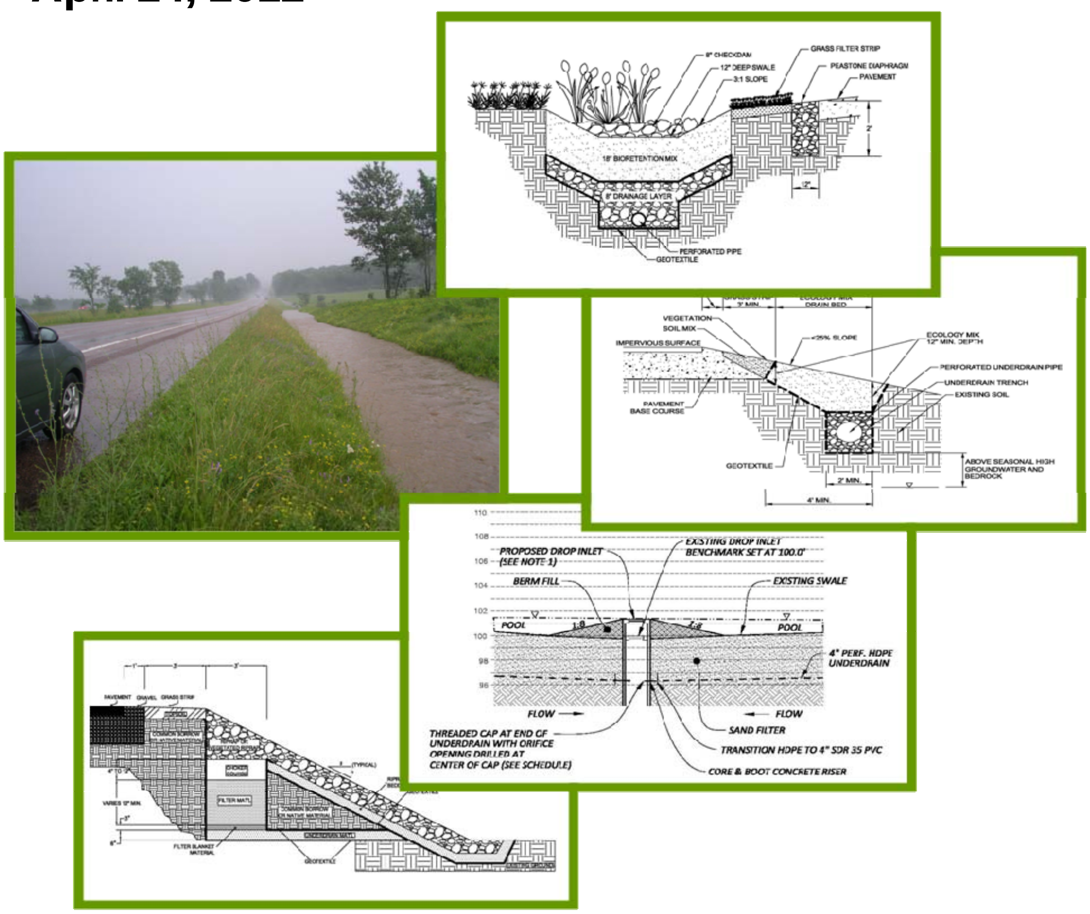
Stormwater Practices Research Project Final Report

April 24, 2012



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Stormwater Practices Research Project

Final Report

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April 24, 2012

ACKNOWLEDGEMENTS

The VTrans BMP/STP Research Project has been completed under the direction of and in collaboration with a Steering Committee representing a cross-section of VTrans professionals as well as representatives of the Vermont Agency of Natural Resources (ANR). The following personnel participated on the Steering Committee:

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Executive Summary

The Vermont Agency of Transportation (VTrans) conducted the Stormwater Practices Research project to identify and evaluate best management practices/stormwater treatment practices (BMPs/STPs) for post-construction stormwater runoff from transportation infrastructure. The study explored potential technologies that would expand upon or supplement those practices currently identified by the Vermont Agency of Natural Resources (ANR) in the *Vermont Stormwater Management Manual.* The study's objective was to identify practices that are suited for the linear configuration of VTrans facilities, sensitive to the constraints of limited rights-of-way in the context of Vermont's geography and land use, practical and affordable to permit and implement, and able to comply with state and federal regulatory requirements.

A Steering Committee representing a cross-section of VTrans professionals and representatives of the ANR stormwater program directed the study. VTrans engaged Comprehensive Environmental Inc. (CEI) to work collaboratively with the Steering Committee to identify and evaluate Stormwater practices for further development by VTrans as it advances its stormwater management program.

The research project included the following components:

- A broad-based search of literature, transportation and environmental agency resources, and other stormwater technical sources, to identify innovations in stormwater management technology, for consideration by this study.

- Steering Committee review of the findings of this initial research, screening of the initial list of potential BMPs/STPs, and selection of candidate BMPs/STPs for further evaluation.

- Identification of criteria for the evaluation of the selected technologies, including:

    - Pollutant removal effectiveness,
    - Cost effectiveness of structural practices,
    - Consistency with roadway design integrity,
    - Operational consistency with roadway safety,
    - Suitability for regional climate, and
    - Potential for ANR acceptance.

- Evaluation of the selected BMPs/STPs applying the agreed evaluation criteria, resulting in the development of detailed descriptions of the practices. From this evaluation, the team compiled the summary comparison matrix presented in Appendix A of the Final Report, to enable a quick comparative review of the practices considered in the study. Appendix B of the Final Report presents the detailed descriptions of the selected BMPs/STPs.

- Steering Committee review of the technical findings of the BMP/STP evaluation and confirmation of the list of selected BMP/STPs.

- Identifying methods to account for volume reduction of infiltration practices in the sizing of facilities to control runoff rates and volumes.

- Preparation of the Final Report summarizing the research and evaluation process and presenting the findings regarding the selected BMPs/STPs..

From this research effort, the Steering Committee and its study team recommend the following practices be considered for inclusion in the list of available tools for addressing stormwater management objectives of VTrans infrastructure; detailed descriptions are included in Appendix B:

Infiltration Practices	Infiltration berms Pervious pavement systems
Bioretention Practice Variations	Micro-bioretention (rain gardens) Media Filter Drains and Embankment Media Filter Compost Amended Vegetated Filter Strips
Filter System Practices	Micro-filter systems, including: Gutter filters OhioDOT "ExfiltrationTrench" VTrans "Micro-pool Filter" Minnesota DOT "Permeable Ditch Blocks"
Open Channels	Bioswale
Non-structural practices	Vegetated Buffers and Filter Strips
Limited applicability practices	Open Graded Friction Course Forebay with Forced Hydraulic Jump

These BMPs/STPs are intended to be used in the context of VTrans's overall stormwater program, which also includes operational practices that contribute to the control of runoff and the pollutants in runoff, or to the mitigation of the effects of runoff. Examples of these practices, which are addressed under other VTrans initiatives, include:

Drain-on control
Street sweeping
Sump cleaning
Pond maintenance
Other stormwater system maintenance
Spill prevention

Illicit discharge prevention
Vegetation management
Sand-use reduction
Salt management
Other snow management measures

Other considerations addressed in this report were methods for quantifying the benefits of dispersed infiltration in the sizing of stormwater peak rate control practices. Currently, the Vermont Stormwater Management Manual only offers credits towards water quality volumes and recharge volumes when infiltration practices are used. The reduced runoff volume cannot currently be applied in the sizing of structures to meet channel protection and flood protection standards. The "Modified Runoff Curve Number Method," described in Section 6 of the report, provides a means to quantitatively account for the reduction in runoff volume resulting from various Low Impact Development practices in the sizing of facilities to control runoff rates and volumes. Acceptance of this or a similar methodology would reduce the size of peak control structures required to meet ANR's design standards. This would provide a significant benefit to VTrans and other transportation agencies that have limited space for BMP/STP implementation.

This research study completes an important initial step in expanding the "Tool Box" of structural and non-structural practices for use by VTrans designers and maintenance staff in addressing stormwater treatment needs. Future collaborative effort by VTrans Executive Staff, Operation Staff, and Designers, working closely with ANR, will be required to develop design standards for these BMPs/STPs, incorporate them into VTrans guidance manuals and procedures, and provide for their application within Vermont's stormwater regulatory framework. In the meantime, those considering these practices should consult the referenced literature for more specific information on the selection, design, and implementation of these practices.

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Acronyms Used in this Report

ANR	Vermont Agency of Natural Resources
BMP	Best Management Practice
CAVFS	Compost Amended Vegetated Filter Strip
CP	Channel Protection
ED	Extended Detention
ESHGW	Estimated Seasonal High Groundwater
GSRD	Gross Solids Removal Device
HSG	Hydrologic Soils Group
LID	Low Impact Development
MFD	Media Filter Drain
OGFC	Open Graded Friction Course
RCN	Runoff Curve Number
STP	Stormwater Treatment Practice
TSS	Total Suspended Solids

1. Introduction

The Vermont Agency of Transportation (VTrans) conducted the Stormwater Practices Research project to identify and evaluate best management practices/stormwater treatment practices (BMPs/STPs) for post-construction stormwater runoff from transportation infrastructure. The study explored potential technologies that would expand upon or supplement those practices currently identified by the Vermont Agency of Natural Resources in the *Vermont Stormwater Management Manual.*

The objectives of the study included the identification of practices that:

- Are suited for the linear configuration of VTrans facilities;
- Are sensitive to the constraints of limited rights-of-way within the context of Vermont's topography and patterns of land use;
- Enable VTrans to comply with state and federal regulatory requirements; and
- Are practical, affordable solutions that reduce permitting time and costs and provide regulatory and operational efficiencies for both VTrans and the Agency of Natural Resources (ANR).

This report describes the Stormwater Practices Research project, and summarizes the results.

Overview of the Research and Evaluation Process

To undertake this study, VTrans established a Steering Committee representing a cross-section of agency professionals involved in project planning and development, hydraulics and environmental design and permitting, operations, and legal considerations. In addition, this Committee included representatives of the Vermont Department of Environmental Conservation involved in the ANR stormwater program. VTrans contracted with Comprehensive Environmental Inc. (CEI), whose staff worked collaboratively with the Steering Committee to identify and evaluate BMPs/STPs for further development by VTrans as it advances its stormwater management program.

The program of study included the following:

1. A project initiation meeting, to confirm the overall direction and scope of the study and initiate the search for potential BMPs/STPs for evaluation.
2. An initial search of literature, transportation and environmental agency resources, and other stormwater technical sources, to identify innovations in stormwater management technology, for consideration by this study. This initial research, summarized in Section 2, compiled a list of candidate Stormwater Treatment

Practices (STPs), developed criteria for their evaluation, and summarized the findings in the initial project deliverable, Technical Memorandum #1.

3. A second working meeting of the Steering Committee and CEI, to review Technical Memorandum #1 and screen the initial list of potential STPs. This meeting resulted in a short list of candidate technologies to be explored further in the remainder of the study. The meeting also confirmed the screening criteria.

4. An evaluation of the selected STPs, including additional literature research and the development of a detailed description of each practice, applying the agreed screening criteria. This phase of the study also developed a summary comparison matrix to enable a quick comparative review of the practices considered in this study. This phase of the work effort was summarized in the second project deliverable, Technical Memorandum #2.

5. A third working meeting of the Steering Committee, to review Technical Memorandum #2, discuss its findings, and provide direction in the preparation of this final report. This meeting confirmed the list of selected STPs and the findings of the evaluation effort.

6. Preparation of this report, the final project deliverable. The Steering Committee reviewed a draft of the final report, with comments incorporated into the final document.

Organization of this Report

The results of this research effort are reported in the following pages, with topics addressed as follows:

- Section 2 summarizes the initial research effort, which canvassed transportation, regulatory, and institutional agencies and resources for information on emerging stormwater management technologies and developed a list of candidate STPs for further evaluation.

- Section 3 describes the evaluation criteria developed for reviewing each of the candidate practices.

- Section 4 summarizes the results of the evaluation, and introduces a series of fact sheets prepared for each BMP/STP. The evaluation is summarized in a matrix attached as Appendix A. The fact sheets are provided in Appendix B.

- Section 5 presents preliminary recommendations regarding the STPs evaluated in the study.

- Section 6 presents a non-structural methodology for accounting for infiltration and Low Impact Development (LID) practices in the sizing of downstream stormwater management facilities. This methodology enables accounting for capture and infiltration of runoff when sizing stormwater management facilities for controlling peak rates to achieve channel protection, overbank flows, and flood protection.

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2. Initial Research

Initial research efforts comprised the search of various sources for information on newly developing stormwater management technologies, to compile a list of candidate stormwater management practices for further evaluation for their applicability for Vermont's transportation system. The study team contacted multiple transportation agencies, environmental agencies, research institutes, and other technical resources for an initial screening of current research and innovative practices for stormwater management. The team concentrated on agencies and institutions active in the development of stormwater technologies, and an effort was made to include organizations with experience in the application of stormwater management measures in cold climates.

Organizations contacted under this effort included the following:

Transportation Agencies:

California Department of Transportation (CALTRANS)
Kansas Department of Transportation (KDOT)
Maine Department of Transportation (MaineDOT)
Maryland Department of Transportation (MDOT)
Massachusetts Department of Transportation (MADOT)
Michigan Department of Transportation (MDOT)
Minnesota Department of Transportation (Mn/DOT)
New Hampshire DOT (NHDOT)
New York State DOT (NYSDOT)
Ohio Department of Transportation (ODOT)
Oregon Department of Transportation (ODOT)
Rhode Island Department of Transportation (RIDOT)
Washington State Department of Transportation (WSDOT)
Wisconsin Department of Transportation (WDOT)

Research Boards and Centers with Stormwater Programs:

Transportation Research Board (TRB)
University of New Hampshire Stormwater Center (UNHSC)
University of Vermont Rubenstein School of Environment and Natural Resources
University of Vermont Transportation Research Center

In many cases, the study team retrieved and reviewed stormwater treatment practices manuals and guidance documents publicly available from each of the above organizations. In some cases, the team was also able to obtain draft or progress documents summarizing ongoing work, including:

- Oregon DOT provided a draft of water quality guidance currently in development;

- The Transportation Research Board provided draft guidance regarding ultra-urban stormwater management practices;
- Minnesota DOT provided working sketches and information regarding the study and development of a practice known as "Permeable Ditch Blocks;"
- Michael E. Barrett of the Center for Research in Water Resources, University of Texas, provided a copy of a paper by Eck, *et.al.*, "Water Quality of Drainage from Permeable Friction Course," accepted but yet to be copy-edited for publication in the Journal of Environmental Engineering.

In addition to contacting organizations as noted above, the team also canvassed internet resources for research and guidance literature from other agencies and organizations, including the following:

Other Agencies/Organizations Accessed for Relevant Publications:

American Association of State Highway and Transportation officials
Center for Watershed Protection
Izaak Walton League
Maine Department of Environmental Protection
National Cooperative Highway Research Program
New Hampshire Department of Environmental Services
New York State Department of Environmental Conservation
Oregon Department of Environmental Quality
Pennsylvania Department of Environmental Protection
The Low Impact Development Center
U.S. Department of Defense
U.S. Environmental Protection Agency
Washington State Department of Ecology

Also, although not specifically listed above, research studies specific to various stormwater management practices are available through a number of educational institutions, industry associations, and product sources. These are noted in citations in relevant sections of this report.

There is considerable redundancy or overlap among the lists of BMPs/STPs from these sources, and many of the practices are familiar ones, already reflected in the list of BMPs/STPs currently approved by the Vermont ANR. Nevertheless, the team was able to identify a selection of innovative measures, as well as variations of previously developed concepts, that merited further review by this study.

The canvass of organizations and scan of the literature yielded a list of candidate Stormwater Treatment Practices (STPs) for discussion and initial screening with input by the Steering Committee. The potential list of practices is provided below, organized by categories consistent with the discussion of Stormwater Treatment Practices in ANR's publication, *The Vermont Stormwater Management Manual, Volume I Stormwater*

Treatment Standards. This list of practices primarily includes measures not currently included in the ANR listed practices. However, the list does include some practices from the ANR list where design variations or recent performance studies suggest exploring these practices further. Candidate STPs included the following:

Infiltration Practices:

- Pervious pavement systems with direct infiltration
  - Porous asphalt
  - Pervious pavers
  - Vegetated grids
- Infiltration Berms

Filtering Practices:

- Enhanced sand filtration
- Micro-bioretention (rain gardens)[1]
- Media filter drain
- Embankment media filter
- Compost Amended Vegetated Filter Strip
- Pervious pavement systems – underdrained
- Gutter filter
  - Porous concrete paved gutter filter (Ohio "Exfiltration Trench")
- Permeable ditch block (under development by the Minnesota DOT)

Open Channels

- Bioswale (variant of bioretention)

Non-structural practices

- Vegetated Buffers and Filter Strips

Limited applicability practices

- Open Graded Friction Course (OGFC)
- Catch basin modifications: deep sumps
- Catch basin retrofits: inserts/treatment systems
- Gross solids removal devices (GSRD)

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[1] ANR guidance documents include bioretention, and discuss application of this practice in conjunction with infiltration, where feasible, or as an under-drained filter. Information from our initial search indicated some variants or adaptations of this technology. We have identified and included bioretention variants in this list, to explore whether specific adaptations of this practice should be considered for their particular applicability for transportation infrastructure.

The study team developed a brief description of each practice for use in an initial screening by the Steering Committee, to identify which practices to carry forward for further evaluation. In screening these potential BMP technologies for further evaluation, the study team noted the following:

- Stormwater management pond technologies are well represented in the list of practices accepted by ANR. The initial search did not identify additional technologies in this category.
- The category referred to in the literature as “vegetated bio-filters” offers technologies particularly applicable to the transportation setting. The study team suggested consideration of additional practices, variations on ANR-accepted practices, and greater scope for some ANR practices under this category. This would give designers access to a full range of these practices, including variations on bioretention, vegetated swales, vegetated filter strips and buffers, and impervious area disconnection.
- Infiltration practices also offer advantageous methods applicable to transportation, providing opportunities to reduce “effective impervious cover.” The study team recommended expanding the palette of STPs in this category; possible candidates include pervious pavement systems and infiltration berms.
- Filter systems in general also appear to offer stormwater management measures adaptable to the highway setting, and devices in this category merit consideration. These systems include some already in the ANR guidance (gravel wetlands, filter trenches, under-drained bioretention areas). Additional measures include gutter filters, media filter drains, and variations on other filter systems currently recognized by ANR and VTrans.
- Under this particular study, the team did not recommend evaluating the universe of proprietary products offered such as catch basin inserts, gross solids removal devices (GSRD), oil and sediment traps, hydrodynamic separators, and special purpose products focused on particular pollutants. The variety of products, the difficulties of identifying and specifying equivalent products under competitive procurement process, the documentation of cost/benefit for the available devices, and the evolving nature of the offered technologies complicate the effort to make a meaningful evaluation of these technologies. This does not mean, however, that such alternative technologies cannot continue to be considered on a project specific basis.

Based on this overview, the following practices were selected by the Steering Committee for further evaluation in this study:

Infiltration Practices

- Infiltration berms
- Pervious pavement systems

Variations on Bioretention Practices (Type of Filter System Practice)

- Micro-bioretention (rain gardens)
- Bio-swales (see Open Channel Practices)
- Media Filter Drains
  - Embankment Media Filter
- Compost Amended Vegetated Filter Strips

Other Variations on Filter System Practices

- Micro-filter systems, including:
  - Gutter filters
  - OhioDOT "ExfiltrationTrench"
  - VTrans "Micro-pool Filter"
  - Minnesota DOT "Permeable Ditch Blocks"

Open Channels

- Bioswale (this open channel practice is a variation of bioretention)

Non-structural practices

- Vegetated Buffers and Filter Strips

Limited applicability practices

- Open Graded Friction Course
- Forebay with Forced Hydraulic Jump[2]

These practices were advanced to further detailed review and evaluation, as described in the remainder of this document. These technologies are introduced in the following sections of the report, with detailed descriptions included in Appendix B.

[2] This practice was added by CEI subsequent to the initial screening meeting with the Steering Committee, based on experience with its successful application on a stormwater system retrofit in Manchester, NH.

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3. Evaluation Criteria

The STPs selected through this research study should be consistent with increasingly challenging state and federal regulatory requirements, while being practical and affordable to implement and maintain. To accomplish this objective, the study team and Steering Committee identified the following criteria to apply in the further evaluation of the various practices identified in the initial search:

Pollutant removal effectiveness:

- The ability of the practices to remove pollutants, including general indicator pollutants (e.g., TSS removal) and also specific pollutants of concern (e.g., pollutants identified relative to Vermont's listing of impaired waters).

Cost effectiveness of structural practices:

- Relative costs for installation, operation and maintenance.
- Accessibility for inspection and ease of maintenance using routine equipment, to ensure the long-term sustainability of such practices.

Consistency with roadway design integrity:

- Operational and structural consistency with the integrity of highway pavement systems. For example, except in certain well-drained soils, measures that introduce water into the sub-base of pavements must be addressed relative to the proper sub-drainage of pavements. This can impose constraints on the locations and designs of some Stormwater Treatment Practices (STPs).

Operational consistency with roadway safety:

- Design addresses applicable safety standards. For example, within highway medians or adjacent to shoulders, there may be limitations on location and depth of practices that impound water.
- Access to STPs for inspection, maintenance and repair in the highway setting considers safety factors for both access personnel and vehicle operators using the highway while such activities are underway.

Suitability for regional climate:

- Ability to account for freeze/thaw conditions affecting Vermont roads, as well as snow and ice management requirements.
- Adaptability to changing climate. Practices will likely require "resiliency" to be sustainable under changing hydrologic conditions.

Potential for ANR acceptance:

- Similarity to practices already accepted by ANR, or potential ability to meet ANR criteria for acceptance and approval. Volume 1, Section 2.5 of ANR's Vermont Stormwater Management Manual establishes criteria for the acceptance of existing and new alternative technologies as approved STPs for use in meeting regulatory requirements. Practices already supported by documentation complying with these criteria should be noted.
- STPs otherwise show merit, but have not been fully tested; these could be considered for laboratory and field studies under future research projects.

These criteria were used to evaluate the short list of STPs identified by the Steering Committee. Fact sheets were developed for each practice (See Appendix B) including commentary on these criteria, and a BMP/STP evaluation matrix (Appendix A) was developed to summarize this information. The evaluations, fact sheets, and evaluation matrix are discussed further in Sections 4 and 5 of this report.

4. STP Evaluations

The study team evaluated each of the candidate technologies selected by the Committee, as described in Section 2 of this report. The evaluation of each technology is described in the form of a "fact sheet" and included in Appendix B.

The fact sheets are intended to provide a conceptual overview of the selected practices. Further work will be required beyond this study by VTrans working in collaboration with ANR, VTrans executive staff, operation staff, and designers to develop accepted procedures and design standards for these STPs and incorporate them into a VTrans Stormwater Design Guidance Document. In the meantime, those considering these practices should consult the reference literature for more specific information on the selection, design, and implementation of these practices.

The evaluation was based on literature compiled as a result of this review, and personal communications with staff of organizations contacted. Using the criteria laid out in Section 3 as a guide, the team developed a detailed description of each BMP/STP reviewed. Appendix B presents each fact sheet in a standardized format, as follows:

- *Description*
  A concise description of the practice.

- *Stormwater Management Processes*
  A summary of the pollutant removal mechanisms that occur in the practice. This section also includes a notation regarding whether the practice would contribute to a reduction in runoff volume from the contributing watershed, potentially reducing the volume required to be treated or conveyed by downstream practices.

- *Advantages and Disadvantages*
  A brief table summarizing advantages and disadvantages associated with the practice.

- *Illustration*
  One or more illustrative diagrams to graphically describe the configuration of the practice.

- *Target Pollutants and Treatment Effectiveness*
  A table and/or discussion of anticipated pollutant removal performance of the practice, based on the literature reviewed.

- *Selection and Design Considerations*
  A brief discussion of conditions and characteristics affecting selection and design of the practice, including the following:
  - Siting and design considerations;
  - Consistency with roadway design integrity;
  - Cost effectiveness;
  - Suitability for cold climate;
  - Adaptability for changing climate; and
  - Potential for ANR acceptance.

- *Operation and Maintenance Considerations*
  A summary of maintenance requirements applicable to the practice, with comments on whether maintenance requires special equipment or procedures that may differ from routine activities currently practiced on Vermont roadways.

- *References*
  A list of primary literature citations for further information about the practice. For each of the practices identified, this study has compiled a file of source information, to support the current evaluation effort, and also for future use by VTrans as it continues to develop engineering design standards for the selected practices. Where applicable, the references identify design references, performance studies, and other more general references pertaining to the practice.

Further comments and observations about the descriptive information are noted below:

Pollutant Removal Effectiveness

Where a practice is unique and has specific study information relevant to its performance, fact sheets in the Appendix report pollutant removals from the applicable studies.

In some cases, the practices are similar to ones that have been reported in the International Stormwater Database (http://www.bmpdatabase.org/). For those STPs, the fact sheets include results as reported by summary documents available through the database website.

In some cases, specific data for STPs may be lacking. In those cases, the fact sheets include comments on whether the practices are variations on STPs already included in the Vermont Stormwater Management Manual. In those cases, the descriptions note the similarities and whether performance would be expected to be comparable to the currently accepted technology.

Siting and Design Considerations

Each fact sheet provides a brief narrative summarizing key items to consider in applying the candidate technology to a given setting. The information provided is intended to assist in determining where the use of the technology is appropriate and to identify constraints that may govern its use.

The Steering Committee anticipates providing more specific design guidance and specifications through future VTrans guidance development. For the current research effort, therefore, comprehensive sizing methodology and specifications are not presented.

Cost effectiveness of Structural Practices

In this report, cost considerations are generally treated qualitatively, and discussed briefly in narrative form.

Relative to capital costs, the study team found it difficult to find cost data in the literature for making direct comparisons among various BMP/STP technologies. Frequently, available references identify unit costs for various materials used in a practice, but do not relate those costs to impervious area treated, or some other measure designed to facilitate comparison. Other considerations, such as regional differences in materials and installation costs, or costs of new versus well-accepted technologies, make comparison among various studies difficult.

Therefore, the fact sheet narratives generally note whether a practice includes materials that are likely more costly than conventional materials (*e.g.*, soil amendments may cost more per unit than typical borrow materials used in the highway setting) and other factors that might affect cost of construction. Where information is available that indicate cost per acre of impervious surface treated, it is noted.

Relative to operating costs, the narrative notes whether maintenance of a practice requires special activities or equipment that would affect cost, or other factors that might affect routine and non-routine maintenance.

Consistency with roadway design integrity

Operational and structural measures need to be consistent with the structural integrity of highway pavement systems. For example, except in certain well-drained soils, measures that introduce water into the sub-base of pavements must be addressed relative to the proper sub-drainage of pavements. The narrative notes whether the BMP/STP may affect drainage performance of the road base, or whether its location is sufficiently outside of the pavement and shoulder limits so as not to pose a concern.

None of the STPs evaluated at this stage included components requiring large structures beneath pavements, so engineering structural considerations relative to highway and other transportation infrastructure design are generally not a concern for these technologies.

Some STPs are limited in applicability because of pavement strength considerations (*e.g.*, pervious pavements, open graded friction course). This condition is noted where applicable.

Operational Consistency with Roadway Safety

Structural STPs need to be consistent with highway safety considerations. For example, the fact sheets note whether practices involve the placement of shallow impoundments near the roadway.

Access to STPs for inspection, maintenance and repair in the highway setting needs to consider safety factors for both access personnel and vehicle operators using the highway while such activities are underway. Where maintenance activities require significant traffic management or disruption of facility use, this is noted.

Suitability for regional climate

The STP fact sheets note whether the technology under consideration is susceptible to variations in performance under cold climate conditions, whether it is consistent with routine winter maintenance practices in Vermont, and whether special seasonally-related maintenance practices are required to ensure satisfactory performance.

The narratives also note whether practices have features that would be sensitive to changing climatic conditions. The practices reviewed under this study are generally resilient, although those that use vegetation may require monitoring and adaptive management to address changing temperatures and rainfall patterns.

Potential for ANR acceptance

Comments are offered on the potential for ANR acceptance based on the following:

- Whether the practice under consideration employs components or variations of STP technologies already included in the Vermont Stormwater Management Manual.
- Whether the literature reports field and/or laboratory performance evaluations specific to the practice. Where field studies are available, the narrative notes whether the studies appear comparable to ANR's acceptance of existing and new alternative technologies (Volume 1, Section 2.5 of the Vermont Stormwater Management Manual).

STPs that otherwise show merit, but have not been fully tested, are noted for consideration for further laboratory and field studies under future research projects.

5. Recommendations Regarding STPs

This Section summarizes the study team's recommendations regarding the STPs reviewed during the course of the study and presented in the fact sheets in Appendix B. This Section of the report also introduces a summary matrix (included as Appendix A) comparing these STPs.

Note that proper stormwater management involves more than the application of structural STPs. There are few, if any, stormwater management practices that can satisfactorily perform all functions to address the ANR stormwater management criteria as stand-alone practices. A holistic stormwater management program is needed to fully address the impacts of stormwater runoff. This should include environmentally sensitive facility design practices, source control, operational practices, and the employment of a variety of treatment practices in a coordinated fashion to address the stormwater management criteria articulated in the ANR regulations. In this context, the following comments are offered before discussing recommendations regarding the STPs included in Appendix B:

VTrans Operational Practices

VTrans undertakes a number of operational practices that contribute to the control of runoff and the pollutants in runoff, or to the mitigation of the effects of runoff. While the current research study focuses on structural STPs, it is important to recognize that STPs should be selected and applied as an integral part of a stormwater management program that includes such operational practices. Examples of these practices, which are or will be addressed under other VTrans initiatives, include:

- Drain-on control
- Street sweeping
- Sump cleaning
- Pond maintenance
- Other stormwater system maintenance
- Spill prevention
- Illicit discharge prevention
- Vegetation management
- Sand-use reduction
- Salt management
- Other snow management measures

The Treatment Train

Most STPs need to be applied in concert with other practices in order to meet all stormwater management objectives. Often, multi-functional practices can be developed that address more than one criterion by integrating several practices into one facility (e.g., a stormwater management basin can be designed with a low stage infiltration basin and higher stage storage for channel protection and flood control). In other cases, a series of devices may be employed to provide required stormwater functions.

In general, the study team's evaluation of STPs favors practices that lend themselves to integration with other practices to provide this "treatment train" functionality. In addition, some stormwater practices implicitly employ multiple pollutant removal mechanisms, allowing the devices to treat a variety of specific pollutants of concern, or providing internal redundancy that enhances effectiveness. Such technologies are generally preferred over "one-process" technologies.

Finally, with few exceptions (notably, pervious pavement), the effective function of stormwater practices depends on providing pre-treatment of runoff prior to discharge to the practice, to trap debris and coarse sediments that can interfere with the operation of the STP. While some practices are more sensitive to fouling by debris or clogging by sediment than others, the evaluation in this study generally favors those practices that either couple easily with a pretreatment practice or integrate some measure of pretreatment within the practice.

Recommended STPs

Appendix A presents a summary matrix that compares the STPs reviewed under this study. The matrix is essentially a distillation, in tabular format, of the information presented in the fact sheets in Appendix B.

The matrix lists Vermont ANR treatment objectives (water quality, recharge, channel protection, overbank flood protection, and extreme storm protection) and indicates whether each STP is capable of addressing each objective. The matrix also identifies factors affecting the selection of the STP for application on linear transportation facilities, including an expanded listing of the evaluation criteria discussed in Section 3 of this report.

Based on this summary matrix and the descriptions provided in Appendix B, this report offers the following recommendations:

1. The Vermont Stormwater Management Manual already includes bioretention as an accepted practice for addressing water quality treatment criteria and, in suitable soil conditions, recharge criteria specified by ANR. Several STPs were identified early in this study and advanced for further evaluation, which are essentially a sub-set of bioretention – although some of these practices also could be classified as "filtration" and/or "open channel" systems under the categories adopted by ANR. These devices are well-adapted for use on linear projects, should have excellent removal rates for TSS, and offer creditable removal rates for other pollutants of concern (notably phosphorus). The study team therefore recommends VTrans consider advancing the following practices for standard acceptance for its facilities:

    a. Micro-bioretention

    b. Media filter drain (including the embankment media filter variation)

c. Compost amended vegetated filter strip

d. Bioswale.

The study team further notes that the primary performance studies of the media filter drain and compost amended vegetated filter strip were conducted in the Northwest. Some further evaluation of the studies may be warranted to assess whether differences in winter conditions between Vermont and the Northwest require further field testing of these practices for cold weather performance in Vermont.

Investigations by the UNH Stormwater Center and others continue to show that pervious pavement is a viable and effective measure for not only treating stormwater, but minimizing the generation of runoff from paved surfaces. In addition, because it so well drained, pervious pavement is less susceptible to icing under winter conditions than conventional pavement. Its major disadvantage is that because of pavement strength, it is only applicable to low traffic volume, low load applications. Nevertheless, it is a promising technology for use in parking areas and other ancillary facilities where the traffic load allows for its use. The study team recommends further research into the development of materials and installation specifications for its application to VTrans projects. The study team also recommends that VTrans work with ANR toward incorporation of this measure as an accepted practice under Vermont stormwater regulations.

2. The study examined several linear filter practices that appeared to be candidates for VTrans consideration. All of these practices are essentially variations on the use of sand filters for stormwater quality treatment. The following comments apply:

    a. Gutter filters and the OhioDOT "exfiltration trench" offer means to incorporate filtration in the ultra-urban setting. There are some constraints on the application of these devices. The gutter filter may have limited hydraulic capacity to begin with, and because of the lack of pretreatment, may be particularly susceptible to clogging, necessitating frequent maintenance.

       The exfiltration trench depends in part on a porous concrete surface. Porous concrete can be problematic, as it is difficult to control its placement in the field to uniformly achieve desired porosity and structural integrity. Concrete can be subject to degradation by the application of salt, and porous pavement in general cannot be treated with sand for snow and ice management due to the potential for clogging the surface. Some manufacturers now offer precast porous concrete paving panels; this offers a means to address the quality control concerns regarding porosity and structural uniformity. Further investigation of this practice could explore ways to incorporate a pre-cast porous concrete panel into the design. Such investigation could include evaluation of means to address resistance to salt deterioration. Further exploration of this technology could also consider using alternative materials, such as porous asphalt, to comprise the surface of the trench.

Another disadvantage of the exfiltration trench is that servicing the underlying filter media requires removal and subsequent replacement of a paved surface that is an integral part of the filter (see graphic illustration provided in the fact sheet in Appendix B). The use of a pre-manufactured porous concrete panel as described above could address this maintenance concern.

The gutter filter options are recommended to be included in the list of available practices, acknowledging these concerns. The availability of such options provides increased flexibility to designers as they address the challenge of designing stormwater improvements on constrained sites, such as found in highly urbanized areas.

b. This study recommends that Vermont's "micro-pool filter" be advanced as an accepted practice, pending field evaluation of its performance. The practice has multiple functions integrated into the design, including vegetative uptake, a surface layer of soil and sand that resembles bioretention media, and an underlying sand filter. This entire system underlies a series of small settling pools. The elements of design for this practice are similar to technologies already accepted in the Vermont Stormwater Management Manual.

   With careful design, this practice not only would provide water quality treatment, but could also meet Channel Protection requirements. The practice uses small storage pools and can be provided with an integral flow control structure to govern release rates. If these features are designed to provide for the storage and extended detention specified in the Vermont Stormwater Management Manual, then the practice would achieve the Channel Protection objective.

   The "permeable ditch block" being evaluated by Minnesota appears to be essentially the same type of practice. Based on the Minnesota experience, the design of the check dams used in either practice needs to consider the conveyance of overtopping events without breaching or eroding these berms.

3. Continuing research on vegetated buffers shows their effectiveness in providing treatment, enhancing recharge, tempering thermal impacts, and attenuating runoff volumes and peak discharges. Research and regulatory applications reviewed for

this study suggest that treatment rates warrant consideration of vegetated filters for primary treatment practices, not just for pretreatment. In addition, while very steep slopes (greater than 2:1) significantly reduce performance, the use of vegetated filters on slopes exceeding 5% (the threshold in Vermont for "disconnection credit") is warranted. This study recommends expanding the criteria for the use of vegetated buffers to include slopes up to at least 15%, and potentially (based on recent Ohio research on outdoor laboratory simulated slopes) on highway embankments with steeper grades.

4. Recent research is showing that open graded friction course (OGFC), a pervious asphalt pavement surface applied over a dense mix asphalt base, results in significant reduction in pollutant discharges from roadways. Generally, this type of surface is selected for other reasons related to pavement performance: it reduces spray and potential for hydroplaning during rainfall events, and can also help control noise from high-speed roadways.

   Offsetting these advantages, OGFC is not a structural pavement, and is not considered suitable for areas subject to significant acceleration, breaking, and turning movements. This essentially limits its application to limited access roadway travel lanes. Also, pavement maintenance concerns must also be considered: patching would likely require use of dissimilar paving materials. Supplying the material for OGFC requires asphalt mix plants to modify the materials mix from their standard operations, so small batches of material for patching activities would not likely be readily available.

   Sanding cannot be used for snow and ice management. Because of the pore spaces, early or pre-storm treatment with de-icing agents may be required. Further research of the specific materials, installation, and operation requirements for this type of surfacing may be necessary before its widespread application on Vermont highways.

   Given those considerations, this study recommends that where this pavement is selected and installed in accordance with VTrans pavement design procedures, that it also be given credit for its stormwater quality treatment benefits. At a minimum, it should be considered as a pre-treatment measure. However, recent research indicates that pollutant concentrations are significantly lower than runoff from conventional pavement, suggesting that a higher level of treatment credit is warranted for this measure.

5. This study includes the "Forebay with Forced Hydraulic Jump" for VTrans and ANR consideration. This practice has been successfully applied on an urban stormwater system retrofit in Manchester, NH. The practice, in conjunction with a second forebay, resulted in substantial reductions of sediment and associated phosphorus and a marked improvement in the water quality of an urban pond. Further exploration of this practice is recommended for inclusion in the available

techniques for addressing stormwater objectives. The practice has particular applicability, either as a stand-alone retrofit practice or as an advanced form of pretreatment, where the contributing watershed has a known high sediment load.

6. A Quantitative Hydrologic Method to Account for Infiltration and LID Practices

The Vermont Stormwater Management Manual describes a number of non-structural practices for managing stormwater, including conservation, rooftop disconnection, non-rooftop disconnection, stream buffers, grass channels, and environmentally sensitive rural development. These practices can reduce the volumes of water requiring treatment and recharge. Implementing these practices can also reduce the volumes requiring management to meet channel protection and flood protection standards. Where these practices result in dispersed infiltration of runoff, the volume reduction benefits may not be fully accounted by conventional hydrologic modeling methods. This Section of the report presents a methodology for quantitatively accounting for dispersed infiltration in the sizing of stormwater peak rate control practices.

Early in this research project, the Steering Committee noted a concern with the sizing of stormwater management practices to achieve compliance with ANR Channel Protection Criteria. Meeting this criteria using detention storage requires sizeable facilities, presenting a significant challenge within the space constraints associated with linear transportation systems.

While the ANR Stormwater Manual, Volume 1, allows credits when Low Impact Development Practices are used, these credits primarily focus on the reduction of stormwater treatment volumes (Water Quality Volume and Recharge Volume) required under current regulatory standards. The credits are only applied to the sizing of "event storm" control facilities to the extent that they reduce impervious surface area. The current system of credits does not specifically provide for hydrologic adjustments for these practices (except for actual reduction in impervious area) for stormwater system design to meet Channel, Overbank Flood, and Extreme Storm Protection objectives.

Implementing infiltration practices, including LID measures, will reduce the volume of stormwater runoff requiring management to meet channel protection and flood protection standards. The hydrologic/hydraulic benefits of some practices (such as infiltration trenches, infiltration basins, and other discrete stormwater infiltration devices) may be specifically modeled using readily available software and modeling methods. However, other practices that provide direct infiltration can be more difficult to model. Also, multiple practices dispersed throughout a site may be impractical to model. Thus, it would be helpful to have a method that would account for the benefits of practices such as roof and pavement disconnection, shallow depression storage, and other forms of dispersed infiltration, in the sizing of structures designed to provide channel protection and flood control.

Accounting for Runoff Captured by Infiltration Practices

Three alternatives for accounting for infiltration practices in the hydrologic analysis of storm events are recommended, depending on the type of infiltration practice and the complexity of the project. The first alternative involves the detailed hydrologic/hydraulic modeling of every infiltration practice. The second alternative involves the use of the TR-55 method for accounting for impervious area disconnection in the development of the Runoff Curve Number (RCN) for a watershed under analysis.

The third alternative, the Modified Runoff Curve Number method, uses an adjusted runoff curve number (or RCN*) that accounts for the overall reduction in runoff volume achieved by the use of infiltration practices distributed over a site. This RCN* can then be employed in TR-55 or TR-20 based hydrologic models to develop designs for stormwater detention practices to meet Vermont ANR requirements for Channel, Overbank, and Flood Protection. This method is presented in detail in this report.

The three alternatives are further discussed below.

Alternative 1: Conventional Hydrologic Routing Methods

This alternative accounts for infiltration measures throughout the site by detailed hydrologic routing through every device. It uses conventional methods to estimate Runoff Curve Numbers and perform hydrologic modeling using widely accepted hydrologic modeling techniques. It is most practical if there are a limited number of control devices and if stage/storage and stage/discharge relationships can be readily derived for each device. The discharge parameters should include appropriate components for exfiltration from each device.

In this case, no modification of Runoff Curve Number should be applied.

Alternative 2: TR-55 Adjusted Runoff Curve Number for Disconnection

This method accounts for dispersed infiltration practices by adjusting the Runoff Curve Number for impervious surface disconnection according to TR-55 methodology. Chapter 2 of TR-55 describes a method for estimating a Runoff Curve Number (RCN) to account for disconnected impervious surfaces. Under this alternative, designers may use Figure 2-4 of the TR-55 documentation to develop Runoff Curve Numbers that reflect dispersed infiltration practices (including rooftop disconnection, non-rooftop disconnection, and flow through riparian buffers). However, this method has limitations:

- It only applies when total impervious cover is less than 30% of the contributing area.
- This method would likely underestimate the performance of devices such as small infiltration trenches, porous pavement surfaces, bioretention areas, and other methods of dispersed infiltration, where small volumes of temporary storage enhance the ability of native soils to infiltrate captured runoff.

- It is not fully consistent with the ANR credits for disconnection or for sheet flow through riparian buffers, which presume that these measures fully infiltrate the recharge volume.

If this alternative is used, it can be used in conjunction with the analysis of discrete basins as in Alternative 1. Using both alternatives accounts for the effects of infiltration from dispersed practices such as disconnection and from direct infiltration through an STP. For example, the flows to a detention/infiltration basin can be computed using the "disconnected" RCN, then those flows can be routed through storage using a hydrologic model of the pond that accounts for exfiltration through the pond bottom.

Alternative 3: Modified Runoff Curve Number Method.

This method involves the development of an adjusted Runoff Curve Number (RCN*) that directly accounts for the runoff volume reduction that results from infiltration. The adjusted RCN* can then be used to size "event storm" control devices using conventional hydrologic modeling techniques. This method is described in detail below.

The Modified Runoff Curve Number Method

Initial research for this study identified reference documents that provide guidance for other methods that account for sizing of STPs for measures that do not reduce total impervious cover, but that account for reductions in "effective impervious cover" through practices such as infiltration.[3] The study team conducted further review of these documents and material referenced by them, and recommended a methodology adapted from McCuen's "Change in Curve Number Method[4]" that can be used for the following:

1. Accounting for Runoff Captured by Infiltration Practices – The method can be applied to account for the hydrologic effects of infiltration practices, where the total volume of runoff intercepted by these practices has been determined by design. The method includes an alternative for using modified Runoff Curve Numbers (RCNs) in TR-55 and TR-20 based models, to account for LID practices in the estimation of peak discharge rates, for sizing of stormwater practices for channel protection and flood control.

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[3] Examples include the US EPA's *Stormwater TMDL Implementation Support Manual* (ENSR Corp., 2006) and the Maryland Department of Environment (MDE) 2009 update of its *2000 Maryland Stormwater Design Manual* (Center for Watershed Protection, 2009). CEI's further evaluation of these materials led us to focus on the MDE 2009 methodology and its primary references describing the "Change in Curve Number Method."

[4] The primary reference for this method is "Modeling Infiltration Practices Using the TR-20 Hydrologic Program" (MDE, 1983). Also, see Appendix B – ESD Computational Methods in the Queen Anne's County *Environmental Site Design Manual* (Queen Anne's County, 2007). This method is the basis for the Runoff Curve Number modification procedure outlined in the 2009 update of the *Maryland Stormwater Design Manual*.

2. Estimating Infiltration Volume to Control Peak Discharge – The method may be used to estimate the total amount of infiltration volume (in watershed inches) required to be captured by BMPs/STPs, where it is desired to meet a specific peak discharge rate. The method uses TR-55 methodology to account for changes in initial abstraction, time of concentration, and runoff curve number to develop a target storage volume for recharge practices that may be dispersed through a site.

Accounting for Runoff Captured by Infiltration Practices

This method consists of the following procedure:

1. For the design rainfall of interest (P, inches), estimate the post-development runoff depth (Q_a, inches) corresponding to the conventionally determined RCN for the contributing area.

2. Estimate the volume of runoff (V, cubic feet) captured and infiltrated by the proposed practices (see discussion under "Volume Credits" below). Convert this volume to runoff depth (ΔQ) based on watershed area (A, acres):

$$\Delta Q = \frac{V * (12\ \text{in/ft})}{A * (43560\ \text{ft}^2/\text{acre})}$$

3. Deduct this runoff depth (ΔQ) from Q_a to obtain an estimate of the runoff depth from the modified site:

$$Q_m = Q_a - \Delta Q$$

4. Compute a modified RCN* that represents the theoretical land cover that would yield the modified runoff depth for the design rainfall (note that RCN* will differ for each rainfall event):

$$RCN^* = \frac{200}{(P+2Q_m+2) - \sqrt{(5PQ_m+4Q_m^2)}}$$

5. Use this modified RCN* and the post-development time of concentration (T_c) as the basis for hydrologic modeling to size conveyance facilities and to design STPs for peak rate control to meet the ANR requirements for Channel, Overbank, and Flood Protection. As noted above, a different RCN* will be required for each rainfall depth analyzed.

Volume Credits for the Modified Runoff Curve Number Method

Table 3-1 presents the basis for estimating infiltration volumes associated with various STPs. All volumes computed following these guidelines should be converted to cubic feet for use in the equations described above. Practices should be designed to meet applicable VTrans and ANR requirements.

Table 3-1 – Design Infiltration Volumes for Selected BMPs/STPs[5]

BMP/STP	Design Infiltration Volume	Remarks
Rooftop disconnection	Re_v Area of roof times recharge factor for applicable HSG[6]	ANR qualifications for disconnection apply
Non-rooftop disconnection	Re_v Area of disconnected impervious surface times recharge factor for applicable HSG	ANR qualifications for disconnection apply
Area discharged to riparian buffer	Re_v Area of disconnected impervious surface times recharge factor for applicable HSG	ANR qualifications for riparian buffer credit apply
Minor depression storage	Volume of the depression	Verify that depression will naturally drain by infiltration within 48 hours
Porous pavement	Volume of storage in pavement filter and reservoir courses	Applicable to pavement surfaces with a minimum infiltration rate of 8 inches per hour
Bioretention areas	Volume of storage in shallow depression, plus volume of void spaces in bioretention media	Applies only to infiltrating bio-retention areas. RCN modification not applicable to under-drained bioretention
Infiltration Berms (or other berms for shallow stormwater retention)	Volume of storage up-gradient of the berm[7]	Verify that temporary inundation will naturally drain by infiltration within 48 hours

[5] Note that for the analysis of any particular storm event P, the design volume of the practice (V) for computing modified RCN* cannot exceed the volume of runoff generated by that storm event. For pervious pavement, this will be equal to P times the area of the pavement, plus any "run-on" (if permitted). For depression storage and bioretention areas, this will be the volume of runoff for rainfall depth P estimated by the runoff curve number method for the contributing area to the device.

[6] HSG = Hydrologic Soil Group.

[7] In developing final design guidance, VTrans may want to consider applying a safety factor to the up-gradient volume of storage, to account for the loss of some storage due to seepage through the berms. Alternatively, the guidance could consider limiting storage credit to the required Re_v.

Estimating Infiltration Volume to Control Peak Discharge

The McCuen method provides for a procedure to estimate the total volume of runoff to be captured and infiltrated on a site to meet a target peak discharge rate from the contributing watershed. The method uses basic TR-55 computational methods.

An example of where such a method could be applied would include the selection and sizing of LID practices (including dispersed measures as well as infiltration basins and similar BMPs/STPs) so that post-development peak rates are equal to or less than existing-condition peak rates (for instance, to meet overbank flood or extreme storm protection criteria).[8]

The procedure is as follows:

1. Determine hydrologic parameters for the base condition (e.g., existing conditions) as applicable to the analysis. These include Area, Soil Hydrologic Groups, Land Use Cover and corresponding Runoff Curve Number, and Time of Concentration.

2. Determine the corresponding post development hydrologic parameters.

3. Compute the estimated Runoff Volume: Q_b (in inches) for "before development" and Q_a (in inches) for "after development" without adjustment for infiltration storage.

4. Compute the corresponding Unit Peak Discharges, q_{ub} and q_{ua} (in units of cubic feet per second per square mile) from Exhibit 4-II of TR-55 (Reprinted as Figure 1.4 in Volume 1 of the Vermont Stormwater Handbook). To estimate the unit peak discharge rates, the analyst will need to determine initial abstraction from TR-55 Table 4.1.

5. Estimate the required infiltration storage (ΔQ) to achieve the desired pre-development peak rate. This is explained as follows:

   Pre-development peak flow = $q_b = (q_{ub})(A)(Q_b)$

   where : q_b is the discharge in cubic feet per second, and
   A is the contributing area in square miles

   Post-development peak flow (without control) = $q_a = (q_{ua})(A)(Q_a)$

   Post-development peak flow (controlled) = $q_a^* = (q_{ua})(A)(Q_a - \Delta Q)$

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[8] Care would be required to use this approach for meeting ANR Channel Protection Criteria, because of the requirement not only to control the rate, but also the duration of the discharge.

The procedure solves for ΔQ, such that q_a*$= q_b$, that is:

$$(q_{ua})(A)(Q_a - \Delta Q) = (q_{ub})(A)(Q_b)$$, or solving for ΔQ:

$$\Delta Q = Q_a - (q_{ub}/q_{ua})(Q_b)$$

6. The value of ΔQ (required infiltration storage) from this procedure will be in units of "inches." If the volume needs to be expressed in units of cubic feet for sizing recharge practices, use the following equation:

   $$V = \Delta Q(A)(43560)/12$$

   where A is the drainage or watershed area in acres.

Note that the volume determined by the above procedure not only accounts for the increase in volume of runoff from impervious surfaces, but also for the influence of the developed surfaces on Initial Abstraction and Time of Concentration.

The volumes of various practices should be determined using the guidelines provided in Table 3-1.

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Appendix A
STP Comparison Matrix

VTrans Stormwater Practices Research Study
Linear Transporation System STP Applicability Matrix

BMP/STP Category and Practice	ANR Criteria							Transportation Infrastructure Criteria																				Notes
															Pavement Integrity Considerations					Regional climate suitability				Operational/safety considerations				
	Water Quality	Recharge	Channel Protection	Overbank Flood	Extreme Storm	Potential Runoff Reduction	Potential ANR Acceptance	Installation cost	O&M Cost	Rural roadway applicability	Ultra-urban applicability	Bicycle and pedestrian path applicability	Parking area applicability	"Hot spot" applicability*	High vehicle loads or high traffic volumes restrict use	BMP discharges water into pavement structure	BMP requires major structure beneath travelled way	Special pavement maintenance practices required for pavement	BMP may affect pavement life expectancy	Freezing temperature adversely affects performance	BMP affects snow and ice management practices	Practice affected by formation of sand/debris berm	Peformance may be adversely affected by changing climate	Inspection requires special procedures or equipment	Inspection requires interruption of traffic	Maintenance requires special equipment	Maintenenance requires interruption of traffic	
Infiltration Practices																												
Pervious Pavement - Infiltrating (See Filtering Practices)	See Filtering Practices for Details																											
Infiltration Berms	x	x	•			H	H	L	L	x		x	x		No	No	No	No	No	No	No	Yes	No	No	No	No	No	
Filtering Practices																												
Bioretention																												
Micro-bioretention	x	•	•			M	H	L	L-M	x	x	x	x	•	No	P	No	No	No	No	No	Yes	P	No	No	No	No	aka Rain Garden
Media Filter Drain	x	•	•			M	H	L-M	M	x		x	x	•	No	P	No	No	No	U	No	Yes	P	No	No	P	No	aka Ecology Embankment, Bioslope
Embankment media filter (CEI)	x	•	•			L-M	M	M-H	M	x		x	x	•	No	P	No	No	No	U	No	Yes	P	No	No	No	No	Concept: no pilot installations to date
Compost Amended Vegetated Filter Strip	x					M	H	L	L	x		x	x	•	No	No	No	No	No	U	No	Yes	P	No	No	P	No	Literature notes runoff volume reduction (retention & infiltration)
Bioswale (see Open Channels)	See Open Channel Practices for Details																											
Pervious Pavement Systems																												
Pervious Pavement Systems (Infitrating)	x	x	•	•	•	H	H	M-H	M		•	x	x		Yes	Yes	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Very high runoff reduction benefit
Pervious Pavement Systems (Underdrained)	x					L-M	H	M-H	M		•	x	x	•	Yes	Yes	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	
Micro-filters																												
Conventional Gutter Filter	x					L	M	M-H	H		x			x	No	No	No	No	No	P	No	Yes	No	Yes	Yes	Yes	Yes	
Porous paved gutter filter (Ohio "Exfiltration Trench")	x	•	•			L-M	M	M-H	H		x				No	P	No	No	No	P	Yes	Yes	No	Yes	Yes	Yes	Yes	
Permeable Ditch Block (Minnesota DOT)	x	•	•			L-M	H	L-M	L-M	x					No	No	No	No	No	P	No	P	P	No	No	No	No	Pilot installation showed stability issues under high flows
Vermont micro-pool filter	x	•	•			L-M	H	L-M	L-M	x					No	No	No	No	No	P	No	P	P	No	No	No	No	Note maximum pond depth for safety requirements
Open Channels																												
Bioswale	x	•	•			L-M	H	L	L	x	x	x	x	•	No	P	No	No	No	No	No	Yes	P	No	No	No	No	swale with bioretention function
Non Structural Practices (See Note)																												
Vegetated buffers																												
Natural vegetated buffer	x	x	•			M	H	L	L	x		x	x	•	No	No	No	No	No	No	No	Yes	P	No	No	No	No	Recommend additional treatment credit for "filter strips" and other
Landscaped buffer	x	x	•			M	H	M	M	x		x	x	•	No	No	No	No	No	No	No	Yes	P	No	No	No	No	buffers, with qualifying slopes as high as 2:1
Other Practices																												
Open Graded Friction Course	x					L	H	M	M	x	x				No	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Pretreatment or retrofit
Forebay with Forced Hydraulic Jump	x					L	M	M	M	x	x	x	x	x	No	No	No	No	No	No	No	No	No	No	No	P	No	Pretreatment (advanced removal) or retrofit

x Applicable
• May be applicable with careful design
Not applicable

Note: all ratings preliminary, subject to modification by VTrans as guidance is developed
*Hot spots include rest areas and maintenance facilities (except for normal parking areas); known areas with prior contamination

L low
M medium
H high

P= potential
U= unknown

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Appendix B
BMP/STP Descriptions

Infiltration Practices:
Infiltration Berms

Description

An infiltration berm is an earthen dike (linear mound of earth) composed of soil and stone that is placed along the contour of a relatively gentle slope, to intercept and filter stormwater and enhance infiltration. The berm itself provides filtration of the stormwater, and helps promote sheet flow for the runoff passing through the berm. It also retards flow, providing an opportunity for infiltration into the native soil material.

This practice is constructed by placing a pervious fill material to create the berm that impedes the flow of stormwater, temporarily storing it upslope of the berm. Stormwater runoff impounded by the berm infiltrates the ground, with the excess filtering through the berm, exiting at the downhill side as sheet flow. Infiltration berms should be used in conjunction with practices that require sheet flow (e.g., sheet flow to buffers) or in a series on steeper slopes to prevent flow concentration. Pervious material is recommended for the berm to minimize overtopping and potential breaching of the berm.

Infiltration berms may be used on gently sloping areas in residential, commercial, open space, or wooded land areas. They must be installed along the contour in order to perform effectively. The purpose of this practice is to augment natural stormwater drainage functions in the landscape by promoting sheet flow and dissipating runoff velocities.

Stormwater Management Processes

The infiltration berm treats stormwater through the processes of filtration, physical settling, and infiltration:

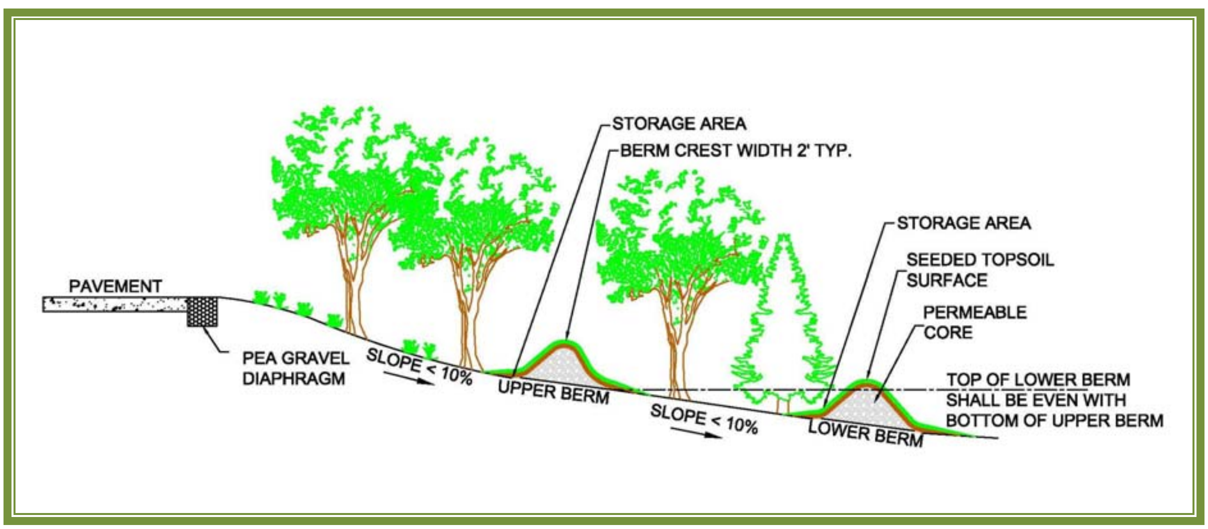
- The berm itself filters stormwater runoff passing through the soil/stone mix within the berm.
- The retention and temporary micro-ponding of stormwater runoff by the berm provides an opportunity for physical settling of particulates.
- Infiltration promoted by micro-ponding and discharge as sheet flow removes pollutants through the natural filtration, chemical bonding, and biological activity occurring within the native soil material.

This practice contributes to overall reduction of runoff by promoting infiltration. As this practice can also be used without significant clearing or land disturbance, it minimizes the loss of natural vegetative cover, retaining the natural system’s capacity to provide interception and evapotranspiration.

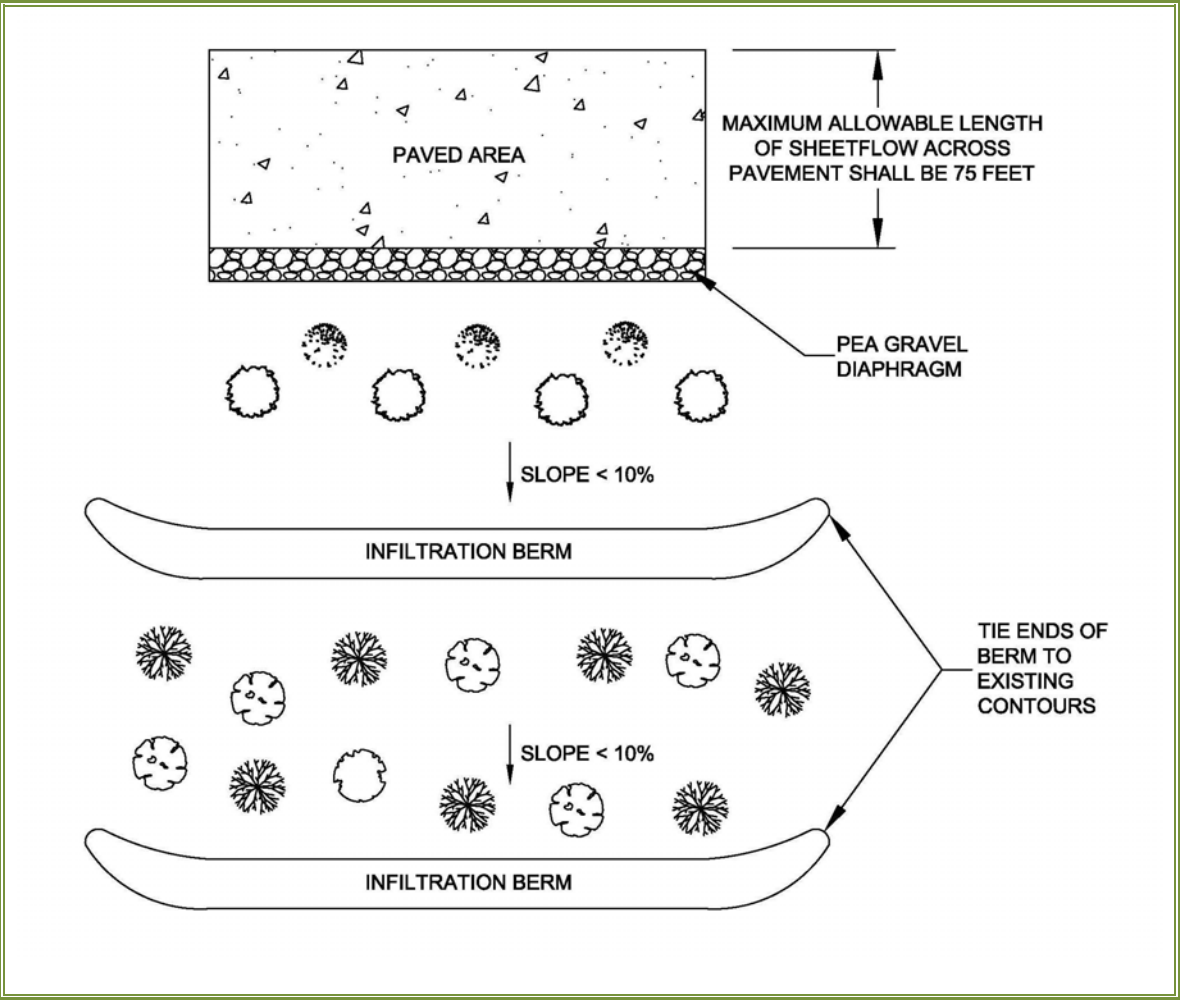
Advantages and Disadvantages

Advantages:	**Disadvantages:**
Capitalizes on the multiple pollutant removal mechanisms associated with natural soils and vegetation Relatively low cost to install and maintain, consistent with routine roadway landscaping practice Effective wherever runoff can be directed into the practice as sheet flow, either directly from roadway shoulder or through a level spreader Particularly suited to rural and limited access roadways May be used on some slopes that are too steep for simple vegetated buffer practices	Cannot be used where sheet flow cannot be maintained Relatively limited storage capacity Not appropriate for treating runoff generated from “hot spots” Limited applicability in urban and ultra-urban areas where development has displaced natural buffer areas Requires permanent control of the area used for micro-ponding of stormwater, which may extend outside right-of-way Siting restricted to slopes no greater than 10%

Illustrations



Cross section of a series of infiltration berms (adapted from CWP, 2009)



Infiltration berm plan view (CWP, 2009)

Target Pollutants and Treatment Effectiveness

A review of current literature did not identify pollutant removal performance data specific to this practice. However, the following considerations are offered:

- In moderately well to excessively well-drained soils (Hydrologic Soil Groups B and A) with at least three feet of clearance to groundwater, we anticipate infiltration into the underlying soils will contribute significantly to treatment, with performance characteristics similar to other infiltration practices.

- In finer textured soils, overland flow will be subject to filtration by vegetation as well as through the earthen berm. Essentially, the system combines aspects of extended detention (settling in the shallow impoundments), vegetated filter strips, and filtration through soils media.

Selection and Design Considerations

Siting and Design Considerations:

- Infiltration berms are suitable for construction in series along a slope.

- If installed with care, the low profile of the berm would even allow placement within wooded areas with a minimum of disturbance, so that the tree canopy is preserved.

- Topography may be a limiting factor:

    - Limited to slopes less than 10%.

    - Sufficient length of slope away from edge of pavement must be available. Separation between berms is governed by berm height and land slope (see below). CEI recommends maximum flow path between berms of 100 feet, to maintain sheet flow and prevent channelization.

    - The practice cannot typically be applied to roadways in “cut” sections (roadways lower than adjacent grades).

    - Topography must be generally conducive to sheet flow.

- Maximum ratio of impervious area to infiltration area: 5:1.
  (Drainage area should be small enough to prevent flow concentration upslope of the berm).

- Maintain a minimum three-foot separation to estimated seasonal high groundwater (ESHGW) table.

- Maximum berm height: 24 inches.
  (Berms should pass flows from design storms greater than the 2-year, 24 hour event. It may be necessary to consider incorporating drainage structures/piping or spillway-type structures to allow bypassing design storms exceeding berm storage capacity, in order to protect the stability of the berm.)

- Maximum embankment slope for berms that will be mowed: 4:1.

- The berm shall be graded with a concave shape at the upgradient toe.

- Berm material typically consists of a six inch-layer of high quality topsoil overlaying a gravel or aggregate core.

- Subsurface soils must not be compacted and may be scarified to encourage infiltration.

- Provide native meadow vegetation and shrubs in planting the berms. Turf grass may be used on berms that will be mowed.

For more detailed siting and design guidance, see citations below for CWP, 2009 and Cahill Associates Inc., 2005.

Consistency with Roadway Design Integrity

Infiltration berms are used in vegetated buffers adjacent to the roadway, in locations that must be down-gradient from the road.

- They would not affect pavement structural integrity, as long as the berms are located a sufficient distance downslope so they do not impound water higher than the bottom of pavement sub-base materials.

- On limited access roadways, the upper-most berm would need to be located outside any unpaved slope designated as driver recovery area.

- Other than measures to maintain sheet flow at the road shoulder, this practice requires no special pavement maintenance practices.

Cost Effectiveness

Infiltration berms do not require extensive clearing or grubbing, which factors into a lower cost relative to other BMPs.

However, depending on width of area required to attain treatment objectives, additional right-of-way or easement area may be required to maintain long-term control over the area used for this practice, affecting project cost.

Suitability for Cold Climate

The colder temperatures common to Vermont do not adversely affect the performance of infiltration berms, as the physical detention process can occur with frozen soils. Because infiltration berms are sited away from paved surfaces, they do not affect snow and ice management practices. The formation of a sand/debris berm along the pavement during colder seasons, however, may interfere with sheet flow to the infiltration berms. This condition may be addressed by appropriate maintenance.

Adaptability for Changing Climate

Changes in climate patterns are not likely to change the physical detention and infiltration encouraged by the installation of infiltration berms along a slope. While sensitive vegetation may be affected by climate changes, planting a diversity of species varying in climate sensitivity can create a more robust set of plantings. As sensitive vegetation dies off with changes in climate, more robust species may take over to maintain dense vegetation. In the event that vegetation is entirely affected by the climate, removal and replanting is required.

Potential for ANR Acceptance

The literature researched for this study identified no performance studies specific to this practice which would meet ANR criteria for alternative technologies. However, infiltration berms make use of processes common to STP technologies already accepted by ANR. Infiltration berms make use of similar principles as the infiltration basin, applied at a smaller scale to create micro-ponding rather than ponding in a basin. Therefore, this practice appears to have high potential for ANR acceptance.

Operation and Maintenance Considerations

Operation and maintenance practices for infiltration berms largely fall within typical highway practices. Generally, routine highway landscape practices should be followed.

Regular inspections of infiltration berms should monitor for:

- consistent vegetative cover,
- stability of the berms,
- evidence of erosion or channelized flow, and
- drawdown time of the micropools behind each berm.

In addition to regular inspections, maintenance practices for infiltration berms include:

- periodic control of invasive species,
- clearing trash and debris, and
- mowing.

If evidence of erosion or channelized flow is discovered upon inspection of the infiltration berms, prompt repair to restore stability and sheet flow is required.

Infiltration berms pose little effect on the highway operation or safety. Inspection and maintenance can be achieved with conventional highway equipment and requires no significant interruption of traffic. The berms are readily accessible for inspection.

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Performance Studies

[None identified]

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Infiltration Practices:
Pervious Pavement Systems

Description

Pervious pavement consists of a porous surface, base, and sub-base materials which allow penetration of runoff through the surface into underlying soils. The surface materials for pervious pavement may consist of porous asphalt, porous concrete, permeable paving block systems, or cellular grids. These materials are installed on an engineered base which serves as a filter course between the pavement surface and the underlying sub-base material. The sub-base material typically comprises a layer of crushed stone that not only supports the overlying pavement structure, but also serves as a reservoir to store runoff that penetrates the pavement surface until it can percolate into the ground. An advantage to the use of pervious pavement is the reduced need for stormwater conveyance systems and other additional BMPs.

Where subsurface conditions are not suitable for infiltration, the reservoir course may be provided with an underdrain, to collect runoff and convey it to a suitable discharge point.

Although traffic loading capacities vary, permeable pavement alternatives are generally appropriate for low traffic areas (e.g. sidewalks, parking lots, overflow parking, residential roads). Pavement type and thickness are selected based on anticipated vehicle load and maintenance requirements.

Frequently, pervious pavements filter only the runoff generated on the pavement surface itself. However, runoff from other areas can be directed to pervious pavement if properly designed. Runoff generated from adjacent areas of the site may require pretreatment prior to discharge to the pavement surface, to prevent clogging of the pavement structure and (where the pavement is used to infiltrate as well as filter the runoff) the underlying soils.

Porous Asphalt

Porous asphalt is very similar to conventional asphalt except that it is mixed without particles smaller than coarse sand (less than 600 µm or No. 30 sieve). Without these smaller size particles, water is able to pass through the asphalt and into a crushed stone storage area. The lack of fine particles in the asphalt, however, limits the loading capacity of the asphalt relative to conventional asphalt. Because of this limitation, porous asphalt should not be used in high-traffic areas or areas subject to maneuvering of heavy vehicles, unless designed for use as a non-infiltrating open graded friction course (see Limited Applicability Practices, Open Graded Friction Course for more information).

Porous Concrete

Porous concrete mixtures contain little to no sand, which creates void space amongst aggregate particles for stormwater infiltration. This void space will account for 15% to 25% of the hardened concrete volume. As with porous asphalt, care must be taken in its application; the low mortar content and high porosity reduces the strength of the porous concrete relative to its conventional counterpart. Typically, the layer of porous concrete is constructed over a base filter course and sub-base reservoir, similar to that of porous asphalt.

Permeable Pavers

Permeable paving block systems use pre-cast concrete pavers instead of porous asphalt or concrete for the pavement surface. The pavers are generally designed to maintain slightly wider joints between the units than found in more conventional landscape-paver installations. The paver units are set on a specially-graded, highly permeable setting bed, and the joints are filled with similar free-draining material. The permeability of these systems is due to the void spaces maintained in these joints, so it is essential that design and construction practices provide for the appropriate joint and setting bed materials. The base filter course and the sub-base reservoir course are similar to that provided for porous asphalt.

Cellular Grids with Free-Draining Aggregate

Cellular grids may also be used to create a pervious pavement surface. These cellular systems typically consist of open-celled concrete units or fabricated synthetic grids. For a fully permeable surface, the grids are installed on a free-draining leveling course and the open cells are backfilled with a free-draining aggregate. Cellular grids with free-draining aggregate are essentially equivalent in treatment performance to pervious pavement.

Vegetated Cellular Grids (Reinforced Grass Paving)

Cellular grids may be installed with a permeable sandy soil mix placed in the openings, with grass planted in this media. This type of installation is sometimes referred to as Reinforced Grass Paving. This vegetated cellular system may not be as permeable as the above alternatives, because of the finer soil materials planting media.

Stormwater Processes

- Reduces volume and peak discharge rates of stormwater runoff through infiltration.
- Increases recharge and reduces pollutant transport over paved surfaces through direct infiltration.
- Pollutant treatment via physical filtration through filter course and other components of pavement system.
- A reservoir course in the permeable pavement storage bed provides storage for infiltrated water and creates a barrier to capillary action associated with winter frost formation.

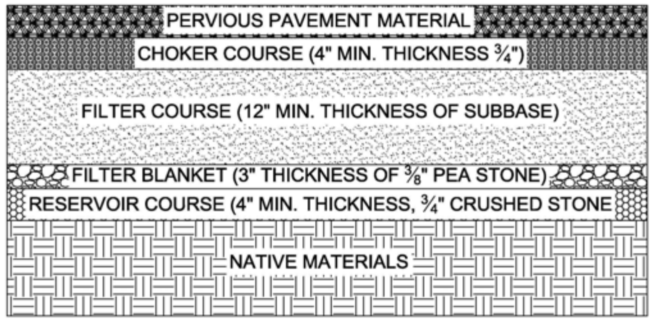
Where this practice can be applied over subgrade soils suitable for infiltration, it is highly effective for achieving an overall reduction of runoff. Underdrained pervious pavements can also help reduce peak discharges through temporary detention of runoff within the pavement structure.

Advantages & Disadvantages

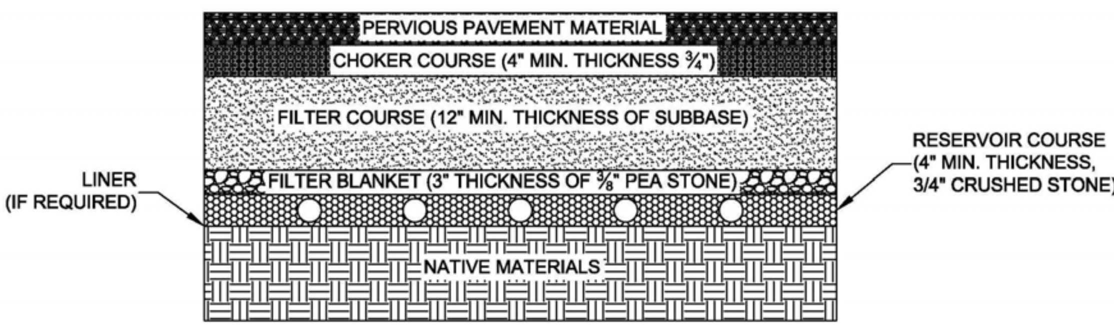
Advantages:	**Disadvantages:**
Where infiltration beneath the pavement is feasible, the high pollutant removals and runoff volume reduction can result in significant savings in the cost of conventional stormwater conveyance and treatment practices Cold weather performance can reduce surface icing, with associated savings in snow and ice management activities Longevity (including in cold climates) if properly designed, installed and maintained[1] Unit paving systems and grassed pavers offer site landscaping aesthetic opportunities Available as a retrofit when parking lots are replaced, although this requires full-depth reconstruction	Applicable only in areas with low traffic loading and low traffic volume, because of limited pavement system strength Frequent maintenance with special equipment (vacuum or regenerative air sweepers) is required to control clogging Winter sanding is not allowed Costs for full depth of this pavement system are significantly higher than conventional pavement (although this may be offset by savings in other stormwater infrastructure)

[1] "Adverse freeze-thaw effects such as heaving, etc. were not observed and for that reason the lifespan is expected to exceed that of typical pavement applications in northern climates." (Roseen et al., UNHSC, 2009)

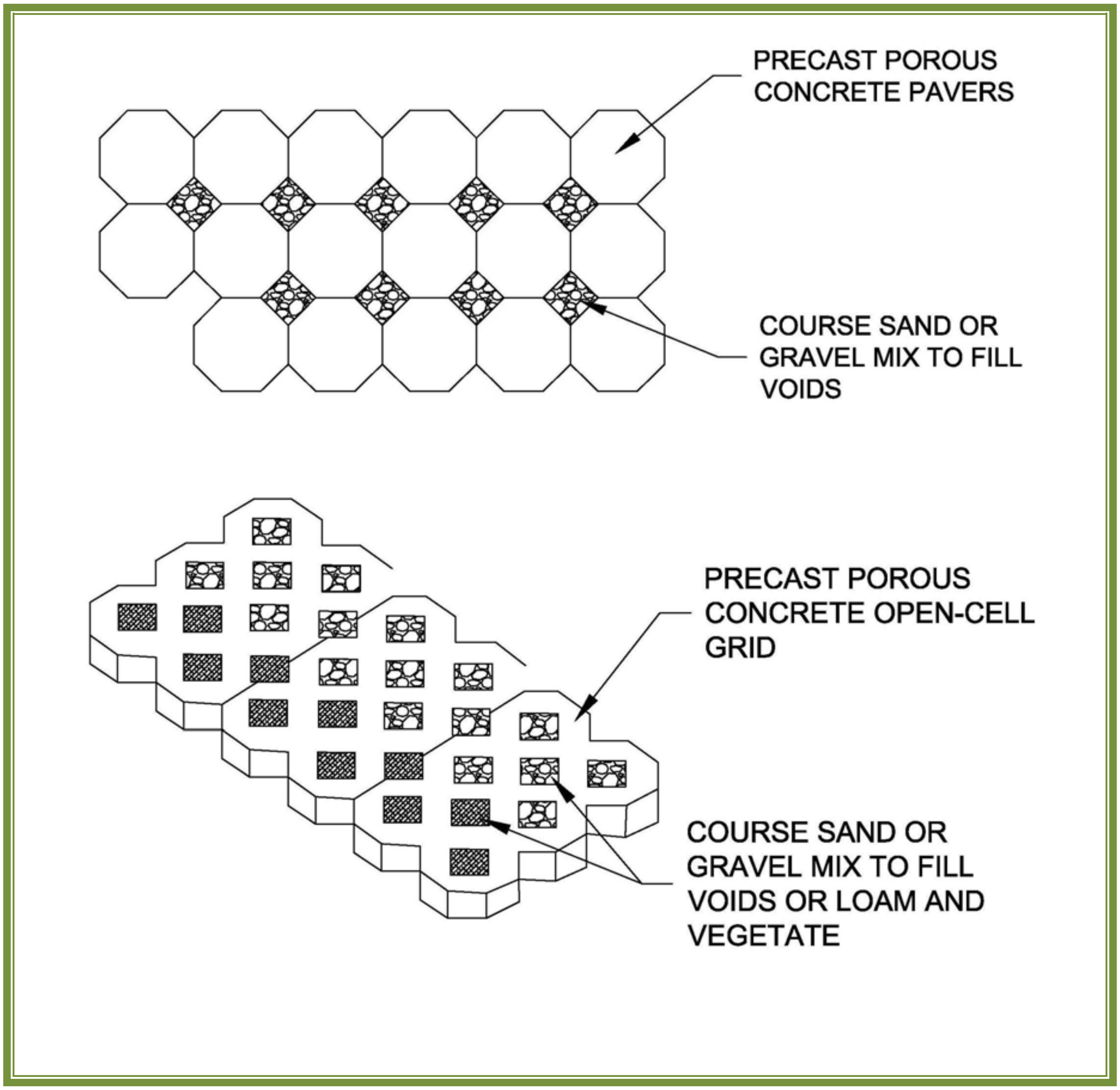
Illustrations



Typical section of pervious pavement (porous asphalt or concrete) with direct infiltration (adapted from the University of New Hampshire Stormwater Center)



Typical section of pervious pavement (porous asphalt or concrete), underdrained (adapted from the University of New Hampshire Stormwater Center)



Examples of Precast Concrete Pavers and Cellular Grids Used for Pervious Paving Systems

Target Pollutants and Treatment Effectiveness

Metals	**UNHSC, 2009**	**Wright Water Engineers & Geosyntec Consultants, 2011**[2]	**Geosyntec Consultants & Wright Water Engineers, 2010**[2]	**Geosyntec Consultants & Wright Water Engineers, 2011**[2]	**Cahill et al., 2005**[2]
Total Copper		22%			42%
Total Lead		58%			74%
Total Nickel		36%			
Total Zinc	75%	71%			81%
Total Phosphorus	60%		17%		66%
TSS	99%			36%	91%

It appears from the University of New Hampshire references that the analyses of pollutant removals for pervious pavement are based on Event Mean Concentrations of influent and effluent, with effluent samples taken from the reservoir course or underdrain. Thus, the removal rates apply to pervious pavement systems with or without under-drains. Also, if a pavement system does drain by infiltration into underlying soils, then removal performance is likely much higher than indicated in the tables above, as the underlying soils provide treatment. It therefore appears that pervious pavement systems are extremely effective, stand-alone treatment systems.

Selection and Design Considerations

Considerations for selecting and designing this stormwater treatment practice can be found below:

Siting and Design Considerations

- Appropriate only for low-volume, low-speed traffic areas such as minor roadways, parking areas, driveways, and pedestrian paths. Load-bearing capacity is lower for pervious pavement than conventional pavement.

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[2] Averages results from several case studies.

- Frequently designed to only receive runoff from the pavement surface itself, not from watershed areas extending outside of the installed pervious pavement. However, careful consideration of pretreatment and design of capacity in the pavement reservoir course may allow for the treatment of some "run-on" using pervious paving.

- Maximum slope: 5%.

- Minimum vertical separation to ESHGW and bedrock for pervious pavement with direct infiltration: 3 feet.

  Minimum separation for under-drained pavement: ESHGW and bedrock must be below bottom of reservoir course.

- No additional land area requirements; particularly appropriate for ultra-urban areas.

- May be installed in cold climates if design includes features to address frost conditions.

- Not appropriate for areas with higher potential pollutant loads, as stormwater cannot be pretreated prior to infiltration.

- Underlying soils must have a permeability of at least 0.17 inches per hour.

- Void space in pervious asphalt pavement: 10% - 25%
  (achieve by mixing asphalt with very low content of fine sand).

- Minimum void space in open-graded subbase: 40%.

- For further design guidance, please refer to UNHSC, 2009.

Consistency with Roadway Design Integrity

Because of its strength characteristics, pervious pavement is not applicable for roadways with high traffic volumes or high vehicle loads. However, it is suitable for parking areas, low volume roadways, emergency access drives, bike and pedestrian access-ways, and other low-intensity traffic areas.

Special pavement management practices are required to maintain pervious pavement. Sand cannot be used for snow and ice management. On the other hand, studies by UNH and others indicate that ice formation is less problematic on pervious paving than on conventional pavement surfaces. Use of salt for winter ice management on porous concrete surfaces would be expected to result in accelerated deterioration of the surface.

Periodic cleaning of the pavement surface using vacuum or regenerative air cleaning equipment is required to maintain the surface, and prevent deterioration of infiltration rate by accumulation of fines in the surface pore spaces.

Research by UNHSC has shown that the pavement substructure for pervious paving prevents adverse affects of frost heaving, resulting in an expectation that the life span of this type of pavement would be enhanced, relative to conventional pavements.

Cost Effectiveness

The UNH Stormwater Center found the cost of pervious pavement in a parking lot application to be 30% more than the cost of conventional pavement (Briggs, 2006). The range of costs can vary considerably for pervious pavement, however. The City of Chicago (2003) found that installation costs can be up to 2-3 times greater for pervious pavement systems than conventional concrete or asphalt. The higher installation costs for permeable pavement may be counterbalanced by a less frequent need for replacement and reduced costs for stormwater engineering infrastructure such as curbs, gutters and drainage systems (City of Chicago, 2003).

Suitability for Cold Climate

Pervious pavement provides water quality and quantity benefits throughout colder seasons as the treatment and infiltration capacities remain high in lower temperatures, despite frost penetration and freeze-thaw cycles (Houle, 2008). Other studies (Roseen et al., 2009 and University of Guelph et al., 2011) corroborate the suitability of pervious systems in cold climate regions.

Pervious pavement maintenance throughout the winter season may require significant alterations of snow and ice management practices already in place. Pervious pavements do not, however, require as much salt as conventional pavements (Houle, 2008). Because of the lower strength of pavement surface on pervious asphalt and concrete systems, these pavements may be more susceptible to plow damage than conventional dense-graded pavement surfaces.

Adaptability for Changing Climate

Relying upon physical filtration for stormwater treatment, the water quality benefits of pervious asphalt and concrete pavements will not likely be affected by climate change. The extremely high permeability of these surfaces may make them advantageous, if underlying soils have the capacity to infiltrate retained runoff, because these surfaces would not be as sensitive to increased frequency and volume of storm events associated with climate change as other STPs may be.

Vegetation used for cellular grid systems may require replacement, if initial plantings prove overly sensitive to climate change.

Potential for ANR Acceptance

The use of pervious pavements is supported by a large number of studies, which have examined pollutant removals, cold climate performance, and the advantages offered over conventional pavements. With this support provided in the literature, pervious pavements are likely candidates for ANR acceptance.

In exploring the use of pervious pavements to meet Vermont stormwater management standards, several issues should be addressed with the ANR:

- Typically, pervious pavements are designed so that they only store and infiltrate rainfall falling directly on the pavement. It is possible, with care in design, to direct runoff from other areas of the site to the pavement. Future development of design guidance should consider whether such "run-on" treatment would be allowable, and if so, what ratio of off-pavement to pavement area is acceptable for such stormwater management.

- Under the typical design where only the pavement runoff is being handled by the pervious pavement system, there is no separate pretreatment. This condition does not seem to be a factor affecting pollutant removal performance of these pavement systems. This particular practice should be considered for inclusion in ANR standards as a standalone practice. The exception would be that if treatment of "run-on" is allowed, the run-on should be subject to pre-treatment to the extent needed to protect permeability of the pavement system.

Operation and Maintenance Considerations

Careful maintenance is essential for long term use and effectiveness of pervious pavements. Periodic cleaning is required to remove sediment, which must be completed with vacuum or regenerative-air sweepers. Routine maintenance also includes regular inspection of the pavement surface for clogging (infiltration rates) and structural issues.

Winter maintenance of any of the pavement types described above must avoid the application of sand for snow and ice management. In addition, porous concrete surfaces are anticipated to be susceptible to damage by salt application, as well as some other deicing chemicals. Some of the concrete unit paver systems available may have an increased resistance to salt damage because of the high-density, low-porosity characteristics of the pavement units. Offsetting the concerns about use of snow and ice management products, the characteristics of pervious pavement can actually reduce ice accumulation on the pavement surface.

Monitoring ports should be considered to enable inspection of water levels within the reservoir course, to monitor infiltration performance in pavements with direct infiltration to sub-soils. Cleanout and monitoring risers should be provided for under-drained pavement systems to allow for inspection and cleaning of the sub-drain system. Other than these measures, inspection of pervious pavements is comparable in effort to the inspection of conventional pavements.

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Bioretention Practices: Micro-bioretention

Description

The micro-bioretention practice[3] captures and treats runoff from a discrete impervious area by passing it through a filter bed mixture of sand, soil, and organic matter. Filtered stormwater is either returned to the conveyance system or partially infiltrated into the soil. Micro-bioretention practices are versatile and may be adapted for use anywhere there is landscaping. The practice is essentially the application of "bioretention" in dispersed, small scale systems.

Micro-bioretention is a multi-functional practice that can be easily adapted for new and redevelopment applications in transportation projects, as well as residential, commercial and industrial projects. Stormwater runoff is stored temporarily and filtered in landscaped facilities shaped to take runoff from various sized impervious areas. Micro-bioretention provides water quality treatment, aesthetic value, and can be applied as concave parking lot islands, linear roadway or median filters, terraced slope facilities, residential cul-de-sac islands, and urban planter boxes. The use of such small-scale "rain-garden" systems is particularly suited to ultra-urban project settings and to highway support facilities (e.g., rest areas, park and ride facilities, and maintenance depots).

Stormwater Management Processes

- Retention and sediment settling in micropools
- Filtration through organic-rich subsurface media
- Chemical and biological water quality treatment processes in soil media
- Filtering and pollutant removal via plant uptake (e.g., phosphorus)
- Encourages recharge to groundwater (where underdrain is not installed)

Where soils are suitable, this practice can contribute to an overall reduction of runoff by promoting infiltration. Also, this practice will result in some incidental storage within the soil media and interception and evapotranspiration by vegetation.

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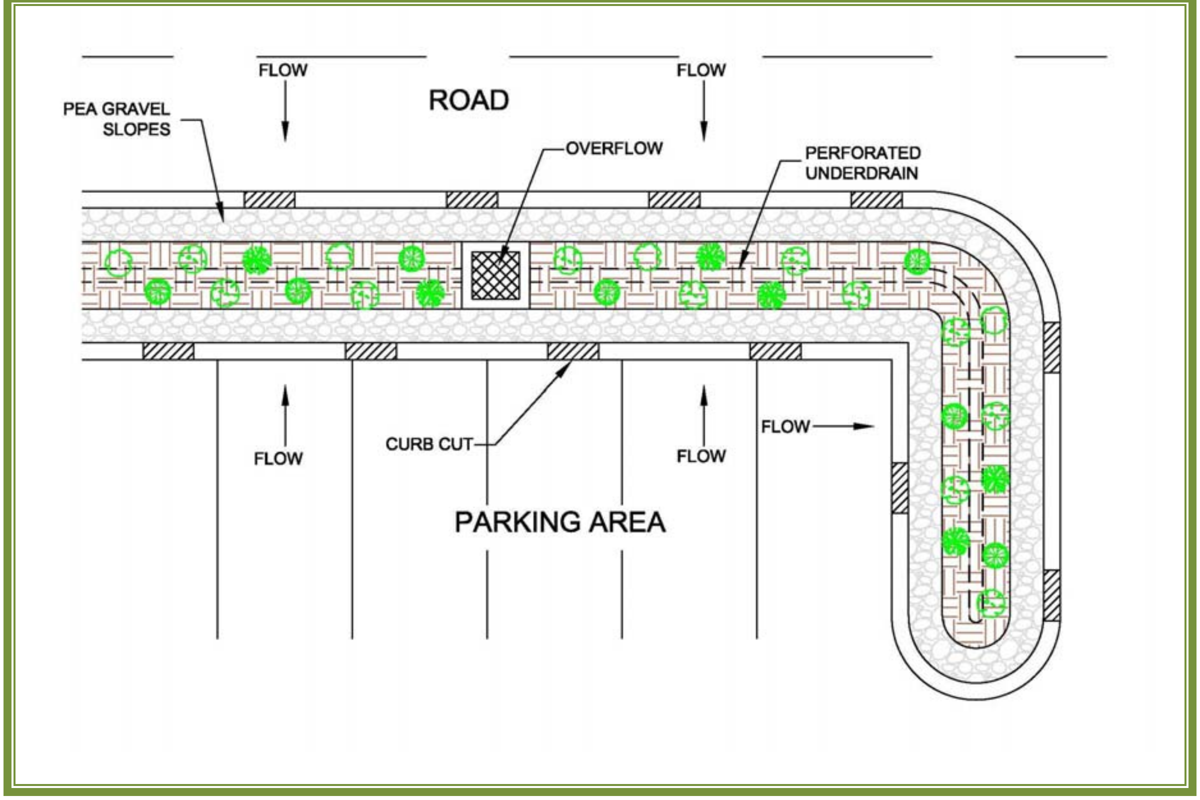
[3] *The source reference for this practice identifies it as "micro-bioretention." The description of the practice indicates that it is essentially what other references describe as "rain gardens."*

Advantages and Disadvantages

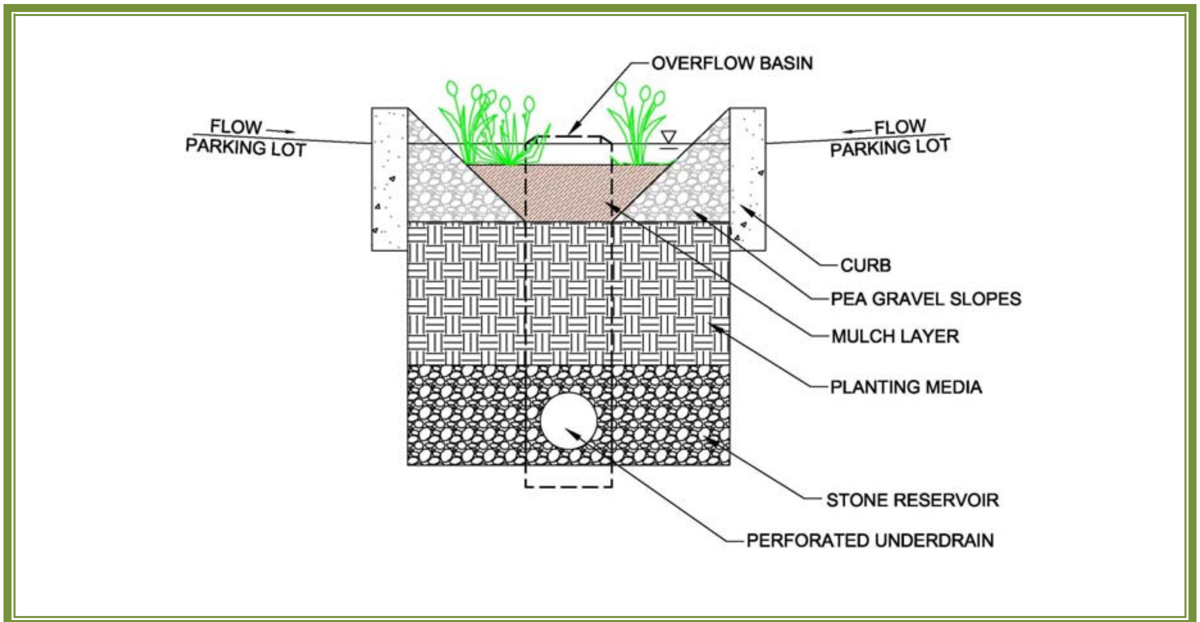
Advantages:	**Disadvantages:**
Variation on STP technology already included in the Vermont Stormwater Management Manual Compact design is versatile and appropriate for linear roadways, urban and ultra-urban settings Readily adaptable to roadside and parking area landscaped areas, with or without infiltration into underlying soils Adds to the aesthetic value of an area with vegetation chosen Treatment occurs through multiple pollutant removal mechanisms Adaptable to cold climate and changing climate conditions Relatively low installation, operation and maintenance costs	Need to line and under-drain where used to treat runoff from "hot spots" (cannot be used with infiltration function). Failure of filtration media over time requires reconstruction of the micro-bioretention area Limited removal and in some cases negative removal (i.e., export) of nitrate-nitrogen[4]

[4] Net export of nitrate-nitrogen due to the incomplete transformation of organic nitrogen within bioretention areas (Hunt, 2003).

Illustrations



Micro-bioretention plan view (MDE, 2008)



Micro-bioretention section detail (MDE, 2008)

Target Pollutants and Treatment Effectiveness

Pollutant removals in the table below are based on literature pertaining to bioretention:

Pollutant	Pollutant Removal (by source study)			
	Wright et al., 2011	Geosyntec et al., 2010	Geosyntec et al., 2011	UNHSC, 2009[5]
Total Copper	48%			
Total Zinc	73%			68%
Total Nitrogen		21%		
Total Phosphorus				34%
TSS			80%	87%

ANR lists bioretention as a water quality practice in the Vermont Stormwater Treatment Standards. One of the criteria required for designation for water quality treatment include potential for removing approximately 80% TSS and 40% Total Phosphorus (even greater removal rates would be anticipated for bioretention systems that infiltrate.

Selection and Design Considerations

Siting and Design Considerations

- Micro-bioretention areas should be sited as off-line practices on flat areas, gradual slopes (<5%), or terraced slopes.
- May be used in conjunction with other BMPs such as conveyance practices or conventional storm drain systems.
- Soil types at the area chosen for installation will affect whether the area can be designed for recharge.

[5] Bio II system, combination sedimentation and bioretention.

- Provide a bypass or device directing overflow stormwater to a downstream conveyance system.

- Select vegetation based on its hardiness for the regional climate and its pollutant uptake potential. Vegetation must also withstand temporary inundation, as well as long dry periods.

- Time construction to allow vegetation to stabilize optimally during the fall planting season.

Consistency with Roadway Design Integrity

Micro-bioretention is applicable wherever landscaping is appropriate near paved areas, and should generally not affect the design or performance of pavements. However, where this practice is used in close proximity to a pavement, care must be exercised to design the sub-drainage of the bioretention cell so that it does not discharge water into the pavement base.

Cost Effectiveness

Costs for installing micro-bioretention systems average approximately two dollars per square foot of drainage area (2008 dollars) (Sarasota County, 2010). Unit costs for installation have also been found to decrease with increases in the size of the bioretention system itself (Hathaway et al., 2007). The cost per unit of design treatment volume has also been shown to decrease as the volume increases (Weiss et al., 2007)

A factor that affects the cost effectiveness of bioretention areas is soil type. Wossink, *et.al.* (2003) noted costs per acre of treated watershed are approximately 2.5 times greater for installations in clay soils.

Suitability for Cold Climate

Similar to bioswales, micro-bioretention areas make use of filter media for treatment. A study from the University of New Hampshire Stormwater Center indicates that STPs relying upon filter media for treatment sustain their performance in cold climate conditions; pollutant removals differ minimally between warm and cold seasons despite the dormancy of vegetation during the cold season (Roseen et al, 2009).

A study of a bioretention system in Connecticut also showed that less than 1% of inflow over a two year period overflowed the system, despite frost during winter months (Dietz and Clausen, 2006).

Adaptability for Changing Climate

Initial plantings should include a variety of species, diverse in sensitivity to climate changes, to ensure that bioretention plantings are robust. Changes in climate may cause sensitive vegetation to die prompting less sensitive vegetation to take over. If the diversity of plantings is not enough for the BMP to adapt to the changing climate, the vegetation must be removed and replaced with new vegetation appropriate to the prevailing climate.

Potential for ANR Acceptance

As a variation of the bioretention system presented in the Vermont Stormwater Management Manual, micro-bioretention systems have a high potential for ANR acceptance.

Operation and Maintenance Considerations

Routine inspection of bioswales is the primary maintenance practice. Inspections should monitor for:

- vegetative cover and health,
- soils stability (erosion),
- flow channelization, and
- infiltration capacity (water-logging).

In addition, maintenance activities include:

- periodic mowing (never below the height of the water quality design depth),
- clearing debris,
- replacement of mulch annually, and
- removing sediment.

Repair or restoration activities include:

- re-vegetating bare areas annually,
- removal of sediment and possibly removing top few inches of filter media if water ponds for more than 48 hours, and
- stabilizing and re-vegetating eroded areas when evident.

Micro-bioretention areas do not require any special operational or safety considerations. Inspection and maintenance can be achieved without special procedures, equipment, or interruption of traffic. Micro-bioretention areas can be maintained using equipment conventionally used for maintenance of highway embankments and landscaped areas.

Most maintenance addresses vegetation or the first few inches of filter media. For repair, the first few inches of filter media may be replaced if water is ponding for greater than 48 hours. If greater repair is necessary, a deeper reconstruction of the filter media may be necessary.

Micro-bioretention areas pose few safety concerns if properly sited and maintained. Where the areas are located close to travel lanes or intersections (in ultra-urban areas, for example), it may be necessary to select vegetation with maximum mature heights such that sight-lines remain unobstructed. Where landscaped bioretention depressions are provided along rural or limited access roadways, they may need to be located outside driver recovery areas or protected by guardrails.

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http://www.neuse.ncsu.edu/Stormwater_BMP_Factsheet.pdf

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Bioretention Practices:
Media Filter Drain and Embankment Media Filter

Description

Media Filter Drain

The media filter drain (MFD), also referred to as the “ecology embankment” or “bio-slope,” is a flow through stormwater runoff treatment device that is especially suited for highway applications where available right of way is limited. It can readily be sited along highway side slopes and medians, and is suitable for both new highways and retrofit applications.

The MFD provides treatment for suspended solids, phosphorus and metals, by rapidly filtering runoff through an engineered soil media consisting of crushed rock, dolomite, gypsum, and perlite[6]. The dolomite and gypsum serve to buffer acidic pH conditions and exchange light metals for heavy metals. The perlite retains moisture to support a biofilm that assists in removal of solids, metals and nutrients (WSDOT, 2008). Media filter drains are similar to vegetated filter strips, but instead of filtering runoff via sheet flow through thatch and surface soils, runoff is rapidly infiltrated into a gravel trench and then filtered via subsurface flow through the engineered soil media, or “ecology mix.” The ecology mix is a blend of crushed stone aggregate, horticultural grade perlite, agricultural grade dolomite, and agricultural grade gypsum.

The ecology mix bed is a flow-through device and does not provide significant detention, and only minimal retention storage. However, some volume and peak discharge rate reduction may be achieved through storage in a gravel underdrain, movement through the ecology mix bed and infiltration into the underlying soil.

Media filter drains consist of a level spreader or gravel “no-vegetation zone,” a grass strip, a filter mix bed, and a gravel-filled underdrain to convey water leaving the filter mix. An aggregate drainage layer may be used in lieu of the underdrain, where topography allows for the placement of this layer where it can freely drain to an existing drainage swale or other conveyance practice. Stormwater runoff must enter the MFD as sheet flow, which is created by the no-vegetation gravel zone and grass strip. The grass strip may be amended with compost (see discussion of Compost Amended Vegetated Filter Strip – CAVFS).

In highway medians, dual Media Filter Drains are often an effective treatment option. The dual media filter drain is fundamentally the same as the single drain but with contributing grass strip and filter mix drain bed on each side of the underdrain trench.

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[6] Material safety data sheets for these materials do not indicate any special concerns that would prompt more than the use of personal dust protection measures during installation.

Prime locations are medians, roadside drainage or borrow ditches, or other linear depressions. It is especially critical for water to sheet flow across the dual media filter drain. Channelized flows or ditch flows running down the middle of the dual media filter drain (continuous off-site inflow) should be minimized.

Embankment Media Filter

The embankment media filter is a variation on the media filter drain, for application on steep embankments and/or restricted rights of way where space constraints do not permit development of a shallow vegetated filter system. The embankment media filter comprises a filter trench installed integrally with a roadway embankment, with the trench backfilled with a filter material. The filter may be composed of similar material as that specified for the Media Filter Drain. Alternatively, it could comprise a sand filter or organic filter material. Drainage is directed into the filter by sheet flow from the pavement shoulder and percolation through an overlying layer of riprap.

This filter system is designed for use on approaches to bridges, roadway embankments crossings or adjacent to wetlands or other water resources, and other locations where the road is elevated above the adjacent landscape and where space is restricted for the placement of other BMPs.

The filter may be under-drained by an aggregate drainage layer. This layer may “day-light” at the toe of the embankment, or it may be drained using perforated pipe discharging to a downstream drainage structure or outlet. Where subsurface soils are suitable, the filter may drain directly to the underlying material by infiltration.

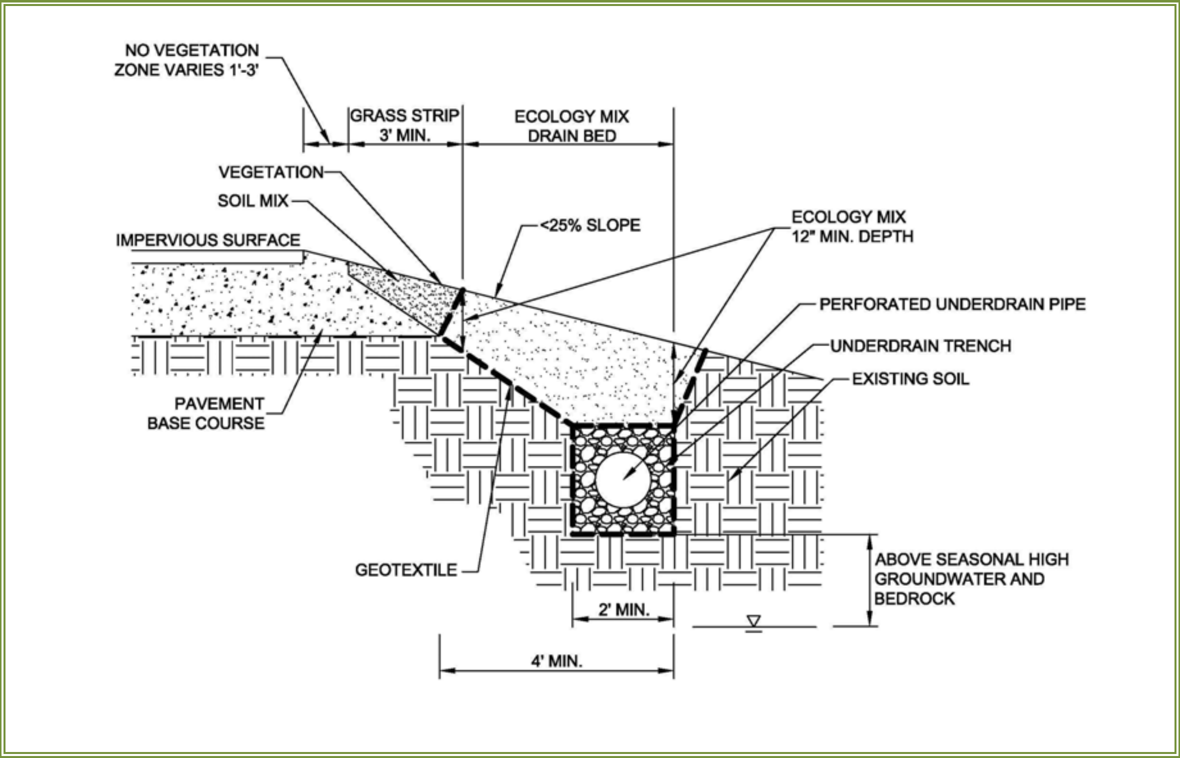
Stormwater Processes

Media Filter Drain:	**Embankment Media Filter:**
Removal of sediment through physical filtration	Removal of sediment through physical filtration
Pollutant treatment via chemical and biological processes in filter media	Pollutant treatment via chemical and biological processes in filter media, depending on media composition
Pollutant removal via vegetative uptake	Incidental infiltration where underlying soils are suitable; if applicable, practice contributes to reduction in runoff
Incidental infiltration where underlying soils are suitable; if applicable, practice contributes to reduction in runoff	Planting media can be placed in voids of riprap embankment and vegetation established to provide ancillary vegetative nutrient uptake

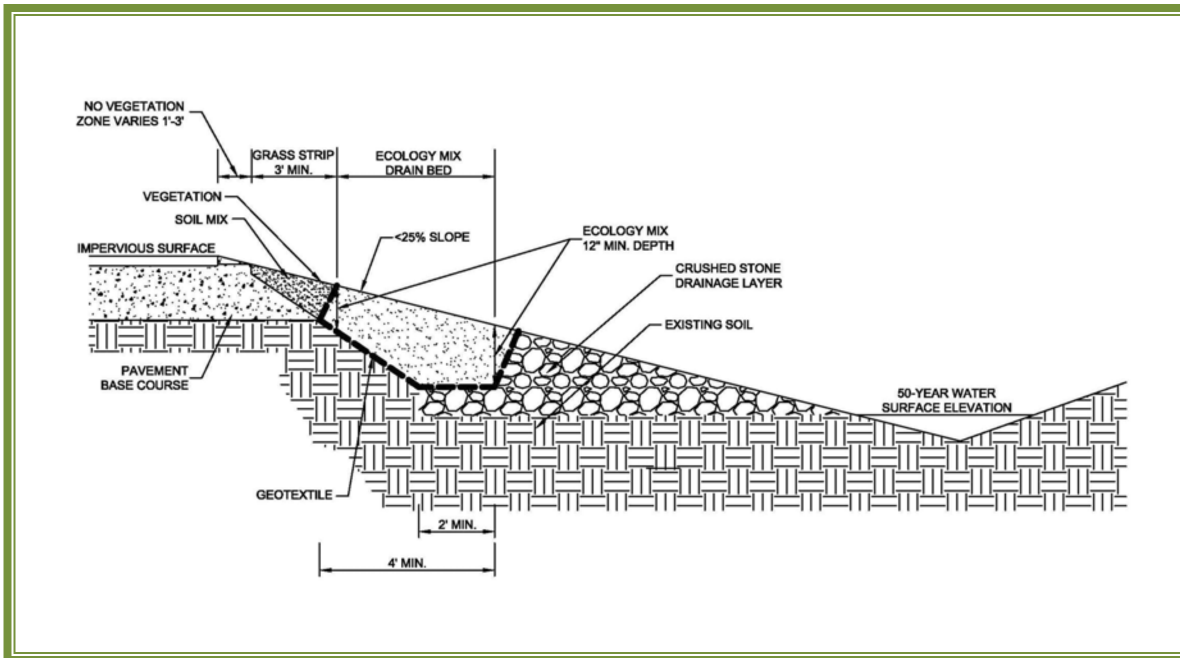
Advantages and Disadvantages

Stormwater Practice	Advantages:	Disadvantages:
Media Filter Drain	Footprint and design are particularly suited for application in highway shoulders or medians (dual media filter drain) Reduces potential for erosion as stormwater travels through subsurface rather than as overland flow Operations and maintenance practices are similar for typical maintenance of highway shoulders Offers greater pollutant removal through chemical treatment provided by specialized media	Requires importing additional specialized materials (perlite, gypsum, dolomite) for incorporation into the filter media. Materials required for filter media may incur greater costs than typical media (e.g., sand) for filtration System failure may require replacement of filter media May be limited by topography and available area within right of way
Embankment Media Filter	Footprint and design are particularly suited for application in highway shoulders Particularly suited for steep embankments or limited area within right of way, design was developed for a causeway type of bridge approach Operations and maintenance practices are similar for typical maintenance of highway shoulders Embankment filter design can be adapted for alternative media (e.g., sand filter material)	Requires importing additional specialized materials for the filter System failure may require replacement of filter media, with replacement potentially requiring embankment reconstruction as well

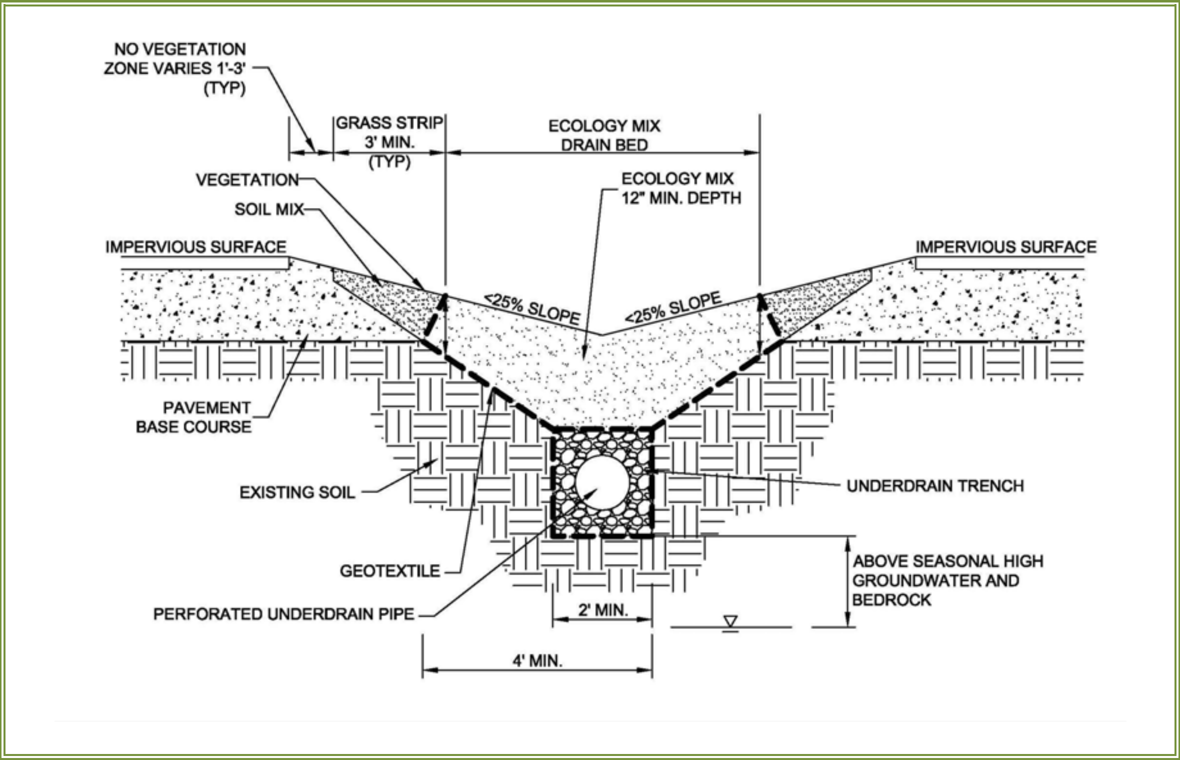
Illustrations



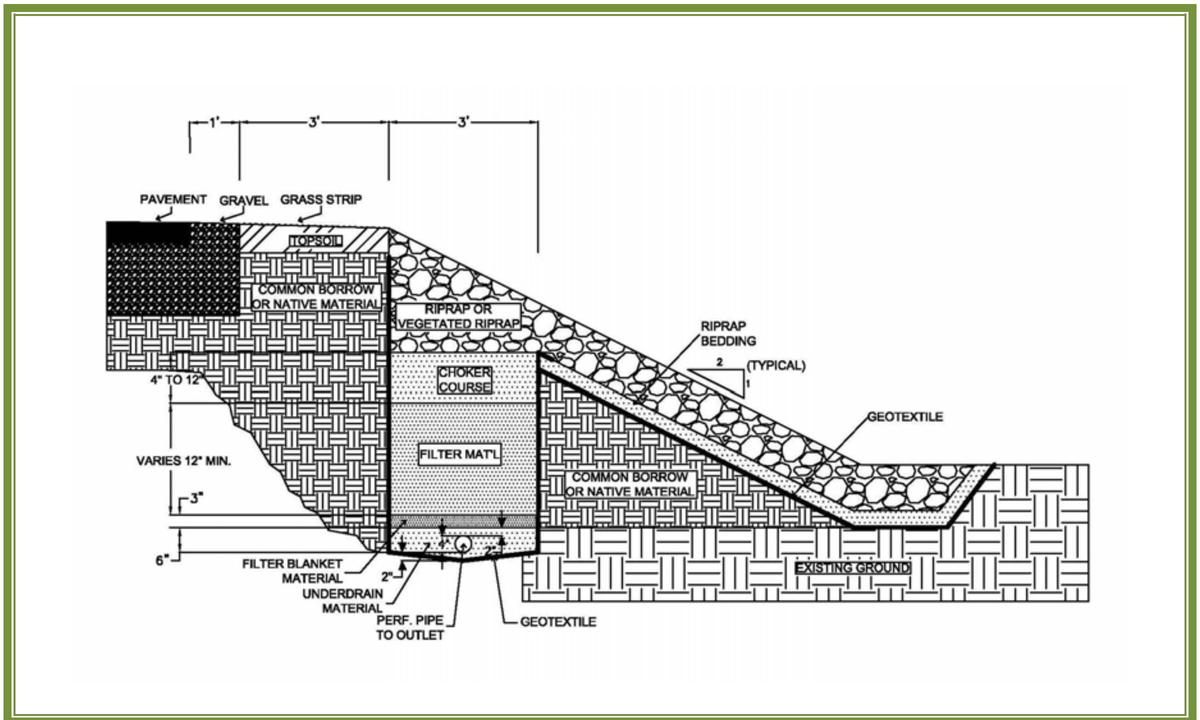
Media filter drain with underdrain (adapted from WSDOT, 2008)



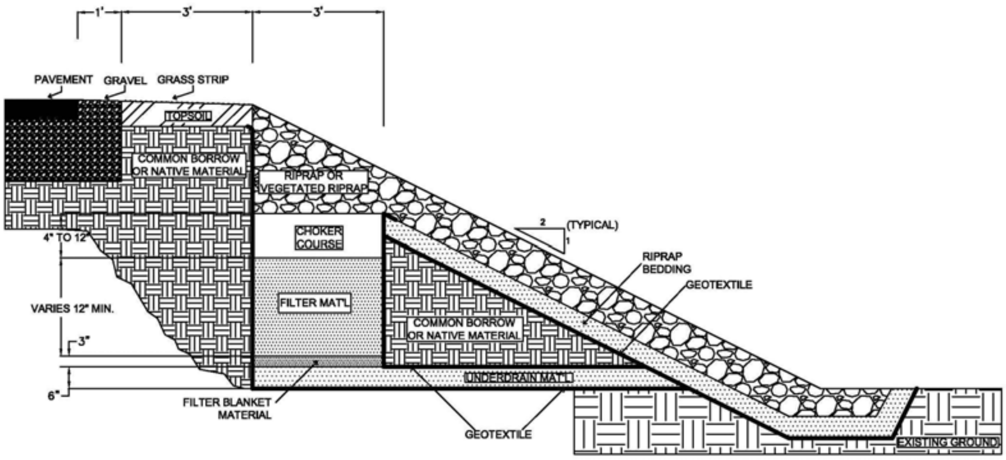
Media filter drain with day-lighted drainage layer (adapted from WSDOT, 2008)



Dual media filter drain for highway median (adapted from WSDOT, 2008)



Embankment media filter with underdrain (CEI)



Embankment media filter with day-lighted drainage layer (CEI)

Target Pollutants and Treatment Effectiveness

Pollutant	**Pollutant Removal for the Media Filter Drain (by source study)**			
	WSDOT, 2005	Wright Water Engineers et al., 2011	Geosyntec et al., 2010	Geosyntec et al., 2011
Total Copper	82%	57%		
Total Lead		67% - 85%		
Total Zinc	89%	59% - 83%		
Total Phosphorus	84%		47%	
Total Nitrogen			42%	
TSS	95%			
Turbidity				80%

The preceding table lists pollutant removals observed in various studies for the media filter drain. The embankment media filter, however, currently comprises a conceptual design, developed as a solution for space limitations at a bridge approach embankment. No field installations or pollutant removal studies have been completed for this device. Removal rates in the embankment filter might be expected to be similar to those shown in the table, but the role of vegetation in pollutant removal may be less with the embankment media filter. The device could also use other media, such as filter sand. Further research with various types of media would be warranted to develop the optimum filter media for this device.

Selection and Design Considerations

Siting and Design Considerations:

Media Filter Drain

- While the practice is particularly suited to roadways and drives, consideration can be given to using this practice in landscaped islands of large parking lots
- Not suitable for areas with steep slopes or large impervious areas generating high velocity runoff
- Requires sufficient vertical separation to seasonal groundwater elevations to prevent groundwater intrusion into the filter bed and underdrain
- Underdrain must be provided for areas with soils having a high clay content
- Sheet flows are required through the filter strip to prevent short-circuiting by concentrated flows
- May be suitable as a stand-alone practice or designed in conjunction with other practices; an underdrain may be used to direct stormwater to other practices
- Minimize water running down the middle of dual media filter drains

Embankment Media Drain

- Suitable for road-side applications where space is limited and slopes are steep
- Requires sufficient vertical separation to seasonal groundwater elevations to prevent groundwater intrusion into the filter bed and underdrain
- Filter media can be adjusted as appropriate for an application (MFD media, sand filter media, or organic filter media)
- Provide a perforated pipe underdrain for discharge to a downstream drainage structure or outlet if soils are not suitable for infiltration

Consistency with Roadway Design Integrity

Media filter drains and embankment filter drains should be compatible with roadway design integrity. They require no direct changes in the pavement surface or sub-grade design, other than they are only applicable where runoff drains freely off the edge of pavement (i.e., no curbing). The gravel spreader and soil amendments are installed outside of the roadway footprint (both pavement and subgrade) and do not affect drainage of the roadway subgrade.

MFDs do not pose potential vehicle safety concerns, as long as plantings used in the stabilization of the surface are consistent with roadside landscaping practices. Also, cleanout risers or wells should be constructed flush with the ground surface to the extent practicable, so that these risers do not comprise potential "fixed-object" hazards.

MFDs are particularly suited to highways because inspection and maintenance does not require interruption of traffic. The surface of the MFD is essentially a roadside landscaping practice, readily observable and easily accessed for inspection and maintenance. Other than cleaning of the underdrain (as warranted by periodic inspection), this practice does not require special equipment or procedures to inspect and maintain.

The Embankment Media Filter is similarly consistent with highway safety, as it integrates the STP into a riprap-stabilized embankment that is constructed according to standard roadway embankment design practices.

Cost Effectiveness

Capital costs for media filter drain installation have been found to be low relative to other BMP options, with low to moderate operation and maintenance costs and an effective life of 5 to 20 years (WSDOT, 2008).

The Low Impact Development Center indicates that the material cost of the "ecology mix" (blend of gravel, perlite, gypsum, and dolomite) is on the order of 30% to 100% greater than the cost of gravel (LIDC et al., 2006). According to a study by Herrera Consultants, a media filter drain with a width of three feet would range in cost from approximately $25 to $40 per linear foot in 2006 dollars (Herrera, 2006). Detailed information on unit costs for various materials required for media filter drain construction can be found in LIDC, et. al. (2006).

Suitability for Cold Climate

Chemical and biological treatment capabilities of media filter drains may be limited by cold climate as vegetation becomes dormant, though dense vegetation will allow physical filtering to continue. Studies done by the University of New Hampshire Stormwater Center on bioretention type systems and sand filters show that infiltration and pollutant treatment are not greatly lessened in the winter season. Media filter drains may be more susceptible to freezing than bioretention areas, because of the shallow depth of this type of filter. Embankment media filters, which have greater depth, are anticipated to perform similarly to the practices examined by UNH.

Adaptability for Changing Climate

The filter media is not anticipated to be greatly affected by changes in climate. As with other vegetated management practices, initial plantings for MFDs should include a diversity of species varying in climate sensitivity. As changes in climate cause sensitive vegetation to die, robust species may take over. If the diversity of plantings is not wide enough for the vegetation to adapt to climate changes, it may be removed and replanted with a new seed mix more appropriate to the prevailing climate.

Potential for ANR Acceptance

The field studies of MFD cited above should be supportive in obtaining ANR acceptance of this practice as a primary form of stormwater treatment in the highway environment. Because the data summaries from the American Society of Civil Engineers BMP Database (Geosyntec and Wright reports cited above) collect data from several applications, the compiled data may not meet ANR criteria for alternative technologies.

The embankment media filter is an adaptation of the MFD, as well as of technology developed for other practices described in this memorandum or adopted by the Vermont ANR. It is a method to incorporate a filter practice into the embankment of a roadway where resource areas, right of way, and site conditions constrain the choice of other practices.

Operation and Maintenance Considerations

Routine inspections of media filter drains and embankment media drains should monitor for:

- vegetative cover and health,
- erosion, compaction or areas damaged by errant vehicles,
- flow channelization,
- sediment accumulation in the underdrain, if present, and
- infiltration capacity (water-logging).

Routine maintenance activities include:

- periodic mowing (avoid the use of heavy equipment that could compact filter media),
- removal of weeds from no-vegetation zone (minimize herbicide use) as necessary,
- clearing debris, and
- removal of sediment that accumulates at the edge of shoulder; the roadway must be maintained so as to prevent the build-up of a sand/silt berm at the edge of pavement, which would interfere with runoff leaving the pavement edge as sheet flow.

Repair or restoration activities include:

- reseeding or replanting bare areas (as warranted by annual inspection), and
- stabilizing and re-vegetating or mulching eroded or damaged areas when evident.

Design References

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Other References

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Bioretention Practices:
Compost Amended Vegetated Filter Strip

Description

The Compost Amended Vegetated Filter Strip (CAVFS) consists of a uniformly graded vegetated buffer adjacent to the roadway. The native surface soil material within this strip is augmented by the addition of compost material.

The CAVFS accepts overland sheet flow runoff from adjacent impervious areas, and treats this runoff as it infiltrates into the surface of the strip. The practice provides for increased treatment capability by the addition of a specified compost material to the native soil. Sufficient compost is tilled with topsoil to a depth of 12 inches, to result in an organic content of the tilled soil of at least 10% by weight.

The CAVFS relies on its mild cross slope and dense vegetation to maintain sheet flows. These filter strips function by slowing runoff velocities and trapping sediment particles. They also provide some infiltration and biologic uptake. Mixing the highly organic compost with native soils improves infiltration, increases surface roughness and improves plant sustainability.

CAVFS are useful in reducing mass loadings of total suspended solids, heavy metals and phosphorus. The addition of compost into the native soils improves removal of soluble cationic contaminants through sorption, and can improve overall vegetative health and thus vegetative uptake of pollutants. CAVFS can also help somewhat reduce peak discharge rate by enhancing water retention and infiltration into native soils.

Because CAVFS can be implemented within the existing footprint of a roadside embankment, they are particularly suited for the highway environment.

Stormwater Management Processes

- Provides stormwater volume reduction via evapotranspiration, infiltration and water retention in the amended soil

- Infiltration is also increased with vegetative cover, which stabilizes the soil and helps to maintain soil permeability

- Provides pollutant treatment via physical filtration, biological and chemical processes in compost amended soil, which provides a growth substrate for both plants and microbes

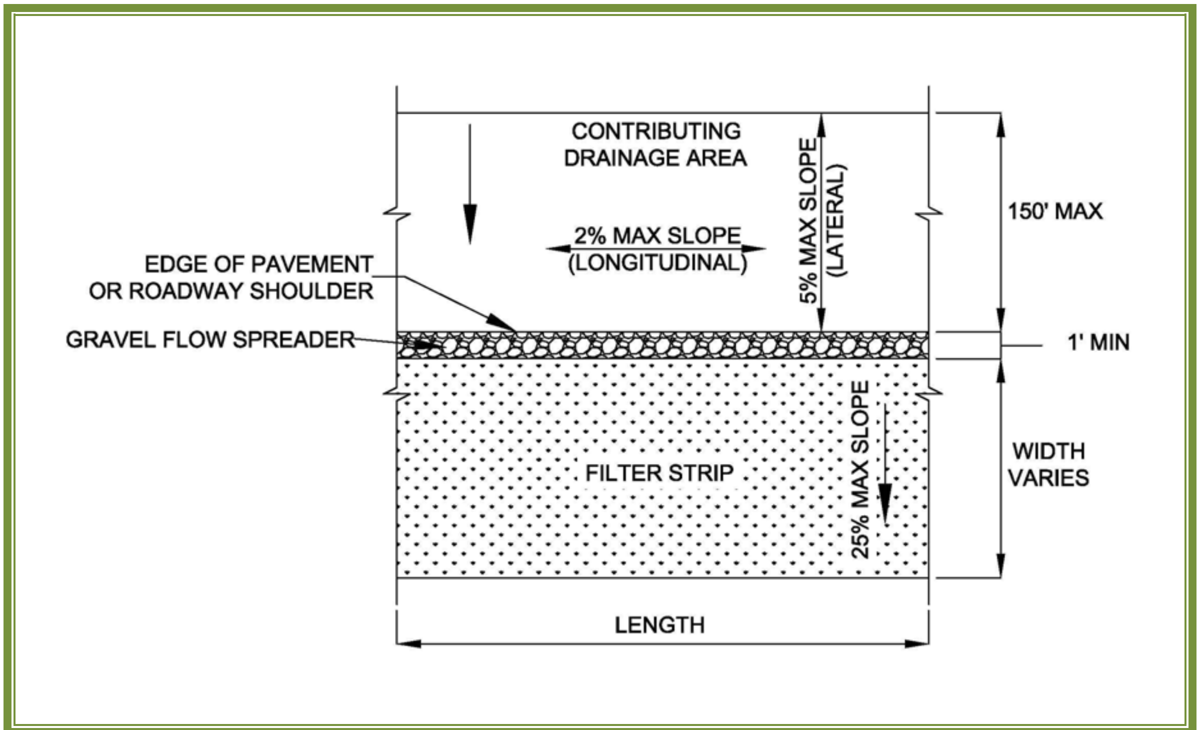
- Pollutant removal via plant uptake (grasses)

This practice will result in some incidental storage within the soil media and interception and evapotranspiration by vegetation. Where underlying soils permit infiltration, the measure will promote recharge. These processes will contribute at least an incidental reduction in overall runoff volume.

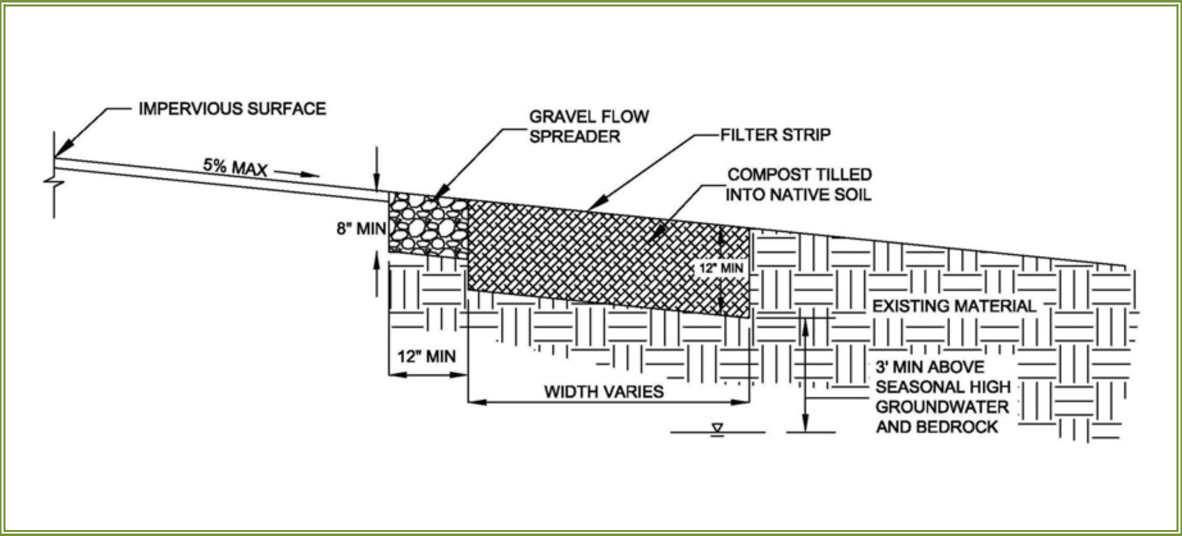
Advantages and Disadvantages

Advantages:	**Disadvantages:**
Suitable for highway applications as CAVFS may typically be installed within the footprint of highway embankments	Suitable sites for CAVFS are limited to slopes and shapes that will maintain sheet flow
Reduces stormwater flow volume and velocity	Limited to roadways with a fairly flat longitudinal gradient
Compost amendments enhance vegetation pollutant uptake	Limited applicability for urban and ultra-urban roadways
Relatively low installation, operation and maintenance costs	Performance of this system under freezing conditions may require further study; compost amended topsoil may be particularly susceptible to freezing (see “Suitability for Cold Climate” discussion for more information)

Illustrations



Compost-amended vegetated filter strip plan view (adapted from WSDOT, 2008)



Compost-amended vegetated filter strip cross section (adapted from WSDOT, 2008)

Target Pollutants and Treatment Effectiveness

Pollutant	Percent Removal (by source study)		Percent Load Reduction (by source study)
	WSDOT, 2005	Herrera, 2007	Herrera, 2007[7]
TSS	84%	94%	98% - 99%
Total Phosphorus	-17%	77% - 84%	96% - 99%
Total Copper	79%	80% - 84%	96% - 100%
Total Zinc	67%	87% - 90%	97% - 100%

In addition to the pollutant removals and load reductions shown above, compost amended filter strips have been shown to reduce runoff volumes by 45 to 50 percent on average relative to filter strips without a similar soil amendment (Herrera, 2007).

[7] Percent reduction in load is calculated for annual loads and includes the effects of water losses through infiltration and transpiration. As a result of the lower runoff volume, load reduction percentages exceed the percentage reductions in concentration.

Selection and Design Considerations

Siting and Design Considerations

- Suitable where slope shape, gradient, or length results in runoff crossing the strip as sheet flow; cannot be used where topographic conditions result in concentrated flow and channelization.
- Generally not suitable for areas with slopes steeper than 25%.
- Generally not suitable for treating large impervious areas that generate high velocity runoff.
- Suitable for small drainage areas with limited contributing flow paths over contributing impervious surfaces (e.g., roadways and drives versus large parking lots).
- Limited to roadways with a fairly flat longitudinal gradient.
- Care must be taken to maintain sheet flows through the filter strip, to prevent short-circuiting and erosive conditions caused by concentrated flows.
- Where roadways are sanded during the winter, the formation of a berm at the edge of the shoulder by accumulated sand and debris can interrupt the discharge of runoff as sheet flow, and must be considered in the maintenance of this practice.
- Vegetative plantings (grass) must be relatively salt-tolerant, able to withstand high flow velocities under wet weather conditions, and tolerant of extended dry periods between storm events.
- Maximum flow path of drainage area: 150 feet (pervious surfaces), or 75 feet (impervious surfaces).
- Maximum longitudinal gradient: 2%.
- Maximum cross-slope (lateral, toward filter strip): 5%.
- Maximum slope: 25% or 4:1 (2 – 15% preferable).
- Slope shape: planar or convex (prevent flow concentration).
- Include level spreader between edge of pavement and upper edge of filter strip.
- Requires three feet of separation to ESHGW and bedrock.
- Guidelines for compost amended soils include the following:
  - Minimum long-term hydraulic conductivity of 1.0 inch/hour at 80% compaction

  - 10% by dry weight minimum organic content (typically achieved by a blend of roughly 2/3 loamy sand and 1/3 compost, or a blend of equal parts sandy loam, coarse sand, and compost.
  - < 5% clay content
  - Free of stones, stumps, roots, or other material larger than 2 inches
  - pH between 5.5 and 7.0

Consistency with Roadway Design Integrity

Compost amended filter strips should have no adverse affect on roadway design integrity.

- They require no direct changes in the pavement surface or sub-grade design, other than they are only applicable where runoff drains freely off the edge of pavement (i.e., no curbing).

- The gravel spreader and soil amendments are installed outside of the roadway footprint (both pavement and subgrade) and do not affect drainage of the roadway subgrade.

- The roadway must be maintained so as to prevent the build-up of a sand/silt berm at the edge of pavement, which would interfere with runoff leaving the pavement edge as sheet flow.

Cost Effectiveness

Construction costs for CAVFS are somewhat higher than for conventional vegetated filter strips due to additional materials and construction effort to incorporate compost into the surface soils. Costs are anticipated to be less than other structural practices, because of the smaller land area requirements and limited earthwork needed to install CAVFS (Herrera, 2007).

For more detailed cost information, see the following references:

- US DOD, 2004

- LIDC et al., 2006 (as “soil amendments”)

Suitability for Cold Climate

MassDEP notes concerns with compost amended media susceptibility to early freezing, with reduction in performance of this system under winter conditions. On the other hand, studies done by the University of New Hampshire Stormwater Center show that infiltration and pollutant treatment are not greatly lessened in the winter season for bioretention and filtering systems (although the systems studied may have a different composition and depth of media than the CAVFS).

The pollutant removals cited above from WSDOT and Herrera reflect cold climate conditions in the northwestern U.S. Data were collected for these installations of CAVFS in Washington from late fall (November) through early to mid-spring (March). Further evaluation of the weather conditions during that study period and comparison with winter conditions in New England would be needed to assess whether additional study specific to Northeast seasonal performance should be undertaken.

Adaptability for Changing Climate

The filter media of the CAVFS is not anticipated to be greatly affected by changes in climate. As with other vegetated management practices, initial plantings for CAVFS should include a diversity of species varying in climate sensitivity. As changes in climate cause sensitive vegetation to die, robust species may take over. If the diversity of plantings is not wide enough for the vegetation to adapt to climate changes, it may be removed and replanted with a new seed mix more appropriate to the prevailing climate.

Potential for ANR Acceptance

The above-cited field studies by WSDOT[8] and Herrera[9] should be supportive in obtaining ANR acceptance of this practice as a primary form of stormwater treatment in the highway environment, though they do not meet all of the ANR criteria for field studies. At the very least, CAVFS could be considered a modification of the "filter strip" presented in the Vermont Stormwater Manual, but the cited field studies indicate a more advanced level of treatment than the Manual attributes to filter strips.[10]

Operation and Maintenance Considerations

CAVFS are particularly suited to highways because inspection and maintenance does not require interruption of traffic. The CAVFS is essentially a roadside landscaping practice, readily observable and easily accessed for inspection and maintenance. This practice does not require special equipment or procedures to inspect and maintain.

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[8] Unclear whether sampling was delayed until one year post-construction.
[9] Sampling occurred within one year of construction.
[10] ANR does not currently consider the filter strip to be a stand-alone practice for water quality, but rather as pretreatment for other devices or efforts to achieve stormwater credits.

Operation and maintenance for CAFVS consist of measures that can be incorporated with typical seasonal highway maintenance practices, such as mowing and debris removal. Care must be taken, however, not to employ heavy equipment that could potentially compact the soil media.

Inspection of CAVFS includes observations of:

- vegetation condition (density, health, presence of invasive species),
- compaction and water-logging
- flow path, including signs of channelization (maintenance of conditions conducive to sheet flow), and
- infiltration effectiveness (evidence of standing water, water "pocket formation", sloughing of the slope or excessive erosion resulting from saturation of the soils).

Maintenance typically requires:

- mowing and weeding (minimizing herbicide use) consistent with promoting a healthy stand of grass and preventing vegetation growth on the gravel flow spreader,
- annual cleaning of accumulated sand or sediment at the edge of pavement, to avoid formation of a berm that would interrupt sheet flow from the edge of the pavement.

As-needed repair includes:

- restoration work where necessary to repair areas that become damaged by errant vehicles,
- repair of eroded or channelized areas,
- re-seeding bare or stressed areas.

Design References

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Other References

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Filter System Practices:
Microfilter Systems

Description

Microfilter systems consist of filtration STPs with compact footprints for application within the gutter of a roadway or within a roadside channel or roadway median. There are several types of these systems, including variations of "gutter filters" and open channel linear filters for use with roadway drainage channels and swales. Gutter filters are particularly applicable for urban road sections, where curbing is typically provided, to treat stormwater runoff at the edge of pavement. Open channel linear filter systems are applicable to rural and limited access roadside areas with "country drainage".

The microfilter systems described in this document include the following:

- Filters installed at pavement gutter line:
    - Gutter filters
    - Ohio DOT "Exfiltration Trench"

- Filters installed in roadside channels or roadway medians:
    - VTrans "Micropool Filter"
    - Minnesota "Permeable Ditch Block

Gutter Filter

Gutter filters typically consist of precast concrete "trench box" structures installed at the gutter line adjacent to a curb or traffic barrier. The trench box has a linear grate that allows stormwater to enter the structure. Gutter filters treat road runoff by way of rapid filtration through sand or other filter medium contained in the trench box. An underdrain is installed either within the filter medium, or in a gravel sub-drainage layer, to collect flows and discharge them to a downstream storm drain. Gutter filters do not provide detention or retention, but do provide water quality treatment , including removal of total suspended solids, metals, phosphorus, and nitrogen. Potentially, the design could be modified by using other media to address removal of other pollutants.

Large debris is captured by the surface grate, while smaller trash and debris is captured in the void space between the grate and filter media below. There is no other pretreatment with this type of filter.

Ohio DOT Exfiltration Trench

A variation of the gutter filter employs porous concrete in the place of a grate. As with the conventional gutter filter, this porous-paved gutter filter, also known as the Ohio DOT "Exfiltration Trench," is designed to capture road runoff at the gutter line and filter it prior to discharge into the storm drainage system. The difference is that filtration is provided by the layer of permeable concrete in addition to the underlying filter media.

This particular trench box is open at the bottom, and is typically installed with an under-drain consisting of an envelope of aggregate with a perforated drain. This system provides some opportunity for exfiltration of water into the underlying soil material, although the underdrain would collect and convey any water that does not rapidly infiltrate into the underlying soil. The trench is situated between catch basins such that runoff bypassing the trench is collected in a downstream catch basin or inlet.

VTrans Micropool Filter

Micropool filters as they have been implemented by VTrans are dry swales with earthen check dams, which create ponding behind each dam. The soils of the check dam consist of a fill material lined with stone on the downstream side. The swale bottom is composed of a 50/50 blend of sand and native soils above a sand filter. A perforated underdrain is set below the sand filter, wrapped in stone. The underdrain is either connected to an outlet structure or day-lighted. (Torizzo, 2011)

MinnesotaDOT Permeable Ditch Block

The permeable ditch block comprises another type of linear micro-filter system that may be used adjacent to the roadway to filter runoff and encourage infiltration. The ditch block is similar in placement to a check dam, yet its structural formation is more similar to the infiltration berm.

Ditch blocks run perpendicular to the direction of flow in a drainage channel to pond water and filter it through a fine filter aggregate. An underdrain lines each block to discharge the filtered water on the downstream side of the ditch block. The detention encouraged by permeable ditch blocks reduces the velocity of stormwater flows and provides sediment settling.[11]

Stormwater Management Processes

Each of the micro-filter systems described above makes use of filtration through a media, with the treated discharge collected and conveyed through an underdrain. The gutter filter variations provide for trapping of coarse debris, but are not readily provided with other forms of pretreatment. The roadside channel filter systems could be used with other forms of pretreatment (e.g., vegetated buffers, grassed swales) and provide greater opportunities for recharge.

The following table describes the pollutant removal mechanisms associated with each of the micro-filter systems.

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[11] Minnesota DOT has reported that pilot application of this BMP has exhibited structural issues at high flows. See discussion under Siting and Design Considerations.

Filter type	Pollutant removal mechanisms
Gutter Filter	Coarse debris removal through grate Physical filtration
Ohio DOT Exfiltration Trench	Coarse debris removal through porous concrete Physical filtration Infiltration (incidental) – potential incidental runoff reduction benefit
VTrans Micropool Filter	Physical settling Physical filtration Infiltration – potential runoff reduction benefit Vegetative uptake
Minnesota Permeable Ditch Block	Physical settling Physical filtration Infiltration – potential runoff reduction benefit

Advantages and Disadvantages

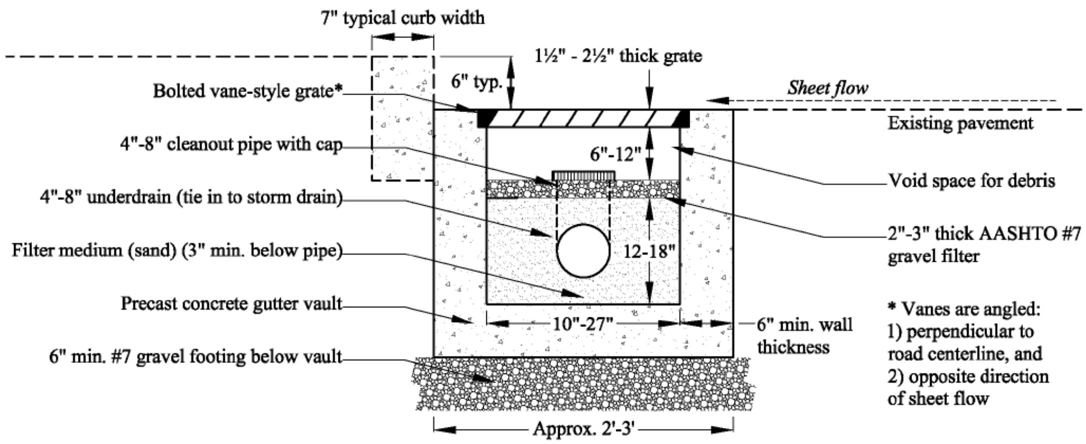
Microfilter Type	Advantages	Disadvantages
Gutter Filter	Suitable for ultra-urban settings Designed to overflow into an existing drainage system Filter media is accessible through trench grate	Does not provide detention or retention Does not provide for pretreatment Filter surface easily susceptible to fouling by debris and sediment Maintenance activities likely to disrupt traffic or parking use

Microfilter Type	**Advantages**	**Disadvantages**
Ohio DOT Exfiltration Trench	Suitable for ultra-urban settings Designed to overflow into an existing drainage system Not enclosed at the bottom and will provide some incidental infiltration	Does not provide detention or retention Filter media is not readily accessible; restoration requires excavation of permeable pavement layer (however, use pre-cast pervious concrete panels may address this potential disadvantage) May affect the structural integrity of the roadway through infiltration into the pavement subgrade Pervious concrete not compatible with typical snow and ice management practices (however, alternative products of materials may address this disadvantage) Does not provide for pretreatment Maintenance activities likely to disrupt traffic or parking use

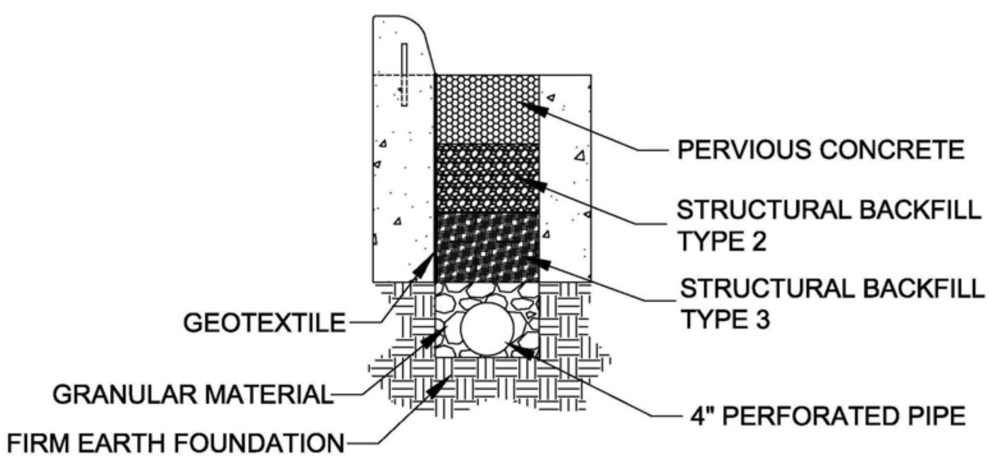
Microfilter Type	**Advantages**	**Disadvantages**
VTrans Micropool Filter	Especially suitable for rural roadway and limited access highway applications Readily adaptable to roadside drainage channels, median strips, and interchange landscaped areas Readily adaptable to alternative types of media; can be constructed as a sand filter, or incorporate bioretention media Where soils and groundwater conditions allow, adaptable to provide for infiltration Generally manageable by routine highway maintenance practices (except for maintenance of underdrain) Suitable for meeting ANR Channel Protection requirements, with careful design	Check dams/berms subject to overtopping and erosion – must be addressed by design and maintenance Safety standards for landscaped “driver recovery” areas may limit the depth of ponding permissible at each check dam Currently no field data specific to this technology available (however, unit processes employed in the practice are similar to others currently accepted by ANR) Limited applicability for urban and ultra-urban areas

Microfilter Type	**Advantages**	**Disadvantages**
Minnesota Permeable Ditch Block	Especially suitable for rural roadway and limited access highway applications Readily adaptable to roadside drainage channels, median strips, and interchange landscaped areas Readily adaptable to alternative types of media; can be constructed as a sand filter, or incorporate bioretention media Where soils and groundwater conditions allow, adaptable to provide for infiltration Generally manageable by routine highway maintenance practices (except for maintenance of underdrain)	Pilot applications have indicated stability problems with the check dams. Check dams/berms subject to overtopping and erosion – must be addressed by design and maintenance Safety standards for landscaped “driver recovery” areas may limit the depth of ponding permissible at each check dam Field data specific to this technology not currently available (however, unit processes employed in the practice are similar to others currently accepted by ANR; also, Minnesota DOT is currently compiling data) Limited applicability for urban and ultra-urban areas

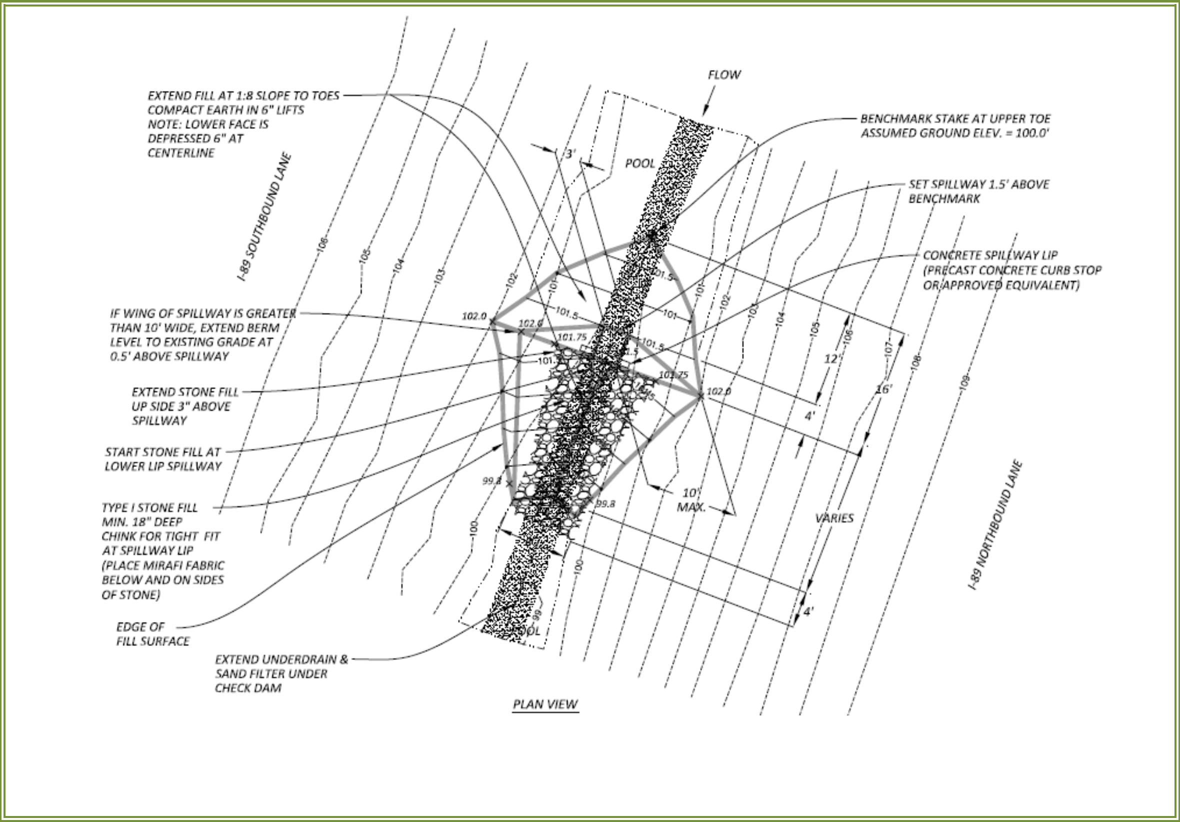
Illustrations



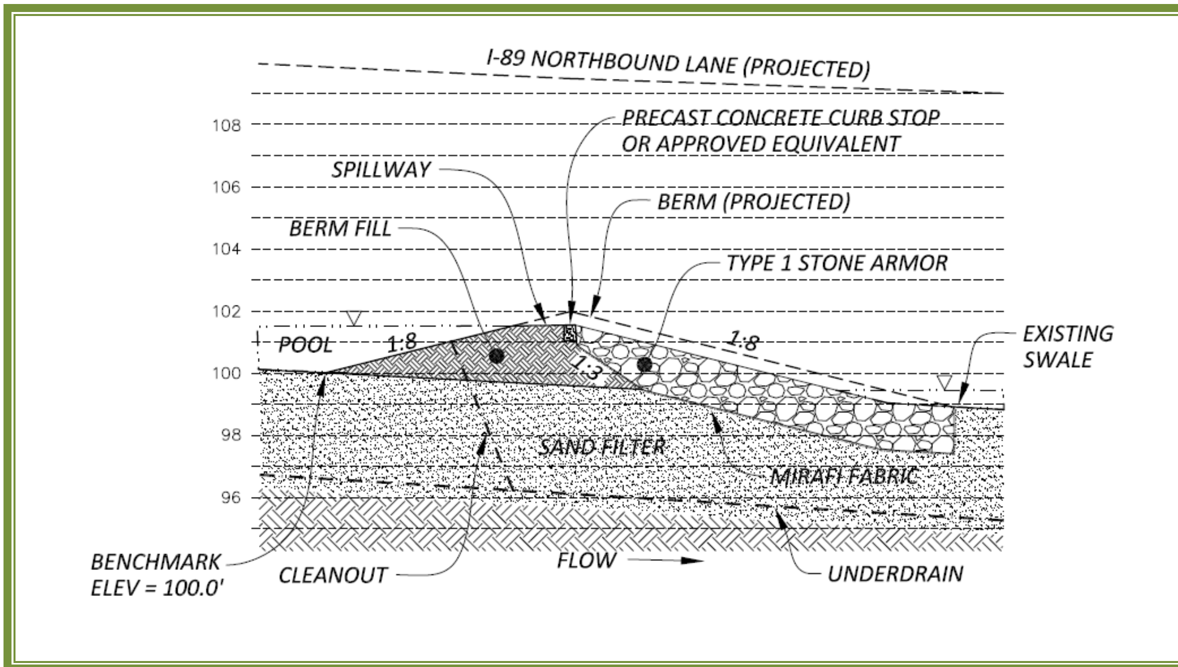
Gutter Filter: typical cross-section (LIDC, 2006)



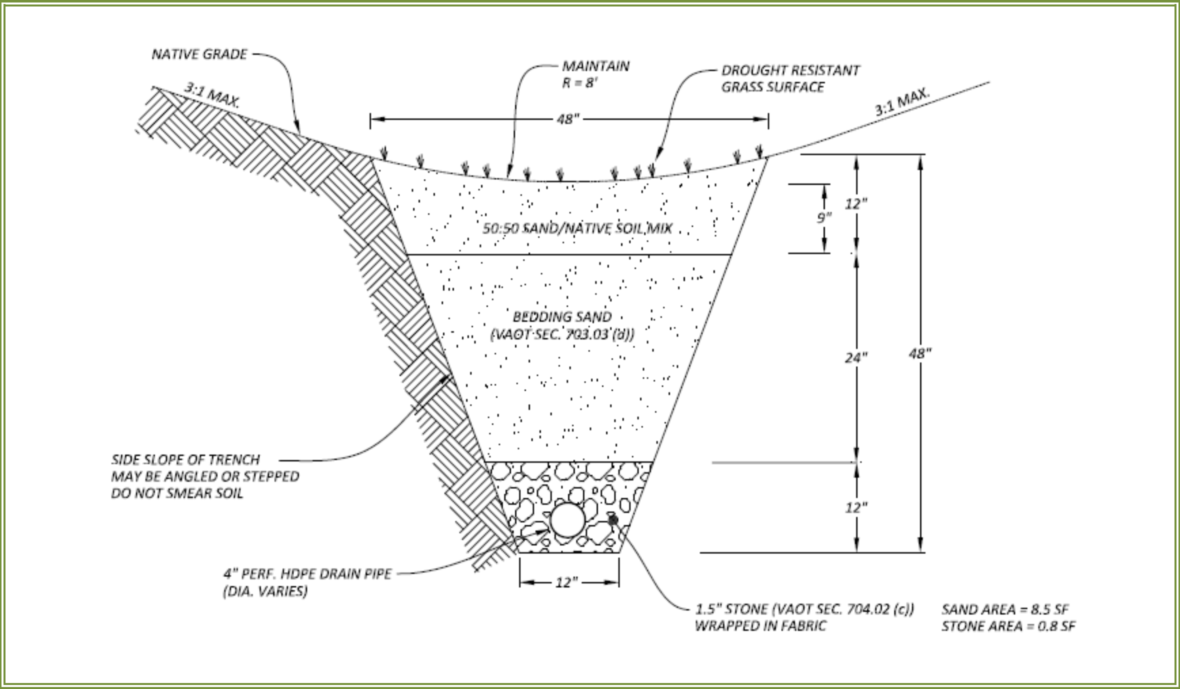
Ohio "Exfiltration Trench" (Porous paved gutter filter) (ODOT, 2008a)



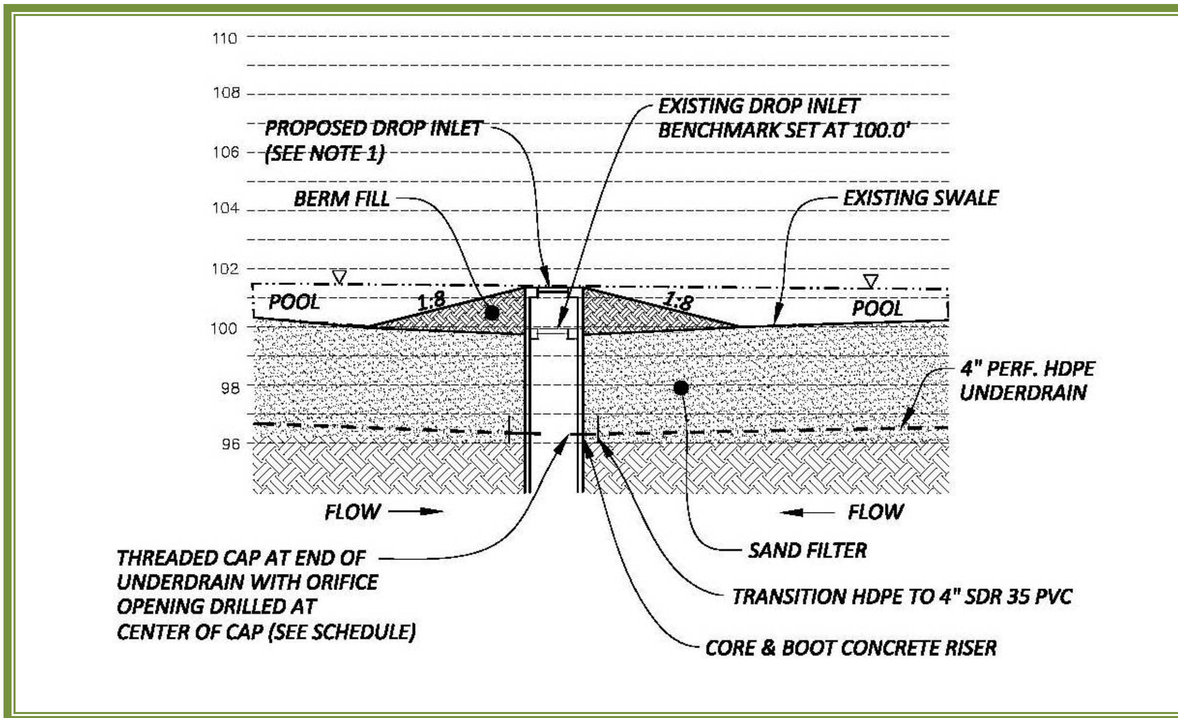
VTrans Micropool Filter: check dam detail in plan view (VTrans, 2011)



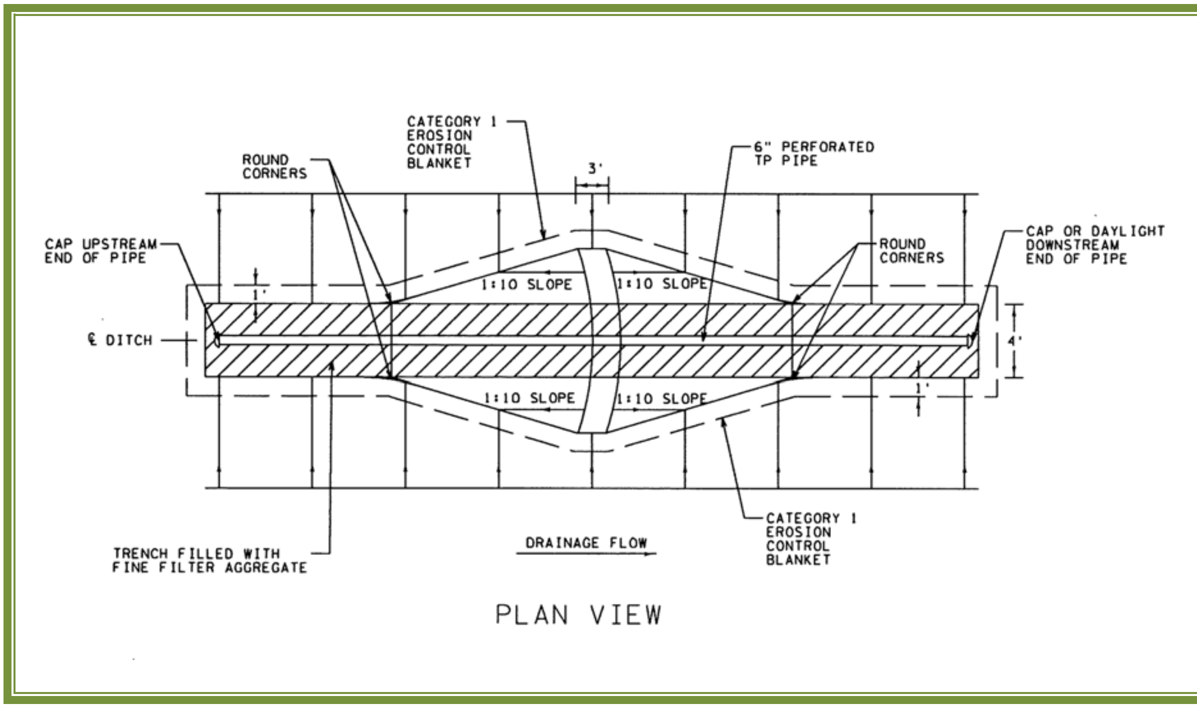
VTrans Micropool Filter: check dam detail in profile (VTrans, 2011)



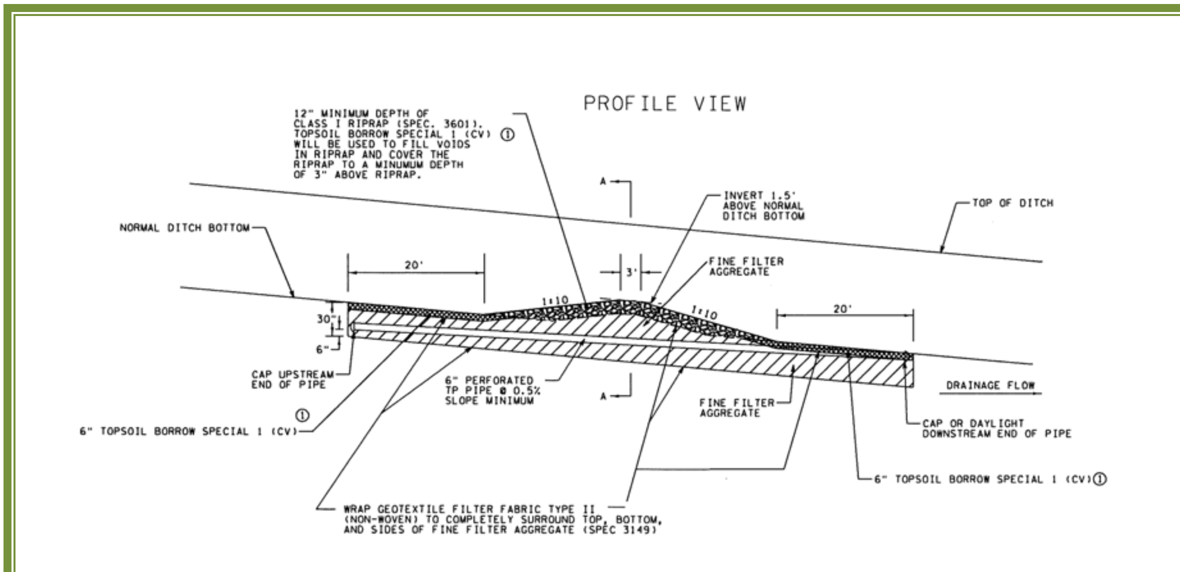
VTrans Micropool Filter: swale sand/filter and underdrain section (VTrans, 2011)



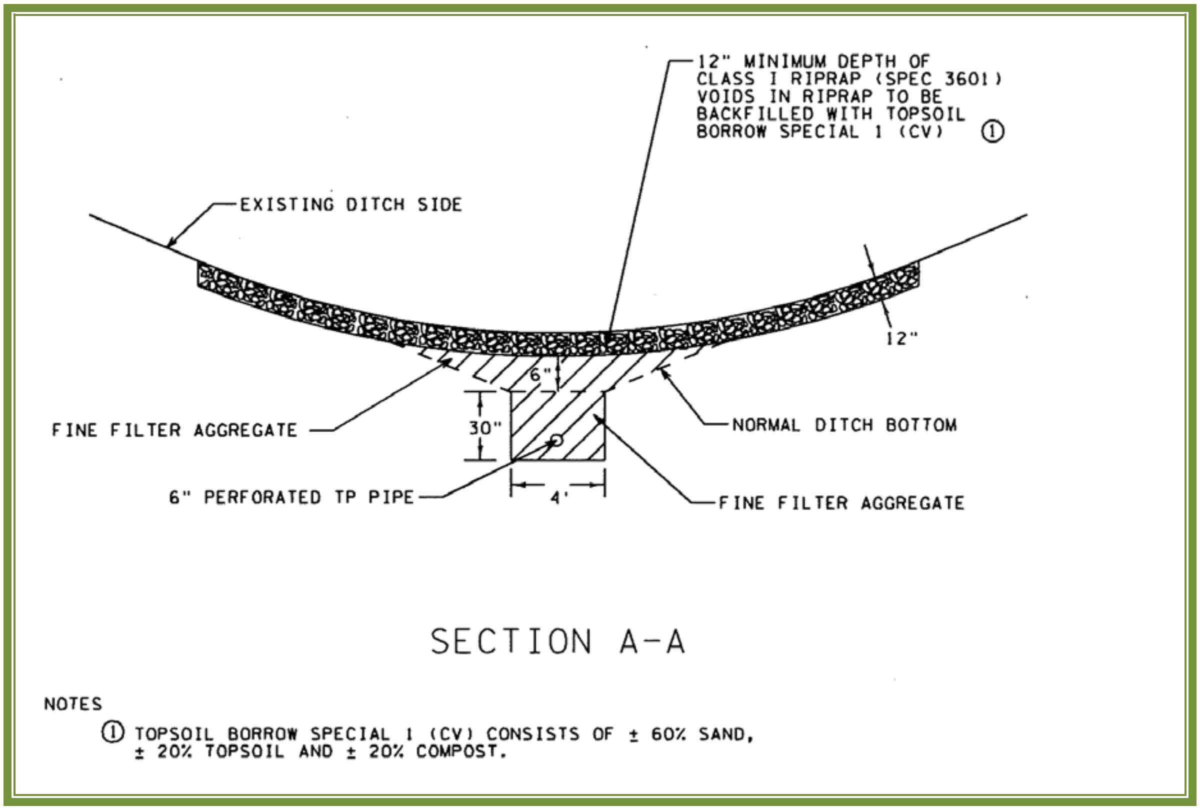
VTrans Micropool Filter: typical swale section showing flow control structure. Note the provision of a cap at the end of the underdrain with an orifice designed to control release rate to meet Channel Protection criteria. (VTrans, 2011)



Minnesota Permeable Ditch Block: plan view (Irish, 2011)



Minnesota Permeable Ditch Block: profile (Irish, 2011)



Minnesota Permeable Ditch Block: section (Irish, 2011)

Target Pollutants and Treatment Effectiveness

Pollutant	**Pollutant Removal by device and source study**			
	Gutter Filter			**Ohio Exfiltration Trench**
	Wright Water Engineers et al., 2011	Geosyntec et al., 2010	Geosyntec et al., 2011	Wawszkiewicz et al., 2011[12]
Total Copper	57%			60%
Total Lead	67% - 85%			73%
Total Nickel				81%
Total Zinc	59% - 83%			51%
Total Phosphorus		47%		
Total Nitrogen		42%		
TSS				91%
Turbidity			80%	

For further lab data on separate pollutant removal capabilities of the pervious concrete and greensand filter used in the Ohio exfiltration trench, see Mahboob, 2011.

There are currently no practice-specific studies for Vermont micropools and Minnesota permeable ditch blocks. These practices are likely similar in performance to sand filter practices already included in the Vermont Stormwater Management Manual.

[12] Study includes laboratory analysis only. Values shown are for “medium concentrations” of metals.

Selection and Design Considerations

This section lists general considerations for selecting and designing microfilter practices. For further design guidance, please refer to one of the design references cited below.

Siting and Design Considerations

Gutter Filter

- Appropriate for ultra-urban settings where roadways are curbed.
- Install on straight segments of roadway only in shoulders or breakdown lanes.
- Filter media infiltration rate will limit the capacity of the gutter filter. Must be used in conjunction with conventional curb inlets to adequately drain the roadway.
- Do not install where backflow from the drainage system is likely.
- Filter is typically designed by using a "first flush" approach. Provide a safety factor to account for the decrease in soil hydraulic conductivity over time.

Ohio "Exfiltration Trench"

- Appropriate for ultra-urban settings where roadways are curbed.
- Filter media infiltration rate will limit the capacity of the gutter filter. Must be used in conjunction with conventional curb inlets to adequately drain the roadway. Typical installation places infiltration trenches between drainage inlets to the roadway stormwater system.
- Do not install where backflow from the drainage system is likely.
- Under-drains should not be connected to the pavement underdrain system, rather provide a separate outlet, to avoid introducing runoff into the road sub-base material.

VTrans Micropool Filters

- Appropriate for highway applications in roadside swales and medians.
- Impoundment depths upstream of check dams should be limited to no greater than two feet.
- Need to consider placement of check dams outside of any designated vehicle recovery area.
- Maximum side slopes of swale: 3:1

- Design needs to consider stability of check dams under overtopping conditions.

- Longitudinal gradient of swales should generally be less than 5%, to control velocities and minimize erosion. Use of geotextiles reinforcement may be considered for steeper gradients on a case by case basis.

- Suitable for providing Channel Protection, if the practice is designed to meet the criteria stipulated in the Vermont Stormwater Management Manual:

    - Extended detention (ED) storage for the one-year, 24 hour rainfall event (12 hours extended detention for discharge to coldwater fish habitat, 24 hours extended detention for discharge to warm-water fish habitat);

    - Minimum recommended orifice size for controlling discharge rate is one inch. If the required storage is provided and the hydraulic analysis shows that a one-inch orifice is warranted, the design only needs to provide for the detention time achieved by the one-inch orifice size.

Minnesota Permeable Ditch Block

- Appropriate for highway applications in roadside swales and medians.

- Impoundment depths upstream of check dams should be limited to no greater than two feet.

- Need to consider placement of check dams outside of any designated vehicle recovery area.

- Design needs to consider stability of check dams under overtopping conditions; pilot application of this practice has exhibited structural problems under overflow conditions.

- Longitudinal gradient of swales should generally be less than 5%, to control velocities and minimize erosion. Geotextile reinforcement of the channel may be considered for steeper gradients on a case by case basis.

Consistency with Roadway Design Integrity

Gutter Filters, Ohio Exfiltration Trench

- Generally consistent with urban design roadway sections, where provision of the gutter filter can be integrated with curbing or barriers, as well as with other inlet structures designed to provide drainage conveyance capacity.

- Exfiltration trench should only be considered in locations where infiltration of water into pavement sub-base is not a concern.

- Both systems involve the use of relatively shallow depth trench box structures, which may be susceptible to lifting by frost action.

VTrans Micropool Filter, Minnesota Ditch Block

- Generally consistent with "country drainage" design cross sections. Installation of check dams should be sufficiently far from pavement edge to place them outside of vehicle recovery zones.

- They would not affect pavement structural integrity, as long as the berms are located a sufficient distance downslope so they do not impound water higher than the bottom of pavement sub-base materials.

- Other than measures to maintain sheet flow at the road shoulder, this practice requires no special pavement maintenance practices.

Cost Effectiveness

Information on the cost effectiveness of microfilter systems is limited. However, itemized costs for materials required for gutter filter installations can be found in LIDC, 2005 and LIDC et al., 2006.

Suitability for Cold Climate

Each of the described micro-filter systems may become saturated and freeze during extended periods of freezing temperatures. Runoff from storm events or meltwater following this freeze-up may bypass the filtration component of the device. These micro-filter systems may, therefore, have lower pollutant removal effectiveness during freezing conditions.

The Vermont ANR Stormwater Manual provides guidance for preventing freezing of the filter bed, freezing of underdrains, and clogging of filters with excess sand from runoff. Some of these guidelines that would be applicable to microfilters include:

- Avoiding the use of organic filters using peat and compost, which retain water and can freeze solid, becoming impermeable and slower to thaw.

- Combining treatment systems with another practice as a backup to the filtration, providing treatment when the filter bed is frozen.

- Careful consideration of the design of underdrain systems, including size of pipe and the depth and gradation of gravel filter drain materials, to assure effective drainage of the bed and reducing freezing in both the filter material and the underdrain.

- Inspection for debris and sediment build-up in the filter following the spring melt event.

Further considerations for cold climate stability in micro-filter systems can be found in the table below.

Micro-Filter Type	**Cold Climate Suitability**
Gutter Filter	Subject to blockage during winter if snow removal operation does not clear gutter line. Susceptible to clogging by leaf drop. Shallow structure design may be susceptible to lifting by frost action
Ohio Exfiltration Trench	Subject to blockage during winter if snow removal operation does not clear gutter line. Susceptible to clogging by leaf drop. Shallow structure design may be susceptible to lifting by frost action. Porous concrete design is problematic on roadways maintained by sand application (clogging of porous surface) or salt application (degradation of concrete).
VTrans Micropool Filter	Similar in application to roadside drainage channel systems of all types. Likely readily adaptable to cold climate applications.
Minnesota Permeable Ditch Block	Similar in application to roadside drainage channel systems of all types. Likely readily adaptable to cold climate applications.

Adaptability for Changing Climate

Micro-Filter Type	Adaptability for Changing Climate
Gutter Filter	Pollutant removal via physical filtration unlikely to be affected by climate change
Ohio Exfiltration Trench	Pollutant removal via physical filtration unlikely to be affected by climate change Porous concrete layer may clog or deteriorate more quickly if changes in climate prompt greater sand and salt application
VTrans Micropool Filter	Pollutant removal via physical filtration unlikely to be affected by climate change Resilience of swale vegetation depends on the diversity and climate sensitivity of plants in the original seed mix
Minnesota Permeable Ditch Block	Pollutant removal via physical filtration unlikely to be affected by climate change Resilience of swale vegetation depends on the diversity and climate sensitivity of plants in the original seed mix

Potential for ANR Acceptance

The microfilters described above are essentially variants of the sand filter, which is included in the ANR Stormwater Manual. To the extent that these microfilters can be designed either to meet the ANR design guidance or provide comparable performance, they are anticipated to have a reasonable likelihood for ANR acceptance. Specific comments applicable to each type of practice are as follows:

Gutter Filter

The gutter filter represents a variation of the ANR surface sand or perimeter filter, except for the gutter filter’s lack of pretreatment. The lack of pre-treatment is of concern, as the filter surface would likely require frequent maintenance to prevent deterioration in filter performance.

Literature reviewed for this study did not identify field studies specific to this device, although some of the information pertaining to the Ohio Exfiltration Trench may be applicable, especially regarding performance without pretreatment.

Ohio Exfiltration Trench

The Ohio exfiltration trench takes the variation of the surface or perimeter sand filter one step further with the porous pavement layer in place of inlet grates. The porous pavement itself serves as a pre-filter for runoff that passes through the device and into the underlying sand filter media.

Full scale laboratory studies have been performed for this practice (Mahboob, 2011 and Wawszkiewicz et al., 2011). Literature reviewed for this study did not identify data from field studies on actual installations.

VTrans Micropool Filter

The VTrans micropool filter combines the ANR dry swale treatment practice with a filter media similar to the ANR surface sand filter. The depth of media used in the micropool filter, however, exceeds the requirement for both surface sand filters and perimeter filters. The VTrans micropool filter design incorporates check dams with small impoundments, which could be considered a form of pretreatment.   The design also includes a surface soil layer that also provides additional filtration capability, as well as the opportunity for pollutant attenuation by microbial activity within the organic media and nutrient and metals uptake by vegetation.

With careful design of the storage pools and integral flow control structures to meet extended detention criteria specified for Channel Protection in the Vermont Stormwater Management Manual, the practice would achieve the Channel Protection objective.

The practice appears to reasonably combine practices already recognized by ANR, and should have a relatively high potential for acceptance.

Minnesota Permeable Ditch Block

Like the VTrans micropool filter, the Minnesota permeable ditch block design combines principles of the dry swale with surface sand filtration. Instead of sand, however, the media below the bottom of the swale is a fine filter aggregate that extends deeper than the minimum required for the surface sand filter. While the permeable ditch design does not specifically identify a pretreatment component, it provides a “micropool” settling basin component similar to the VTrans design. As with the VTrans design, the practice appears to reasonably combine practices already recognized by ANR, and should have a relatively high potential for acceptance.

Minnesota Department of Transportation is currently working with recent installations to study the performance of permeable ditch blocks. However, field study data are not available at this time.

Operation and Maintenance Considerations

Gutter Filter

Gutter filters are applicable for urban roadways and are required to be installed in the gutter line, adjacent to curbing. Inspection and maintenance of gutter filters may require parking and traffic control. Access for inspection and maintenance of the underdrain is provided with a combination of cleanouts and connections to catch basins or drainage manholes. Restoration of the filter media requires the use of a vacuum truck for removal of clogged media.

The gutter filter's small footprint and lack of pretreatment could create a need for frequent cleaning and media restoration, with associated disruption of routine traffic and parking; this may be of special concern in ultra-urban areas that depend on on-street parking.

The gutter filter is likely problematic for areas depending on use of sand for snow and ice management, as applied sand may fill the filter and interfere with its normal operation.

Ohio Exfiltration Trench

Similar in placement to the gutter filter, the Ohio exfiltration trench may also require parking and traffic control for inspection and maintenance. Also, with a small footprint and no pretreatment, the exfiltration trench may require frequent cleaning. Removal of sediment from the porous pavement layer requires a regenerative air sweeper.

The porous concrete layer is likely problematic for sand and salt application.

Inspection of the filter system is achieved by observing the infiltration rate from the pavement surface. Access to the filter media is limited and repair requires excavation and re-construction of the trench.

VTrans Micropool Filters & Minnesota Permeable Ditch Blocks

The VTrans micropool filter and Minnesota permeable ditch block are located off-pavement. Depending on their proximity to the edge of pavement and the accessibility for equipment and personnel for maintenance, these microfilter systems would not typically pose particular concerns for safety. Both the micropool filter and permeable ditch block can be maintained with a minimum disruption to the use of the roadway. Access for inspection and maintenance of the micropool filter underdrain is provided with a series of cleanouts.

Major rehabilitation work for these microfilter systems would likely be infrequent, though it would require the use of construction equipment. Including runoff pretreatment in the application of these microfilter systems (e.g., use of a grass filter strip between the edge of pavement and filter) will help extend service life between cleanings. The vegetated surface also helps maintain porosity despite the accumulation of sediments in micropools upstream of the check dams. Either of these filter types appears compatible with routine maintenance practices for Vermont roadways.

Typical inspection and maintenance requirements for each type of Microfilter are further described below:

Micro-Filter Type	**Inspection**	**Maintenance**	**Repair**
Gutter Filter	Monitor for signs of filter failure (e.g., first flush is bypassing system) Annual spring inspections of the concrete structure for cracking and spalling Inspect underdrain regularly	Debris removal from surface Removal of grate, clean surface of filter media Clean underdrain as warranted by inspection	Replacement of filter material when contaminated by debris
Ohio Exfiltration Trench	Inspect underdrain regularly (inspection/ cleanout ports should be provided)	Debris removal from surface Regenerative air sweeping of concrete surface Clean underdrain as warranted by inspection	Repair pavement surface as necessary Replace pavement and underlying media as necessary Note: If cast-in-place pervious concrete is used for the surface, there is no way to directly inspect or maintain the filter media without removing (and subsequently replacing) the surface pavement

Micro-Filter Type	Inspection	Maintenance	Repair
VTrans Micropool Filter	Inspection of underdrain Monitor dewatering rate as an indicator of filtration performance Monitor check dams for signs of erosion and breaching Monitor vegetation for loss Monitor for erosion of the channel bottom and side slopes	Mowing Debris cleanup Clean underdrain as warranted by inspection	Reconstruct filter layer as warranted by observation of extended ponding (indicator of loss of filtration capacity) Repair and stabilize check dams with signs of erosion and breaching Restore vegetation with signs of loss or disease Re-grade and replant for stability with signs of erosion
Minnesota Permeable Ditch Block	Inspection of underdrain Monitor dewatering rate as a sign of filtration rate Monitor check dams for signs of erosion and breaching Monitor vegetation for loss Monitor for erosion of channel and side slopes	Mowing Debris cleanup Clean underdrain as warranted by inspection	Reconstruct filter layer with observation of extended ponding Repair and stabilize check dams with signs of erosion and breaching Restore vegetation with signs of loss or disease Regrade and replant for stability with signs of erosion

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Open Channel Practices: Bioswale

Description

Bioswales are essentially linear bioretention systems.[13] They consist of vegetated swales modified to filter stormwater through bioretention media. The media layer may drain directly via infiltration into the underlying soil or alternatively, the bioretention material may be underlain by an aggregate drainage layer and perforated pipe designed to convey the captured runoff to a downstream drainage structure or outlet.

Bioswales not only provide stormwater conveyance, but also accomplish pollutant removal through sedimentation, enhanced filtration, and nutrient uptake. Biological activity within the bioretention soil media and nutrient uptake through vegetation contributes to the pollutant removal. The use of bioswales may reduce runoff volume and peak runoff rate through retention within the swale and underlying media. The addition of a gravel layer beneath the bioretention soil media may enhance the infiltration capacity of the swale by providing temporary storage, allowing time for infiltration to occur.

Vegetation in a bioswale must be tolerant of extended periods of inundation and prolonged time periods of dryness between storm events. Depending on the width of the swale and prevailing groundwater conditions, vegetation planted in the bottom of the swale may need to differ from vegetation planted along the upper slopes, to account for differences in exposure to inundation.

The design of the swale for conveyance capacity must consider the density and height of plantings. Check dams may be used to act as flow spreaders to maintain sheet flow along the width of the bioswale under low-flow conditions. Check dams may also be used to increase detention and create infiltration cells to offset the effects of slope where channel gradients are greater than 4%.

Stormwater Management Processes

- Sediment settling as dense vegetation slows stormwater flow velocity or check dams (optional) increase flow detention

- Pollutant treatment via physical filtration, biological and chemical processes in topsoil, sod, and bioretention soil media, which provides a growth substrate for both plants and microbes

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[13] Some literature references to bioswales refer to stormwater practices with different designs or treatment mechanisms than what is presented in this document.

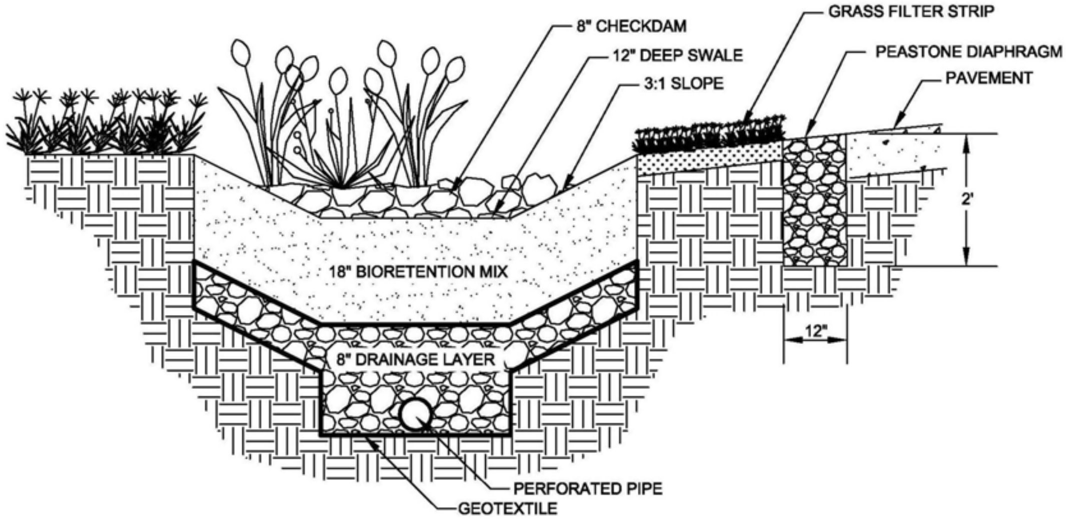
- Pollutant removal via plant uptake (grasses, wetland and non-wetland plants) and nutrient cycling
- Stormwater runoff volume reduction via infiltration and storage in void spaces within permeable bioretention media and underlying gravel
- Further incidental stormwater volume reduction via interception and evapotranspiration provided by plants

Advantages and Disadvantages

Advantages:	**Disadvantages:**
Variation on STP technology already included in the Vermont Stormwater Management Manual Treatment occurs through multiple pollutant removal mechanisms Compact design is versatile and appropriate for linear roadways, urban and ultra-urban settings Readily adaptable to roadside drainage channels, with or without infiltration into underlying soils Reduces stormwater flow volume and velocity Can be designed to add to the aesthetic value of an area with vegetation chosen Adaptable to cold climate and changing climate conditions Relatively low installation, operation and maintenance costs	Need line and under-drain where used to treat runoff from "hot spots" (cannot be used with infiltration function). Failure of filtration media over time would require reconstruction of the bioswale area Limited removal and in some cases negative removal (i.e., export) of nitrate-nitrogen[1]

[1] Net export of nitrate-nitrogen due to the incomplete transformation of organic nitrogen within bioretention areas (Hunt, 2003). Some sources also indicate a net export of phosphorus.

Illustration



Bioswale section with underdrain[14] **(Source: http://www.starkvillestormwater.com/bioswale-design.html)**

[14]The bioswale may also be designed without an underdrain, to infiltrate into the ground where soils and groundwater conditions are favorable.

Target Pollutants and Treatment Effectiveness

	Pollutant Removal (by source study)			
	BMP Database Report: Bioswale	**BMP Database Report: Bioretention**	**Jurries, et al.** [15]	**University of New Hampshire Stormwater Center (UNHSC)**[16]
Metals				
Total Copper	36%	48%	46%	
Total Zinc	25%	73%	63%	99%
Total Lead	49%		67%	
Nutrients				
Total Nitrogen		21%		
Total Phosphorus	-67%		29% - 80%	5%
Nitrate-N			39% - 89%	
Solids				
Total Suspended Solids	52%	80%	83% - 92%	99%
Turbidity			65% [17]	

Selection and Design Considerations

Considerations for selecting and designing this stormwater treatment practice can be found below:

Siting and Design Considerations:

- Roadside ditches provide significant potential as bioswale sites
- Channel slope 1% to 5%

[15] This report does not present data in a way that its original source can be verified.
[16] Bio II system, combination sedimentation and bioretention
[17] Nine minutes residence time.

- Longitudinal slope: 1.5% to 5%
- Length to width ratio: 5:1
- Cross-section should be trapezoidal
- Side slopes: 3H:1V or flatter
- Provide an underdrain unless designed to infiltrate
- Provide level spreader at the entrance end of swales with a bottom width > 6 ft.
- Where swale is designed to infiltrate, provide vertical separation from bottom of bioretention media to ESHGW of 3 ft. minimum
- Vegetative plantings (grass) must be relatively salt-tolerant, able to withstand high flow velocities under wet weather conditions, and tolerant of extended dry periods between storm events.

For further design guidance, refer to one or more of the following references:

- WSDOT, 2008
- LIDC, 2005
- LIDC et al., 2006
- Jurries, 2003

Consistency with Roadway Design Integrity

Bioswales comprise a variation on roadside channel design and are not generally anticipated to adversely affect the performance of the pavement surface or roadway base.

- Bioswales are appropriate to treat runoff from adjacent roadways or paved areas of varying vehicle loads or traffic volumes.
- Bioswales do not affect the life expectancy of the pavement.
- Maintenance may be required to address sand/debris accumulation at the edge of roadway that would interfere with sheet flow from the pavement surface. Otherwise, bioswales do not require special pavement maintenance practices.
- As with any roadside channel, bioswale design should consider the elevation of the channel relative to pavement sub-base materials, to allow for proper sub-drainage of the pavement system.

Cost Effectiveness

The Low Impact Development Center found that installation of a bioswale in Fairfax, Virginia cost about $20,000 per acre of impervious area treated in 2005 dollars. The cost for maintenance (mowing and reseeding/replanting) was about $400 per year per impervious acre treated (LIDC, 2005) over the assumed 25-year lifespan of the STP.

Some other considerations regarding cost include:

- Weiss et al. found the cost per unit of water quality volume to decrease as the treated water quality volume increased (Weiss et al, 2007).

- Soil type significantly affects the cost of installation for bioretention practices. Construction costs may be up to 16 times greater for clay than sandy soils (Weiss et al., 2003).

- Annual maintenance costs for bioretention practices may range from 1% to 11% of the construction costs (Weiss et al., 2005).

Suitability for Cold Climate

A study from the University of New Hampshire Stormwater Center indicates that BMPs relying upon filter media for treatment sustain their performance in cold climate conditions; pollutant removals differ minimally between warm and cold seasons despite the dormancy of vegetation during the cold season (Roseen et al., 2009).

Adaptability for Changing Climate

Initial plantings should include a variety of species, diverse in sensitivity to climate changes, to ensure that bioretention plantings are robust. Changes in climate may cause sensitive vegetation to die, prompting less sensitive vegetation to take over. If the diversity of plantings is not enough for the BMP to adapt to the changing climate, the vegetation must be replaced with new plantings appropriate to the prevailing climate.

Potential for ANR Acceptance

The bioswale essentially combines an open channel design with bioretention. As both the bioretention and the open channel systems are included in the Vermont Stormwater Management Manual, bioswales have a high potential for ANR acceptance.

Operation and Maintenance Considerations

Routine inspection of bioswales is the primary maintenance practice. Inspections should monitor for:

- vegetative cover and health,

- soils stability (erosion),

- flow channelization, and
- infiltration capacity (water-logging).

In addition, maintenance activities include:

- periodic mowing (never below the height of the water quality design depth),
- clearing debris, and
- removing sediment.

Repair or restoration activities include:

- reseeding or replanting bare areas (as warranted by annual inspection), and
- stabilizing and re-vegetating eroded areas when evident.

Bioswales do not require special operational or safety considerations. Inspection and maintenance can be achieved using standard procedures, without significant interruption of traffic. Bioswales can be maintained using equipment conventionally used for maintenance of highway embankments.

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Non-structural Practices: Vegetated Buffers

Description

Vegetated buffers consist of natural or established vegetated areas adjacent to the roadway. They may involve the preservation of existing vegetated areas or the development of planted strips to filter stormwater runoff. Vegetated buffers differ from "vegetated filter strips" in that buffers encompass a wider expanse of land adjacent to the roadway typically including more dense vegetation such as trees and shrubs at a consistently shallow slope to enable stormwater to runoff as sheet flow. Vegetated buffers are often associated with riparian areas adjacent to waterbodies.

The Vermont ANR Stormwater Management Manual provides for vegetated filter strips for pretreatment for various stormwater treatment practices, and also indirectly provides for natural buffers through stormwater management credits for rooftop and non-rooftop disconnection. However, these practices are generally limited to buffers with slopes less than 5%. Recent research literature suggests that there may be a broader range of applicability for both designed filter strips and natural buffers, including accounting for removal of other pollutants such as phosphorus.

- A study done at Ohio University, sponsored by the Ohio Department of Transportation, tested simulated vegetated buffers at varying slopes and found that, while pollutant removals varied between 2:1 (50%), 4:1 (25%) and 8:1 (12.5%) slopes, the variances were not significant (Mitchell et al., 2010). The same study found that greater variability of performance was likely at steeper slopes, and recommended that slopes flatter than 2:1 be used in the field (Mitchell et al., 2010).

- A study sponsored by California Department of Transportation revealed effective sediment removal in a highway embankment with a 50% slope (Lantin and Alderete, 2002).

- A study sponsored by the Kansas DOT supported the use of typical highway embankments (around 6:1 (~17%) slopes) as vegetated filter strips, though noted that steeper (3:1 or 2:1) slopes may be used to provide stormwater treatment benefits as well (Ebihara et al., 2009).

- A study done at the University of Texas at Austin for two highway embankment vegetated filter strips showed effective pollutant removals at 10-15% slopes (Barrett et al., 1997).

- The Oregon Department of Transportation (ODOT) is currently incorporating low impact development approaches with respect to roadside BMPs/STPs in their draft water quality guidance. As part of this guidance, ODOT will encourage stormwater treatment through preserving roadside vegetated buffers in their natural state.

- Since the early 1990’s, the Maine DEP has developed guidance for forest and meadow buffer areas on varying slopes to meet stormwater treatment objectives, with specific provisions for phosphorus treatment credits. This guidance provides for vegetated buffer widths based on soils, slope, and vegetation treatment, designed to meet phosphorus removal objectives, with slopes as steep as 15% allowed.

A general review of these sources suggests that application of vegetated buffers may be effective not only for solids removal, but also for reducing other pollutants, and that effective results may be achieved on slopes as steep as 2:1 (50%).

Furthermore, there are a number of configurations for using vegetated buffers; examples are found in current stormwater management guidance published by Maine DEP and New Hampshire DES. These include buffers used to intercept sheet flow directly from the road shoulder, and buffers used in conjunction with conveyance measures and level spreaders. The latter measures allow taking advantage of natural or landscaped vegetative buffers where sheet flow cannot be achieved at the edge of traveled way, but where topographic conditions provide for suitable slopes in the near vicinity.

Stormwater Processes

- Reduces volume and peak discharge rates of stormwater runoff through interception, evapotranspiration, infiltration, and lengthened times of concentration

- Reduces velocity of stormwater, increasing time of concentration and promoting deposition of particulates

- Provides physical filtration through soil and plant stem and root structure

- Provides biological pollutant removal through vegetation uptake and microbial action

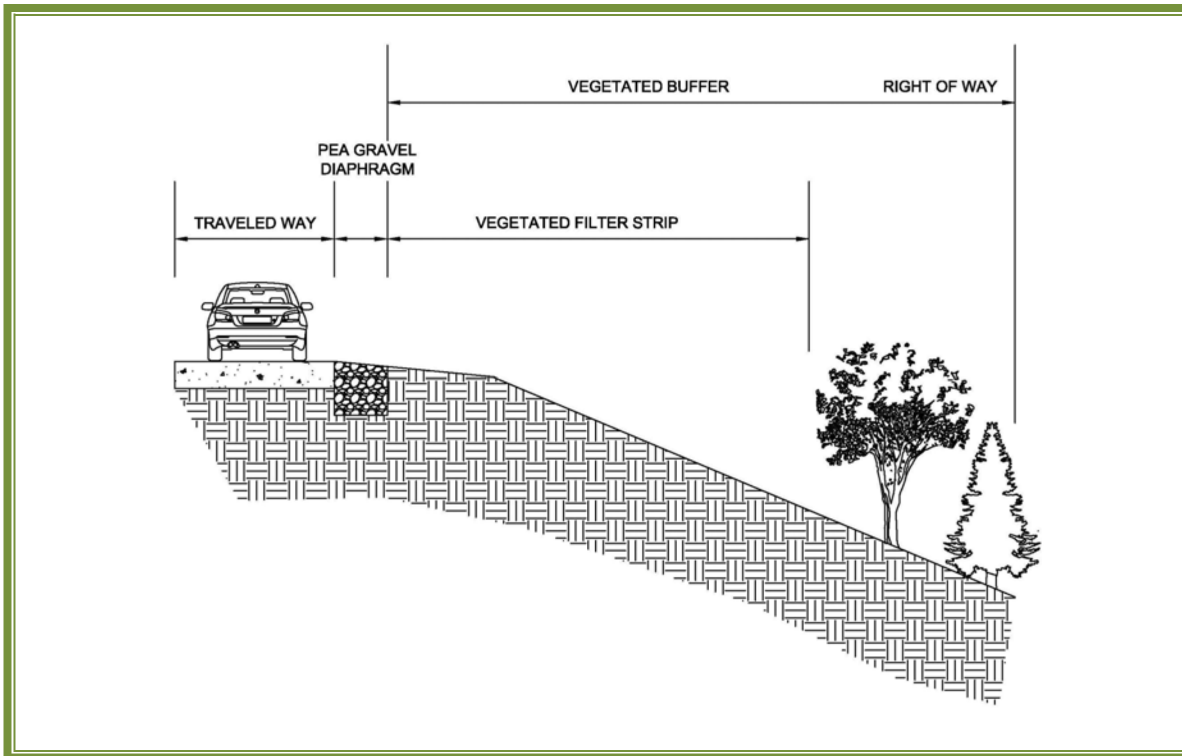
- Shaded buffers reduce thermal impacts of runoff to receiving waters

On an annual basis, areas of vegetation, particularly forested areas, can contribute significantly to the reduction of runoff volume, through interception and evapotranspiration.

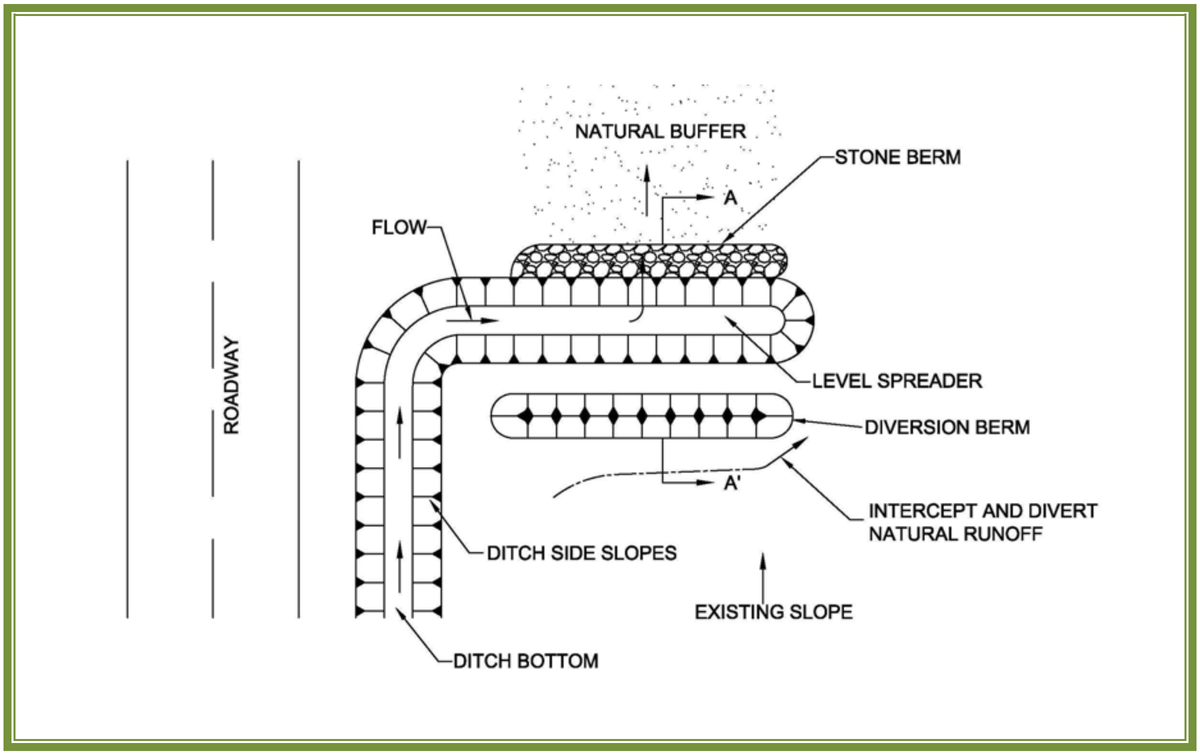
Advantages & Disadvantages

Advantages:	Disadvantages:
Maintains and may preserve natural landscape Highly suitable for highway embankments Less costly than structural treatment practices Adaptable to cold climate and changing climate conditions; may require adaptive management to assure vegetative species are compatible with new conditions	Applicability is limited where slopes result in concentration of flows; sheet flow must be maintained for maximum effectiveness

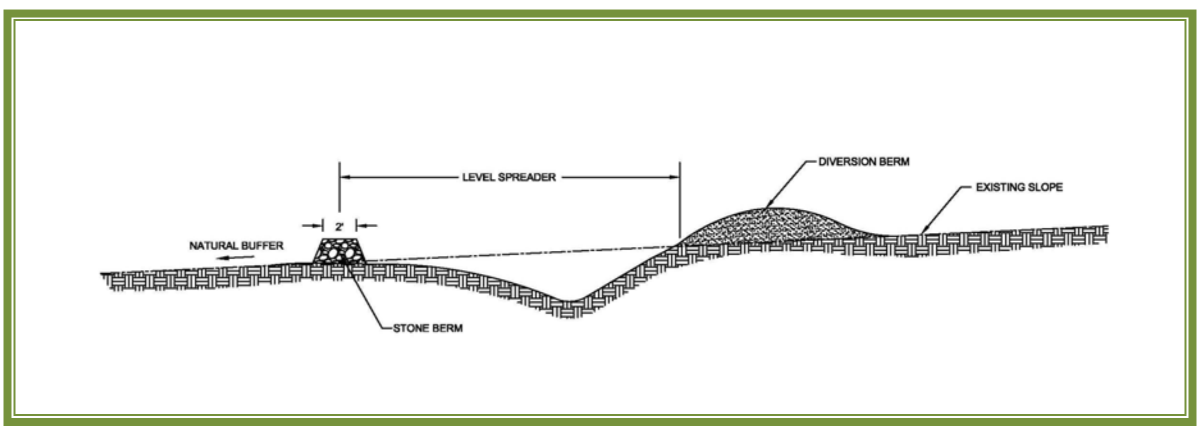
Illustrations



Vegetated buffer with pea gravel diaphragm for pretreatment



Roadside ditch turnout to a vegetated buffer – plan view (adapted from Maine DEP, 2006)



Roadside ditch turnout to a vegetated buffer – cross section A-A (adapted from Maine DEP, 2006)

Target Pollutants and Treatment Effectiveness

Pollutant	Pollutant Removal (by source study)						
	Mitchell et al., 2010[18]	Lantin & Alderete, 2002[19]	Ebihara, 2009[20]	Barrett et al., 1997[21]	Wright et al., 2011[22]	Geosyntec et al., 2011[22]	Barrett et al., 2006[23]
Total Copper	96%		11%		69%		
Total Iron				77%	38%		
Total Lead	98%			29%			17% - 41%
Total Zinc	94%		85%	83%	76%		75% - 91%
Total Phosphorus				39%			-21% - 45%
Nitrate							23% - 50%
TSS	83%	72%		86%		64%	50% - 87%

Selection and Design Considerations

General Considerations

- Buffers should be located directly adjacent to the stormwater runoff source
- Maximum slopes of 15% are recommended in other New England states such as Maine and New Hampshire. A study from Ohio University advises that greater slopes can be considered, though flatter than 2:1 (50%) are advisable (Mitchell et al., 2010)

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[18] Laboratory study of simulated grassed filter strips. Pollutant removals shown represent 2:1 slopes with "high" flows (7.5 in/hr) of simulated runoff.
[19] Several field sites; highway embankments as grassed filter strips.
[20] Average of three field sites; highway embankments as grassed filter strips.
[21] Average of two field sites; highway embankments as grassed filter strips.
[22] Values from these reports are from the ASCE BMP Database, for vegetated filter strips.
[23] Three field sites; highway embankments as vegetated buffers.

- Slope of buffer should be planar or convex to prevent flow channelization and maintain sheet flow

- Runoff flow must enter the buffer as sheet flow; a stone-berm level spreader graded parallel to the contour may be provided for larger drainage areas

- Buffer area should not be interrupted by intermittent or perennial streams, swales or drainage ditches

- Vegetative cover type will affect sizing (forest, meadow, or combined)

- Hydrologic soil group will affect sizing

Consistency with Roadway Design Integrity

Vegetated buffers are generally consistent with the design integrity of roadways. Buffers are appropriate for both low- and high-volume roadways and do not require special maintenance practices for the roadway itself. Maintenance practices are also generally consistent with typical highway maintenance.

For limited access and arterial roadways, vegetation within the right-of-way may need to be selected and controlled to maintain herbaceous (grass) cover and minimize woody vegetation that may interfere with sight-lines or become roadside obstacles. Also, some dense canopy conditions can exacerbate localized icing conditions, by preventing exposure to sunlight to promote melting.

Cost Effectiveness

Cost to install vegetated buffers can range from nearly no cost (where vegetation within the right of way can be preserved) to moderate or even high costs where extensive landscaping is required and/or where easements are needed to place the buffer under VTrans control. In some cases, even with a native stand of vegetation, a level spreader may be necessary to achieve sheet flow at the top of slope.

The use of vegetated buffers for stormwater treatment may offset costs typically required for stormwater infrastructure. Buffers usually require no “replacement,” and therefore have low operation and maintenance costs. The use of a vegetated buffer may also lower the maintenance costs for downstream BMPs/STPs (City of Chicago et al., 2003).

Suitability for Cold Climate

Some studies claim that vegetated practices such as a buffer become ineffective with frozen soils (Storey et al., 2009). Studies from the University of New Hampshire Stormwater Center (UNHSC) suggest, however, that infiltration continues to be effective for stormwater treatment through colder weather (Roseen et al., 2009); further research may be warranted to determine whether the UNHSC can be extended to vegetated buffers.

Adaptability for Changing Climate

The resilience of vegetated stormwater treatment practices for climate change depends greatly on the climate tolerance of the vegetation. For vegetated buffers that preserve the natural vegetation in an area, species composition may need to be monitored to assure that climate change does not result in colonization by exotic invasive species, with corrective action if warranted to control such species. For landscaped buffers, a variety of species diverse in climate tolerance should be used. With climate change, stormwater management practices that rely on vegetation may require monitoring for intrusion of invasive species, with corrective action as warranted.

Potential for ANR Acceptance

Vegetated filter strips are currently presented in the Vermont Stormwater Management Manual for pretreatment and recharge. Performance studies suggest that the vegetated buffer provides treatment comparable in effectiveness to structural stormwater practices; this warrants further exploration of ANR credit for this practice as a treatment measure.

Vegetated filters are implicitly accepted as a treatment and recharge practice for those roof and paved surfaces that can be "disconnected" in accordance with the Vermont Stormwater Management Manual. The literature suggests further exploration with ANR for providing this disconnection credit when slopes exceed 5%.

Based on the information reviewed, likelihood of ANR acceptance of vegetated buffers as stormwater treatment practices and on greater slopes appears moderately high.

Operation and Maintenance Considerations

Inspection of vegetated buffers includes monitoring:

- Soil for signs of channelized flow or erosion
- Vegetative health
- Signs of waterlogging or poor infiltration
- Intrusion by invasive plant species

Maintenance of vegetated buffers includes:

- Typical practices such as weeding, pruning, mowing (for grassed, non-wooded buffers)
- Replacing or repairing vegetation as needed
- Repairing eroded or channelized areas based on inspection

- Removal of accumulated sediment within the vegetated buffer and at the top of slope (to prevent formation of a flow-restricting berm)

Generally, vegetated buffers require minimal maintenance. The maintenance that is required is also within typical highway practices. Maintenance and inspection can typically be performed without significant interruption of traffic or use of exceptional equipment.

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Limited Applicability Practices:
Open Graded Friction Course

Description

Open Graded Friction Course (OGFC) is a permeable surface of hot mix asphalt pavement. It is typically used on limited access roadways as a surface treatment when prescribed under applicable pavement selection and design protocols.

While OGFC is permeable, its typical application comprises placement as an overlay on conventional asphalt base material. It therefore differs from "pervious pavement" in that water penetrates and flows through the surface course, but does not infiltrate the underlying pavement structure.[24] Water then flows laterally over the dense asphalt sub-surface to the edge of pavement.

OGFC allows water to drain from the driving surface below the tire-pavement interface, reducing hydroplaning, tire spray and tire noise while improving skid resistance and visibility. However, because of its open-graded material, it does not have the structural characteristics of conventional dense-graded asphalt, and its use is therefore limited to areas where pavement is not subject to high stresses of frequent vehicle turning, acceleration, and breaking activity.

Recent research has shown that the use of OGFC results in significantly lower amounts of pollutants in runoff than observed for conventional pavement. Where the material is selected for use as a pavement surface, this additional environmental benefit warrants including this practice in the array of BMPs/STPs available to the roadway designer.

Stormwater Management Processes

From the literature published to date, further research appears required to more fully understand the processes that result in lower pollutant concentrations and loads from open graded friction course. Initial findings suggest that the primary reason for reduced pollutant discharges from this type of pavement may be that the reduction in splash and spray minimizes vehicular "wash-off." The retention and treatment of pollutants in the pavement surface itself may be limited. Essentially then, OGFC can be considered a form of source control.

This practice does not typically contribute to runoff volume reduction.

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[24] Research continues to be conducted into the use of permeable pavements. These pavement systems have the potential to improve safety, reduce runoff and reduce noise. Permeable pavement materials may be used to construct full-depth porous pavements or surface friction courses. Full-depth porous pavements are discussed elsewhere in this document.

Advantages and Disadvantages

Advantages:	**Disadvantages:**
Primary reason for selecting OGFC is its safety benefits, as well as noise reduction Where this is a viable paving surface alternative for safety considerations, it provides the additional benefit of reduced stormwater pollutant discharge Readily adaptable to existing roadway surfaces, as well as new roads	This type of surfacing can only be used for • travel lanes and shoulders of limited-access highways • surface course of pervious pavement Cannot be used where snow and ice management requires use of sand May require pre-treatment with ice management materials prior to an expected storm event Service life is less than conventional asphalt surface, although ongoing research of materials has resulted in improvements in life expectancy Because surface material is typically only available on a job-specific basis, patching of damaged areas may require the use of dissimilar paving materials Stormwater management benefits limited to water quality treatment; does not provide benefits for recharge, channel protection, or flood control

Illustration

Open-graded friction course (left) compared with conventional pavement (right) (Barrett & Shaw, 2006, used with permission)

Target Pollutants and Treatment Effectiveness

Pollutant	**OGFC Pollutant Reduction Relative to Conventional Pavements (by Source Study)**			
	Barrett & Shaw, 2006[25]	**Barrett et al., 2005[25]**	**Barrett et al., 2006[25]**	**Pagotto et al., 2000**
TSS	91%	93%	94%	81%
Total Phosphorus	35%			
Total Copper		79%	75%	35%
Total Lead	90%	95%	93%	78%
Total Zinc	75%	73%	76%	66%

[25] Pollutant removals observed were not based on flow-weighted concentrations. Some of the sites and data are redundant amongst these studies.

Selection and Design Considerations

Siting and Design Considerations

- OGFC should only be used where warranted by pavement design (including traffic and safety reasons)
- Serves incidentally as a stormwater management practice
- Applicable for high-volume limited access roadways
- Not effective as a stormwater management practice where sand is used for snow and ice management
- Appropriate for roadway retrofit projects
- Maximum cross slope: 2%
- If this pavement option is to be used in Vermont, further study by VTrans pavement design personnel should be conducted to determine acceptable materials composition consistent with availability of aggregates, binder materials, and other pavement mix products used in Vermont
- Prohibition of the use of reclaimed materials may need to be considered for OGFC
- Consider the use of epoxy pavement markings in the place of thermoplastic pavement markings. Experience by other agencies has indicated that stability/longevity of markings can be problematic

Note that the same material used for open graded friction course may also be used as a surface course for pervious asphalt pavement.

Consistency with Roadway Design Integrity

Safety benefits comprise the primary reason for selection of this type of pavement. Removal of water from the surface reduces the potential for hydroplaning, and also reduces spray, increasing visibility during rainfall events. The use of this pavement surface is restricted to travel lanes and shoulders of limited access highways, and as a surface treatment for pervious asphalt pavement.

The installation of OGFC, if provided through VTrans pavement selection and design practices, would be generally consistent with the integrity of the roadway design, and not restrict vehicle loads or traffic volumes. OGFC surfaces do not typically require a change in the design of the pavement subgrade. These surfaces discharge runoff to the pavement shoulder as conventional pavement would do.

The studies cited report that data is available to show the durability of OGFC as the pavement surface ages, and also that its treatment performance persists as it ages.

A survey done for the Transportation Research Board shows that the average life of OGFC is 7.3 years. The longest lifespan was reported at 15 years, or roughly half that of conventional pavement (Huber, 2000)[26]. The operating life of OGFC can be increased by the use of asphalt modifiers (e.g., mineral wool, cellulose fiber), which increases cost as well. A study by Mallick et al. shows that the addition of modifiers can counteract material losses due to abrasion, which increase for coarser materials. Modifiers can also increase the durability of OGFC for freeze-thaw cycles (Mallick et al.).

Special pavement maintenance practices are required, however. See further discussion under Operation and Maintenance Considerations below.

Cost Effectiveness

A comparison of a limited representation of unit bid prices for OGFC with those for conventional hot mix asphalt materials in Massachusetts indicates the costs of the materials are generally comparable (MassDOT, 2011). The Transportation Research Board notes that OGFC with an unmodified asphalt binder is 6 to 38% more expensive than dense mix asphalt, while the use of a modified binder can increase OGFC costs 50 to 80% greater (Huber, 2000). Another primary cost differential between OGFC and conventional asphalt would be a function of service life.

Suitability for Cold Climate

OGFC is suitable for cold climates and its stormwater benefits remain during the cold season. However, OGFC should not be applied where sanding is used for snow and ice management due to potential clogging of the void spaces, and other snow and ice management practices may require modification to prevent freezing of water within interstitial pore spaces of the surface.

Adaptability for Changing Climate

Use of this material does not appear to be sensitive to changes in temperature or precipitation patterns associated with climate change.

Potential for ANR Acceptance

As noted above, runoff from OGFC results in a lower discharge of contaminants compared to conventional pavements. There have now been several studies showing the pollutant removal performance associated with this type of surface. Pagotto (2000)

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[26] Huber (2000) did not include information regarding the sustained permeability of OGFC throughout this lifespan. Later study by Eck, et.al., 2011 (pending) indicates permeability is not adversely affected by age. CEI personal communication with MassDOT indicates life expectancy may exceed these values.

describes a field study that appears to meet the ANR criteria for verification of new technologies. Other studies cited are supportive, although removal rates reported in those studies are not based on flow-weighted data. A study by Eck, et.al., (2011, pending publication) is cited in the references, and provides the most recent analysis of performance of this material, further reinforcing its effectiveness in reducing stormwater pollutant discharges compared with conventional asphalt pavements.

At the very least, it is recommended that OGFC be considered an accepted measure for pretreatment under ANR regulatory requirements. However, the performance studies indicate higher credit for pollutant removal for this type of surface is warranted.

Operation and Maintenance Considerations

Access for inspection and maintenance is comparable to conventional pavement.

Primary concerns regarding operation and maintenance practices for OGFC are as follows:

- Routine patching of damaged areas may require the use of conventional asphalt, which may locally affect the drainage performance of the OGFC, depending on how extensive the repair area is.
- Vacuum sweepers (versus conventional brush sweepers) should be used for pavement cleaning.
- OGFC should not be used with winter sand application.
- This type of surface may require pre-treatment with deicing agents when wet, freezing weather is anticipated, to prevent ice formation in the pavement voids.

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Limited Applicability Practices:
Forebay with Forced Hydraulic Jump

Description

A Stormwater Treatment Forebay can be designed to maximize sediment capture by conversion of turbulent inflow to laminar flow at the forebay inlet, and by sizing the surface area of the forebay and providing a weir-controlled overflow discharge to maximize discrete particle settling (Type 1 sedimentation). In this document, this practice is referred to as a Forebay with Forced Hydraulic Jump.

Where a stormwater pipe or channel discharges into a forebay with a permanent pool (or a forebay that fills with impounded water before subsequently discharging into a downstream treatment practice or receiving water), there is a transition from the high-energy flow regime in the conduit to the relatively low energy, quiescent flow in the pool. The high-velocity, high energy, turbulent flow in the conduit results in mixing that entrains the stormwater sediment load. The sudden loss of energy and velocity as the discharge enters the relatively quiescent pool reduces sediment carrying capacity of the discharge, essentially resulting in the formation of a delta in the inlet end of the forebay. The quiescent conditions in the forebay, and withdrawing overflow from the surface of the impounded water, allows for further Type-1 sedimentation to occur, maximizing the forebay's role in clarifying the stormwater of all but the finest suspended materials.

In this design, the incoming pipe or channel is configured to provide turbulent supercritical flow velocities, to keep sediment in suspension in the conveyance system. At the point of discharge, the design provides for a "backwater" condition imposed by the receiving pool at the outlet end of the conduit. This condition results in an instantaneous drop in velocity to sub-critical flow, with velocities designed to be below the scour velocity, which results in the hydraulic jump and sediment deposition. Instead of sizing the forebay to a "rule of thumb" criterion (e.g., specified fraction of water quality volume), the forebay pool is designed with sufficient cross section area to result in a transition to relatively laminar flow downstream of the inlet. This design promotes the sudden energy transition (hydraulic jump) to initiate the deposition of entrained sediment.

Furthermore, the forebay surface area, relative to the design flow rate, is designed to maximize settling of suspended material through Type-1 sedimentation (i.e. down to silt-size particles, where feasible). The forebay outlet must be designed to withdraw water from the <u>surface</u> of the impounded water for subsequent treatment and/or ultimate discharge, for this clarification process to be most effective. For a stormwater system retrofit, this device can be used as a "stand-alone" practice. For a new STP system, especially in a watershed that has a high sediment load (because of size, topography, soils, or urbanization), this device can provide advanced pre-treatment to protect and enhance subsequent STP components of the treatment train.

This practice was used in conjunction with another forebay to successfully treat stormwater runoff from a major stormwater system discharge (42-inch storm drain collector system) serving a highly urbanized area draining to Nutt's Pond in Manchester, New Hampshire. The design effectively removed sediment and associated adsorbed phosphorus, resulting in significant improvements in the water quality of the pond.

Stormwater Management Processes

This practice uses physical sediment removal mechanisms for water quality treatment:

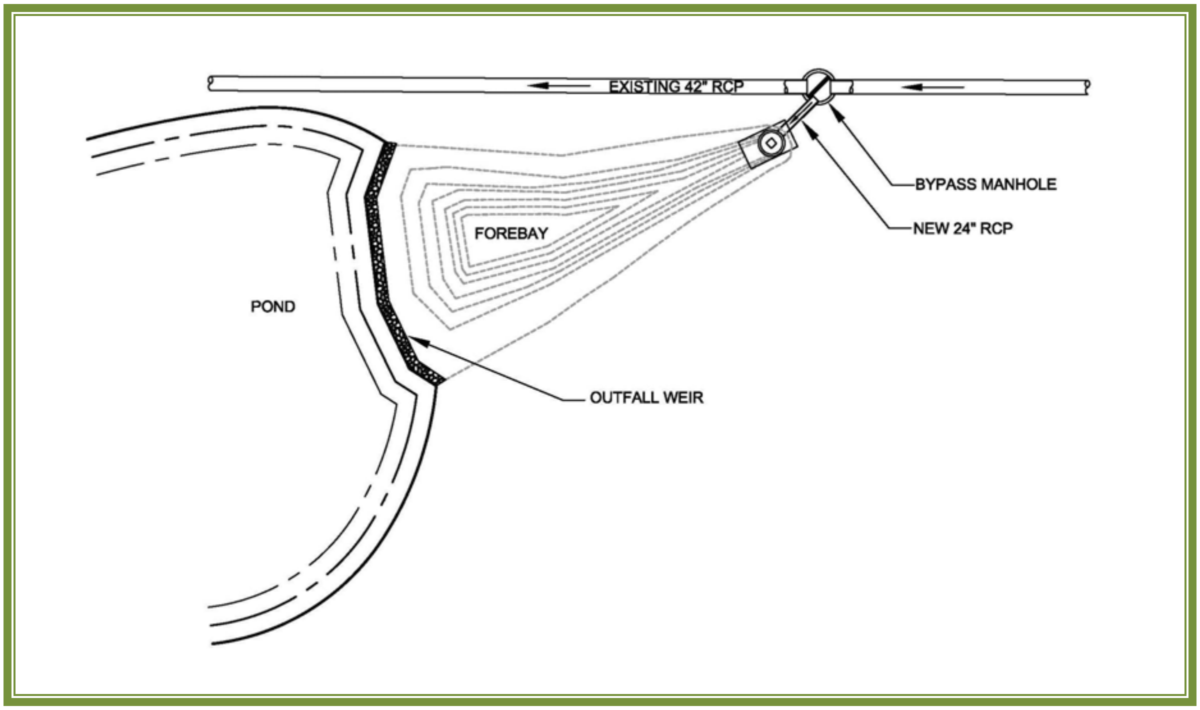
- Precipitation of entrained sediment by converting turbulent to laminar flow and a sudden reduction in velocity/energy at the inlet to the device;
- Sedimentation through discrete particle settling based on Stoke's Law (Type 1 sedimentation).

This practice does not typically contribute to runoff volume reduction.

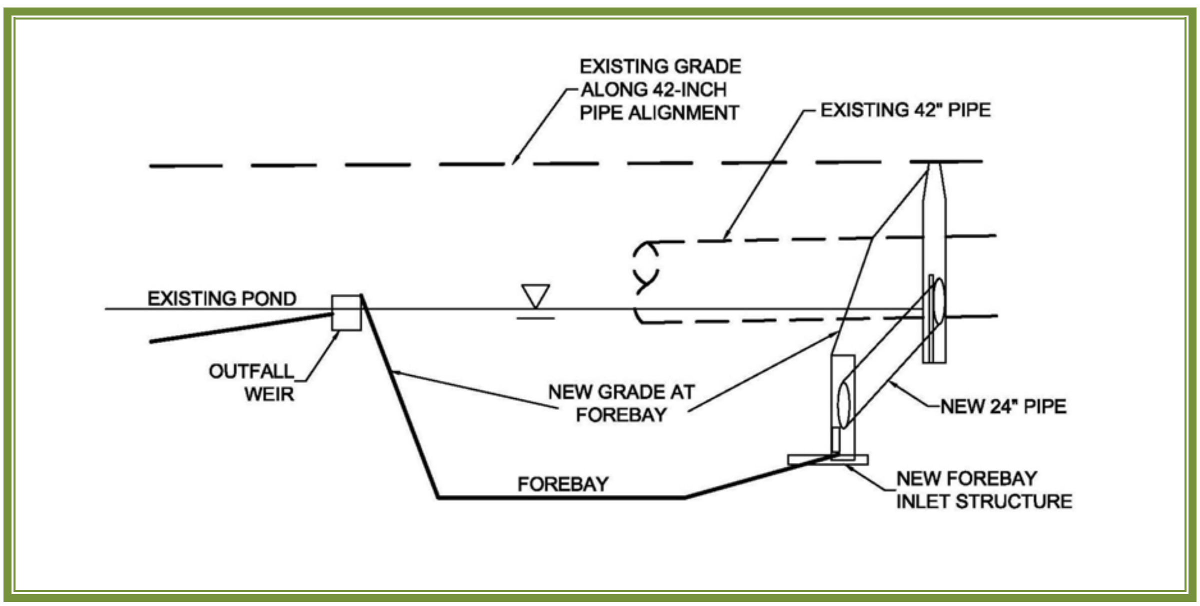
Advantages and Disadvantages

Advantages:	**Disadvantages:**
Can be designed for effective removal of non-colloidal sediments, and adsorbed contaminants, protecting capacity of downstream treatment system components Can be used as a stormwater system retrofit, particularly for conditions with large tributaries or with other sources of high entrained sediment loads Can be designed to facilitate sediment removal maintenance activities Adaptable to cold climate and changing climate conditions	Limited removal of colloidal size particles from the stormwater stream Does not address dissolved pollutants Practice requires sufficient vertical drop in the contributing conveyance system to maintain turbulent flow prior to discharge into the device, and ability to maintain a backwater condition and surface withdrawal from the impoundment. This may limit the application of the practice in some settings

Illustrations



Forebay with Forced Hydraulic Jump – Plan View



Forebay with Forced Hydraulic Jump – Profile

Target Pollutants and Treatment Effectiveness

Target pollutants include non-colloidal coarse and fine sediments that can be readily removed from the stormwater flow under Type-1 sedimentation. Removal of adsorbed contaminants would be associated with this sediment capture.

There are no published papers or field studies regarding pollutant removal performance completed for the Nutt's Pond application of this concept. A study by Suzuki, *et.al.* (2002), which analyzed the deposition patterns of sediment in a steeply sloped reservoir with a hydraulic jump, may provide guidance in further refinement of the design of this type of practice.

Selection and Design Considerations

Siting and Design Considerations

- Forebay should be sited such that impounded water "backwaters" the incoming channel or pipe, without causing water to intrude into the pavement sub-base material or into the drainage collection system.

- Sufficient vertical relief is required between the drainage collection system and the forebay to maintain turbulent flow conditions in the discharge pipe/channel as it approaches the forebay.

- Consider provision of the forebay as an "off-line" system so that flows exceeding the design storm condition are bypassed around the device.

- As the device is designed for effective sediment capture in systems with high sediment loads, it will require storage capacity for the captured sediment. This must be considered in determining the volume and the depth of the device.

- The need for periodic sediment removal requires that design consider access for maintenance, and treatment of the interior surfaces of the forebay to allow for maintenance to occur with minimum potential for damaging the bottom and side slopes.

- Design of inlet configuration, slope protection (especially at the working water elevation), and outlet structure needs to consider the impacts of ice formation during winter months.

Consistency with Roadway Design Integrity

This practice would be sited similar to a conventional forebay, detention basin, or other water quality treatment basin that results in impoundment of stormwater. Depending on site conditions and constraints, the space for the facility might require additional right-of-way acquisition.

As with any impoundment practice, the operating level of the water surface should be designed to allow proper drainage of roadway sub-grade materials. Otherwise, the practice poses no specific impacts to roadway design.

Cost Effectiveness

This practice may require larger forebay volumes than “rule of thumb” sizing approaches. However, the volume of the device may count toward total capture/treatment volumes to meet other stormwater management objectives.

As an impoundment practice, costs for installation and maintenance are anticipated to be comparable to other “basin” type systems. As this design can be integrated as a modification of the typical forebay design used for these systems, it is anticipated to offer significant savings over the provision of proprietary sediment trapping devices.

Suitability for Cold Climate

Freezing conditions may affect performance, and will require consideration in design of overflow outlets, which typically should be designed for withdrawal of water from the surface. However, this type of basin should not present significantly different challenges than the design of wet-pond type treatment systems.

Adaptability for Changing Climate

This practice is not anticipated to be significantly sensitive to climate change. For large watersheds, it can be designed as an “off-line” device, allowing by-passing of extreme storm events, maintaining its capacity to handle its design event. This design approach minimizes the devices sensitivity to changes in frequency or intensity of storm events that may be associated with climate change.

Potential for ANR Acceptance

Further information on theoretical pollutant removal performance, as well as field studies of existing installations, may be required to establish sufficient documentation for ANR acceptance of this practice, beyond use as a pre-treatment measure.

However, the potential to specifically design the structure for increased effectiveness for sediment removal warrants further investigation, so that the device can receive appropriate credits for its performance as a stand-alone retrofit or as a part of an effective treatment train.

Operation and Maintenance Considerations

General

The forebay would be typically located outside the immediate traveled way and vehicle recovery area. Maintenance access should be considered during the design. Normal maintenance activities would not be anticipated to affect or be affected by normal use of the roadway.

Operation and maintenance includes:

- Inspection at least annually;
- Removal of accumulated sediment, based on inspection. Recommend provision of staff gage or alternative measure to indicate depth of accumulation.
- Removal of debris from shoreline and outlet structure, as indicated by inspection;
- Periodic mowing of vegetated embankments to control growth of woody vegetation.

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