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Final Report

# Impact of Alternative Storm Water Management Approaches on Highway Infrastructure:

## Project Task Reports--Volume 2

Research

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16. Abstract (Limit: 200 words)

Highway infrastructure represents a substantial portion of the total impervious areas that generate runoff water. Because of long winters in congested areas that require frequent applications of de-icing materials, much of the runoff has the potential for affecting downstream water quality. However, storm water management techniques themselves have the potential for compromising the integrity of adjacent highways when they result in significant increases of water content in the soil beneath the roadway.

Because of impacts and the costs associated with construction and maintenance, any storm water management system needs to be assessed before any decisions are made regarding new highway development or redevelopment. The authors consider Best Management Practices (BMPs) as they relate to the most commonly used storm water management approaches including dry ponds, wet ponds, infiltration trenches, infiltration basins, constructed wetlands, grassed swales, bioretention cells, sand filters and porous pavements. They provide a framework for considering cost of practices, negative impact on infrastructure, results from a BMP-related survey of highway design and maintenance professionals and cost-estimation formulas for each of the most commonly used storm water management approaches in urban Minnesota.

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# Impact of Alternative Storm Water Management Approaches on Highway Infrastructure: Project Task Reports – Volume 2

## Final Report

*Prepared by:*
Dr. Caleb Arika, Ph.D.
Dr. Dario Canelon, Ph.D.
Dr. John Nieber, Ph.D.

University of Minnesota
Department of Biosystems and Agricultural Engineering

Robert Sykes, MLA

University of Minnesota
Department of Landscape Architecture

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# Executive Summary

It is well-known that storm water runoff from developed areas can degrade the quality of downstream receiving waters in terms of sediment delivery, chemical constituents and elevated water temperature. Storm water runoff volumes and peak flows are also larger from developed areas and this can also adversely impact receiving waters. To protect receiving waters from these negative impacts a variety of storm water best management practices (BMPs) have been developed for use in areas that are already developed and in developing areas. In many instances, storm water BMPs are located adjacent to roadways, some concern has been expressed that these BMPs might have adverse impacts on the roadway function and long-term cost.

The study presented in this report had a goal of evaluating storm water BMPs that are located adjacent to roadway infrastructures. The primary objective was to assess the potential adverse impact of storm water BMPs on the function and long-term operational cost of roadways. A secondary objective was to evaluate a method for assessing the effectiveness of storm water BMPs in controlling storm water runoff volume.

One task of the study was to assess the degree of acceptability of storm water BMPs among professionals most commonly associated with roadway planning, design and maintenance. This assessment was performed through a web-based opinion survey concentrated within the counties of the Twin Cities Metro area. Overall, the conclusion of the survey indicated a high degree of acceptability and satisfaction with the function of storm water BMPs. There was no strong indication that benefits of storm water BMPs are outweighed by the costs.

To evaluate the effectiveness of storm water BMPs with respect to controlling storm water runoff volume, three methods of measuring the infiltration capacities of several types of storm water BMPs were tested in the field. Infiltration measurements, storage capacity, and soil properties were acquired for a total of 24 BMPs. Infiltration capacity data from these measurements were used to assess whether a given storm water BMP would have the capacity to capture and control the volume of storm water generated from a ¼" runoff event. Of the 24 BMPs only six had information about the runoff contributing area. Of these six BMPs two were determined to have insufficient capacity to control the specified runoff volume. Several of the other BMPs characterized were also considered to have insufficient capacity for runoff control because they had persistent standing water, a sign of inadequate capacity.

Cost estimation is a very important step in the decision-making process of any new development. Due to the uncertainty in the data needed to perform an accurate determination of costs, they are estimated in this report following what is known as the top-down approach, which is based on statistical relationships between costs and design parameters, such as the water quality volume or the area of the facility. Maintenance costs are a part of the total costs of a project, and are estimated as a percentage of the construction costs. In order to facilitate comparison between several alternatives, the life cycle cost of a project is also estimated. The storm water best management practices analyzed include: Dry Ponds, Wet Ponds, Constructed Wetlands, Infiltration Basins, Infiltration Trenches, Sand Filters, Grassed Swales and Bio-retention Areas.

Evaluation of the potential negative impact of storm water BMPs on roadway function and cost was based on the idea that extra moisture introduced into pavement subgrade material from an adjacent BMP would reduce the strength of the pavement foundation, and therefore could decrease pavement life-cycle. This idea was tested in two ways. The first was with observations of pavements in the field using the Mn/DOT distress index represented by the surface rating index (SR). Field measurements of SR's for 45 pavement sections located adjacent to BMPs were compared to control sections (located far from BMPs). Statistical analysis of these data indicated that the BMPs had no measurable adverse effect on the investigated pavements. The limitation of this analysis was that many of the investigated pavements were fairly recently overlaid and therefore it is possible that visible stress might not have had time to be manifested. Field observations should continue to be taken in the future to determine whether pavement stress can be related to the presence of BMPs.

The second way to evaluate the potential negative impact of BMPs on roadways was to use the Mn/DOT pavement design and performance model, MnPAVE. This model allows the direct calculation of pavement longevity as related to subgrade properties. Subgrade moisture content influences pavement foundation strength, and therefore it was possible with MnPAVE to model the tie between a potential increase in moisture content to pavement life-cycle conditions. Within this part of the project it was shown that increases in moisture content, whether from BMPs or other sources of moisture, can significantly reduce a pavement's life-cycle. This reduction leads to an increase in long-term costs for construction and maintenance. Additional work is needed to acquire observations of subgrade moisture contents to determine whether BMPs actually increase subgrade moisture contents in comparison to control sections.

# Introduction

Alternative stormwater practices are defined here as being those approaches for stormwater control that reduce the impact of generated stormwater runoff on offsite receiving waters. These include practices such as infiltration basins, infiltration trenches, infiltration beds, porous pavements, sand filters, peat/sand filters, oil/grid separators, dry swales, wet swales, extended detention dry ponds, wet ponds, bio-retention areas, and rain gardens, and storm water wetlands. In the most common terminology these practices are referred to as Stormwater Best Management Practices (BMPs). These practices are increasingly being recommended to meet state and federal requirements (via NPDES/SDS permitting) for reducing the impact of suburban and urban development.

The research project, "Impact of Alternative Storm Water Management Approaches on Highway Infrastructure", was initiated to quantify the potential negative physical and subsequent economic impacts of alternative stormwater practices on roadway infrastructure. The report, "Guide for selection of alternative storm water control facilities for roadway infrastructures" is Volume 1 of the final report for the project, and contains summary information regarding alternative stormwater practices associated with highway infrastructures. The present document is the companion to the Volume 1 report, and contains the details of the work completed for the research project.

The objectives of the research project were to:

1. Complete an annotated bibliography of research related to impact of alternative stormwater control facilities on transportation infrastructures,
2. Determine whether existing alternative stormwater control facilities meet design recommendations,
3. Determine possible negative impacts of alternative stormwater control facilities on transportation infrastructures,
4. Assess the level of acceptance of alternative stormwater control practices among public works directors, land developers, and private property owners,
5. Assess the benefits of alternative stormwater control practices and weigh those benefits against the possible costs to the transportation infrastructure, and
6. Develop a resource that provides criteria for making decisions on the use of alternative stormwater control practices.

This volume is a compilation of the individual task reports associated with the objectives of the research project. There were seven tasks for the research project. These tasks included:

1. The development of an annotated bibliography on research and reports related to stormwater control related to highways;
2. The selection of study sites in the field and develop a description of those field sites;
3. The completion of an opinion survey of persons responsible for highway infrastructure facilities;
4. The characterization of the studied field sites for infiltration properties;

5. The assessment of the stormwater control capacity of the studied field sites relative to stormwater control recommendations;
6. The assessment of the potential physical damage to roadways from alternative stormwater practices; and
7. The assessment of the costs for implementing alternative stormwater practices and the potential costs associated with damages to roadways.

The chapters of this volume, called tasks, are composed of the detailed reports for each of the project tasks. We hope the reader finds these details helpful in understanding the summary information presented in Volume 1.

***Task 1. Annotated Bibliography on Stormwater Practices***

Caleb N. Arika, Research Associate

Dario J. Canelon, Visiting Associate Profesor

John L. Nieber, Professor

**March 14, 2005**

# Contents

# Summary

Highway infrastructure is an essential element in the development of a country, a state and even a city, because allows the massive transportation of people, equipment and materials in a fast and safe way. Highway infrastructure, however, requires a good operation and maintenance program in order to function, and stay functioning, properly and according to the design specifications. Storm-water management is a key issue in any operation and maintenance program not only because highway infrastructure represents impervious areas that generate runoff water but also because the heavy traffic on them is an important source of pollution that affects that runoff water and, therefore, the downstream water bodies. In the state of Minnesota, due to the fact that cold climate is present several months during the year, additional sources of pollution arise because of the products applied to deice the highway infrastructure. There is a number of storm-water best management practices (BMPs) that have been implemented with a relative degree of success both in the state and in the country. However, new alternative practices are being developed and installed and need to be evaluated to assess their performance. These alternative BMPs could improve the lifespan of the highway infrastructure as well as reduce the pollution of the water bodies in the state.

This document contains summaries of publications covering various aspects of storm-water management and its impact in highway infrastructure. Included are discussions on various topics which are listed and briefly discussed here in the following subjects: storm-water and its management, effects of storm-water management on water quality and highway infrastructure, BMPs and economics of highway infrastructure maintenance, and innovative BMPs and highway infrastructure.

<u>Storm-water and Its Management: Clean Water Act, Federal Grants Program Requirements</u>

This section covers articles that reflect the interest of both the state and the federal government in the maintenance of roads and bridges. As an example of this interest, a 1987 amendment to the federal Clean Water Act required implementation of a two-phase comprehensive national program to address storm-water runoff. Usually, budget limitations are a big concern and a significant factor in selection of storm-water Best Management Practices (BMPs) to be adopted, being infiltration management one of the approaches considered to be most effective to solve all the problems of urban runoff as well as the regulation of non-point source pollution. Another important BMP is street sweeping, which is reportedly one of the most cost-effective BMPs in an urban environment for minimizing runoff pollution from paved surfaces, primarily because it reduces pollutant levels at the source. However, several institutions, such as Environmental Protection Agency and the Minnesota Pollution Control Agency, as well as numerous books and publications, push for non-structural BMPs as a portion of the solution to the urban non-point storm-water treatment problem. The adoption of maintenance management programs within the state is expected to improve the quality of highway infrastructure, increase customer service, reduce complaints and reduce costs.

Impact of Storm-water Management on Water Quality and Highway Infrastructure

In this section of the bibliography, articles about storm-water management practices and their impacts on the quality of the water and also on the highway infrastructure are presented. The applicability of these storm-water management practices in different sites and conditions is studied, as well as their strengths and weaknesses with respect to the quality of water in the downstream receiving environment. The articles cover both nationwide and statewide effects of storm-water management, and provides guidance on the most effective structural and non-structural BMPs for development sites, and to improve the quality of BMPs, specifically with regard to performance, longevity, safety, ease of maintenance, community acceptance and environmental benefit. In some states, studies have showed that on-site treatment of storm-water runoff from highways might not be cost-effective in terms of protecting the water quality at the watershed level.

Best Management Practices (BMPs) and Economics of Highway Infrastructure Maintenance

This section of the bibliography is the largest one. It presents a number of articles that includes a wide variety of control measures (BMPs) for storm-water management. Both structural and non-structural best management practices for highway infrastructure are discussed. The importance of economics in highway infrastructure maintenance is also addressed. Several articles show concerns about maintenance costs for select BMPs due to the cost of land. Some of the BMPs discussed here have been reportedly used also abroad. In general, water diversion devices improve operating conditions, increasing the lifespan of roads and reducing maintenance costs. Some authors refer to the use of low impact development (LID) methods that can be used in conjunction with conventional BMPs to maintain the natural hydrology of a site. Other authors state that if storm-water BMPs are not properly installed and maintained, the BMPs themselves can become sources of water pollution. Among the most often cited BMPs are: infiltration drain-fields, infiltration trenches, on-site surface and underground retention/detention facilities, porous pavement, sand filters, bio-retention areas, detention basins, baffle boxes, road salt, vacuum sweeping, jet hosing, low impact development (LID) methods, dry wells and swales.

Innovative BMPs and Highway Infrastructure

This part of the bibliography presents articles that discuss new approaches to deal with storm-water management and their impact in highway infrastructure. They try new design concepts that are of potential interest to those in charge of managing ultra-urban runoff. Some of these innovative designs, although have been installed and operated at relatively few locations, indicate noteworthy performance. Some of these practices are: alum injection systems, multi-chamber treatment train (MCTT) systems, biofilters (e.g., StormTreat® System), vegetated rock filters (VRF), and vertical filter systems (VFS).

# Bibliography

## I. Storm-water and its Management: Clean Water Act, Federal Grants Program Requirements

**Title:** Funding Street Construction and Maintenance in Minnesota's Cities: Providing the tools to help cities preserve their road and bridge capital assets
**uthor:** City Engineers Association of Minnesota, the Minnesota Chapter of the American Public Works Association, and League of Minnesota Cities
**Date:** 2002
**Source:** Transportation Policy Institute
**Link:** http://www.lmnc.org/pdfs/StreetStudy/Section4.pdf; http://www.lmnc.org/pdfs/StreetStudy/streetstudyexecsumm.pdf

This report assembles in one place much of the "need-to-know" information on municipal road and bridge funding in Minnesota's 854 cities. This report builds off of the outstanding work done by Minnesota Department of Transportation (MN/DOT) and others in their efforts to inform policy makers and citizens of the state who are interested in gaining a better understanding of the workings of road and bridge infrastructure investment in Minnesota. According to the most recent information from MN/DOT, the state has over 135,000 miles of roadway. About 14 percent of these total miles are owned and operated by the state's cities. The most significant state source of funding is the Municipal State Aid program (MSA), which is available only to cities over 5,000 in population and only supports 20 percent of total mileage in the state. Reportedly, MSA funding has since 1988 failed to keep up with inflation.  Reported spending trends suggest that the larger cities in Minnesota are dedicating slightly more than half of their annual road improvement budgets to maintenance. Obviously, budget limitations would be a significant factor in selection of storm-water BMPs adopted by state transportation department.

**Title:** Storm-water Management and Storm-water Restoration.
**Author:** Ferguson, B.K.
**Year:** 2002
**Source:** Handbook of Water Sensitive Planning and Design. Robert L. France (ed.) Lewis Publishers, Boca Raton

In this paper, the author describes sealing by impervious cover, which deflects runoff across the surface and carries pollutants into streams, as "the fundamental disease of urban watersheds". A watershed maintains its natural health and its benefits to human beings by the assimilation, storage, and gradual flow of subsurface water. Conventional approaches that manage storm-water on the land surface treat only the downstream symptoms, thus fails to eliminate the fundamental urban problem of excess surface water volume. Infiltration management approach is capable, within limitations of specific sites, of solving all the problems of urban runoff, because it calls on the power of the underlying landscape. These approaches infiltrate urban runoff directly where the rain falls. For many porous pavements, long-term infiltration rate is sufficient to absorb and treat rain that falls in almost all storm events.

**Title:** Maintenance of Storm-water Quality Treatment Facilities Engineering and Research, Storm-water Management, Inc.
**Author:** James H. Lenhart, J.H., Harbaugh, R.
**Year:** 2000.
**Source:** Storm-water Management Facilities Management Group, Inc.
**Link:** http://www.storm-waterinc.com/pdfs/maintenance_facil.pdf

As the regulation of non-point source pollution becomes more prevalent, public agencies and private landowners are realizing an increasing need to maintain storm sewer systems. Much of this need is arising from new federal and state regulatory requirements to address water quality.
To meet the needs of the Clean Water Act, a new environmental paradigm is being integrated into the fabric of these maintenance organizations. The economic implications are significant, not only in the first costs of facility installation but also in the notion of providing some form of perpetual maintenance of these facilities. There is the increased need to maintain the facilities and devices that trap pollutants. The authors have mentioned and discussed several of these facilities and devices in this publication. This paper reports on maintenance needs and maintenance costs of some of these BMPs from case studies in select district in USA.

**Title:** Overview of Minnesota's NPDES/SDS Storm-water Permit Program
**Author:** Minnesota Pollution Control Agency.
**Year:** July 2003
**Source:** Regional Environmental Management Water Quality/Storm Water #1.02,

A 1987 amendment to the federal Clean Water Act required implementation of a two-phase comprehensive national program to address storm-water runoff. Phase I (FORM 1990s) regulated large construction sites, 10 categories of industrial facilities, and major metropolitan municipal separate storm sewer systems (MS4s). On March 10, 2003 the program broadened to include smaller construction sites, municipally owned or operated industrial activity, and many more municipalities. Phase II of the act is designed to further reduce adverse impacts to water quality and puts controls on runoff that have the greatest likelihood of causing continued environmental degradation. Storm-water permits require permittees to control polluted discharges. As with most MPCA programs, citizens, regulated parties and other stakeholders have the opportunity to comment on the permits and rule changes.

**Title:** Storm-Water and Wetlands: Planning and Evaluation Guidelines for Addressing Potential Impacts of Urban Storm-Water and Snow-Melt Runoff on Wetlands
**Author:** State of Minnesota Storm-Water Advisory Group
**Year:** June, 1997
**Source:** Minnesota Pollution Control Agency.

The purpose of this document is to provide guidance to local governmental units (LGUs) on what they must do if they wish to protect wetlands from storm-water and snow-melt discharges to wetlands. The implementation of urban storm-water management plans that minimize adverse impacts to wetlands and other waters can be achieved through the use of a comprehensive management approach. All elements of a storm-water plan must consider a watershed or other large-scale areas as opposed to piecemeal, project-by-project approaches. Types of BMPs: Prevention: Low Impact Development; Storm-water: Detention / Retention / Infiltration / Filtration / Constructed Wetlands; Sediment Control: Soil Erosion / Sediment Control

**Title:** Federal grant program merits support of wastewater industry
**Authors:** Curtis, Lamont W.
**Year:** Jan 2001
**Source:** Water Engineering & Management p5 (1)
**Database:** Academic Journals, Gale Group

A new legislation aimed at helping cities and counties comply with clean water standards has been introduced in the House of Representatives. The bill, HR 828, will standardize the Combined Sewer Overflow Control policy and will offer $45 million in technical assistance and grants for projects included in Watershed Management of Wet Weather Discharges and Storm-water Best Management Practices.

**Title:** Storm-water Conservation and Management
**Author:** Clifton J. Aichinger,
**Date:** May 1, 2003
**Source:** National Storm-water Workshop, Minneapolis, MN
**Link:** http://www.bae.umn.edu/storm-water/presentations/Aichinger.pdf

Demands of the Clean Water Act (NPDES Phase II) and the proposed TMDL program are high and difficult to achieve under many watersheds conditions. Despite the efforts of watershed and local water management programs, the commonly-accepted BMPs used today are barely keeping pace with the water quality impacts and cannot significantly move us toward restoration of water quality to unimpaired conditions. Further, adoption of some of the BMPs in that fully developed communities lack available land area to build or retrofit drainage systems with conventional BMP treatment systems. In the current suite of generally accepted BMPs for urban areas, there are very few BMPs with research data to show their benefit. With a quick analysis it often appears that these alternative BMPs are costly and do not deliver the benefit of conventional treatment alternatives. EPA, PCA, and numerous books and publications push for non-structural BMPs as a portion of the solution to our urban non-point storm-water treatment problem. The Minnesota Association of Watershed Districts (MAWD) passed a resolution at its December 2002 convention to work with other organizations and agencies to develop a cold climate water quality research agenda and program.

**Title:** Costs of Urban Non-point Source Water Pollution Control Measures: Technical Report Number 31
**Author:** Southeastern Wisconsin Regional Planning Commission.
**Year:** June, 1991
**Source:** Storm-water BMP Design Manual. Southeastern Wisconsin Regional Planning

The primary purpose of this report is to provide assistance in estimating the capital and annual operation and maintenance costs of urban non-point source water pollution control measures including: wet detention basins, infiltration trenches, infiltration basins, grassed swales, vegetated filter strips, porous pavement, catch basin cleaning, and street sweeping. Cost data are also presented for nine temporary construction / erosion control measures: filter fabric fences, straw bales carriers, diversion swales, inlet protection devices, temporary seeding, mulching, sodding, sediment traps, and sedimentation basins. Types of BMPs: Prevention: Housekeeping / Operations and Maintenance; Storm-water: Detention / Retention / Infiltration / Filtration; Sediment Control: Construction / Soil Erosion / Sediment Control

**Title:** Minnesota Urban Small Sites BMP Manual: Storm-water Best Management Practices for Cold Climates
**Author:** Barr Engineering
**Year:** 2001
**Source:** Metropolitan Council
**Link:** http://metrocouncil.org/environment/watershed/bmp/manual.htm

The most effective control of non-point source pollution is to prevent its release. The manual presents the approach of using five families of BMPs for runoff pollution prevention, and storm-water treatment using five different approaches. For storm-water treatment, the manual filtering storm-water, reducing the speed at which it leaves a site, and reducing the volume of runoff as actions critical to reducing non-point-source water pollution and protecting downstream water bodies. Six families of BMP affect this.

**Title:** Road Maintenance (4720P)
**Author:** Public Works Agency, County of San Mateo.
**Year:** 2003
**Source:**

**Link:** http://www.co.sanmateo.ca.us/bos.dir/Budget/recommend2003/publicworks/4-42.pdf

This publication discusses functions and challenges faced by the county road maintenance section. This unit ensures that County maintained roads are safe, accessible and well maintained by providing responsive, cost effective and quality maintenance and repair of concrete, asphalt, drainage facilities and vegetation management at all times under all conditions for the traveling public. During 2002 and 2003 the Section received the results of a consultant's analysis of current practices and recommendations for future development of a maintenance management program for road maintenance. The adoption and utilization of a maintenance management system is expected to improve the quality of roads within the County, increase customer service, reduce complaints and reduce costs within the Department. Maintenance measures show 50:50 time expenditure between asphalt maintenance and vegetation and drainage systems maintenance for the County for the years 2001 – 2003.

**Title:** Highway Runoff Manual
**Author:** Washington State Department of Transportation.
**Year:** 1995.
**Source:** Environmental and Engineering Service Center. Publication #: M 31 - 16
**Link:** http://www.wsdot.wa.gov/hq/library/Ref/pubs.htm#wsdot

This manual provides background information on storm-water hydrology and water quality issues with an emphasis on transportation related issues. Significant portions of the manual are devoted to runoff issues, hydrology, minimum treatment recommendations, storm-water BMPs, erosion and sediment control BMPs, maintenance requirements and operational guidelines.

**Title:** Better Site Design: Watershed Protection Techniques
**Author:** Center for Watershed Protection.
**Year:** 1999
**Source:** Quarterly Bulletin on Urban Watershed Restoration and Protection Tools, Vol 3.No. 2

Special issues with articles focusing on model land development principles that can reduce impervious cover conserve natural areas and improve storm-water treatment, quantifying economic and environmental benefits associated with better site design, benefits of open space design in new communities.
Types of BMPs: Prevention: Low Impact Development; Storm-water: Infiltration / Filtration; Sediment Control: Soil Erosion Control

**Title:** Minnesota Urban Small Sites Best Management Practice Manual: Storm-water Best Management Practices for Cold Climates
**Author:** Metropolitan Council

**Year:** 2001
**Source:** Metropolitan Council
**Link:** http://metrocouncil.org/environment/watershed/bmp/manual.htm

This manual offers detailed discussions on design of various BMPs for runoff pollution prevention and storm-water treatment. Under runoff pollution control, BMPs have been categorized into groupings: impervious surface reduction, housekeeping, construction practices, and soil erosion control. Under storm water treatments are infiltration systems, filtration systems, constructed wetlands, retention systems, detention systems, and flow control structures.

**Title**: An Assessment of Road Maintenance Activities in Frederick County and Their Effect on Storm-water Runoff Quality
**Author:** Versar, Inc. 9200 Rumsey Road Columbia, Maryland.
**Date:** May 29, 2002
**Source:** Division of Public Works, Frederick County, Maryland
**Link:** http://www.co.frederick.md.us/npdes/files%5Croadmaint.pdf

This report offers an assessment of the road maintenance practices currently followed by the Fredrick County (MD) and the environmental impacts that such activities have on storm-water runoff. Street sweeping is reportedly one of the most cost-effective BMPs in an urban environment for minimizing runoff pollution from paved surfaces, primarily because it reduces pollutant levels at the source. Hydrocarbons, pesticides, animal waste, antifreeze, and heavy metals, as well as silt and sand, reside on the roadways (inside minute cracks and adhering to aggregate) waiting for a good rain that will carry them to a surface water body. If these pollutants can be captured effectively right off the roadway, it reduces the need for other, more expensive BMPs. Many of the recommended BMPs in the report can be instituted at nominal cost, as part of the County's regular road maintenance programs. It was noted that some specific recommendations may incur additional costs, such purchase of sophisticated sweeping equipment, and alternative deicing chemicals and chemical herbicides.

**Title:** Municipal Technologies: Technologies Fact-sheets
**Author:** United States Environmental Protection Agency
**Date:** November 2003
**Source:** United States Environmental Protection Agency,
**Link:** http://www.epa.gov/owm/mtb/mtbfact.htm

This publication presents fact-sheets on the use of different BMPs for urban storm-water management. It details applicability in different sites and conditions, disadvantages and advantages, design criteria, performance/efficiency, operation and maintenance, as well as construction, operation and maintenance costs. Further, it presents valuable working tables data for initial installation, and determination of average annual operation and maintenance costs of some BMPs, together with relevant references.

**Title:** Storm Water O&M Fact Sheet: Handling and Disposal of Residuals
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-015
**Link:** http://www.epa.gov/owm/mtb/handdisp.pdf

Polluted urban runoff can be a major source of water quality problems in receiving waters. Urban storm water Best Management Practices, or BMPs, are intended to remove these pollutants from runoff and to improve water quality in downstream waters. Yet if storm water BMPs are not properly operated and maintained, the BMPs themselves can become sources of storm water pollutants, as the material removed during previous storms becomes resuspended by subsequent storm events. This fact sheet describes structural BMP maintenance programs and discusses methods for handling and disposing of residual materials from storm water BMPs. A report on performed cost analysis specifically for the handling and disposal of urban storm runoff residuals is presented. This cost analysis compared six alternative residuals handling scenarios for either swirl or sedimentation concentrated solids. Tables showing ranking on cost effective solids handling scenario based on annual costs are given, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: On-Site Underground Retention / Detention
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 2001
**Source:** United States Environmental Protection Agency, EPA 832-F-01-005
**Link:** http://www.epa.gov/owm/mtb/runoff.pdf

This fact-sheet presents details on use of onsite surface and underground retention/detention BMPs for urban storm-water management. Details are given on applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, construction / installation, operation and maintenance costs. Case studies on application of this method at various locations in the US are presented, offering valuable findings on performance, cost, etc. of different BMPs employed.

## II. Effects of Storm-water Management on Water Quality and Highway Infrastructure

**Title:** Municipal Technologies: Technologies Fact-sheets
**Author:** United States Environmental Protection Agency
**Date:** November 2003
**Source:** United States Environmental Protection Agency,
**Link:** http://www.epa.gov/owm/mtb/mtbfact.htm

This publication presents fact-sheets on the use of different BMPs for urban storm-water management. It details applicability in different sites and conditions, disadvantages and advantages, design criteria, performance/efficiency, operation and maintenance, as well as construction, operation and maintenance costs. Further, it presents valuable working tables data for initial installation, and determination of average annual operation and maintenance costs of some BMPs, together with relevant references.

**Title:** Forest Road Maintenance for Forest Landowners
**Author:** Brinker, R.W.
**Year:** 2002.
**Source:** School of Forestry, Auburn University, and Alabama Cooperative Extension System
**Link:** http://www.pfmt.org/roads/maintena.htm

Rainfall that is allowed to accumulate and remain in or adjacent to the forest (unpaved) roadway can result in expensive maintenance problems. A wet road surface or saturated foundation often will not support the weight of a vehicle. This can result in irregular access, impassable sections of roadway, and potential environmental degradation. The author discusses storm-water and forest roads management. Infiltration enhancing BMPs would not be recommended adjacent to these roads.

**Title:** Are Best-Management-Practice Criteria Really Environmentally Friendly?
**Author:** Roesner, L.A., Bledsoe, B.P., and Brashear, R.W.
**Year:** 2001
**Source:** J. Water Res. Planning and Management 127(3):150-154

Several papers have investigated the effectiveness of Best Management Practices (BMPs) used in protecting small urban watercourses, and have concluded that they do not. Investigation of both design practices and effectiveness reveals that there is a lot of ignorance in the scientific and engineering community about what constitutes a properly designed BMP and what it really achieves, with respect to environmental protection. This paper discusses the state-of-practice in BMP design in the United States and points out its strengths and weaknesses with respect to real protection of the downstream receiving water environment. The paper recommends an approach to design criteria development that can be applied over a wide variety of climatologic, topologic, and geologic conditions to protect receiving waters systems.

**Title:** Maryland Storm-water Design Manual
**Author:** Maryland Department of the Environment.
**Year:** 1998
**Link:** http://www.mde.state.md.us/environment/wma/storm-watermanual/

This manual provides guidance to protect the waters of the State from adverse impacts of urban runoff, provides guidance on the most effective structural and non-structural BMPs for development sites, and to improve the quality of BMPs that are constructed in the State, specifically with regard to performance, longevity, safety, ease of maintenance, community acceptance and environmental benefit. Types of BMPs considered are: **Prevention – which is** Housekeeping / Low Impact Development / Operations and Maintenance; **Storm-water facilities including** Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices; and **Sediment Control**: Construction / Soil Erosion / Sediment Control.

**Title:** Highway Runoff Manual
**Author:** Washington State Department of Transportation.
**Year:** 1995.
**Source:** Environmental and Engineering Service Center. Publication #: M 31 - 16
**Link:** http://www.wsdot.wa.gov/hq/library/Ref/pubs.htm#wsdot

This manual provides background information on storm-water hydrology and water quality issues with an emphasis on transportation related issues. Significant portions of the manual are devoted to runoff issues, hydrology, minimum treatment recommendations, storm-water BMPs, erosion and sediment control BMPs, maintenance requirements and operational guidelines.

**Title:** Final Contract Report: Development of a Storm-water Best Management Practice Placement Strategy for the Virginia Department of Transportation
**Author:** Shaw L. Yu, Jenny Xiaoyue Zhen, Sam Yanyun Zhai
**Year:** October 2003
**Source:** Virginia Transportation Research Council, VTRC 04-CR9

Since the implementation of the federal and state storm-water management regulations, the Virginia Department of Transportation (VDOT) has constructed hundreds of best management practices (BMPs) for controlling storm-water runoff from highways and its other facilities, such as maintenance headquarters, storage areas, etc. In recent years, the U.S. Environmental Protection Agency (USEPA) has promoted the watershed approach in controlling pollution from various sources in a watershed. In the present study, a holistic methodology for determining the cost-effective placement and configuration of storm-water BMPs for VDOT was developed. The methodology consists of three interacting functional components: a watershed simulation model, a BMP simulation module (the impoundment routine), and an optimization model. A highway application case study was conducted using the VDOT Rt. 288 Project in Chesterfield County, Virginia. The results showed that the current VDOT BMP placement approach (which consists of on-site treatment of storm-water runoff from highways), might not be cost-effective in terms of protecting the water quality at the watershed level. The results of the case study indicate that if VDOT were to work with other stakeholders in developing a BMP placement strategy for the entire watershed, greater cost-effectiveness would be achieved as a result of fewer BMPs being required for VDOT to construct than would otherwise be the case. The methodology developed in the present study can be modified and expanded into a decision support system, which can include more types of BMPs and which would allow more BMP placement scenarios.

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| **Title:** | Minnesota Urban Small Sites Best Management Practice Manual: Storm-water Best Management Practices for Cold Climates |
| **Author:** | Metropolitan Council |
| **Year:** | 2001 |
| **Source:** | Metropolitan Council |
| **Link:** | http://metrocouncil.org/environment/watershed/bmp/manual.htm |

The Urban Small Sites Best Management Practice (BMP) Manual provides information on tools and techniques to assist Twin Cities municipalities and WMOs in guiding development and redevelopment. The manual includes detailed information on 40 BMPs that are aimed at managing storm-water pollution for small urban sites in a cold-climate setting. The goal of the manual is to support the principles of accommodating growth while preserving the environment

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| **Title:** | Storm Water Technology Fact Sheet: Vegetated Swales |
| **Author:** | Office of Wastewater Management, Office of Water, USEPA |
| **Date:** | September 1999 |
| **Source:** | United States Environmental Protection Agency, # 832-F-99-006 |
| **Link:** | http://www.epa.gov/owm/mtb/vegswale.pdf |

The publication presents fact sheet on the use of vegetated swale for urban storm-water management. It details applicability in different sites and conditions, disadvantages and advantages, design criteria, performance/efficiency, operation and maintenance, as well as construction, operation and maintenance costs. According to Schueler (1987) as reported here, vegetated swales typically cost less to construct than curbs and gutters or underground storm sewers, that costs may vary from $16-$30 per linear meter for a 4.5 meter wide channel (top width). The Southeastern Wisconsin Regional Planning Commission (SEWRPC, 1991) reported that costs may vary from $28 to $164 per linear meter depending upon swale depth and bottom width. Further, according to SEWRPC

(1991) annual costs for maintaining vegetated swales are approximately $1.90 per linear meter for a 0.5 meter deep channel. Average annual operating and maintenance costs of vegetated swales can be estimated using given Table 3 in this publication.

**Title:** Storm Water Technology Fact Sheet: Dust Control
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-003
**Link:** http://www.epa.gov/owm/mtb/dustctr.pdf

Dust controls reduce the surface and air transport of dust, thereby preventing pollutants from infiltrating into storm water. Control measures are often instituted in industrial areas or in areas where land is being disturbed. This publication discusses details on applicability, advantages, disadvantages, design criteria, performance / efficiency, operation and maintenance, and finally, installation, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Minimizing Effects from Highway Deicing
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-016
**Link:** http://www.epa.gov/owm/mtb/ice.pdf

Beginning in the late 1940s and 1950s, the "bare pavement" policy was gradually adopted by highway agencies as the standard for pavement condition during inclement weather. The policy provided safer travel conditions on roadways and became a useful concept for roadway maintenance because it was a simple and self-evident guideline for highway crews. Salt was first used on roads in the United States for snow and ice control in the 1930s (Salt Institute, 1994). The United States and Canada spend over $2 billion dollars each year on snow and ice control (SHRP, 1993). However, very little cost data has been generated to show the direct costs of, or the cost reductions due to, the specific snow removal alternatives and process improvements discussed in this fact sheet. NaCl is both the most common and the most cost-effective deicing agent, with costs per ton ranging from $17 to $30 (Lord 1988; Jesperson, 1995).

**Title:** Storm Water Technology Fact Sheet: Infiltration Trench
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-019
**Link:** http://www.epa.gov/owm/mtb/infltrenc.pdf

This fact-sheet presents details on use of Infiltration Trench for urban storm-water management. It details applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, construction / installation, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: On-Site Underground Retention / Detention
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 2001
**Source:** United States Environmental Protection Agency, EPA 832-F-01-005
**Link:** http://www.epa.gov/owm/mtb/runoff.pdf

This fact-sheet presents details on use of On-site surface and underground retention/detention BMPs for urban storm-water management. Details are given on applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance and, finally, construction / installation, operation and maintenance costs. Case studies on application of this method at various locations in the US are presented, offering valuable findings on performance, cost, etc. of different BMPs employed. Tables on application, operation and maintenance costs of specific BMPs are presented in tables, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Porous Pavement
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-023
**Link:** http://www.epa.gov/owm/mtb/porouspa.pdf

This fact-sheet presents details on use of porous pavement for urban storm-water management. Porous pavement is a special type of pavement that allows rain and snowmelt to pass through it, thereby reducing the runoff from a site and surrounding areas. In addition, porous pavement filters some pollutants from the runoff if maintained. Details are given on applicability, advantages & disadvantages, design criteria, performance, efficiency, and on installation, operation and maintenance costs. In addition to documented pros and cons of porous pavements, several questions still remain regarding their use, such as whether they can maintain porosity over a long period of time, if the pavement will remain capable of removing pollutants after subfreezing weather and snow removal, as well as cost of maintenance and rehabilitation options for restoration of porosity. Application, operation and maintenance costs tables are presented, together with relevant references.

**Title:** Maintenance of Storm-water Quality Treatment Facilities Engineering and Research, Storm-water Management, Inc.

**Author:** James H. Lenhart, J.H., Harbaugh, R.
**Year:** 2000.
**Source:** Storm-water Management Facilities Management Group, Inc.
**Link:** http://www.storm-waterinc.com/pdfs/maintenance_facil.pdf

In this paper, the authors describe sand filter as one of the most effective BMPs, but which is sensitive to solids loading and befouling. Their maintenance frequency recommendations range from annual light maintenance (removal of trash and debris) to periodic media replacement every five years. Major maintenance procedures included complete removal and replacement of the sand layer and under drain system. For privately owned underground facilities contractors charge from $300.00 to $400.00 per cubic yard for removal and replacement (Harbaugh, personal communication). In a reported case study, five sand filters were proposed for the Downtown Silver Spring project in Silver Spring Maryland. These filters contained 380 cubic yards of sand and rock. The five-year maintenance cost was estimated at $350,000 over a five-year period, with the main assumption of annual light maintenance with pretreatment cleanout and one major maintenance at the end of the five-year period. As a comparison the Storm Filter technology was used instead based on a five-year maintenance cost of $174,000.

**Title:** Maintenance of Storm-water Quality Treatment Facilities Engineering and Research, Storm-water Management, Inc.
**Author:** James H. Lenhart, J.H., Harbaugh, R.
**Year:** 2000.
**Source:** Storm-water Management Facilities Management Group, Inc.
**Link:** http://www.storm-waterinc.com/pdfs/maintenance_facil.pdf

In a section of this paper, **grassed swales** BMPs are represented, highlighting recent changes in their design necessitated by the high failure rates associated with saturated soils and/or lack of water supply. Newer designs utilize plants which survive in saturated conditions but are also drought tolerant. Other problems associated with function of the BMP is the need to meet visual needs, whereby the swales are mowed at incorrect heights, fertilized and managed with pesticides and herbicides. Other systems fall into neglect and significant die off of the vegetation can result from saturated conditions or toxicity effects from petroleum hydrocarbons. This significantly affects maintenance costs, particularly if the facility requires reconstruction.

## III. Best Management Practices (BMPs) and Economics of Highway Infrastructure Maintenance

**Title:** Maintenance of Storm-water Quality Treatment Facilities Engineering and Research, Storm-water Management, Inc.
**Author:** James H. Lenhart, J.H., Harbaugh, R.
**Year:** 2000.
**Source:** Storm-water Management Facilities Management Group, Inc.
**Link:** http://www.storm-waterinc.com/pdfs/maintenance_facil.pdf

The author present a comparative analysis of facility maintenance costs for select BMPs. The cost of land is significant for some BMPs that may render their adoption uneconomical in situations where land availability and/or affordability value is a problem. In an infill property development in the City of Renton, WA, the developer proposed replacing an existing swale with an alternate facility so additional land space would be available, (Hinthorne, 2000). The first costs and maintenance costs of alternate facilities were analyzed and presented to the City for consideration. In this case, land costs had a major influence on long term costs of the BMP.

**Title:** Performance of Storm-water Infiltration Basins on the Long Term
**Authors:** Dechesne, M., Barraud S., and Bardin, Jean-Pascal**.**
**Year:** 2002
**Source:** Global Solutions for Urban Drainage: 9ICUD, Proceedings of the Ninth International Conference on Urban Drainage, Sept. 8-13, 2002, Lloyd Center Doubletree Hotel, Portland, Oregon. **Eric W. Strecker**, (ed.) and **Wayne C. Huber**, (ed..)

Infiltration basins are good systems to decentralize storm-water management. They are reportedly widely used in Lyon, France, as a result of urban development. But, because of topsoil clogging, which has been found to increase as a function of time, infiltration basins can become unsustainable over time.

**Title:** Managing Water on Roads, Skid Trails, and Landings. Forest Management Practices Fact Sheet: Managing Water Series #2
**Author**: Regents of the University of Minnesota
**Year:** 2002
**Link:** http://www.extension.umn.edu/distribution/naturalresources/DD6971.html

Water diversion devices improve operating conditions. They increase the lifespan of roads and reduce maintenance costs. Good planning and proper use of these practices can reduce long-term costs for the operator and landowner. The relative cost for installation and maintenance of some of the water diversion devices are reported: Water bars are low-moderate, broad-based dips, crowning and insloping/outsloping are all moderate, while road ditches and open-top culverts are reportedly high installation and maintenance costs.

**Title:** Urban Small Sites Best Management Practice (BMP) Manual
**Author:** Barr Engineering/Metropolitan Council.
**Link:**
http://www.metrocouncil.org/environment/Watershed/BMP/CH3_RPPHousBMPMaint.pdf

All BMPs require periodic maintenance to maintain and enhance their performance. This section summarizes some of the general maintenance of select BMPs as well as routine maintenance that should be applied to existing devices. Maintenance schedules vary greatly depending on BMP location, surrounding land use and soil stability in the watershed. Sand filters, infiltration trench, detention basin and filter strip all require at least annual cycle of maintenance or as needed. Besides the annual maintenance, Infiltration basin, retention ponds/wetlands and grass swales require another five-year cycle maintenance for sediment removal. These would add to the maintenance cost for these structures.

**Title:** Costs of best management practices and associated land urban storm-water control
**Author:** Sample, David J., Heaney, James P., Wright, Leonard T., Fan, Chi-Yuan M., Lai, Fu-Hsiung, Field, R.
**Year:** 2003.
**Source:** *J. of Water Resources Planning and Management* 129(6):59-68

New methods are used to evaluate storm-water controls and best management practices (BMPs) within a land development context. Costs are developed using published literature and standard cost estimation guides. A method is developed in which costs are determined for each parcel within a development for specific land uses. The effect of including the opportunity cost of land in the analysis is evaluated. Costs attributable to storm-water controls are allocated among purposes. A method is developed in which storm-water control costs are assigned at the parcel level.

**Title:** Using Low Impact Development Methods to Maintain Natural Site Hydrology
**Author:** Browne, F.X.,
**Year:** 2003.
**Source:** Proc. World Water & Environmental Resources Congress 2003 and Related Symposia

Low impact development (LID) methods can be used in conjunction with conventional Best Management Practices (BMPs) to maintain the natural hydrology of a site. The use of LID methods to maintain natural site hydrology requires a new approach to storm-water management. It requires use of innovative design concepts, and an iterative approach to designing a site development. The goal of LID is to mimic pre-development hydrological conditions such as peak flow, time of concentration, and runoff volume. LID can reduce the amount of non-point source pollution caused by storm-water runoff and erosion from a development site, and from stream bank erosion.

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| **Title:** | Low-Impact Development: An Alternative Storm-water Management Technology |
| **Author:** | Coffman L.S. |
| **Year:** | 2002. |
| **Source:** | Handbook of Water Sensitive Planning and Design. Robert L. France (ed.) Lewis Publishers, Boca Raton |

This chapter discusses a new approach to storm-water management in new and existing developments, referred to as Low Impact Development (LID). This is an alternative innovative comprehensive suite of lot-level land development principles and practices designed to create a more hydrological and functional urban landscape to better maintain or restore ecosystem's hydrologic regime in a watershed. This new approach combines a variety of conservation strategies, minimization measures, strategic timing techniques, integrated small-scale site-level management practices, and pollution prevention measures to achieve desired storm-water management or ecosystem protection goals. Through the combined cumulative beneficial impacts of all the possible integrated LID site design management techniques, it is now technically feasible to develop a site with little impact on hydrology or water quality. The basic goal of LID is to engineer a site with as many small-scale retention, detention, prevention, and treatment techniques as needed to achieve the hydrologic functional equivalent to pre-development conditions.

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| **Title:** | Storm Water Technology Fact Sheet: Vegetated Swales |
| **Author:** | Office of Wastewater Management, Office of Water, USEPA |
| **Date:** | September 1999 |
| **Source:** | United States Environmental Protection Agency, # 832-F-99-006 |
| **Link:** | http://www.epa.gov/owm/mtb/vegswale.pdf |

The publication presents fact-sheet on the use of vegetated swale for urban storm-water management. It details applicability in different sites and conditions, disadvantages and advantages, design criteria, performance/efficiency, operation and maintenance, as well as construction, operation and maintenance costs. According to Schueler (1987) as reported here, vegetated swales typically cost less to construct than curbs and gutters or underground storm sewers, that costs may vary from $16-$30 per linear meter for a 4.5 meter wide channel (top width). The Southeastern Wisconsin Regional Planning Commission (SEWRPC, 1991) reported that costs may vary from $28 to $164 per linear meter depending upon swale depth and bottom width. Further, according to SEWRPC (1991) annual costs for maintaining vegetated swales are approximately $1.90 per linear meter for a 0.5 meter deep channel. Average annual operating and maintenance costs of vegetated swales can be estimated using Table 3 in this publication.

**Title:** Storm Water Technology Fact Sheet: Baffle Boxes
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 2001
**Source:** United States Environmental Protection Agency, EPA 832-F-01-004
**Link:** http://www.epa.gov/owm/mtb/baffle_boxes.pdf

The publication presents fact-sheet on the use of baffle boxes in urban storm-water management. It details applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, its construction, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Bio-retention
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-012
**Link:** http://www.epa.gov/owm/mtb/biortn.pdf

The publication presents fact-sheet on the bio-retention, a best management practice (BMP) developed in the early 1990's by the Prince George's County, MD, Department of Environmental Resources (PGDER). Details are given on applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, construction, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Dust Control
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-003
**Link:** http://www.epa.gov/owm/mtb/dustctr.pdf

Dust controls reduce the surface and air transport of dust, thereby preventing pollutants from infiltrating into storm water. Control measures are often instituted in industrial areas or in areas where land is being disturbed. This publication discusses details on applicability, advantages, disadvantages, design criteria, performance / efficiency, operation and maintenance, and finally, installation, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Minimizing Effects from Highway Deicing
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-016
**Link:** http://www.epa.gov/owm/mtb/ice.pdf

Beginning in the late 1940s and 1950s, the "bare pavement" policy was gradually adopted by highway agencies as the standard for pavement condition during inclement weather. The policy provided safer travel conditions on roadways and became a useful concept for roadway maintenance because it was a simple and self-evident guideline for highway crews. Salt was first used on roads in the United States for snow and ice control in the 1930s (Salt Institute, 1994). The United States and Canada spend over $2 billion dollars each year on snow and ice control (SHRP,1993). However, very little cost data has been generated to show the direct costs of, or the cost reductions due to, the specific snow removal alternatives and process improvements discussed in this fact sheet. NaCl is both the most common and the most cost-effective deicing agent, with costs per ton ranging from $17 to $30 (Lord 1988; Jesperson, 1995).

**Title:** Storm Water O&M Fact Sheet: Handling and Disposal of Residuals
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-015
**Link:** http://www.epa.gov/owm/mtb/handdisp.pdf

Polluted urban runoff can be a major source of water quality problems in receiving waters. Urban storm water Best Management Practices, or BMPs, are intended to remove these pollutants from runoff and to improve water quality in downstream waters. Yet if storm water BMPs are not properly operated and maintained, the BMPs themselves can become sources of storm water pollutants, as the material removed during previous storms becomes re-suspended by subsequent storm events. This fact sheet describes structural BMP maintenance programs and discusses methods for handling and disposing of residual materials from storm water BMPs. A report on performed cost analysis specifically for the handling and disposal of urban storm runoff residuals is presented. This cost analysis compared six alternative residuals handling scenarios for either swirl or sedimentation concentrated solids. Tables showing ranking on cost effective solids handling scenario based on annual costs are given, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Infiltration Drain-fields
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-018
**Link:** http://www.epa.gov/owm/mtb/infltdrn.pdf

This fact-sheet presents details on use of Infiltration Drain-fields for urban storm-water management. It details applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, construction / installation, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Infiltration Trench
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-019
**Link:** http://www.epa.gov/owm/mtb/infltrenc.pdf

This fact-sheet presents details on use of Infiltration Trench for urban storm-water management. It details applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, construction / installation, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: On-Site Underground Retention / Detention
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 2001
**Source:** United States Environmental Protection Agency, EPA 832-F-01-005
**Link:** http://www.epa.gov/owm/mtb/runoff.pdf

This fact-sheet presents details on use of On-site surface and underground retention/detention BMPs for urban storm-water management. Details are given on applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, construction / installation, operation and maintenance costs. Case studies on application of this method at various locations in the US are presented, offering valuable findings on performance, cost, etc. of different BMPs employed. Tables on application, operation and maintenance costs of specific BMPs are presented in tables, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Porous Pavement
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-023
**Link:** http://www.epa.gov/owm/mtb/porouspa.pdf

This fact-sheet presents details on use of porous pavement for urban storm-water management. Porous pavement is a special type of pavement that allows rain and snowmelt to pass through it, thereby reducing the runoff from a site and surrounding areas. In addition, porous pavement filters some pollutants from the runoff if maintained. Details are given on applicability, advantages & disadvantages, design criteria, performance, efficiency, and on installation, operation and maintenance costs. In addition to documented pros and cons of porous pavements, several questions still remain regarding their use, such as whether they can maintain porosity over a long period of time, if the pavement will remain capable of removing pollutants after subfreezing weather and snow removal, as well as cost of maintenance and rehabilitation options for restoration of porosity. Application, operation and maintenance costs tables are presented, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Sand Filters
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-007
**Link:** http://www.epa.gov/owm/mtb/sandfltr.pdf

This fact-sheet presents details on use of sand filters for urban storm-water quality control. Details are given and on installation, operation and maintenance as well as costs for the latter three.

**Title:** Low Impact Development (LID): A Literature Review
**Author:**
**Date:** October 2000
**Source:** United States Environmental Protection Agency, Office of Water (4203) EPA-841-B-00-005
**Link:** http://www.epa.gov/owow/nps/lid/lid.pdf

This publication offers a literature review conducted to determine the availability and reliability of data to assess the effectiveness of low impact development (LID) practices for controlling storm-water runoff volume and reducing pollutant loadings to receiving waters. The most successful installations of alternative **(porous) pavements** are found in coastal areas with sandy soils and flatter slopes (Center for Watershed Protection,1998). Costs for paving blocks and stones range from $2 to $4, whereas asphalt costs $0.50 to $1 (Center for Watershed Protection, 1998). **Grass swales** or channels are adaptable to a variety of site conditions, are flexible in design and layout, and are relatively inexpensive (USDOT, 1996). Engineered swales are less costly than installing curb and gutter/storm drain inlet and storm drain pipe systems. The cost for traditional structural conveyance systems ranges from $40–$50 per running foot (Center for Watershed Protection, 1998). Concerns that open channels are potential nuisance problems, present maintenance problems, or impact pavement stability can be alleviated by proper design. **A bio-retention** area can be composed of a mix of functional components, each performing different functions in the removal of pollutants and attenuation of storm-water runoff conveyance systems. Construction of a typical bio-retention area in Prince George's County, Maryland is between $5,000 and $10,000 per acre drained, depending on soil type (Weinstein, 2000). Other sources estimate the costs for developing bio-retention sites at between $3 and $15 per square foot of bio-retention area.

**Title:** Winter Road Management
**Author:**
**Year:** Dec 1992
**Link:** http://www.deq.state.mi.us/documents/deq-swq-nps-wrm.pdf

Use of road salt (sodium chloride) has many drawbacks. Some reports have estimated that the damage done by salt ranges from 6-30 times the initial cost of the salt, with 90% of the damage due to corrosion. With the corrosive damage to bridges, highways, and vehicles factored in, one study concluded that the actual cost of salt may be closer to $775/ton. The total annual national cost of salt-related damage is estimated at $5.5 million. However, there are advantages to its use, which are discussed in this report. Alternatives to road salt include calcium magnesium acetate (CMA), calcium chloride, urea, sand, natural brines, potassium chloride, magnesium chloride (Freeze Guard), sodium format, and regular salt such as Quick Salt, TCI, and CG-90. **CMA** (ICE-B-GON), is reported to be 10-15 times less corrosive than salt, with little or no effects on terrestrial vegetation or soil physical properties. CMA seems to be the alternative of choice. However, it can result in significant organic loadings to receiving waters caused by chemical oxygen demand. It can also cause increased organic loadings to wastewater treatment plants, which serve combined sewers.

**Title:** Report 5.1. Review of the Use of Storm-water BMPs in Europe
**Author:** Middlesex University
**Year:** 18 August 2003
**Source:** Project under EU RTD 5th Framework Programme. Contract No EVK1-CT-2002-00111 "***Adaptive Decision Support System (ADSS) for the Integration of Storm-water Source Control into Sustainable Urban Water Management Strategie***s", WP5/T5.1/D5.1 - PU

This report represents a comprehensive review of the current state of knowledge on the use and performance of BMPs for storm-water treatment and control. It has been prepared as part of the EC funded Day Water project through contributions provided by several partners based on both their extensive knowledge and specific expertise of storm-water BMPs. An emphasis has been placed on the design, operation, and maintenance and costing of storm-water BMPs, with particular regard to country specific factors. The accepted use of these systems varies with a wide range of structural and non- structural BMPs being employed in northern and temperate European countries for storm-water control, whereas their applicability is less well developed in southern European countries such as Spain, Italy, Greece and Portugal. An exception to this is street cleaning, which appears to be a common practice throughout Europe. There also appear to be patterns or trends in the types of BMPs preferred within various countries, with for example, rainwater harvesting being a popular storm-water BMP in France and Germany, but practiced to a lesser extent in other European countries.

**Title:** Storm-water Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring
**Source:** Fact Sheet - Porous Pavements
**Link:** http://www.fhwa.dot.gov/environment/ultraurb/3fs15.htm

Porous pavements have the potential to be an effective ultra-urban BMP because they allow some of the storm-water to percolate through the pavement and enter the soil below. To maintain the infiltrative capacity of porous pavements such as asphalt, quarterly vacuum sweeping in conjunction with jet hosing or jet hosing alone is recommended (Schueler et al., 1992). Therefore, the installation of porous pavement BMPs in regions that lack the equipment or resources for routine maintenance is not recommended. High failure rate for these installations in Maryland is attributed in part to a lack of routine maintenance (Lindsey et al., 1991). Failures at sites in the Middle Atlantic States have also been attributed to poor site conditions and installation practices. Pratt et al. (1995) estimated the useful life of these types of permeable surfaces to be between 15 and 20 years. Since paving stones can be lifted and reused, the repair or reconstruction of these surfaces is also expected to be less than that associated with porous asphalt or concrete. Costs for porous asphalt are approximately 10 to 15 percent higher than those for regular asphalt; porous concrete is about 25 percent more expensive than regular concrete. Requirements for site preparation or the use of specialized equipment may also increase these costs. The higher costs of installation of porous pavements can be offset to some extent by the elimination of curbs, gutters, and storm drains. In some cases this may lower the overall cost for a project (Field et al., 1982). The final economics associated with a particular site are also affected by site-specific conditions, such in situ permeability, and the cost and proximity of gravel supplies.

**Title:** King County, Washington Surface Water Design Manual
**Author:** King County Department of Natural Resources
**Year:** 1998.

This is a comprehensive storm-water BMP design manual. It provides information necessary to storm-water management systems and BMPs. This includes hydrologic analyses of storm events and BMP performance, design of storm-water conveyance systems, flow control and treatment BMP design and a number of appendices which address maintenance requirements, small site considerations and erosion and sediment control standards. It covers the following Storm-water BMPs: Detention / Retention / Infiltration / Filtration / Constructed Wetlands /Hydraulic devices.

**Title:** Protecting Water Quality in Urban Areas: Best Management Practices for Dealing with Storm Water Runoff from Urban, Suburban and Developing Areas of Minnesota
**Author:** Minnesota Pollution Control Agency.

**Year:** 2000
**Source:** Storm-water BMP Design Manual. Minnesota Pollution Control Agency
**Link:** http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html

It is a comprehensive BMP reference, and provides a good deal of information on pollution prevention, erosion control, and sediment control. Some generalized information regarding the use of proprietary devices is included.

**Title:** Storm-water Best Management Practices. General Storm-water and BMP Manual
**Author:** North Carolina Department of Environment and Natural Resources – Water Quality,
**Year:** April, 1999.
**Source:** Publication #: EPA 841-K-94-003
**Link:** http://www.bts.gov/smart/cat/RUNOFF.html

This manual offers a concise storm-water BMP reference. The document is very comprehensive with a chapter devoted to each of the most commonly used storm-water treatment BMPs in North Carolina.
Types of BMPs (Storm-water): Detention / Retention / Infiltration / Filtration / Constructed Wetlands

**Title:** Storm-water Management Planning and Design Manual: Draft Final Report
**Author:** Ministry of the Environment, Ontario, Canada. Storm-water BMP Design Manual.
**Year:** November, 1999
**Link:** http://www.ene.gov.on.ca/envision/env%5Freg/er/documents/storm-watermanual/index

A very well researched planning and design manual that provides a breadth of information for all types of BMPs ranging from lot level housekeeping practices to regional storm-water treatment facilities. Also included are design examples, operations and maintenance costs, capital costs, and appendices addressing processes fundamental to the appropriate design and implementation of BMPs. Cold climate considerations are addressed. Types of BMPs: Prevention: Housekeeping / Low Impact Development / Operations and Maintenance; Storm-water: Detention / Retention / Infiltration / Filtration / Constructed Wetlands / Hydraulic Devices and Sediment Control: Construction / Soil Erosion / Sediment Control

**Title:** Texas Non-point Sourcebook Storm-water BMP Handbook
**Author:** Statewide Storm Water Quality Task Force, Texas Department of Environmental Resources.

**Link**: http://www.txnpsbook.org/default.htm

It is an online guide to storm-water BMPs. The guide includes background information on the impacts of urbanization on hydrology, programs for managing runoff, and section on storm-water runoff BMPs. BMPs are differentiated based on their roles in pollution prevention, runoff prevention, and storm-water treatment. Target pollutants are identified for each BMP as well as qualitative ratings of general BMP performance and operational considerations. Construction considerations are not addressed. Types of BMPs: Prevention: Housekeeping / Low Impact Development / Operations and Maintenance; Storm-water: Detention / Retention / Infiltration / Filtration / Constructed Wetlands; Sediment Control: Construction / Soil Erosion / Sediment Control

**Title:** Riparian Buffer Strategies
**Author:** Metropolitan Washington Council of Governments
**Year:** 1995
**Source:** Metropolitan Washington Council of Government. Publication #: 95703

This document is organized into four chapters. The first chapter presents an overview of current buffer programs, particularly those designed to achieve water quality objectives. This is followed by a chapter on the pollutant removal mechanisms of urban riparian buffers. The third chapter describes design criteria for water quality buffers and the final chapter presents guidelines for implementing buffer programs.
Types of BMPs: Prevention: Housekeeping / Operations and Maintenance; Storm-water: Filtration / Infiltration; Sediment Control: Construction / Soil Erosion / Sediment Control

**Title:** Maintaining Your Storm-water Management Structure
**Author:** Geiser, Lou.
**Year:** 1999.
**Source:** Howard County, Maryland (?)…….

This is a brief manual which prescribes maintenance practices to maximize the longevity and performance of common storm-water BMPs. Treatment methods for retention and detention ponds, infiltration devices, grit chambers and underground structures are presented. The information in this manual is qualitative in nature. Types of BMPs: Storm-water: Detention / Retention / Infiltration / Filtration

**Title:** Controlling Urban Runoff: A practical Manual for Planning and Designing Urban BMPs.
**Author:** Thomas R. Schueler
**Year:** 1987
**Source:** Metropolitan Washington Council of Governments. Publication #: 87703

The manual summarizes local and national research on BMP performance, design and costs, as well as the practical experience grained in urban BMP implementation at the local level. Specific attention includes extended detention ponds, wet ponds, infiltration trenches, infiltration basins, porous pavement, water quality inlets, vegetative systems, storm-water benefits, performance, costs, and maintenance.
Types of BMPs:_Prevention: Housekeeping / Low Impact Development / Operations and Maintenance; Storm-water: Detention / Retention / Infiltration / Filtration / Constructed Wetlands /Hydraulic Devices; Sediment Control: Construction / Soil Erosion / Sediment Control

**Title:** Design of Storm-water Filtering Systems
**Author:** Richard A. Claytor and Thomas R. Schueler
**Year:** 1999
**Source:** The Center for Watershed Protection
**Link:** http://www.cwp.org/

The manual presents detailed engineering guidance on eleven different filtering systems. The storm-water filters referred to is a diverse spectrum of storm-water treatment methods utilizing various media (sand, peat, grass, soil or compost to filter) out pollutants entrained in urban storm-water. These filters are typically designed solely for pollutant removal, and to serve small development sites. The three broad groups include sand filters, bio-retention, and vegetated channels

**Title:** Inspection and Maintenance of Infiltration Facilities
**Authors:** Lindsey, Greg, Les, William
**Year:** 1992
**Source:** Journal of Soil and Water Conservation, 47(6):481-485
**Database:** Academic Journals, Gale Group

A 1990 field survey of storm-water infiltration facilities constructed in Maryland as required by the Management Act was conducted. Infiltration basins trenches, dry wells, porous pavement facilities and swales were some of the facilities examined. The study revealed that half of the facilities were not as designed already. Two thirds of them need repairs. It was also found out that some function better than the other.

**Title:** Maintenance of Storm-water BMPS in Four Maryland Counties: A Status Report
**Author:** Lindsey, Greg Roberts, Les Page, and William
**Year:** Sept-Oct, 1992
**Source:** Journal of Soil and Water Conservation, v47, n5, p417 (6)
**Database:** Academic Journals, Gale Group

A survey of more than 250 storm-water facilities in Maryland has revealed the need for better inspection and maintenance of the facilities. Detention basins, infiltration basins and trenches as well as dry wells and underground facilities were some of the kinds of facilities that were inspected. Inspection results clearly show the shortcomings of current facilities maintenance and the necessity of solving the maintenance problems to achieve the aims of the Storm-water Management Act.

**Title:** Final Contract Report: Development of a Storm-water Best Management Practice Placement Strategy for the Virginia Department of Transportation
**Author:** Shaw L. Yu, Jenny Xiaoyue Zhen, Sam Yanyun Zhai
**Year:** October 2003
**Source:** Virginia Transportation Research Council, VTRC 04-CR9

Since the implementation of the federal and state storm-water management regulations, the Virginia Department of Transportation (VDOT) has constructed hundreds of best management practices (BMPs) for controlling storm-water runoff from highways and its other facilities, such as maintenance headquarters, storage areas, etc. In recent years, the U.S. Environmental Protection Agency (USEPA) has promoted the watershed approach in controlling pollution from various sources in a watershed. In the present study, a holistic methodology for determining the cost-effective placement and configuration of storm-water BMPs for VDOT was developed. The methodology consists of three interacting functional components: a watershed simulation model, a BMP simulation module (the impoundment routine), and an optimization model. A highway application case study was conducted using the VDOT Rt. 288 Project in Chesterfield County, Virginia. The results showed that the current VDOT BMP placement approach (which consists of on-site treatment of storm-water runoff from highways), might not be cost-effective in terms of protecting the water quality at the watershed level. The results of the case study indicate that if VDOT were to work with other stakeholders in developing a BMP placement strategy for the entire watershed, greater cost-effectiveness would be achieved as a result of fewer BMPs being required for VDOT to construct than would otherwise be the case. The methodology developed in the present study can be modified and expanded into a decision support system, which can include more types of BMPs and which would allow more BMP placement scenarios.

**Title:** Minnesota Urban Small Sites Best Management Practice Manual: Storm-water Best Management Practices for Cold Climates
**Author:** Metropolitan Council
**Year:** 2001
**Source:** Metropolitan Council
**Link:** http://metrocouncil.org/environment/watershed/bmp/manual.htm

This manual offers detailed discussions on design of various BMPs for runoff pollution prevention and storm-water treatment. Under runoff pollution control, BMPs have been categorized into groupings: impervious surface reduction, housekeeping, construction practices, and soil erosion control. Under storm water treatments are infiltration systems, filtration systems, constructed wetlands, retention systems, detention systems, and flow control structures.

**Title:** Revised Manual for New Jersey: Best Management Practices for Control of Non-point Source Poll
**Author:** New Jersey Department of Agriculture, New Jersey Department of Community Affairs, New Jersey Department of Environmental Protection, and New Jersey Department of Transportation
**Date:** Fifth draft May 3, 2000
**Source:** http://www.state.nj.us/dep/watershedmgt/bmpmanual.htm

As a minimum, storm-water BMPs should be inspected annually and after any storm larger than the design storm in term of rainfall amount, runoff, or intensity. Sediment and debris will gradually accumulate in practically every type of BMP, to varying degrees. Sediment removal and disposal is usually the largest single cost of maintaining a BMP system; therefore, it is best to plan ahead and set aside the necessary funds in advance. Because of the variability of BMPs and site conditions, no set 'rules of thumb' exist for sediment removal procedures and timetables.

**Title:** Storm-water Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring
**Author:** United States Department of Transportation, Federal Highway Administration.
**Date:**
**Source:** http://www.fhwa.dot.gov/environment/ultraurb/index.htm

The publication offers a broad coverage on use of BMPs for urban storm-water control, their effectiveness and limitations, selection criteria, and relative costs and the final prioritization and recommendation of methods. When space is too limited for the use of structural BMPs, such as in ultra-urban areas, nonstructural BMPs may be among the most cost-effective options available for reducing water quality constituents in storm-water runoff. When used in conjunction with structural BMPs, they may improve BMP efficiency and help to reduce maintenance requirements by reducing the accumulation of trash and sediment. The problem of lack of data on cost and effectiveness of nonstructural BMPs (a primary component in analysis of cost effectiveness of the method) is addressed. Further, problems associated with the adoption of non-structural BMPs, such as capital cost, material storage, etc, are discussed.

**Title:** Low-Impact Development: An Innovative Alternative Approach To Storm-water Management
**Author:** Chao-Hsien Liaw, Mow-Soung Cheng, and Yao-Lung Tsai
**Date:** 2000

**Source:** Journal of Marine Science and Technology, Vol. 8, No. 1, pp. 41-49
**Link:** http://ind.ntou.edu.tw/~jmst/8-1/41-49.pdf

To assist local governments in their efforts to develop more effective storm-water management programs, an innovative comprehensive approach to storm-water management referred to as Low-Impact Development (LID) has been developed. Low-Impact Development technology employs micro scale and distributed management techniques. This paper briefly outlines the development of LID technology and discusses its basic hydrological control principles. However, LID's source control techniques are an economical common sense approach that can be used to better manage new development or retrofit existing development. Adopting this technology, short and long-term infrastructure would reduce short- and long-term costs by reducing impervious areas, eliminating curbs/gutters and storm-water ponds. Reduction of the infrastructure also reduces infrastructure maintenance burdens making LID development more economically sustainable. LID promotes public awareness, education and participation in environmental protection.

**Title:** Environmentally Sensitive Low-Impact Development
**Author:** Larry S. Coffman, Jennifer Smith, and Mohammed Lahlou.
**Date:** 2002 (revision)
**Source:** Watershed 96 Proceeding
**Link:** http://www.epa.gov/owowwtr1/watershed/Proceed/coffman.html

Urban development has proven to greatly alter the quantity and quality of receiving water resulting in cumulative impacts on the physical, chemical, and biological integrity of ecosystems (Galli, 1992). Zoning and site planning requirements reduce impacts by preserving sensitive areas such as wetland and floodplains. This publication presents the Prince George's County, Maryland, Low-Impact Development (PGLID) approach, a new perspective in urban development, which integrates site ecological and environmental requirements into all phases of urban planning and design. Changing the storm-water management approach from a "collect and treat/pipe and pond" strategy to the low-impact approach has significantly reduced site development costs. Cost savings are achieved as a result of less clearing; less earth work; less pipe; fewer drainage control structures; minimum use of roadside curb and gutter; less road pavement; fewer sidewalks; and lower wetland, tree and stream mitigation costs. This approach has also resulted in reduced local government BMP maintenance costs and a potential savings to residents through tax reduction.

**Title:** Town of Hampstead Community Environmental Review: Summary Report and Findings
**Author:** Center for Chesapeake Communities, Inc.
**Year:** 1999
**Source:** Town of Hampstead and the Chesapeake Bay Program's
**Link:** http://www.chesapeakecommunities.org/hampstead.html#toc

This publication addresses adoption of LID in the Town of Hampstead's identified downtown revitalization programme. It reports LID case studies and pilot programs, which show at least a 25 percent to 30 percent reduction in site development, storm-water and maintenance costs for residential development with LID. This is achieved by reducing clearing, grading, pipes, ponds, inlets, curbs and paving. A result of LID's on lot micro-scale approach is that the storm-water management controls become a part of each property owner's landscape. This reduces the public burden to maintain large centralized management facilities and reduces the cost and scale of maintenance to a level the homeowner can easily afford - the cost of routine landscape / yard care and pollution prevention.

**Title:** Winter Road Management
**Author:** WRM
**Year:** 1992
**Source:**
**Link:** http://www.deq.state.mi.us/documents/deq-swq-nps-wrm.pdf

This publication addresses the proper use and storage of road salt, its relation with other BMPs, and discusses alternatives to road salt. Advantages of use of road salt (low cost, does not drain clogging, is effective…) in road deicing as well as disadvantages (corrosion, storage,) are highlighted. Alternatives to road salt include calcium magnesium acetate (CMA), calcium chloride, urea, sand, natural brines, potassium chloride, magnesium chloride (Freeze Guard), sodium format, and regular salt such as Quik Salt, TCI, and CG-90. The alternatives cause various types of environmental damage, and/or may be relatively expensive. Calcium chloride is an effective deicer but contains chloride and costs $250/ton. Urea costs $250/ton and may result in nitrogen contamination. Sand costs only $3/ton but can clog drains and settle out in streams. The cost of CMA material ($650-700/ton) is related to the expense of producing acetic acid. CMA seems to be the alternative to road salt as it is reported to be 10-15 times less corrosive than salt, with little or no effects on terrestrial vegetation or soil physical properties. Alternatives such as ethylene glycol, diethylene glycol, methanol, and propylene glycol have a high chemical oxygen demand. The former two chemicals are also toxic to humans and wildlife if ingested, and methanol is toxic if ingested or absorbed through the skin.

**Title:** California Storm-water BMP Handbook: New Development and Redevelopment (Infiltration Basins)
**Author:** California Storm-water Quality Association (CASQA)
**Year:** January 2003
**Link:** http://www.cabmphandbooks.com/Documents/Development/TC-11.pdf

Infiltration basins are relatively cost-effective practices because little infrastructure is needed when constructing them. One study estimated the total construction cost at about $2 per ft of storage for a 0.25-acre basin (SWRPC, 1991). Caltrans spent about $18/cubic foot for two infiltration basins constructed in southern California. Published cost estimates may deviate greatly from what might be incurred at a specific site. One concern associated with infiltration practices is the maintenance burden (5 to 10% of construction costs) and longevity. If improperly maintained, infiltration basins have a high failure rate. Other limitations associated with use of infiltration basins are presented in the publication

**Title:** Overview of porous pavement research.
**Author:** Singer, M; Field, R; Masters, H
**Year:** 1982
**Source:** Storm and Combined Sewer Sect., U.S. EPA, WATER RESOUR. BULL., vol. 18, no. 2, pp. 265-270, 1982.

This paper discusses the economics, advantages, potential applications, and status and future research needs of porous pavements. Porous pavements are an available storm water management technique, which can be used on parking lots and low volume roadways in order to reduce both storm water runoff volume and pollution. In addition, ground water recharge is enhanced. Also, cost reductions result due to elimination of curbs, drains, and small sized storm sewers. Porous asphalt pavements consist of a relatively thin course of open graded asphalt mix over a deep base of large size crushed stones. Water can be stored in the crushed stone base until it can percolate into the sub base or drain laterally. Other porous pavement types include concrete lattice blocks and a porous concrete mix.

**Title:** Municipal Technologies: Technologies Fact-sheets
**Author:** United States Environmental Protection Agency
**Date:** November 2003
**Source:** United States Environmental Protection Agency,
**Link:** http://www.epa.gov/owm/mtb/mtbfact.htm

This publication presents fact-sheets on the use of different BMPs for urban storm-water management. It details applicability in different sites and conditions, disadvantages and advantages, design criteria, performance/efficiency, operation and maintenance, as well as construction, operation and maintenance costs. Further, it presents valuable working tables data for initial installation, and determination of average annual operation and maintenance costs of some BMPs, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Baffle Boxes
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 2001
**Source:** United States Environmental Protection Agency, EPA 832-F-01-004
**Link:** http://www.epa.gov/owm/mtb/baffle_boxes.pdf

The publication presents fact-sheet on the use of baffle boxes in urban storm-water management. It details applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, its construction, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Bio-retention
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-012
**Link:** http://www.epa.gov/owm/mtb/biortn.pdf

The publication presents fact-sheet on the bio-retention, a best management practice (BMP) developed in the early 1990's by the Prince George's County, MD, Department of Environmental Resources (PGDER). Details are given on applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, construction, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Infiltration Drain-fields
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-018
**Link:** http://www.epa.gov/owm/mtb/infltdrn.pdf

This fact-sheet presents details on use of Infiltration Drain-fields for urban storm-water management. It details applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, construction / installation, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Infiltration Trench
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-019
**Link:** http://www.epa.gov/owm/mtb/infltrenc.pdf

This fact-sheet presents details on use of Infiltration Trench for urban storm-water management. It details applicability, advantages, disadvantages, design criteria, performance/efficiency, operation and maintenance, and finally, construction / installation, operation and maintenance costs. Figures on cost for specific application conditions are cited, together with relevant references.

**Title:** Storm Water Technology Fact Sheet: Sand Filters
**Author:** Office of Wastewater Management, Office of Water, USEPA
**Date:** September 1999
**Source:** United States Environmental Protection Agency, EPA 832-F-99-007
**Link:** http://www.epa.gov/owm/mtb/sandfltr.pdf

This fact-sheet presents details on use of sand filters for urban storm-water quality control. Details are given on applicability, advantages & disadvantages, design criteria, performance, efficiency, and also on installation, operation and maintenance as well as costs for the latter three.

**Title:** Low Impact Development (LID): A Literature Review
**Author:**
**Date:** October 2000
**Source:** United States Environmental Protection Agency, Office of Water (4203) EPA-841-B-00-005
**Link:** http://www.epa.gov/owow/nps/lid/lid.pdf

This publication offers a literature review conducted to determine the availability and reliability of data to assess the effectiveness of low impact development (LID) practices for controlling storm-water runoff volume and reducing pollutant loadings to receiving waters. The most successful installations of alternative **(porous) pavements** are found in coastal areas with sandy soils and flatter slopes (Center for Watershed Protection, 1998). Costs for paving blocks and stones range from $2 to $4, whereas asphalt costs $0.50 to $1 (Center for Watershed Protection, 1998).

**Title:** Maintenance of Storm-water Quality Treatment Facilities Engineering and Research, Storm-water Management, Inc.
**Author:** James H. Lenhart, J.H., Harbaugh, R.
**Year:** 2000.
**Source:** Storm-water Management Facilities Management Group, Inc.
**Link:** http://www.storm-waterinc.com/pdfs/maintenance_facil.pdf

In this paper, the authors describe sand filter as one of the most effective BMPs, but which is sensitive to solids loading and befouling. Their maintenance frequency recommendations range from annual light maintenance (removal of trash and debris) to periodic media replacement every five years. Major maintenance procedures included complete removal and replacement of the sand layer and under drain system. For privately owned underground facilities contractors charge from $300.00 to $400.00 per cubic yard for removal and replacement (Harbaugh, personal communication). In a reported case study, five sand filters were proposed for the Downtown Silver Spring project in Silver Spring Maryland. These filters contained 380 cubic yards of sand and rock. The five-year maintenance cost was estimated at $350,000 over a five-year period, with the main assumption of annual light maintenance with pretreatment cleanout and one major maintenance at the end of the five-year period. As a comparison the Storm Filter technology was used instead based on a five-year maintenance cost of $174,000.

**Title:** Maintenance of Storm-water Quality Treatment Facilities Engineering and Research, Storm-water Management, Inc.
**Author:** James H. Lenhart, J.H., Harbaugh, R.
**Year:** 2000.
**Source:** Storm-water Management Facilities Management Group, Inc.
**Link:** http://www.storm-waterinc.com/pdfs/maintenance_facil.pdf

In a section of this paper, **grassed swales** are BMPs are represented, highlighting recent changes in their design necessitated by the high failure rates associated with saturated soils and/or lack of water supply. Newer designs utilize plants which survive in saturated conditions but are also drought tolerant. Other problems associated with function of the BMP is the need to meet visual needs, whereby the swales are mowed at incorrect heights, fertilized and managed with pesticides and herbicides. Other systems fall into neglect and significant die off of the vegetation can result from saturated conditions or toxicity effects from petroleum hydrocarbons. This significantly affects maintenance costs, particularly if the facility requires reconstruction.

**Title:** Maintenance of Storm-water Quality Treatment Facilities Engineering and Research, Storm-water Management, Inc.
**Author:** James H. Lenhart, J.H., Harbaugh, R.
**Year:** 2000.
**Source:** Storm-water Management Facilities Management Group, Inc.
**Link:** http://www.storm-waterinc.com/pdfs/maintenance_facil.pdf

The author present a comparative analysis of facility maintenance costs for select BMPs. The cost of land is significant for some BMPs that may render their adoption uneconomical in situations where land availability and/or affordability value is a problem. In an infill property development in the City of Renton, WA, the developer proposed replacing an existing swale with an alternate facility so additional land space would be available, (Hinthorne, 2000). The first costs and maintenance costs of alternate facilities were analyzed and presented to the City for consideration. In this case, land costs had a major influence on long term costs of the BMP.

# IV. Innovative BMPs and Highway Infrastructure

**Title:** Storm-water Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring
**Author:** United States Department of Transportation, Federal Highway Administration.
**Date:**
**Source:** http://www.fhwa.dot.gov/environment/ultraurb/index.htm

Discussed in this report it is a number of new BMP designs and design concepts, which are of potential interest to those managing ultra-urban runoff. Although these designs have been installed and operated at relatively few locations, the field trials clearly indicate noteworthy performance. The practices described in the report are alum injection systems, MCTT system, bio-filters (e.g., StormTreat® System), vegetated rock filters, and vertical filter systems.

**Title:** Storm-water Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring
**Author:** United States Department of Transportation, Federal Highway Administration.
**Date:**
**Source:** http://www.fhwa.dot.gov/environment/ultraurb/index.htm

The multi-chamber treatment train (MCTT), an innovative approach for storm-water management practice, is here discussed. It is reportedly applicable to small and isolated paved critical source areas from about 0.1 to 1 ha (0.25 to 2.5 ac). This is a relatively expensive BMP, and is reserved for those locations equipped with electric power, and where regular maintenance is feasible. For example, a recent retrofit installation cost $95,000 to tie an MCTT into an existing storm drain system for a 1 ha (2.5 ac) drainage area (Pitt, 1996). Installation cost would reportedly be lower if the installations were in new, developing areas.

**Title:** Storm-water Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring
**Author:** United States Department of Transportation, Federal Highway Administration.
**Date:**
**Source:** http://www.fhwa.dot.gov/environment/ultraurb/index.htm

Bio-filter is a recent design innovation, developed in the mid-1990s, which uses bio-filters for storm-water treatment. First developed in 1994, the StormTreat® System (STS) uses sedimentation, filtration, and biological action to manage the common storm-water pollutants. Storm-water pretreated to remove large-diameter sediment is piped into the STS tank, where the captured runoff, is treated over the course of a 5- to 10-day period before conveying it into the subsurface of the wetland and through the root zone. Based on product literature, the cost to purchase STS and install a single tank is between $3,600 and $4,000 (1996 dollars). The maintenance costs have been estimated at $100 to $150 per tank cleaning, which is typically required every two to three years. This maintenance cost does not include the cost to remove sediment from any upstream pretreatment (e.g., catch basins).

**Title:** Storm-water Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring
**Author:** United States Department of Transportation, Federal Highway Administration.
**Date:**
**Source:** http://www.fhwa.dot.gov/environment/ultraurb/index.htm

**Vegetated Rock Filters (VRF)** is a recent design innovation for storm-water. Although wetland treatment systems similar to the VRF have long been used to treat wastewater, only since the mid-1990s has the design concept been applied to storm-water. A number of design variants exist for VRF. Although specific information is not available, it is easy to state that the cost of a VRF is high when compared to other BMPs. However, the additional expense of VRF systems can result in consistent removal of nutrients (principally nitrogen) that might not be sufficiently removed by other less expensive BMPs.

**Title:** Storm-water Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring
**Author:** United States Department of Transportation, Federal Highway Administration.
**Date:**
**Source:** http://www.fhwa.dot.gov/environment/ultraurb/index.htm

**Vertical Filter Systems (VFSs)** are Storm-water BMPs being developed that use vertically mounted filters. Specifications, design, and current problems in its use are presented in the publication. Although laboratory, pilot, and field tests of the vertical filter design have been performed (Tenney et al., 1995), as of this time the design parameters have not been fully developed. Some of the design problems encountered relate to clogging of the geo-textile fabric incorporated into the filter, loss of the sand medium due to high hydraulic pressures, and piping flow at the interface of the vertical filter and adjacent walls. Some design modifications that are under evaluation include installation of baffles within the storage chamber to minimize sediment transport and layered multi-media filters (compost, zeolites, sand) that are resistant to clogging and effective on a wide range of pollutants.

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*Task 2. Description of Select Best Management Practices Sites*

# Impact Perception of Alternative Storm Water Best Management Practices (BMPs) on Highway Infrastructure

Conducted by

**Robert D. Sykes, MLA**
Associate Professor and Co-Principal Investigator
Department of Landscape Architecture

**Dr. Caleb Arika, PhD**
Research Associate
Department of Biosystems and Agricultural Engineering

**Dr. John Nieber, Ph.D.**
Professor, and Principal Investigator
Department of Biosystems and Agricultural Engineering

University of Minnesota
Twin Cities

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## Introduction

This report is a descriptive presentation of data and other information gathered during visits of various alternative best management practices (BMP) in the twin cities metro area. The main objective of the visits was to study and document condition and performance of various BMPs used for management of storm water generated in roadways and other transportation and utilities associated infrastructure. The practices which were surveyed are a small sample of the large number of alternative BMPs in use in this region. Selection of BMPs to study was intentionally biased in attempt to have representation of the various hydrologic types in use. However, due to the scope of the project, it was impossible to generate a fairer sample or sampling technique. Information collected on the visited practices includes subjective descriptions of the condition and visual appearance of each practice, results of conducted measurements, among others. Observations were obtained for the following tests: infiltration/hydraulic conductivity, soil moisture content, soil profile descriptions, bulk density, vegetation cover, runoff contributing area, elevation difference between BMP and infrastructure pavement, distance to infrastructure, infrastructure characteristics, and infrastructure stress indicators. Further, the location and outflow for the various alternative BMPs have been determined and recorded using the Geographical Positioning System (GPS). This data, together with other attribute information have been incorporated into GIS.

Daily precipitation data was also obtained for the study sites.

### Dry Swale located at the Caterpillar facility in Roseville

This practice measures approximately 80 meters long by 10 m top width. It is located approximately 20 feet east of the Caterpillar parking lot in Roseville (1901 County Rd B2 Roseville) – see map, figure 1. Elevation difference between its outlet and the parking lot pavement was estimated at 0.5 m. Inspection of the site was conducted on April 21, 2004. The swale runs north-south along the east side of the Caterpillar's east parking lot, receiving runoff from both the parking lot and the extensive 'go-down' roofs. A grated outlet is located near the midway point along its length. No standing water was observed at the time of the inspection, though there was modest rainfall event less than a week previously. Runoff is conveyed into the swale from the parking lot area via curbless sections of the parking lot. The grass sides and bottom of the swale appears stabilized with little signs of erosion, except in areas with less than 100% grass cover as well as relatively steep slopes next to the outlet. Well established grass cover was observed along most of the swale. There was significant erosion or sedimentation observed in the swale.

**Figure 1. Photograph of the Dry Swale at the Caterpillar facility, Roseville**

The practice appears to be functioning according to design and purpose of installation.

Further investigations to determine the size of contributing area, and the impact of the practice on adjacent infrastructure, are recommended. Also required to be determined is the channel grade, infiltration rate, and the return period design storm.

Location of the practice together with its outflow point were mapped on December 5, 2004 using GPS unit, and a GIS database created. Elevation of the outflow point was also recorded, and been displayed in the GIS. Samples were extracted for soil profile descriptions. Other measurements and tests for the site have been planned for a later date. Table 1a is a presentation of the data collected for this practice using the GPS technology.

## Constructed Infiltration Basin located next to the Inter-Bank (US Bank), County Road B2, Roseville

Inspection of this site was carried out on April 21, 2004. The site consists of two adjacent basins located east of the bank parking lot (1875 County Rd B2 Roseville) – see map, figure 1. The basins run west-east away from the parking lot, with the large basin (30 x 15 m) located adjacent to the infrastructure. Elevation difference between parking lot pavement and the basins' outlets is approximately 3 feet, with the basin and infrastructure located less than 10 feet apart. Over-flow from the first basin is conveyed to the second one via a connecting 12-inch PVC pipe. A main outlet located at a slightly higher elevation directs further over-flow from the first basin to the municipal drainage network. At the time of inspection, both basins contained significant amounts of water reaching the connecting overflow pipe, but still below the main outlet. There was significant precipitation (total of 1.9 inches past 5 days ) prior to date of this inspection.

Runoff from contributing areas is conveyed into the first basin via curb weirs. The grassed sides of both basins appear well stabilized with little signs of erosion. There was however, significant erosion along the rip-rap stabilized curb-weirs from both the bank parking lot and the service road due north of the basins.

Further investigations were recommended for the following: elevation difference between pavement and basin floor, infiltration rate at basin floor, water table elevation (through coring), and area of watershed served by the practices. Further, need for periodic monitoring of water level in basin was felt justifiable, because the practice is serving apparently large 'watershed' area. A map (or GIS database if available) of the stormwater drain system would also be useful.

**Figure 2. Photograph of Constructed infiltration Basins at the Inter-bank, Roseville**

The practice was mapped by tracing its perimeter using GPS unit on December 5, 2004. Coordinates and elevation data for the inlet and outflow points were recorded. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. Details on data collected using GPS for the site are presented in table 1a. Further measurements and tests for the site will be completed at a later date.

## Rain Water Garden located at Como Park

The site is located at the SE quadrant of the Lexington pkwy N & Nebraska ave W by Como Park – see map, figure 1. This was inspected on April 21, 2004. The practice is constructed on a steep topography watershed sloping south-east towards lake Como. The garden comprises of two sections, each approximately 40 yards long, with a 'dyke' separating them. It is has top width of approximately 20 yards, and an elevation difference with the adjacent road of between 2 and 3 feet. The practice is located within a few feet of the Lexington Parkway, with a narrow grassy strip separation.

Its floor is vegetated predominantly with annuals; its steep east side slope is planted with grass, shrubs and trees which are as yet to be well established. The surface is covered with what appears to be fiber glass sheet mulch. The rest of the contributing area is covered with well established grass cover. A small section near head of garden (from Nebraska avenue) is being re-sodded following what appears to be sheet erosion damage.

Further investigations into infiltration capacity of garden were considered important. This is because the structure is placed very close to the road, hence is likely to impact the infrastructure.

**Figure 3. Photograph Rain Garden, Como Park, Roseville**

The practice was mapped by tracing its perimeter using GPS unit on December 5, 2004. Coordinates and elevation data for the inlet and outflow points were recorded. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. Other planned measurements and tests will be completed at a later date

Information which has been made available to us (Terry Noonan[1]) on results of past monitoring exercises on the garden's infiltration characteristics, show that of the runoff generated from the contributing area (3.5 acres) following rainfall events (upto 1 inch), 100% was infiltrated by the garden!

## Infiltration Trench at Kline Volvo & Lexus

The site is located at the Kline Volvo & Lexus dealerships along highway 61 Maplewood. Inspections of the site were conducted on April 29, 2004. This sub-terrain trench has been placed along the north side of the Kline Volvo parking lot, adjacent to the wetland by Nissan Trucks. A second trench is located next to Lexus north parking lot.

[1] Terry Noonan, Capitol Region Watershed District Ramsey County Public Works.
Como Rain Garden: Monitoring Our Progress (a PowerPoint Presentation)

A briefing provided by Cliff Aichinger (Administrator, Ramsey-Washington Metro WD) at the site, revealed that the trench on Kline Volvo side was monitored for water level, sediment depositions, and out flow rate for two years, and that this data is available. The monitoring revealed that minimal outflow and sedimentation occurred in the trench. The effect of the adjacent wetland on the water level in the trench was noticeably insignificant.

Apparent, appropriate parking lot maintenance appear to have effectively excluded sediment deposition in trench. Cliff availed a report - "Effectiveness of a subsurface rock trench infiltration system for a small commercial site:  The 2001 Kline Volvo study site[2]", prepared by the Ramsey-Washington Water shed District and Metropolitan Council. In this report, findings of the monitoring study of the practice are reported. In the 2001 sampling season, 22.5 inches of rain was recorded at the site, generating approximately 145,000 cubic feet of stormwater. Interestingly, 87 per cent of this stormwater was infiltrated in the trench system! It was estimated that nearly 0.2 mg/l of total phosphorous and 75 mg/l of total suspended solids were directed into the trench system. The study of performance of the two main trenches (the south and north trenches), revealed that infiltration rate in the south trench exceeded rate of rainfall, whereas that of the north trench (located much closer to wetlands, and only a few feet away from the drainage ditch) was highly variable (2 to over 32 inches per day). Following analysis of infiltration data, the authors proposed that the south trench offered somewhat limited treatment of the stormwater due to rapid infiltration rates and short distance for water to travel to the ditch system.

Further study to determine current status of the trench, such as its infiltration, out-flow, sediment deposition, etc. recommended.

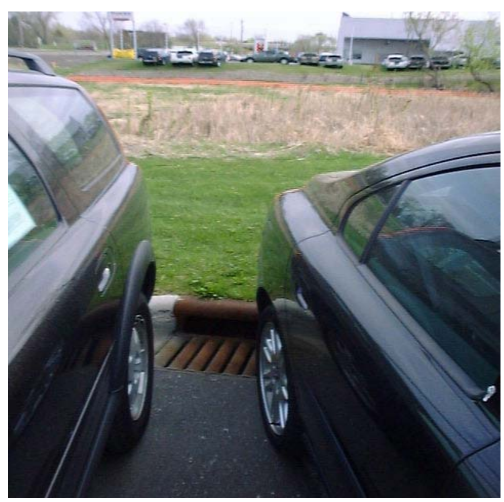

**Figure 4. Photograph of site and entry into Kline Volvo Infiltration Trench**

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[2] Ramsey-Washington Metro Watershed District, in cooperation with the Metropolitan Council. 2001. The Effecxtiveness of a Subsurface Rock Trench Infiltration Systems for a Small Commercial Sites: The 2001 Kline Volvo Site.

## Wet Swale at Century Ave. and I-94, Ramsey-Washington Metro Watershed District

This site was inspected on April 29, 2004. There are two swales running along both sides of Century Avenue, north of I-94 – see map, figure 1. The wet swales are not designed to infiltrate. Storm water coming from the east side of Century avenue flows through the corrugated metal pipes (CMP) connecting the two swales on either side of the street. Further twin corrugated metal pipes (CMP) carry the water into Tanners Lake further east of the road.

The distance between swales floor and edge of infrastructure is approximately 30 feet. The elevation difference between road pavement and swale floor was approximately 10 feet. The west side swale had water flowing north to south, with a fairly large gradient, while that one in the east side flowed south to north with a more gradual gradient. There was standing water in both swales.

**Figure 5. Photograph of Wet Swales on the west and east sides, respectively, of Century Avenue, Maplewood**

The contributing areas adjacent to the swales had established well maintained grass. Muddy depositions, especially in sections of the west side swale, offer evidence of sedimentation. There were no observable eroded sites in or next to the swales.

Although there is a fairly large elevation difference between the swales and road pavement, more investigation would be appropriate to establish the impact of the practice on the adjacent road. Infiltration, flow rate, channel gradient, measured elevation difference as well as distance to infrastructure would be necessary to determine more accurately.  Further studies on impact on pavement also recommended.

The practice was mapped with aid of GPS unit on December 5, 2004; its outflow point was located and its elevation noted. GIS has been created incorporating this BMP. Samples were extracted fir soil profile descriptions. Other measurements and tests have been planned for a later date.

## Infiltration Basin at Pony Express

This site is located due south of the SE quadrant of MN-5 and Hwy36, next to the Pony Express car wash in Oak Park heights. Inspection was conducted on May 5, 2004. The practice is in the wedge of land bounded by MN-5 overpass, south trunk of Hwy 36, and the on-ramp MN-5 to east Hwy 36. The triangular shaped basin measured approximately 50m at its base by 100m height. The distance between water edges in the basin and the MN-5 was more than 50 feet, while the same was less than 20 feet to the Pony Express car wash parking lot. Runoff from the Oak Park heights shopping center parking lot appears to discharge into this basin. This appears to be too large an area served by this practice. Overflow from the basin appeared to be directed into grassy swale due south of the basin along the east side of MN-5.

Further investigations to determine size of actual contributing area served by the practice, infiltration measurements at floor of basin, map flow into and out of the basin as well as to establish if the adjacent swales served as extra storm treatment area.

**Figure 6. Photograph of Constructed Infiltration Basin at the Pony Express Car Wash in Oak Park Heights**

The various measurements and tests for this site have been planned for a later date.

## Constructed Infiltration Basin/Rain Garden at the Realife Coop Apartments, Bloomington

This site is located adjacent to the Realife Coop apartment complex at the 87th St. and Nicollet Ave. S. intersection, Bloomington. It has been described elsewhere as an infiltration basin, yet could be a rain garden. The site was inspected on May 5, 2004. It runs north to south along Nicollet Ave., starting from 86th St. sloping northwards towards 87th St.

A variety of well established, well maintained vegetation cover, comprising of young trees, shrubs and grasses populate the structure. Cattails predominate the low, wet portion of the BMP. Some standing water (less than1 foot depth) was observed towards the outlet. The structure measured approximately 60 yards long by 20 yards wide, and was situated about 50 feet away from Nicollet Ave. Elevation difference between basin outlet and road pavement was approximately 10 feet.

Further study of BMP may not be useful to this project. Further study to establish actual infiltration compared to design values recommended.

**Figure 7. Photograph of Constructed Infiltration Basin at Realife Coop apartment complex in Bloomington**

## Grassed Swale East of County Road 13, Lake Elmo Dental Clinic

Inspection of the site was conducted on the 10th of June, 2004. The BMP is located in the SE quadrant of Hudson Bvld. and CR 13, across from the Wildwood Lodge – see map, Figure 1. The site appears to be a new development (less than 10 years with roads still in very good condition). The BMP runs north – south along county road 13. The elevation difference is about 5.5 ft near the intersection, decreasing gradually to 3.5ft towards the south. It is constructed along the road, with distance of 15ft from road pavement to the swale floor. The swale runs the entire block length parallel to CR 13, and has a top width of approximately 25 feet.

There was some standing water (less than 1 inch) at few spots along floor of the swale. Daily rainfall data showed a 0.4 inch cumulative for previous 5 days. The road is smooth and well maintained with no stress signs.

**Figure 8. Photograph of Grassed Swale east of CR 13, Lake Elmo Dental Clinic**

There were signs of slight sheet erosion by surface flow at intersection flowing towards culvert and swale floor.

Location information has been obtained via GPS, which include shape outline, location and elevation of the outflow. Details are presented in Table 1. Infiltration and other tests for this site are yet to be carried out.

### Grassed Swale with check dams on County Road 13, Bremer Bank (United Properties)

BMP is located at the NE quadrant of Hudson Bvld and CR 13, running north to Eagle Point Blvd. – see map, Figure 1. Site appears is a new development (less than 10 years) with roads still in very good condition. Elevation difference 4 ft near Hudson-CR 13 Blvd. intersection, sloping Northwards to 3 ft  near Eagle Point Blvd.

Extent of the swale is 1 block length running north – south, parallel to CR 13, with a 25 ft top width. The center of the swale floor is located 10-12 feet away from the edge of road (CR 13)  infrastructure. The road condition is smooth and well maintained, with no signs of stress.

Grass along the entire swale is well maintained (mowed). There is slight signs of erosion and sedimentation (gravel sediment trapped in grass along sloping swale sides).

Some standing water (less than 1 inch) observed at few spots along bottom of swale.

**Figure 9. Photograph of Grassed Swale with check dams at Bremer Bank, CR 13**

Location information has been obtained via GPS, which include shape outline, location and elevation of the outflow. Details are presented in table 1a. Infiltration and other tests for this site are yet to be carried out.

## Constructed Infiltration Basin at NW quadrant of 93rd and Hampshire Ave. N, Brooklyn Park

Runs north-south along Hampshire Ave. This structure serves the 93rd Ave., Hampshire Ave. and the Star Exhibits parking lot. It measures approximately 70 ft top width, 1.5 blocks long along 93rd ave, and is located a approximately 30 feet from either street.

There is a large elevation difference between this BMP's outlet and the infrastructure pavements. No visible stress was observed on the relatively new road pavements. Further study of this site may not yield useful data for this project.

**Figure10. Photograph of Infiltration Basin NW quadrant of 93rd and Hampshire Ave. N, Brooklyn Park**

The various measurements and tests for this site have been planned for a later date.

## Grassed Swale by Fortune Financial, Minnetonka

This swale is located on the inner side of 10261 Yellow Circle Dr., adjacent to Fortune Financial in Opus-2 Business Park in the city of Minnetonka, and was inspected on October 8, 2004. The practice serves the Yellow Circle Drive and the adjacent business parking lots.

The swale lies 12 feet away from the road, with an elevation difference between road pavement and swale floor of about 2 ft. Location information was obtained using a GPS unit on November 21, 2004. This included shape outline, location and elevation of the outflow point. Details are presented in Table 1a. Infiltration and other tests for this site are yet to be carried out. Preceding 5 day total precipitation was recorded as "T" – trace.

## Grassed Swale at 6109 Blue Circle Drive, Minnetonka

This swale is located on the inner side of 6109 Blue Circle Drive, in Opus-2 Business Park in the city of Minnetonka, and was inspected on October 8, 2004. The practice serves the blue circle drive and adjacent business parking lots.

The swale lies next to the road, with a distance of approximately 10 feet measured from the bottom of the practice. Elevation difference between road pavement and swale floor was about 2.5 ft. Location information was obtained using a GPS unit on November 21, 2004. This included shape outline, location and elevation of the outflow point. Details are presented in table 1a. Infiltration and other tests for this site are yet to be carried out. Preceding 5 day total precipitation was recorded as “T” – trace.

## Grassed Swale by Rapala/Normark

The swale at 10395 Yellow Circle Drive, Minnetonka, was inspected on October 8, 2004. It is located on the inside of the street, next to the Rapala/Normark business lot, directly across from Electrosonic and Gift Mark (10301 Bren Rd. E).

The practice serves part of Yellow Circle Drive and Bren Road. Lower section of the swale had standing water, with cattails growing. Distance of the swale center point to the road was measured, found to be 10 feet. Elevation difference between road pavement and swale floor was about 2.5 ft. Location information was obtained using a GPS unit on November 21, 2004. This included shape outline, location and elevation of the outflow point. Details are presented in table 1a. Infiltration and other tests for this site are yet to be carried out. Preceding 5 day total precipitation was recorded as “T” – trace.

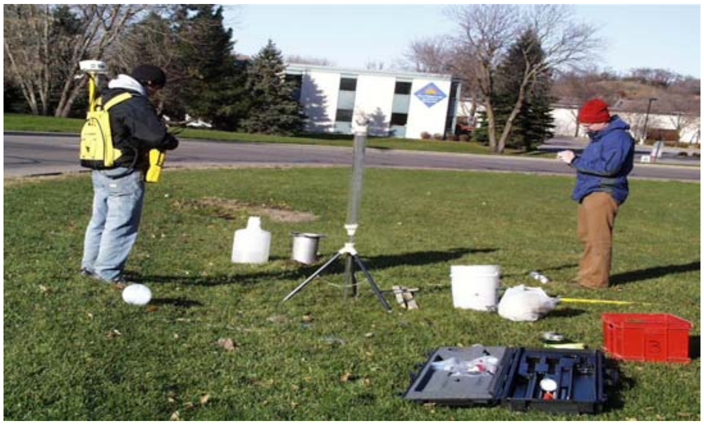

**Figure 11. Conducting infiltration and GPS measurements on Grassed Swale Opus-2 business park, Minnetonka**

## Grassed Swale by Security Life/Musicland Group

This swale located between 10901 & 10601 Red Circle Drive, Minnetonka, was inspected on October 8, 2004. It is located on the inside of the street, next Security Life/Musicland group lot. The swale serves Red circle drive and the adjacent parking lots. The distance of the swale center point to the road was measured as 10 feet, with an elevation difference between road pavement and swale floor of about 2.5 ft. Location information was obtained using a GPS unit on November 14, 2004. This included shape outline, location and elevation of the outflow point. Details are presented in table 1a. Infiltration and other tests for this site are yet to be carried out. Preceding 5 day total precipitation was recorded as "T" – trace.

## Grassed Swale by LecTect Corporation/Marketing Focus

This swale located at 10701 Red Circle Drive, Minnetonka, was inspected on October 8, 2004. It is located on the inside of the street, next to LecTect Corporation lot. The swale serves Red circle drive and the adjacent parking lots. The distance of the swale center point to the road was measured as 10 feet, with an elevation difference between road pavement and swale floor of about 2.5 ft. Location information was obtained using a GPS unit on November 14, 2004. This included shape outline, location and elevation of the outflow point. Details are presented in table 1a. Infiltration and other tests for this site are yet to be carried out. Preceding 5 day total precipitation was recorded as "T" – trace.

## Grassed Swale by Xerxes Computer Corporation

This swale located 10701-10999Bren road E, Minnetonka, was inspected on October 8, 2004. It is located on the inside of the street, next to LecTect Corporation lot. The swale serves Bren road and Xerxes corporation parking lots. The distance of the swale center point to the road was measured as 12 feet, with an elevation difference between road pavement and swale floor of about 2.5 ft. Location information was obtained using a GPS unit on November 14, 2004. This included shape outline, location and elevation of the outflow point. Details are presented in table 1a. Infiltration and other tests for this site are yet to be carried out. Preceding 5 day total precipitation was recorded as "T" – trace.

## Rain Garden at Brand and Ferndale Street, Maplewood

The site is located at the intersection of Brand and Ferndale streets. This site was inspected on 8$^{th}$ September 2004. Infiltration tests were conducted using Guelph permeameter, with soil moisture content determined by gravimetric method (results table 1) on October 16, 2004.

The garden was determined to be located at a distance of 10 feet from the Brand street pavement, with an elevation difference of 2.5 feet. The practice was mapped by tracing its perimeter using GPS unit on October 16, 2004. Coordinates and elevation data for the outflow point were recorded. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. The rest of the planned measurements and tests for the site will be completed at a later date.

### Rain Garden at Barclay Street and Gulden Place, Maplewood

This site is located at the intersection of Barclay St. and Gulden Place, Maplewood. Inspections of the practice were conducted on 8th September 2004. Infiltration tests were attempted using Guelph permeameter, and soil moisture content determined by gravimetric method on October 24, 2004. During the visit, the site was found have standing water (at least 2 inch depth), probably due to recent rains (more than ¼ inches total for past 3 days) in the area. Infiltration tests did not yield any results under the circumstances (standard Guelph permeameter tests are usually possible under unsaturated soil conditions).

The distance between the garden and Gulden place was pavement recorded as 10 feet, with an elevation difference of 2.5 feet. The practice was mapped by tracing its perimeter using GPS. Coordinates and elevation data for the outflow point were recorded. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. The rest of the planned measurements and tests for the site will be completed at a later date.

### Rain Garden at Barclay Street and Hazelwood Avenue, Maplewood

The site is located at the intersection of Barclay Street and Hazelwood Avenue, Maplewood. Inspections of the practice were conducted on 8th September 2004. Infiltration tests were attempted using Guelph permeameter, and soil moisture content determined by gravimetric method on October 24, 2004. During the visit, the site was found to be water saturated to the surface due to recent rains (more than ¼ inches total for past 3 days). Infiltration tests did not yield any results under the circumstances (standard Guelph permeameter tests are usually possible under unsaturated soil conditions).

Distance between the garden and Hazelwood avenue pavement was determined to be more than 15 feet from the, with an elevation difference of about 7 feet. The practice was mapped by tracing its perimeter using GPS unit on October 16, 2004. Coordinates and elevation data for the outflow point were recorded. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. The rest of the planned measurements and tests for the site will be completed at a later date.

## Rain Garden at Ripley Avenue and Clarence Street, Maplewood

The site is located at the intersection of Ripley Avenue and Clarence Street, Maplewood. Inspections of the practice were conducted on 8$^{th}$ September 2004. Infiltration tests were carried out using Guelph permeameter, with soil moisture content determined by gravimetric method on October 24, 2004. The practice has a thick layer of sandy material; hence, infiltration was rapid, as observed in the high value of obtained hydraulic conductivity, Ksat (Table 1).

The garden is located at a distance 10 feet from the Ripley avenue pavement, with an elevation difference of about 7 feet. The practice was mapped by tracing its perimeter using GPS unit on October 16, 2004. Coordinates and elevation data for the outflow point were recorded. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. The rest of the planned measurements and tests for the site will be completed at a later date.

## Rain Garden at Ferndale Street and Harvester Avenue, Maplewood

The site is located at the intersection of Ferndale Street and Harvester Avenue, Maplewood. Inspections of the practice were conducted on 8$^{th}$ September 2004. Infiltration tests were carried out using Guelph permeameter, and soil moisture content determined by gravimetric method on October 24, 2004. Obtained data is as presented in Table 1. Despite recent rains (0.20 inch total past 3 days), no standing water was observed at the site, probably due to nature of surrounding terrain.

Distance between the garden and Hazelwood avenue pavement was measured as 10 feet, with an elevation difference of less than 5 feet. The practice was mapped by tracing its perimeter using GPS unit on October 16, 2004. Coordinates and elevation data for the outflow point were recorded. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. The rest of the planned measurements and tests for the site will be completed at a later date.

## Rain Garden at 50th Street and Leaf Avenue, Stillwater

The site is located at the intersection of 50th Street and Leaf Avenue, Stillwater. Site inspections were carried out on 24$^{th}$ August 2004.

Distance between the garden and 50th Street pavement was measured as 25 feet, with an elevation difference of more than 5 feet. The practice was mapped by tracing its perimeter using GPS unit on December 5, 2004. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. There was significant depth of standing water in the garden. Total recorded precipitation over the three days prior to site inspection was 0.01 inches. The rest of the planned measurements and tests for the site will be completed at a later date.

### Rain Garden at 50th Street and Linden Trail N, Stillwater

The site is located at the south side of the intersection of 50th Street and Linden Trail, Stillwater. Site inspections were carried out on $24^{th}$ August 2004.

The measured distance between the garden and 50th street pavement was 18 feet, with an elevation difference of less than 5 feet. The practice was mapped by tracing its perimeter using GPS unit on December 5, 2004. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. The rest of the planned measurements and tests for the site will be completed at a later date.

### Rain Garden at 50th Street and Linden Trail N, Stillwater

The site is located at the south side of the intersection of 50th Street and Linden Trail, Stillwater. Site inspections were carried out on $24^{th}$ August 2004.

The distance between the garden and 50th street pavement was measured as 18 feet, with an elevation difference of less than 5 feet. The practice was mapped by tracing its perimeter using GPS unit on December 5, 2004. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. There was significant depth of standing water in the garden. Total recorded precipitation over the five days prior to site inspection was a 0.01 inches. The occurrence of this amount of precipitation cannot be reason for the observed wetness condition of the practice.

The rest of the planned measurements and tests for the site will be completed at a later date.

### Rain Garden at 50th Street and Linden Trail N, Stillwater

The site is located at the north side of the intersection of 50th Street and Linden Trail, Stillwater. Site inspections were carried out on $24^{th}$ August 2004.

The distance between the garden and 50th Street pavement was measured as 31 feet, with an elevation difference of less than 5 feet. The practice was mapped by tracing its perimeter using GPS unit on December 5, 2004. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. There was significant depth of standing water in the garden. Total recorded precipitation over the three days prior to site inspection was 0.01 inches. The rest of the planned measurements and tests for the site will be completed at a later date.

## Rain Garden at 50th Street and Linden Trail N, Stillwater

The site is located at the north side of the intersection of 50th Street and Linden Trail, Stillwater. Site inspections were carried out on 24th August 2004.

The distance between the garden and 50th Street pavement was measured as 21 feet, with an elevation difference of more than 5 feet. The practice was mapped by tracing its perimeter using GPS unit on December 5, 2004. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. There was significant depth of standing water in the garden. Total recorded precipitation over the five days prior to site inspection was 0.01 inches. The rest of the planned measurements and tests for the site will be completed at a later date.

## Rain Garden at 50th Street and Linden Trail N, Stillwater

The site is located at the north side of the intersection of 50th Street and Linden Trail, Stillwater. Site inspections were carried out on 24th August 2004.

The distance between the garden and 50th Street pavement was measured as 20 feet, with an elevation difference of more than 5 feet. The practice was mapped by tracing its perimeter using GPS unit on December 5, 2004. A GIS database has been created using this data, together with other attribute information collected with the GPS unit. Soil samples were collected for profile descriptions. There was significant depth of standing water in the garden. Total recorded precipitation over the three days prior to site inspection was 0.01 inches. The rest of the planned measurements and tests for the site will be completed at a later date.

**Table 1. Infiltration and Soil Moisture measurements for studied alternative BMPs at indicated location**

| DATE | SITE ID | Address | Initial MC (%) | $K_{sat}$ (cm/s) | $K_{sat}$ (in/hr) |
|---|---|---|---|---|---|
| | | | | | |
| 11/14/2004 | Site 3 (Normark) | 10395 Yellow Circle dr | 28.95 | * | * |
| 11/14/2004 | Site 3 (Normark) | 10395 Yellow Circle dr | 23.25 | * | * |
| 11/14/2004 | Site 3 (Normark) | 10395 Yellow Circle dr | 23.47 | * | * |
| 11/14/2004 | Site 3 (Normark) | 10395 Yellow Circle dr | 22.39 | * | * |
| 11/14/2004 | Site 5 (LECTEC) | 10701 Red Circle Drive | 25.07 | * | * |
| 11/14/2004 | Site 5 (LECTEC) | 10701 Red Circle Drive | 19.70 | * | * |
| 11/14/2004 | Site 5 (LECTEC) | 10701 Red Circle Drive | 23.95*** | * | * |
| 11/14/2004 | Site 5 (LECTEC) | 10701 Red Circle Drive | 17.27 | * | * |
| 11/14/2004 | Site 5 (LECTEC) | 10701 Red Circle Drive | 26.45*** | * | * |
| 11/7/2004 | Site 2 | 6109 Blue circle dr | 19.97 | 2.15E-07 | 3.05E-04 |
| 11/7/2004 | Site 2 | 6109Blue circle dr | 18.21 | 2.15E-07 | 3.05E-04 |
| 10/16/2004 | RG1 | Brand & Ferndale | 26.93 | 2.04E-06 | 2.89E-03 |
| 10/16/2004 | RG1 | Brand & Ferndale | 29.22 | 2.45E-04 | 3.47E-01 |
| 10/16/2004 | RG2 | Nebraska and Harvester | 16.27 | 3.40E-06 | 4.81E-03 |
| 10/16/2004 | RG2 | Nebraska and Harvester | 18.33 | 2.16E-04 | 3.06E-01 |
| 10/24/2004 | RG5 | Ripley & Clarence | 8.90 | -1.23E-02 | -1.74E+01 |
| 10/24/2004 | RG5 | Ripley & Clarence | 9.35 | 6.34E-03 | 8.99E+00 |
| 10/24/2004 | RG5 | Ripley & Clarence | 15.93* | * | * |
| 11/14/2004 | AG1 | UoM plot | 25.95 | PD | PD |
| 11/14/2004 | Ag1 | UoM Plot | 26.71 | PD | PD |
| | | | | | |

***   - Infiltration tests conducted, Ksat not possible to determine from obtained data**

**PD  - Philip Dunne method (Calculations to be completed later)**

*****   Post infiltration (Philip Dunne) moisture content**

**Table 2. GPS attribute information for studied alternative BMPs at indicated locations**

| GPS_Date | Location | BMP_Type | Elevation_Diff | Dist_to_ Road (ft) | Comment | Pre-5 day Total ppt. (in) | Max_PDOP | GPS_Area (ha) |
|---|---|---|---|---|---|---|---|---|
| *Lake Elmo* | | | | | | | | |
| 12/5/2004 | 8300 hudson BLVD N | Dry Swale | 5-10 ft | 10 | standing water | 0.00 | 2.0 | 0.11 |
| 12/5/2004 | 1901 CR B2 | Dry Swale | 0-2.5 ft | 10 | | 0.00 | 3.4 | 0.06 |
| 12/5/2004 | Centruy Av and I-94 | Dry Swale | 2.5-5 ft | 10 | standing water | 0.00 | 2.2 | 0.07 |
| 12/5/2004 | Nebraska and lexington | RainGarden | 0-2.5 ft | 10 | | 0.00 | 4.0 | 0.08 |
| 12/5/2004 | 1875 CR B2 | RainGarden | 2.5-5 ft | 10 | standing water | 0.00 | 2.6 | 0.04 |
| 12/5/2004 | 1875 CR B2 | RainGarden | 2.5-5 ft | 10 | standing water | 0.00 | 2.5 | 0.02 |
| 12/5/2004 | 8300 hudson BLVD N | Dry Swale | 2.5-5 ft | 10 | little standing w | 0.00 | 2.4 | 0.12 |
| | | | | | | | | |
| *Stillwater* | | | | | | | | |
| 11/21/2004 | 50th st rg 3 | RainGarden | 5-10 ft | 18 | standing water | 0.01 | 2.7 | 0.03 |
| 11/21/2004 | 50 th st rg 4 | RainGarden | 5-10 ft | 20 | standing water | 0.01 | 2.6 | 0.04 |
| 11/21/2004 | 50 th st rg 2 | RainGarden | 5-10 ft | 21 | standing water | 0.01 | 2.2 | 0.02 |
| 11/21/2004 | 50 th st rg 5 | RainGarden | 0-2.5 ft | 31 | | 0.01 | 2.0 | 0.01 |
| 11/21/2004 | 50 th st rg 6 | RainGarden | 2.5-5 ft | 18 | standing water | 0.01 | 2.3 | 0.02 |
| 11/21/2004 | 50 th st rg 7 | RainGarden | 5-10 ft | 25 | standing water | 0.01 | 2.3 | 0.04 |
| | | | | | | | | |
| *Minnetonka* | | | | | | | | |
| 11/21/2004 | 10261 yellow circle | Dry Swale | 0-2.5 ft | 12 | | 0.63 | 2.7 | 0.02 |
| 11/21/2004 | 10701-10999 e bren | Dry Swale | 0-2.5 ft | 12 | | 0.63 | 3.8 | 0.02 |
| 11/14/2004 | 10395 Red circle | Dry Swale | 2.5-5 ft | 10 | | tr | 2.5 | 0.01 |
| 11/14/2004 | 10395 red circle | Dry Swale | 2.5-5 ft | 10 | | tr | 3.8 | 0.04 |
| 11/14/2004 | 6109 blue circle | Dry Swale | 0-2.5 ft | 10 | | tr | 3.3 | 0.01 |
| 11/14/2004 | 10701 red circle | Dry Swale | 0-2.5 ft | 10 | slope slope | tr | 4.7 | 0.02 |
| 11/14/2004 | 10601 red circle | Dry Swale | 2.5-5 ft | 10 | steep slope | tr | 3.8 | 0.04 |
| | | | | | | | | |
| *Maplewood* | | | | | | | | |
| 10/24/2004 | brand and ferndale | RainGarden | 0-5 ft | 0-10 ft | | 0.00 | 3.7 | 0.02 |
| 10/24/2004 | barclay and gulden | RainGarden | 0-5 ft | 0-10 ft | standing water | 0.00 | 3.0 | 0.02 |
| 10/24/2004 | barclay and ripley | RainGarden | 5-10 ft | 10-50ft | standing water | 0.00 | 4.0 | 0.06 |
| 10/24/2004 | ripley and clarence | RainGarden | 0-5 ft | 0-10 ft | | 0.00 | 2.9 | 0.01 |
| 10/16/2004 | brand and ferndale | RainGarden | 0-5 ft | 0-10 ft | | 0.15 | 3.6 | 0.02 |
| 10/16/2004 | ferndale and harvester | RainGarden | 0-5 ft | 0-10 ft | | 0.15 | 3.0 | 0.0 |

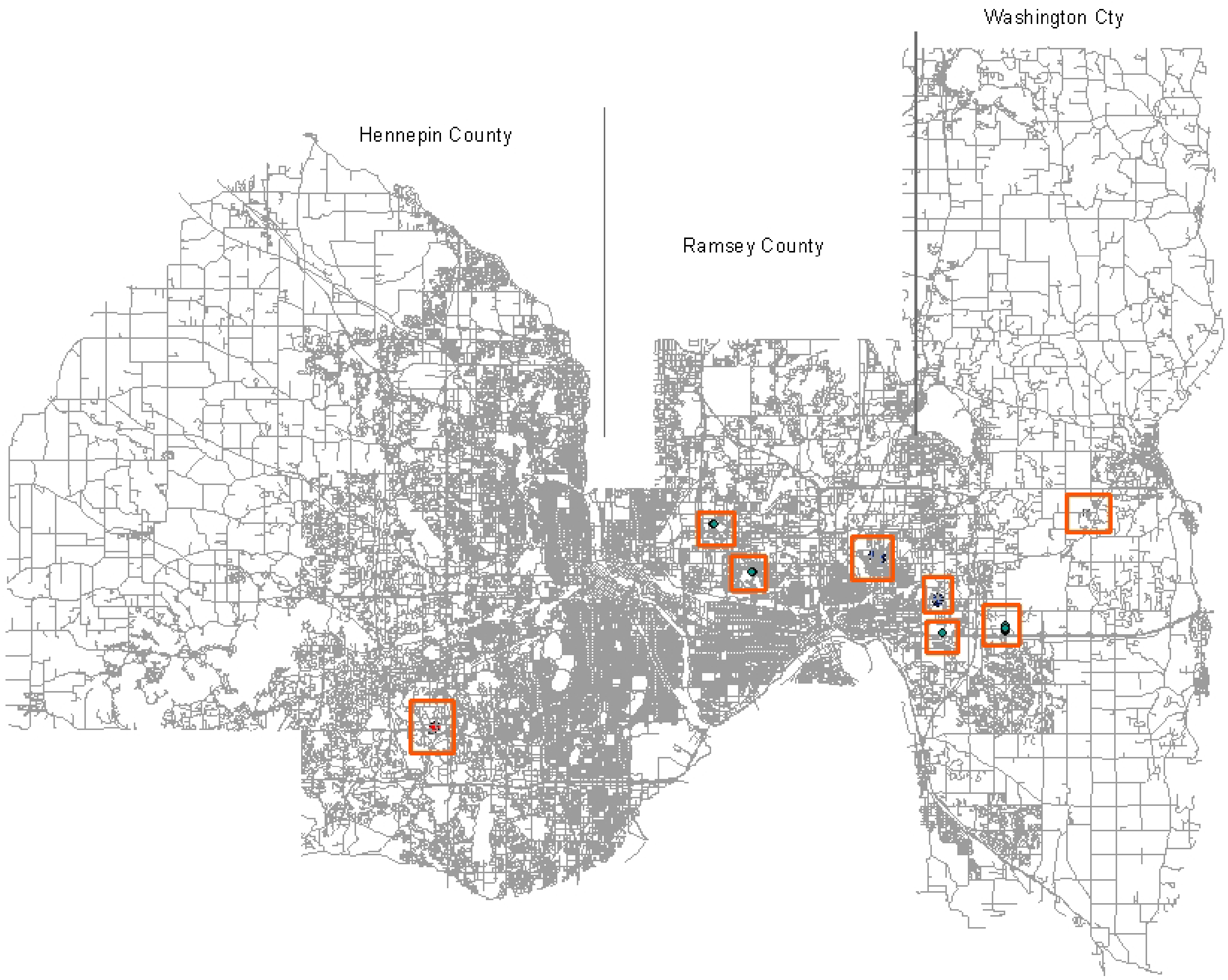


**Figure 12. Field visits locations in the St. Paul-Minneapolis Metro Area**

*Task 3. Survey of Practices in Minnesota*

# Impact Perception of Alternative Storm Water Best Management Practices (BMPs) on Highway Infrastructure

Conducted by


**Robert D. Sykes, MLA**
Associate Professor and Co-Principal Investigator
Department of Landscape Architecture

**Dr. Caleb Arika, PhD**
Research Associate
Department of Biosystems and Agricultural Engineering

**Dr. John Nieber, Ph.D.**
Professor, and Principal Investigator
Department of Biosystems and Agricultural Engineering

University of Minnesota
Twin Cities



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**Minnesota Local Roads Research Board**

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**Center for Transportation Studies**
University of Minnesota
Twin Cities

Report Date: July 30, 2005

## Introduction

This survey was conducted to better understand the perceptions of alternative best management practices (BMPs) for water quality protection of stormwater runoff. These perceptions were solicited from a range of individuals engaged in the design and maintenance of highway and public utility infrastructure in the metropolitan twin cities region of Minneapolis-St. Paul, Minnesota. This study was part of a larger study that focused on field examination and evaluation of installations many of the BMPs evaluated in this survey. The idea being to compare the opinions held by those in a position to influence BMP use with respect to their effect on elements of adjacent infrastructure, with the factual information in this regard presented by BMPs actually existing in highway and public utility infrastructure settings.

In reviewing the results of this survey, it is absolutely critical to keep in mind that the results shown here represent *opinions of BMP performance* only, *not* results of objective measurements of actual BMP performance.

## Summary of Conclusions

Full presentation of responses to questions, together with discussion and conclusions follows the presentation of the survey design and execution. The conclusions presented there are repeated here for convenience:

**Conclusion 1:** To the extent sufficient responses were obtained in any single BMP type category to represent a general opinion, the viewpoint represented is that of only the most local level of government officials. (See questions 1 and 2.)

**Conclusion 2:** Individually, only those BMP types that clustered in the "broadest experience" category had a broad enough representation of the response pool (>60% of the respondents) on which to base reasonably reliable conclusions as to general opinion about them. (See question 3.)

**Conclusion 3:** From the responses to question 4, the observers surveyed are generally quite experienced about the design, construction and maintenance issues of the BMP types for which they entered responses.

**Conclusion 4:** Although the observations were not systematically gathered, the number of observations suggests a very significant depth of experience base is represented in the pool of survey respondents.

**Conclusion 5:** The base of observations from which respondents formed their opinions of impacts on infrastructure appears to be balanced in terms of BMP proximity to infrastructure element. This provides the respondents with a broad base of experience from which to compare and assess impacts between those BMPs near highway and utility infrastructure and those not in close proximity to that infrastructure.

**Conclusion 6:** By a large margin – more than 4 to 1 – opinion represented in this survey regards the group of BMPs surveyed  as productive of positive impacts on infrastructure.

**Conclusion 7:** By a substantial margin (nearly 2:1), opinion represented in this survey regards BMPs as generally NOT productive of negative impacts on infrastructure. Of the third of respondents indicating some degree of negative impact, two third of that third regarded the impacts as minor.

**Conclusion 8:** Opinion about the quality of the design of BMPs observed can be regarded as positive for BMPs in general. However, with respect to individual BMPs, quality of design varies widely. The results suggest a need for educational efforts to raise the quality of the design of BMPs to better meet the design quality expectations of experienced observers. This is especially the case for design of infiltration basins, infiltration trenches, infiltration beds and bio-retention.

**Conclusion 9:** Opinion about the quality of the functioning of BMPs observed can be regarded as positive for BMPs in general, but slightly less positive than quality of design. However, with respect to individual BMPs, quality of functioning varies widely. This suggests that investigation into the actual design practices for and function of BMPs would likely be productive of useful information. Further, more educational efforts about the design of BMPs (especially those that are regarded as both poorly designed and functioning poorly) would be the best place to target effort to produce improvement in opinion about BMPs.

**Conclusion 10:** Opinion about the maintenance costs associated with BMPs in general leans toward regarding them as acceptable, and in some cases better than average compared to those for the range of typical infrastructure items. Infiltration basins and infiltration beds are notable exceptions to this generalization.

## Survey Design

The survey was conducted through the use of a world-wide-web-based survey instrument that allowed participants to directly enter their responses with keystrokes or the click of a mouse button. The survey questions were prepared by the principal investigators in consultation with the Technical Advisory Panel for the larger study and the staff of the Office of Measurement Services of the University of Minnesota. The Office of Measurement Services staff prepared the web pages used for the survey from the questions, and managed the capture of data generated.

To recruit participants, email messages were sent to a list people gleaned from various sources. The list was constructed to focus on key individuals in public works departments and related organizations with responsibility for, interest in and technical capability to attend to the use of BMPs in the course of their work. The list contacted included 105 individuals. The web site was open to receive responses from 23 November 2004 through 15 January 2005. We received responses from 26 of those contacted, a return of 24.8%. The first response activity occurred on 23 November 2003 and the last on 14 December 2004. Time taken by respondents for completion of the survey can be characterized as follows

| | |
|---|---|
| Average completion time: | 8.2 minutes |
| Most frequent completion time: | 7 minutes |
| Shortest completion time: | 2 minutes |
| Longest completion time: | 22 minutes |

The survey was comprised of 13 questions, 12 of which focused on answering the following four general questions:

(1) Who are the respondents?
(2) What is the experience base from which the opinions of the respondents are drawn?
(3) What is the perception of impacts of the BMPs on highway and utility infrastructure?
(4) What is the perception of the quality of design and functioning of the BMPs?

Questions 1 and 2 were focused on defining the categories of individuals responding based on job type and level.

Question 3 was used identify the specific BMP types that the respondent had actually critically observed as constructed examples in the field. Responses to this question were used to tailor subsequent screens presented to the respondent to limit the types of BMPs asked about to only those the respondent had identified as having critically observed in this question.

Questions 4 through 6 were used to further measure observer experience by practice type and to understand the perspective of the observer.

Questions 7 through 11 focused on measuring opinions as to impact on adjacent infrastructure and the general quality of BMP design, function and maintenance.

Question 12 allowed open-ended comments by the respondents (only three offered any).

Question 13 enabled the respondent to allow follow up contact.

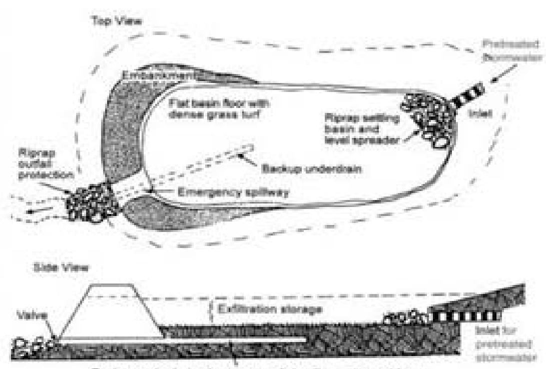
## The Best Management Practices Surveyed

In each of the questions asked in the survey about specific BMP types inventoried responses for fourteen BMP types:

•Infiltration Basins
•Infiltration Trenches
•Infiltration Beds
•Porous Pavements
•Sand Filters
•Peat/Sand Filters
•Oil/Grit Separators
•Dry Swales
•Wet Swales
•Extended Detention Dry Ponds
•Wet Ponds
•Bio-Retention
•Rain Gardens
•Storm Water Wetlands

To help insure that the respondents were clear about the definition and use of terms for each BMP, the web survey provided respondents a mechanism to check their understanding. The web site allowed respondents, at any point in the survey, to select and "click" the name of the BMP about which they had a question to go to a separate web page that gave a definition and showed an image or images of the BMP. The following images and definitions were presented to the respondents:

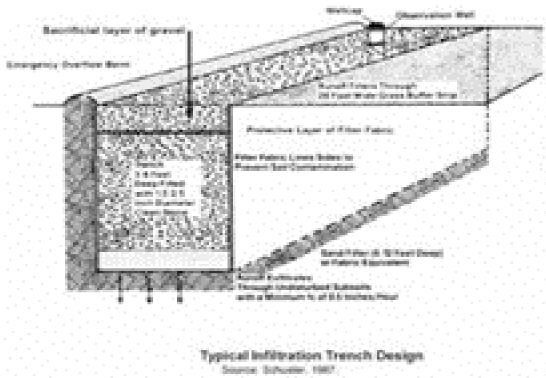
**Infiltration Basin.**

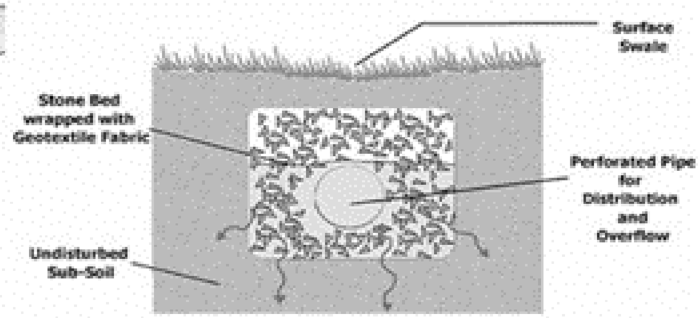



Schematic of an Infiltration Basin

A normally dry depression or basin constructed in undisturbed soil to capture and infiltrate the first flush of storm water runoff into the ground. The floor of the basin is typically flat and vegetated with grasses. Flows in excess of the first flush are directed to overflow or otherwise bypass the infiltration basin.

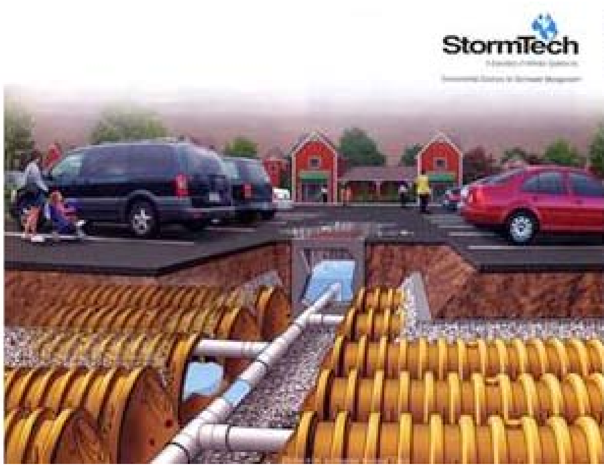
**Infiltration Trench.**

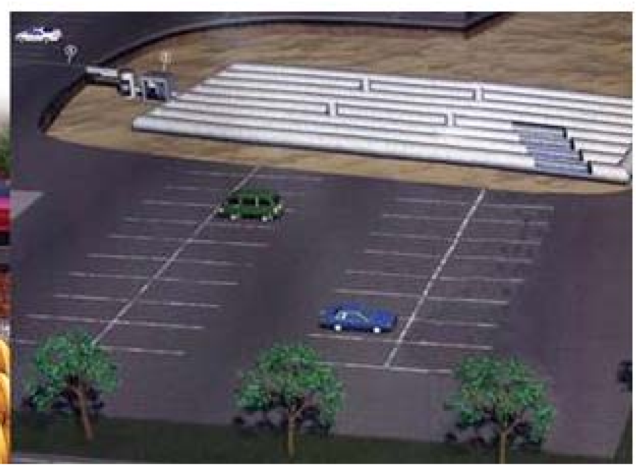



A shallow trench excavated in undisturbed soil to accept runoff and infiltrate it into the soil. The trench is filled with drainage rock or stone to create an underground reservoir. The reservoir should be shielded geotextile wrapping to prevent sediment from migrating into it. May or may not have a sacrificial layer on top of it made of pea gravel or other rock to trap oils, sediment and trash.

**Infiltration Bed.**



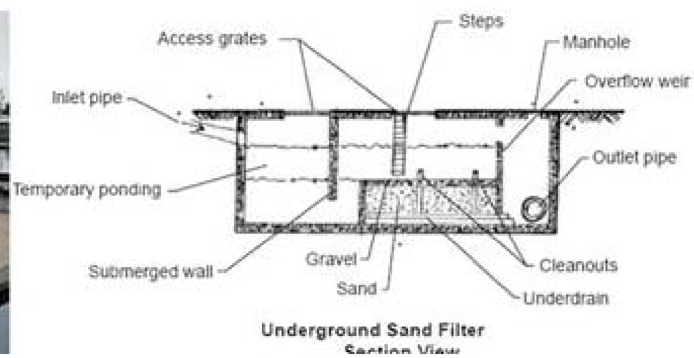



A constructed bed (or layer) of drainage rock or stone used either alone, or in combination with large diameter perforated pipes or a system of proprietary modules, to create a large underground reservoir from which storm water may infiltrate into the ground. Infiltration beds are typically set below lawns or parking areas and used in lieu of, or to reduce, the land area that would otherwise be committed to surface pond storage. Storm water runoff is typically admitted to the bed through a pre-treatment device such as an oil/grit separator or water quality inlet.

**Porous Pavement.**

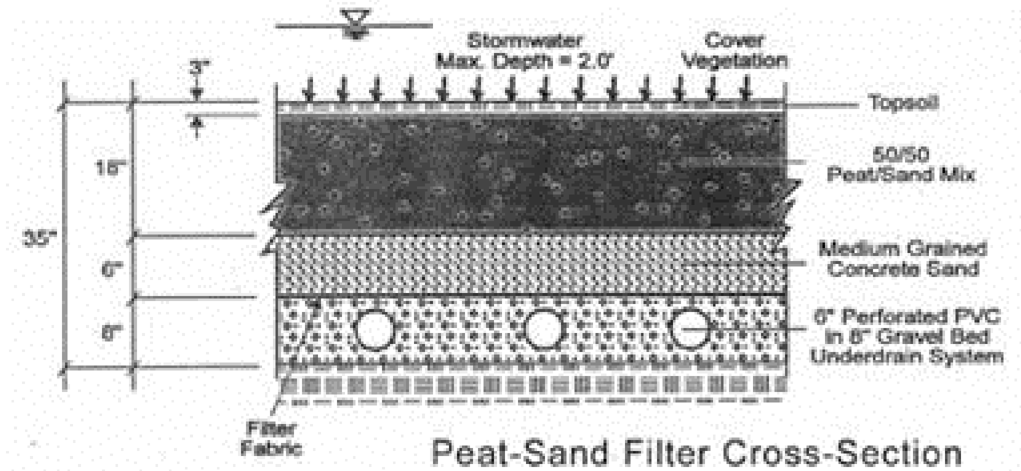

Porous pavement may be open–graded asphaltic aggregate pavement, pervious concrete pavement, pre-cast concrete unit pavers, or plastic grid paving (typically filled with soil and vegetated) systems. Storm water infiltrates through the porous upper pavement layer and then into a storage reservoir of stone or rock below. Water from the reservoir either percolates into the soil beneath or is collected by a perforated pipe underdrain system and carried to a surface discharge location.

**Sand Filter**.



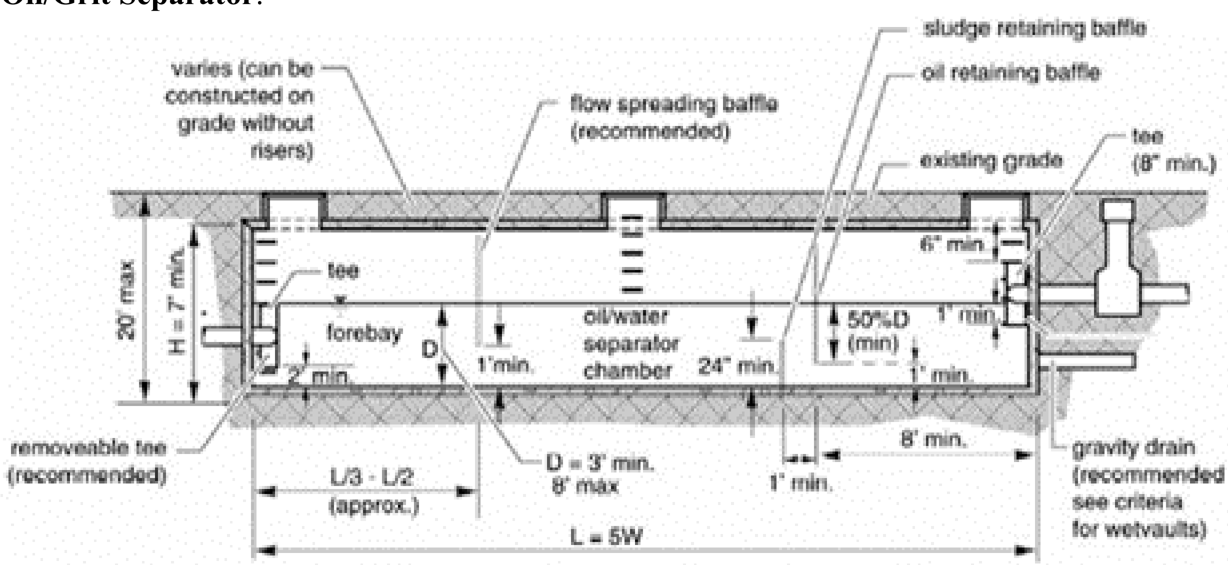

A device, usually a chamber, that cleans runoff water by passing a specified design flow through a bed of sand to reduce the concentration of pollutants to an acceptable level and then discharging it into the surface environment. May be above ground or below ground and is typically designed to treat the first flush of runoff, bypassing larger flows.

**Peat-Sand Filter.**




A device, usually a chamber, that cleans runoff water by passing a specified design flow through a bed of alternating layers of sand and peat moss to reduce the concentration of pollutants to an acceptable level and then discharging it into the surface environment. May be above ground or below ground and is typically designed to treat the first flush of runoff, bypassing larger flows.

**Oil/Grit Separator**.



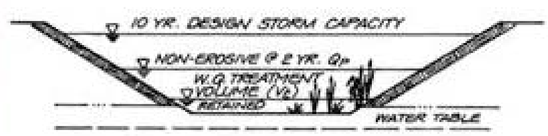

Also known as a Water Quality Inlet. Typically an underground retention system with two or more chambers designed to remove heavy particles and hydrocarbons from storm water runoff. Water passes from chamber to chamber via weirs, baffles and skimmers. May incorporate a battery or sandwich of coalescing plates.

**Dry Swale.**


Dry Swale

A normally dry, vegetated, earth-lined channel constructed to convey runoff flow from specific design storms from one place to another. A dry swale reduces pollution in runoff by passing flows from first flush runoff in close contact with vegetation leaf and root structures, and by allowing water to exfiltrate from the swale into the ground as it flows downstream.

**Wet Swale**.




Wet Swale

A vegetated, earth-lined channel that normally has standing water in its bottom. It is constructed to convey runoff flow from specific design storms from one place to another. A wet swale reduces pollution in runoff by passing flows from first flush runoff in close contact with vegetation leaf and root structures, by allowing water to exfiltrate from the swale into the ground as it flows downstream, and by settling action.

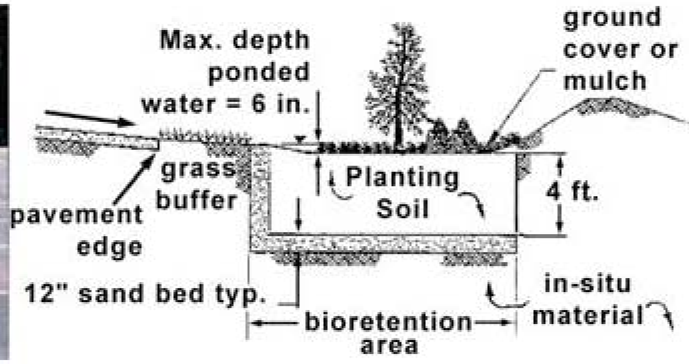
**Extended Dry Detention Basin**.

A normally dry detention pond that drains completely over a specified extended period time sufficient to remove settleable pollutants to acceptable levels of concentration. An extended dry detention basin may or may not include features to provide flood control functions.

**Wet Pond.**

A pond that normally has water in it and is designed to slowly release water over a specified period of time sufficient to remove settleable pollutants to acceptable levels of concentration. Requires an outlet structure that controls the release velocity of water from the target storm and enables larger storms to be released at higher rates. A wet pond may or may not include features to provide flood control functions.

**Bio-Retention Pond.**

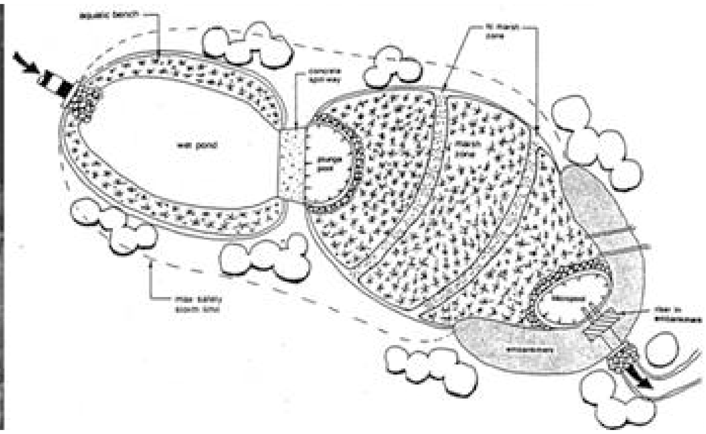



A shallow, normally dry basin that is designed to capture the first flush of runoff and pass it through a constructed artificial soil profile two to five feet deep put in place beneath the floor of the basin to filter and clean it. The floor of the basin is usually planted with a community of plants selected to provide a high degree of plant uptake of water and nutrients in addition to the filtering effect the soil profile. It is hydraulically designed to bypass flows in excess of its treatment capacity. Water leaving the bottom of the soil profile is typically picked up by an under-drain system of perforated pipe and directed to a surface water body. Alternatively, cleaned runoff may be allowed to infiltrate into undisturbed soil beneath the artificial soil profile without the presence of an under-drain system.

**Rain Garden.**

A small, shallow, normally dry basin, constructed to capture runoff and treat it by exposing it to plant use and infiltration. The floor of the basin is usually planted with a community of plants selected to provide a high degree of plant uptake of water and nutrients, and to promote infiltration. Rain gardens are typically not hydraulically designed, and do not have the constructed artificial soil profile associated with bio-retention. Water outflow is by infiltration only.

**Storm Water Wetland.**




An artificial wetland specifically constructed to treat runoff water by removing pollutants by sedimentation, plant filtration and plant uptake. May or may not be a open water wetland

## Results of the Survey by Category of Question

The questions and responses are organized by category of question. In each category, each question is restated with its designated number together with a table or tables showing the responses obtained. N means number of responses obtained for each category. Some respondents who indicated experience with a particular BMP type chose not to answer all the questions pertaining to that BMP type, therefore the total number of responses sometimes varies from question to question for specific BMP. Following the presentation of questions and responses is a discussion of the results in terms of the more general category question.

***Question 1. What is your job designation/Title?***

**Table 1: Repondents by Job Designation/Title**

| **Self-identified title** | N |
|---|---|
| Director of Public Works | 4 |
| Director of Public Works/City Engineer | 4 |
| City Engineer | 10 |
| Asst. City Engineer | 1 |
| Water Resources Coordinator | 1 |
| Watershed District Engineer | 1 |
| Principal Engineer | 1 |
| Project Engineer | 1 |
| Civil Engineer/Watershed District Engineer | 1 |
| Sewer Utility Manager | 1 |
| Civil Engineer | 1 |
| Total | 26 |

***Question 2. What is your type of affiliation (choose only one)?***

**Table 2: Repondents by Type of Affiliation**

| **Type of Affiliation** | **N** |
|---|---|
| State Department of Transportation – Design | 0 |
| State Department of Transportation – Maintenance | 0 |
| State Department of Transportation – Other | 0 |
| County Department of Public Works – Design | 0 |
| County Department of Public Works – Maintenance | 0 |
| County Department of Public Works – Other | 0 |
| Watershed District or Organization Staff | 2 |
| Watershed District or Organization Board Member | 0 |
| Municipal Department of Public Works | 18 |
| Municipal Parks Department | 0 |
| Municipal Planning Department | 1 |
| Consulting Engineer under contract as Municipal Engineer | 5 |
| Other | 0 |
| Total | 26 |

**Commentary.** Based on the responses to questions 1 and 2, it is clear that the opinions gathered represent those of officials from the most local units of government, and especially those of engineers. No responses were received from state and county level officials.

**Conclusion 1:** To the extent sufficient responses were obtained in any single BMP type category to represent a general opinion, the viewpoint represented is that of only the most local level of government officials.

**What is the experience base from which the opinions of the respondents are drawn?**

Question 3. For each of the following BMPs please check the adjacent box if you have critically observed an example of it in the field:

**Table 3: Repondent Experience by BMP Type With Rank Order of Response Counts**

| BMP Type | Number of respondents with experience | Rank in number of responses |
|---|---|---|
| Wet Ponds | 26 | 1 |
| Dry Swales | 19 | 2 |
| Storm Water Wetlands | 17 | 3 |
| Extended Detention Dry Basins | 16 | 4 |
| Infiltration Basins | 14 | 5 |
| Rain Gardens | 13 | 6 |
| Oil-Grit Separators | 11 | 7 |
| Wet Swales | 8 | 8 |
| Infiltration Trenches | 5 | 9 |
| Porous Pavements | 5 | 9 |
| Bio-Retention | 4 | 10 |
| Infiltration Beds | 3 | 11 |
| Peat/Sand Filters | 1 | 12 |
| Sand Filters | 1 | 12 |

**Commentary.** From the responses to question 3, it is clear no single respondent had experience with all 14 of the BMPs surveyed. Wet ponds appears to be the most commonly encountered BMP, garnering responses from all 26 respondents. Peat/sand filters and sand filters appear to be the least commonly encountered BMPs. The experience level of the respondent pool roughly breaks down into three categories with respect to the BMP types:

- Broadest experience: Wet ponds, dry swales, extended detention dry basins and storm water wetlands (more than 60% of the respondents).
- Moderate experience: Infiltration basins, rain gardens and oil-grit separators (42-54% of respondents

• Limited experience: Wet swales, infiltration trenches, porous pavements, bio-retention, infiltration beds, peat/sand filters and sand filters (less than 31% of respondents.

Although the BMPs in the moderate experience group represent 42% to 54% of the respondents, but the actual numbers in the pool of responses for them is too small from which to generalize an opinion about them. The responses for this group suggest a trend, but that would have to be confirmed by a larger sample of people with experience with these BMPs.

It is difficult to say anything significant about the opinions regarding those in the "limited experience" category. This is because of the small numbers of respondents who had experience with them.

**Conclusion 2.** Individually, only those BMP types that clustered in the "broadest experience" category had a broad enough representation of the response pool (>60% of the respondents) on which to base reasonably reliable conclusions as to general opinion about them.

Question 4. What responsibilities do you have for each BMP type?

**Table 4: Repondent Responsibilities by BMP Type**

| BMP Type | Design/ Construction | Maintenance | Both | Neither or None |
|---|---|---|---|---|
| Infiltration Basins | 0 | 2 | 9 | 3 |
| Infiltration Trenches | 0 | 1 | 3 | 1 |
| Infiltration Beds | 0 | 0 | 2 | 1 |
| Porous Pavements | 0 | 0 | 2 | 3 |
| Sand Filters | 0 | 0 | 1 | 0 |
| Peat/Sand Filters | 0 | 0 | 1 | 0 |
| Oil/Grit Separators | 1 | 0 | 7 | 3 |
| Dry Swales | 5 | 1 | 11 | 2 |
| Wet Swales | 1 | 1 | 5 | 1 |
| Wet Ponds | 6 | 2 | 14 | 4 |
| Extended Detention Dry Basins | 1 | 1 | 14 | 0 |
| Bio-Retention | 1 | 1 | 1 | 1 |
| Rain Gardens | 1 | 2 | 7 | 3 |
| Storm Water Wetlands | 3 | 3 | 10 | 1 |
| Totals by response | 19 | 14 | 87 | 23 |

**Commentary.** Based on the responses to question 4, the opinions obtained in this survey were predominantly from individuals who had responsibilities for both design/construction and maintenance of the BMPs surveyed.

**Conclusion 3.** From the responses to question 4, the observers surveyed are generally quite experienced about the design, construction and maintenance issues of the BMP types for which they entered responses.

Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?

**Table 5A: Numbers of Respondent Observed Installations by BMP Type**

| BMP Type | 1-2 | 3-4 | 5-7 | 8-10 | More than 10 |
|---|---|---|---|---|---|
| Infiltration Basins | 6 | 4 | 3 | 0 | 1 |
| Infiltration Trenches | 3 | 2 | 0 | 0 | 0 |
| Infiltration Beds | 1 | 1 | 1 | 0 | 0 |
| Porous Pavements | 4 | 1 | 0 | 0 | 0 |
| Sand Filters | 0 | 1 | 0 | 0 | 0 |
| Peat/Sand Filters | 0 | 1 | 0 | 0 | 0 |
| Oil/Grit Separators | 5 | 2 | 0 | 1 | 0 |
| Dry Swales | 6 | 4 | 3 | 2 | 4 |
| Wet Swales | 2 | 2 | 3 | 1 | 0 |
| Extended Detention Dry Ponds | 3 | 2 | 3 | 2 | 6 |
| Wet Ponds | 7 | 5 | 4 | 1 | 8 |
| Bioretention | 3 | 0 | 1 | 0 | 0 |
| Rain Gardens | 6 | 1 | 3 | 1 | 1 |
| Storm Water Wetlands | 7 | 3 | 3 | 3 | 0 |

**Table 5B: Minimum Number of Respondent Observations of BMP Installations by Type, Ranked by Minimum and Maximum Possible Observations**

| BMP Type | Minimum number of observations | Rank in minimum number of observations | Maximum number of observations | Rank in maximum number of observations |
|---|---|---|---|---|
| Wet Ponds | 138 | 1 | >160 | 1 |
| Extended Detention Dry Ponds | 106 | 2 | >121 | 2 |
| Dry Swales | 93 | 3 | >113 | 3 |
| Storm Water Wetlands | 55 | 4 | 77 | 4 |
| Infiltration Basins | 44 | 5 | >60 | 5 |
| Rain Gardens | 43 | 6 | >58 | 6 |
| Wet Swales | 31 | 7 | 43 | 7 |
| Oil/Grit Separators | 19 | 8 | 28 | 8 |
| Infiltration Trenches | 9 | 9 | 14 | 9 |
| Infiltration Beds | 9 | 9 | 13 | 10 |
| Bioretention | 8 | 10 | 13 | 10 |
| Porous Pavements | 7 | 11 | 12 | 11 |
| Sand Filters | 3 | 12 | 4 | 12 |
| Peat/Sand Filters | 3 | 12 | 4 | 12 |
| Total BMP Observations | 568 | | 720 | |

**Commentary.** The responses to this question allow us to get an idea of the number of facility observations upon which the opinions registered in the other questions were based. The table immediately above was constructed from the response table above it, by taking number of observers represented in each class and multiplying it times the minimum and maximum values for each category. The sum of the products of the minimums for each BMP type are listed in the column headed "Minimum number of observations". The sum of the products of the maximums for each BMP type are listed in the column headed "Maximum number of observations". The opinions expressed in this survey by the 26 respondents thus represent opinions formed by between 568 and 720 separate BMP facility observations by the respondent pool. This is an average of between 21 to 26 BMP examples observed per respondent.

**Conclusion 4.** Although the observations were not systematically gathered, the number of observations suggests a very significant depth of experience base is represented in the pool of survey respondents.

Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of hwy or utility infrastructure?

**Table 6: Respondent Approximations of Percentage of BMPs Observed Located Adjacent to or Within 100 Feet of Highway or Utility Infrastructure**

| BMP Type | None | 1-20% | 20-40% | 40-60% | 60-80% | 80-99% | 100% |
|---|---|---|---|---|---|---|---|
| Infiltration Basins | 1 | 0 | 2 | 4 | 2 | 1 | 3 |
| Infiltration Trenches | 0 | 0 | 1 | 0 | 1 | 0 | 3 |
| Infiltration Beds | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| Porous Pavements | 2 | 0 | 0 | 1 | 0 | 0 | 1 |
| Sand Filters | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| Peat/Sand Filters | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Oil/Grit Separators | 1 | 2 | 0 | 2 | 0 | 1 | 4 |
| Dry Swales | 1 | 3 | 2 | 1 | 3 | 2 | 7 |
| Wet Swales | 1 | 0 | 0 | 1 | 1 | 2 | 3 |
| Wet Ponds | 2 | 4 | 5 | 1 | 6 | 3 | 4 |
| Extended Detention Dry Ponds | 0 | 4 | 2 | 2 | 5 | 1 | 2 |
| Bioretention | 0 | 0 | 1 | 0 | 0 | 0 | 2 |
| Rain Gardens | 0 | 0 | 0 | 3 | 1 | 1 | 8 |
| Storm Water Wetlands | 1 | 2 | 3 | 7 | 1 | 0 | 2 |
| Number of observer reports of frequency of a BMP type by percentage category | 11 | 17 | 16 | 22 | 20 | 11 | 40 |
| Percent of sum of the number (N=137) of observer reports of frequency of a BMP type in all percentage categories | 8.03 | 12.41 | 11.68 | 18.57 | 14.60 | 8.03 | 29.20 |

**Commentary.** One of the intentions of this survey was to measure opinions of BMP impact on highway and utility infrastructure. Responses to this question provide a picture of the respondents' experience base with respect their ability to observe BMPs that were close enough to have the potential for direct impact on that infrastructure. 29% of the observation responses indicated an experience base where 100% of the observed BMPs in the experience pool were within 100 feet of such infrastructure. The remaining responses were rather nicely distributed among the other categories offered. This suggests not only a good base of experience from which to observe impacts on infrastructure, but also an equally large base of facilities not within impact range of such infrastructure from which to make a comparison.

**Conclusion 5.** The base of observations from which respondents formed their opinions of impacts on infrastructure appears to be balanced in terms of BMP proximity to infrastructure element. This provides the respondents with a broad base of experience from which to compare and assess impacts between those BMPs near highway and utility infrastructure and those not in close proximity to that infrastructure.

**What is the perception of impacts of the BMPs on highway and utility infrastructure?**

Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure?

**Table 7: Respondent Categorization of the Extent of POSITIVE Impacts by BMP on Road or Utilities Infrastructure**

| BMP Type | Major | Moderate | Minor | None | Not Sure |
|---|---|---|---|---|---|
| Infiltration Basins | 1 | 4 | 4 | 4 | 1 |
| Infiltration Trenches | 0 | 3 | 1 | 0 | 1 |
| Infiltration Beds | 1 | 0 | 1 | 0 | 1 |
| Porous Pavements | 0 | 3 | 0 | 1 | 0 |
| Sand Filters | 1 | 0 | 0 | 0 | 0 |
| Peat/Sand Filters | 1 | 0 | 0 | 0 | 0 |
| Oil/Grit Separators | 2 | 3 | 2 | 0 | 2 |
| Dry Swales | 3 | 6 | 9 | 1 | 0 |
| Wet Swales | 1 | 5 | 1 | 1 | 0 |
| Wet Ponds | 5 | 12 | 4 | 2 | 2 |
| Extended Detention Dry Ponds | 4 | 6 | 3 | 2 | 1 |
| Bioretention | 0 | 3 | 0 | 0 | 1 |
| Rain Gardens | 3 | 5 | 4 | 1 | 0 |
| Storm Water Wetlands | 2 | 9 | 2 | 1 | 0 |
| Frequency of all BMPs in category | 24 | 59 | 31 | 13 | 9 |
| % of sum (N=136) of responses in all BMP categories | 17.65 | 43.38 | 22.79 | 9.56 | 6.62 |

**Commentary.** Nearly 84% of the responses to this question fell in a positive impact category. 10% said there were no positive impacts and nearly 7% were not sure if there were any positive impacts. Eleven BMPs earned one or more estimates of having produced major positive impacts on infrastructure. The BMPs that scored strongest in perceived major positive impacts on highway and utility infrastructure were wet ponds (5 responses), extended detention dry ponds (4 responses), rain gardens (3 responses , and dry swales (3 responses). Infiltration basins had the highest number of respondents (4) reporting them having no positive impacts on infrastructure, but this is offset by 5 responses of moderate and major positive impacts.

**Conclusion 6.** By a large margin – more than 4 to 1 – opinion represented in this survey regards the group of BMPs surveyed as productive of positive impacts on infrastructure.

Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?

**Table 8: Respondent Categorization of the Extent of NEGATIVE Impacts by BMP on Road or Utilities Infrastructure**

| BMP Type | Major | Moderate | Minor | None | Not Sure |
|---|---|---|---|---|---|
| Infiltration Basins | 0 | 4 | 1 | 8 | 0 |
| Infiltration Trenches | 0 | 0 | 0 | 4 | 1 |
| Infiltration Beds | 0 | 0 | 1 | 1 | 1 |
| Porous Pavements | 0 | 1 | 1 | 1 | 1 |
| Sand Filters | 0 | 0 | 0 | 1 | 0 |
| Peat/Sand Filters | 0 | 0 | 0 | 1 | 0 |
| Oil/Grit Separators | 0 | 0 | 1 | 8 | 0 |
| Dry Swales | 0 | 1 | 3 | 13 | 0 |
| Wet Swales | 0 | 1 | 3 | 4 | 0 |
| Wet Ponds | 0 | 1 | 5 | 16 | 1 |
| Extended Detention Dry Ponds | 0 | 1 | 3 | 10 | 1 |
| Bioretention | 0 | 0 | 0 | 3 | 1 |
| Rain Gardens | 0 | 2 | 5 | 5 | 0 |
| Storm Water Wetlands | 0 | 1 | 4 | 10 | 1 |
| Frequency of all BMPs in category | 0 | 12 | 27 | 85 | 7 |
| % of sum (N=131) of responses in all BMP categories | 0.00 | 9.16 | 20.61 | 64.89 | 5.34 |

**Commentary.** 30% of the responses to this question fell in a negative impact category. Nearly two-thirds of the responses (65%) said the BMPs produced no negative impacts on highway and utility infrastructure. 5% were not sure if there were any. The percentage of responses in the "Not Sure" category are nearly the same for both the positive and negative impact questions (7% and 5% respectively). 39 of the responses (30%) registered opinions that BMPs, produced some degree of negative effects, 27 (20.61% – just over two-thirds) indicated the negative impacts were minor.

No BMP type recorded any score in the "Major" negative impacts category. Infiltration basins alone accounted for four of the 12 responses in the "Moderate" impacts category.

The BMPs that had no scores indicating negative impacts on infrastructure were: Infiltration trenches, sand filters, peat/sand filters, and bio-retention, however the number of respondents participating in these cases was very small (five for infiltration trenches, four for bio-retention and one each for the other two BMPs).

**Conclusion 7.** By a substantial margin (nearly 2:1), opinion represented in this survey regards BMPs as generally NOT productive of negative impacts on infrastructure. Of the third of respondents indicating some degree of negative impact, two third of that third regarded the impacts as minor.

**What is the perception of the quality of design and functioning of the BMPs?**

***Question 9. What is your impression of the typical quality of design of each BMP type?***

**Table 9: Respondent Opinion of Typical Design Quality of BMPs by Type**

| BMP Type | Excellent | Good | Average | Poor |
|---|---|---|---|---|
| Infiltration Basins | 0 | 3 | 4 | 6 |
| Infiltration Trenches | 0 | 2 | 0 | 3 |
| Infiltration Beds | 1 | 0 | 0 | 2 |
| Porous Pavements | 0 | 2 | 1 | 1 |
| Sand Filters | 0 | 0 | 1 | 0 |
| Peat/Sand Filters | 0 | 0 | 1 | 0 |
| Oil/Grit Separators | 1 | 4 | 4 | 0 |
| Dry Swales | 0 | 9 | 7 | 2 |
| Wet Swales | 0 | 6 | 1 | 1 |
| Wet Ponds | 1 | 19 | 3 | 1 |
| Extended Detention Dry Ponds | 2 | 9 | 4 | 0 |
| Bioretention | 0 | 0 | 2 | 2 |
| Rain Gardens | 1 | 4 | 4 | 3 |
| Storm Water Wetlands | 1 | 10 | 3 | 2 |
| Frequency of all BMPs in category | 7 | 68 | 34 | 23 |
| % of sum (N=132) of responses in all BMP categories | 5.30 | 51.52 | 25.76 | 17.42 |

**Commentary.** 57% of the responses to this question fell good and excellent categories. 17% fell in the poor categories. Wet ponds and storm water wetlands had the strongest positive response to quality of design. Some practices showed themselves to be highly likely to have poor design: Infiltration basins, infiltration trenches, infiltration beds and bio-retention had half or more of their scores in the poor category.

**Conclusion 8.** Opinion about the quality of the design of BMPs observed can be regarded as positive for BMPs in general. However, with respect to individual BMPs, quality of design varies widely. The results suggest a need for educational efforts to raise the quality of the design of BMPs to better meet the design quality expectations of experienced observers. This is especially the case for design of infiltration basins, infiltration trenches, infiltration beds and bio-retention.

***Question 10. What is your impression of the typical functioning of each BMP type?***

**Table 10: Respondent Opinion of Typical Functioning of BMPs by Type**

| BMP Type | Excellent | Good | Average | Poor |
|---|---|---|---|---|
| Infiltration Basins | 0 | 1 | 5 | 7 |
| Infiltration Trenches | 0 | 1 | 3 | 4 |
| Infiltration Beds | 1 | 0 | 0 | 2 |
| Porous Pavements | 0 | 2 | 1 | 1 |
| Sand Filters | 0 | 1 | 0 | 0 |
| Peat/Sand Filters | 0 | 1 | 0 | 0 |
| Oil/Grit Separators | 1 | 4 | 3 | 1 |
| Dry Swales | 1 | 6 | 8 | 3 |
| Wet Swales | 0 | 3 | 4 | 1 |
| Wet Ponds | 3 | 16 | 5 | 0 |
| Extended Detention Dry Ponds | 3 | 8 | 4 | 0 |
| Bioretention | 0 | 1 | 3 | 0 |
| Rain Gardens | 1 | 3 | 8 | 0 |
| Storm Water Wetlands | 4 | 9 | 3 | 0 |
| Frequency of all BMPs in category | 14 | 56 | 46 | 16 |
| % of sum (N=132) of responses in all BMP categories | 10.61 | 42.42 | 34.85 | 12.12 |

**Commentary.** 53% of the responses to this question fell good and excellent categories. 12% fell in the poor categories. As with quality of design, wet ponds and storm water wetlands had the strongest positive response to quality of functioning. Some practices showed themselves to be highly likely to appear to have poor function: Infiltration basins and infiltration beds had more than half of their responses in the poor category. Interestingly, although more than half of the respondents for infiltration trenches and bio-retention rated their design as poor, some who rated the design poor did not do so for typical function. In other words, they apparently seemed to function better than poorly – in spite of poor design. At the same time, parallel ratings in function were given for the other two BMPs that had similar ratings of poor design quality: infiltration basins and infiltration beds were both regarded as functioning poorly.

**Conclusion 9.** Opinion about the quality of the functioning of BMPs observed can be regarded as positive for BMPs in general, but slightly less positive than quality of design. However, with respect to individual BMPs, quality of functioning varies widely. This suggests that investigation into the actual design practices for and function of BMPs would likely be productive of useful information. Further, more educational efforts about the design of BMPs (especially those that are regarded as both poorly designed and functioning poorly) would be the best place to target effort to produce improvement in opinion about BMPs.

Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?

**Table 11A: Respondent Impresssion of Typical Maintenance Costs of BMPs Compared to Range of Public Works Infrastructure Items**

| BMP Type | Lower | Similar | Higher |
|---|---|---|---|
| Infiltration Basins | 4 | 2 | 7 |
| Infiltration Trenches | 0 | 3 | 2 |
| Infiltration Beds | 0 | 1 | 2 |
| Porous Pavements | 0 | 1 | 3 |
| Sand Filters | 0 | 1 | 0 |
| Peat/Sand Filters | 0 | 1 | 0 |
| Oil/Grit Separators | 0 | 5 | 4 |
| Dry Swales | 8 | 7 | 3 |
| Wet Swales | 3 | 3 | 2 |
| Wet Ponds | 8 | 13 | 3 |
| Extended Detention Dry Ponds | 3 | 9 | 3 |
| Bioretention | 0 | 3 | 1 |
| Rain Gardens | 2 | 5 | 5 |
| Storm Water Wetlands | 8 | 6 | 2 |
| Frequency of responses for all BMPs in category | 35 | 60 | 37 |
| % of sum (N= 132) of responses in all BMP categories | 26.52 | 45.45 | 28.03 |

**Commentary.** Of all the questions, this one elicited information that is probably the most far removed from a factual basis because it asks for impressions about maintenance costs. Most municipalities do not appear to capture maintenance costs by infrastructure item for BMPs. Thus, it is important to understand that the responses to this question convey more about "attitude" toward maintenance costs of BMPs than anything else. Attitude can be important with respect to acceptance of use of technology. Therefore, it was felt to be important to take a measure of that attitude with this question.

45% of the responses indicated an opinion that maintenance costs for BMPs were comparable to those of the range of infrastructure items associated with public works. 27% felt that the maintenance costs for BMPs were actually lower in comparison. Taken together, that means at least 72% could reasonably be regarded as having the opinion that BMPs have acceptable maintenance costs.

Interestingly, three BMPs had more than 50% of their total number of responses to this question in the "higher" than typical maintenance cost category (see Table 11B). Those BMPs were:

- Infiltration Basins
- Infiltration Beds
- Porous Pavements

Again, infiltration basins and infiltration beds appear to be regarded as a "problem" practices for maintenance, parallel to the opinion about them reflected in the responses to questions 9 and 10 where both design and functioning were regarded as generally poor. It is worth noting that the rating of porous pavements may reflect a broad tendency to make comparisons of the porous pavement to conventional pavement simply in terms of pavement only . In actuality, porous pavement is a combined pavement-storm drainage system that is more comparable to pavement plus curb-gutter-storm sewer system.

**Table 11B: Percent of Respondent Impresssions of Typical Maintenance Costs of BMPs Compared to Range of Public Works Infrastructure Items by BMP Type**

| BMP Type | Number Lower | Percent Lower | Number Similar | Percent Similar | Number Higher | Percent Higher |
|---|---|---|---|---|---|---|
| Infiltration Basins | 4 | 31 | 2 | 15 | 7 | 54 |
| Infiltration Trenches | 0 | 0 | 3 | 60 | 2 | 40 |
| Infiltration Beds | 0 | 0 | 1 | 33 | 2 | 67 |
| Porous Pavements | 0 | 0 | 1 | 25 | 3 | 75 |
| Sand Filters | 0 | 0 | 1 | 100 | 0 | 0 |
| Peat/Sand Filters | 0 | 0 | 1 | 100 | 0 | 0 |
| Oil/Grit Separators | 0 | 0 | 5 | 56 | 4 | 44 |
| Dry Swales | 8 | 44 | 7 | 39 | 3 | 17 |
| Wet Swales | 2 | 29 | 3 | 43 | 2 | 29 |
| Extended Detention Dry Ponds | 3 | 20 | 9 | 60 | 3 | 20 |
| Wet Ponds | 8 | 33 | 13 | 54 | 3 | 13 |
| Bioretention | 0 | 0 | 3 | 75 | 1 | 25 |
| Rain Gardens | 2 | 17 | 5 | 42 | 5 | 42 |
| Storm Water Wetlands | 8 | 50 | 6 | 38 | 2 | 12 |

**Conclusion 10.** Opinion about the maintenance costs associated with BMPs in general leans toward regarding them as acceptable, and in some cases better than average compared to those for the range of typical infrastructure items. Infiltration basins and infiltration beds are notable exceptions to this generalization.

Question 12. Any comments/remarks?

Only four items were entered by three respondents in response to this question. Two of the items (from different respondents) called attention to a structural problem with the survey web site that made an incorrect linkage for data entry. This problem was detected and corrected on the first day the web site began receiving visitors. The web site was set up to track data entry for each respondent, so it was possible to correct the data entries.

The other two items speak for themselves and are included here without comment:

- "Am not convinced that any of thes [sic] other than ponds and swales are cost effective. Only works out if you want to show that it is...."

- "'Rain Gardens' experience was in a different municipality and more than 5 years ago."

Question 13.Would you be willing to be contacted for follow-up?

Nine of the 26 participants responded positively to this question by providing contact information. 16 of the 26 responded “No” to this question. One gave no response.

## Profiles of Opinions Reported by BMP Types

This section of the report shows a break-out of responses to each question by BMP type. Each BMP type is set in context by giving the total number of responders claiming field observation experience with the specific BMP type and the type's ranking in terms of highest frequency of claimed observational experience of all BMP types surveyed. The actual responses to each of questions 4 through 11 are shown in tables appearing immediately under a restatement of the question. Profiles of the BMP types in the order in which they appeared in the survey instrument.

Note that the total number of responses for a given question is not always the same for all the questions pertaining to a given BMP type. This reflects individual respondents' choices whether to answer each specific question for the BMP type. No control was used in the survey instrument to require respondents to answer all questions for a given BMP type once they had answered one question for that type.

A discussion of the results concludes each profile, and each profile begins with a new page.

## Infiltration Basins

Number of responders claiming field observation experience with this BMP: 14
Rank in terms of highest frequency of claimed observational experience of all BMPs: 5th

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 0 | 1: 1 -2 | 6 | 1. None | 1 |
| 2 Maintenance | 2 | 2: 3-4 | 4 | 2. 1-20% | 0 |
| 3 Both | 8 | 3: 5-7 | 3 | 3. 20-40% | 2 |
| 4 Neither/None | 3 | 4: 8-10 | 0 | 4. 40-60% | 4 |
| Total responses | 13 | 5: More than 10 | 1 | 5. 60-80% | 2 |
| | | Totals | 14 | 6. 80-99% | 1 |
| | | | | 7. 100% | 3 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 1 | 1. Major | 0 |
| 2. Moderate | 4 | 2. Moderate | 4 |
| 3. Minor | 3 | 3. Minor | 1 |
| 4. None | 4 | 4. None | 8 |
| 5. Not sure | 1 | 5. Not sure | 0 |
| Totals: | 13 | Totals | 13 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 0 | 1. Excellent | 0 | 1. Lower | 4 |
| 2. Good | 3 | 2. Good | 1 | 2. Similar | 2 |
| 3. Average | 4 | 3. Average | 5 | 3. Higher | 7 |
| 4. Poor | 6 | 4. Poor | 7 | Totals: | 13 |
| Totals: | 13 | Totals: | 13 | | |

With 14 respondents, infiltration basins was one of seven BMPs falling in the moderate experience category of BMPs. Eight of the respondents had responsibility for both design and maintenance of infiltration basins. The respondents were roughly equally divided between those who had experience with only one or two facilities, and those who had broader experience. Only one of the respondents had no experience with infiltration basins within 100 feet of highway or utility infrastructure .

Slightly more than 60% of the respondents were of the opinion that infiltration basins produced at least a few positive impacts on road or utilities infrastructure. Only 38% of the respondents were of the opinion that infiltration basins produced negative impacts on roads or utilities infrastructure. 60% felt that infiltration basins produced no negative impacts on infrastructure.

Interestingly, nearly half felt that the quality of infiltration basin design was poor. Also, 7 of the respondents were of the opinion that infiltration basins had poor functionality, and higher maintenance costs. This suggests that there may be some need for improvement of knowledge of design techniques, improvement in the technique itself or that the infiltration basins may not be a good choice as a BMP for storm water runoff quality improvement.

## Infiltration Trenches

Number of responders claiming field observation experience with this BMP: 5
Rank in terms of highest frequency of claimed observational experience: 9th (Tie with Porous Pavement BMP)

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 0 | 1: 1 -2 | 3 | 1. None | 0 |
| 2 Maintenance | 1 | 2: 3-4 | 2 | 2. 1-20% | 0 |
| 3 Both | 3 | 3: 5-7 | 0 | 3. 20-40% | 1 |
| 4 Neither/None | 1 | 4: 8-10 | 0 | 4. 40-60% | 0 |
| Total responses | 5 | 5: More than 10 | 0 | 5. 60-80% | 1 |
| | | Totals | 5 | 6. 80-99% | 0 |
| | | | | 7. 100% | 3 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 0 | 1. Major | 0 |
| 2. Moderate | 3 | 2. Moderate | 0 |
| 3. Minor | 1 | 3. Minor | 0 |
| 4. None | 0 | 4. None | 4 |
| 5. Not sure | 1 | 5. Not sure | 1 |
| Totals: | 5 | Totals | 5 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 0 | 1. Excellent | 0 | 1. Lower | 0 |
| 2. Good | 2 | 2. Good | 1 | 2. Similar | 3 |
| 3. Average | 0 | 3. Average | 3 | 3. Higher | 2 |
| 4. Poor | 3 | 4. Poor | 1 | Totals: | 5 |
| Totals: | 5 | Totals: | 5 | | |

With only 5 respondents, the infiltration trench was one of the seven BMP types falling in the limited experience category. Three of the five respondents had responsibility for both design and maintenance of infiltration trenches. The respondents were nearly equally divided between those who had experience with only one or two facilities, and those with three or four facilities. None had broader experience. All had at least some experience with infiltration trenches within 100 feet of highway or utility infrastructure.

Four of the five respondents were of the opinion that infiltration trenches produced at least a few positive impacts on road or utilities infrastructure. Four of the five the respondents were of the opinion that infiltration trenches produced no negative impacts on roads or utilities infrastructure. One was unsure.

There is nothing to say about the distributions of responses to Questions 9, 10 and 11. They offer no basis from which to draw conclusions because the sample of opinion on infiltration trenches is too small.

## Infiltration Beds

Number of responders claiming field observation experience with this BMP: 3
Rank in terms of highest frequency of claimed observational experience of all BMPs: 11th

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 0 | 1: 1 -2 | 2 | 1. None | 1 |
| 2 Maintenance | 0 | 2: 3-4 | 1 | 2. 1-20% | 1 |
| 3 Both | 3 | 3: 5-7 | 1 | 3. 20-40% | 0 |
| 4 Neither/None | 1 | 4: 8-10 | 0 | 4. 40-60% | 1 |
| Total responses | 4 | 5: More than 10 | 0 | 5. 60-80% | 0 |
| | | Totals | 4 | 6. 80-99% | 0 |
| | | | | 7. 100% | 1 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 1 | 1. Major | 0 |
| 2. Moderate | 0 | 2. Moderate | 0 |
| 3. Minor | 1 | 3. Minor | 1 |
| 4. None | 1 | 4. None | 1 |
| 5. Not sure | 1 | 5. Not sure | 1 |
| Totals: | 4 | Totals | 3 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 1 | 1. Excellent | 1 | 1. Lower | 0 |
| 2. Good | 0 | 2. Good | 0 | 2. Similar | 1 |
| 3. Average | 0 | 3. Average | 0 | 3. Higher | 2 |
| 4. Poor | 2 | 4. Poor | 2 | Totals: | 3 |
| Totals: | 3 | Totals: | 3 | | |

With only four respondents, the infiltration bed was one of the seven BMP types falling in the limited experience category. The most that can be said of the opinion about the infiltration bed is that there is not enough experience with it among those surveyed to identify a significant opinion.

## Porous Pavements

Number of responders claiming field observation experience with this BMP: 5
Rank in terms of highest frequency of claimed observational experience of all BMPs: 9th (Tied with Infiltration Trenches BMP).

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 0 | 1: 1 -2 | 4 | 1. None | 2 |
| 2 Maintenance | 0 | 2: 3-4 | 1 | 2. 1-20% | 0 |
| 3 Both | 2 | 3: 5-7 | 0 | 3. 20-40% | 0 |
| 4 Neither/None | 3 | 4: 8-10 | 0 | 4. 40-60% | 2 |
| Total responses | 5 | 5: More than 10 | 0 | 5. 60-80% | 0 |
| | | Totals | 5 | 6. 80-99% | 0 |
| | | | | 7. 100% | 1 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 0 | 1. Major | 0 |
| 2. Moderate | 4 | 2. Moderate | 1 |
| 3. Minor | 0 | 3. Minor | 1 |
| 4. None | 1 | 4. None | 1 |
| 5. Not sure | 0 | 5. Not sure | 1 |
| Totals: | 5 | Totals | 4 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 0 | 1. Excellent | 0 | 1. Lower | 0 |
| 2. Good | 2 | 2. Good | 2 | 2. Similar | 1 |
| 3. Average | 1 | 3. Average | 1 | 3. Higher | 3 |
| 4. Poor | 1 | 4. Poor | 1 | Totals: | 4 |
| Totals: | 4 | Totals: | 4 | | |

With only 5 respondents, porous pavement was one of the seven BMP types falling in the limited experience category. Half of the respondents had responsibility for both design and maintenance of porous pavement, the remaining half had no responsibility for either. Five of the respondents answered Question 5, with all five indicating field experience with porous pavement, and four of them in the range of one or two installations. One had broader experience. Three of the respondents had at least some experience with porous pavement within 100 feet of highway or utility infrastructure.

Only five respondents answered Question 7 (positive impacts) and four answered Question 8 Question 8 (negative impacts) about impacts of porous pavement on road or utilities infrastructure. There is nothing to say about the distribution of responses to these questions except that they offer no basis from which to draw conclusions.

Only four respondents answered Questions 9, 10 and 11 about the quality of porous pavement design, maintenance and maintenance cost. There is nothing to say about the distributions of responses to these questions except that they offer no basis from which to draw conclusions because there is not broad enough experience with porous pavement among the sample surveyed.

## Sand Filters

Number of responders claiming field observation experience with this BMP: 1
Rank in terms of highest frequency of claimed observational experience of all BMPs:
12th (Tied with Peat/Sand Filters).

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 0 | 1: 1 -2 | 0 | 1. None | 0 |
| 2 Maintenance | 0 | 2: 3-4 | 2 | 2. 1-20% | 1 |
| 3 Both | 2 | 3: 5-7 | 0 | 3. 20-40% | 0 |
| 4 Neither/None | 0 | 4: 8-10 | 0 | 4. 40-60% | 1 |
| Total responses | 2 | 5: More than 10 | 0 | 5. 60-80% | 0 |
| | | Totals | 2 | 6. 80-99% | 0 |
| | | | | 7. 100% | 0 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 1 | 1. Major | 0 |
| 2. Moderate | 1 | 2. Moderate | 0 |
| 3. Minor | 0 | 3. Minor | 0 |
| 4. None | 0 | 4. None | 1 |
| 5. Not sure | 0 | 5. Not sure | 0 |
| Totals: | 2 | Totals | 1 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 0 | 1. Excellent | 0 | 1. Lower | 0 |
| 2. Good | 0 | 2. Good | 1 | 2. Similar | 1 |
| 3. Average | 1 | 3. Average | 0 | 3. Higher | 0 |
| 4. Poor | 0 | 4. Poor | 0 | Totals: | 1 |
| Totals: | 1 | Totals: | 1 | | |

With only one respondent, the sand filter was one of the seven BMP types falling in the limited experience category. The most that can be said of the opinion about sand filters is that there is not enough experience with it among those surveyed to identify a significant opinion.

## Peat/Sand Filters

Number of responders claiming field observation experience with this BMP: 1
Rank in terms of highest frequency of claimed observational experience of all BMPs: 12th (Tied with Sand Filters).

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 0 | 1: 1 -2 | 1 | 1. None | 1 |
| 2 Maintenance | 0 | 2: 3-4 | 1 | 2. 1-20% | 0 |
| 3 Both | 2 | 3: 5-7 | 0 | 3. 20-40% | 0 |
| 4 Neither/None | 0 | 4: 8-10 | 0 | 4. 40-60% | 1 |
| Total responses | 2 | 5: More than 10 | 0 | 5. 60-80% | 0 |
| | | Totals | 2 | 6. 80-99% | 0 |
| | | | | 7. 100% | 0 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 1 | 1. Major | 0 |
| 2. Moderate | 0 | 2. Moderate | 0 |
| 3. Minor | 0 | 3. Minor | 0 |
| 4. None | 1 | 4. None | 1 |
| 5. Not sure | 0 | 5. Not sure | 0 |
| Totals: | 2 | Totals | 1 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 0 | 1. Excellent | 0 | 1. Lower | 0 |
| 2. Good | 0 | 2. Good | 1 | 2. Similar | 1 |
| 3. Average | 1 | 3. Average | 0 | 3. Higher | 0 |
| 4. Poor | 0 | 4. Poor | 0 | Totals: | 1 |
| Totals: | | Totals: | | | |

With only one respondent, the peat/sand filter was one of the seven BMP types falling in the limited experience category. The most that can be said of the opinion about peat/sand filters is that there is not enough experience with it among those surveyed to identify a significant opinion.

## Oil/Grit Separators

Number of responders claiming field observation experience with this BMP: 11
Rank in terms of highest frequency of claimed observational experience of all BMPs: 7th

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 1 | 1: 1 -2 | 5 | 1. None | 1 |
| 2 Maintenance | 0 | 2: 3-4 | 2 | 2. 1-20% | 2 |
| 3 Both | 6 | 3: 5-7 | 0 | 3. 20-40% | 0 |
| 4 Neither/None | 3 | 4: 8-10 | 1 | 4. 40-60% | 2 |
| Total responses | 10 | 5: More than 10 | 0 | 5. 60-80% | 0 |
| | | Totals | 8 | 6. 80-99% | 1 |
| | | | | 7. 100% | 3 |

| ***Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure?*** | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 2 | 1. Major | 0 |
| 2. Moderate | 3 | 2. Moderate | 0 |
| 3. Minor | 3 | 3. Minor | 1 |
| 4. None | 0 | 4. None | 8 |
| 5. Not sure | 2 | 5. Not sure | 0 |
| Totals: | 10 | Totals | 9 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 1 | 1. Excellent | 1 | 1. Lower | 0 |
| 2. Good | 4 | 2. Good | 4 | 2. Similar | 5 |
| 3. Average | 4 | 3. Average | 3 | 3. Higher | 4 |
| 4. Poor | 0 | 4. Poor | 1 | Totals: | 9 |
| Totals: | 9 | Totals: | 9 | | |

With 11 respondents, oil/grit separators was one of three BMP classes that fell into the moderate experience category. Six of the respondents had responsibility for both design and maintenance of oil/grit separators. Taken as a whole, the experience frequency with oil/grit separators was low, with the large majority being one to two facilities observed in the last five years.

Of those responding to Question 7, the large majority felt oil/grit separators was of the opinion that oil/grit separators produced positive impacts on road or utilities infrastructure. Of those responding to Question 8, the large majority was of the opinion that oil/grit separators produced no negative impacts on highway or utility infrastructure.

The predominant opinion regarding the design and functionality fell in the good to average range, although that for maintenance cost fell in the similar to higher range compared to typical maintenance costs for the range of public works infrastructure items.

Opinion about oil/grit separators as a BMP was generally positive, indicating positive impact with no negative impact on infrastructure, and a generally positive opinion about design and function.

## Dry Swales

Number of responders claiming field observation experience with this BMP: 19
Rank in terms of highest frequency of claimed observational experience of all BMPs: 2nd.

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 4 | 1: 1 -2 | 6 | 1. None | 1 |
| 2 Maintenance | 1 | 2: 3-4 | 3 | 2. 1-20% | 3 |
| 3 Both | 11 | 3: 5-7 | 3 | 3. 20-40% | 2 |
| 4 Neither/None | 2 | 4: 8-10 | 2 | 4. 40-60% | 1 |
| Total responses | 18 | 5: More than 10 | 4 | 5. 60-80% | 3 |
| | | Totals | 18 | 6. 80-99% | 2 |
| | | | | 7. 100% | 7 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 3 | 1. Major | 0 |
| 2. Moderate | 6 | 2. Moderate | 1 |
| 3. Minor | 9 | 3. Minor | 3 |
| 4. None | 1 | 4. None | 13 |
| 5. Not sure | 0 | 5. Not sure | 0 |
| Totals: | 19 | Totals | 17 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 0 | 1. Excellent | 1 | 1. Lower | 8 |
| 2. Good | 9 | 2. Good | 6 | 2. Similar | 7 |
| 3. Average | 7 | 3. Average | 8 | 3. Higher | 3 |
| 4. Poor | 2 | 4. Poor | 3 | Totals: | 18 |
| Totals: | 18 | Totals: | 18 | | |

With 19 respondents, the dry swale was one of the top four BMPs with which respondents had the most field experience. Ten of the respondents had responsibility for both design and maintenance of dry swales. A third of the respondents had experience with only one or two facilities, but just less than one-fourth had experience with more than 10 facilities. Only one of the respondents had no experience with dry swales within 100 feet of highway or utility infrastructure.

All but one of the respondents were of the opinion that dry swales produced at least a few positive impacts on road or utilities infrastructure. Only 24% of the respondents were of the opinion that dry swales produced negative impacts on roads or utilities infrastructure, and those fell in the few to some categories only. 76% felt that dry swales produced no negative impacts on infrastructure.

The predominant opinion regarding the design and functionality of dry swales fell in the good to average range. Interestingly, eight of respondents actually felt that dry swales were less costly to maintain compared to that of the range of infrastructure items normally associated with public works. Another seven felt dry swales had average maintenance costs. Thus, along with storm water wetlands, dry swales are regarded to be the most economical of the BMPs surveyed.

## Wet Swales

Number of responders claiming field observation experience with this BMP: 8
Rank in terms of highest frequency of claimed observational experience of all BMPs: 8th

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 1 | 1: 1 -2 | 2 | 1. None | 1 |
| 2 Maintenance | 1 | 2: 3-4 | 2 | 2. 1-20% | 0 |
| 3 Both | 5 | 3: 5-7 | 3 | 3. 20-40% | 0 |
| 4 Neither/None | 1 | 4: 8-10 | 1 | 4. 40-60% | 1 |
| Total responses | 8 | 5: More than 10 | 0 | 5. 60-80% | 1 |
| | | Totals | 8 | 6. 80-99% | 2 |
| | | | | 7. 100% | 3 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 1 | 1. Major | 0 |
| 2. Moderate | 4 | 2. Moderate | 1 |
| 3. Minor | 2 | 3. Minor | 3 |
| 4. None | 1 | 4. None | 4 |
| 5. Not sure | 0 | 5. Not sure | 0 |
| Totals: | 8 | Totals | 8 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 0 | 1. Excellent | 0 | 1. Lower | 2 |
| 2. Good | 5 | 2. Good | 3 | 2. Similar | 3 |
| 3. Average | 1 | 3. Average | 3 | 3. Higher | 2 |
| 4. Poor | 1 | 4. Poor | 1 | Totals: | 7 |
| Totals: | 7 | Totals: | 7 | | |

With only 8 respondents, the wet swale was one of the seven BMP types falling in the limited experience category. However, five of the respondents had responsibility for both design and maintenance of wet swales, the remaining three were equally distributed among the other choices. Only seven of the respondents answered Question 5, with a fairly even distribution among the first four categories of field experience with wet swales. Only one of the respondents had no experience with wet swales within 100 feet of highway or utility infrastructure.

From the responses to Question 7, it is clear that to those with field experience with wet swales, the vast majority regard them as producing positive impacts on highway or utility infrastructure. The responses to Question 8 the vast majority regard wet swales as producing few or no negative impacts on highway or utility infrastructure.

The predominant opinion regarding the design and functionality of wet swales fell in the good to average range. Six out of the eight respondents also felt that wet swales were less costly or similar in cost to maintain compared to that of the range of infrastructure items normally associated with public works. The responses to Question 11 placed wet swales among the seven for which at least some proportion of respondents regarded the BMP to have lower maintenance costs compared to the range of typical public works infrastructure items.

## Extended Detention Dry Ponds

Number of responders claiming field observation experience with this BMP: 16
Rank in terms of highest frequency of claimed observational experience of all BMPs: 4th.

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 1 | 1: 1 -2 | 3 | 1. None | 0 |
| 2 Maintenance | 1 | 2: 3-4 | 2 | 2. 1-20% | 4 |
| 3 Both | 14 | 3: 5-7 | 3 | 3. 20-40% | 2 |
| 4 Neither/None | 0 | 4: 8-10 | 1 | 4. 40-60% | 2 |
| Total responses | 16 | 5: More than 10 | 6 | 5. 60-80% | 5 |
| | | Totals | 15 | 6. 80-99% | 1 |
| | | | | 7. 100% | 2 |

| ***Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure?*** | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 4 | 1. Major | 0 |
| 2. Moderate | 6 | 2. Moderate | 1 |
| 3. Minor | 3 | 3. Minor | 3 |
| 4. None | 2 | 4. None | 10 |
| 5. Not sure | 1 | 5. Not sure | 1 |
| Totals: | 16 | Totals | 15 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 2 | 1. Excellent | 3 | 1. Lower | 3 |
| 2. Good | 9 | 2. Good | 8 | 2. Similar | 9 |
| 3. Average | 4 | 3. Average | 4 | 3. Higher | 3 |
| 4. Poor | 0 | 4. Poor | 0 | Totals: | 15 |
| Totals: | 15 | Totals: | 15 | | |

With 19 respondents, the extended detention dry basins was one of the top four BMPs with which respondents had the most field experience. 14 of the respondents had responsibility for both design and maintenance of extended detention dry basins. Six of the respondents (one-third) had experience with more than ten of these facilities, but just less than one-fifth had experience with only one or two facilities.

All but three of the respondents were of the opinion that extended detention dry basins produced at least a few positive impacts on road or utilities infrastructure. 27% of the respondents were of the opinion that extended detention dry basins produced negative impacts on roads or utilities infrastructure, and those fell in the moderate and minor categories only. Two-thirds of the respondents felt that extended detention dry basins produced no negative impacts on infrastructure.

The predominant opinion regarding the design and functionality of extended detention dry basins fell in the good to average range. Four-fifths of the respondents regarded extended detention dry basins comparable to or less costly to maintain compared to that of the range of infrastructure items normally associated with public works.

## Wet Ponds

Number of responders claiming field observation experience with this BMP: 26
Rank in terms of highest frequency of claimed observational experience of all BMPs: 1st

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 6 | 1: 1 -2 | 7 | 1. None | 2 |
| 2 Maintenance | 2 | 2: 3-4 | 5 | 2. 1-20% | 4 |
| 3 Both | 14 | 3: 5-7 | 4 | 3. 20-40% | 5 |
| 4 Neither/None | 3 | 4: 8-10 | 1 | 4. 40-60% | 1 |
| Total responses | 25 | 5: More than 10 | 7 | 5. 60-80% | 6 |
| | | Totals | 24 | 6. 80-99% | 3 |
| | | | | 7. 100% | 4 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 5 | 1. Major | 0 |
| 2. Moderate | 12 | 2. Moderate | 1 |
| 3. Minor | 4 | 3. Minor | 5 |
| 4. None | 2 | 4. None | 16 |
| 5. Not sure | 2 | 5. Not sure | 1 |
| Totals: | 25 | Totals | 23 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 1 | 1. Excellent | 3 | 1. Lower | 8 |
| 2. Good | 19 | 2. Good | 16 | 2. Similar | 13 |
| 3. Average | 3 | 3. Average | 5 | 3. Higher | 3 |
| 4. Poor | 1 | 4. Poor | 0 | Totals: | 24 |
| Totals: | 24 | Totals: | 24 | | |

With 26 respondents, the wet ponds was the BMP type with which all respondents had field experience. 14 of the respondents had responsibility for both design and maintenance of wet ponds. Seven of the respondents (27%) had experience with more than ten of these facilities, and the same number had experience with only one or two facilities.

All but four of the respondents were of the opinion that wet ponds produced at least a few positive impacts on road or utilities infrastructure. One-fourth of the respondents were of the opinion that wet ponds produced negative impacts on roads or utilities infrastructure, and those fell primarily in the minor category. Over 60% of the respondents felt that wet ponds produced no negative impacts on infrastructure.

All but one respondent regarded the design and functionality of wet ponds as being in the good to average range. 88% of the respondents regarded wet ponds comparable to or less costly to maintain compared to that of the range of infrastructure items normally associated with public works.

## Bio-Retention

Number of responders claiming field observation experience with this BMP: 4
Rank in terms of highest frequency of claimed observational experience of all BMPs: 10th

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 1 | 1: 1 -2 | 3 | 1. None | 0 |
| 2 Maintenance | 1 | 2: 3-4 | 0 | 2. 1-20% | 0 |
| 3 Both | 1 | 3: 5-7 | 1 | 3. 20-40% | 1 |
| 4 Neither/None | 1 | 4: 8-10 | 0 | 4. 40-60% | 0 |
| Total responses | 4 | 5: More than 10 | 0 | 5. 60-80% | 0 |
| | | Totals | 4 | 6. 80-99% | 0 |
| | | | | 7. 100% | 2 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 0 | 1. Major | 0 |
| 2. Moderate | 3 | 2. Moderate | 0 |
| 3. Minor | 0 | 3. Minor | 0 |
| 4. None | 0 | 4. None | 3 |
| 5. Not sure | 1 | 5. Not sure | 1 |
| Totals: | 4 | Totals | 4 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 0 | 1. Excellent | 0 | 1. Lower | 0 |
| 2. Good | 0 | 2. Good | 1 | 2. Similar | 3 |
| 3. Average | 2 | 3. Average | 3 | 3. Higher | 1 |
| 4. Poor | 2 | 4. Poor | 0 | Totals: | 4 |
| Totals: | 4 | Totals: | 4 | | |

With only four respondents, the bioretention pond was one of the seven BMP types falling into the limited experience category. The most that can be said of the opinion about bioretention is that there is not enough experience with it among those surveyed to identify a significant opinion.

## Rain Gardens

Number of responders claiming field observation experience with this BMP: 13
Rank in terms of highest frequency of claimed observational experience of all BMPs: 6th

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 1 | 1: 1 -2 | 6 | 1. None | 0 |
| 2 Maintenance | 1 | 2: 3-4 | 1 | 2. 1-20% | 0 |
| 3 Both | 7 | 3: 5-7 | 3 | 3. 20-40% | 0 |
| 4 Neither/None | 3 | 4: 8-10 | 1 | 4. 40-60% | 3 |
| Total responses | 12 | 5: More than 10 | 1 | 5. 60-80% | 1 |
| | | Totals | 12 | 6. 80-99% | 1 |
| | | | | 7. 100% | 8 |

| Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure? | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 3 | 1. Major | 0 |
| 2. Moderate | 5 | 2. Moderate | 2 |
| 3. Minor | 3 | 3. Minor | 5 |
| 4. None | 1 | 4. None | 5 |
| 5. Not sure | 0 | 5. Not sure | 0 |
| Totals: | 12 | Totals | 12 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 1 | 1. Excellent | 1 | 1. Lower | 2 |
| 2. Good | 4 | 2. Good | 3 | 2. Similar | 5 |
| 3. Average | 4 | 3. Average | 8 | 3. Higher | 5 |
| 4. Poor | 3 | 4. Poor | 0 | Totals: | 12 |
| Totals: | 12 | Totals: | 12 | | |

With 14 respondents, raingardens was one of three BMP classes that fell into the moderate experience category. Seven of the respondents had responsibility for both design and maintenance of raingardens. Taken as a whole, the experience frequency with raingardens was low, with half of the respondents placing themselves into the category of one to two facilities observed in the last five years.

Of those responding to Question 7, all but one respondent felt raingardens produced positive impacts on road or utilities infrastructure. Of those responding to Question 8, the 7 respondents were of the opinion that raingardens produced negative impacts on highway or utility infrastructure.

The predominant opinion regarding the design and functionality fell in the good to average range, although that for maintenance cost fell in the similar to higher range compared to typical maintenance costs for the range of public works infrastructure items.

## Storm Water Wetlands

Number of responders claiming field observation experience with this BMP: 17
Rank in terms of highest frequency of claimed observational experience of all BMPs: 3rd

| ***Question 4. What responsibilities do you have for each BMP type?*** | | ***Question 5. With approximately how many installations of each BMP have you had experience in the past 5 years?*** | | ***Question 6. Of the BMPs below in your experience, categorize the approximate percentage with locations adjacent to or within 100 feet of highway or utility infrastructure*** | |
|---|---|---|---|---|---|
| 1 Design/Constr. | 3 | 1: 1 -2 | 7 | 1. None | 1 |
| 2 Maintenance | 2 | 2: 3-4 | 3 | 2. 1-20% | 2 |
| 3 Both | 10 | 3: 5-7 | 3 | 3. 20-40% | 3 |
| 4 Neither/None | 1 | 4: 8-10 | 3 | 4. 40-60% | 6 |
| Total responses | 16 | 5: More than 10 | 0 | 5. 60-80% | 1 |
| | | Totals | 16 | 6. 80-99% | 0 |
| | | | | 7. 100% | 2 |

| ***Question 7. In your estimation, to what extent does each BMP produce POSITIVE impacts on road or utilities infrastructure?*** | | ***Question 8. In your estimation, to what extent does each BMP produce NEGATIVE impacts on road or utilities infrastructure?*** | |
|---|---|---|---|
| 1. Major | 2 | 1. Major | 0 |
| 2. Moderate | 9 | 2. Moderate | 1 |
| 3. Minor | 3 | 3. Minor | 4 |
| 4. None | 1 | 4. None | 10 |
| 5. Not sure | 0 | 5. Not sure | 1 |
| Totals: | 15 | Totals | 16 |

| ***Question 9. What is your impression of the typical quality of design of each BMP type?*** | | ***Question 10. What is your impression of the typical functioning of each BMP type?*** | | ***Question 11. What is your impression of typical maintenance cost of each BMP compared to that of range of infrastructure items associated with Public Works?*** | |
|---|---|---|---|---|---|
| 1. Excellent | 1 | 1. Excellent | 4 | 1. Lower | 8 |
| 2. Good | 10 | 2. Good | 9 | 2. Similar | 6 |
| 3. Average | 2 | 3. Average | 3 | 3. Higher | 2 |
| 4. Poor | 2 | 4. Poor | 0 | Totals: | 16 |
| Totals: | 15 | Totals: | 16 | | |

With 17 respondents, storm water wetlands was one of the top four BMPs with which respondents had the most field experience. Ten of the respondents had responsibility for both design and maintenance of dry swales. Nearly half of the respondents had experience with only one or two facilities, and none had experience with more than 10 facilities.

All but one of the respondents were of the opinion that storm water wetlands produced at least a few positive impacts on road or utilities infrastructure. One-third of the respondents were of the opinion that storm water wetlands produced negative impacts on roads or utilities infrastructure, and those fell in the few to some categories only. 63% felt that storm water wetlands produced no negative impacts on infrastructure.

The predominant opinion (73%) regarding the design and functionality of storm water wetlands fell in the good to excellent range. Interestingly, half of the respondents actually felt that storm water wetlands were less costly to maintain compared to that of the range of infrastructure items normally associated with public works. Another six felt storm water wetlands had average maintenance costs. Thus, along with dry swales, storm water wetlands are regarded to be the most economical of the BMPs surveyed.

# *Task 4. Characterization of Alternative Practice Field Sites*

Survey and measure/assess infiltration capacity of selected sites

Samuel Johnson
Graduate Research Assistant

Eric Otto
Graduate Research Assistant

John L. Nieber
Professor

Department of Biosystems and Agricultural Engineering
University of Minnesota

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**University of Minnesota**

## Introduction

This report is a summary reporting measured data and associated calculations of infiltration capacity. Parameters measured include field-saturated hydraulic conductivity, matric flux potential, wetting front suction, and sorptivity. Measurements were taken using a Philip-Dunne Permeameter, Guelph Permeameter, and Tension Infiltrometer. Study sites consisted of various alternative stormwater best management practices (BMPs) and were chosen based on interviews conducted with persons responsible for the maintenance and/or design of the sites. Study sites include four infiltration basins, eight swales, and twelve rainwater gardens. These BMPs are located around the metro area in Roseville, St. Paul, Oakdale, Oak Park Heights, Bloomington, Lake Elmo, Minnetonka, Maplewood, and Stillwater. Sites were visited multiple times. Wet conditions early in the summer made measurements difficult at many of the sites.

## Methods

Parameters. Field-saturated hydraulic conductivity, wetting front suction, and sorptivity are some of the important factors governing liquid transmission in unsaturated soils. Field-saturated hydraulic conductivity ($K_{f_s}$) is the measure of the ability of a soil to conduct water under a unit of hydraulic potential gradient. It is one of the most important soil properties controlling water infiltration and surface runoff, but it is also one of the most problematic measurements at field scale in regard to variability and uncertainty (Munoz-Carpena et al., 2002). $K_{f_s}$ is extremely sensitive to sample size, flow geometry, measurement procedures, and various physical-hydrological characteristics (Bouma 1983). Also, many methods often yield substantially different $K_{f_s}$ values (Reynolds et al., 2000).

Hydraulic conductivity is the measure of a soil's ability to pull water, by capillary and gravitational forces, through a unit cross sectional area in a unit time. The prediction of infiltration of water using many techniques requires measurements of the hydraulic conductivity corresponding to field saturation (Elrick et al., 1995). Sorptivity is the measure of the ability of a soil to absorb a wetting liquid. Sorptivity characterizes the early stages of water infiltration representing the effect of the soil's matric potential (Regalado et al., 2005). The greater the sorptivity, the more rapidly the liquid may be absorbed. Wetting front suction is a relevant parameter to water movement in the vadose zone. In this study, the wetting front suction was measured using the Philip-Dunne permeameter for use in the Green-Ampt model to determine water infiltration.

Soil moisture content and bulk density were measured in the field to determine the change in volumetric water content, a parameter needed to quantify sorptivity. Moisture contents were taken prior to and after each permeameter or infiltrometer measurement. Together with bulk density, the change in volumetric water content was determined.

Philip-Dunne Permeameter (PD). A PD is a simplified falling-head technique based on the apparatus used by T. Dunne and E. Safran in the Amazon River Basin as reported by Philip (1993). It consists of a tube with radius R, inserted into the soil to a certain depth and filled with water. During infiltration, the time when the tube is half empty ($t_{med}$) and the time when the tube is empty ($t_{\max}$) are recorded, along with soil moisture before ($\theta_{pre}$) and after ($\theta_{post}$) the measurement (Munoz-Carpena et al., 2002). To determine field-saturated hydraulic conductivity ($K_{f_s}$), sorptivity ($S$), and the wetting front suction ($\psi_{wf}$), equations modified from the spherically symmetric Green-Ampt model were used (Munoz-Carpena et al., 2002). The following four equations are used for this determination.

$$\tau_{\max} = 0.73\left(t_{\max}/t_{med}\right) - 1.112 \quad t_{\max}/t_{med} < 5.4$$
$$\tau_{\max} = 8K_{f_s}t_{\max}/\pi^2 R$$
$$\log\psi_{wf} = -13.503 + 19.678\left(t_{\max}/t_{med}\right)^{-1/2}$$
$$S = \left(2K_{f_s}\psi_{wf}\Delta\theta\right)^{1/2}$$

Tension Infiltrometer (TI). Data was obtained with the TI using the Mariotte-based apparatus and multiple head-single disk ($R$ = 10cm) procedures (Reynolds and Elrick, 1991). For this study, we desired conductivity values for near saturated conditions ($K_{f_s}$). To accomplish this, two positive pressure heads were used ($\psi_1$= 10cm and $\psi_2$= 20cm) (Reynolds and Zebchuk, 1996). Measurements at sites where the soil was compacted or fine-textured required a tension (negative pressure) be applied. For successive tensions, we used –10 cm($\psi_1$) and –1 cm($\psi_2$), so the condition was still near saturation. Pressure heads were established in ascending order on the soil surface and the corresponding steady-state flow rates measured. The steady-state flow rates ($Q_1$ and $Q_2$) and change in volumetric moisture content ($\Delta\theta$) were used in relationships described by Reynolds and Elrick (1991) to find the desired soil properties. The relations employed are given by,

$$K_{f_s} = \left(G_d\alpha Q_1\right)/\left[R\left(1 + G_d\alpha\pi R\right)\left(Q_1/Q_2\right)^P\right]$$
$$S = \left(2K_{f_s}\phi_m\Delta\theta\right)^{1/2}$$
$$G_d = 0.25$$
$$P = \psi_1/\left(\psi_1 - \psi_2\right)$$
$$\alpha = \ln\left(Q_1/Q_2\right)/\left(\psi_1 - \psi_2\right)$$
$$\phi_m = K_{f_s}/\alpha$$

Guelph Permeameter (GP). The GP is a constant-head well permeameter consisting of a mariotte bottle that maintains a constant water level inside an augered hole into unsaturated soil. This permeameter requires steady flow rates from two different water levels (heads) in the augered hole. Steady-state flow rates were measured with a 5cm head ($\psi_1$) and a 10cm head ($\psi_2$), as recommended by the manufacturer. The flow rates were used with the change in volumetric water content ($\Delta\theta$) to determine field-saturated hydraulic conductivity ($K_{f_s}$), matric flux potential ($\phi_m$), and sorptivity ($S$). The relations used for calculations of the parameters with this method are,

$$K_{f_s} = A\left(0.0041\psi_2 - 0.0054\psi_1\right)$$
$$\phi_m = A\left(0.0572\psi_1 - 0.0237\psi_2\right)$$
$$S = \left(2K_{f_s}\phi_m\Delta\theta\right)^{1/2}$$

where $A$ is a constant for the particular reservoir used.

## Results

Field-saturated hydraulic conductivity, sorptivity, matric flux potential (GP and TI), and wetting front suction (PD) data were determined from measurements taken at each site. Data from measurements taken with the PD (Appendix A), TI (Appendix B), and the GP (Appendix C) are attached to the end of this report. Specific data from each site, including hydraulic conductivity values, soil texture within the practice, soil texture between the practice and the road, and practice size and distance between the practice and the adjacent road is also attached (Appendix D).

For each site where contributing area was available, we estimated the volume and the surface area of the practice. We used the average $K_{f_s}$ values (PD and TI) from each of these sites to develop a conservative infiltration rate throughout the practice. We measured the time it would take these sites to infiltrate all the water from rain events that create certain depths of runoff across the whole drainage area (reported in the Task 5 report).

## Discussion

<u>Infiltration basins</u>. Four of the 24 study sites are infiltration basins. Two of these infiltration basins were designed as wet basins, and we were unable to conduct infiltration measurements at them, as they were permanently saturated. The other two basins were designed as dry infiltration basins. At these basins, $K_{f_s}$ values ranged from 0.376 in/hr to 1.01 in/hr with the TI and 0.362 in/hr to 2.55 in/hr with the PD (Appendix A).

<u>Swales</u>. Eight of the 24 study sites are swales. One of the swales (Denny's) appears to have been designed as a wet swale system and we were unable to conduct field measurements due to saturated conditions. Of the seven dry swale systems, the mean $K_{f_s}$ value with the TI was 1.53 in/hr and 4.9 in/hr with the PD.

Rainwater gardens. Twelve of the 24 study sites are rainwater gardens. One of the rainwater gardens had standing water during every visit and we were unable to conduct any field measurements. Of the eleven effective gardens, the mean $K_{f_s}$ value with the TI was 1.19 in/hr and 6.02 in/hr with the PD.

Method Comparison. Because the GP involves an augered hole, it is not appropriate to compare this method with the PD and TI. It was used in this project, because it helps one understand more about how the practice functions. For example, a site may have low infiltration rates on the surface due to siltation or compaction. Auguring through the top layer and measuring permeability of the underlying material, plus measuring the permeability of the upper surface allows one to determine if this is so.

Data from measurements taken with the PD and the TI are often quite similar. However, some sites show differences between the two methods to an order of magnitude. A statistical comparison is beyond the scope of this Task report. However, there are several reasons why the numbers may be different. First, much research has documented that $K_{f_s}$ values are extremely hard to measure and different methods often yield substantially different results (Bouma, 1983; Reynolds et al., 2000). Munoz-Carpena et al. (2002) compared the PD (augered hole method) with the GP (augered hole method) and found that the two methods were related by a factor of three (the PD had values three times as high as the GP).

Soil hydraulic properties such as $K_{f_s}$ are also quite variable, so even though measurements were taken close to each other, soil variability within the practices may have contributed to the differences in values. The PD may smear or compact the soil upon insertion and the pouring of water may have sealed the soil, even though straw and wire mesh was used to prevent this. Also, positive pressures used with the TI may have created too much overland flow through the contact material (fine sand). Ponding and overland flow occurred at several of the sites where compaction or fine-textured soils slowed infiltration. TI measurements at two of these sites were conducted using negative pressures (tensions). If time had time allowed, TI measurements with negative pressures would have been taken at several more of the sites. Additional studies for a related project are intended to be completed to assess differences between TI measurements made with negative pressures and the PD method.

*NOTE: A complementary report, the report for Task 5, which outlines the degree of practice effectiveness compared to design recommendations further discusses much of the results presented here.

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# Appendix A: Philip-Dunne Permeameter

| | | t max | t med | T max | radius | Ks | | MC | Sorptivity | Pre 5 day | Pre 10 day |
|---|---|---|---|---|---|---|---|---|---|---|---|
| SITE | DATE | (sec) | (sec) | (sec/sec) | (cm) | (cm/sec) | (cm) | | (cm/sec-1/2) | precip. (in) | precip. (in) |
| 6109 Blue Circle Drive | 11/14/2004 | 1189 | 490 | 0.662 | 10 | 6.87E-03 | 0.134 | NA | NA | 0.01 | 0.01 |
| LecTec | 11/7/2005 | 2884 | 1215 | 0.623 | 10 | 2.67E-03 | 0.186 | NA | NA | 0 | 2.85 |
| Normark | 11/7/2005 | NA | NA | NA | 10 | NA | NA | NA | NA | 0 | 2.85 |
| Caterpillar | 4/30/2005 | 4365 | 1860 | 0.603 | 10 | 1.71E-03 | 0.22 | 0.06 | 6.72E-03 | 0.08 | 0.24 |
| Como Park | 4/30/2005 | 375 | 150 | 0.716 | 10 | 2.35E-02 | 8.80E-02 | 0.055 | 1.50E-02 | 0.08 | 0.24 |
| Swede Hollow | 4/30/2005 | 11100 | 4680 | 0.622 | 10 | 6.91E-04 | 0.188 | 0.01 | 5.10E-04 | 0.41 | 0.47 |
| Bremer | 5/1/2005 | NA | NA | NA | 10 | NA | NA | NA | NA | 0.13 | 0.29 |
| Xerxes | 5/24/2005 | 9600 | 3600 | 0.837 | 10 | 1.08E-03 | 3.53E-02 | 0.08 | 2.47E-03 | 0.08 | 1.29 |
| LecTec | 5/24/2005 | 1740 | 660 | 0.815 | 10 | 5.78E-03 | 4.10E-02 | 0.039 | 4.32E-03 | 0.08 | 1.29 |
| LecTec | 5/24/2005 | 1320 | 480 | 0.898 | 10 | 8.40E-03 | 2.30E-02 | 0.039 | 3.89E-03 | 0.08 | 1.29 |
| Ripley at Clarence | 6/2/2005 | 706 | 238 | 1.06 | 2.65 | 4.89E-03 | 8.36E-03 | 0.07 | 2.39E-03 | 0.04 | 0.66 |
| Ferndale at Harvester | 6/2/2005 | 3010 | 1132 | 0.832 | 10 | 3.41E-03 | 3.70E-02 | 0.02 | 2.24E-03 | 0.04 | 0.66 |
| Bremer | 6/3/2005 | NA | NA | NA | 10 | NA | NA | NA | NA | 0.02 | 0.81 |
| Bremer | 6/3/2005 | NA | NA | NA | 2.65 | NA | NA | NA | NA | 0.02 | 0.81 |
| Caterpillar | 6/3/2005 | 7500 | 2135 | 1.46 | 10 | 2.39E-03 | 9.91E-04 | 0.05 | 4.87E-04 | 0.05 | 0.78 |
| Como Park | 6/13/2005 | 1020 | 368 | 0.914 | 2.65 | 2.93E-03 | 2.07E-02 | 0.04 | 2.20E-03 | 0.54 | 1.95 |
| Ripley at Clarence | 6/15/2005 | 4800 | 1640 | 1.03 | 2.65 | 7.00E-04 | 9.98E-03 | 0.07 | 9.89E-04 | 2.86 | 4.26 |
| Ripley at Barclay | 6/21/2005 | 2921 | 1090 | 0.847 | 10 | 3.58E-03 | 3.29E-02 | 0.03 | 2.66E-03 | 0.58 | 2.61 |
| Ripley at Barclay | 6/21/2005 | 2150 | 840 | 0.759 | 2.65 | 1.15E-03 | 6.26E-02 | 0 | 1.20E-02 | 0.58 | 2.61 |
| Ripley at Barclay | 6/21/2005 | 4380 | 1890 | 0.582 | 2.65 | 4.34E-04 | 0.265 | 0.07 | 4.01E-03 | 0.58 | 2.61 |
| Swede Hollow | 6/22/2005 | 10200 | 3900 | 0.8 | 2.65 | 2.56E-04 | 4.62E-02 | 0.05 | 1.08E-03 | 0.58 | 2.18 |
| Wildwood | 6/23/2005 | 23100 | 7950 | 1.01 | 10 | 5.40E-04 | 1.10E-02 | 0.05 | 7.70E-04 | 0.62 | 2.39 |
| Bremer | 6/23/2005 | NA | NA | NA | 2.65 | NA | NA | NA | NA | 0.62 | 2.39 |
| Normark | 6/25/2005 | NA | NA | NA | 2.65 | NA | NA | NA | NA | 1.25 | 1.62 |
| Normark | 6/25/2005 | NA | NA | NA | 10 | NA | NA | NA | NA | 1.25 | 1.62 |
| 6109 Blue Circle Drive | 6/25/2005 | 9900 | 2940 | 1.35 | 10 | 1.68E-03 | 1.66E-03 | 0.05 | 5.28E-04 | 1.25 | 1.62 |
| 50th (6) | 7/7/2005 | 10140 | 2640 | 1.7 | 10 | 2.06E-03 | 3.45E-04 | 0.08 | 3.37E-04 | 0.39 | 2.68 |
| 50th (4) | 7/8/2005 | 27300 | 10200 | 0.845 | 10 | 3.82E-04 | 3.35E-02 | 0.03 | 8.76E-04 | 0.39 | 2.68 |
| 50th (1) | 7/8/2005 | NA | NA | NA | 2.65 | NA | NA | NA | NA | 0.39 | 2.68 |
| 50th (5) | 7/12/2005 | NA | NA | NA | 2.65 | NA | NA | NA | NA | 0 | 0.39 |
| 50th (2) | 7/12/2005 | NA | NA | NA | 10 | NA | NA | NA | NA | 0 | 0.39 |
| Realife Coop | 7/13/2005 | 1590 | 585 | 0.875 | 2.65 | 1.80E-03 | 2.71E-02 | 0.03 | 1.71E-03 | 1.86 | 2.2 |
| Brand at Ferndale | 7/25/2005 | 2400 | 960 | 0.716 | 10 | 3.68E-03 | 8.76E-02 | 0.18 | 1.07E-02 | 1 | 1.21 |
| | | | | | | | | | | | |

# Appendix B: Tension Infiltrometer

| SITE | DATE | Q1 (cm3/sec) | Q2 (cm3/sec) | alpha (cm-1) | Kfs (cm/sec) | Matric Flux (cm2/sec) | Change in MC | S (cm/sec-1/2) | Pre 5 day Precip. (in) | Pre 10 day Precip. (in) |
|---|---|---|---|---|---|---|---|---|---|---|
| Como Park | 6/13/2005 | 1.88 | 1.41 | -0.0287 | -2.30E-03 | 8.01E-02 | 0 | NA | 0.54 | 1.95 |
| Como Park (2) | 6/13/2005 | 1.06 | 1.17 | 0.0105 | 2.31E-04 | 2.20E-02 | 0.04 | 4.20E-02 | 0.54 | 1.95 |
| Ripley at Clarence | 6/15/2005 | 1.76 | 2 | 0.0125 | 4.42E-04 | 3.54E-02 | 0.08 | 7.50E-02 | 2.86 | 4.26 |
| Ripley at Clarence (2) | 6/15/2005 | 1.29 | 2 | 0.0435 | 6.77E-04 | 1.56E-02 | 0.06 | 4.32E-02 | 2.86 | 4.26 |
| Realife Coop | 6/16/2005 | 2.94 | 1.76 | -0.051 | -1.04E-02 | 0.204 | 0.05 | 0.143 | 1.25 | 2.9 |
| Ferndale at Harv. | 6/21/2005 | 1.29 | 1.06 | -0.02 | -9.36E-04 | 4.68E-02 | 0.01 | 3.06E-02 | 0.58 | 2.61 |
| Ferndale at Harv. (2) | 6/21/2005 | 2.7 | 3.29 | 0.0197 | 9.46E-04 | 4.80E-02 | 0.05 | 6.93E-02 | 0.58 | 2.61 |
| Ripley at Barclay | 6/21/2005 | 1.88 | 2 | 0.0061 | 2.56E-04 | 4.19E-02 | 0 | NA | 0.58 | 2.61 |
| Ripley at Barclay (2) | 6/21/2005 | 2.11 | 3.4 | 0.0477 | 1.14E-03 | 2.39E-02 | 0.01 | 2.18E-02 | 0.58 | 2.61 |
| Caterpillar | 6/22/2005 | 1.76 | 2.11 | 0.0182 | 5.85E-04 | 3.22E-02 | 0.01 | 2.54E-02 | 0.58 | 2.18 |
| Swede H. Café | 6/22/2005 | 1.29 | 2.23 | 0.0547 | 7.15E-04 | 1.31E-02 | 0.02 | 2.29E-02 | 0.58 | 2.18 |
| Wildwood | 6/23/2005 | 3.99 | 4.23 | 0.0057 | 5.16E-04 | 9.05E-02 | 0.01 | 4.25E-02 | 0.62 | 2.39 |
| Bremer | 6/23/2005 | 5.28 | 5.4 | 0.002197 | 2.79E-04 | 0.1271 | 0.04 | 0.101 | 0.62 | 2.39 |
| Normark | 6/25/2005 | 0.029 | 2.7 | 0.4522 | 7.92E-07 | 1.75E-06 | 0.04 | 3.74E-04 | 1.25 | 1.62 |
| 6109 Blue Circle Dr | 6/25/2005 | 6.1 | 9.98 | 0.0491 | 3.31E-03 | 6.74E-02 | 0.04 | 7.35E-02 | 1.25 | 1.62 |
| LecTec | 6/25/2005 | 5.87 | 7.87 | 0.0293 | 2.61E-03 | 8.89E-02 | 0.11 | 0.14 | 1.25 | 1.62 |
| Xerxes | 6/25/2005 | 2.94 | 8.57 | 0.1072 | 1.46E-03 | 1.36E-02 | 0.12 | 5.72E-02 | 1.25 | 1.62 |
| 50th (6) | 7/7/2005 | 1.29 | 1.88 | 0.0375 | 6.43E-04 | 1.72E-02 | 0.01 | 1.85E-02 | 0.39 | 2.68 |
| 50th (4) | 7/8/2005 | 2.58 | 7.04 | 0.1003 | 1.33E-03 | 1.33E-02 | 0.09 | 4.88E-02 | 0.39 | 2.68 |
| 50th (1) | 7/8/2005 | 3.87 | 7.63 | 0.0678 | 2.18E-03 | 3.31E-02 | 0.02 | 3.64E-02 | 0.39 | 2.68 |
| 50th (2) | 7/12/2005 | 0.235 | 2.23 | 0.2251 | 5.03E-05 | 2.23E-04 | 0.04 | 4.22E-03 | 0 | 0.39 |
| 50th (5) | 7/12/2005 | 2 | 2.11 | 0.0057 | 2.58E-04 | 4.52E-02 | 0 | NA | 0 | 0.39 |
| Realife Coop | 7/13/2005 | 2.58 | 2.7 | 0.0045 | 2.65E-04 | 5.97E-02 | -0.01 | NA | 1.86 | 2.2 |
| Brand at Ferndale* | 7/25/2005 | 2.82 | 3.52 | 0.0223 | 1.71E-03 | 7.68E-02 | 0.04 | 7.84E-02 | 1 | 1.21 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| * = -10cm and -1cm pressure heads | | | | | | | | | | |

# Appendix C: Guelph Permeameter

| SITE | DATE | Kfs | Matric flux | Change in MC | S | Pre-5 day | Pre 10 day |
|---|---|---|---|---|---|---|---|
| | | (cm/sec) | (cm2/sec) | | (cm/sec-1/2) | Precip. (in) | Precip. (in) |
| Ripley at Barclay | 10/24/2004 | NA (augered hole | filled with water | immediately) | NA | 0.49 | 0.91 |
| Barclay at Ripley | 10/24/2004 | NA (augered hole | filled with water | immediately) | NA | 0.49 | 0.91 |
| Ripley at Clarence | 10/24/2004 | 1.49E-03 | 3.87E-02 | not taken | NA | 0.49 | 0.91 |
| Barclay at Gulden | 10/24/2004 | NA (augered hole | filled with water | immediately) | NA | 0.49 | 0.91 |
| Brand at Ferndale | 10/24/2004 | 2.11E-06 | 4.83E-05 | not taken | NA | 0.49 | 0.91 |
| 6109 Blue Circle Drive | 11/14/2004 | 3.58E-07 | 1.37E-04 | not taken | NA | 0.01 | 0.01 |
| Lectec | 11/7/2004 | NA (augered hole | filled with water | immediately) | NA | 0 | 2.85 |
| Normark | 11/7/2004 | NA (augered hole | filled with water | immediately) | NA | 0 | 2.85 |
| Xerxes | 5/24/2005 | 1.65E-04 | -8.96E-04 | 0.08 | NA | 0.08 | 1.29 |
| Lectec | 5/24/2005 | 1.39E-05 | -5.88E-06 | 0.01 | NA | 0.08 | 1.29 |
| Ripley at Clarence | 6/2/2005 | 2.88E-03 | 4.13E-02 | 0.07 | 7.61E-02 | 0.04 | 0.66 |
| Ferndale at Harvester | 6/2/2005 | 1.14E-05 | 5.86E-04 | 0.01 | 3.40E-03 | 0.04 | 0.66 |
| Bremer | 6/3/2005 | -3.58E-06 | 1.51E-04 | 0.01 | 1.70E-03 | 0.02 | 0.81 |
| Brand at Ferndale | 6/3/2005 | 2.16E-04 | -8.60E-04 | 0.07 | NA | 0.04 | 0.66 |
| Caterpillar | 6/3/2005 | 2.97E-05 | 1.10E-04 | 0.01 | 1.50E-03 | 0.05 | 0.78 |
| Ripley at Barclay | 6/21/2005 | 6.31E-03 | 1.88E-02 | 0.01 | 1.94E-02 | 0.58 | 2.61 |
| Swede H. Café | 6/22/2005 | NA (augered hole | filled with water | immediately) | NA | 0.58 | 2.61 |
| Wildwood | 6/23/2005 | 3.02E-04 | -1.64E-03 | 0.01 | NA | 0.62 | 2.39 |
| Normark | 6/25/2005 | 4.90E-06 | -9.46E-06 | 0.01 | NA | 1.25 | 1.62 |
| 6109 Blue Circle Drive | 6/25/2005 | 4.19E-05 | -2.31E-04 | 0.01 | NA | 1.25 | 1.62 |
| 50th (6) | 7/7/2005 | 9.46E-05 | -5.05E-04 | 0.01 | NA | 0.39 | 2.68 |
| Como | 7/7/2005 | 2.00E-03 | 0.10916 | 0.06 | 5.12E-03 | 0.39 | 2.94 |
| 50th (4) | 7/8/2005 | 9.12E-05 | -4.72E-04 | 0 | NA | 0.39 | 2.68 |
| 50th (1) | 7/8/2005 | 9.07E-05 | -4.64E-04 | 0.02 | NA | 0.39 | 2.68 |
| 50th (5) | 7/12/2005 | 2.08E-05 | 3.45E-04 | 0 | 2.63E-02 | 0 | 0.39 |
| 50th (2) | 7/12/2005 | 2.29E-06 | 1.17E-04 | 0.01 | 1.53E-03 | 0 | 0.39 |
| Swede H. Café | 7/12/2005 | 3.08E-05 | 3.81E-04 | 0.01 | 2.76E-03 | 0 | 0.39 |
| Realife Coop | 7/13/2005 | 1.22E-05 | 8.61E-04 | -0.01 | NA | 1.86 | 2.2 |
| | | | | | | | |
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## Appendix D: Specific site characteristics

### BMP #1: Caterpillar. Dry swale located at 1901 County Rd B2, Roseville.

Area = 0.06 ha
Distance to infrastructure = 10 ft
Elevation difference between practice and infrastructure = 0-2.5 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Sandy loam |
| 6-12 | Sand |
| 12-18 | Sand |
| 18-24 | Sand |
| 24-30 | Sand |
| 30-36 | No sample (gravel) |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Clay loam |
| 12-18 | Clay |
| 18-24 | Clay loam |
| 24-30 | Clay loam |
| 30-36 | Clay |

**Field-saturated hydraulic conductivity**

TI = 5.85E –04 cm/sec = .829 in/hr
PD = 1.71E –03 cm/sec = 2.42 in/hr
GP = 2.97 E –05 cm/sec = .043 in/hr

PD = 2.39E –03 cm/sec = 3.39 in/hr

### BMP #2: USBank. Infiltration basin located at 1875 County Rd B2, Roseville.

Area = 0.04 ha
Distance to infrastructure = 10 ft
Elevation difference between practice and infrastructure = 2.5-5 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | No samples taken |
| 6-12 | Ponded water |
| 12-18 | Every visit |
| 18-24 | No sample |
| 24-30 | No sample |
| 30-36 | No sample |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Clay |
| 6-12 | Clay |
| 12-18 | Clay |
| 18-24 | Clay loam |
| 24-30 | Clay loam |
| 30-36 | Clay |

**Field-saturated hydraulic conductivity**

Unable to conduct any measurements as practice had standing water during every visit.

**BMP #3: Como Park. Rainwater garden located SE of the Lexington Pkwy N and Nebraska Ave intersection, St. Paul.**

Area = 0.08 ha
Distance to infrastructure = 10 ft
Elevation difference between practice and infrastructure = 2.5-5 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Sandy loam |
| 6-12 | Sand |
| 12-18 | Sand |
| 18-24 | Coarse sand and gravel |
| 24-30 | Coarse sand and gravel |
| 30-36 | Coarse sand and gravel |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Clay loam |
| 12-18 | Sand and gravel |
| 18-24 | Sand and gravel |
| 24-30 | Sand and gravel |
| 30-36 | Sand and gravel |

**Field-saturated hydraulic conductivity**

TI: 2.31E –04 cm/sec = .327 in/hr
PD: 2.93E –03 cm/sec = 4.15 in/hr
GP: 2.00E –03 = 2.83 in/hr

TI: 1.12E –03 cm/sec = 1.59 in/hr
PD: 2.35E –02 cm/sec = 33.3 in/hr

**BMP #4: Denny's. Swale located east of Century Ave, north of I-94, in front of Denny's Restaurant, Oakdale.**

Area = 0.07 ha
Distance to infrastructure = 10 ft
Elevation difference between practice and infrastructure = 5 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Loam |
| 12-18 | Loam |
| 18-24 | Loam |
| 24-30 | Loam |
| 30-36 | No sample (too wet) |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loamy sand |
| 6-12 | Loam |
| 12-18 | Loam |
| 18-24 | Sandy loam |
| 24-30 | Sandy loam w/ gravel |
| 30-36 | No sample (gravel) |

**Field-saturated hydraulic conductivity**

Unable to conduct any measurements as practice had standing water during every visit.

## BMP #5: Pony Express. Infiltration basin located at 5970 Neal Ave, Oak Park Heights.

Area = .289 ha

Distance to infrastructure = 20 ft

Elevation difference between practice and infrastructure = ? (pond too deep)

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | No sample taken |
| 6-12 | Standing water |
| 12-18 | Every visit |
| 18-24 | No sample |
| 24-30 | No sample |
| 30-36 | No sample |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Silty clay loam |
| 6-12 | Clay loam |
| 12-18 | Clay loam |
| 18-24 | Clay loam |
| 24-30 | Clay |
| 30-36 | Clay |

**Field-saturated hydraulic conductivity**

Unable to conduct any measurements as practice had standing water during every visit.

## BMP #6: Realife Coop. Infiltration basin located at 87th St. and Nicollet Ave., Bloomington.

Area = 0.068 ha

Distance to infrastructure = >50 ft

Elevation difference between practice and infrastructure = 10 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Sandy clay loam |
| 12-18 | Sandy clay loam |
| 18-24 | Sand |
| 24-30 | Sand |
| 30-36 | Sand |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | No samples taken |
| 6-12 | Infrastructure |
| 12-18 | Is over 50 ft away |
| 18-24 | From practice |
| 24-30 | No sample |
| 30-36 | No sample |

**Field-saturated hydraulic conductivity**

TI: 2.65E –04 cm/sec = .376 in/hr

PD: 1.80E –03 cm/sec = 2.55 in/hr

GP: 1.22E –05 = .017 in/hr

## BMP #7: Wildwood Lodge. Dry swale located east of Co Rd. 13, south of Hudson Blvd., Lake Elmo.

Area = .097 ha

Distance to infrastructure = 15 ft

Elevation difference between practice and infrastructure = 5-10 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Loam |
| 12-18 | Loam w/gravel |
| 18-24 | Loam w/gravel |
| 24-30 | No sample (gravel) |
| 30-36 | No sample (gravel) |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Sandy clay loam |
| 12-18 | Sandy loam |
| 18-24 | Sandy loam |
| 24-30 | Sandy loam |
| 30-36 | Sandy loam |

**Field-saturated hydraulic conductivity**

TI: 5.16E –04 cm/sec = .732 in/hr

PD: 5.40E –04 cm/sec = .768 in/hr

GP: 3.02E –04 cm/sec = .428 in/hr

## BMP #8: Bremer. Dry swale located east of Co Rd. 13, north of Hudson Blvd, Lake Elmo.

Area = .121 ha

Distance to infrastructure = 20 ft

Elevation difference between practice and infrastructure = 3-6 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Silt loam |
| 12-18 | Silt loam |
| 18-24 | Silt loam |
| 24-30 | Silt loam |
| 30-36 | Silt loam |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Clay loam |
| 6-12 | Silty clay loam |
| 12-18 | Silt loam |
| 18-24 | Silt loam |
| 24-30 | Silt loam |
| 30-36 | Silt loam |

**Field-saturated hydraulic conductivity**

TI: 2.79E –04 cm/sec = .395 in/hr

PD: measurement taken, but no data

GP: measurement taken, negative value

## BMP #9: Normark. Dry swale located at 10395 Yellow Circle Drive, Minnetonka.

Area = .01 ha
Distance to infrastructure = 5 ft
Elevation difference between practice and infrastructure = 1-2 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Clay loam |
| 6-12 | Loam |
| 12-18 | Loam |
| 18-24 | Clay loam |
| 24-30 | Clay loam |
| 30-36 | Loam |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Clay loam |
| 6-12 | Loam |
| 12-18 | Loam |
| 18-24 | Clay loam |
| 24-30 | Clay loam |
| 30-36 | Loam |

**Field-saturated hydraulic conductivity**

TI: 7.92E –07 cm/sec = 1.12E –03 in/hr
PD: measurement attempted, but no data
GP: 4.90E –06 cm/sec = 6.96E –03 in/hr

## BMP #10: LecTec: Dry swale located at 10701 Red Circle Drive, Minnetonka.

Area = .02 ha
Distance to infrastructure = 12 ft
Elevation difference between practice and infrastructure = 1-3 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Loam w/gravel |
| 12-18 | Sandy loam |
| 18-24 | Loamy sand |
| 24-30 | Loamy sand |
| 30-36 | Sand and gravel |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Clay loam |
| 6-12 | Clay loam |
| 12-18 | Clay |
| 18-24 | Loamy sand |
| 24-30 | Loamy sand |
| 30-36 | Sand |

**Field-saturated hydraulic conductivity**

TI: 2.61E –03 cm/sec = 3.70 in/hr
PD: 2.67E –03 cm/sec = 3.79 in/hr
GP: 1.39E –05 cm/sec = 1.97E -02 in/hr

PD: 5.78E –03 cm/sec = 8.19 in/hr
PD: 8.40E –03 cm/sec = 11.9 in/hr

## BMP #11: Xerxes. Dry swale located at 10701-10999 Bren Rd E, Minnetonka.

Area = 0.02 ha
Distance to infrastructure = 12 ft
Elevation difference between practice and infrastructure = 1-3 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Loam |
| 12-18 | Sandy loam |
| 18-24 | Loam |
| 24-30 | Clay loam |
| 30-36 | Loam |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Clay loam |
| 6-12 | Clay |
| 12-18 | Clay w/gravel |
| 18-24 | Clay loam w/gravel |
| 24-30 | Clay loam w/gravel |
| 30-36 | No sample (gravel) |

**Field-saturated hydraulic conductivity**

TI: 2.54E -04 cm/sec = .360 in/hr
PD: 1.08E –03 cm/sec = 1.53 in/hr
GP: 1.64E –04 cm/sec = .232 in/hr

## BMP #12: 6109 Blue Circle Drive. Dry swale located at 6109 Blue Circle Drive, Minnetonka.

Area = .01 ha
Distance to infrastructure = 10 ft
Elevation difference between practice and infrastructure = 1-3 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Clay loam |
| 12-18 | Clay loam |
| 18-24 | Clay |
| 24-30 | Clay |
| 30-36 | Clay |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Clay loam |
| 6-12 | Clay |
| 12-18 | Clay |
| 18-24 | Clay |
| 24-30 | Clay |
| 30-36 | Clay |

**Field-saturated hydraulic conductivity**

TI: 3.31E –03 cm/sec = 4.69 in/hr
PD: 1.68E –03 cm/sec = 2.38 in/hr
PD: 6.87E –03 cm/sec = 9.74 in/hr
GP: 3.58E -07 cm/sec = 5.07E –04 in/hr
GP: 4.19E –05 cm/sec = 5.94E –02 in/hr

## BMP #13: Barclay at Gulden. Rainwater garden located at Barclay and Gulden, Maplewood.

Area = 0.02 ha
Distance to infrastructure = 10 ft
Elevation difference between practice and infrastructure = 5-10 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Loam |
| 12-18 | Loam |
| 18-24 | Clay loam |
| 24-30 | Silt loam |
| 30-36 | Silt loam |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Sandy loam |
| 6-12 | Loamy sand |
| 12-18 | Loamy sand |
| 18-24 | Sandy loam |
| 24-30 | Sandy loam |
| 30-36 | Sandy loam |

**Field-saturated hydraulic conductivity**

Unable to conduct any measurements as practice had standing water during every visit.

## BMP #14: Brand at Ferndale. Rainwater garden located at Brand and Ferndale, Maplewood.

Area = 0.02 ha
Distance to infrastructure = 10 ft
Elevation difference between practice and infrastructure = 5 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Sandy loam |
| 12-18 | Sandy loam |
| 18-24 | Sandy loam |
| 24-30 | Sandy loam |
| 30-36 | Sandy clay loam |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Clay loam |
| 12-18 | Sandy clay loam |
| 18-24 | Clay loam |
| 24-30 | Clay loam |
| 30-36 | No sample (rocks) |

**Field-saturated hydraulic conductivity**

*TI: 1.71E –03 cm/sec = 2.42 in/hr
PD: 3.68E –03 cm/sec = 5.22 in/hr

GP: 2.11E –06 cm/sec = 2.99E -03 in/hr

* = Measured using negative pressures (tensions) = -10cm and 0cm

## BMP #15: Ripley at Clarence. Rainwater garden located at Ripley and Clarence, Maplewood.

Area = 0.01 ha
Distance to infrastructure = 10 ft
Elevation difference between practice and infrastructure = 5-10 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-4 | Organic litter |
| 4-12 | Sand |
| 12-18 | Sand |
| 18-24 | Sand |
| 24-30 | Coarse sand |
| 30-36 | Sand |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Clay loam |
| 6-12 | Loamy sand |
| 12-18 | Clay |
| 18-24 | Sand |
| 24-30 | Sand |
| 30-36 | Sand |

**Field-saturated hydraulic conductivity**

TI: 6.77E –04 cm/sec = .96 in/hr
PD: 7.00E –04 = .99 in/hr

TI: 4.42E –04 cm/sec = .624 in/hr
PD: 4.89E –03 cm/sec = 6.93 in/hr
GP: 1.49E –03 cm/sec = 2.11 in/hr
GP: 2.88E –03 cm/sec = 4.08 in/hr

## BMP #16: Ferndale at Harvester. Rainwater garden located at Ferndale and Harvester, Maplewood.

Area = 0.01 ha
Distance to infrastructure = 10 ft
Elevation difference between practice and infrastructure = 2.5-5 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Coarse sandy loam |
| 6-12 | Coarse sandy clay loam |
| 12-18 | Sand |
| 18-24 | Loamy sand |
| 24-30 | Sand w/gravel |
| 30-36 | No sample (gravel) |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Clay |
| 12-18 | Clay |
| 18-24 | Clay loam |
| 24-30 | Loamy sand |
| 30-36 | Sand and gravel |

**Field-saturated hydraulic conductivity**

TI: 9.46E –04 cm/sec = 1.34 in/hr
PD: 3.41E –03 cm/sec = 4.82 in/hr
GP: 1.14E –05 cm/sec = 1.62E -02 in/hr

## BMP #17: Ripley at Barclay. Rainwater garden located at Ripley and Barclay, Maplewood.

Area = 0.06 ha
Distance to infrastructure = 20 ft
Elevation difference between practice and infrastructure = 5-10 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loamy sand |
| 6-12 | Sandy loam |
| 12-18 | Loam |
| 18-24 | Clay loam |
| 24-30 | Sandy clay loam |
| 30-36 | Loamy sand |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Clay loam |
| 12-18 | Loam |
| 18-24 | Clay loam |
| 24-30 | Gravel |
| 30-36 | No sample |

**Field-saturated hydraulic conductivity**

TI: 1.14E –03 cm/sec = 1.61 in/hr
PD: 1.15E –03 cm/sec = 1.63 in/hr

TI: 2.56E –04 cm/sec = .363 in/hr
PD: 4.34E –04 cm/sec = .618 in/hr
PD: 3.58E –03 cm/sec = 5.08 in/hr
GP: 6.31E –03 cm/sec = 8.95 in/hr

## BMP #18: 50th Street (1). Rainwater garden located along 50th Street, Stillwater. (1st garden east of Linden Trl)

Area = 0.03 ha
Distance to infrastructure = 18 ft
Elevation difference between practice and infrastructure = 5-10 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Clay loam |
| 6-12 | Loam |
| 12-18 | Loam |
| 18-24 | Loam |
| 24-30 | Loam |
| 30-36 | No sample (too wet) |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Silty clay loam |
| 12-18 | Silty clay loam |
| 18-24 | Silty clay loam |
| 24-30 | Silty clay loam |
| 30-36 | Silt loam |

**Field-saturated hydraulic conductivity**

TI: 2.18E –03 cm/sec = 3.09 in/hr
PD: measurement attempted, but no data
GP: 9.07E –05 cm/sec = .128 in/hr

## BMP #19: 50th Street (2). Rainwater garden located along 50th Street, Stillwater. (2nd garden east of Linden Trl)

Area = 0.04 ha
Distance to infrastructure = 20 ft
Elevation difference between practice and infrastructure = 5-10 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Silt loam |
| 6-12 | Silt loam |
| 12-18 | Silt loam |
| 18-24 | Silt loam |
| 24-30 | Silt loam |
| 30-36 | Silt loam |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Silt loam |
| 6-12 | Loam w/gravel |
| 12-18 | Loam w/gravel |
| 18-24 | Loam w/gravel |
| 24-30 | Silty clay loam |
| 30-36 | Silt loam |

**Field-saturated hydraulic conductivity**
TI = 5.03E –05 cm/sec = 7.13E –02 in/hr
PD: measurement attempted, but no data
GP: 2.29E –06 cm/sec = 3.25E –03 in/hr

## BMP #20: 50th Street (3). Rainwater garden located along 50th Street, Stillwater. (3rd garden east of Linden Trl)

Area = 0.02 ha
Distance to infrastructure = 21 ft
Elevation difference between practice and infrastructure = 5-10 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Silt loam |
| 6-12 | Silt loam |
| 12-18 | Silt loam |
| 18-24 | Silt loam |
| 24-30 | Loam |
| 30-36 | Silt loam |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Sandy loam |
| 12-18 | Silt loam |
| 18-24 | Silt loam |
| 24-30 | Silt loam |
| 30-36 | Silt loam |

**Field-saturated hydraulic conductivity**
Unable to conduct any measurements as practice had standing water during every visit.

## BMP #21: 50th Street (4). Rainwater garden located along 50th Street, Stillwater. (NE corner of 50th and Linden Trl)

Area = 0.01 ha
Distance to infrastructure = 31 ft
Elevation difference between practice and infrastructure = 2.5-5 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Sandy loam |
| 12-18 | Sandy loam |
| 18-24 | Sandy loam |
| 24-30 | No sample (wet) |
| 30-36 | No sample (wet) |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Silt loam |
| 6-12 | Silt loam |
| 12-18 | Silt loam |
| 18-24 | Silt loam |
| 24-30 | Silt loam |
| 30-36 | Silt loam |

**Field-saturated hydraulic conductivity**
TI: 1.33E –03 cm/sec = 1.89 in/hr
PD: 3.82E –04 cm/sec = .541 in/hr
GP: 9.12E –05 cm/sec = .129 in/hr

## BMP #22: 50th Street (5). Rainwater garden located along 50th Street, Stillwater. (1st garden west of Linden Trl)

Area = 0.02 ha
Distance to infrastructure = 18 ft
Elevation difference between practice and infrastructure = 2.5-5 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Silt loam |
| 6-12 | Silt loam |
| 12-18 | Silt loam |
| 18-24 | Silt loam |
| 24-30 | Loam |
| 30-36 | Loam |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Loamy sand |
| 12-18 | Sandy loam |
| 18-24 | Sandy loam |
| 24-30 | Sandy loam |
| 30-36 | Clay loam |

**Field-saturated hydraulic conductivity**
TI: 2.58E –04 cm/sec = .366 in/hr
PD: measurement attempted, but no data
GP: 2.08E –05 cm/sec = .025 in/hr

**BMP #23: 50th Street (6). Rainwater garden located along 50th Street, Stillwater. (2nd garden west of Linden Trl)**

Area = 0.04 ha

Distance to infrastructure = 25 ft

Elevation difference between practice and infrastructure = 5-10 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Loam |
| 12-18 | Sand |
| 18-24 | Sand |
| 24-30 | Loamy sand |
| 30-36 | Loamy sand |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Loam |
| 12-18 | Loam |
| 18-24 | Loam |
| 24-30 | Loam |
| 30-36 | Loam |

**Field-saturated hydraulic conductivity**

TI: 6.43E –04 cm/sec = .912 in/hr

PD: 2.06E –03 cm/sec = 2.92 in/hr

GP: 9.46E –05 cm/sec = .134 in/hr

**BMP #24: Swede Hollow Café. Rainwater garden located on the NW corner of 7th St. E and Bates Ave, St. Paul.**

Area = 0.014 ha

Distance to infrastructure = 20 ft

Elevation difference between practice and infrastructure = 2.5-5 ft

Soil texture within practice

| Depth | Texture |
|---|---|
| 0-6 | Loamy sand |
| 6-12 | Loamy sand |
| 12-18 | Loamy sand |
| 18-24 | Loamy sand |
| 24-30 | Loamy sand |
| 30-36 | Loamy sand |

Soil texture between road and practice

| Depth | Texture |
|---|---|
| 0-6 | Loam |
| 6-12 | Loam |
| 12-18 | Sandy loam |
| 18-24 | Sand and gravel |
| 24-30 | No sample (gravel) |
| 30-36 | No sample (gravel) |

**Field-saturated hydraulic conductivity**

TI: 7.15E –04 cm/sec = 1.01 in/hr

PD: 6.91E –04 cm/sec = .978 in/hr

PD: 2.56E –04 cm/sec = .362 in/hr

GP: 3.08E –05 cm/sec = .044 in/hr

# *Task 5. Effectiveness Assessment of Alternative Practices*

Compare existing alternative stormwater facilities to design recommendations

Samuel Johnson
Graduate Research Assistant

John L. Nieber
Professor

Department of Biosystems and Agricultural Engineering
University of Minnesota

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## Introduction

This report is a summary outlining the degree to which each site meets design recommendations for such a practice. Where available, specific design plans were used from the sites and compared with field measurements. When the design plans were not available to us, general design recommendations for the type of practice were used in comparison with field measurements. The practices were labeled as infiltration basins, swales, or rain gardens, based on interviews conducted with persons responsible for the design and/or maintenance of the sites. Information gathered from these interviews can be found in a prior report (Report for Task 3). Parameters measured and methods used are discussed in a Task 4 summary report. Field measurement data, separated by site and method can be found in the Appendices (A-D) of that report.

Calculations of the stormwater capacity of the various practice sites assessed are summarized in Appendix A of this report. Photographs of the sites considered to not be functioning per their intended purposes are also attached (Appendix B).

## Results

BMP #1: Caterpillar. This dry swale accepts runoff from the Caterpillar Company parking lot and extensive “go-down” roofs (1.96 acres). Runoff is conveyed into the swale from the parking lot area via curb-less sections of the lot. The swale was designed for safe water conveyance as the main consideration, with some infiltration, as there is a grated outlet at a lower point in the swale. The swale will overflow at an elevation of 964 ft to a drainage ditch north of the site that flows to an in-place storm sewer of West County Rd B2 in Roseville.

Carl Almer of the Rice Creek Watershed District (RCWD) and Emmons and Olivier Resources (EOR) was interviewed regarding this practice, as he was involved with the design of the swale. He noted that there was no review of soil borings taken before construction, which led to maintenance hassles due to accumulation of sediment from the ponding of water.

However, no standing water was witnessed over many visits to the site, though several visits followed soon after rain events (up to 2” over previous five days). Also, there was no evidence of significant erosion or sedimentation in the swale and grass cover was well established along most of the swale. Some areas along the slopes next to the outlets showed less than 100% grass cover. Soil textures in the swale ranged from sandy loam to sand and field-saturated hydraulic conductivities ($K_{f_s}$) ranged from 0.83 in/hr to 3.4 in/hr with the Philip-Dunne (PD) and Tension Infiltrometer (TI), respectively.

This practice appears to be functioning per its intended purpose. Infiltration rates associated with the swale are high enough to infiltrate all the water from a rainfall event producing 1” of runoff depth across the contributing area in less than 4 hours. The Caterpillar Company parking lot adjacent to the swale does not seem to be negatively affected by the presence of the practice. Soil textures between the road and practice range from loam in the upper 6" to clay and clay loam beneath.

BMP #2: USBank. This site consists of two adjacent infiltration basins located east of the bank parking lot. The large basin is located adjacent to the infrastructure and was chosen as a study site for this project. This basin accepts water from a 1.25-acre watershed, 0.85 acres of which are impervious, via curb weirs. It was designed to treat the 2.5 in. rain event and overflows to the second basin via a connecting 12-inch PVC pipe. A main outlet located at a slightly higher elevation directs further over-flow from the first basin to a municipal drainage network.

Carl Almer of RCWD and EOR was involved with the design of this practice. He feels that the practice is not functioning per its intended purpose as the basin consists of a nearly impermeable bottom. Almer feels that this is due to the fact that no test borings were taken prior to construction.

We were unable to take soil samples or infiltration measurements within the basin, as there was standing water during every visit to the site (Appendix B, Figure 1). This practice is not functioning per its intended purpose, due to the nearly impermeable bottom. There is little to no infiltration occurring in the basin, as the water level was similar over each visit, regardless of prior rain events.

There is likely little impact on the adjacent infrastructure from the practice itself, due to the nearly impermeable bottom and heavy soils between the practice and the infrastructure. However, there is significant erosion along the rip-rap-stabilized curb weirs from the bank parking lot and the service road north of the basin. Gully erosion and headwall retreat from runoff to the basin has left an open space under the parking lot beneath the curb weir into the basin, which will lead to eventual failure of the pavement (Appendix B, Figure 2).

BMP #3: Como Park. This rain garden accepts runoff from a 3.5-acre watershed. Runoff enters the garden on the west end from a pipe that sends water from the steep-topography above the basin (Nebraska Ave). The garden consists of two separate sections, which are separated by a higher elevation "dyke" near the middle of the practice. Measurements were taken in the west portion where the water enters; as Terry Noonan of the Capitol Region Watershed District (CRWD) indicated that runoff has never flowed over the dyke into the second portion of the rain garden. Previous monitoring of the garden has indicated an infiltration rate of about 5 in/hr.

Soil textures within the garden ranged from sandy loam on the surface to coarse sand and gravel below. $K_{f_s}$ values ranged from 0.33 in/hr to 33.3 in/hr from measurements taken with the PD and TI. The highest value (33.3 in/hr) was measured using a PD and was much larger than other measurements, demonstrating the variability of $K_{f_s}$. This practice is functioning per its intended purpose, as it would take about an hour to infiltrate the water from practice capacity. Also, the water has never overflowed into the second portion of the basin, indicating a more than sufficient infiltration capacity of the site. There were no signs of erosion, sedimentation, or ponded water over many visits to the site, and the vegetation was well established.

The practice is placed close to the road in distance (10ft) and elevation difference (2.5-5ft) and consists of sandy soils within the practice and between the practice and the infrastructure. The effect of the garden on the adjacent infrastructure (Lexington Pkwy) was examined, and found to not have an impact (Task 6).

<u>BMP #4: Denny's</u>. This site consists of a swale "system" running along the east side of Century Ave. The system is separated into three distinct sections (Appendix B, Figure 3). The north section functions as a wet swale, and accepts water from the west side of Century Ave, via storm sewers, and from the south portion (wet swale) upon overflow. Between the north and south wet sections is a grassed section.

Cliff Aichinger was interviewed regarding the swale along Century Ave, as he is familiar with the practice. He noted that the swale seems to be functioning per its intended purpose, although it probably isn't helping with the removal of particulate material. The swale has to be rebuilt every 4 to 5 years with costs greater then $5000. Aichinger feels that maintenance costs may be higher than a vegetated ditch, but the higher costs are not a hindrance.

The grassed swale section was chosen for conducting field measurements since the north and south "wet swales" were assumed to be permanently saturated. Field visits confirmed the permanent saturation status of those swales. The grass section consists of loam throughout the soil profile, but we were unable to conduct any infiltration measurements. The grass section was saturated during every visit, even after little previous rainfall (Appendix B, Figure 3). The grass in this section was not well established due to this saturation. This practice does not negatively affect the adjacent infrastructure, as there appears to be little infiltration.

It is difficult to determine if this practice is effective, as we do not know what the design plans intended. There is little infiltration occurring, even in the grassed portion of the swale. However, if it is assumed that this swale was designed with runoff rate control and safe water conveyance as the primary objective, we judge that it is functioning per its intended purpose.

<u>BMP #5: Pony Express</u>. This infiltration basin accepts runoff from a 1.07-acre contributing area, most of which appears to be impervious. The bottom of the basin is at an elevation of 928 ft and will overflow at 943 ft. Karen Kill of the Washington Conservation District (WCD) was interviewed regarding this basin. She noted that "as far as she knows," this basin is functioning per its intended purpose. The basin was designed to "store and release runoff from a 100-year storm event without flooding the adjacent buildings."

We were unable to conduct field measurements of infiltration rates or soil textures, as the basin was permanently ponded over several visits. Although exact measurements were not taken, the water elevation in the basin appeared to decrease slightly when visited after drier periods. There was not enough of a drop in water elevation to conclude that there is much infiltration occurring within the basin. However, because the water level dropped somewhat, we cannot conclude that the practice is not functioning per its intended purpose, which is essentially as a wet infiltration basin. Soil textures between the practice and the road ranged from clay loam to clay. These fine-textured soils combined with little infiltration suggest that the practice has no affect on the adjacent infrastructure. Pavement quality index (PQI) measurements confirmed this (Task 6).

BMP #6: Realife Coop. This infiltration basin was designed to provide runoff rate control and volume reduction through infiltration, while collecting sediment and debris. Scott Anderson from the city of Bloomington noted that the basin is operating exactly as it was designed to. The basin accepts runoff from a 1.8-acre drainage area, which includes the Realife apartment complex, other buildings, and a large parking lot.

Ponded water was observed during two visits to the site in the middle of June 2005, after considerable precipitation during the previous two weeks. No standing water was witnessed during later visits after less rain before visits. Soils within the basin consisted of loam to sandy clay loam in the upper 18” with sand below. $K_{f_s}$ values ranged from 0.376 in/hr with the TI to 2.55 in/hr with the PD.

This practice appears to be functioning per its intended purpose, as it would take just over 7 hours to infiltrate all the water from a rain event that produces 1” runoff depth across the contributing area. Runoff from this rain event would only fill the basin to 64% of its storage volume. The water would be completely infiltrated from an event that fills the practice to capacity in less than 11.5 hours. Vegetation is well established in the basin and there were no signs of erosion. There was some sedimentation near the inlet. This basin does not probably impact the adjacent infrastructure as it is over 50ft away.

BMP #7: Wildwood Lodge. This site consists of a grassed swale sloping south to north along County Rd 13 in Lake Elmo. There is a grated outlet near the bottom of the swale and was likely designed for safe water conveyance as the primary objective with some infiltration.

Soils within the swale are loam, with some gravel at12” and deeper. Standing water was witnessed after considerable precipitation (4” over previous two weeks). Visits after moderate precipitation (1” over previous two weeks) showed no standing water. $K_{f_s}$ values range from 0.732 in/hr with the TI to 0.768 in/hr with the PD. This practice appears to be functioning per its intended purpose, although there are areas in the bottom of the basin without 100% grass cover. Also, there are some signs of sedimentation along the basin and signs of erosion near the outlet. It is unlikely that this practice affects the adjacent infrastructure as it is set low in relation to the road (5-10ft difference).

BMP #8: Bremer Bank. This site consists of a vegetated swale with check dams. About half of a business building and parking lot drains to the north and west to the swale, while the other half drains south to a pond. There is little additional drainage to the swale, except for some direct drainage from the farm field to the north. The swale and check dams slope to the west where water from the swale enters a stormwater pond. The swale was designed to slow and control runoff rate and promote some infiltration. Some maintenance work has been required to improve vegetation and control erosion near the check dams.

There is a loam cap in the swale, with silt loam beneath. $K_{f_s}$ values were 0.395 in/hr with the TI. Field measurements provided no data with the PD. A large volume of water appears to flow through the swale and standing water and erosion was witnessed near the check dams over several visits. The practice seems to be functioning per its intended purpose, as the vegetated swale and rock check dams slow runoff and some infiltration is occurring. PQI measurements conducted at this site demonstrated that there is no impact to the infrastructure from this practice. Soils between the practice and the road range from silt loam to silty clay loam.

BMP #9: Normark. This swale accepts runoff from part of Yellow Circle Drive and Bren Road via curb-less roads. There is a grated outlet near the lower elevation of the swale and it was designed for runoff rate control and some infiltration. No standing water was observed in the grassed section of the swale, although there was permanently standing water at the bottom of the swale (lower than the outlet) with well-established cattails. During a visit in the middle of June 2005, after considerable rainfall (2" over previous five days), the water had overflowed the bottom, wet portion of the swale and was ponded in the road.

Soils within the swale and between the practice and the road range from loam to clay loam in texture. $K_{f_s}$ values ranged from 0.0012 in/hr with the TI to .007 in/hr with the GP. Field measurements provided no data with the PD as the soil was compacted and infiltration was very slow. Slightly higher values with the GP indicate the compaction of the upper layer of soil.

This practice seems to be functioning per its intended use to a certain point. However, after a large amount of rain, the ponding of water on the road demonstrates that the swale may not be large enough to handle the size of the contributing area. Also, the outlet maybe should have been located further down the slope of the swale. Sedimentation and erosion was witnessed along the edge of the curb-less roads where the water flowed into the swale. Very slow infiltration rates demonstrate that the practice essentially just promotes runoff rate control and safe water conveyance through the grassed swale. PQI measurements taken demonstrated that the practice has no impact on the infrastructure.

BMP #10: LecTec. This grassed swale accepts runoff from Red Circle Drive and adjacent parking lots. The swale was designed to control runoff rates with some infiltration. There is a grated outlet at the low point of the swale. There was no standing water in the swale during any visits. There is some sign of sedimentation and the grass cover isn't 100% established in some areas in the bottom of the swale. This is likely due to the fact that the swale and adjacent road have fairly steep slopes and a large volume of water flows through the swale during rain events.

Soils in the swale range from loam to sand, with some gravel present throughout the profile. $K_{f_s}$ values ranged from 3.70 in/hr with the TI and 3.79 in/hr to 11.9 in/hr with the PD. This practice is functioning per its intended purpose to some extent, as the grassed swale slows runoff and infiltration is occurring. However, while the $K_{f_s}$ values indicate potential for high infiltration rates, it appears that the water flows down the steep slope too quickly for much infiltration to occur. A couple of small check dams could slow the water enough during a rain event to promote more infiltration of the water. PQI measurements taken demonstrated that the practice has no impact on the infrastructure. Soil texture between the practice and the road ranges from clay and clay loam in the upper 18" to sand and loamy sand between 18–36".

BMP #11: Xerxes. This swale accepts runoff from Bren Road and the Xerxes Corporation parking lots via curb-less roads. The swale was designed to control runoff rates with some infiltration. There is a grated outlet near the low point of the swale. There was no standing water in the swale during any visits. There is some sign of sedimentation and the grass cover isn't 100% established in some areas in the bottom of the swale. This is likely due to the fact that the swale and adjacent road have fairly steep slopes and a large volume of water flows through the swale during rain events.

Soils in the swale range from sandy loam to clay loam. $K_{f_s}$ values ranged from 0.36 in/hr with the TI to 1.53 in/hr with the PD. This practice is functioning per its intended purpose, slowing the runoff and promoting infiltration. PQI measurements taken demonstrate that the practice has little to no impact on the adjacent road. Soil texture between the road and the practice ranges from clay to clay loam with gravel throughout the profile.

BMP #12: 6109 Blue Circle Drive. This swale accepts runoff from Blue Circle Drive and adjacent business parking lots via curb-less roads. The swale was designed to control runoff rates with some infiltration. There is a grated outlet near the low point of the swale. There was no standing water in the swale during any visits. There is no sign of sedimentation and the grass cover is 100% established. Unlike the other swales in this Minnetonka business park (BMPs 9-11), this swale has little slope and a basin-like shape. Because of this, it appears that this swale is the most effective of the four in this business park at water infiltration.

Soil textures in the practice consist of a loam cap, underlain by clay loam to clay soils. $K_{f_s}$ values range from 4.69 in/hr with the TI and 2.38 in/hr to 9.74 in/hr with the PD. $K_{f_s}$ values taken with the GP range from 0.00051 in/hr to 0.059 in/hr. Lower Kfs values from the GP are representative of the finer-textured soils under the loam cap. This swale is functioning per its intended purpose, as high Kfs values combined with a basin-like shape contribute to high infiltration rates and runoff rate control. PQI measurements taken demonstrate that the practice has little to no impact on the adjacent road. Soil textures between the road and the practice consist of clay with a clay loam cap.

BMP #13: Barclay at Gulden. This rain garden accepts water from a 6.18-acre watershed via curb-less streets and stormwater inlet. Peak storage of the garden is 435 $ft^3$ at an elevation of 890 ft. The garden was designed to handle ½ - 1" rain events. Also, the garden was designed to infiltrate all the water within 24 hours of the last rain event. Standing water was observed at the site during every visit, regardless of the prior rainfall amount (Appendix B, Figure 4). Vegetation is not well established in the garden due to these saturated conditions.

This practice is not functioning per its intended purpose, as a rain garden should not have permanently standing water. Soil textures in the practice range from loam to clay loam, with the upper 18" of the profile being loam, indicating that another factor contributes to the slow infiltration. Further measurements should be conducted to determine if there is a high water table in this area, or if some other factor such as compaction or sedimentation causes the low infiltration. It is unlikely that this garden impacts the adjacent infrastructure, as there is little water infiltration. PQI measurements taken confirm this. Soil textures between the road and the practice range from loamy sand to sandy loam.

BMP #14: Brand at Ferndale. This rain garden accepts runoff from a 1.26-acre watershed via a curb-less street. Two roads slope to the rain garden, intersecting at their lowest point. The garden has a storage volume of 2288 $ft^3$ and a surface area of 2153 $ft^2$. The garden was designed to handle ½ - 1" rain events. Also, the garden was designed to infiltrate all the water within 24 hours of the last rain event. Standing water was observed in the garden during visits where previous ten-day precipitation was greater than 4". Vegetation in the garden is well established.

Soils within the practice consist primarily of sandy loam with a loam cap. $K_{f_s}$ values range from 2.42 in/hr with the TI to 5.22 in/hr with the PD. This practice is functioning per its intended purpose, as $K_{f_s}$ values are high enough for sufficient infiltration rates. It would take 1.68 hours for the garden to infiltrate all the water from a rain event that produces ¼" runoff depth across the contributing area. All the water from a rain event that produces enough runoff to fill the garden to capacity would infiltrate completely within 3.36 hrs. Soil textures between the road and the practice range from loam to clay loam.

BMP #15: Ripley at Clarence. This rain garden accepts runoff from an 8.74-acre watershed via a curb-less street and stormwater inlet. The garden has a storage volume of 1904 $ft^3$ and a surface area of 1326 $ft^2$. The garden was designed to handle ½ - 1" rain events. Also, the garden was designed to infiltrate all the water within 24 hours of the last rain event. There was no standing water present during any visit. Vegetation in the garden is well established.

Soil textures in the practice consist of sand, with 4" of organic litter on top. $K_{f_s}$ values range from 0.624 in/hr to 0.96 in/hr with the TI and 0.99 in/hr to 6.93 in/hr with the PD. This practice is functioning per its intended purpose, as infiltration rates are sufficiently high to infiltrate all the water from the garden's capacity within 24 hours. It would take 7.25 hours to infiltrate all the water from the garden when starting at capacity (1904 $ft^3$).

<u>BMP #16: Ferndale at Harvester</u>. This rain garden is the smallest practice among our study sites. We were unable to find any information regarding the design of the practice. It appears to function primarily as a BMP to accept direct runoff from the adjacent street and adjacent lawn. Similar to other rain gardens in the area, it is assumed that it was designed to handle the ½" –1" rain event, and completely infiltrate all the water within 24 hours of the last event. There was no standing water present during any of the visits over the last year. Vegetation in the garden is well established.

Soil textures within the practice range from sand and gravel to sandy clay loam. $K_{f_s}$ values range from 1.34 in/hr with the TI to 4.82 in/hr with the PD. This practice is functioning per its intended purpose, as no standing water was observed, and $K_{f_s}$ values appear high enough for infiltration rates sufficient to drain a small contributing area. This practice probably has little to no impact on the adjacent road due to the small volume of water infiltration; PQI measurements confirm this.

<u>BMP #17: Ripley at Barclay</u>. This rain garden accepts runoff from a 26.16-acre watershed via a curb-less street and stormwater inlet. The garden has a storage volume of 3830 $ft^3$ and a surface area of 4032 $ft^2$. The garden was designed to handle ½ - 1" rain events. Also, the garden was designed to infiltrate all the water within 24 hours of the last rain event. The garden overflows to the adjacent Wakefield Lake. There was no standing water present during any visit in the majority of the garden, although the end furthest away from the inlet seemed to function as a wet infiltration basin, with well-established cattails. This end is separated from the main rain garden by a higher elevation "dyke." Vegetation in the main section of the rain garden is well established.

Soil textures in the practice consist of loamy sand to clay loam. $K_{f_s}$ values range from 0.363 in/hr to 1.61 in/hr with the TI and .618 in/hr to 5.08 in/hr with the PD. This practice is functioning per its intended purpose, as infiltration rates are sufficiently high to infiltrate all the water from the garden's capacity within 24 hours. It would take 6.13 hours to infiltrate all the water from the garden when starting at capacity (3830 cf).

*<u>*NOTE: BMP #18-23: 50$^{th}$ Street Gardens</u>. There is a series of six rain gardens along 50$^{th}$ Street in Stillwater. Design information regarding the gardens was limited. For these six gardens it is assumed that they were designed similar to other rain gardens. Thus, those gardens that had standing water more than 72 hours after the last rain event are considered to not be functioning per intended use. We were unable to find contributing areas for these gardens. Tom Prew of Toltz, King, Duvall, Anderson, and Associates (TKDA) was interviewed regarding these gardens, as he was the lead engineer in their design. Prew indicated that some of the gardens are functioning per their intended uses, and some are not. He noted that this is because of the variable geology in the area. Some gardens have frequently ponded water in them due to the*

*underlying soils, while others had sufficient infiltration rates for water removal. He noted that they must "take what they get," in regards to the variability in soils. And although they might not meet rain garden design requirements exactly, he still feels they are serving an important purpose in runoff rate control and stormwater treatment.*

*There is likely some error involved with the* $K_{f_s}$ *values obtained for BMPs #18, 19, and 22 (50th Street (1)(2)(5)). Fine-textured soils in these gardens caused the water to pond and some overland flow through the sand contact material was observed. This was because two positive pressure heads were used to conduct the experiments. After ruther investigation it was fond that it would have been possible to use slightly negative pressures (tensions) when working with these soils and still find* $K_{f_s}$ *values. The tensions would not have allowed the water to flow out of the side of the contact material. However, since discovering this possible approach the gardens have had standing water in them, thus not allowing further measurements to be made prior to the due date for this report. TI measurements were therefore not included in the report for Task 4 (Appendix B) for the sites at 50th St (1), 50th St (2), and 50th St (5). Also, PD measurements did not yield any data at these sites. For these three gardens,* $K_{f_s}$ *values from the GP method, which was done correctly, were reported. However, these values are representative of the soil beneath the surface (augered hole = 15cm) so they are not exactly representative of the infiltration capacity of the sites.*

PQI measurements taken along 50th Street demonstrated that the gardens have no impact on the adjacent infrastructure (50th Street) (Task 6). Soil textures between the road and each practice are reported in Appendix D of the report for Task 4.

<u>BMP 18: 50th Street (1)</u>. This rain garden had standing water during visits where dry conditions had persisted for more than 72 hours, so it is considered to not be functioning per its intended use (Appendix B, Figure 5). There was no vegetation established in the garden. Unsaturated conditions were observed after a week without a rain event, and the GP yielded $K_{f_s}$ values of 0.128 in/hr (Appendix B, Figure 6). Soil textures in the garden consist of loam overlain by a clay loam cap.

<u>BMP 19: 50th Street (2)</u>. This rain garden had standing water during visits where dry conditions had persisted for more than 72 hours, so it is considered to not be functioning per its intended use (Appendix B, Figure 7). There was fair vegetation established in the garden. Unsaturated conditions were observed after a week without a rain event, and the GP yielded $K_{f_s}$ values of 0.00325 in/hr (Appendix B, Figure 8). Soil textures in the garden consist of silt loam.

<u>BMP 20: 50th Street (3)</u>. This rain garden had standing water during every visit, so it is considered to not be functioning per its intended use (Appendix B, Figures 9, 10). There was no vegetation established in the garden. Soil textures in the garden consist of silt loam.

BMP 21: $50^{th}$ Street (4). This rain garden had standing water after 3" of rain over the previous five days. Unsaturated conditions were observed thereafter, even after moderate rainfall (0.3" over previous five days). $K_{f_s}$ data ranged from 1.89 in/hr with the TI to 0.541 in/hr with the PD. This practice appears to be functioning per its intended purpose. The vegetation is well established. Soil textures within the practice range from sandy loam to loam.

BMP 22: $50^{th}$ Street (5). This rain garden had standing water during visits where dry conditions had persisted for more than 72 hours, so it is considered to not be functioning per its intended use (Appendix B, Figure 11). There was very little vegetation establishment in the garden. Unsaturated conditions were observed after a week without a rain event, and the GP yielded $K_{f_s}$ values of 0.025 in/hr (Appendix B, Figure 12). Soil textures in the garden consist primarily of silt loam.

BMP 23: $50^{th}$ Street (6). No standing water was observed in this rain garden during any of the visits, even after considerable rain events prior to the visit (3" over previous five days). $K_{f_s}$ data ranged from 0.912 in/hr with the TI to 2.92 in/hr with the PD. This practice appears to be functioning per its intended purpose. The vegetation is well established. Soil textures within the practice range from sand to loam.

BMP 24: Swede Hollow Café. This infiltration basin was designed to "function as a stormwater purification and infiltration for storm events of 1.5" or less." It was also designed to serve as a stormwater purification interpretive element and a neighborhood amenity. We were unable to find information on the exact size of the contributing area, but it takes low flow from one catch basin on North Street. It should also be noted that some sources refer to this practice as an infiltration basin, while others call it a rain garden.

Soil textures in the practice consist of loamy sand. $K_{f_s}$ values range from 1.01 in/hr with the TI and 0.362 in/hr to 0.978 in/hr with the PD. $K_{f_s}$ values taken with the GP were smaller (0.044 in/hr) and several other visits we were unable to get data using the GP. This may signify the presence of a high water table. This practice appears to be functioning per its intended use, as no standing water was ever witnessed and the vegetation is well established.

**Appendix A: Infiltration Capacity of Sites**

**Ripley at Clarence**
Rain garden located at Ripley and Clarence, Maplewood.

Storage volume = 1904 cf
Contributing area = 8.74 acres
Surface area = 1326 $ft^2$

Average $K_{fs}$ value (PD and TI) = 1.68E –03 cm/sec = .198 ft/hr
Infiltration rate = 262.5 $ft^3$/hr

¼" runoff depth = 7932 cf of water
Practice not large enough to hold this amount of water
Assuming excess will overflow,
it would take 7.25 hours to infiltrate 1904 cf of water (capacity)

**Ripley at Barclay**
Rain garden located at Ripley and Barclay, Maplewood.

Storage volume = 3830 cf
Contributing area = 26.16 acres
Surface area = 4032 $ft^2$

Average $K_{fs}$ value (PD and TI) = 1.31E –03 cm/sec = .155 ft/hr
Infiltration rate = 625 $ft^3$/hr

¼" runoff depth = 23,740 cf of water
Practice not large enough to hold this amount of water
Assuming excess will overflow,
it would take 6.13 hours to infiltrate 3830 cf of water (capacity)

**Brand at Ferndale**
Rain garden located at Brand and Ferndale, Maplewood.
Storage volume = 2288 cf
Contributing area = 1.26 acres
Surface area = 2153 $ft^2$

Average $K_{fs}$ value (PD and TI) = 2.68E -03 cm/sec = .316 ft/hr
Infiltration rate = 680 $ft^3$/hr

¼" runoff depth = 1143 cf of water
It would take 1.68 hours to infiltrate 1143 cf of water

Practice capacity = 2288 cf of water

It would take 3.36 hrs to infiltrate 2288 cf of water (capacity)

## Caterpillar

Dry swale located at 1901 County Rd B2, Roseville

Storage volume = 21,780 cf
Contributing area = 1.96 acres
Surface area = 10,794 $ft^2$

Average $K_{fs}$ value (PD and TI) = 1.56E –03 cm/sec = .184 ft/hr
Infiltration rate = 1991 $ft^3$/hr

¼" runoff depth = 1779 cf of water
It would take 0.894 hours to infiltrate 1779 cf of water

1" runoff depth = 7115 cf of water
it would take 3.57 hrs to infiltrate 7115 cf of water

Practice capacity = 21,780 cf of water
It would take 10.9 hrs to infiltrate 21,780 cf of water (capacity)

## Como Park

Rain garden located at Nebraska and Lexington Pkwy, St Paul

Storage volume = 7592 cf
Contributing area = 3.5 acres
Surface area = 8611 $ft^2$

Average $K_{fs}$ value (PD and TI) = 6.95E -03 cm/sec = .8203 ft/hr
Infiltration rate = 7064 $ft^3$/hr

¼" runoff depth = 3176 cf of water
It would take .450 hours to infiltrate 3176 cf of water

Practice capacity = 7592 cf of water
It would take 1.07 hrs to infiltrate 7592 cf of water (capacity)

**Realife Coop**

Infiltration basin located at 87th St and Nicollet Ave, Bloomington

Storage volume = 10,223 cf
Contributing area = 1.8 acres
Surface area = 7320 $ft^2$

Average $K_{fs}$ value (PD and TI) = 1.03E –03 cm/sec = .122 ft/hr
Infiltration rate = 892 $ft^3$/hr

¼" runoff depth = 1634 cf of water
It would take 1.83 hours to infiltrate 1634 cf of water

1" runoff depth = 6534 cf of water
It would take 7.33 hrs to infiltrate 6534 cf of water

Practice capacity = 10,223 cf of water
It would take 11.46 hrs to infiltrate 10,223 cf of water (capacity)

## Appendix B: Pictures of practices not functioning per intended use

**Figure 1:** USBank infiltration basin.
Photo taken 6/22/05 (Pre-10-day precip. >2")

**Figure 2:** Erosion at USBank.
Taken 6/22/05 (Pre-10-day precip. >2")

**Figure 3:** Denny's swale.
Photo taken 6/15/05 (Pre-10-day precip. >4")

**Figure 4:** Rain garden at Barclay and Gulden
Taken 6/15/05 (Pre-10-day precip. >4")

**Figure 5:** 50th Street (1). Rain garden.
Photo taken 6/15/05 (Pre-10-day precip. >4")

**Figure 6:** 50th Street (1). Rain garden.
Taken 7/12/05 (Pre-10-day precip.< 1/2" )


**Figure 7:** 50th Street (2). Rain garden
Photo taken 6/15/05 (Pre-10-day precip. >4")


**Figure 8:** 50th Street (2). Rain garden
Taken 7/12/05 (Pre-10-day precip.< 1/2" )


**Figure 9:** 50th Street (3). Rain garden
Photo taken 6/15/05 (Pre-10-day precip. >4")


**Figure 10:** 50th Street (3). Rain garden
Taken 7/12/05 (Pre-10-day precip.< 1/2" )


**Figure 11:** 50th Street (5). Rain garden
Photo taken 6/15/05 (Pre-10-day precip. >4")


**Figure 12:** 50th Street (5). Rain garden
Taken 7/12/05 (Pre-10-day precip.< 1/2" )

# *Task 6. Evaluation of Physical Impact of Alternative Practice on Pavement*

**Evaluate the potential impact of existing alternative stormwater control facilities on roadway infrastructure**


Eric Otto
Graduate Research Assistant

Samuel Johnson
Graduate Research Assistant

John L. Nieber
Professor

Department of Biosystems and Agricultural Engineering
University of Minnesota


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Project Sponsor
Minnesota Local Roads Research Board

# Part A
# Using MnDOT Surface Rating (SR) to evaluate impact of potential excess moisture

## Introduction

There are many alternative stormwater management approaches, such as rain gardens, wet ponds, biofilter swales, and porous pavements, that are becoming more common with respect to traditional stormwater management approaches, such as curb and gutter and underground storm sewer systems. However, it is doubtful that a city engineer would be interested in using one of these relatively new approaches if they impart a negative impact on other highway infrastructure, particularly roadway pavement. This report attempts to evaluate the potential impact of existing alternative stormwater control facilities on roadway infrastructure. One way to do this is to look at the physical condition of the pavements adjacent to alternative stormwater best management practices (BMPs). If the pavements adjacent to alternative stormwater BMPs show signs of failure, these failures can possibly be attributed to the adjacent BMPs.

A useful tool to evaluate and quantify a pavement's physical condition is a pavement condition index. In particular, the Surface Rating (SR), developed by the Minnesota Department of Transportation (MnDOT), is a crack and surface distress index. The SR uses a 0.0–4.0 rating scale, where the higher number, the less distress present. The SR will decrease as the severity and amount of distress increases. (MnDOT, 2003)

## Methods

To evaluate the potential impact of existing alternative stormwater control facilities on roadway infrastructure, we completed 45 SR analyses on roadway pavements adjacent to alternative stormwater BMPs. The BMPs adjacent to the pavements in this study included 20 rain gardens, 12 dry swales, 7 infiltrations basins, 2 depressed parking lot islands, 2 bioretention facilities, 1 dry pond, and 1 wet pond. Alone, these 45 SR analyses do not tell us if the distresses identified were a result of the adjacent alternative stormwater BMP. To increase the possibility that any distress identified was a result of the adjacent BMP and not poor pavement construction or faulty pavement material, we compared each of the 45 pavements adjacent to alternative stormwater BMPs to similar, if not identical, pavement with no adjacent BMP. For the remainder of this report, the pavements with no adjacent BMPs are referred to as the "control." It is our hypothesis that there will be no difference between the SR calculated for pavement adjacent to an alternative stormwater control facility and the SR calculated for the control.

To identify and measure pavement distresses, we used the MnDOT Distress Identification Manual (MnDOT, 2003). The manual provides many helpful pictures to aid in distress identification. In addition to identification, the manual also explains the procedure for calculating the SR from the pavement distresses identified. We followed this procedure to calculate the 90 SRs (45 adjacent to BMPs, 45 controls) in this study.

The total length of pavement evaluated as the SR-Adjacent to BMP includes the total length of the BMP adjacent to the pavement plus an additional 50 foot section of pavement on either side of the BMP. It should be noted that all lengths are measured along the centerline of the roadway. The SR evaluated as the SR-Control consists of two 50 foot sections of pavement on either side of the pavement evaluated as "adjacent to BMP." These two 50 foot sections were added together to produce one 100 foot section. Appendix A contains a schematic to help illustrate the above pavement evaluation.

## Results

The SR-Adjacent to BMP and SR-Control for each of the 45 analyses can be found in Appendix B. We found that many of the SRs calculated, both SR-Adjacent to BMP and SR-Control, were equal to 4.0, the highest value possible for the SR, indicating that there was little or no distress present. This is not surprising—many of the pavements analyzed were recently constructed and have not had time to display any surface distresses. The lowest SR value calculated was 2.3 for the SR-Control at site 51. The corresponding SR-Adjacent to BMP calculated at site 51 was 2.5 and was for a dry swale.

To test our hypothesis that there is no difference between the SR-Adjacent to BMP and the SR-Control, we first computed the SR-Difference, which is equal to the SR-Control minus the SR-Adjacent to BMP. The SR-Difference, along with selected summary statistics, is reported in Appendix B. Next we developed a hypothesis to test using a statistical hypothesis test, namely that the mean SR-Difference was not statistically different from zero. Finally, as shown in Appendix C and using a level of significance of $\alpha = 0.01$, we fail to reject the hypothesis that the mean of the SR-Difference is not statistically different from zero. In other words, we accept the hypothesis that there is no difference between the SR-Adjacent to BMP and the SR-Control.

## Conclusion

Based on our analyses using the MnDOT Surface Rating pavement quality index and statistical test of our hypothesis, there is no impact of existing alternative stormwater control facilities on roadway infrastructure. This conclusion corresponds with the responses to a survey directed at city engineers and public works staff from Task 3 of this project. The overwhelming response from those who participated in the survey was that there was no negative impact from alternative stormwater control facilities on roadway infrastructure.

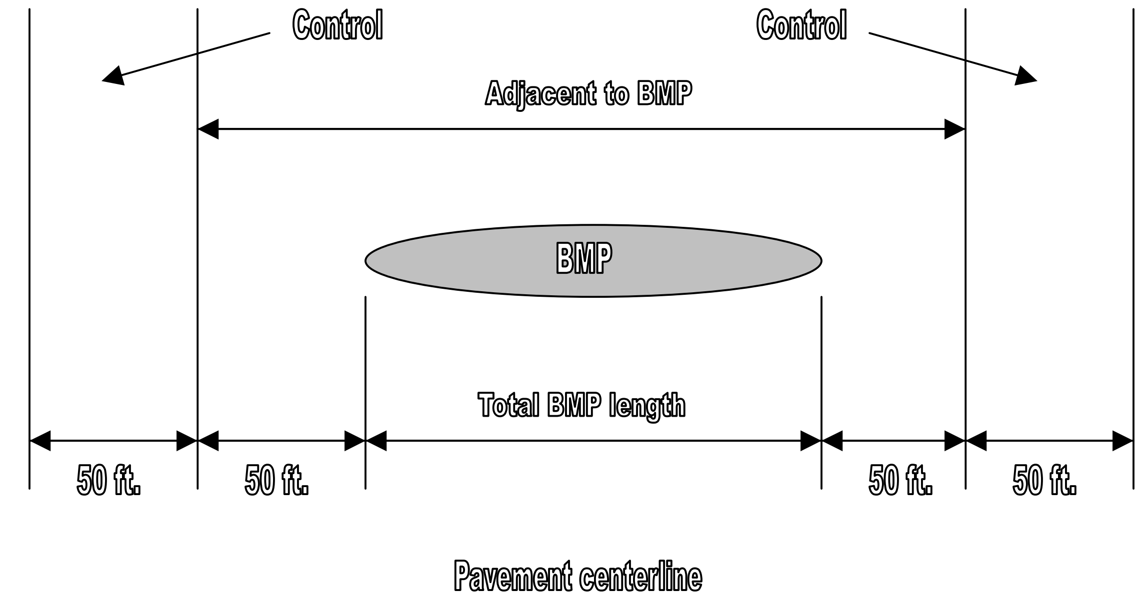
It should be noted that the use of rain gardens, wet ponds, biofilter swales, porous pavements, and other alternative stormwater BMPs is relatively new. Perhaps the impact of these practices on highway infrastructure has not had sufficient time to appear. It is our estimate that many of the practices observed for this study were less than five years old. If the design life of typical roadway infrastructure is 20 years, there is still time for negative impacts to occur.

## References

Haan, C.T. 1977. *Statistical Methods in Hydrology.* The Iowa State University Press, Ames, Iowa.

Minnesota Department of Transportation (MnDOT). 2003. *MnDOT Distress Identification Manual.* Office of Materials and Road Research, Pavement Management Unit. Maplewood, Minnesota.

**Appendix A: Pavement Evaluation Schematic (not to scale)**



# Appendix B: SR Summary

| Site Number | BMP Type | SR-Adjacent to BMP | SR-Control | SR Difference |
|---|---|---|---|---|
| 3 | Rain Garden | 2.70 | 2.60 | -0.10 |
| 4 | Dry Swale | 2.70 | 2.90 | 0.20 |
| 8 | Dry Swale | 4.00 | 4.00 | 0.00 |
| 10 | Dry Swale | 3.60 | 3.80 | 0.20 |
| 11 2nd time | Dry Swale | 2.70 | 3.60 | 0.90 |
| 12 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 13 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 15 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 16 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 19 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 20 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 21 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 22 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 23 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 24 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 25 | Infiltration Basin | 4.00 | 4.00 | 0.00 |
| 26 | Depressed Parking Lot Island | 4.00 | 4.00 | 0.00 |
| 42 North | Infiltration Basin | 4.00 | 4.00 | 0.00 |
| 42 South | Infiltration Basin | 4.00 | 4.00 | 0.00 |
| 45 | Infiltration Basin | 4.00 | 4.00 | 0.00 |
| 48 (1) | Rain Garden | 4.00 | 4.00 | 0.00 |
| 48 (2) | Rain Garden | 4.00 | 4.00 | 0.00 |
| 50 2nd time | Dry Swale | 2.90 | 2.70 | -0.20 |
| 51 | Dry Swale | 2.50 | 2.30 | -0.20 |
| 57 | Infiltration Basin | 2.70 | 2.90 | 0.20 |
| 64 | Rain Garden | 3.80 | 3.80 | 0.00 |
| 71 | Dry Swale | 4.00 | 4.00 | 0.00 |
| 79 | Infiltration Basin | 4.00 | 4.00 | 0.00 |
| 84 (1) | Rain Garden | 4.00 | 4.00 | 0.00 |
| 84 (2) | Rain Garden | 4.00 | 4.00 | 0.00 |
| 91 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 93 | Depressed Parking Lot Island | 4.00 | 4.00 | 0.00 |
| 115 | Rain Garden | 4.00 | 4.00 | 0.00 |
| 118 | Bioretention | 4.00 | 4.00 | 0.00 |
| 121 | Dry Pond | 4.00 | 4.00 | 0.00 |
| 123 | Dry Swale | 4.00 | 3.80 | -0.20 |
| 124 | Dry Swale | 3.60 | 3.80 | 0.20 |
| 125 | Dry Swale | 4.00 | 3.80 | -0.20 |
| 126 | Dry Swale | 4.00 | 4.00 | 0.00 |
| 127 | Bioretention | 3.20 | 3.00 | -0.20 |
| 134 | Wet Pond | 4.00 | 4.00 | 0.00 |
| 142 | Dry Swale | 4.00 | 4.00 | 0.00 |
| 161 | Infiltration Basin | 4.00 | 4.00 | 0.00 |
| 168 East | Rain Garden | 4.00 | 4.00 | 0.00 |
| 168 West | Rain Garden | 4.00 | 4.00 | 0.00 |

| | | | | |
|---|---|---|---|---|
| | Mean | 3.78667 | 3.80000 | 0.01333 |
| | Standard Deviation | 0.45657 | 0.44004 | 0.16321 |

**Appendix C: SR Difference Statistical Analysis**

Hypothesis, $H_o$: $\mu_0 = 0$, where $\mu_0$ is the hypothetical mean of the SR-Difference

The hypothesis, $H_o$, is tested using:

$t = \sqrt{(n)}\ (X-\mu_0) / (S_X) = \sqrt{(45)}\ (0.01333-0) / (0.16321) = 0.54789$, where n is the number of values, X is the mean of the SR-Difference, $\mu_0$ is the hypothetical mean of the SR-Difference, and $S_X$ is the standard deviation of the SR-Difference.

$H_o$ is rejected if:

$\left| t \right| = \left| \sqrt{(n)}\ (X-\mu_0) / (S_X) \right| > t_{1-\alpha/2\ ,\ n-1}$

Using $\alpha = 0.01$, $t_{1-\alpha/2\ ,\ n-1} = t_{0.995\ ,\ 44} = 2.70$

0.54789 > 2.70 is FALSE

Therefore, we fail to reject the hypothesis, and accept that the mean of the SR difference is not significantly different from zero.

(Haan, 1977)

# Part B
# MnPAVE analysis of potential excess moisture impact

## Introduction

With a growing interest in improving water quality and the National Pollution Discharge Elimination System's Phase II stormwater requirements, there is great stock placed in alternative stormwater control facilities, commonly referred to as stormwater best management practices (BMPs). These BMPs, including rain gardens, wet and dry ponds, bioretention facilities, and porous pavements, come in various shapes and sizes, and function in many different ways. It is important to know what impact, if any, these BMPs may impart on existing and proposed infrastructure, namely roadways. This knowledge has the ability determine what type of BMP is used in a particular situation or how other parts of the system are designed based on the particular BMP. This report attempts to reveal potential impacts of existing alternative stormwater control facilities on roadway infrastructure.

One way to evaluate the impact of existing alternative stormwater control facilities on roadway infrastructure is to model the performance of the roadway pavement under a range of possible conditions that it might experience if located adjacent to these stormwater BMPs. In particular, we were interested in the impact of increased water contents in the pavement subgrade soil due to the proximity of the adjacent BMPs.

The model that we used to accomplish this task was MnPAVE Beta Version 5.2. The MnPAVE software is typically used to design flexible pavements given climatic conditions, pavement structures, material properties, and traffic volumes. The software can also estimate pavement design life given the same inputs. To calculate the stresses, strains, and displacements of the pavement, MnPAVE uses the U.S. Army Corps of Engineers Waterways Experiment Station's Layered Elastic Analysis method (Chadbourn et al., 2002). The stresses, strains, and displacements are then converted into estimates of pavement life using transfer functions from the Asphalt Institute model and the Illinois rutting model (Chadbourn et al., 2002).

While there is no direct way to model the effects of increased subgrade soil water contents using MnPAVE, there is the ability to model the effects of variable subgrade soil resilient modulus ($M_r$) on pavement life. The $M_r$ is a representation of the stiffness of a soil. As water content increases, the $M_r$ of most fine-grained soils decreases (Drumm et al., 1997). Using the "Procedure for Correcting Resilient Modulus for Increased Degree of Saturation" from Drumm et al. (1997), we were able to vary the subgrade soil $M_r$ inputs into MnPAVE based on increased subgrade soil water contents and model the impacts of existing alternative stormwater control facilities on roadway infrastructure.

## Methods

The $M_r$ at optimum water content for each of the four subgrade soil types (American Association of State Highway and Transportation Officials [AASHTO] soil classes A-4, A-6, A-7-5, and A-7-6) from Drumm et al. (1997) was calculated as the mean of the $M_r$ values at the lowest degree of saturation (S) for each subgrade soil type from Figure 7 (Effect of Postcompaction Saturation on Resilient Modulus) of Drumm et al. (1997). The $M_r$ at optimum water content for each subgrade soil type was then modified by increasing the subgrade soil water content in one percent (1%) increments using the "Resilient modulus gradient ($dM_{rclass}/dS$)" from Table 4 (Gradient of Resilient Modulus with Respect to Degree of Saturation) of Drumm et al. (1997). The $M_r$ values, along with the corresponding subgrade soil water content, degree of saturation, and other soil parameters, can be found in Appendix A.

Using the $M_r$ values in Appendix A, we then used MnPAVE to perform two separate analyses to determine the effect of increased subgrade soil water contents on pavement life. Both analyses were performed in MnPAVE's Research Mode and used MnPAVE's default climatic values for the Minneapolis-St. Paul metro area. The traffic volumes for both MnPAVE analyses were calculated using a First Year Design Lane Average Annual Daily Traffic (AADT) of 1000 vehicles, design life of 20 years, zero percent (0%) growth rate, and a Low Volume Traffic Type Load Spectrum. The difference between the two MnPAVE analyses occurred in the pavement structure.

For the first analysis, we modeled two actual pavement structures adjacent to rain gardens in Maplewood and Lake Elmo, Minnesota. Information about these pavement structures can be found in Appendix B. The $M_r$ at the various water contents for the four subgrade soil types from Appendix A was then input as the $M_r$ for the Engineered Soil in MnPAVE's intermediate design mode to observe the effects on MnPAVE's predicted pavement life.

For the second analysis, we designed a hypothetical pavement structure for each of the four subgrade soil types. These hypothetical pavement structures were specifically designed to have a MnPAVE-predicted design life of 20 years. This was done by holding the thickness of hot mix asphalt (HMA) and engineered soil (EngSoil) constant at 3.5 and 12.0 inches, respectively, and then finding the thickness of aggregate base (AggBase) necessary for MnPAVE to predict a design life of 20 years. The optimum water content $M_r$ for the four classes of engineered soil was used in this procedure. Descriptions of these pavement structures can be found in Appendix C.

Next, we applied the $M_r$ at the various water contents for the four subgrade soil types from Appendix A as the $M_r$ for the Engineered Soil in MnPAVE's intermediate design mode. After that, we increased the HMA layer thickness while holding the AggBase layer thickness constant to observe the HMA layer thickness increase required to maintain a 20 year design life at the various water contents and $M_r$. The same procedure was performed holding the HMA layer thickness constant and increasing the AggBase layer thickness.

## Results

From the results of the first MnPAVE analysis, found in Appendix D, we can see that as subgrade soil water content increases and $M_r$ decreases, the fatigue and rutting lives predicted by MnPAVE decrease. This is also shown graphically in Figures 1–4.

Pavement #1, with A-7-5 and A-7-6 subgrade soils, experienced the greatest decrease in design life. The MnPAVE Rutting Life for these two pavements decreased from greater than 50 years to twelve years with an increase in soil water content of two percent (2%). The same pavement with A-4 and A-6 subgrade soils experienced a decrease in MnPAVE Rutting Life of 29 and 23 years, respectively, with an increase in soil water content of five and three percent (5 and 3%), respectively. For all four subgrade soil types, the decrease in MnPAVE Rutting Life was greater than the decrease in MnPAVE Fatigue Life under the same increases in soil water content.

Pavement #2, which is thicker than Pavement #1, did not reveal a decrease in MnPAVE Fatigue or Rutting Life under the same increases in soil water content as Pavement #1.

From the results of the second MnPAVE analysis, found in Appendix E, we can see that as subgrade soil water content increases and $M_r$ decreases, the thickness of HMA and AggBase required by MnPAVE to maintain a 20 year design life increases. This is also shown graphically in Figures 5–8.

The hypothetical pavement structure with A-4 subgrade soil required the largest increases in HMA and AggBase thickness, 3.1 and 7.8 inches, respectively, to maintain a 20 year MnPAVE Rutting Life when subjected to a five percent (5%) increase in subgrade soil water content. The smallest HMA and AggBase increases, 2.3 and 5.9 inches, respectively, required to maintain a 20 year MnPAVE Rutting Life corresponded to the hypothetical pavement structure with A-7-5 subgrade soil. This pavement was subjected to a two percent (2%) increase in subgrade soil water content.

It should be noted that the increases in subgrade soil water contents that were modeled were applied uniformly over an entire year. In other words, a two percent (2%) increase in subgrade soil water content was modeled as a two percent (2%) increase from the optimum soil water content for the entire year. In reality, it is unlikely that uniform increases in soil water content such as this would occur. It is more realistic for soil water contents to fluctuate and be both above and below the optimum subgrade soil water content.

Also important to note is the range of subgrade soil water contents that were used in these analyses. The A-4 soils ranged from a minimum of 15 percent to a maximum of 20 percent water content. The A-6, A-7-5, A-7-6 soils ranged from minimums of 17.7, 26.7, and 25.8 percent, respectively, to maximums of 20.7, 28.7, and 27.8 percent, respectively. To give this context, the minimum and maximum subgrade soil water contents observed under low-volume road cells 28, 29, and 30 at the MnROAD test facility were 7.8 and 34.7 percent (Roberson, personal communication, August 2005). The mean and standard deviation of the subgrade soil water contents for these cells were 24.1 and 6.7 percent, respectively.

In addition to this comparison, the subgrade soil under low-volume road cells 28, 29, and 30 at the MnROAD facility is classified as clay-loam (Roberson, personal communication, August 2005). Typically, clay-loam soils correspond to AASHTO class A-7-5 and A-7-6 soils.

## Conclusion

Based on this analysis using the MnPAVE software, there is the potential for decreased pavement performance, in the form of reduced design lives, if the subgrade soil water content is increased. It is our assumption that a stormwater BMP might increase the adjacent subgrade soil water content, and as a result, be responsible for the negative impact on the roadway infrastructure. However, there is no analysis contained in this report that either confirms of denies this assumption. This report also provides an analysis of the necessary increases in pavement layers, or modifications to the pavement design, that are necessary to offset these negative impacts.

## References

Chadbourn, B., S. Dai, P. Davich, J. Siekmeier, D. VanDeusen. 2002. *Pavement Designer's Guide, Mn/DOT Flexible Pavement Design, MnPAVE Beta Version 5.1.* Minnesota Department of Transportation, Office of Materials and Road Research, Minnesota Road Research Section, Pavement Section.

Drumm, E.C., J.S. Reeves, M.R. Madgett, W.D. Trolinger. 1997. Subgrade Resilient Modulus Correction for Saturation Effects. *Journal of Geotechnical and Geoenvironmental Engineering.* 123(7):663–670.

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# Appendix A: $M_r$ and Other Soil Parameters

Optimum Water Content

| Soil Classification (AASHTO) | Specific Gravity | Maximum Dry Density (Mg/m^3) | Optimum Water Content (%) | Optimum Degree of Saturation (%) | Optimum Resilient Modulus (Mpa) | Resilient Modulus Gradient (Mpa) |
|---|---|---|---|---|---|---|
| A-4 | 2.63 | 1.76 | 15.0 | 79.8 | 106 | -300 |
| A-6 | 2.63 | 1.72 | 17.7 | 88.0 | 90 | -400 |
| A-7-5 | 2.67 | 1.50 | 26.7 | 91.4 | 129 | -1200 |
| A-7-6 | 2.71 | 1.53 | 25.8 | 90.7 | 179 | -1900 |

Optimum Water Content + 1.0%

| Soil Classification (AASHTO) | Change in Water Content (%) | Water Content (%) | Degree of Saturation (%) | Change in Degree of Saturation (%) | Resilent Modulus (Mpa) |
|---|---|---|---|---|---|
| A-4 | 1.0 | 16.0 | 85.1 | 5.3 | 90 |
| A-6 | 1.0 | 18.7 | 93.0 | 5.0 | 70 |
| A-7-5 | 1.0 | 27.7 | 94.8 | 3.4 | 88 |
| A-7-6 | 1.0 | 26.8 | 94.2 | 3.5 | 113 |

Optimum Water Content + 2.0%

| Soil Classification (AASHTO) | Change in Water Content (%) | Water Content (%) | Degree of Saturation (%) | Change in Degree of Saturation (%) | Resilent Modulus (Mpa) |
|---|---|---|---|---|---|
| A-4 | 2.0 | 17.0 | 90.4 | 10.6 | 74 |
| A-6 | 2.0 | 19.7 | 97.9 | 9.9 | 50 |
| A-7-5 | 2.0 | 28.7 | 98.2 | 6.8 | 47 |
| A-7-6 | 2.0 | 27.8 | 97.7 | 7.0 | 46 |

Optimum Water Content + 3.0%

| Soil Classification (AASHTO) | Change in Water Content (%) | Water Content (%) | Degree of Saturation (%) | Change in Degree of Saturation (%) | Resilent Modulus (Mpa) |
|---|---|---|---|---|---|
| A-4 | 3.0 | 18.0 | 95.8 | 16.0 | 58 |
| A-6 | 3.0 | 20.7 | 102.9 | 14.9 | 30 |
| A-7-5 | 3.0 | 29.7 | 101.7 | 10.3 | 6 |
| A-7-6 | 3.0 | 28.8 | 101.2 | 10.5 | -20 |

Optimum Water Content + 4.0%

| Soil Classification (AASHTO) | Change in Water Content (%) | Water Content (%) | Degree of Saturation (%) | Change in Degree of Saturation (%) | Resilent Modulus (Mpa) |
|---|---|---|---|---|---|
| A-4 | 4.0 | 19.0 | 101.1 | 21.3 | 42 |
| A-6 | 4.0 | 21.7 | 107.9 | 19.9 | 11 |
| A-7-5 | 4.0 | 30.7 | 105.1 | 13.7 | -35 |
| A-7-6 | 4.0 | 29.8 | 104.7 | 14.0 | -87 |

Optimum Water Content + 5.0%

| Soil Classification (AASHTO) | Change in Water Content (%) | Water Content (%) | Degree of Saturation (%) | Change in Degree of Saturation (%) | Resilent Modulus (Mpa) |
|---|---|---|---|---|---|
| A-4 | 5.0 | 20.0 | 106.4 | 26.6 | 26 |
| A-6 | 5.0 | 22.7 | 112.8 | 24.8 | -9 |
| A-7-5 | 5.0 | 31.7 | 108.5 | 17.1 | -76 |
| A-7-6 | 5.0 | 30.8 | 108.2 | 17.5 | -154 |

Notes:
1. Soil classifications from Drumm et al. 1997, Table 1
2. Specific gravities are the mean of the specific gravities for each soil classification from Drumm et al. 1997, Table 1
3. Maximum dry densities are the mean of the maximum dry densities for each soil classification from Drumm et al. 1997, Table 1
4. Optimum water contents are the mean of the optimum water contents for each soil classification from Drumm et al. 1997, Table 1
5. Optimum degree of saturation calculated assuming the density of water equals 1.0 Mg/m^3
6. Optimum resilient modulii are the mean of the optimum resilient modulii for each soil classification from Drumm et al. 1997, Fig. 7
7. Resilient modulii gradient for each soil classification from Drumm et al. 1997, Table 4

# Appendix B: Actual Pavement Structures

**Pavement #1**

| | |
|---|---|
| City of Maplewood | 1.5"-Bituminous Wear Course |
| Typical Residential Street Section | 2.0"-Bituminous Base Course |
| Relaxed Urban Design | 8.0"-Aggregate Base MnDOT Class 6 |
| Plate No. 115 | 24.0"-Select Granular Borrow (based on soil conditions) |

**Pavement #2**

| | |
|---|---|
| City of Lake Elmo | 1.5"-2350, Type LV 4 Bituminous Wearing Course |
| 50th Street Improvements | 2.0"-2350, Type LV 3 Bituminous Non Wearing Course |
| From Lake Elmo Ave. to Stillwater Blvd. | 6.0"-Aggregate Base, Class 5 |
| | 18.0"-Aggregate Base, Class 3 |

# Appendix C: Hypothetical Pavement Structure

**AASHTO Class A-4 Soil**
3.5"-HMA, PG 58-34
5.8"-AggBase, Cl. 6
12.0"-EngSoil, A-4
UndSoil, A-4

**AASHTO Class A-6 Soil**
3.5"-HMA, PG 58-34
6.2"-AggBase, Cl. 6
12.0"-EngSoil, A-6
UndSoil, A-6

**AASHTO Class A-7-5 Soil**
3.5"-HMA, PG 58-34
4.4"-AggBase, Cl. 6
12.0"-EngSoil, A-7-5
UndSoil, A-7-5

**AASHTO Class A-7-6 Soil**
3.5"-HMA, PG 58-34
2.7"-AggBase, Cl. 6
12.0"-EngSoil, A-7-6
UndSoil, A-7-6

# Appendix D: MnPAVE Actual Pavement Structure Analysis Results

| Pavement # 1 | Optimum Water Content | | | | Optimum + 1% Water Content | | | | Optimum + 2% Water Content | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil Classification (AASHTO) | Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) | Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) | Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) |
| A-4 | 15.0 | 106 | 49 | 35 | 16.0 | 90 | 48 | 27 | 17.0 | 74 | 47 | 21 |
| A-6 | 17.7 | 90 | 48 | 31 | 18.7 | 70 | 47 | 21 | 19.7 | 50 | 44 | 14 |
| A-7-5 | 26.7 | 129 | 50 | 50 | 27.7 | 88 | 48 | 28 | 28.7 | 47 | 43 | 12 |
| A-7-6 | 25.8 | 179 | 50 | 50 | 26.8 | 113 | 50 | 42 | 27.8 | 46 | 43 | 12 |

| | Optimum + 3% Water Content | | | | Optimum + 4% Water Content | | | | Optimum + 5% Water Content | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil Classification (AASHTO) | Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) | Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) | Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) |
| A-4 | 18.0 | 58 | 45 | 15 | 19.0 | 42 | 42 | 10 | 20.0 | 26 | 39 | 6 |
| A-6 | 20.7 | 30 | 40 | 8 | 21.7 | 11 | Note 1 | | 22.7 | 1 | Note 1 | |
| A-7-5 | 29.7 | 6 | Note 1 | | 30.7 | -35 | | | 31.7 | -76 | | |
| A-7-6 | 28.8 | -20 | | | 29.8 | -87 | | | 30.8 | -154 | | |

| Pavement # 2 | Optimum Water Content | | | | Optimum + 1% Water Content | | | | Optimum + 2% Water Content | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil Classification (AASHTO) | Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) | Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) | Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) |
| A-4 | 15.0 | 106 | 38 | 50 | 16.0 | 90 | 38 | 50 | 17.0 | 74 | 38 | 50 |
| A-6 | 17.7 | 90 | 38 | 50 | 18.7 | 70 | 38 | 50 | 19.7 | 50 | 38 | 50 |
| A-7-5 | 26.7 | 129 | 37 | 50 | 27.7 | 88 | 38 | 50 | 28.7 | 47 | 38 | 50 |
| A-7-6 | 25.8 | 179 | 37 | 50 | 26.8 | 113 | 37 | 50 | 27.8 | 46 | 38 | 50 |

| Soil Classification (AASHTO) | Optimum + 3% Water Content: Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) | Optimum + 4% Water Content: Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) | Optimum + 5% Water Content: Water Content (%) | Resilient Modulus (Mpa) | MnPAVE Fatigue Life (yr) | MnPAVE Rutting Life (yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A-4 | 18.0 | 58 | 38 | 50 | 19.0 | 42 | 38 | 50 | 20.0 | 26 | 38 | 50 |
| A-6 | 20.7 | 30 | 38 | 50 | 21.7 | 11 | Note 1 | | 22.7 | -9 | Note 1 | |
| A-7-5 | 29.7 | 6 | Note 1 | | 30.7 | -35 | | | 31.7 | -76 | | |
| A-7-6 | 28.8 | -20 | | | 29.8 | -87 | | | 30.8 | -154 | | |

Notes:

1. MnPAVE does not allow Resilient Modulus inputs below 20.68 MPa
2. MnPAVE Fatigue Life and Rutting Life output values of ">50 yr." have been reported as 50 yr.

# Appendix E: MnPAVE Hypothetical Pavement Structure Analysis Results

**AASHTO Class A-4 Soil**

**Water Content Variations**

| | |
|---|---|
| Water Content (%) | 15.0 |
| Resilient Modulus (Mpa) | 106 |
| Resilient Modulus (ksi) | 15 |

**Improved Pavement Section-HMA**

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 5.8 |
| 3 | EngSoil | Mr15 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

**MnPAVE Output**

| | |
|---|---|
| Fatigue Life (yr) | 46 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.43 |
| Rutting Damage | 0.96 |

**Improved Pavement Section-AggBase**

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 5.8 |
| 3 | EngSoil | Mr15 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

**MnPAVE Output**

| | |
|---|---|
| Fatigue Life (yr) | 46 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.43 |
| Rutting Damage | 0.96 |

| | |
|---|---|
| Water Content (%) | 16.0 |
| Resilient Modulus (Mpa) | 90 |
| Resilient Modulus (ksi) | 13 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.9 |
| 2 | AggBase | Cl.6 | 5.8 |
| 3 | EngSoil | Mr15 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 21 |
| Fatigue Damage | 0.33 |
| Rutting Damage | 0.95 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 6.7 |
| 3 | EngSoil | Mr15 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | 46 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.43 |
| Rutting Damage | 0.97 |

| | |
|---|---|
| Water Content (%) | 17.0 |
| Resilient Modulus (Mpa) | 74 |
| Resilient Modulus (ksi) | 11 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 4.3 |
| 2 | AggBase | Cl.6 | 5.8 |
| 3 | EngSoil | Mr11 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.26 |
| Rutting Damage | 0.98 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 7.8 |
| 3 | EngSoil | Mr11 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | 46 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.43 |
| Rutting Damage | 0.98 |

| | |
|---|---|
| Water Content (%) | 18.0 |
| Resilient Modulus (Mpa) | 58 |
| Resilient Modulus (ksi) | 8 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 4.9 |
| 2 | AggBase | Cl.6 | 5.8 |
| 3 | EngSoil | Mr8 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.18 |
| Rutting Damage | 0.96 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 9.4 |
| 3 | EngSoil | Mr8 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | 47 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.42 |
| Rutting Damage | 0.96 |

| | |
|---|---|
| Water Content (%) | 19.0 |
| Resilient Modulus (Mpa) | 42 |
| Resilient Modulus (ksi) | 6 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 5.6 |
| 2 | AggBase | Cl.6 | 5.8 |
| 3 | EngSoil | Mr6 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.13 |
| Rutting Damage | 0.97 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 11.2 |
| 3 | EngSoil | Mr6 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | 49 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.40 |
| Rutting Damage | 0.96 |

| | |
|---|---|
| Water Content (%) | 20.0 |
| Resilient Modulus (Mpa) | 26 |
| Resilient Modulus (ksi) | 4 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 6.6 |
| 2 | AggBase | Cl.6 | 5.8 |
| 3 | EngSoil | Mr4 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.08 |
| Rutting Damage | 0.98 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 13.6 |
| 3 | EngSoil | Mr4 (A-4) | 12.0 |
| 4 | UndSoil | A-4 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.38 |
| Rutting Damage | 0.97 |

**AASHTO Class A-6 Soil**

**Water Content Variations**

| | |
|---|---|
| Water Content (%) | 17.7 |
| Resilient Modulus (Mpa) | 90 |
| Resilient Modulus (ksi) | 13 |

**Improved Pavement Section-HMA**

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 6.2 |
| 3 | EngSoil | Mr13 (A-6) | 12.0 |
| 4 | UndSoil | A-6 | n/a |

**MnPAVE Output**

| | |
|---|---|
| Fatigue Life (yr) | 46 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.43 |
| Rutting Damage | 0.98 |

**Improved Pavement Section-AggBase**

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 6.2 |
| 3 | EngSoil | Mr13 (A-6) | 12.0 |
| 4 | UndSoil | A-6 | n/a |

**MnPAVE Output**

| | |
|---|---|
| Fatigue Life (yr) | 46 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.43 |
| Rutting Damage | 0.98 |

| | |
|---|---|
| Water Content (%) | 18.7 |
| Resilient Modulus (Mpa) | 70 |
| Resilient Modulus (ksi) | 10 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 4.1 |
| 2 | AggBase | Cl.6 | 6.2 |
| 3 | EngSoil | Mr10 (A-6) | 12.0 |
| 4 | UndSoil | A-6 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.29 |
| Rutting Damage | 0.97 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 7.7 |
| 3 | EngSoil | Mr10 (A-6) | 12.0 |
| 4 | UndSoil | A-6 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | 46 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.43 |
| Rutting Damage | 0.97 |

| | |
|---|---|
| Water Content (%) | 19.7 |
| Resilient Modulus (Mpa) | 30 |
| Resilient Modulus (ksi) | 7 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 4.9 |
| 2 | AggBase | Cl.6 | 6.2 |
| 3 | EngSoil | Mr7 (A-6) | 12.0 |
| 4 | UndSoil | A-6 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 21 |
| Fatigue Damage | 0.18 |
| Rutting Damage | 0.95 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 9.7 |
| 3 | EngSoil | Mr7 (A-6) | 12.0 |
| 4 | UndSoil | A-6 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | 48 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.41 |
| Rutting Damage | 0.97 |

| | |
|---|---|
| Water Content (%) | 20.7 |
| Resilient Modulus (Mpa) | 50 |
| Resilient Modulus (ksi) | 4 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 6.0 |
| 2 | AggBase | Cl.6 | 6.2 |
| 3 | EngSoil | Mr4 (A-6) | 12.0 |
| 4 | UndSoil | A-6 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.10 |
| Rutting Damage | 0.97 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 12.5 |
| 3 | EngSoil | Mr4 (A-6) | 12.0 |
| 4 | UndSoil | A-6 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.39 |
| Rutting Damage | 0.97 |

**AASHTO Class A-7-5 Soil**

Water Content Variations

| | |
|---|---|
| Water Content (%) | 26.7 |
| Resilient Modulus (Mpa) | 129 |
| Resilient Modulus (ksi) | 19 |

Improved Pavement Section-HMA

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 4.4 |
| 3 | EngSoil | Mr19 (A-7-5) | 12.0 |
| 4 | UndSoil | A-7-5 | n/a |

MnPAVE Output

| | |
|---|---|
| Fatigue Life (yr) | 47 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.42 |
| Rutting Damage | 0.97 |

Improved Pavement Section-AggBase

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 4.4 |
| 3 | EngSoil | Mr19 (A-7-5) | 12.0 |
| 4 | UndSoil | A-7-5 | n/a |

MnPAVE Output

| | |
|---|---|
| Fatigue Life (yr) | 47 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.42 |
| Rutting Damage | 0.97 |

| | |
|---|---|
| Water Content (%) | 27.7 |
| Resilient Modulus (Mpa) | 88 |
| Resilient Modulus (ksi) | 13 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 4.4 |
| 2 | AggBase | Cl.6 | 4.4 |
| 3 | EngSoil | Mr13 (A-7-5) | 12.0 |
| 4 | UndSoil | A-7-5 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 21 |
| Fatigue Damage | 0.24 |
| Rutting Damage | 0.95 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 6.5 |
| 3 | EngSoil | Mr13 (A-7-5) | 12.0 |
| 4 | UndSoil | A-7-5 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | 46 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.43 |
| Rutting Damage | 0.98 |

| | |
|---|---|
| Water Content (%) | 28.7 |
| Resilient Modulus (Mpa) | 47 |
| Resilient Modulus (ksi) | 7 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 5.8 |
| 2 | AggBase | Cl.6 | 4.4 |
| 3 | EngSoil | Mr7 (A-7-5) | 12.0 |
| 4 | UndSoil | A-7-5 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 21 |
| Fatigue Damage | 0.12 |
| Rutting Damage | 0.95 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 10.3 |
| 3 | EngSoil | Mr7 (A-7-5) | 12.0 |
| 4 | UndSoil | A-7-5 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | 48 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.41 |
| Rutting Damage | 0.96 |

**AASHTO Class A-7-6 Soil**

Water Content Variations

| | |
|---|---|
| Water Content (%) | 25.8 |
| Resilient Modulus (Mpa) | 179 |
| Resilient Modulus (ksi) | 19 |

Improved Pavement Section-HMA

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 2.7 |
| 3 | EngSoil | Mr26 (A-7-6) | 12.0 |
| 4 | UndSoil | A-7-6 | n/a |

MnPAVE Output

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.38 |
| Rutting Damage | 0.96 |

Improved Pavement Section-AggBase

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 2.7 |
| 3 | EngSoil | Mr26 (A-7-6) | 12.0 |
| 4 | UndSoil | A-7-6 | n/a |

MnPAVE Output

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.38 |
| Rutting Damage | 0.96 |

| | |
|---|---|
| Water Content (%) | 26.8 |
| Resilient Modulus (Mpa) | 113 |
| Resilient Modulus (ksi) | 13 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 4.6 |
| 2 | AggBase | Cl.6 | 2.7 |
| 3 | EngSoil | Mr16 (A-7-6) | 12.0 |
| 4 | UndSoil | A-7-6 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 21 |
| Fatigue Damage | 0.21 |
| Rutting Damage | 0.93 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 5.4 |
| 3 | EngSoil | Mr16 (A-7-6) | 12.0 |
| 4 | UndSoil | A-7-6 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | 46 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.43 |
| Rutting Damage | 0.97 |

| | |
|---|---|
| Water Content (%) | 27.8 |
| Resilient Modulus (Mpa) | 46 |
| Resilient Modulus (ksi) | 7 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 6.4 |
| 2 | AggBase | Cl.6 | 2.7 |
| 3 | EngSoil | Mr7 (A-7-6) | 12.0 |
| 4 | UndSoil | A-7-6 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | >50 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.11 |
| Rutting Damage | 0.99 |

| Layer | Type | Subtype | Height (in) |
|---|---|---|---|
| 1 | HMA | PG 58-34 | 3.5 |
| 2 | AggBase | Cl.6 | 10.4 |
| 3 | EngSoil | Mr7 (A-7-6) | 12.0 |
| 4 | UndSoil | A-7-6 | n/a |

| | |
|---|---|
| Fatigue Life (yr) | 48 |
| Rutting Life (yr) | 20 |
| Fatigue Damage | 0.41 |
| Rutting Damage | 0.97 |

# Appendix F: Effect of Water Content on Pavements

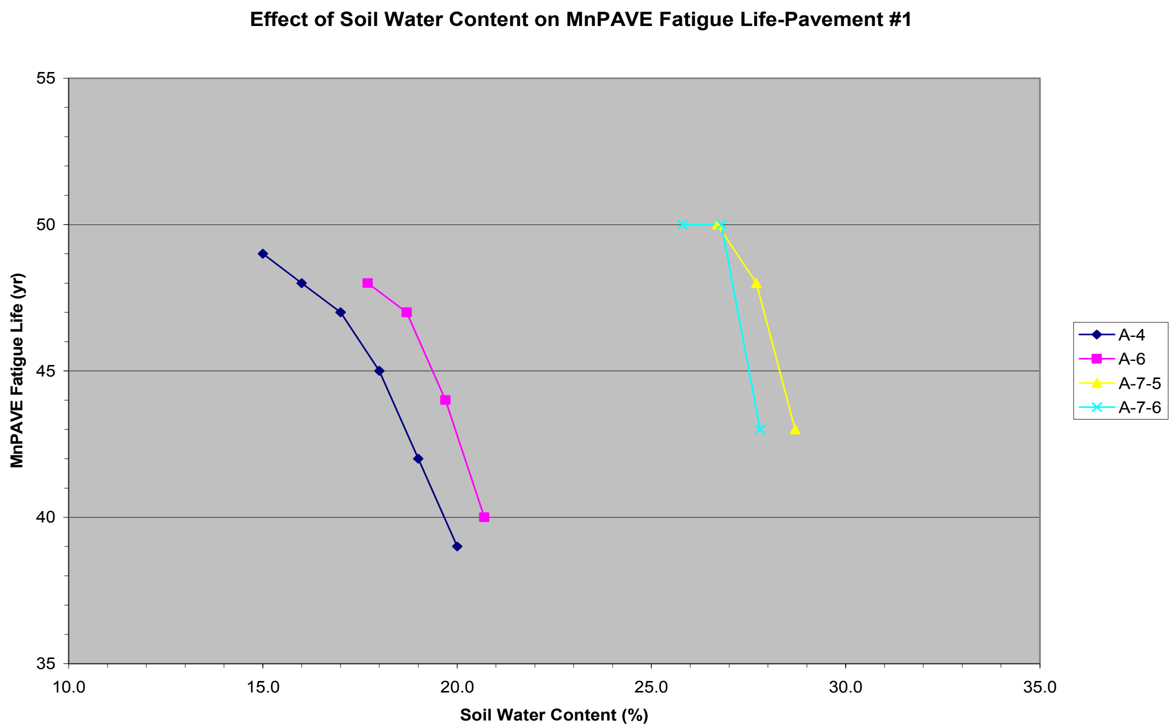


**Figure 1: Effect of Soil Water Content on MnPAVE Fatigue Life-Pavement #1**

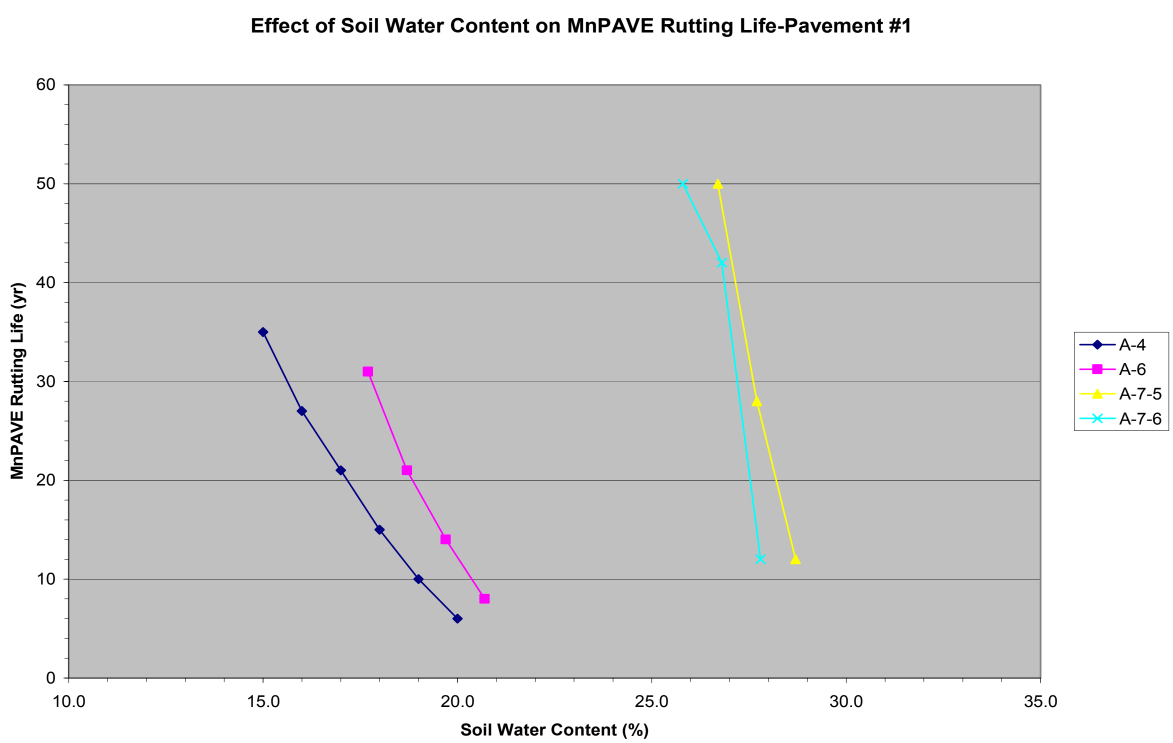


**Figure 2: Effect of Soil Water Content on MnPAVE Rutting Life-Pavement #1**

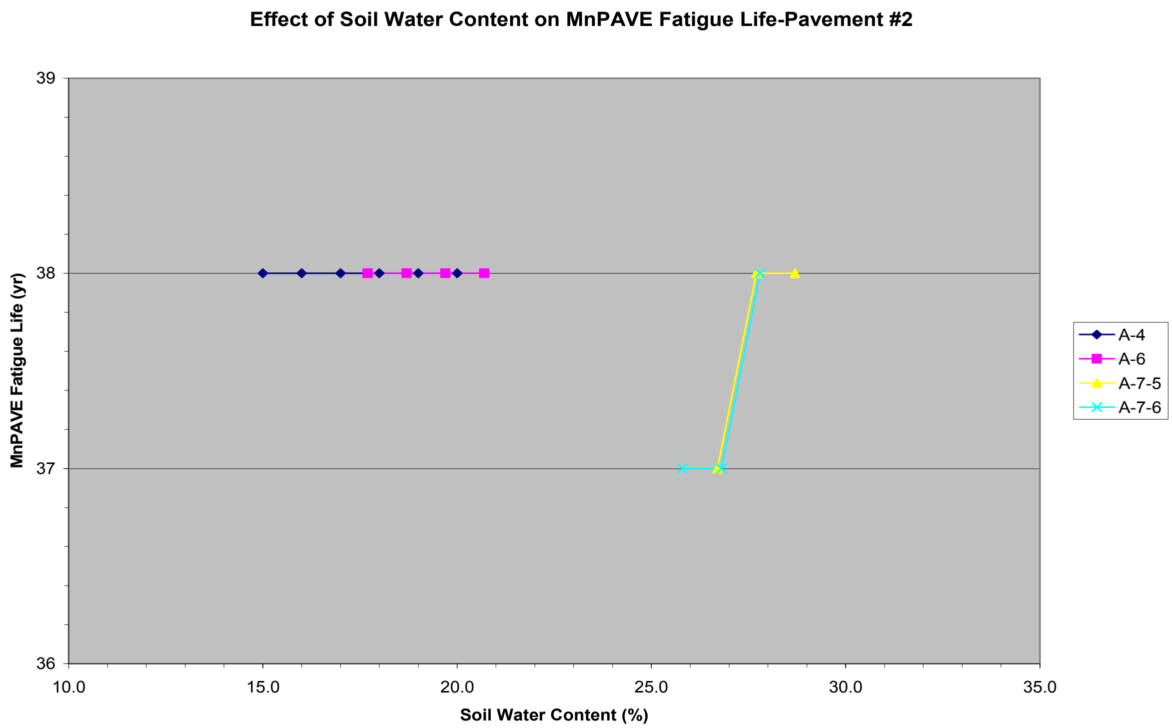


**Figure 3: Effect of Soil Water Content on MnPAVE Fatigue Life-Pavement #2**

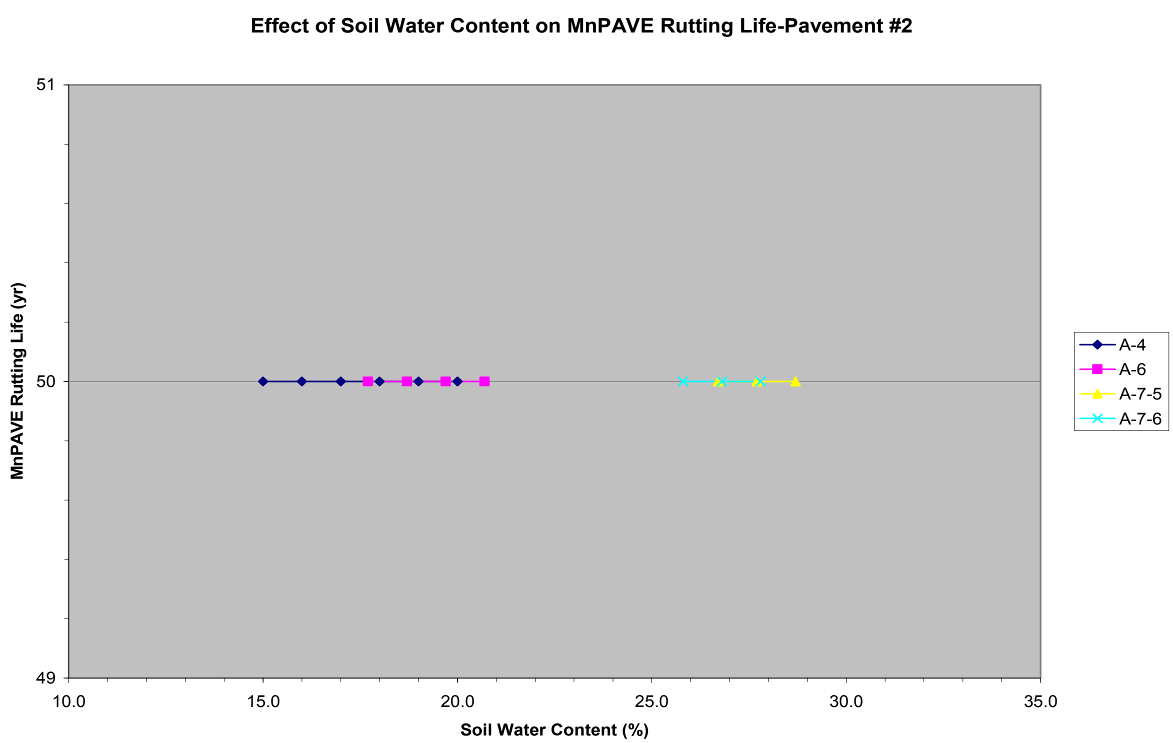


**Figure 4: Effect of Soil Water Content on MnPAVE Rutting Life-Pavement #2**

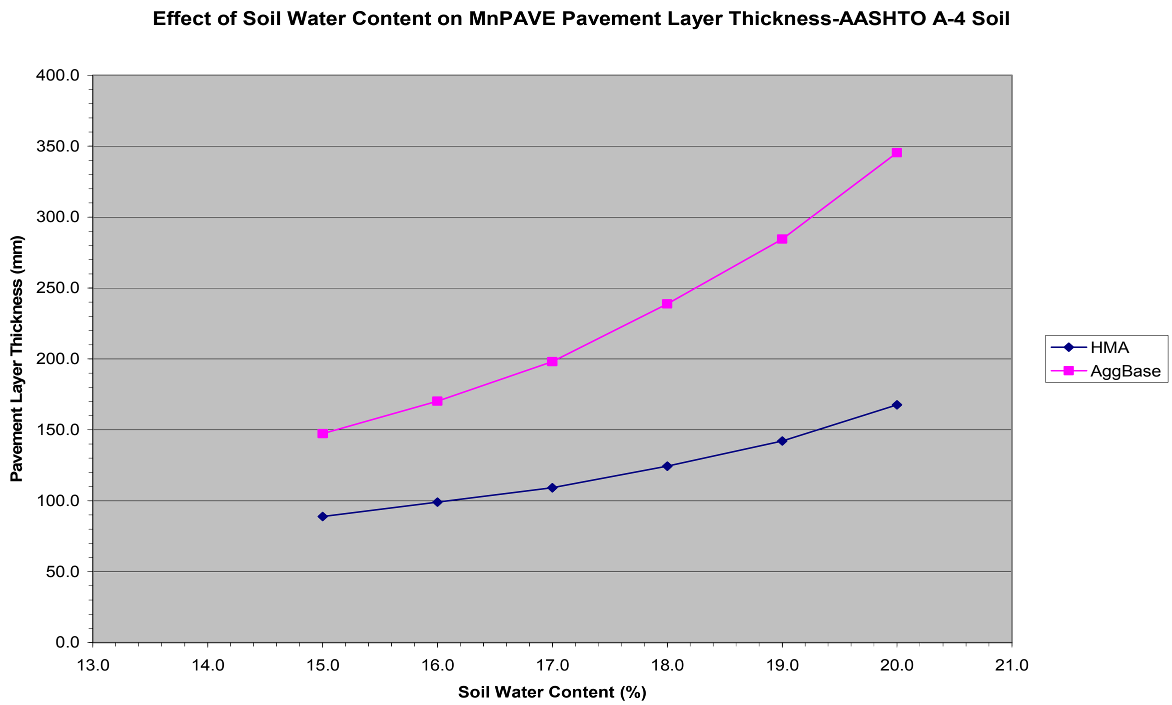


**Figure 5: Effect of Soil Water Content on MnPAVE Pavement Layer Thickness-AASHTO A-4 Soil**

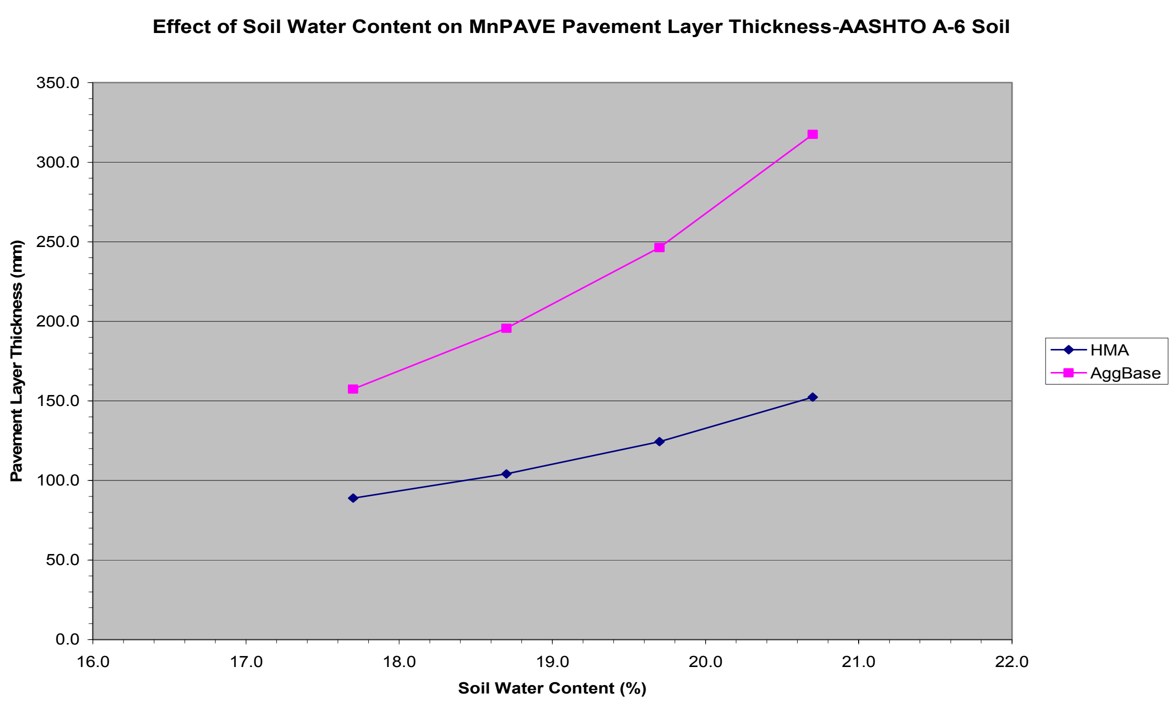


**Figure 6: Effect of Soil Water Content on MnPAVE Pavement Layer Thickness-AASHTO A-6 Soil**

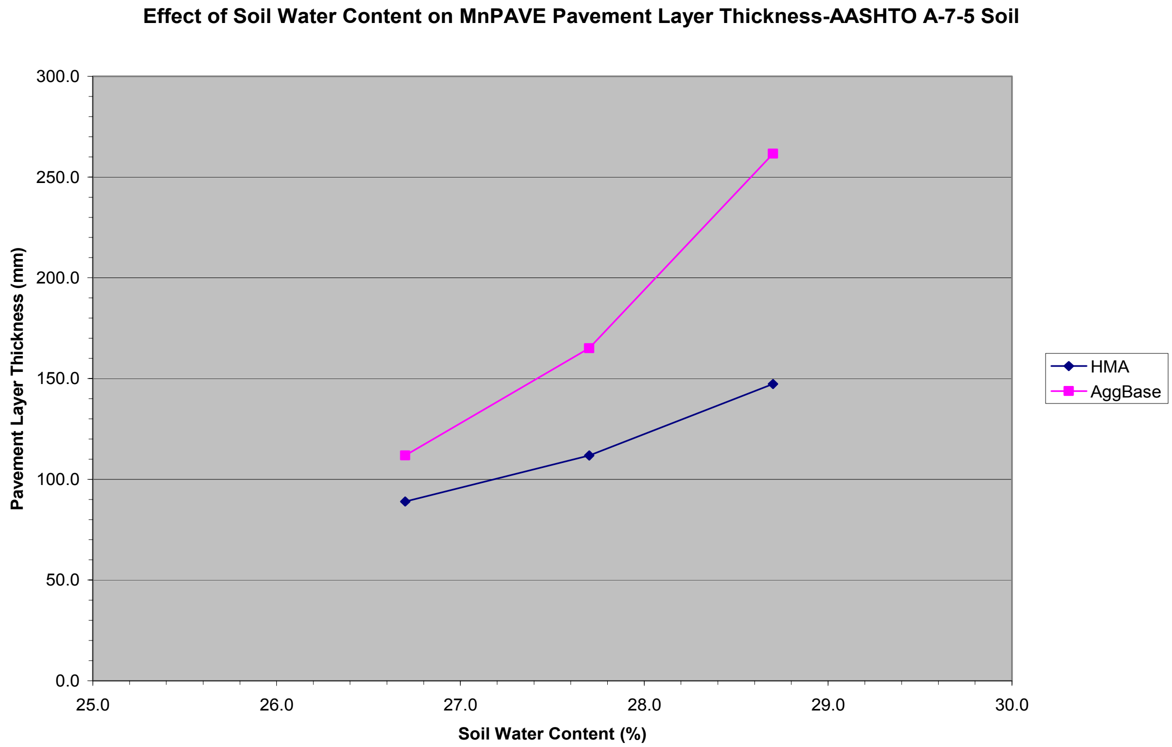


**Figure 7: Effect of Soil Water Content on MnPAVE Pavement Layer Thickness-AASHTO A-7-5 Soil**

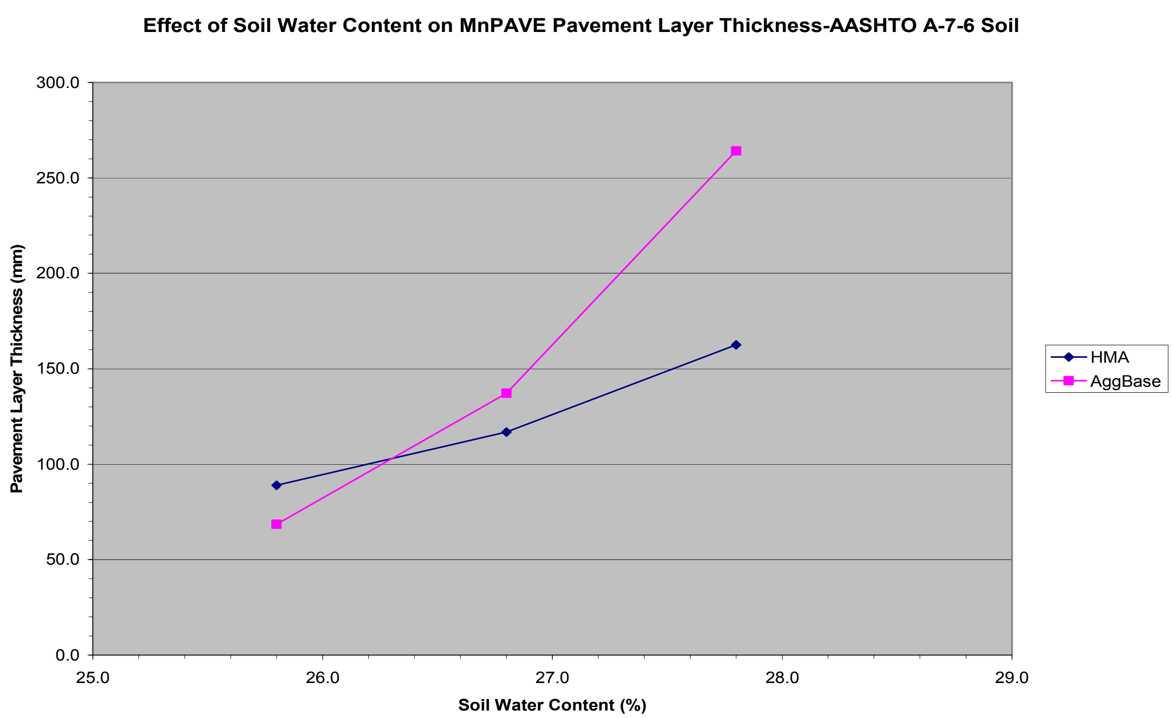


**Figure 8: Effect of Soil Water Content on MnPAVE Pavement Layer Thickness-AASHTO A-7-6 Soil**

## *Task 7. Assessment of Costs of Alternative Practices*

# *Estimation of the Long-term Present Value Maintenance Costs of Alternative Storm Water Control Facilities*

**by**

**Dario J. Canelon, Visiting Associate Professor**
**John L. Nieber, Professor**

**Department of Biosystems and Agricultural Engineering**
**University of Minnesota**

**August 22, 2005**

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# Chapter 1

# Introduction

Alternative storm water management practices represent a different approach to treat the quantity and quality of runoff water. One common alternative practice is known as the Infiltration Approach because it promotes the evacuation of runoff water through an infiltration process. During this infiltration process, some pollutants are removed from the water, improving its quality; moreover, runoff water reaches downstream water bodies gradually. In contrast, the conventional approach to treat storm water, known as the Conveyance Approach, is intended to take water away from the roads as soon as possible, without favoring water quality. These alternative storm water management practices, however, represent an additional cost in the construction of highway infrastructure; they could also affect its life span and the associated maintenance costs if any negative impact on the infrastructure is detected, and attributed to the practices.

The present report summarizes accepted procedures to estimate the maintenance cost of selected storm water best management practices. It also relates the potential impact of these practices in the long-term maintenance cost of highway infrastructure.

Chapter 2 is dedicated to the problem of cost estimation for well known storm water best management practices. (How does this relate to the topic?) Emphasis is made in the estimation of the Water Quality Volume, or runoff volume needed to size the different BMP's and estimate the cost for most of them. Runoff volume is estimated for a rainfall depth of one (1) inch, as it is recommended in the literature. Also in this chapter, a brief discussion of the potential negative impact of alternative storm water BMPs in the long-term maintenance cost is presented.

Finally, the Appendix contains all the computations performed in the process of estimating the maintenance cost for each of the selected alternative storm water best management practices.

# Chapter 2

# Estimation of Maintenance Costs

## 2.1 Introduction

The estimation of the maintenance costs for alternative storm water management approaches will be made using the methodology proposed by the Environmental Protection Agency for Best Management Practices (USEPA, 2004), which is outlined in the following paragraphs.

The cost estimation method to follow will be the Parametric Method, which relies on relationships between cost and design parameters. These relationships are usually statistically-based or model-based. This method, also known as top down estimating is used when costs per component of the design are not available.

The elements considered in the cost analysis are **Total Costs** and **Life Cycle Costs**. Total Costs include both capital (construction and land) and annual Operation and Management costs. Life Cycle Costs refers to the total project costs across the life span of a BMP, including design, construction, O&M, and closeout activities.

**Capital Costs** are those expenditures that are required to construct a BMP. Typically these can be estimated using equations based on the size or volume of water to be treated, such as in the relation, $\mathbf{C = a \cdot P^b}$. For this report, those equations are developed using data derived from Weiss *et al*. (Mn/DOT, 2005), who carried out an excellent work about the cost and effectiveness of storm water management practices.

**Design, Permitting, and Contingency Costs** include costs for site investigations, surveys, design and planning of a BMP. Contingency costs are unexpected costs during construction of a BMP. This type of cost will be estimated as 32% of the capital costs (USEPA, 2004).

**Operation and Maintenance Costs** are those post-construction costs necessary to ensure or verify the continued effectiveness of a BMP. These costs are seldom available in a comprehensive basis and have been expressed as a fraction of capital costs. In this report, that fraction will vary between 1% and 20%, depending on the BMP under consideration (USEPA, 2004). Weiss *et al*. (Mn/DOT, 2005) collected data from several sources and, in some cases, found considerable differences with respect to values from USEPA (2004).

**Land Costs** are site specific and extremely variable both regionally and by surrounding land use. They will not be taken into account in the present study.

**Inflation and Regional Cost Adjustments** are needed for inflation and regional differences. For the Twin Cities area, this adjustment factor is approximately 1.04, which comes from the ratio between the regional adjustment factor (1.16) and a precipitation adjustment factor (1.12) (USEPA, 2004).

**Life Cycle Costs** refer to the total project costs across the life span of a BMP, including design, construction, O&M, and closeout activities. They include the initial capital costs and the present worth of annual O & M costs, less the present worth of the salvage at the end of the service life. Life cycle cost analysis can be used to choose the most cost effective BMP from a series of alternatives so that the least long term cost is achieved. The present worth (PW) of a series of future payments is calculated using the following equation:

$$PW_{total} = \sum_{i=1}^{i=n} \frac{x_t}{(1+i)^t} \tag{2.1}$$

Where $x_t$ is the payment in year $t$, $i$ is the discount rate and $n$ is the period of time considered. Common values for $n$ and $i$ are 20 and 0.07, respectively (USEPA, 2004).

## 2.2 Water Quality Volume

The cost of any storm water best management practice depends upon the size of the facility, and this size usually is based on the volume of water the facility will treat. This volume of water is called the Water Quality Volume (WQV), and can be calculated as follows (Mn/DOT, 2005):

$$WQV = \left(\frac{43560}{12}\right) \cdot P \cdot Rv \cdot A \tag{2.2}$$

where **P** is the design precipitation depth (in), Rv is the ratio of runoff to rainfall in the watershed, and A is the watershed area (ac). The value of Rv can be calculated as follows:

$$Rv = P/Q = \frac{K \cdot T^x}{(D+b)^n} \Bigg/ \frac{(P-0.2S)^2}{(P+0.8S)} \tag{2.3}$$

where **T** is the return period (yr), **D** is the storm duration (hr), **Q** is the runoff depth (in), **S** is the potential runoff (in), and **K**, **x**, **b**, and **n** are coefficients. For the Twin Cities area, **K** = 1.258, **x** = 0.176, **b** = -0.076, and **n** = -0.239 (Wilson, 2005); for other areas, appropriate values for those coefficients must be used.

The value of **S** can be calculated as follows:

$$S = \frac{1000}{CN} - 10 \tag{2.4}$$

where CN is the curve number.

The procedure to calculate runoff depth (Q) and runoff volume (Qv or WQV) is shown next in Table 2.1. This table includes different sizes of drainage areas. A rainfall depth of 1 inch was assumed for runoff depth, which is a common value recommended in the literature (USEPA, 2004). The Water Quality Volume for the Twin Cities area is shown in Fig. 1.

**Table 1. Estimation of Water Quality Volume in the Twin Cities Area**

$$Q = \frac{(P-0.2\,S)^2}{(P+0.8\,S)}$$ where **Q** is the runoff depth (in), **P** is the rainfall depth (in), **S** is the potential runoff (in)

$$S = \frac{1000}{CN} - 10$$ where **CN** is the Curve Number

S = 1.7647 (for a CN ≈ 85)

| VARIABLES | DRAINAGE AREA | | | | |
|---|---|---|---|---|---|
| | **0.5 ac** | **1 ac** | **5 ac** | **10 ac** | **50 ac** |
| **P** (in) | 1 | 1 | 1 | 1 | 1 |
| **Q** (in) | 0.1736 | 0.1736 | 0.1736 | 0.1736 | 0.1736 |
| **Qv** (in-sm) | 0.0001 | 0.0003 | 0.0014 | 0.0027 | 0.0136 |
| **Qv** (cf) | 315 | 630 | 3151 | 6302 | 31511 |
| **Qv** (ac-ft) | 0.0072 | 0.0145 | 0.0723 | 0.1447 | 0.7235 |

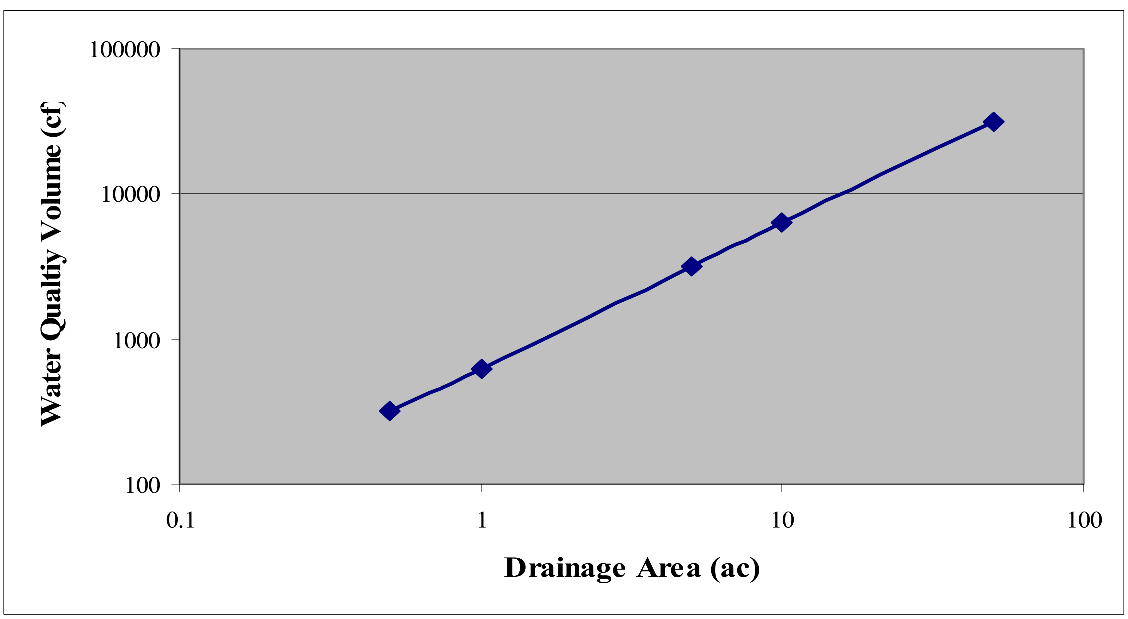


**Figure 1. Water Quality Volume computed for the Twin Cities Area**

### 2.3 Cost Estimation

Although the general approach followed to estimate cost is similar for all the BMP's, there are some differences for a few of them in part of the process, especially in the estimation of the construction cost and the maintenance cost. The equations presented next can be used to estimate construction costs for common BMPs; data needed to develop them was taken from the work of Weiss *et al*. (Mn/DOT, 2005).

- Dry Pond $CC = 97.338 \cdot WQV^{-0.3843}$
- Wet Pond $CC = 230.16 \cdot WQV^{-0.4282}$
- Constructed Wetland $CC = 53.211 \cdot WQV^{-0.3576}$
- Infiltration Trench $CC = 44.108 \cdot WQV^{-0.1991}$
- Sand Filter $CC = 389.00 \cdot WQV^{-0.3951}$
- Bioretention $CC = 0.0001 \cdot WQV + 9.00022$
- Grass Swales $CC = 21.779 \cdot \ln(A) - 42.543$

Regarding maintenance cost, it is usually estimated as a fraction of construction cost; values used for common BMPs are presented next (taken from USEPA, 2004).

- Dry Pond <1%
- Wet Pond 3 to 6%
- Constructed Wetland 3 to 6%
- Infiltration Trench 5 to 20%
- Infiltration Basin 1 to 3%
- Sand Filter 11 to 13%
- Bio-Retention 5%

The computational process to estimate the present worth maintenance cost for Dry Ponds is presented in Table 3, as an example; details for other best management practices are presented in Appendixes A1 to A7.

Figure 2 shows the present worth maintenance cost, based on water quality volume from 1-inch rainfall depth, for selected storm water best management practices, such as Dry Ponds, Wet Ponds/Infiltration Basins, Infiltration Trenches, Sand Filters, Constructed Wetlands, and Bioretention Areas. On the other hand, Figure 3 shows the present worth maintenance cost, based on the treated area, for Grassed Swales. Details of total cost estimation for all of those storm water best management practices are also presented in Appendixes A1 to A7.

### 2.4 Potential Negative Impact

Storm water best management practices constitute a very important alternative to treat urban runoff, because they promote its infiltration and, therefore, improve its quality and decrease the risk of potential flooding. They have been widely implemented both in the state of Minnesota and nationwide, and are currently the subject of intense evaluation in order to improve their performance. However, a concern about these alternative storm water management practices is the potential negative impact on the highway infrastructure itself, due to the fact that water is held for a certain period of time on the

**Table 2. Present Worth Cost Estimation for Dry Ponds, for a period of analysis (n) of 20 years and a discount rate (i) of 7%**

**BASIC DATA AND EQUATIONS**

| | |
|---|---|
| **LFC = CC + DC + MC** | **LFC** is the life cycle cost ($)<br>**CC** is the construction cost ($)<br>**DC** is the design, permitting, erosion control, and contingency cost ($) |
| $CC = 97.338\ Qv^{-0.3872}$ | **CC** in $/cf  **DC = 32% CC** |
| **MC = 1% CC x MDF** | **MDF** is the multiyear discount factor |
| $MDF = \sum_{t=1}^{t=n} \frac{1}{(i+1)^t}$ | **i** is the discount rate (fraction)<br>**t** is the period of analysis (year) |

| | **DRAINAGE AREA** | | | | |
|---|---|---|---|---|---|
| **COST TYPE** | **0.5 ac** | **1 ac** | **5 ac** | **10 ac** | **50 ac** |
| **Qv (cf)** | 315 | 630 | 3151 | 6302 | 31511 |
| **CC ($)** | 3306 | 5056 | 13556 | 20730 | 55582 |
| **DC ($)** | 1058 | 1618 | 4338 | 6634 | 17786 |
| **MC ($)** | 350 | 536 | 1436 | 2196 | 5888 |
| **LCC ($)** | 4715 | 7210 | 19330 | 29560 | 79257 |

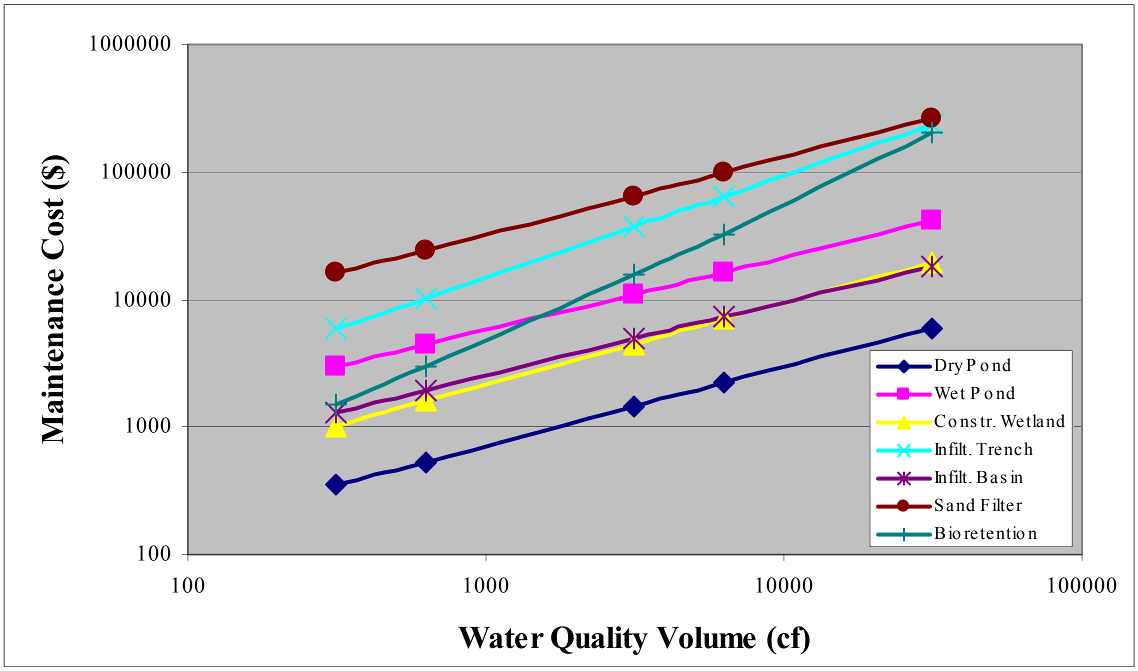


**Figure 2. Present Worth Maintenance Costs for Selected Storm Water BMP, for a period of analysis (n) of 20 years and a discount rate (i) of 7%**

surface while it infiltrates and could increase the water content of adjacent roads. In order to address that concern, Otto and Nieber (2005) evaluated the potential negative impact using two different approaches, the MnDOT Surface Rating Index (MnDOT SR) and the MnDOT PAVE Model (MnDOT PAVE).

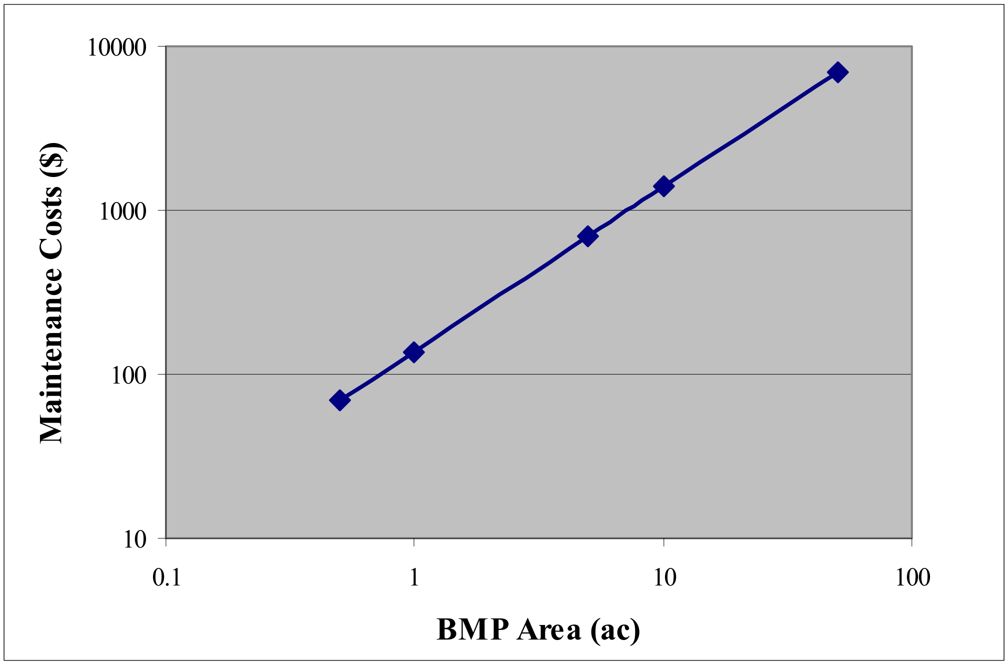


**Figure 3. Present Worth Maintenance Costs for Grassed Swales, for a period of analysis (n) of 20 years and a discount rate (i) of 7%**

The Surface Rating (SR), a tool developed by the Minnesota Department of Transportation (MnDOT), is a crack and surface distress index that evaluates the pavement condition (Reference). The SR uses a 0.0–4.0 rating scale, where the higher number, the less distress present. On the other hand, MnPAVE is software used to design flexible pavements given the climatic conditions, pavement structure, material properties, and traffic volumes. The software can also estimate pavement design life given the same inputs. MnPAVE is capable of modeling the effects of variable subgrade soil resilient modulus ($M_r$) on pavement life. The Mr is a representation of the stiffness of a soil. As water content increases, the $M_r$ of most fine-grained soils decreases.

Based on the analyses using the MnDOT Surface Rating pavement quality index and statistical test of their hypothesis, Otto and Nieber (2005) concluded that there is no negative impact of existing alternative storm water control facilities on roadway infrastructure. When using MnPAVE, they found that as water content increases and $M_r$ decreases, the fatigue and rutting lives decrease. On a second MnPAVE analysis, it was found that as water content increases and $M_r$ decreases, it requires more pavement and foundation material to be able to achieve a 20 year design life.

According to these results of the SR analysis, it is not possible to conclude that negative impacts are currently present due to the alternative storm water best management practices located adjacent to the roads. However, more research needs to be done in this regard because it was demonstrated with the MnPAVE analysis that any increase in the water content of the pavement subgrade soil will decrease the lifetime of the road.

### 2.5 Tentative Approach to Estimate Increase in Maintenance Costs

The increase in maintenance costs due to the potential increase in water content in best management practices located adjacent to roads can also be calculated as a fraction of the increase of construction costs. Now, the increase of construction cost could be estimated in a preliminary way using different approaches.

**Approach 1:** To install tile drains in the vicinity of the BMPs adjacent to roads, either edge drains or central drains. By doing this, the water content of the subgrade material will not increase due to the presence of the BMPs. The construction cost of the road will increase because of installation cost of these drains.

**Approach 2:** To increase the thickness of the pavement to avoid decrease in both the Fatigue Life and the Rutting Life of the pavement. By doing this, the estimated lifetime of the road will not decrease even if water content increases. The construction cost of the road will increase because more material is needed to build it.

**Approach 3:** To estimate the decrease in fatigue life of the road due to the increase in water content in the subgrade material. By doing this, it will be possible to determine the actual lifetime of the road and, therefore, when this road needs to be replaced. The construction will increase, in the long range, because the road will be replaced earlier than expected. This approach is developed next.

From Otto and Nieber (2005) it can be observed that the fatigue life of the road decreases consistently when the water content of it increases (Fig. 4). In other words, any relative increase in water content of the road can be associated with a relative decrease in fatigue life of the road (Fig. 5). The cost analysis of a road is commonly based on its estimated lifecycle and a market discount rate using the following equation:

$$\mathrm{CRF} = \frac{i(i+1)^n}{(i+1)^n - 1} \tag{2.5}$$

Where,

| | |
|---|---|
| CRF | is the capital recovery factor |
| i | is the market discount rate |
| n | is the lifecycle of the road |

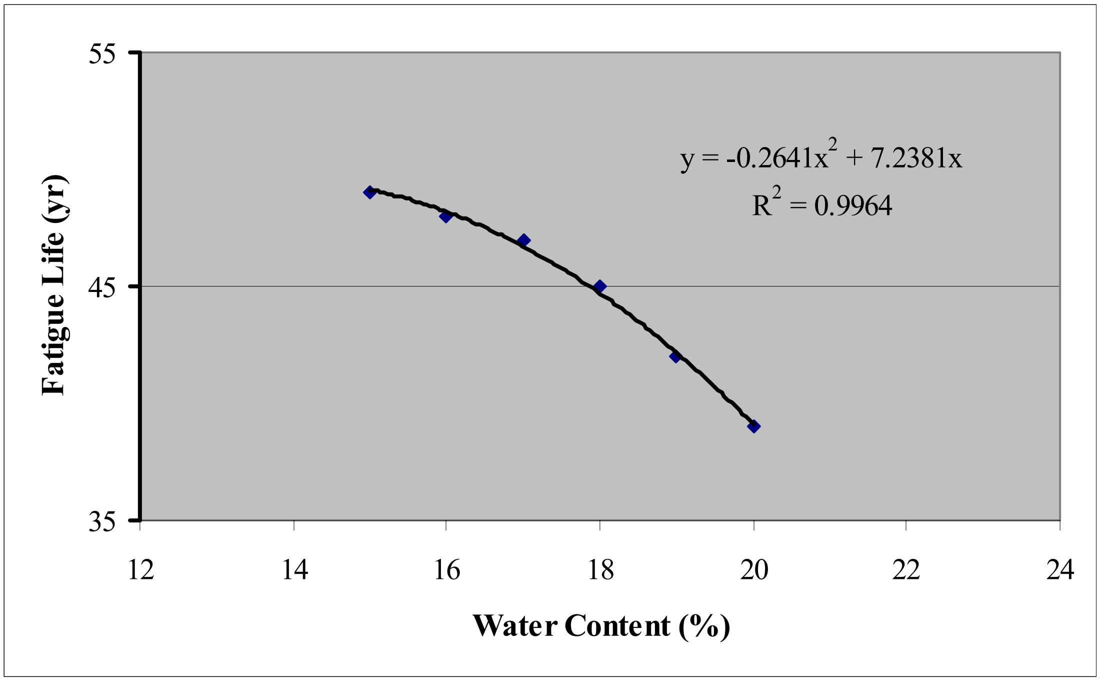


**Figure 4. Relationship between Fatigue Life and Water Content**

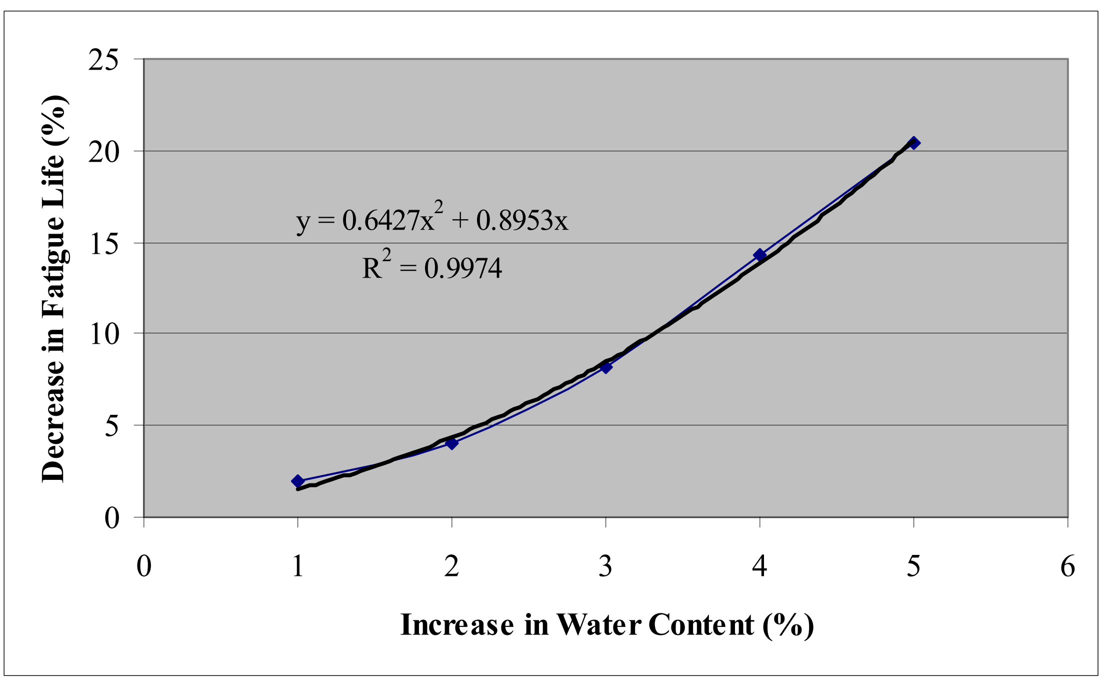


**Figure 5. Decrease in Fatigue Life due to Increase in Water Content**

Using this equation, it is possible to calculate the annual construction cost of the road along its lifecycle. So, if the decrease in fatigue life of the road, from Fig. 5, is associated with a similar decrease in its lifecycle, it would be possible to calculate a new CRF and, therefore, the increase in the construction cost of the road. In other words, if the lifecycle decreases, the CRF will increase and, accordingly, the annual construction cost of the road will also increase, such as it is shown in Fig. 6.

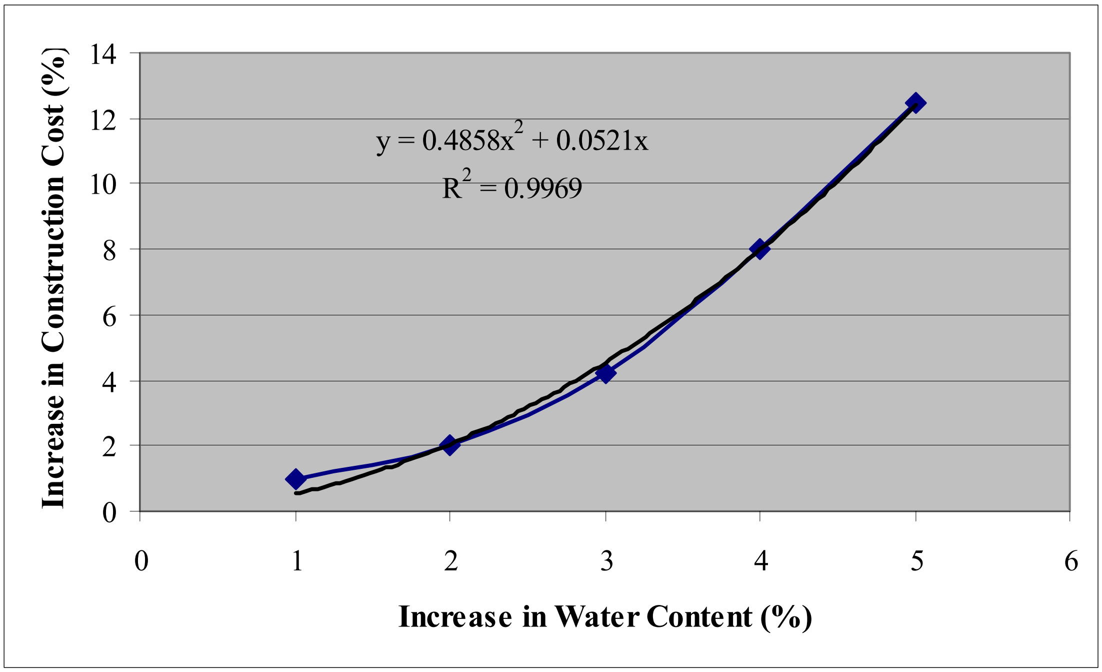


**Figure 6. Increase in Construction Costs due to Increase in Water Content**

As an example, using the equation from Fig. 6, for an increase of water content of 5%, the decrease in fatigue life of the road and, therefore, in its lifecycle, will be of 20.41%. For a normal lifecycle of 20 years, the reduced lifecycle will be now around 16 years. Using a market discount rate (i) of 0.07, the new CRF will be 0.1062, instead of 0.0944, representing an increase in construction costs of 12.47%. For an increase of water content of 8%, the new lifecycle will be 10.34 years, and the increase in the construction cost will be 47.36%.

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# Appendix A

# Cost Estimation of Selected Storm Water Best Management Practices

## Appendix A1: Cost Estimation for Wet Ponds

**BASIC DATA AND EQUATIONS**

**LFC = CC + DC + MC** — **LFC** is the life cycle cost ($); **CC** is the construction cost ($); **DC** is the design, permitting, erosion control and contingency cost ($)

$$CC = 230.16\ Qv^{-0.4282}$$

**CC** in $/cf — **DC = 32% CC**

**MC = 4.5% CC x MDF** — **MDF** is the multiyear discount factor

$$MDF = \sum_{t=1}^{t=n} \frac{1}{(i+1)^t}$$

**i** is the discount rate (fraction)
**t** is the period of analysis (year)

| | DRAINAGE AREA | | | | |
|---|---|---|---|---|---|
| **COST TYPE** | **0.5 ac** | **1 ac** | **5 ac** | **10 ac** | **50 ac** |
| **Qv (cf)** | 315 | 630 | 3151 | 6302 | 31511 |
| **CC ($)** | 6175 | 9179 | 23038 | 34243 | 85950 |
| **DC ($)** | 1976 | 2937 | 7372 | 10958 | 27504 |
| **MC ($)** | 2944 | 4376 | 10983 | 16325 | 40975 |
| **LCC ($)** | 11095 | 16491 | 41393 | 61526 | 154429 |

## Appendix A2: Cost Estimation for Constructed Wetlands

**BASIC DATA AND EQUATIONS**

**LFC = CC + DC + MC** — **LFC** is the life cycle cost ($); **CC** is the construction cost ($); **DC** is the design, permitting, erosion control and contingency cost ($)

$$CC = 53.211\ Qv^{-0.3576}$$

**CC** in $/cf — **DC = 32% CC**

**MC = 4.5% CC x MDF** — **MDF** is the multiyear discount factor

$$MDF = \sum_{t=1}^{t=n} \frac{1}{(i+1)^t}$$

**i** is the discount rate (fraction)
**t** is the period of analysis (year)

| | DRAINAGE AREA | | | | |
|---|---|---|---|---|---|
| **COST TYPE** | **0.5 ac** | **1 ac** | **5 ac** | **10 ac** | **50 ac** |
| **Qv (cf)** | 315 | 630 | 3151 | 6302 | 31511 |
| **CC ($)** | 2143 | 3345 | 9406 | 14682 | 41287 |
| **DC ($)** | 686 | 1070 | 3010 | 4698 | 13212 |
| **MC ($)** | 1022 | 1595 | 4484 | 6999 | 19683 |
| **LCC ($)** | 3850 | 6010 | 16900 | 26380 | 74181 |

## Appendix A3: Cost Estimation for Infiltration Trenches

**BASIC DATA AND EQUATIONS**

**LFC = CC + DC + MC** — **LFC** is the life cycle cost ($)
**CC** is the construction cost ($)
**DC** is the design, permitting, erosion control and contingency cost ($)

$CC = 44.108\ Qv^{-0.1991}$ — **CC** in $/cf — **DC = 32% CC**

**MC = 12.5% CC x MDF** — **MDF** is the multiyear discount factor

$$MDF = \sum_{t=1}^{t=n} \frac{1}{(i+1)^t}$$

**i** is the discount rate (fraction)
**t** is the period of analysis (year)

| **COST TYPE** | **DRAINAGE AREA** | | | | |
|---|---|---|---|---|---|
| | **0.5 ac** | **1 ac** | **5 ac** | **10 ac** | **50 ac** |
| **Qv (cf)** | 315 | 630 | 3151 | 6302 | 31511 |
| **CC ($)** | 4421 | 7702 | 27953 | 48700 | 176739 |
| **DC ($)** | 1415 | 2465 | 8945 | 15584 | 56556 |
| **MC ($)** | 5855 | 10200 | 37017 | 64491 | 234046 |
| **LCC ($)** | 11691 | 20367 | 73915 | 128774 | 467341 |

## Appendix A4: Cost Estimation for Infiltration Basins

**BASIC DATA AND EQUATIONS**

**LFC = CC + DC + MC** — **LFC** is the life cycle cost ($)
**CC** is the construction cost ($)
**DC** is the design, permitting, erosion control and contingency cost ($)

$CC = 230.16\ Qv^{-0.4282}$ — **CC** in $/cf — **DC = 32% CC**

**MC = 2% CC x MDF** — **MDF** is the multiyear discount factor

$$MDF = \sum_{t=1}^{t=n} \frac{1}{(i+1)^t}$$

**i** is the discount rate (fraction)
**t** is the period of analysis (year)

| **COST TYPE** | **DRAINAGE AREA** | | | | |
|---|---|---|---|---|---|
| | **0.5 ac** | **1 ac** | **5 ac** | **10 ac** | **50 ac** |
| **Qv (cf)** | 315 | 630 | 3151 | 6302 | 31511 |
| **CC ($)** | 6175 | 9179 | 23038 | 34243 | 85950 |
| **DC ($)** | 1976 | 2937 | 7372 | 10958 | 27504 |
| **MC ($)** | 1308 | 1945 | 4881 | 7255 | 18211 |
| **LCC ($)** | 9460 | 14061 | 35292 | 52457 | 131666 |

## Appendix A5: Cost Estimation for Sand Filters

**BASIC DATA AND EQUATIONS**

| | |
|---|---|
| **LFC = CC + DC + MC** | **LFC** is the life cycle cost ($)<br>**CC** is the construction cost ($)<br>**DC** is the design, permitting, erosion control, and contingency cost ($) |
| $CC = 389\ Qv^{-0.3951}$ | **CC** in $/cf  **DC = 32% CC** |
| **MC = 12% CC x MDF** | **MDF** is the multiyear discount factor |
| $MDF = \sum_{t=1}^{t=n} \frac{1}{(i+1)^t}$ | **i** is the discount rate (fraction)<br>**t** is the period of analysis (year) |

| | DRAINAGE AREA | | | | |
|---|---|---|---|---|---|
| **COST TYPE** | **0.5 ac** | **1 ac** | **5 ac** | **10 ac** | **50 ac** |
| **Qv (cf)** | 315 | 630 | 3151 | 6302 | 31511 |
| **CC ($)** | 12626 | 19203 | 50835 | 77314 | 204676 |
| **DC ($)** | 4040 | 6145 | 16267 | 24741 | 65496 |
| **MC ($)** | 16051 | 24412 | 64626 | 98288 | 260200 |
| **LCC ($)** | 32718 | 49759 | 131729 | 200343 | 530372 |

## Appendix A6: Cost Estimation for Bio-Retention Areas

**BASIC DATA AND EQUATIONS**

| | |
|---|---|
| **LFC = CC + DC + MC** | **LFC** is the life cycle cost ($)<br>**CC** is the construction cost ($)<br>**DC** is the design, permitting, erosion control and contingency cost ($) |
| **CC = 0.0001 Qv + 9.0002** | **CC** in $/cf  **DC = 32% CC** |
| **MC = 5% CC x MDF** | **MDF** is the multiyear discount factor |
| $MDF = \sum_{t=1}^{t=n} \frac{1}{(i+1)^t}$ | **i** is the discount rate (fraction)<br>**t** is the period of analysis (year) |

| | DRAINAGE AREA | | | | |
|---|---|---|---|---|---|
| **COST TYPE** | **0.5 ac** | **1 ac** | **5 ac** | **10 ac** | **50 ac** |
| **Qv (cf)** | 315 | 630 | 3151 | 6302 | 31511 |
| **CC ($)** | 2846 | 5712 | 29353 | 60692 | 382894 |
| **DC ($)** | 911 | 1828 | 9393 | 19421 | 122526 |
| **MC ($)** | 1508 | 3026 | 15548 | 32149 | 202819 |
| **LCC ($)** | 5264 | 10565 | 54295 | 112262 | 708239 |

## Appendix A7: Cost Estimation for Vegetated Swales

**BASIC DATA AND EQUATIONS**

**LFC = CC + DC + MC** — **LFC** is the life cycle cost ($)
**CC** is the construction cost ($)

**DC = 32% CC** — **DC** is the design, permitting, erosion control, and contingency cost ($)

**CC = $0.50 A** — **A** is the surface area of the swale (sf)

**MC = 6% CC x MDF** — **MDF** is the multiyear discount factor

$$MDF = \sum_{t=1}^{t=n} \frac{1}{(i+1)^t}$$

**i** is the discount rate (fraction)
**t** is the period of analysis (year)

| **COST TYPE** | **DRAINAGE AREA** | | | | |
|---|---|---|---|---|---|
| | **0.5 ac** | **1 ac** | **5 ac** | **10 ac** | **50 ac** |
| **A (sf)** | 218 | 436 | 2178 | 4356 | 21780 |
| **CC ($)** | 109 | 218 | 1089 | 2178 | 10890 |
| **DC ($)** | 35 | 70 | 348 | 697 | 3485 |
| **MC ($)** | 69 | 138 | 692 | 1384 | 6922 |
| **LCC ($)** | 213 | 426 | 2130 | 4259 | 21297 |