration	Trapezoid or parabolic
Contributing Drainage Area	Preferred: Equal to 1 percent of swale surface area
Flow Type	Concentrated flow
Flow Velocity	Between 0.27 and 1.5 m/s [1 to 5 fps]
Hydraulic Residence Time	9 minutes
Velocity Controls	Use of check dams to increase performance
Flow Depth	100 to 150 mm [4 to 6 in] or 2/3 grass height
Vegetation Density	Minimum 80 percent Preferred 90 percent
Vegetation Type	Select vegetation based upon soil type, inundation tolerance, filtering capabilities, typical mowing height and design flow velocities
Vegetation Height	Generally 100 to 150 mm [4 to 6 in]
Preferred NRCS Soil Types	A, B, or C Minimum 7 mm [0.27 in] per hour infiltration
Depth to Water Table	Minimum 0.6 m [2 ft]
Depth to Bedrock	Minimum 0.9 m [3 ft]

6.3.3 Maintenance Requirements

There is minimal maintenance required. Inspection of the grass swale will determine areas of erosion, vegetation loss, and sediment accumulation. Depending upon location and vegetation used, periodic mowing may be necessary. Repair eroded areas to avoid further damage. Remove sediment build-up behind check dams as necessary.

CHAPTER 7 GAINING REGULATORY ACCEPTANCE

Gaining regulatory acceptance of stormwater best management practices has been challenging for many state transportation agencies. The use of vegetated stormwater quality treatments is widely accepted throughout the country whether in urban or rural applications. State transportation, environmental and regulatory agencies recognize their performance capabilities and their use as part of LID. The NCHRP Report 565, *Evaluation of Best Management Practices for Highway Runoff Control (22)*, outlines several regulatory factors, not only for choosing the most effective BMP, but also in having the regulating authority recognize and accept those choices. These consist of compliance with numerous federal, state and local rules and regulations that may include:

- Section 303(d) and TMDLs,
- NPDES Permit Program,
- Section 404 Permit,
- Water quality criteria,
- National Estuary Program,
- Coastal Zone Act Reauthorization Amendments,
- Safe Drinking Water Act,
- Endangered Species Act,
- Resource Conservation and Recovery Act,
- National Wild and Scenic Rivers Act, and
- National Environmental Policy Act (NEPA).

The report further acknowledges that many state agencies do not have the facilities or funding to conduct their own research. Programs and databases that have accumulated research and technologies related to stormwater management that can facilitate the approval of specific stormwater treatments are becoming more prevalent. The EPA has the Environmental Technology Verification (ETV) Program, http://www.epa.gov/etv/ that “verifies the performance of innovative technologies that have the potential to improve protection of human health and the environment. ETV accelerates the entrance of new environmental technologies into the domestic and international marketplaces.”

Another innovative approach to regulatory approval is the Technology Acceptance and Reciprocity Partnership (TARP) endorsed by the following state agencies:

- California State Water Resources Board and Environmental Protection Agency,
- Illinois,
- Maryland Department of the Environment,
- Massachusetts Department of Environmental Protection,
- New Jersey Department of Environmental Protection,
- New York,
- Pennsylvania Department of Environmental Protection, and
- Virginia Department of Environmental Quality.

The above state agencies have formed this partnership for technology evaluation. Their document, *The Technology Acceptance Reciprocity Partnership, Protocol for Stormwater Best Management Practice Demonstrations (67)*, has some stated objectives.

- Address technology review and approval barriers in policy and regulations that do not advance knowledge of a technology's performance or recognize innovative approaches to meet environmental protection goals;
- Accept the performance tests and data, and acknowledge the approval results of a partner's review of a technology demonstration, as appropriate, in order to reduce subsequent review and approval time;
- Increase expertise in the applications and advantages of technologies that may have superior environmental and economic benefits for controlling stormwater pollution;
- Use the protocol, as appropriate, for state-led initiatives, grants, and verification or certification programs where the objective is to document performance efficiency and cost of best management practices;
- Share technology information with potential users in the public and private sectors using existing state supported programs; and
- Monitor and evaluate the results of using this protocol, and periodically review and revise the Protocol to maintain its viability *(67).*

Within this program, TARP has established a review process for BMP performance claims to ensure that it meets their program criteria as shown in Figure 16.

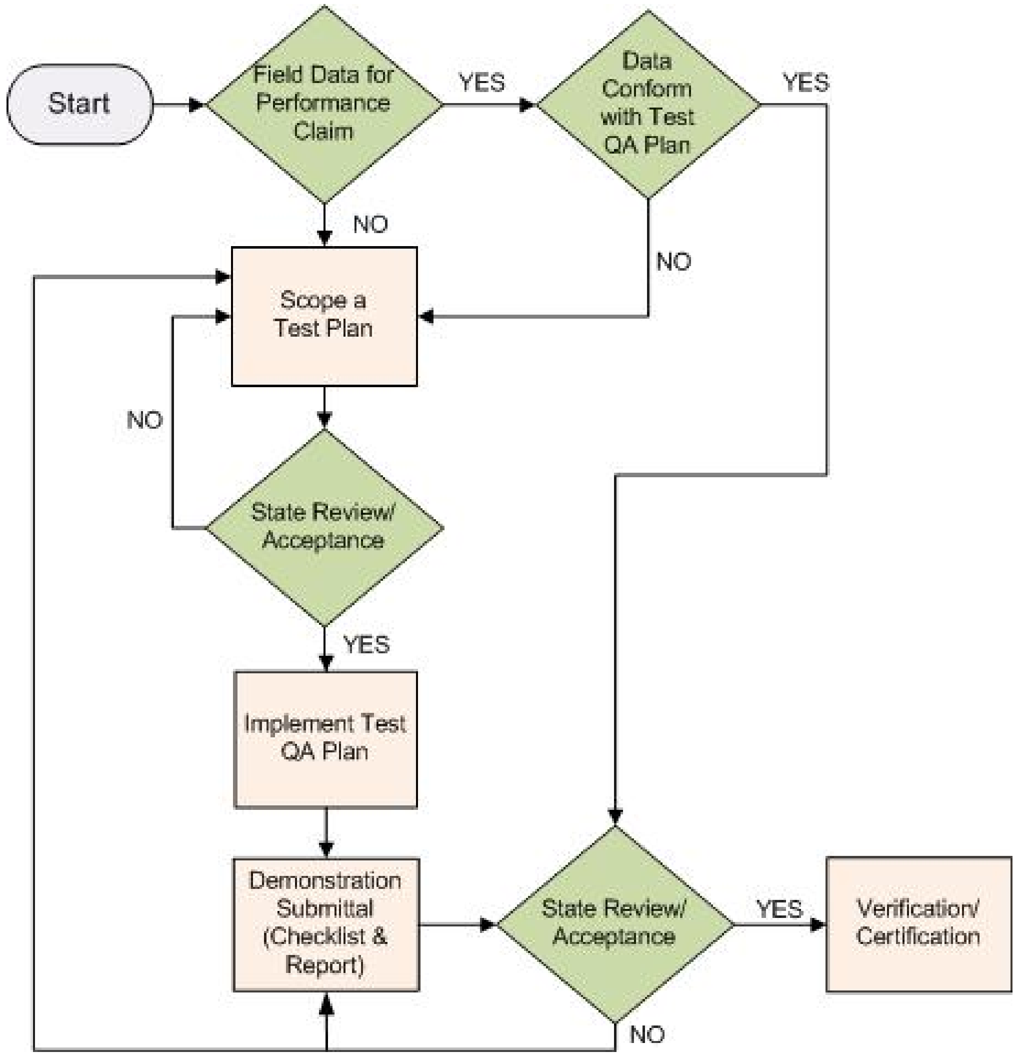


Figure 16: TARP Decision Process *(67)*

The Virginia Department of Conservation and Recreation's *Stormwater Management Requirements Guidance on the Chesapeake Bay Preservation Area Designation and Management Regulations (68)* has revised their regulations to change the language from treatment requirements to either a performance or technology-based approach to determine if a specific BMP will meet their water quality requirements. A performance-based approach associates pollutant loads (based on a given pollutant loading concentration) with the percentage of impervious cover. "The method assumes the amount of runoff, and the corresponding pollutant loads, are directly proportional to the degree of impervious cover. BMPs with given pollutant removal efficiencies are applied to the site to reduce post-development loads to pre-development levels associated with an average land cover condition, or default" *(68)*. A technology-based approach considers the site characteristics such as drainage area, total impervious cover, engineering constraints, etc. to select the most technologically appropriate BMP to reduce the post-construction pollutant load. The *Virginia Stormwater Management*

Handbook (69) references the specific BMP design criteria used. According to the document, the reason for the language change is to "shift the focus of BMP selection and design from debates over a few percentage points worth of pollutant removal efficiency to a new focus on the application of the most appropriate level of treatment technology for the site" (See Figure 17).

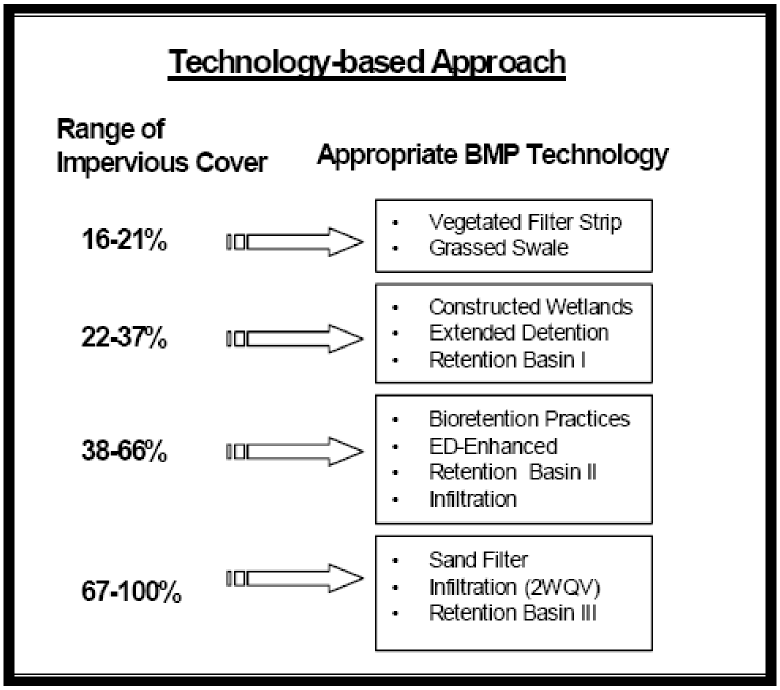


Figure 17: Virginia DCR Technology-based Approach *(69)*

The Washington State Department of Ecology (Ecology) developed the *Guidance for Evaluating Emerging Stormwater Treatment Technologies, Technology Assessment Protocol – Ecology (TAPE) (70)*. "Ecology established the Technical Review Committee (TRC) to evaluate and recommend new treatment technologies for addition to the list of technologies deemed to be all known, available, and reasonable methods of prevention, control, and treatment (AKART). Local governments statewide can use the emerging technology level designations posted on Ecology's website where applicable, depending on local conditions "testing protocol and process for evaluating and reporting on the performance and appropriate uses of emerging stormwater treatment technologies. By obtaining accurate and relevant data, Ecology and the TRC can assess performance claims."

The Arizona DOT (AZDOT) has developed criteria for approving post-construction BMPs. Its process in the *ADOT Post-Construction Best Management Practices Manual for Highway Design and Construction (33)* is as follows:

- Review of BMPs currently used
  - A list of existing post-construction BMPs was compiled and formalized after reviewing current practices, institutional AZDOT knowledge, past erosion control field studies, and published drainage design guidance. In many cases, AZDOT also implements post-construction BMPs by retaining or modifying temporary BMPs.

- Process of elimination
  - For some post-construction BMPs, particularly water quality/treatment BMPs, a "common sense" approach was used to eliminate BMP technologies that were deemed inappropriate for ADOT's needs. Examples of these "common sense" reasons to automatically not consider certain BMPs include:
    - Excessively high construction and/or operation and maintenance costs;
    - Not appropriate in any climatic zone of Arizona; and
    - Experimental or currently lacking well-documented data on the operation and maintenance costs.

The summary of the regulatory acceptance challenges in *NCHRP Report 565, Chapter 7 Regional Drivers of BMP/LID Selection (22)* specifically speaks of proprietary BMPs (usually a manufactured device or system), but the same statement can be applied to any stormwater treatment. It acknowledges that the emerging programs listed in this chapter have a very promising start on the testing and approval or disapproval of innovative technologies, but those BMPs not verified may have a limited chance at approval by regulatory agencies even if the "fundamental unit processes provided by the BMP can be theoretically demonstrated."

The research conducted regarding the effectiveness of vegetated buffers, filter strips, and grass swales as primary stormwater treatments is becoming more consolidated and accessible through the ever-growing number of websites and databases. This endeavor of the stormwater management community acknowledges the performance capabilities of these BMPs and has provided direction for state agencies in their efforts to gain acceptance of the use of specific stormwater treatments by regulatory agencies. The public's desire for more green technology designs and use has become more prevalent. Vegetated buffers, filter strips and grass swales can meet the environmental and regulatory criteria as well as satisfying the public's awareness of the available design alternatives.

CHAPTER 8 CONCLUSIONS AND RESEARCH NEEDS

8.1 Conclusions

Vegetated buffer, filter strips and grass swales are part of the rural roadside geometry used for conveying and/or treating stormwater runoff. Recent research clearly demonstrates that the water quality performance of these roadside components is comparable to other post-construction BMPs for reducing the pollutant constituents transported to receiving water bodies.

The majority of state agencies that use vegetated buffers, filter strips, and grass swales as a primary stormwater treatment for post-construction rural roadside applications have specific criteria that qualify their use for primary stormwater treatment. For vegetated buffers and filter strips, this usually includes filter strip length, slope and soil type. For grass swales, this may include design storm, longitudinal slope, soil type, the use of velocity controls, residence time, and vegetation type and density. Many states are including the use of bioswales (many different terms for the same application) or swales designed specifically for water quality treatment. These swales are similar in design to a standard roadside swale but may utilize different soils, subsurface drain, or may be wider and flatter to maximize the hydraulic residence time and surface contact within the swale.

Research demonstrates that the most effective area of the roadside for removing pollutants is the vegetated area directly adjacent to the roadway edge. Effective pollutant removal can be accomplished using filter strips with a minimum length (measured parallel to flow) of 8 m [26 ft], a maximum slope of 20 percent, and a vegetation density of 80 percent. Grass swales can be used for primary stormwater treatment in most conditions (site-specific) by the addition of velocity controls to increase the hydraulic residence time, infiltration, and sedimentation through short-term ponding of runoff upstream.

The results of Task 53 demonstrate that most state transportation, environmental, and regulatory agencies use vegetated practices for post-construction stormwater treatments, whether as a pretreatment for other water quality practices or as primary treatment. The focus of the project was on rural post-construction applications. Data gathered for post-construction BMPs shows that many state agencies:

- do not differentiate between urban and rural in their stormwater manuals,
- specify only for urban applications, or
- focus on temporary/construction BMPs.

Many DOTs only have manuals that specify construction or temporary BMPs with little information regarding post-construction treatments. Some of these simply list acceptable post-construction BMP with no further information. Others, such as the Maine DOT who defers to the Maine Department of Environmental Protection’s *Stormwater Management for Maine (26)* for post-construction BMPs, direct the reader to another agency’s documents, such as the EPA. The Connecticut Department of Environmental Protection’ *Connecticut Stormwater Quality Manual (58)* summarizes the difference between urban and rural in performance expectations and stormwater runoff characteristics.

> "Rural areas are typically characterized by low-density development (i.e., few neighbors) and relatively large amounts of available space. Stormwater treatment practices with larger area demands may be easier to locate with appropriate buffers in rural areas. Additionally, typical stormwater pollutants from rural areas include sediments and nutrients, which can be effectively managed by most stormwater treatment practices. As a result, most treatment practices are suitable for rural areas."

Although some state regulatory agencies have not fully accepted the use of vegetated buffers, filter strips, and grass swales as primary water quality treatments, over 50 percent have. These are in Table 3. The states that have not sponsored their own research have readily adopted other state agency protocols or have looked to EPA for guidance. The decisions for use of vegetated systems as primary water quality treatments by most regulatory agencies were based upon:

- national and international research data that demonstrates effective performance,
- their own research data,
- practical application or field demonstration,
- years of successful use, and
- other state agency criteria from existing manuals, either environmental, regulatory or DOT (most occurring).

There were three main reasons given by transportation, environmental and regulatory agencies for not specifying vegetated stormwater treatments for use in post-construction rural roadside applications:

1. The state regulatory agency does not require post-construction treatments.
2. The state regulatory agency does not require post-construction treatments in rural applications or only regulates within urban areas.
3. The region cannot support the vegetation density levels required for effective pollutant removal due to minimal annual rainfall, high altitude, or extended winter seasons.

The majority of the regulatory agencies that do not require post-construction treatments in rural applications do not disallow the use of vegetated systems; they simply do not recommend specific practices, monitor, and/or require their use other than final stabilization.

Federal, state and local transportation, environmental, and regulatory agencies regard the use of vegetated stormwater treatments very positively. This is due, in part, to implementation and maintenance costs and a growing public awareness and acceptance of "green" or LID techniques. Providing evidence that supports the specific water quality performance and demonstrates how the BMP meets water quality requirements for the federal, state or local jurisdictional regulatory agency facilitates the acceptance of a BMP by regulatory agencies. A common problem with securing regulatory approval includes the "insufficient assessment of the potential environmental impacts or unfamiliarity with the proposed project design features or mitigation measures by the regulatory community" *(22)*. The historic recognition and use of vegetated buffers, filter strips, and grass swales has been as secondary or pretreatment controls for other water quality structures. However, designed and located appropriately, these BMPs can provide primary stormwater treatment with minimal cost and maintenance as compared to other stormwater facilities. Recent data provides the necessary evidentiary support that these vegetated stormwater treatments have sufficient, reliable pollutant removal capabilities based upon the research and design parameters. Therefore, when constructed according to the design parameters within the research and listed as suggested best practices in this report, the use of vegetated buffers, filter strips and grass swales should be considered for use by state regulatory agencies and be considered as primary stormwater treatments for rural roadside applications.

8.2 Research Needs

The most pronounced problem discovered during the course of this project is the inconsistent terms and definitions. There is a need for more standardized terminology in the research and state agency documents. Employing common or more consistent definitions for similar vegetated stormwater treatments will enable a more direct comparison of pollutant removal performance, design parameters, and implementation techniques as well as facilitating communication among agencies and researchers.

One of the issues found while compiling literature from various state agencies and through the survey and follow-up interviews was that many state agencies use or adopt other states' manuals, documents, and design criteria as their own. This common practice, in itself, is neither good nor bad; however, it does tend to perpetuate outdated research data simply because funding is limited for many states to conduct their own research. Several state agency manuals may need to be updated to reflect current research findings.

Data regarding the effects of maintenance activities, whether it is mowing cycles or herbicide treatments, is limited. The performance of vegetated buffers, filter strips and grass swales are directly affected by changes in vegetation types (i.e., from woody to grass) and density levels. Research needs include investigating the relationship between maintenance and pollutant removal performance of vegetated water quality practices.

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Appendix A: State Agency Use of Vegetated Stormwater Treatments

State-of-the-Practice Summary

This appendix contains the detailed information collected from the various state agencies through a review of the available manuals and documents, survey of practice and follow-up interviews. There are numerous documents from respective agencies. They fall into the hierarchical categories of performance standards, technical standards and guidance documents. Unfortunately, this distinction is not clear for most agencies. Many DOTs defer to local, state or federal regulatory documents for guidance. The same holds true for state environmental and regulatory agencies.

The researcher collected and evaluated the available design criteria for each agency regarding the physical characteristics of vegetated buffers, filter strips, and grass swales to determine recommended best practices detailed in Chapter 6. Below is a summary of the information.

Filter Strips

There was a great deal of variation in the specifications for filter strips. In general, vegetated buffers and filter strips are used less often as primary stormwater treatments than are grass swales. Vegetated buffer and filter strip use is inconsistent with their proven performance through recent research. The following is a summary of those findings for filter strips.

Design Storm

Specifying a design storm for filter strips is rare within the literature. Alaska and Colorado DOTs use a 2-year storm, and North Carolina and South Carolina regulatory agencies use a 10-year storm.

Slope

Most states that have any type of specifications for filter strip included slope criteria. The range had a minimum of 1 percent and a maximum of 25 percent with the average specified slope ranging between 2.2 percent and 12.5 percent. This seems to be consistent with research and the EPA recommendation of slopes between 2 and 4 percent.

Length

Just as with slope criteria, there is a great range of acceptable lengths for roadside applications. As mentioned in previous sections, there are inconsistencies throughout the state agency documents as to how length and width are determined. Some agencies consider length parallel to flow, other use perpendicular to flow, and the majority do not specify. This makes an accurate assessment difficult. The least minimum recommended length of a filter strip found is 4.5 m [15 ft] with the greatest minimum length being 45.7 m [150 ft]. Some states have site-specific recommendations based upon slope, soil type, vegetation type, and design storm. The Massachusetts Department of Environmental Protection recommends 6 m [20 ft] for 1 percent slope with an additional 1.2 m [4 ft] for every 1 percent increase in slope stating an ideal length of 15 to 23 m [50-75 ft]. The Virginia Department of Conservation and Recreation recommends a minimum of 7.6 m [25 ft] at 2 percent slope increase 1.2 m [4 ft] for any 1 percent increase in slope as well stating an optimum length of 24 to 30 m [80-100 ft].

Width

The average specified width is approximately 7.6 m [25 ft], which coincides with the EPA's recommended minimum width. The least recommended width is 1.5 m [5 ft] and the greatest is 30 to 60 m [100-200 ft]. The Tennessee Department of Environment and Conservation specifies a width of 15 m [50 ft] with an increase of 0.6 m [2 ft] in width for every 1 percent of slope measured along a line perpendicular to the stream bank. The Virginia Department of Conservation and Recreation recommends a width equal to the width of the contributing drainage area. In analyzing the given dimensions of width and length, it is probable that the width specified is determined as parallel to the flow direction and is therefore the length of the filter strip, and some of the specified lengths are actually widths as measured perpendicular to the flow.

Contributing Drainage Area

Of the specifications found, a contributing drainage area of 2 ha [5 ac] or less was most prevalent. Washington DOT recommends a 45.7 m [150 ft] flow path. Most rural roadside filter strips will generally have a contributing drainage area the width of the adjacent travel lanes.

Flow Velocity

Few states have specifications for flow velocity and depth for filter strips. The average flow velocity for filter strips is 0.3 meters per second (m/s) [1 fps] with a range of 0.14 to 0.9 m/s [0.5 to 3 fps].

Flow Depth

The typical flow depth is ≤25 mm [1 in].

Vegetation/Grass Height

The most commonly found grass height is 150 to 300 mm [6 to 12 in] or greater than flow depth.

Soil Type

State agencies use all soil types contingent upon site-specific conditions with a typical infiltration rate of 13 mm/hr [0.5 in/hr].

Hydrologic Residence Time

The hydrologic residence time is typically specified for swales rather than filter strips. However, two DOTs, Oregon and Washington that use filter strips as primary treatment BMPs have a 9-minute residence time requirement. The Idaho Department of Environmental Quality recommends a 20-minute residence time.

Depth to Water Table or Bedrock

The typical recommendation for distance from the bottom of a filter strip to the water table is a minimum of 0.6 m [2 ft] and a minimum of 1.5 m [5 ft] above bedrock. This is consistent with the EPA recommendation of a minimum distance above the water table of 0.6 m [2 ft].

Grass Swales

The information regarding the use of grass swales as stormwater treatment was more detailed than that of filter strips. Grass swales are common to most rural roadsides, which makes their use in some manner for water quality treatment readily available. For use as a primary water quality treatment, several agencies required an improved or water quality swale. This usually consisted of an under-drain system and porous soil material to maximize infiltration or the use of specific soil treatments. Some states require a specific slope and other criteria to qualify as a primary treatment. The following summarizes the findings from the state agencies for grass swales.

Design Storm

The most common design storm chosen for grass swales is the 10-year storm. Over 75 percent of the state agencies with specifications used this design storm. Most of the other agencies used a 2-year storm. The EPA recommends designing for the 2-year storm with a 10-year capacity.

Longitudinal Slope

The longitudinal slope for grass swales varied with a minimum slope of 1 percent to a maximum of 10 percent. The average slope ranged between 2 and 5 percent falling within the EPA recommendation of less than or equal to 4 percent.

Side Slope

Side slopes on grass swales are usually a maximum of 1V:3H or 33 percent. Some states prefer a flatter slope of 1V:4H to 1V:5H or 25 to 20 percent for ease of maintenance such as mowing.

Swale Length

The recommended grass swale length varied from 7.6 to 152 m [25-500 ft]. The average length is approximately 45.7 m [150 ft]. Three state environmental agencies set the swale length to achieve the required hydrologic residence time: Maine at 9 minutes, Iowa at 10 minutes, and Georgia at 5 minutes. The North Carolina DOT specifies the length based upon the contributing drainage area at 30 m [100 ft] per contributing acre.

Swale Width

The width of the swale usually means the bottom of the swale. This width range is 0.6 to 3 m [2-10 ft] with a maximum of 4.5 m [15 ft]. The width relates to ease of mowing maintenance as well as the water quality benefit of greater surface contact within the swale.

Contributing Drainage Area

Contributing drainage area for grass swales averages approximately 10 ha [25 ac]. The Idaho Department of Environmental Quality accepts grass swales as primary stormwater treatment facilities. It specifies a drainage area up to 6 ha [15 ac], but states that the total surface area of the swale should be 1 percent of the contributing drainage area. The EPA recommends a contributing drainage area of less than 2 ha [5 ac].

Flow Velocity

The average specified maximum velocity for grass swales used for stormwater quality treatment is 0.6 m/s [2 ft/s]. The range of velocities is between 0.3 m/s and 1.5 m/s [1 and 5 ft/s]. The range of required freeboard is 76 mm to 300 mm [3 to 12 in], averaging approximately 180 mm [7 in].

Flow Depth

The optimal flow depth for grass swales throughout the literature is less than the height of the vegetation. When the water depth exceeds grass height, the effectiveness decreases. This is usually about 100 to 150 mm [4 to 6 in]. The average state agency documents specify the same or state that the water depth should be one-third to two-thirds the height of the grass.

Vegetation/Grass Height

Typical grass height is 100 to 150 mm [4 to 6 in] with a minimum density of 70 percent.

Soil Type

Infiltration rate is a performance factor for grass swales. NRCS Soils Types A and B were the most common used; however, all soil types were specified. The typical infiltration rate is 0.2 mm/s [0.5 in/hr].

Hydrologic Residence Time

The hydrologic residence time for grass swales plays an important role in its effectiveness as a water quality BMP. Most state agencies use a residence time of 9 minutes. Grass swale slope and length is determined to accommodate for the specified residence time. Velocity controls or check dams use increases the stormwater residence time within the swale.

Depth to Water Table or Bedrock

The typical distance to the water table from the bottom of the swale is 0.6 m [2 ft], the same as the EPA. The most common distance to bedrock is 0.9 m [3 ft].

State Agency Documentation

Alabama

State agencies include the Alabama DOT, Department of Environmental Management and Department of Conservation and Natural Resources. The Alabama DOT defers to the Alabama Soil & Water Conservation Committee's Alabama *Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas*. The Alabama Chapter of the Soil and Water Conservation Society, the Alabama Soil and Water Conservation Committee, the Alabama Association of Conservation Districts, the Alabama Department of Environmental Management, the Alabama Department of Transportation, the Home Builders Association of Alabama, and the USDA Natural Resources Conservation Service prepared this document. It addresses construction or temporary BMPs, listing only porous pavement and stormwater detention basins for stormwater management (post-construction). The document lists buffer zone (BZ) for stream protection, filter strip (FS) for sediment control, and grass swale (GS) for runoff conveyance as erosion and sediment controls.

Alabama Soil and Water Conservation Committee. 2003. *Alabama Handbook for Erosion Control, Sediment Control and Stormwater Management on Construction Sites and Urban Areas.* http://swcc.alabama.gov/pdf/Handbooks&Guides/ASWCC_June_2003_Alabama_Handbook_Construction_E&S_Control.pdf.

Alaska

State agencies include the Alaska DOT and Public Facilities and Alaska Department of Environmental Conservation (AKDEC). The AKDEC Water Quality Program's *Alaska Storm Water Guide; Chapter 5 Permanent Storm Water Management Controls* developed a matrix of BMP suitable to the Alaska climate. It rates their rate control and volume reduction. Under water quality benefits, it identifies the BMP use as primary or secondary for each constituent of TSS, P and N, metals and fecal coliform. The document also rates each BMP for regional climate suitability stating whether it is widely feasible, might be feasible in certain situations, feasible only with major design adaptation and infeasible and not recommended.
The recommendations include the following:

- **Dry swale**
  - medium rate control
  - low volume reduction
  - ***primary for TSS and metals***
  - secondary for P and N
  - minor for fecal coliform
  - widely feasible for coastal and interior
  - might be feasible in south central
  - infeasible in western and arctic
- **Wet swale**
  - low rate control
  - low volume reduction
  - ***primary for TSS***

  - secondary for P and N, and metals
  - minor for fecal coliform
- Filter strips
  - medium rate control
  - medium volume reduction
  - secondary for TSS
  - minor for P and N, metals, and fecal coliform
  - widely feasible for south-central, western and interior
  - feasible with adaptation in coastal and arctic

Alaska Department of Environmental Management. 2009. *Alaska Storm Water Guide, Chapter 5 Permanent Storm Water Management Controls.* http://www.dec.state.ak.us/water/wnpspc/stormwater/AKSWGuide_Chapter5.pdf.

Alaska Department of Transportation. 2006. *Highway Drainage Manual*, *Chapter 16 Erosion and Sediment Control*. http://www.dot.state.ak.us/stwddes/desbridge/assets/pdf/hwydrnman/ch16_all.pdf.

Arizona

State agencies include the Arizona DOT and the Arizona Department of Environmental Quality. The AZDOT has a post-construction document, *ADOT Post-Construction Best Management Practices Manual for Highway Design and Construction.* The manual is thorough in its discussion of regulations, criteria, planning, principles, how to gain acceptance of BMPs, and practices. It recommends **vegetated filter strips as primary treatment** for sheet flow.

Arizona Department of Transportation. 2009. *ADOT Post-Construction Best Management Practices Manual for Highway Design and Construction.* Arizona Department of Transportation. http://www.azdot.gov/ADOT_and/Storm_Water/PDF/adot_post_construction_bmp_manual.pdf.

Arizona Department of Environmental Quality. 2008. *Arizona Pollutant Discharge Elimination System General Permit for Discharge from Construction Activities to the Waters of the US.* http://www.azdeq.gov/environ/water/permits/download/2008_cgp.pdf.

Arizona Highway and Transportation Department. 2004. *Erosion and Sediment Control Design & Construction Manual 2004*. http://www.arkansashighways.com/Construc/2004_E&S_Control_Manual/11-04%20E%20%20SC%20APPENDIX.pdf.

Arkansas

State agencies include the Arkansas Highway and Transportation Department (AHTD) and the Arkansas Department of Environmental Quality (ARDEQ). There was very little information available regarding post-construction BMPs. The AHTD lists open vegetated swales and natural depressions for flow attenuation as post-construction stormwater management BMPs in their *Erosion and Sediment Control Design and Construction Manual.* The ARDEQ refers to other sources for stormwater treatment information.

Arkansas Highway and Transportation Department. 2009. *Erosion and Sediment Control Design and Construction Manual*. http://www.arkansashighways.com/stormwater/content/E%20SC%20Manual%2004%2030%2009.pdf.

California

See Chapter 5 State of the Practice.

Caltrans. 2003. *Caltrans Storm Water Quality Handbooks, Project Planning and Design Guide Construction Site Best Management Practices (BMPs) Manual*. California Department of Transportation. http://www.dot.ca.gov/hq/construc/stormwater/CSBMPM_303_Final.pdf.

California Stormwater Quality Association. 2003. *California Stormwater BMP Handbook New Development and Redevelopment Section 5, Treatment Control BMPs*. www.cabmphandbooks.com.

Colorado

State agencies include Colorado DOT and the Colorado Department of Public Health and Environment (CODPHE). The Colorado DOT has two main documents. These are the *CDOT Erosion Control and Stormwater Quality Guide* and the *CDOT Drainage Design Manual*. Chapter six of *CDOT Erosion Control and Stormwater Quality Guide* contains the post-construction BMPs. These include dry swale, wet swale and sheet flow to buffer. The DOT has a final justification worksheet for stormwater permanent BMPs requiring information such as:

- Phase I + II areas/strategy chosen to meet Tier I requirements
  - 100% WQCV or
  - 80% TSS removal
- Project able to meet chosen criteria?
- Describe other BMPs utilized to assist in meeting intent of above chosen criteria
  - structural
  - non-structural
  - administrative

The CODPHE Water Quality Control Division's *Chapter 6 Urban and Construction Management Program* lists DOT **primary stormwater treatments as grass swales and grass buffer strips.** "These highway construction practices are recommended for use in the Colorado Nonpoint Source Management Program. The highway construction best management practices used by CDOT are applicable to all highway and road construction projects in Colorado. The Water Quality Control Division recommends adopting these practices for all highway or road construction projects in Colorado."

Colorado Department of Transportation. 2002. *CDOT Erosion Control and Stormwater Quality Guide*. http://www.dot.state.co.us/environmental/envWaterQual/docs/StormWaterQ/swqChapter6.pdf.

Colorado Department of Public Health and Environment Water Quality Control Division. 2000. *Chapter 6 Urban and Construction Management Program.* Colorado Nonpoint Source Council Urban and Construction Committee. http://www.cdphe.state.co.us/wq/nps/2000MgtProg/2000urbanfinal.pdf http://www.dot.state.co.us/environmental/envWaterQual/docs/NewDev/NewDevelopmentProgram_PermanentBMP_Factsheets.pdf.

Connecticut

See Chapter 5 State of the Practice.

Connecticut Department of Environmental Protection. 2007. *Reissuance of the General Permit for the Discharge of Stormwater and Dewatering Wastewater from Construction Activities.* http://www.ct.gov/dep/lib/dep/Permits_and_Licenses/Water_Discharge_General_Permits/storm_const_gp_reissue07.pdf.

Delaware

State agencies include Delaware DOT (DEDOT) and the Delaware Department of Natural Resources and Environmental Control (DEDNREC). DEDOT has the *Road Design Manual, Highway Drainage and Stormwater Management* that lists biofiltration techniques that include biofiltration swale-grass and filter strips as post-construction stormwater treatment BMPs. The **biofiltration swale** is a **primary treatment** BMP and filter strips are pretreatment. From the survey of practice, the DEDOT commented that for transportation projects, the vegetated buffers have been invaluable in saving costs of purchasing right-of-way, while also still hopefully providing environmentally sensitivity and compliance. The survey confirmed that vegetated BMPs are primary stormwater treatments.

The DEDNREC Division of Soil and Water Conservation's *Green Technology: The Delaware Urban Runoff Management Approach, Standards Specifications and Details for Green Technology BMPs to Minimize Stormwater Impacts from Land Development* has specific recommendations for soils used for filter strips (Table A1). These are for optimal filter strip performance.

Table A1: DEDNREC Filter Strip Soil Properties

PROPERTY	RECOMMENDATION	PROPERTY	RECOMMENDATION
pH	6.0-7.0	Organic Matter	1.0-4.0%
Mg	35 lb./ac.	Sand	30-80%
Po	75 lb./ac.	Silt	30-60%
K	85 lb./ac.	Clay	5-35%
Salts	<500 ppm	Porosity	25-40%

The DEDNREC states in the document that "The use of vegetative swales and buffer strips can provide a significant water quality benefit in addition to reducing the total volume of stormwater runoff…In sum, properly designed and maintained filter strips and buffers can be expected to achieve the 80 percent total suspended solids reduction rate, as specified by Delaware regulation. Of course, the State's stormwater law is also intended to reduce other pollutants contained in stormwater flows and as indicated above, filter strips and buffers have the capability to remove an array of these contaminants and nutrients."

Delaware Department of Transportation. 2008. *Road Design Manual, Highway Drainage and Stormwater Management, Chapter Six.* http://www.deldot.gov/information/pubs_forms/manuals/road_design/pdf/06_drainage_stormwater_mgmt.pdf.

Lucas, W.C. 2005. *Green Technology: The Delaware Urban Runoff Management Approach, Standards Specifications and Details for Green Technology BMPs to Minimize Stormwater Impacts from Land Development.* Delaware Department of Natural Resources and Environmental Control Division of Soil and Water Conservation. http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/New/GT_Stds%20%26%20Specs_06-05.pdf.

Delaware Department of Natural Resources and Environmental Control. 2003. *Delaware Erosion & Sediment Control Handbook.* Sediment and Stormwater Program, Division of Soil and Water Conservation. http://www.dnrec.state.de.us/dnrec2000/Divisions/Soil/Stormwater/New/Delaware%20ESC%20Handbook_06-05.pdf.

Florida

State agencies include the Florida DOT, Florida Department of Environmental Protection (FDEP), and Florida Department of Environmental Regulation. The FDEP's response to the survey of practice stated **grass swales are primary stormwater treatments**. Filter strips are for pretreatment. The follow-up interview confirmed this.

- Florida Department of Environmental Protection, Watershed Management
  - FDEP has been using grass swales as primary treatment for over 20 years.
  - FDEP uses a 3 yr-1 hr storm design.
  - Performance is based on 80 percent removal efficiency.
  - Basis for use is from 1978 research from University of Central Florida.
  - Infiltration is the major pollutant removal mechanism due to sandy soils.
  - FDEP recommends the use swale blocks (check dams) for better removal efficiency but does not require them.

Florida Department of Transportation. 2007. *Erosion and Sediment Control Designer and Reviewer Manual.* Florida Department of Transportation and Florida Department of Environmental Protection. http://www.dot.state.fl.us/rddesign/dr/files/Erosion-and-Sediment-Control-Manual-June-2007.pdf.

Florida Department of Transportation. 2004. *Drainage Handbook Stormwater Management Facility.* Florida Department of Transportation. http://www.dot.state.fl.us/rddesign/dr/files/StrmWtrMgmtFacHB.pdf.

Florida Department of Environmental Protection. *Chapter 6, Stormwater and Erosion and Sediment Control Best Management Practices for Developing Areas.* http://www.dep.state.fl.us/water/nonpoint/docs/nonpoint/erosed_bmp.pdf.

Florida Department of Environmental Regulation. *Stormwater Management: A Guide for Floridians.* Florida Department of Environmental Regulation Stormwater/Nonpoint Source Management. http://www.dep.state.fl.us/water/nonpoint/docs/nonpoint/Stormwater_Guide.pdf.

Florida Department of Environmental Protection. 62-25 Regulation of Stormwater Discharge. http://www.dep.state.fl.us/water/stormwater/index.htm.

Georgia

State agencies include the Georgia DOT and Georgia Department of Natural Resources (GADNR). The DOT lists the use of "vegetated swales/ditches where practical" under post-construction BMPs in their Erosion and Sediment Control Plans (*ESPCP) General Notes*. The GADNR's *Georgia Stormwater Management Manual, Volume 2 Technical Handbook* has grass channel and filter strip as stormwater pretreatment only.

Georgia Department of Transportation. 2007. *ESPCP General Notes*. http://www.dot.state.ga.us/doingbusiness/consultants/Documents/ESPCP%20GENERAL%20NOTES%20October%2007.doc.

Georgia Department of Transportation. 2005. *GADOT Manual on Drainage Design for Highways*. http://www.dot.state.ga.us/doingbusiness/PoliciesManuals/roads/Documents/Drainage%20Manual.pdf.

Department of Natural Resources. 2001. *Georgia Stormwater Management Manual, Volume 2 Technical Handbook*. Georgia Environmental Protection Division. http://www.georgiastormwater.com/.

Hawaii

State agencies include the Hawaii DOT and Hawaii Department of Land and Natural Resources. The DOT's *Storm Water Permanent Best Management Practices Manual* contains a vegetative swales category with **dry and wet swales for primary stormwater treatment.** Page 42 of this document has a BMP selection matrix with the criteria as follows for all of their listed BMPs:

- safety concerns
- space requirement
- accept heavily polluted runoff
- soils
- water table
- drainage area (acres)
- slope restrictions

- ultra urban
- ease of maintenance
- community acceptance
- relative cost
- habitat quality

Hawaii Department of Transportation. 2007. *Storm Water Permanent Best Management Practices Manual.* Highways Division. http://www.stormwaterhawaii.com/pdfs/PermanentManual.pdf.

Hawaii Department of Transportation. 2005. *Standard Specifications & Special Provisions, 209A Water Pollution, Dust, and Erosion Control*. http://hawaii.gov/dot/highways/specifications2005/specifications/specspdf/specspdf-200-399/209A%20%28Water%20Pollution%2C%20%20Dust%2C%20%20and%20Erosion%20Control%29%20%28Print%29.pdf/view?searchterm=erosi.

Idaho

See Chapter 5 State of the Practice.

Idaho Transportation Department. 2005. *Best Management Practice – Erosion and Sediment Control*. http://itd.idaho.gov/manuals/Online_Manuals/BMP/.

Illinois

State agencies include the Illinois DOT, Illinois EPA, and Illinois Pollution Control Board. There is a reference to post-construction stormwater management in the DOT's *Bureau of Design and Environment Manual* regarding the use of open vegetated swales for flow attenuation. This is the limit of documentation found. The agencies refer the reader to other sources for guidance.

Illinois Environmental Protection Agency. 2008. *General NPDES Permit for Stormwater Discharges from Construction Site Activities.* Division of Water Pollution Control. http://www.epa.state.il.us/water/permits/storm-water/general-construction-permit.pdf.

Illinois Department of Transportation. 2003. *Illinois DOT Storm Water Management Plan*. http://www.dot.state.il.us/desenv/environmental/pdf/SWMP_061207.pdf.

Illinois Department of Transportation. 2002. *Bureau of Design and Environment Manual*. http://www.dot.il.gov/desenv/bdemanual.html.

Indiana

State agencies include the Indiana DOT, Indiana Department of Environmental Management, and Indiana Department of Natural Resources. There is little information regarding post-construction BMPs. The DOT has provisions for temporary controls. The *Indiana Design Manual* lists vegetated filter strips as temporary erosion control.

Indiana Department of Transportation. 2009. *Indiana Design Manual.* http://www.in.gov/dot/div/contracts/standards/dm/english/index.html

Indiana Department of Transportation. *Indiana DOT Rule 5 - Erosion Control Storm Water Run-Off Associated with Construction Activity*. http://www.in.gov/indot/3304.htm, http://www.in.gov/indot/files/45_rule.pdf.

Iowa

State agencies include the Iowa DOT and Iowa Department of Natural Resources. The only documents found for the DOT focused on temporary BMP for construction activity. In a follow-up interview, the Iowa Department of Natural Resources, Stormwater Program stated that there were no post-construction requirements. The researchers did not find a post-construction BMP document from either agency. However, the researchers assumed that the *Iowa Stormwater Management Manual* from the Center for Transportation Research and Education serves as their comprehensive guidance document. It lists native landscaping under infiltration practices, **vegetated swale system, and filter strips as primary stormwater treatments.** The vegetated swale system category has grass swales, dry and wet swales and vegetated filter strips. Each of these BMPs has extensive design criteria for use as water quality treatment. The vegetated filter strip categories are constructed filter strips, natural vegetative strips and riparian vegetative buffer strips. They further categorize them as those with a permeable berm at the bottom to increase residence time and reduce the overall width required and a simple filter strip. They recommend a minimum length of 4.5 m [15 ft] with 7.6 m [25 ft] preferred.

Center for Transportation Research and Education. 2008. *Iowa Stormwater Management Manual*. Iowa State University. http://www.ctre.iastate.edu/pubs/stormwater/index.cfm.

Iowa Department of Transportation. 2004. *IowaDOT Storm Water Discharge Permits Design Manual Chapter 10 Roadside Development and Erosion Control*. ftp://165.206.203.34/design/dmanual/10d-01.pdf.

Kansas

State agencies include the Kansas DOT and Kansas Department on Health and Environment (KSDHE). The KSDHE survey of practice response indicated that they use vegetated BMPs as pretreatment only. The Kansas City Mid-America Regional Council (MARC) and the Kansas City Metro Chapter of the American Public Works Association (APWA) have prepared the *Manual of Best Management Practices for Stormwater Quality* regarding wetland swales, bioswales, native vegetation swales, and turf swales.

Mid-America Regional Council. 2008. *Manual of Best Management Practices for Stormwater Quality*. http://kcmetro.apwa.net/chapters/kcmetro/specs/APWA_BMP_Manual_Mar08.pdf.

Kansas Department of Transportation. 2007. *Standard Specifications for State Road and Bridge Construction 901 - Temporary Erosion and Pollution Control*. http://www.ksdot.org:9080/burConsMain/specprov/2007SSDefault.asp#900.

Kentucky

State agencies include the Kentucky Transportation Cabinet (KTC), Kentucky Environmental Quality Commission, and Kentucky Department for Natural Resources. The KTC *Drainage Manual* lists **vegetated channels** as a post-construction **primary stormwater treatment** stating they are perhaps the most cost effective post-construction BMP. The *Kentucky Best Management Practice (BMPs) for Controlling Erosion, Sediment, and Pollutant Runoff from Construction Sites, Construction Sites Planning and Technical Specifications Manual* has a section for Stream and Wetland Protection. This lists buffer zones and filter strips as BMPs.

Kentucky Transportation Cabinet. 2009. *Drainage Manual, DR 200 – Stormwater & Floodplain Management.* http://transportation.ky.gov/design/drainage/Drainage%20Manual09/DR-200%20Stormwater%20&%20Floodplain%20Management.pdf.

Kentucky Environmental and Public Protection Cabinet and Transportation Cabinet. *Kentucky Best Management Practice (BMPs) for Controlling Erosion, Sediment, and Pollutant Runoff from Construction Sites, Construction Sites Planning and Technical Specifications Manual.* http://www.water.ky.gov/NR/rdonlyres/3782CC45-B5AD-4D3A-A064-D0E2C8DA358D/0/KY_BMP_Manual_6Stream_Wetland_Protection.pdf.

Louisiana

State agencies include the Louisiana Department of Transportation and Development and Louisiana Department of Environmental Quality (LADEQ). The LADEQ lists vegetated practices (filter strips, grassed swales, basin landscaping) as urban best management practices for stormwater treatment. They are pretreatment BMPs.

Louisiana Department of Transportation and Development. 2006. *Louisiana Standard Specifications for Roads and Bridges*. http://www.dotd.la.gov/highways/project_devel/contractspecs/2006_Cover.pdf.

Maine

State agencies include the Maine DOT and Maine Department of Environmental Protection (MEDEP). The *MaineDOT Best Management Practices for Erosion and Sediment Control* focuses on temporary construction controls with little information regarding post-construction BMPs. The DOT refers to the MEDEP for post-construction BMPs. The survey response stated the Maine DOT uses **filter strips** as **primary stormwater treatment** and that the State Resource Agency is receptive to use of filter strips on steeper in-slopes with documented treatment. Grass swales are for pretreatment. The MEDEP has *Stormwater Management for Maine (26)* containing numerous post-construction BMPs. These include vegetated buffers and a grassed under-drain soil filter system. Vegetated buffers categories are:

- buffer adjacent to residential, largely pervious or small impervious areas,
- buffer with stone bermed level lip spreader,
- buffer adjacent to the downhill side of a road, and
- ditch turn out buffer.

Each buffer type has specific criteria for use. The general guidance tips are:

- Buffers shall be directly adjacent to areas being treated.
- Buffer slope must be less than 15 percent.
- Runoff must enter the buffer as sheet flow.
- Manipulate sites to maximize buffer flow path length.
- Only continuous flow path length may be counted for treatment.
- Flow paths of runoff through a buffer must be parallel or diverging; they must not converge.

Information from the follow-up interview with the Maine DEP, Bureau of Land & Water Quality:

- Swales must be improved swales for use as a water quality BMP per the specifications in their manual.
- Filter strips used as primary treatments need to be 10.6 to 15 m [35-50 ft] with runoff from one or two traffic lanes.
- Soil types are C and D in the area.
- No D soils can be used for vegetated buffer.
- Data used as basis comes from Maryland and EPA.

Maine Department of Transportation. 2008. *Maine DOT Best Management Practices for Erosion and Sedimentation Control*. http://www.maine.gov/mdot/environmental-office-homepage/pdf/bmpmanual2008/cover&table-of-contents.pdf.

Maryland

State agencies include the Maryland DOT, Maryland State Highway Administration, and Maryland Department of the Environment. The Maryland DOT defers to the Department of the Environment's *Maryland Stormwater Design Manual* as the authority. This document lists **dry swales, wet swales, and sheet flow to buffer as primary stormwater treatments**. The document contains specific criteria for each for credit as a water quality BMP.

Maryland State Highway Administration. 2001. *Maryland State Highway Administration Standard Specifications for Construction and Materials*. http://www.sha.state.md.us/businesswithsha/bizStdsSpecs/desManualStdPub/publicationsonline/ohd/PDFS/Trsec03.pdf.

Maryland Department of the Environment. 2000. *Maryland Stormwater Design Manual.* http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp.

Maryland Department of Transportation. *Maryland Chesapeake and Atlantic Coastal Bays Critical Area 10% Rule Guidance Manual* http://www.mdot.state.md.us/Planning/Environmental%20Permits-Construction/Documents/Stormwater%20Calculation%20Forms.pdf.

Massachusetts

State agencies include the Massachusetts Highway Department and Massachusetts Department of Environmental Protection (MADEP). The *MassHighway Storm Water Handbook for Highways and Bridges* has a "water quality swale" category with dry swale, biofilter swale and wet swale. Vegetated filter strip is also in the document. The MADEP gives some credit for the use of **swales as primary stormwater treatment** but it relies upon site-specific criteria. "Vegetated filter strips are not currently included in the Stormwater Policy BMP listing. Designer will need to document removal efficiencies."

The MADEP has the *Massachusetts Stormwater Handbook.* Pretreatment BMPs include vegetated filter strips. Drainage channels are conveyance BMPs. A **grassed channel (biofilter swale)** receives credit as **primary stormwater treatment** if it has a pretreatment forebay or equivalent. Water quality swales include dry and wet swales. The document has specific design criteria for each BMP.

Massachusetts Highway Department. 2004. *The MassHighway Storm Water Handbook for Highways and Bridges*. http://www.mhd.state.ma.us/downloads/projDev/swbook.pdf#65.

MassHighway. 2006. *Project Development & Design Guide*. Boston, MA: Massachusetts Highway Department. http://www.mhd.state.ma.us/downloads/designGuide/CH_8_a.pdf.

Massachusetts Department of Environmental Protection. 2003. *Erosion and Sedimentation Control Guidelines: A Guide for Planners, Designers, and Municipal Officials.* Bureau of Resource Protection. http://www.mass.gov/dep/water/essec2.pdf.

Massachusetts Department of Environmental Protection. *Volume 2 Chapter 2: Structural BMP Specifications for the Massachusetts Stormwater Handbook.* http://www.mass.gov/dep/water/laws/v2c2.pdf.

Michigan

State agencies include the Michigan DOT (MIDOT) and Michigan Department of Environmental Quality (MIDEQ). The DOT Phase II Storm Water Management Plan lists MIDOT best management practices. The vegetated BMP category has vegetated buffers at watercourse and vegetated buffer strips. The majority of the DOT information is temporary BMPs. The survey-of-practice response from the DOT stated, "Anecdotal evidence of vegetated swales and ditch lines supports continued use to remove sediment and associated pollutants from storm water."

The MIDEQ's *Stormwater Management Guidebook* lists **grassed (vegetated) swale** as a possible primary **stormwater treatment** with grass filter strip as pretreatment.

Michigan Department of Transportation. 2006. *Soil Erosion and Sedimentation Control Manual.* http://www.michigan.gov/documents/2006_SESC_Manual_165226_7.pdf.

Michigan Department of Environmental Quality. 2005. *Stormwater Management Guidebook* Chapter 5 Other Infiltration Devices. http://www.michigan.gov/documents/deq/lwm-smg-05_202868_7.pdf.

Michigan Department of Transportation. 2004. *Michigan DOT Phase II Stormwater Management Plan*. http://www.michigan.gov/stormwatermgt/0,1607,7-205--114322--,00.html.

Michigan Department of Transportation. 2003. *Drainage Manual.* http://www.michigan.gov/stormwatermgt/0,1607,7-205--93193--,00.html.

Minnesota

State agencies include the Minnesota DOT, Minnesota Pollution Control Agency and Minnesota Department of Natural Resources. The Pollution Control Agency is very active in stormwater. There are several documents at the Stormwater Research and Assessment section of their website http://www.pca.state.mn.us/water/stormwater/stormwater-research.html. The *Minnesota Stormwater Manual* is a comprehensive document and a good resource. It has vegetated BMPs in the filtration chapter. Vegetative filters consist of filter strips, grass channels, and combination media/vegetative filters such as dry swales. "Media and media/vegetative filters operate similarly and provide comparable water quality capabilities as bioretention. **Vegetative filters** are generally more suitable as pretreatment practices, but in some situations **can be used on a stand alone basis…**A well drained swale can be a very effective BMP for both reducing volume through infiltration and for improving water quality through filtration, settling and vegetative uptake." Grass channels are pretreatment unless designed for water quality credit. There is very detailed information regarding how to choose the appropriate BMP. The document also addresses cold climate issues. The DOT has documents that focus on temporary BMPs.

Minnesota Pollution Control Agency. 2008. *Minnesota Stormwater Manual.* http://www.pca.state.mn.us/publications/wq-strm9-01.pdf.

Minnesota Department of Transportation. 2003. *Erosion Control Handbook for Local Roads.* http://www.lrrb.org/pdf/200308.pdf.

Mississippi

State agencies include the Mississippi DOT and Mississippi Department of Environmental Quality ((MSDEQ). As with many other agencies, there is minimal information regarding post-construction BMPs. Mississippi DOT's reply to the survey of practice is that these types of BMPs have never been suggested for use or required by the State DEQ. The MSDEQ provides minimal guidance on what BMP MDOT should use to reduce pollutant loadings. The MSDEQ suggests the use of grass swales and filter strips in their *Mississippi's Department of Transportation Phase II Storm Water Guidance Manual.*

Mississippi Department of Transportation. *Mississippi DOT Stormwater Management Plan*. http://www.gomdot.com/Divisions/Highways/Resources/SWMP/pdf/Plan.pdf.

Mississippi Department of Environmental Quality. 2002. *Mississippi's Department of Transportation Phase Ii Storm Water Guidance Manual.* http://www.deq.state.ms.us/MDEQ.nsf/pdf/epd_MDOTPhaseIIStormWaterGuidanceManualDraft/$File/25General.pdf?OpenElement.

Mississippi Department of Environmental Quality. *Field Manual for Erosion & Sediment Control on Construction Sites in Mississippi*. http://www.deq.state.ms.us/MDEQ.nsf/pdf/NPS_Field_Manual_for_Erosion_and_Sediment_Control/$File/Field%20Manual%20for%20Erosion%20and%20Sediment%20Control.pdf?OpenElement.

Missouri

State agencies include Missouri DOT and Missouri Department of Natural Resources (MODNR). The MODNR lists **buffer zone and filter strip as primary stormwater treatment,** and grass-lined channels as conveyance systems. The DOT's survey response indicated vegetated BMP use as primary stormwater treatments.

Missouri Department of Transportation. 2008. *Engineering Policy Guide Category: 806 Pollution, Erosion and Sediment Control.* http://epg.modot.mo.gov/index.php?title=Category:806_Pollution%2C_Erosion_and_Sediment_Control.

Missouri Department of Natural Resources. 2000. *State of Missouri Nonpoint Source Management Plan*. http://www.dnr.mo.gov/env/wpp/nps/mgmtplan/nps_mp_appen_a-e.pdf.

Montana

State agencies include the Montana DOT (MTDOT) and Montana Department of Environmental Quality. The DOT has the *Permanent Erosion and Sediment Control Guidelines* that list the roadway feature of "direct discharge into TMDL streams [303(d)]" application as vegetated buffer (with a slope < 20:1) and preserving vegetation requiring hydraulic design. Vegetated buffer strip use is for bridge ends, and sanding material collection on mountain passes. The BMP having specific criteria is the natural and engineered dispersion. This vegetated buffer has an average slope, length (measured perpendicular to flow per MTDOT) and width (measured parallel to flow per MTDOT) of 6:1 or flatter. The document contains comprehensive information on limitations and use. Other criteria are in the matrix section of the appendix. This is a **primary stormwater treatment.** The MTDOT survey-of-practice response stated vegetated stormwater treatments as primary.

The DEQ lists examples of permanent measures in their Stormwater Pollution Prevention Plan (SWWWP) documents including grassed waterways and vegetative buffer strips. They refer the reader to other sources, such as EPA, for post-construction BMPs.

Montana Department of Environmental Quality. 2008. *Storm Water Pollution Prevention Plan (SWPPP) Form Storm Water Discharge Associated With Construction Activity MTR100000*. http://www.deq.state.mt.us/wqinfo/WPBForms/SWPPPfrm.pdf.

Montana Department of Transportation. 2007. *Permanent Erosion and Sediment Control Guidelines*. http://mdt.mt.gov/business/docs/contracting/detailed_drawings_jan08_supplement.pdf http://mdt.mt.gov/publications/docs/manuals/pesc_manual.pdf.

Nebraska

State agencies include the Nebraska Department of Roads (NEDOR) and Nebraska Department of Environmental Quality. There is little information regarding post-construction BMPs. The NEDOR survey response stated, "Our regulatory agencies are recognizing these as BMP's; however we have no data as to effectiveness." They listed vegetated BMPs as **primary stormwater treatment.** In the follow-up interview, the NEDOR said that no post-construction BMPs are required for rural roadways, just meet 70 percent vegetative cover for permit requirements.

Nebraska Department of Roads. 2006. *Drainage Design and Erosion Control Manual.* http://www.dor.state.ne.us/roadway-design/dd-ec-manual.htm.

Nevada

State agencies include the Nevada DOT and Nevada Division of Environmental Protection (NVDEP). The DOT's S*torm water Quality Handbooks Planning and Design Guide* shows **biofiltration swales and strips as primary treatment controls.** The response to the survey from the NVDEP confirmed this. In contract to this, the Nevada DOT stated that they do not typically use vegetated BMP due to difficulty establishing and sustaining vegetation; it is too arid and DOT would not use as a primary BMP because of this.

Nevada Department of Environmental Protection. 2008. *Nevada Contractors Field Guide for Construction Site Best Management Practices (BMPs).* http://ndep.nv.gov/bwqp/file/bmp_081808.pdf.

Nevada Department of Transportation. 2006. *Nevada DOT Storm Water Quality Handbooks Planning and Design Guide Appendix B Permanent Best Management Practices.* http://www.nevadadot.com/.

New Hampshire

See Chapter 5 State of the Practice.

New Hampshire Department of Environmental Services. 2006. *Guidelines and Standard Operating Procedures Illicit Discharge Detection and Elimination and Pollution Prevention/Good Housekeeping for Stormwater Phase II Communities in New Hampshire*. http://des.nh.gov/organization/divisions/water/stormwater/documents/nh_idde_sop.pdf.

New Jersey

State agencies include the New Jersey DOT and New Jersey Department of Environmental Protection (NJDEP). The NJDOT's *Drainage Design Manual* lists vegetated or biofilter swales as a water quality treatment facility and refers the reader to the NJDEP's *New Jersey Stormwater Best Management Practices Manual* for further guidance. This document has specific criteria for vegetative filters. It states, "Depending upon their TSS removal rate, vegetated filter strips can be used separately or in conjunction with other stormwater quality practices to achieve an overall pollutant removal goal." Therefore, given site-specific consideration, **vegetative filters are primary stormwater treatments.** However, the survey response from the DOT stated that vegetated BMPs are pretreatment only.

New Jersey Department of Transportation. 2006. *New Jersey DOT Drainage Design Manual*. http://www.state.nj.us/transportation/eng/documents/drainage/drainage.shtm.

New Jersey Department of Environmental Protection. 2004. *New Jersey Stormwater Best Management Practices Manual*. http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.10.pdf.

New Mexico

State agencies include the New Mexico Department of Highway and Transportation (DOHT), and New Mexico Environmental Department. The survey responses form the DOHT and New Mexico Environment Department Surface Water Quality Bureau state that both consider vegetated BMPs as **primary stormwater treatment.** There is little information regarding post-construction BMPs. Most documents pertain to construction activity. The website refers the reader to other resources.

New Mexico Highway and Transportation Department. 2007. *New Mexico Highway and Transportation Department National Pollutant Discharge Elimination System Manual Revision 0 Appendix A1 – Stabilization Practices.* http://nmshtd.state.nm.us/upload/images/Contracts_Unit/2007_Specs_for_Highway_and_Bridge_Construction.pdf.

New Mexico State Department of Transportation. 2007. *Standard Specifications for Highway and Bridge Construction.* http://www.nmshtd.state.nm.us/upload/images/drainage_design/Appendix%20B1_Construction%20Forms.pdf

New Mexico Department of Highways and Transportation. 2003. *NPDES Manual Stormwater Management Guidelines for Construction and Industrial Activities.* http://www.nmshtd.state.nm.us/upload/images/drainage_design/Front%20Matter.pdf.

New York

State agencies include the New York State DOT and New York State Department of Environmental Conservation (NYSDEC). The NYSDEC's *New York State Stormwater Management Design Manual Chapter 5: Acceptable Stormwater Management Practices (SMPs)* lists **dry and wet swales as primary stormwater treatment** and filter strips as pretreatment. The DOT's survey response stated vegetated BMP use as pretreatment.

New York State Department of Environmental Conservation. 2008. *New York State Stormwater Management Design Manual Chapter 5: Acceptable Stormwater Management Practices*

(SMPs). http://www.dec.ny.gov/docs/water_pdf/swdmchapter5.pdf.

New York State Department of Transportation. 2006. *Highway Design Manual Chapter 8 Highway Drainage*. https://www.nysdot.gov/portal/page/portal/divisions/engineering/design/dqab/hdm/hdm-repository/chapt_08.pdf.

New York State Department of Transportation. 1995. *New York State DOT Environmental Procedures Manual, Chapter 4.3*. Environmental Analysis Bureau. https://www.nysdot.gov/portal/page/portal/divisions/engineering/environmental-analysis/manuals-and-guidance/epm/repository/4-3erosi.pdf.

North Carolina

See Chapter 5 State of the Practice.

North Carolina Department of Transportation. *North Carolina DOT Roadside Environmental Unit: Soil & Water Section - Erosion and Sedimentation Control: Measures.* http://www.ncdot.org/doh/operations/dp_chief_eng/roadside/soil_water/erosion_control/mea.

North Dakota

State agencies include the North Dakota DOT, North Dakota State Water Commission, and North Dakota Department of Health-Environmental Section. The *North Dakota DOT Erosion and Sediment Control Handbook* covers temporary BMPs only. There is little information regarding post-construction BMPs. Both the DOT and Department of Health refer the reader to other resources. The presentation by the Department of Health has information regarding vegetative buffer strip use but within the context of construction activity.

North Dakota Department of Health. *Best Management Practices Common Issues and Solutions.* http://www.ndhealth.gov/WQ/Storm/Presentation/BMP_CommonIssues.pdf.

North Dakota Department of Transportation. 2004. *North Dakota DOT Erosion and Sediment Control Handbook.* http://www.dot.nd.gov/manuals/environmental/escm/escmfinal.pdf.

Ohio

State agencies include the Ohio DOT, Ohio Department of Natural Resources (OHDNR), and Ohio EPA. The OHDNR Division of Soil and Water Conservation's *Rainwater and Land Development* has a variety of post-construction BMPs that mainly target urban areas. Grass filter strips are for pretreatment only. Stream setback areas (riparian buffer and streamway) are for stormwater treatment adjacent to a stream. There are specifications for the stream setback in the document that accounts for the numerous variables of stream configurations.

The OHIO EPA's response to the survey of practice stated that filter strips are for pretreatment. The reason stated that treatment based on standard roadway cross-section would not be effective. The Ohio DOT replied that the Ohio EPA states in their NPDES Construction General Permit that filter strips are acceptable. However, they have associated a 24-hour drawdown time with these slopes. Therefore, there is very low probability of meeting the drawdown time requirement on a sheet flow application.

The Ohio DOT's *Location and Design Manual, Volume 2 Drainage Design* has **vegetated biofilter** as a post-construction water quality **treatment BMP**. It does not use these to treat water quantity. "Vegetated Biofilter (VBF) is a BMP that filters storm water through vegetation. The vegetated biofilter consists of the vegetated portion of the graded shoulder, vegetated slope, and vegetated ditch." The design for this BMP focuses on the swale portion. Specific calculations include:

- Determine the vegetated biofilter ditch width required for water quality treatment as described below:
  - If the enhanced bankfull width (EBW) is less than or equal to the "standard" ditch width, furnish the "standard" ditch.
  - If the EBW is greater than the "Standard" width, furnish the EBW to a maximum bottom width of ten (10) feet.
- The EBW can be calculated at multiple locations along its length. This would allow the width to be reduced where there is less tributary area (i.e., the upstream area of the ditch). However, the entire contributing drainage area to the location in the ditch being evaluated shall be considered whenever the EBW is determined.
- For projects utilizing ditch conveyance, provide a bottom ditch width using the EBW or "standard" ditch width to provide water quality treatment. Use the following steps to determine the ditch width:
  Determine Enhanced Bankfull Width:
  $EBW = 5.4A^{0.356}$
  EBW = Enhanced Bankfull Width (feet)
  A = Total contributing drainage area to the ditch (acres)
- The enhanced bankfull width corresponds to the dimension of the bottom width of the ditch.

Ohio Department of Transportation. 2009. *Location & Design Manual - Volume 2 Drainage Design*. http://www.dot.state.oh.us/Divisions/HighwayOps/Structures/Hydraulic/LandD/Documents/entireLandDbookmarked.pdf

Ohio Department of Natural Resources. 2006. *Rainwater and Land Development, Ohio's Standards for Stormwater Management Land Development and Urban Stream Protection Third Edition.* Division of Soil and Water Conservation. http://ohiodnr.com/tabid/9186/Default.aspx.

Ohio Department of Transportation. 2004. *Ohio DOT Supplemental Specification 832 Temporary Sediment and Erosion Control*. http://www.dot.state.oh.us/Divisions/ConstructionMgt/Specs%20and%20Notes%20for%202005/832041604for2005.PDF.

Oklahoma

State agencies include the Oklahoma DDOT and Oklahoma Department of Environmental Quality. Neither agency has much information regarding post-construction BMPs. However, the survey response from the DOT stated that vegetated BMPs are **primary stormwater treatment.** The DOT's Stormwater Programs (http://www.okladot.state.ok.us/env/stormwater/index.htm) states:

> The Oklahoma DOT uses best management practices (BMPs) to control and manage storm water. These include structural devices, maintenance procedures, and management practices that prevent or reduce the harmful effects of storm water runoff, such as pollution, erosion and flooding. BMPs may include:
>
> - Detention and infiltration ponds, wide grass ditches, catch basins, and culverts
> - Maintenance operations that keep highways clean of sand, litter and debris that could make its way into streams and rivers
> - Increasing the monitoring and maintenance frequency of structural BMPs.

Oklahoma Department of Transportation. 1999. *Oklahoma DOT Standard Specification for Highway Construction*. http://www.okladot.state.ok.us/construction/specbook/specbook-1999.pdf.

Oregon

State agencies include the Oregon DOT and Oregon Department of Environmental Quality (ORDEQ). The DOT states in their *Geo-Environmental Bulletin GE09-02(B)* that the "preferred" stormwater treatments include bioslope, grass swale with soil amendment, and filter strip with soil amendment (http://www.oregon.gov/ODOT/HWY/TECHSERV/technicalguidance.shtml).

The Water Quality Guidance Document contains specific criteria for use found at the Stormwater Management Program website: http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/Storm_Management_Program.shtml. These BMPs are **primary stormwater treatment.**

The ORDEQ's *Biofilters for Storm Water Discharge Pollution Removal* has very complete design criteria for bioswales and numerous application photos. This is a good reference document. **Bioswales are primary stormwater treatment.**

Oregon Department of Transportation. 2005. *Oregon DOT Erosion Control Manual Guidelines for Developing and Implementing Erosion and Sediment Controls*. http://www.oregon.gov/ODOT/HWY/GEOENVIRONMENTAL/docs/Erosion_Control_Manual_nav.pdf.

Jurries, D. 2003. *Biofilters for Storm Water Discharge Pollution Removal*. Oregon Department of Environmental Quality. http://www.deq.state.or.us/wq/stormwater/docs/nwr/biofilters.pdf.

Pennsylvania

State agencies include the Pennsylvania DOT and Pennsylvania Department of Environmental Protection (PADEP). The PADEP's *Pennsylvania Stormwater Best Management Practices Manual* lists vegetated swales as possible **primary stormwater treatment** (site-specific) and vegetated filter strips as pretreatment**.** However, the survey response from the PADEQ stated grass swales are pretreatment.

"Vegetated swales are sometimes used as pretreatment devices for other structural BMPs, especially roadway runoff. However, when swales themselves are intended to effectively treat runoff from highly impervious surfaces, pretreatment measures are recommended to enhance swale performance."

Pennsylvania Department of Transportation. 2008. *Pennsylvania DOT Erosion and Sediment Pollution Control Publication 13M Chapter 13 - (DM-2).* ftp://ftp.dot.state.pa.us/public/Bureaus/design/PUB13M/Chapters/Chap13.pdf.

Pennsylvania Department of Environmental Protection. 2006. *Pennsylvania Stormwater Best Management Practices Manual.* http://www.elibrary.dep.state.pa.us/dsweb/View/Collection-8305.

Rhode Island

State agencies include the Rhode Island DOT and Rhode Island Department of Environmental Management. The DOT's *Storm Water Design and Installation Standards Manual* lists vegetated BMPs as vegetated filter strips and grassed swales. "The use of a **filter strip as the sole water quality BMP is permissible** only when no other BMP method, as described in this manual, can be utilized because of site constraints. This has to be clearly demonstrated by the applicant and approved by the permitting agency." Grassed swales are for pretreatment.

Rhode Island Department of Transportation. 1993. *Rhode Island DOT Storm Water Design and Installation Standards Manual.* http://www.dot.ri.gov/programs/enviro/stormwater/StormWtrDesMnl.pdf.

Rhode Island Department of Environmental Management and Rhode Island Coastal Resources Management Council. 1993. *State of Rhode Island Storm Water Design and Illustration Standards Manual.* http://www.dem.ri.gov/programs/benviron/water/permits/ripdes/stwater/pdfs/desman.pdf.

South Carolina

State agencies include South Carolina DOT and South Carolina Department of Health and Environmental Control (SCDHEC). The SCDHEC's *South Carolina DHEC Storm Water Management BMP Handbook* has numerous LID techniques including enhanced swales and vegetated filter strips. Filter strips are **primary stormwater treatment**. The DOT has minimal information for post-construction BMPs.

South Carolina Department of Transportation. 2008. *Erosion Control Data Sheet*. http://www.scdot.org/doing/Hydrology/ecds.xls.

South Carolina Department of Health and Environmental Control. 2006. *NPDES Qualifying Local Programs (QLPs) for Construction Site Storm Water Runoff Control and Post-Construction Storm Water Management in New Development and Redevelopment*. Bureau of Water. http://www.scdhec.net/environment/water/docs/erfqlpfact.pdf.

South Carolina Department of Health and Environmental Control. 2005. *South Carolina DHEC Storm Water Management BMP Handbook.* http://www.scdhec.gov/environment/ocrm/pubs/docs/SW/BMP_Handbook/Structural_controls.pdf.

South Carolina Department of Transportation. 1993. *South Carolina DOT Interim Stormwater Control Manual*. http://www.scdot.org/doing/pdfs/InterimStormwaterManual.pdf.

South Dakota

State agencies include the South Dakota DOT and South Dakota Department of Environment and Natural Resources (SDDENR). The SDDENR lists BMPs in its General Construction Permit that includes buffer zones. The DOT has information pertaining to construction site BMPs but minimal regarding post-construction practices. The survey response from the SDDENR stated that vegetated BMPs are for pretreatment.

South Dakota Department of Transportation. 2006. *South Dakota DOT / Road Design / Plans Prep. / Water Quality Enhancement Program Design Manual.* http://www.sddot.com/pe/projdev/environment_stormwater.asp.

South Dakota Department of Environment and Natural Resources. 2002. *South Dakota Dept of Environment and Natural Resources General Permit for Stormwater Discharges Associated with Construction Activities*. http://www.state.sd.us/denr/DES/Surfacewater/IPermits/ConstructionPermit.pdf.

Tennessee

State agencies include the Tennessee DOT and Tennessee Department of Environment and Conservation (TNDEC). The TNDEC's *Erosion & Sediment Control Handbook: A Guide for Protection of State Waters through the Use of Best Management Practices during Land Disturbing Activities* has a buffer zones category containing general buffers and vegetated riparian buffers. The vegetated riparian buffers categories are:

- Zone 1 - First 20 ft nearest the stream should consist of trees and shrubs spaced 6-10 ft apart to provide stabilization of the bank deep into the soil.
- Zone 2 - Next 10 ft should consist of managed forest for chemical absorption and wildlife habitat.
- Zone 3 - Upper 20 ft should be comprised of grasses for sediment and chemical capture.

Buffers are legally protected areas along jurisdictional waters such as wetlands, streams, and lakes. Specific areas within the state have specific buffer requirements along streams and floodways (e.g., average of 25 feet to 60 feet, respectively). Buffer zone requirements may also be dictated by water quality (i.e., average of 60-foot buffer or BMPs providing equivalent protection adjacent to impaired and high quality waters from the NPDES Construction General Permit.

Tennessee Department of Transportation. 2007. T*ennessee DOT Statewide Stormwater Management Program.* http://www.tdot.state.tn.us/sswmp/pdfs/ProgEvalRecs.pdf.

Tennessee Department of Environment and Conservation. 2002. *Erosion & Sediment Control Handbook: A Guide for Protection of State Waters through the Use of Best Management Practices during Land Disturbing Activities.* http://tennessee.gov/environment/wpc/sed_ero_controlhandbook/2.%20Vegetative%20Practices.pdf.

Texas

State agencies include the Texas DOT and Texas Commission on Environmental Quality (TCEQ). TxDOT has little information regarding post-construction BMPs. TCEQ lists **filter strips** for use as **primary stormwater treatment**. TCEQ states in the Description of BMPs (Tier I Projects) "they can provide water quality benefits even where the impervious cover is as high as 50%. The primary highway application for vegetative filter strips is along rural roadways where runoff that would otherwise discharge directly to receiving water, passes through the filter strip before entering a conveyance system. Properly designed roadway medians and shoulders make effective buffer strips." TxDOT and TCEQ replied to the survey stating that vegetated BMPs are **primary stormwater treatments**. TCEQ further stated that the state construction permit does not specify BMPs. MS4 program provides flexibility. TCEQ …does not mandate or endorse particular BMPs for stormwater runoff [in rural applications]. It is approval by default. The follow-up interview with TCEQ confirmed stating there are no requirements for post-construction outside of the municipal separate storm sewer system (MS4).

Texas Commission on Environmental Quality. 2004. *Description of BMPs (Tier I Projects).* http://www.tceq.state.tx.us/assets/public/permitting/waterquality/attachments/401certification/401tier1des.pdf.

Texas Commission on Environmental Quality. 2003. *BMP FINDER: Best Management Practices to Address Nonpoint Source Pollution: Definitions and Categorization by Sources and Pollutants Addressed.* http://www.tceq.state.tx.us/assets/public/compliance/monops/nps/mgmt-plan/BMP%20Finder2.pdf.

Texas Department of Transportation. 2002. *Stormwater Pollution Prevention Plans, Storm Water Management.* ftp://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/storm_water/2preventionplans.pdf.

Utah

State agencies include the Utah DOT and Utah Department of Environmental Quality (UTDEQ). The *Utah Department of Transportation Stormwater Management Plan UPDES Phase II* lists **grassed swale and filter strip** as post-construction **primary stormwater treatments**. "Filter strips can be useful in rural situations where storm water runoff is allowed to sheet flow and dissipate into the surrounding vegetated areas." The UTDEQ lists their MS4 post-construction structural stormwater management BMPs including grassed or vegetative swales, stream buffers, and vegetative filter strips.

Utah Department of Transportation. 2008. *Utah DOT Temporary Erosion & Sediment Control Manual.* http://www.udot.utah.gov/main/f?p=100:pg:881933497248514:::1:T,V:2122.

Utah Department of Transportation. 2006. Stormwater Management Plan UPDES Phase II.

Utah Department of Environmental Quality. *Municipal Separate Storm Sewer System (MS4) Permitting.* http://www.waterquality.utah.gov/UPDES/MS4permit-audit_SS.pdf march 2009.

Vermont

State agencies include the Vermont Agency of Transportation (VTrans) and Vermont Agency of Natural Resources. VTrans states in the *Stormwater Management Plan* "Applicable controls could include preventative actions such as protecting sensitive areas (e.g., wetlands) or the use of structural BMPs such as grassed swales or porous pavement." The *Vermont Stormwater Treatment Standards* lists open channel systems with **dry swale, wet swale and grass channel.** These are **primary stormwater treatments.** The section on Voluntary Stormwater Management Credits recommends the use of **stream buffers and filter strips as primary stormwater treatment** in certain applications. This document also addresses the issues regarding stormwater treatment in cold climates.

Vermont Agency of Transportation. 2007. *Vermont Standards & Specifications for Erosion Prevention and Sediment Control.* http://www.aot.state.vt.us/techservices/envpermit/erosionpreventionandsedimentcontrol.htm.

Vermont Agency of Transportation. 2004. *Stormwater Management Plan.* http://www.aot.state.vt.us/techservices/envpermit/Stormwater04.htm.

Vermont Agency of Natural Resources. 2002. *Vermont Stormwater Management Manual, Volume I – Stormwater Treatment Standards.* http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf.

Virginia

State agencies include the Virginia DOT (VADOT), Virginia Department of Environmental Quality and Virginia Department of Conservation and Recreation (VADCR). The VADOT *Manual of Practice for Stormwater Management,* Chapter 4, directly addresses stormwater management for linear projects. **Vegetated filter strips and grassed swales are primary**

stormwater treatments. The VADCR's *Virginia Stormwater Management Handbook* lists **vegetated filter strips and grassed swales that** can be used as **primary stormwater treatment.**

Virginia Department of Environmental Quality. 2008. *General Virginia Pollutant Discharge Elimination System (VPDES) Permit Regulation for Discharges of Storm Water from Construction Activities.* Commonwealth of Virginia. State Water Control Board. http://www.deq.virginia.gov/waterguidance/pdf/992008.pdf.

Yu, S., and R.L. Stanford. 2004. *VDOT Manual of Practice for Stormwater Management.* Virginia Department of Transportation. http://www.virginiadot.org/vtrc/main/online_reports/pdf/05-cr5.pdf.

Virginia Department of Conservation and Recreation. 2002. *Stormwater Management Requirements Guidance on the Chesapeake Bay Preservation Area Designation and Management Regulations.* http://www.dcr.virginia.gov/chesapeake_bay_local_assistance/documents/SWM.pdf.

Virginia Department of Conservation and Recreation. 1999. *Virginia Stormwater Management Handbook, Volumes 1 and 2.* Virginia Department of Conservation and Recreation. http://www.dcr.virginia.gov/soil_&_water/stormwat.shtml.

Washington

See Chapter 5 State of the Practice.

West Virginia

The agencies include the West Virginia DOT and West Virginia Department of Environmental Protection. There are numerous specifications and information about temporary BMPs. The only post-construction BMP found is sediment basins. The survey of practice response from West Virginia DOT stated that vegetated BMPs are **primary stormwater treatments**. However, the researchers could not find this documentation. The West Virginia Department of Environmental Protection replied that the state of WV does not have post-construction stormwater regulations.

West Virginia Department of Transportation. 2007. *Drainage Manual 3rd Edition*. Division of Highways, Engineering Division. http://www.wvdot.com/engineering/manuals/drainage/wvdoh_2007_drainage_manual.pdf.

West Virginia Department of Environmental Protection. 2006. *West Virginia Erosion and Sediment Control Best Management Practice Manual.* http://www2.wvdep.org/dwwm/stormwater/BMP/index.html.

West Virginia Department of Transportation. 2003. *Erosion and Sediment Control Manual*. Division of Highways. http://www.wvdot.com/engineering/files/EROSION/Erosion2003.pdf.

Wisconsin

See Chapter 5 State of the Practice.

Wisconsin Department of Transportation. 2008. *Facilities Development Manual Chapter 10: Erosion Control and Storm Water Quality.* http://roadwaystandards.dot.wi.gov/standards/fdm/10-00-000toc.pdf.

Wisconsin Department of Natural Resources. 2004. *Distinguishing between Performance Standards, Technical Standards, and Guidance Documents, Post-Construction Stormwater Management Workshops*. http://dnr.wi.gov/runoff/stormwater/post-constr/StandardsandGuidance.pdf.

Donavan, T., M.A. Lowndes, P. McBrien, and J. Pfender. 2000. *Wisconsin Stormwater Manual: Technical Guidelines for Stormwater Management Practices*. http://learningstore.uwex.edu/Wisconsin-Storm-Water-Manual-P603C0.aspx.

Wyoming

The agencies are the Wyoming Department of Transportation and Wyoming Department of Environmental Quality (WYDEQ). The WYDEQ directs the reader to other resources for stormwater treatments. The DOT did not appear to have any post-construction guidance either. However, the survey response indicated that Wyoming DOT uses vegetated BMP for **primary stormwater treatment.**

Wyoming Department of Transportation. http://dot.state.wy.us/Default.jsp?sCode=hom.

STATE REGULATORY AND/OR ENVIRONMENTAL AGENCY DESIGN CRITERIA FOR VEGETATED BUFFERS AND FILTER STRIPS FROM LITERATURE, MANUALS, DOCUMENTS AND SURVEY RESULTS

Agency	BMP	Design Storm	Slope	Length	Width	Contributing Drainage Area	Flow Velocity	Flow Depth	Grass Height	Soil Types	Residence Time (minutes)	Depth to Water Table or Bedrock	Remarks
US EPA	Vegetated filter strip		2 to 6%		≥ 7.6 m [25 ft]					Should not be used on high clay content soils		0.6 to 0.9 m [2 to 4 ft] above water table	A pea gravel diaphragm should be used at the top of the slope.
CA EPA	Vegetated filter strip		≤6%			≤ 2 ha [5 ac]				13 mm/hr [0.5 in/hr]		1.2 to 2.7 m [4 to 9 ft] above water table	Can be used for volume reduction
CA DWR	Vegetated buffer strip		<15% but >1%	≤18.3 m [60 ft] but ≥4.6 m [15 ft]	Width should be the same as the contributing area.		0.27 m/s [1 fps]						
DE DNREC	Filter strip	≤0.8 m³/0.3 m [30 cf/ft]	1 to 25%		For urban, ≥1.5 m [5 ft]	≤30 m [100 ft] impervious							
GA DNR	Strip		2 to 6%	> 4.6 m [15 ft]					High retardance dense grass				
IADNR	Strip		2 to 6%	>4.6 m [15 ft] (depending on surface type, slope, design storm)		≤2 ha [5 ac]			50 to 100 mm [2 to 4 in]				Use pea gravel diaphragm as level spreader at top of slope
IDDEQ	Vegetated filter strip		<14% most effective up to 10%	impervious drainage area ≤23 m [75 ft] pervious drainage area ≤46 m [150 ft]		2 ha [5 ac]	0.14 m/s [0.5 fps]	13 mm [0.5 in]		Types B, C, D	20	≥0.9 m [3 ft] above water table ≥1.5 m [5 ft] above bedrock	
MADEP	Strip		<15%	6 m [20 ft] for 1% slope, additional 1.2 m [4ft] for every 1% increase (15 to 23 m [50 to 75 ft] preferred)	30 to 60 m [100 to 200 ft]		<0.27 m/s [1 fps]	<1/3 vegetation height					
MDDEP	Sheet flow to buffer		5% unless level spreader		15 m [50 ft]	pervious 46 m [150 ft] impervious 23 m [75 ft]							
MEDEP	Buffer adjacent to the downhill side of a road		<20%	Forested buffer – 1 travel lane - 10.6 m [35 ft] 2 travel lanes – 16.7 m [55 ft] Meadow Buffer 1 travel lane – 15 m [50 ft] 2 travel lanes 24 m [80 ft]						does not include wetland soil types			

STATE REGULATORY AND/OR ENVIRONMENTAL AGENCY DESIGN CRITERIA FOR VEGETATED BUFFERS AND FILTER STRIPS FROM LITERATURE, MANUALS, DOCUMENTS AND SURVEY RESULTS													
Agency	BMP	Design Storm	Slope	Length	Width	Contributing Drainage Area	Flow Velocity	Flow Depth	Grass Height	Soil Types	Residence Time (minutes)	Depth to Water Table or Bedrock	Remarks
MIDEQ	Grass filter strip		1%		6 m [20 ft]	≤2 ha [5 ac]				A, B preferred C, D			
MODEQ	Filter strip		<15%	15 m [50 ft] plus an additional 1.2 m [4 ft] for each 1% slope increase over a 5% slope up to a maximum of 15% slope	15 m [50 ft] plus 1.2 m [4 ft] for each 1% slope increase over a 5% slope up to a maximum of 15% slope								
MSDEQ	Strip			>9 m [30 ft] (Increase if stream is on state's list of impaired waters)									
NCNENR	Filter strip	10-yr	<15% (<5%) grass ≤8% 3.9 m/ 0.03 m^3 [13 ft/1cfs] forest ≤6% 20 m/0.03 m^3 [65 ft/1cfs]	15 m [50 ft] 9 m [30 ft] when used as a companion BMP	3.9 to 39.6 m [13 to 130 ft]								
NDDEH	Vegetative buffer strip		≤5%		7.6 m [25 ft]	<38 m [125 ft] upslope drainage with ≤6% slope			≥90% density ≤10% woody 150 to 300 mm [6 to 12 in]				
NHDES	Roadway buffer		Constructed buffer uniform ≤15% except ≤ 6 m [20 ft] vegetated embankment ≤3:1 counts toward length Natural buffer ≤20%	1 travel lane – 15 m [50 ft] 2 travel lanes 24 m [80 ft]									
NJDEP	Strip		<8%	>7.6 m [25 ft] (depending on slope, soil and vegetation type)					85% density				
OHEPA DNR	Vegetated filter strip		<5%	≥7.6 m [25 ft]		0.4 ha [I ac] impervious per 177 m [580 ft] pervious per 88 m [290 ft]						0.6 to 0.9 m [2 to 4 ft] above water table	Use level spreader

STATE REGULATORY AND/OR ENVIRONMENTAL AGENCY DESIGN CRITERIA FOR VEGETATED BUFFERS AND FILTER STRIPS FROM LITERATURE, MANUALS, DOCUMENTS AND SURVEY RESULTS													
Agency	BMP	Design Storm	Slope	Length	Width	Contributing Drainage Area	Flow Velocity	Flow Depth	Grass Height	Soil Types	Residence Time (minutes)	Depth to Water Table or Bedrock	Remarks
ORDEQ	Vegetated filter strip		≤5%	≥15 m [50ft]	≥6 m [20 ft]	≤4 ha [10 ac]							
SCDHEC	Vegetated filter strip	10-yr 24-hr	1 to 10%		Width equal to contributing area ≥4.6 m [15 ft]								TSS removal 80% assumed
TNDEC	Vegetated buffer			15 m [50 ft] - increase 0.6 m [2 ft] in width for every 1% of slope (perpendicular to stream)									
PADEP	Vegetated filter strip		≤8%	≥7.6 m [25 ft] but recognizes performance with less	Equal to width of drainage area								
VTDEC	Stream buffer				≥15 m [50 ft] (perpendicular to stream) from bank	Pervious ≤46 m [150 ft] impervious ≤23 m [75 ft] with slope ≤5%							Use level spreader where necessary
VADEQ	Vegetated filter strip		≤5%	≥7.6 m [25 ft] at 2% slope increase 1.2 m [4 ft] for any 1% increase in slope. Optimum length 24 to 30 m [80-100 ft]	Equal to width of contributing area When not practical, use level spreader to reduce flow width to filter strip width					13 mm/hr [0.5 in/hr] infiltration rate		0.6 m [2 ft] above water table	To force ponding in a vegetated filter strip, a pervious berm may be installed with ≤0.3 m [1 ft] ponding depth behind berm
WIDNR	Filter strip		<10%			≤2 ha [5 ac]	≤0.84 m/s [3 fps] 0.52 m/s [2 fps] desired	≤25 mm [1 in]	150 to 300 mm [6 to 12 in]				

Bold Underlined Text designates use as primary stormwater treatment BMP
Note: Most states have their own specification of vegetation (seed mix, management, etc).

STATE TRANSPORTATION AGENCY DESIGN CRITERIA FOR VEGETATED BUFFERS AND FILTER STRIPS FROM LITERATURE, MANUALS, DOCUMENTS AND SURVEY RESULTS													
Agency	BMP	Design Storm	Slope	Length	Width	Contributing Drainage Area	Flow Velocity	Flow Depth	Grass Height	Soil Types	Residence Time (minutes)	Depth to Water Table or Bedrock	Remarks
AKDOT	Strip	2-yr		5.5 to 18.3 m [18 to 60 ft]									
ALDOT	Strip												do not meet TSS requirement
ALSWCC	Filter strip				Based on % slope and length, predicted amount and particle size distribution of sediment delivered to the filter strip, density and height vegetation, and runoff volume.	drainage area to filter strip < 50:1			Stem density < 25 mm [1 in]				
AZDOT	Vegetated filter strip		Maximum upstream contributing slopes 2 to 10%	25% of site required for BMP		≤ 2 ha [5 ac]				Finer soils require wider strip		0.6 to 0.9 m [2 to 4 ft] above water table	Small setback may be required between the VFS and the edge of the road if frost heave is a concern. Use cold and salt-tolerant vegetation. Plowed snow can be stored in the VFS.
CADOT	Biofiltration strip		As long and flat as site will allow	≤30 m [100 ft]					≥70% density				Use the Rational Method to determine the Water Quality Flow (WQF) and peak flows for the peak drainage design event
CODOT	Sheet flow to buffer	2-yr	<5%	>15 m [50 ft]	>2.4 m [8 ft]	pervious ≤46 m [150 ft] Impervious ≤23 m [75 ft] slope ≤5%		6.4 mm [0.25 in]					Use level spreader where necessary
DEDOT	Filter strip	≤0.8m^3/0.3m [30 cf/ft]	≥1% but ≤25%	unlimited Impervious Length +/- 30 m [100 ft]	≥1.5 m [5 ft]					assume topsoil			
MEDOT	Strip		<5:1	depending on slope	≥7.5 m [24.5] ft								
MTDOT	Natural and engineered dispersion		≤6:1	See width	Soil Types A and B – For every 6 m [20 ft] of impervious drainage area – 3 m [10 ft] of width (parallel to flow). For every 300 mm [1 ft] add 76 mm [0.25 ft] Pervious – 2 m [6 ft] add 300 mm [1 ft]		0.14 m/s [0.5 fps]			All with specific criteria for each		1 m [3 ft] above water table	30 m [100 ft] for drinking wells, septic tanks, springs used for drinking supply

STATE TRANSPORTATION AGENCY DESIGN CRITERIA FOR VEGETATED BUFFERS AND FILTER STRIPS FROM LITERATURE, MANUALS, DOCUMENTS AND SURVEY RESULTS

Agency	BMP	Design Storm	Slope	Length	Width	Contributing Drainage Area	Flow Velocity	Flow Depth	Grass Height	Soil Types	Residence Time (minutes)	Depth to Water Table or Bedrock	Remarks
MTDOT					For Soil Type C and D - For every 300 mm [1 ft] impervious width, 2 m [6.5 ft] dispersion with a minimum of 30 m [100 ft]								
NVDOT	Biofiltration strip		As flat as the site will reasonably allow	As long as the site will allow Maximum determined by sustainable flow conditions no minimum length			Use where flow velocities will not cause scour	As shallow as the site will reasonably permit					Use where site conditions and climate allow vegetation to be established
OHDOT	Vegetated buffer strip		≤20%	15 to 25 m [50 to 82 ft]	≥6 m [20 ft] ≥30 m [100 ft] along streams of above wetlands	unlimited			≥75% density	all		1 m [3 ft] above water table 1.5 m [5 ft] above bedrock	
ORDOT	Filter strip		≤5%				0.14 m/s [0.5 fps]	≤25 mm [1 in]			9		Level spreader required
RIDOT	Vegetated filter strip		≤5%	Equal to contributing area	7.6 m [25 ft] unless used as pretreatment for infiltration trench					A, B, C			Level spreader required
WADOT	Strip		2-15%	depending on slope		46 m [150 ft] flow path	0.14 m/s [0.5 fps]	25 mm [1 in]		uses compost amended soils in some applications	9		compost amended vegetated filter strip (CAVFS), and narrow area vegetated filter strip
WIDOT	Filter strip				≥6 m [20 ft] add 1.2 m [4 ft] for each 1% slope								Good performance for pollutant removal can be expected if the filter is 15 to 23 m [50 to 75 ft] wide with an additional 1.2 m [4 ft] (1.2 m) for each one percent of slope at the site.

Bold Underlined Text designates use as primary stormwater treatment BMP
Note: Most states have their own specification of vegetation (seed mix, management, etc).

STATE REGULATORY AND/OR ENVIRONMENTAL AGENCY DESIGN CRITERIA FOR GRASS SWALES FROM LITERATURE, MANUALS, DOCUMENTS AND SURVEY RESULTS														
Agency	BMP	Design Storm	Longitudinal Slope	Side Slope	Length	Width	Contributing Drainage Area	Flow Velocity	Flow Depth	Grass Height	Soil Types	Residence Time (minutes)	Depth to Water Table or Bedrock	Remarks
USEPA	Vegetated swale	2-yr design with 10-yr capacity	≤4% - 1 to 2% preferred use check dams for steeper slopes	<3:1		Manning's or 1% of drainage area	1% of drainage area	≤140 L/sec [5 cfs]	<grass height	Dense vegetation	Restrictions on impermeable soil types Alkaline soils and subsoils to remove and retain metals Infiltration 0.2 mm/sec [0.5 in/hr]		≥0.6 m [2 ft] above water table	small forebay should be used at the front of the swale to trap incoming sediments
CAEPA	Grassed channel		1 to 3%				≤2 ha [5 ac]				0.2 mm/sec [0.5 in/hr] infiltration		4 to 9 ft above groundwater	Can be used to reduce volume
CAEPA	Vegetated swale		≤2.5%	≤3:1	30 m [100 ft]	≤3 m [10 ft] 0.25 for Manning's n.			2/3 grass height or 100 to 150 mm [4 to 6 in]			10		
DEDNREC	Vegetated channel	10-yr	2%, ≤5% <2% requires under-drain unless HSG A soils or plants wet tolerant	>10% but ≤3:1	≥30 m [100 ft] but ≤300 m [1000 ft]	<4.6 m [15 ft] usually 0.6 to 3 m [2 to 10 ft]								design sheer stress <2psf
FLDEP	Swale	80% of 3-yr, 1-hr storm within 72 hr		≤ 3:1		Width to depth ratio ≥6:1						9		
GADNR	Swale			<3:1	>7.6 m [25 ft] (to satisfy 5min residence time)	0.6 to 1.8 m [2 to 6 ft]						5		
IADNR	Swale	<10-yr		<3:1	should satisfy 10 min residence time	0.6 to 2.4 m [2 to 8 ft] (up to 3.6 m [12 ft] if separated by a structure)		<0.27 m/s [1 fps]	<1/3 of vegetation			10		
IDDEQ	Swale	2-yr 24 hr for rural roads use Manning's n value 0.235 ≤0.3 m [1 ft] freeboard	2 - 4% ideal ≤6%	3:1	60 m [200 ft] continuous swale, if <60 m [200 ft], increase swale cross section by amount proportional to reduction in length to maintain	Ideal 0.6 m [2 ft] bottom width to facilitate mowing	6 ha [15 ac] total surface area of swale 1% of drainage area		≤grass height ≤150 mm [6 in] use level spreader if necessary		Type B, C	9	≥0.6 m [2 ft] above water table ≥ 0.9 m [3 ft] above bedrock	use check dams

STATE REGULATORY AND/OR ENVIRONMENTAL AGENCY DESIGN CRITERIA FOR GRASS SWALES FROM LITERATURE, MANUALS, DOCUMENTS AND SURVEY RESULTS														
Agency	BMP	Design Storm	Longitudinal Slope	Side Slope	Length	Width	Contributing Drainage Area	Flow Velocity	Flow Depth	Grass Height	Soil Types	Residence Time (minutes)	Depth to Water Table or Bedrock	Remarks
					residence time									
KSMARC	Native vegetation swale	Swales - 10% and 1% storm volumes channels 50% storm.	1 - 2.5% without check dams	≤3:1	30 m [100 ft]	Bottom width 0.6 to 2.4 m [2 to 8 ft]	≤2 ha [5 ac]	≤0.27 m/s [1 fps]	<100 mm [4 in]		no gravelly or coarse sandy soils	10		
LADEQ			4:1											
MADEP	Biofilter swale, Water quality swales	2 and 10 yr			to achieve minimum 9-minute residence time				≤150 mm [6 in]		sandy loam with 10 to 20% organic and ≤20% clay do not use gravelly, coarse or impermeable soil	9	do not use in locations with high groundwater	
MDDE	Dry swale	10 yr with 3in min freeboard	4%	3:1 max 4:1 preferred	30 m [100 ft]	0.6 to 2.4 m [2 to 8 ft]	≤2 ha [5 ac]						≥0.6 m [2 ft] above water table	50 ft from wells
MEDEP	Vegetated swale			<3:1		0.3m [1 ft] minimum 3 times depth		≤0.27 m/s [1 fps] for treatment	≤0.3 m [1 ft]	50 to 100 mm [2 to 4 in] above flow depth	Type A and B for goon infiltration		≥ 0.9 m [3 ft] above water table and bedrock	Check dams recommended for greater removal efficiency
MIDEQ	Grassed swale		2% gradient greater than 2% use check dams	≤4:1				<0.14 m/s [5 fps] with 150 mm [6 in] freeboard		dense vegetation	Type A or B Infiltration 0.2 mm/sec [0.5 in/hr]			
MNPCA	Grass channel	2-yr	≤3%	<3:1		0.6 to 2.4 m [2 to 8 ft]		≤0.27 m/s [1 fps]				10		For dry swale 0.8 m [30 in] of prepared soil and check dams wet swale use check dams
MSDEQ	Swale	10-yr 24 hr		≤4:1		15 m [50 ft]		≤1.35 m/s [5 fps] ≥100 mm [4 in] freeboard						
NCDENR	Swale	10-yr 24 hr	≤5%	≤5:1	>46 m [150 ft]	≤ 1.8 m [6 ft]		≤0.27 m/s [1 fps] ≥ 1 ft freeboard					0.3 m [1 ft] above seasonal water table	
NEDEQ	Swale	10-yr 24-hr			≥46 m [150 ft]	typically 3 m [10 ft] flat bottom								
NHDES	Vegetated treatment swales	10-yr 24-hr 0.3 m [1 ft] freeboard	0.5 to 2% w/out check dams 2 to 5% with check dams	<3:1	30 m [100 ft]	1.2 to 2.4 m [4 to 8 ft] 4.8 m [16 ft] with dividing berm			≤0.3 m [1 ft]	100 mm [4 in]				

STATE REGULATORY AND/OR ENVIRONMENTAL AGENCY DESIGN CRITERIA FOR GRASS SWALES FROM LITERATURE, MANUALS, DOCUMENTS AND SURVEY RESULTS														
Agency	BMP	Design Storm	Longitudinal Slope	Side Slope	Length	Width	Contributing Drainage Area	Flow Velocity	Flow Depth	Grass Height	Soil Types	Residence Time (minutes)	Depth to Water Table or Bedrock	Remarks
NJDES	Enhanced swale	10-yr	10%				<10 ha [25 ac]	0.46 m/s [1.5 fps]						
NYDEC	Grass channel	2-yr 4 to 5 fps 10-yr ≤ 7 fps	1-2% preferred ≤4%	≤3:1		0.6 to 2.4 m [2 to 8 ft] bottom		≤ 0.27 m/s [1 fps]	≤100 mm [4 in]			10		
ORDEQ	Bioswale	2-yr 24-hr 150 mm [6 in] freeboard	1 to 2% slope 2 to 6% requires check dams or weirs every 15 to 30 m [50 to 100 ft]	As flat as possible 5:1 best for mowing	Determine length to get 5 min residence time	0.6 to 2.4 m [2 to 8 ft]		0.46 m/s [1.5 fps] for WQ				5		Check dams recommended
PADEQ	Vegetated swale	2-yr design Treat 1" Convey 10-yr with 150 mm [6 in] freeboard	1-6%	3:1 to 5:1		0.6 to 2.4 m [2 to 8 ft]	<4 ha [10 ac]				≥0.7 m [30 in] permeable soil over 12-24 in aggregate Infiltration rate 0.2 mm/sec [0.5 in/hr]	5 to 9		Check that dams use soil with high level of organic material to enhance pollutant removal.
TNDEC	grass swale	10-yr storm	≤1 – 2% No credit as WQ BMP if steeper		100 ft	2-10 ft		≤5 cf/s for WQ	≤100 mm [4 in]		Highly permeable 0.2 mm/s [0.5 in/hr]		≥0.6 m [2 ft] above water table	Check dams
VADDNR	grassed swale and water quality swale	10-yr with 150 mm [6 in] freeboard	>0.75% ≤5%	3:1		0.6 to 1.8 m [2-6 ft] bottom		(45.7 cm/s) 1.5 fps for WQ	100 mm [4 in] or grass height		infiltration rate 0.1 mm/s [[0.27 in/hr]		≥0.6 m [2 ft] above water table	
VTDEC	Grass channel, also dry and wet swale	10-yr 150 mm [6 in] freeboard		≤3:1		0.6 to 2.4 m [2 to 8 ft]						10		Check dams
WIDNR	Vegetated	2-yr 24hr for water quality	≤5% and >1%	≤3:1 4:1 Preferred for mowing	60 m [200 ft]		<20 ha [50 ac]	(45.7 cm/s) 1.5 fps			0.2 to 20 mm/sec [0.5 to 5 in/hr] infiltration rate			can include a no mow 3 to 3.6 m [10 to 12 ft] buffer adjacent to swale for increased performance and wildlife habitat

Bold Underlined Text designates use as primary stormwater treatment BMP
Note: Most states have their own specification of vegetation (seed mix, management, etc).

STATE TRANSPORTATION AGENCY DESIGN CRITERIA FOR GRASS SWALES FROM LITERATURE, MANUALS, DOCUMENTS AND SURVEY RESULTS														
Agency	BMP	Design Storm	Longitudinal Slope	Side Slope	Length	Width	Contributing Drainage Area	Flow Velocity	Flow Depth	Grass Height	Soil Types	Residence Time (minutes)	Depth to Water Table or Bedrock	Remarks
ALDOT	Swale	10-yr		<3:1	Manning's equation									rural permanent
CADOT	Biofiltration swales		Min 0.25%, max. 6% 1 – 2% preferred	≤4:1	length of swale qualifying as a Biofiltration Treatment BMP must be upstream of where either the maximum depth or velocity was exceeded.	0.6 to 3 m [2 to 10 ft]		≤ 0.14 m/s [0.5 fps]	≤150 mm [6 in]	70% density		≥ 5		Use the Rational Method to determine the Water Quality Flow (WQF) and peak flows for the peak drainage facility design event
CODOT	Swale	2 or 10-yr		<2:1		0.6 to 2.4 m [2 to 8 ft]								
DEDOT								≤0.27 m/s [1 fps]	150 mm [6 in] or 1/2 vegetation height		assume topsoil is used	9		
FLDOT	Vegetated swale (grassed waterway)	10-yr 24-hr	≤10%	≤ 3:1			≤61 ha [150 ac]		high speed highways - ≤0.46 m [1.5 ft]		Type A or B			High speed highways flow line slopes on the check dams of 20:1 are recommended. Along residential streets and lower speed highways, steeper flow line berm slopes (1:6) are acceptable.
HIDOT	Dry swale Wet swale		≤4%	≤ 3:1 max 2:1	30 m [100 ft]	≤2.4 m [8 ft]	≤2 ha [5 ac]		100 mm [4 in] for WQ			30 min 48 hr max	0.6 m [2 ft]	Wet swales "ideal for highway runoff in low lying areas or flat areas."
MADOT	Dry swale Wet swale Biofilter swale	10-yr 1 ft freeboard	≤5%	≤3:1		0.6 m to 2.4 m [2 to 8 ft]		≤ 0.3 m/s [1 fps] for treatment ≤ 0.91 m/s [3 fps] for conveyance	0.3 m [1ft] for treatment			9 min for 80% TSS removal 5 min for 60% TSS		
MEDOT	Swale			<3:1		0.3m [1 ft] minimum 3 times depth			≤1 ft		Type A or B for infiltration			
MIDOT					≥150 m [500 ft] from edge of water or outfall									
MSDOT	Ditch			<3:1										

STATE TRANSPORTATION AGENCY DESIGN CRITERIA FOR GRASS SWALES FROM LITERATURE, MANUALS, DOCUMENTS AND SURVEY RESULTS														
Agency	BMP	Design Storm	Longitudinal Slope	Side Slope	Length	Width	Contributing Drainage Area	Flow Velocity	Flow Depth	Grass Height	Soil Types	Residence Time (minutes)	Depth to Water Table or Bedrock	Remarks
NCDOT			≤4%		Contributing area 30 m/0.4 ha [100 ft/ac]									
NHDOT										85% density				
NVDOT	Biofiltration swale	sized as a conveyance system						where flow velocities will not cause scour	as shallow as the site will reasonably permit					Use where site conditions and climate allow vegetation to be established. Use vegetation mix appropriate for climates and location
OHDOT	Vegetated biofilter / ditch		2%	Foreslope 4:1 backslope 2:1		1.2 to 3 m [4 to 10 ft]	2.8 ha [6.85 ac]							
ORDOT	Grassed swales -biofiltration swales	0.3 m [1 ft] freeboard	Min. 0.5%	4:1	≥30 m [100 ft]	≥2.7 m [9 ft]		0.54 m/s [2 fps]	150 mm [6 in] 100 mm [4 in] recommended			9		
RIDOT	Grassed swale	25-yr peak discharge						<1.35 m/s [5 fps]			0.2 mm/sec [0.5 in/hr] infiltration		≥0.6 m [2 ft] above water table	Check dam use encouraged for better performance Not within 30 m [100 ft] of public or private well 15 m [50 ft] to septic
WADOT	Biofiltration swale			<3:1		2-10 ft								
VADOT	Grassed swale		0.2 to 8%	≤3:1	30 m [100 ft] where possible	Top width 3 m [10 ft] where possible		(45.7 cm/s) 1.5 fps	100 mm [4 in]			9		Check dams
WIDOT	Vegetated swale		≤2%					0.6 m/s [2 fps]	0.3 m [1 ft]		Type A, B		0.3 to 0.6 m [1 to 2 ft] above water table	Check dams

Bold Underlined Text designates use as primary stormwater treatment BMP
Note: Most states have their own specification of vegetation (seed mix, management, etc).

Appendix B:
Survey – State Transportation and Environmental/Regulatory Agencies

1. Stormwater Treatment with Vegetated Buffers in Rural Roadside Applications

Thank you for taking the time to complete this survey. The information gathered from this survey will be used in conjunction with data from literature, state transportation, environmental, and regulatory agencies on the use of vegetated buffers such as vegetated filter strips and grass swales for stormwater treatment in rural roadside applications. The data will be compiled and analyzed to develop recommendations on effective best management practices in rural roadside applications. This research is being conducted for the Standing Committee on Environment (SCOE) of the American Association of State Highway and Transportation Officials (AASHTO). Many states have different terms for the same types of stormwater treatments. For the purposes of this survey, vegetated buffers will be separated into two categories, concentrated flow and sheet flow. The term grass swales will be used for stormwater treatments that manage concentrated flows (i.e., roadside ditch, grass channel, vegetated swale, etc.). The term vegetated filter strip will be used for stormwater treatments that manage sheet or overland flow (i.e., grass buffer, vegetated buffer, filter strip, etc.).

To complete the survey, please answer the following 23 questions. The survey will allow an opportunity to include any additional comments and information.

If this survey has reached you in error please forward it to the correct person in your organization. Also, please complete this survey by November 2, 2008. Again, thank you in advance for your participation in this survey.

If you have any questions please contact:
Beverly Storey
Program Manager
Environmental Management Program
Texas Transportation Institute
Texas A&M University
Email: NCHRPSurvey@TTIMAIL.TAMU.EDU

2. General Information

Please complete the following.

* indicates required field.

1. Name:

2. State:*

3. Agency:*

4. Email Address:

5. Telephone:

3. GRASS SWALES

The following 8 questions pertain to GRASS SWALES.

1. Does your State Environmental Agency accept grass swales as stormwater treatment structures in rural highway settings?

2. If you answered YES to Question #1, which of the following roadside locations apply?

Primary treatment (used alone)
Secondary treatment (used in conjunction with other treatments)

3. If you answered NO to Question #1, please indicate reason why they are not allowed:

4. If your Agency has specifications and/or construction details for grass swales please provide the following information and its source (document titles, website address, etc.):

Soil type
Width (ft)
Length (ft)
Vegetative cover (%)
Vegetation type
Depth (ft)
Slope (% or H:V)
Document title (i.e., Roadside Design Manual)
Website address

5. Does your Agency adhere to or participate in a credit-system for the use of grass swales for treating stormwater in rural roadside applications?

6. If you answered Yes to Question #5, please provide source information on your credit-system (website address, document title/location, etc.):

7. Does your Agency have data demonstrating the effectiveness of grass swales?

8. If you answered YES to Question #7, please provide source of data (website address, document title/location, etc.):

4. VEGETATED FILTER STRIPS

The following 8 questions pertain to VEGETATED FILTER STRIPS.

1. Does your State Environmental Agency accept the use of vegetated filter strips as stormwater treatment structures in rural highway settings?

2. If you answered YES to Question #1, which of the following roadside applications apply?

Primary treatment (used alone)
Secondary treatment (used in conjunction with other treatments)

3. If you answered NO to Question #1, please indicate why they are not allowed:

4. If your Agency has specifications and/or construction details for vegetated filter strips please provide the following information and its source (document titles, website address, etc.):

Soil type
Width (ft)
Length (ft)
Vegetative cover (%)
Vegetation type
Slope (% or H:V)
Document title (i.e., Roadside Design Manual)
Website address

5. Does your Agency adhere to or participate in a credit-system for the use of vegetated filter strips for treating stormwater in rural roadside applications?

6. If you answered YES to Question #5, please provide source information on your credit-system (website address, document title/location, etc.):

7. Does your Agency have data demonstrating the effectiveness of vegetated filter strips?

8. If you answered YES to Question #7, please provide source of data (website address, document title/location, etc.):

5. Conclusion

1. Please provide any additional comments and/or information on the use of vegetated buffers for stormwater treatment in rural roadside applications:

2. May we contact you?