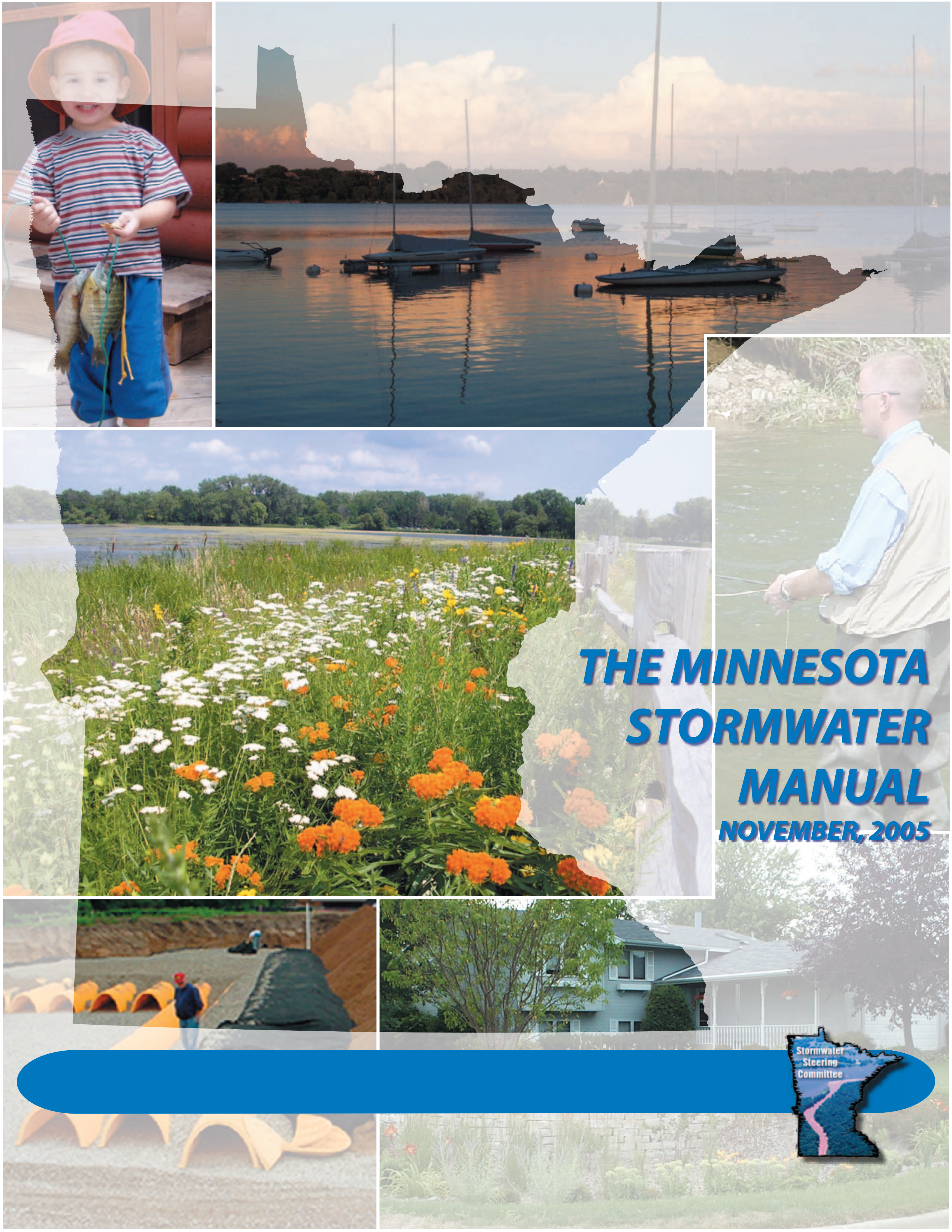

THE MINNESOTA STORMWATER MANUAL

NOVEMBER, 2005

Stormwater Steering Committee

The Minnesota Stormwater Manual

Version 1.0
November 2005

Created by the Minnesota Stormwater Steering Committee

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VOLUME 1: INTEGRATED STORMWATER MANAGEMENT

Stormwater Steering Committee Vision:

To ensure a high quality of life, Minnesotans must manage stormwater in a way that conserves, enhances and restores high-quality water in our rivers, lakes, streams, wetlands, and ground water.

Message from the Stormwater Steering Committee

This Manual provides direction and guidance for stormwater management in Minnesota. The Stormwater Steering Committee wants you, through your active use of and feedback on the Manual, to help Minnesota reach our vision for stormwater management in Minnesota.

The Manual is intended as a guidance document. It will help users identify and appropriately use the best practices to protect Minnesota's water resources from adverse impacts associated with stormwater runoff. Some practices in the Manual go beyond today's requirements, and are so identified. Others help to clarify how and when to use currently accepted practices to meet water quality goals. The Manual looks beyond current practices and addresses special situations such as protection of a trout stream or stormwater management in karst areas. Some practices discussed are designed to address unique site conditions and may not be readily adaptable for across-the-board applications.

The Manual does not establish new regulatory requirements and does not supersede existing local, state or federal requirements. Because the Manual combines standard practices with innovative and site specific recommendations, it is strongly recommended that regulators use this Manual only as supporting guidance and not wholly incorporate the Manual by reference in regulatory requirements.

Feedback from users is needed to gauge the Manual's use and to justify ongoing updates. Case studies on the use and implementation of the Manual recommendations will be particularly useful. Please submit comments and suggested updates based on new technologies, better information, or new studies, to assist us in keeping the Manual accurate and relevant. Feedback on the Manual can be submitted through the Manual Web-site at: http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html.

The Stormwater Steering Committee hopes you find the Manual to be an effective tool in managing stormwater runoff in Minnesota.

Preface

Welcome to the *Minnesota Stormwater Manual*. This Manual was initiated by the Minnesota Stormwater Design Team, which evolved into the Minnesota Stormwater Steering Committee (SSC). Manual production was directed by the SSC's Manual Sub-Committee (MSC). A listing of contributors and participants in the process appears in the Acknowledgement section.

Throughout the production of the Manual, one singular goal was kept in mind –to produce a useful product that helps the everyday user better manage stormwater. The purpose, goal (see box below), vision and tenets of the original Stormwater Design Team are available at http://www.pca.state.mn.us/publications/wq-strm8-01a.pdf. Although stormwater management to control the pollution of receiving waters has been around in earnest for over 20 years in Minnesota, the advent of many new programs means that guidance is needed more than ever. Such programs as the NPDES (National Pollutant Discharge Elimination System) Phase I and II program, the TMDL (Total Maximum Daily Load) program, and strong runoff control programs at the local and watershed levels have all contributed to the need for this information to be compiled in a comprehensive, technically sound document.

The directive the Manual Sub-Committee received from the SSC was to produce a document that could be used as a single source to guide stormwater managers through the maze of regulations, Best Management Practices (BMP) designs, models/techniques and terminology that constitute "good stormwater management." It does not address the requirements of other non-stormwater related regulatory programs that can have an effect on stormwater. Related to this was the charge to produce a Manual that does not duplicate the many good sources of information already available. Because Minnesota is fortunate enough to have had many additional tools created over the years, the Manual will often forego detailed explanation of a particular element and send the user directly to another resource via electronic linkage or cited reference. These linked resources provide information that Minnesota stormwater managers can put to use in conjunction with this *Minnesota Stormwater Manual*. The Manual is intended to be flexible, easily updated and responsive to the needs of the Minnesota stormwater community.

The Stormwater Steering Committee members agreed to support this Manual and relay it to the public. Although all members do not agree with all elements or concepts contained in the Manual, they did support release of the Manual as a constructive tool for use by stormwater professionals, regulators, plan reviewers, and the public. Concepts presented in this Manual are intended to be flexible guidance for users rather than stringent rules. Each stormwater problem is different, so solutions will need to be customized to address this variation. This Manual provides the tools, but the user must provide the ingenuity.

Goal of the Stormwater Design Team:

Using expertise from a wide range of stakeholders, design a long-term state effort to reduce or eliminate the adverse environmental effects of stormwater discharge to Minnesota's lakes, rivers, streams, wetlands, and ground water.

Acknowledgements

The Minnesota Stormwater Steering Committee had its genesis in the Stormwater Design Team, which began its activities in September of 2003. Discussion within this Team led to the recognition that a state-sponsored stormwater Manual was needed to provide guidance for the many practitioners trying to make their way through a complicated stormwater management program in the state. The Stormwater Design Team evolved into the Minnesota Stormwater Steering Committee, which initiated the production of this *Minnesota Stormwater Manual*. Preparation of the Manual was guided by the SSC's Manual Sub-Committee (MSC). The following individuals were involved in the initiation, preparation or review of this document:

State of Minnesota Authorized Representative

- Brian Livingston, MPCA Stormwater Coordinator

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- Ted Brown, P.E.
- Sally Hoyt
- Jennifer Zielinski, P.E.

Introduction to the Manual

"Land of 10,000 Lakes" does not capture the abundance of water and water-related resources in the state of Minnesota. Not only is Minnesota the home of more than 10,000 lakes, but there are also some 69,000 miles of rivers and streams, over nine million acres of wetlands, nearly 2,000 miles of trout streams, and ground water aquifers and surface water sources capable of producing drinking water for about four million residents. The headwaters of the Mississippi River are located in the state and we border the largest freshwater lake in the world, Lake Superior. Protecting, restoring, and maintaining these natural resources, although challenging, must be a priority for all Minnesotans. We all contribute to the contamination that deteriorates our waterways, so it is everyone's responsibility to minimize these threats and keep our water clean. Protecting the waters of our state plays a huge role in protecting the culture and heritage of our home.

Minnesota's water and related environment is complex which can, in turn lead to very complicated management systems. As thousands of acres of land are converted annually from rural and open areas to urbanized communities, the impacts on stormwater runoff can become extreme. With these changes to the surface of the land comes the responsibility of assuring that surrounding waters are not adversely affected. As development escalates, so does runoff. With urbanization, the natural infiltration of water into the ground is reduced. Larger runoff volumes, quicker and higher runoff peaks, and increased erosion are a few of the results that lead to more pollutants eventually making their way to the receiving waters. The challenge for all Minnesotans is to control runoff rate and volume as well as the material that this water picks up on its way to a receiving water.

This Manual explores a variety of management approaches designed to lesson the impacts of development. Although other sources of runoff, such as agriculture and forestry can contribute to water quality deterioration, this Manual focuses on urban sources related to development. Totally eliminating land conversion is not a feasible option, so appropriate and innovative measures must be taken to minimize the negative impact of development. The Manual explores an array of best management practices (BMPs) that can be implemented to control sediment and reduce runoff in a practical and flexible manner on the site. The term "integrated stormwater management" encompasses all aspects of precipitation as it moves from the land surface to the receiving water. The focus of this Manual is to guide users in such a way that all possible measures are taken to ensure proper, responsible stormwater management.

There are many bodies of water in Minnesota that have already been impacted by various pollutants and are in need of improvement. Any water that does not meet the water

MN Resource Facts:

Number of lakes: 11,842 (10+ acres)

Number of natural rivers and streams: 6,564 (69,200 miles)

Lakes/Rivers (deep water): 2,560,299 acres

Total surface water area including wetlands: 13,136,357 acres (20,525.56 sq. mi.)

Wetlands present in 1850 (estimated): 18.6 million acres

Wetlands present in 2003 (estimated): 9.3 million acres (14,531.25 square miles)

Surface water acreage if estimated wetlands subtracted from total above: 3,836,357 acres (5,994 sq. mi.)

Minnesota is first nationally in the sales of fishing licenses per capita.

Fishing waters: 3,800,000 acres

Fishable lakes: 5,493

Fishable streams (cold and warm water): 15,000 miles

Trout streams: 1,900 miles

Forest land: 16.7 million acres

Total area: 86,938.87 sq. mi.

State population: 4,919,479

Population density (people per square mile): 61.8

Source: http://www.dnr.state.mn.us/faq/mnfacts/water.html (last updated 2003) quality standards established to protect it and deem it useable for its intended purpose is classified by the Minnesota Pollution Control Agency (MPCA) as an “Impaired Water.” The 2004 Minnesota (303d) list of impaired waters contains 1,890 impairments for 1,115 water bodies, many of which are impaired for more than one pollutant. This number is an increase from the 2002 list, and it is anticipated that there will be another increase observed when the April 2006 list is published. This is the result of better data collection that allows for more assessment of where actual impairments are occurring.

There are no proposals for regulatory changes in the Manual; however, there are some recommendations to improve the stormwater standards that are typically used in Minnesota. This was done with the hope of initiating discussions on methods to improve stormwater management, the definition of what constitutes an improvement, and better options for implementing such improvements. As a result of the discussions and input form Minnesota’s stormwater community, there may be the potential at some point to include some of these ideas into regulatory framework. The intent of the Manual is to promote innovation and generate ideas of new stormwater management practices.

Users will also note that this Manual is not an erosion and sediment control handbook, nor is it a BMP manual, although there are features of each within the Manual. Again, users are directed to available resources so that this Manual did not become so long as to be cumbersome and therefore unused.

Finally, the Manual primarily addresses the post-construction requirements of the NPDES MS4 permit program. Elements of the Manual exist for each of the six required Municipal Separate Storm Sewer System (MS4) components and could be used by communities to assist in preparing their permit material. Readers interested in MS4 guidelines are referred to the MPCA Web site for the MS4 program at http://www.pca.state.mn.us/water/stormwater/stormwater-ms4.html. An additional handbook on MS4 requirements was prepared by the League of Minnesota Cities (for more information contact Randy Neprash (rneprash@bonestroo.com).

What's New in the *Minnesota Stormwater Manual*

- All pertinent urban stormwater information is presented or referenced and linked in a single document, including resource and climate maps, regulatory framework, BMP design and performance, available tools and a glossary of common and uncommon terms.
- An explanation of concepts such as integrated stormwater management, better site design, low impact development, best management practices (BMP) treatment train, and unified sizing criteria.
- Methods to improve the stormwater treatment for receiving waters deemed "sensitive" by state or local interests.
- BMP screening and selection, performance, design, cost, and maintenance.
- Model and methods evaluation and choice of factors to use in various calculations.
- Cold climate impacts and management applications.
- Mosquitoes and the impact of stormwater management on their breeding habitat are discussed.
- Case study successes are presented.
- Research and data needs are identified, including the need for an update of TP-40 rainfall frequency data and BMP performance in cold climates.
- Recommendations for the next round of state stormwater permitting through the NPDES construction permit including:
  - integration of a recharge volume into the runoff treatment sizing criteria;
  - replacement of the two-year peak matching with a one-year, 24-hour extended detention for channel protection volume;
  - an expectation of 12 hours detention time and protected outflows from ponds and a 0.1-0.2 watershed-inch (depending on receiving water) minimum for non-ponds;
  - consideration of constructed wetlands as bioretention systems;
  - development of a credit system to provide an incentive for alternative and innovative approaches to runoff treatment;
  - and incorporation of locally approved pre-treatment into accepted BMP design.

Chapter 1

Use and Organization of the Manual

VOLUME 1 - INTEGRATED STORMWATER MANAGEMENT

Chapter 1

Use and Organization of the Manual

This chapter discusses the general philosophy, organization and use of the Manual and introduces the complexity of the regulatory framework within which it operates. It discusses the means of obtaining the Manual and contacting the MPCA. A "How Do I..." section is included to guide the user to information that might be of particular interest to them.

Contents

I. Manual Organization

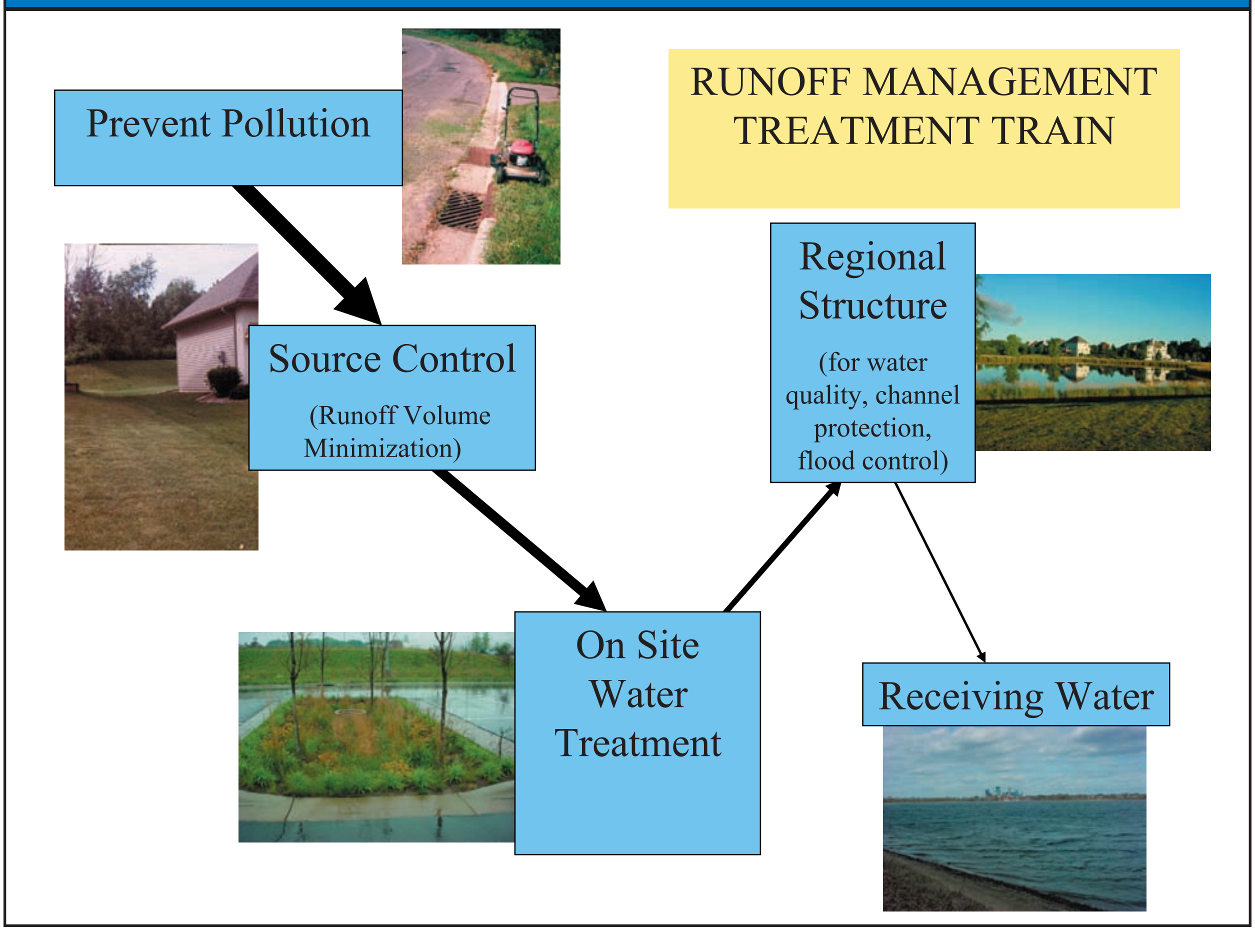
The *Minnesota Stormwater Manual* is designed to be a user-friendly and flexible document that guides users directly to the information they need, depending upon the question they need to answer or Best Management Practice (BMP) they need to design. The full scope of the Manual is outlined in the Table of Contents. The Manual is divided into two parts to assist the reader in obtaining either general or specific design information.

Volume 1 - Integrated Stormwater Management

Integrated stormwater management is an approach that acknowledges the relationship among the many factors that influence stormwater behavior. It recognizes the volume, rate, and quality aspects of stormwater management, as well as the relationship between ground water and surface water. It recognizes that dealing with one factor can lead to repercussions with other factors. Fore example, infiltrating water to improve a volume problem could lead to ground water impacts at an entirely different location. Integrating all of the factors affecting stormwater is also a basic tenet of the treatment train approach. Chapter 3 continues the discussion of integrated stormwater management techniques.

Volume 1 contains the background information necessary to apply proper stormwater management techniques. This volume contains information on management principles and the basis for them in Chapters 1 and 2. It walks the user through a series of steps in Chapters 3 and 4 to assure that good site design is the first step to proper stormwater management. The Manual is organized around a "treatment train" approach (Figure 1.1) that begins with simple pollution prevention and runoff volume reduction and proceeds through the details of designing, installing and operating a structural

Figure 1.1 The Treatment Train Approach to Runoff Management



runoff management facility. It is always assumed that the first step in stormwater management is to reduce the amount of runoff occurring by soaking in as much precipitation as possible where it falls. Because full runoff reduction is usually not possible, the Manual demonstrates ways to reduce exposing polluting material to runoff by keeping our land surfaces clean. When polluting materials cannot be kept out of runoff, a mix of simple to complex BMPs are presented to reduce the amount of pollution that gets to our state's receiving waters. Under this strategy, illustrated in Figure 1.1, potential pollutants are kept off of the land surface and simple methods are used to keep water in place after rainfall or snowmelt events. Then, if needed, further controls are implemented to manage water that is moving within or away from the site.

Chapter 5 summarizes the existing stormwater regulatory framework in Minnesota and aids the reader in identifying the proper agency or program, dependent upon the type of resource in question. This chapter is also linked to additional information in the appendices.

Chapter 6 includes a discussion of stormwater management and mosquito impacts. Chapters 6 and 7 describe the process of BMP selection and provide guidance for choosing the single best BMP or group of BMPs to address a particular stormwater management objective.

Volume 2 - Technical and Engineering Guidance

Volume 2 contains the technical detail that stormwater managers need to design and implement specific practices and regulators need to check the efficiency of designs. The basic climatic (rainfall) patterns, runoff quality characteristics and methods/models used to assess different management approaches are contained in Chapter 8, with further detail contained in Appendices A and B.

Chapter 9 discusses the complications that cold weather presents and some of the ways that those problems can be managed, including suggestions for a snow management plan.

The design calculations for determining runoff volumes, where water goes and how it can be routed begin in Chapter 10 with the Unified Sizing Criteria. This chapter was developed in response to the repeated request by stormwater managers to use a consistent minimum approach statewide. Chapter 11 follows this up with suggestions for how state and local government units can offer credits for good water management practices that may be used to offset some of the requirements that otherwise would be in place.

Chapter 12 contains two levels of BMP design information. The first level is a series of Fact Sheets that were developed to present summary information that summarizes the practice and refers the reader elsewhere for details. The second level are Guidance Sheets, which provide in-depth engineering detail for the design of more structural BMPs for which Minnesota-specific guidance is needed.

Chapter 13 addresses various physical and land use factors that impact stormwater management. Geology , soils and land use variations are discussed in terms of their potential impact.

Chapter 14 winds-up the Manual with some case study examples of how good, innovative stormwater management has occurred in Minnesota.

Twelve appendices (A-L) contain supplemental information on such variable items as construction support documents, computer modeling, Minnesota plant lists, and special and other sensitive waters locations. Appendix J links the reader to a series of ten Issue Papers on key topics that were prepared for review by the Manual Sub-Committee during Manual preparation.

II. Users of the Manual

The sheer complexity of Minnesota's stormwater management framework requires that state-of-the-art guidance and technology updates be available to stormwater managers at all levels of involvement and knowledge.

The target audience for the Manual is the stormwater practitioner who needs to know about all facets of good stormwater management in urban and urbanizing areas. This could include a city water planner wondering what to add to an MS4 BMP section, an engineering consultant serving many different clients in need of good stormwater management, a contractor in need of guidance to properly implement regulations, a state or local regulator, a watershed manager or any of a number of other potential users. The Manual is designed to address variable levels of expertise in a flexible manner. It is by no means all-inclusive. For this reason, when appropriate, links will take the user to many excellent documents available elsewhere. Those users who are already familiar with background material presented in the Manual need only peruse it for a refresher.

III. The Regulatory Relationship of the Manual

The stormwater regulatory framework in Minnesota can be complex and confusing even to those dealing with it on a frequent basis. Many regulated parties might argue that too much regulation occurs, whereas those interested in resource protection could argue the opposite. The goal in providing regulatory information in the *Minnesota Stormwater Manual* is to provide a "road-map" that directs the potential regulated party or permit reviewer to the appropriate agency and/or regulatory program. Answers to all of the regulatory questions that might arise cannot possibly be contained in a single document. Instead, this document identifies the agency or program to contact for the appropriate up-to-date interpretation needed.

Chapter 5 and Appendices F and G provide the detail needed to work through the stormwater regulatory program in Minnesota. The major federal, state, regional, and local agencies, programs and regulations related to stormwater are summarized, including those of the following agencies :

- U.S. Environmental Protection Agency (USEPA)
- Federal Emergency Management Agency (FEMA)
- U. S. Army Corps of Engineers (USACE)
- Minnesota Pollution Control Agency (MPCA)
- Minnesota Department of Health (MDH)
- Minnesota Department of Natural Resources (DNR)
- Board of Water and Soil Resources (BWSR)
- Metropolitan Council (sub-unit of the State)
- Watershed Management Organizations, including Watershed Districts
- Counties
- Municipalities (cities and townships)

This Manual also provides assistance to communities, industries and agencies needing to produce Stormwater Pollution Prevention Programs or Plans (SWPPPs). SWPPP plans are required for Industrial and Construction National Pollutant Discharge and Elimination System (NPDES) permit holders, whereas a SWPPP program is required for Municipal Seperate Storm Sewer System (MS4) permit holders. SWPPPs are mandated pollution control plans that must be produced by NPDES program permit holders and kept on-site for easy reference. They carefully lay-out the means through which a potential pollution source will be identified and controlled. Details on the SWPPP requirements can be found at the MPCA's Stormwater Program Web site.

Attention has been paid in the Manual to avoid language that appears to mandate new stormwater requirements. This Manual is intended to be a flexible guidance document for stormwater managers to use in their everyday activities. Because the Manual attempts to capture state-of-the-art stormwater management techniques, however, some have interpreted this leap forward as "new regulation." It is possible that new regulations could be an outcome of material contained in the Manual. MPCA has stated its commitment to keeping Minnesota stormwater regulations current with advances in the field. This commitment could mean regulatory revisions in the future, but this is not the intent of this Manual.

IV. This Manual's Relationship to Other Manuals

Throughout the Manual preparation process the question has been asked as to why the state is producing another Manual when at least two others already exist. The MPCA's *Protecting Water Quality in Urban Areas* (2000) and the Metropolitan Council's *Minnesota Urban Small Sites BMP Manual* (2001) are both readily available and still actively used.

The MPCA's manual was originally produced in 1989 and was updated in 2000. Much of the concepts and information presented in the manual is out-of-date because of the rapidly changing stormwater field. The Metropolitan Council's manual was intended to address a select set of BMPs for small urban sites; it was never intended to be a comprehensive stormwater management guide for statewide application. This Manual will supplement the other two, and in combination they will provide a more comprehensive overview of stormwater management in Minnesota.

Why not simply use one of the large number of stormwater manuals available through other states? These are readily obtained via the Web sites of the states and the best examples are linked through the appendices of this Manual. The whole purpose of initiating a Minnesota Manual was to get a guidance document for Minnesota programs, suited to the state's cold climate. Although some cold weather states have manuals, the Stormwater Steering Committee determined that a manual that contains information directly applicable to Minnesota would best serve users. A Vermont design strategy might not come close to the requirements of the Minnesota Construction General Permit, for example. Links direct Minnesota users to out-of-state resources if the resource could be of further assistance.

V. Contact Information, Obtaining Copies and Updating of the Manual

It is the intent of the SSC to keep this Manual as up-to-date as possible. Material in the rapidly changing field of stormwater management can become obsolete very quickly. The most current version of the full Manual, with each of its sections, will be kept available at the MPCA's stormwater management Web site at http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html. Readers are encouraged to record and bookmark any changes in this address that might occur with future revisions.

The Manual has been prepared to be predominantly an electronic resource. The intent is to have the Manual n an evolving electronic format. Check the following MPCA Web-site for information on hard-copy availability: http://www.pca.state.mn.us/publications/stormwater-manual.html.

The Manual has always been viewed by the SSC as a fluid and flexible document that must be updated when new information becomes available or when ideas change. The formal updating process will not be determined until after the Manual is accepted by the SSC. Possibilities for updating include a round of revisions after the public training sessions in early 2006, continual updating on the MPCA Web site whenever new information is available or periodic (perhaps biennial) review and updating.

This is Version 1.0 of the Minnesota Stormwater Manual. Each section will be marked with the current version number. Subsequent small-scale changes in chapters will be noted as changes to Version 1.0 (ex. Version 1.x). Major or large-scale changes in the entire document could lead to a change to Version numbering (ex. Version 2.0), but only if the content change warrants such a review.

VI. Manual Effectiveness Tracking, User Comments

The revisions referred to in the previous section will occur as new techniques become available and as experience in use of the Manual grows. Users of the Manual are encouraged to submit their experiences in using the Manual and their suggestions for improving it to the MPCA via the Manual Web site, http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html. Finally, those finding technical errors or noting omissions are encouraged to follow the process above for submitting comments to the MPCA staff.

VII. How Do I...

- Determine if I am covered by the Phase II Construction, MS4 or Industrial permit rules? > Ch. 5
- Pick proper quantity and quality modeling/hydrological factors? > Ch. 8 & App. B
- Pick a BMP? > Ch. 6 & Ch. 7
- Design a BMP? > Ch. 12
- Consider the effects of cold weather on the choice and operation of a BMP? > Ch. 9
- Incorporate better site design/low impact development into my stormwater management work? > Ch. 4
- Find out if my site impacts a "special water" ? > App. F
- Find out what is included under the "special water" or other sensitive receiving waters categories? > Ch. 5, Ch. 10, & App. F
- Select the proper model to use for my unique situation? > Ch. 8 & App. B
- Know what plants to use when I'm planting a rain garden? > App. E
- Make sure everything I need for a particular permit is accounted for? > Ch. 5 & App. G
- Find out what a calcareous fen is and what's required to protect it? > App. F
- Find out how to maintain a bioretention facility or any other BMP? > Ch. 12
- Find sample/model ordinances? > App. G
- See what sample BMP applications have been done in the state? > Ch. 14
- Identify the potential for ground water/surface water interactions? > Ch. 3
- Minimize the potential for my BMP to breed mosquitoes? > Ch. 6 & Ch. 12
- Incorporate channel protection into my pond outlet design? > Ch. 10
- Identify which MPCA Eco-region I am operating within? > App. A
- Explore more deeply one of the Issue Paper topics that was considered by the Manual Sub-Committee? > App. J
- Find out which watershed (and organization) I am located within? > App. A
- Determine the criteria I need to meet for runoff volume control? > Ch. 5 & Ch. 10
- Quantify my water quality and flood control volume requirements? > Ch. 10
- Maintain my rain garden? > Ch. 12
- Deal with karst geology, tight soils, and potential stormwater hotspots of toxicity? > Ch. 13
- Check that my BMP is suitable based on site conditions or receiving water criteria? > Ch. 7

Chapter 2

General Stormwater Background and the Minnesota Perspective

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VOLUME 1 - INTEGRATED STORMWATER MANAGEMENT

Chapter 2

General Stormwater Background and the Minnesota Perspective

This chapter defines the reasons stormwater management is important in the state and introduces the general stormwater management principles that are used throughout the Manual. The unique framework and stormwater management approach needed in Minnesota to address the variation in physical conditions that might affect surface water management are discussed.

Contents

I. Educating Minnesotans on the Importance of Stormwater in Their Decisions

The material contained in this Manual, and especially the background material comprising this chapter, can be used to educate public officials and citizens on the necessity to plan adequately for stormwater. Although the average Minnesotan is very water-savvy, there is a continual need to keep our youth and those desiring to learn better served.

Minnesota is very fortunate to have a great many educational programs available to its citizens. Such efforts as the University of Minnesota Extension, Project NEMO, Watershed Partners, and all of the Phase II education programs developed by MS4 communities are but a few of the many available. Because this list is far too long to include in this document, the reader is referred to the Minnesota Sustainable Communities Network "Next Step" Web site to obtain a comprehensive list of education programs and contacts.

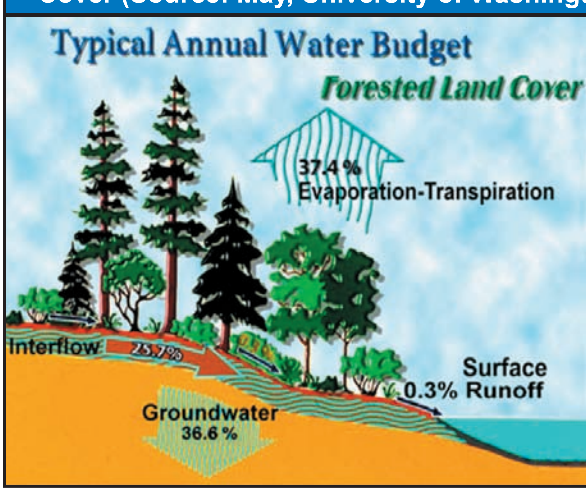
II. What is Stormwater

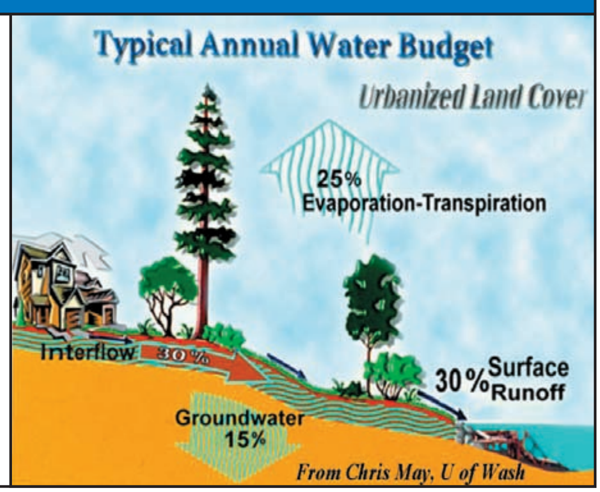
Stormwater is an all-inclusive term that refers to any of the water running off of the land's surface after a rainfall or snowmelt event. Prior to development, stormwater is a small component of the annual water balance. However, as development increases, the paving of pervious surfaces (that is, surfaces able to soak water into the ground) with new roads, shopping centers, driveways and rooftops all adds up to mean less water soaks into the ground and more water runs off. Figure 2.1 is a variation on a classic diagram that has appeared in many documents describing the effects of urbanization. This adaptation from the University of Washington shows how the relative percentages of water soaking into the ground change once development begins in a forested area. Note that the numbers assigned to the arrows depicting the movement of water will vary depending upon location within Minnesota. General information on regional precipitation, infiltration, evapotranspiration, etc. in Minnesota is contained in Chapter 8, but local details should be obtained from an appropriate source knowledgeable about local water data.

The Center for Watershed Protection has helped document the adverse impact that increased imperviousness (that is, water not able to soak into the ground) has on the health of receiving streams. Further information is contained on its Web site www.cwp.org. Similar impacts occur when the watersheds surrounding lakes experience an increase in impervious cover, although in both stream and lake cases this simplistic explanation is only part of the problem. Other factors such as morphology, landscape setting, inherent soils and geology, and land use history could be equally as important.

It is important to note that the *Minnesota Stormwater Manual* has an urban or developing/developed area focus. This is not meant to ignore or minimize

Figure 2.1 Differences in Annual Water Budget from Natural Land Cover to Urbanized Land Cover (Source: May, University of Washington)





the impact that agricultural or silvicultural activities can have on our receiving waters. Rather, the Manual focuses on the transition from rural and open space to urban uses, and on the management of stormwater from the increased impervious surfaces that result. Readers are referred to the Minnesota Pollution Control Agency Web site, the Minnesota Department of Natural Resources Web site, or the Minnesota Department of Agriculture Web site for further information on agricultural and silvicultural activities.

III. Why Stormwater Matters

The passage of the federal Clean Water Act (CWA) in the 1970s initiated a change in the view of pollution in the U.S. No longer was it acceptable to pollute our country's water resources. The initial focus of implementing the provisions of the CWA was logically on point sources of pollution, or those discharges coming from the end of an industrial or municipal wastewater pipe. Progress in addressing these discharges was made rapidly, although vigilance is still required to assure continued protection.

In the 1990s the United States Environmental Protection Agency (USEPA) began to apply requirements of the CWA to stormwater runoff. Owners and operators of certain storm drainage systems are now required to comply with design, construction, and maintenance requirements set by the MPCA for the State of Minnesota (http://www.pca.state.mn.us/water/stormwater/) Manual users are also encouraged to check the Center for Watershed Protection's Web site for much more information on the behavior of stormwater and links to many additional sources of information.

Physical Changes to the Drainage System

The changes in the landscape that occur during the transition from rural and open space to urbanized land use have a profound effect on the movement of water off of the land. The problems associated with urbanization originate in the changes in landscape, the increased volume of runoff, and the quickened manner in which it moves. Urban development within a watershed has a number of direct impacts on downstream waters and waterways, including changes to stream flow behavior and stream geometry, degradation of aquatic habitat, and extreme water level fluctuation. The cumulative impact of these changes should be recognized as a stormwater management approach is assembled.

Changes to Stream Flow

Urban development alters the hydrology (rate and volume) of watersheds and streams by disrupting the natural water cycle (Georgia Stormwater Manual, 2001). The changes in streams draining altered watersheds are very apparent (Figure 2.2) as they respond to the altered hydrology during this transition. Although similar changes can occur from intensive agricultural or silvicultural activities, the Manual focuses on the impacts of changes associated with development. Notable responses include:

- ***Increased Runoff Volumes***
  Land surface changes can dramatically increase the total volume of runoff generated in a developed watershed through compaction of soils and introduction of impervious surfaces.
- ***Increased Peak Runoff Discharges***
  Rainfall quickly runs off impervious surfaces instead of being released gradually as in more natural landscapes. Increased peak discharges for a developed watershed can be two- to five- times higher than those for an undisturbed watershed. Control programs that may address runoff rates do not fully address many of the problems associated with stormwater runoff.
- ***Greater Runoff Velocities***
  Impervious surfaces and compacted soils, as well as improvements to the drainage system such as storm drains, pipes, and ditches, increase the speed at which rainfall runs off land surfaces within a watershed.
- ***Shorter Times of Concentration***
  As runoff velocities increase, it takes less time for water to run off the land and reach a stream or other waterbody.
- ***Increased Frequency of Bank-full and Near Bank-full Events***
  Increased runoff volumes and peak flows increase the frequency and duration of smaller bank-full and near bank-full events, which are the primary channel forming events.

Figure 2.2 Alteration in Riparian Condition and Land Use within a Watershed Can Lead to Accelerated Channel Erosion (Vermillion River)

- ***Increased Flooding***
  Increased runoff volumes and peaks also increase the frequency, duration and severity of out-of-bank flooding.
- ***Lower Dry Weather Flows (Baseflow)***
  Reduced infiltration of stormwater runoff could cause streams to have less baseflow through shallow ground water inflow during dry weather periods and reduces the amount of rainfall recharging ground water aquifers.

Changes to Stream Geomorphology

The changes in the rate and volume of runoff from developed watersheds directly affect the morphology, or physical shape and character, of urban streams, rivers, and often ravines and ephemeral (intermittent) drainageways. Some of the impacts due to urban development include (adapted from the Georgia Stormwater Manual, 2001):

- ***Stream Widening and Bank Erosion***
  Stream channels widen to accommodate and convey the increased runoff and higher stream flows from developed areas. More frequent small and moderate runoff events undercut and scour the lower parts of the streambank, causing the steeper banks to slump and collapse during larger storms.
- ***Higher Flow Velocities***
  Increased streambank erosion rates can cause a stream to widen many times its original size due to post-development runoff.
- ***Stream Downcutting***
  Another way that streams accommodate higher flows is by downcutting their streambed. This causes instability in the stream profile, or elevation along a stream's flow path, which increases velocity and triggers further channel erosion both upstream and downstream.
- ***Loss of Riparian Canopy***
  As streambanks are gradually undercut and slump into the channel, the vegetation (trees, shrubs, herbaceous plants) that had protected the banks are exposed at the roots. This leaves them more likely to be uprooted or eroded during major storms, further weakening bank structure.

- ***Changes in the Channel Bed Due to Sedimentation***
  Due to channel erosion and other sources upstream, sediments are deposited in the stream as sandbars and other features, covering the channel bed, or substrate, with shifting deposits of mud, silt and sand.

- ***Increase in the Floodplain Elevation***–
  To accommodate the higher peak flow rate, a stream's floodplain elevation typically increases following development in a watershed due to higher peak flows. This problem is compounded by building and filling in floodplain areas, which cause flood heights to rise even further. Property and structures that had not previously been subject to flooding may now be at risk.

Impacts to Aquatic Habitat

Perhaps the most significant impact that results from the physical change to urban streams occurs in the habitat value of streams. Impacts on habitat include (adapted from the Georgia Stormwater Manual, 2001):

- ***Degradation of Habitat Structure***
  Higher and faster flows due to development can scour channels and wash away entire biological communities. Streambank erosion and the loss of riparian vegetation reduce habitat for many fish species and other aquatic life, while sediment deposits can smother bottom-dwelling organisms and aquatic habitat.

- ***Loss of Pool-Riffle Structure***
  Streams draining undeveloped watersheds often contain pools of deeper, more slowly flowing water that alternate with "riffles" or shoals of shallower, faster flowing water. These pools and riffles provide valuable habitat for fish and aquatic insects. As a result of the increased flows and sediment loads from urban watersheds, the pools and riffles disappear and are replaced with more uniform, and often shallower, streambeds that provide less varied aquatic habitat.

- ***Reduced Baseflows***
  Reduced baseflows possibly due to increased impervious cover in a watershed and the loss of rainfall infiltration into the soil and water table adversely affect in-stream habitats, especially during periods of drought.

- ***Increased Stream Temperature***
  Runoff from warm impervious areas (e.g.. streets and parking lots), storage in impoundments, loss of riparian vegetation and shallow channels can all cause an increase in temperature in urban streams. Increased temperatures can reduce dissolved oxygen levels and disrupt the food chain. Certain aquatic species, such as trout, can only survive within a narrow temperature range.

- ***Decline in Abundance and Biodiversity***
  When there is a reduction in various habitats and habitat quality, both the number and the variety, or diversity, of organisms (e.g.. wetland plants, fish, and macroinvertebrates) are also reduced. Sensitive fish species and other life forms disappear and are replaced by those organisms that are better adapted to the poorer conditions. The diversity and composition of the benthic, or streambed, community have frequently been used to evaluate the quality of urban streams. Aquatic insects are a useful environmental indicator as they form the base of the stream food chain. Fish and other aquatic organisms are impacted not only by the habitat changes brought on by increased stormwater runoff quantity, but are often also adversely affected by water quality changes due to development and resultant land use activities in a watershed.

Water Quality Impacts

As impervious surfaces increase, more water flows off of urban surfaces and is delivered faster to receiving waters. The increased activity on these surfaces means that more polluting material is available, as well. Minimizing the mobilization of this material and its impact is the goal of good runoff management and the purpose of this Manual.

Sources of Pollution

Diffuse sources of pollution, such as that resulting from construction (Figure 2.3), roadways,

Figure 2.3 Uncontrolled Construction Erosion

parking lots and farm fields, have been a focus for Minnesota water management because they surpass point sources in severity for many pollutants of concern. The conversion of rural and open space land to urban uses is the particular focus of this Manual.

The problems associated with the conversion of land emerge as the land surface changes from one that soaks water into the ground to one that inhibits this infiltration. What used to be a small portion of runoff from a rainfall or snowmelt event becomes a major source of runoff volume. Water that used to soak in collects and flows from these new surfaces with enough energy to erode soil that was formerly held in place with protective vegetative cover and strong roots. Streams generally depend on ground water supplies during dry periods of the year. When infiltration is reduced or eliminated, this ground water is no longer available to supply baseflow and support the life of the channel. For the same reason, deeper ground water aquifer units receive less recharge.

Quantity is not the only problem resulting from changing runoff patterns. The water that washes over these new urban surfaces picks up materials laying upon those surfaces. The sediment from construction erosion, the oil, grease and metals from many automobiles, the fertilizer and pesticides from lawns, and many more new pollutants can adversely impact the receiving waters. Table 2.1 lists some of the many nonpoint pollutants of concern and the sources of these pollutants.

Pollutant Impacts

The impacts of the various pollutants listed in Table 2.1 are felt to varying levels. It is important to recognize that the hydrologic balance of most receiving water depends on this runoff water. Simply diverting all of the flow around a water body might help reduce a pollution load, but it could also cause the water body to dry up.

The receiving water quality impacts from urban runoff vary depending upon the quality and quantity of the stormwater and the assimilative capacity, or its natural ability to absorb or accommodate certain pollutants without adverse effects, of the receiving waterbody (Conservation Toronto and Region, 2001). Depending on the chemical, biological and physical character of the waterbody, its assimilative capacity can be quite different and tolerance to pollutants may vary greatly. Some waterbodies are inherently more sensitive to types or classes of pollutants than others; for example, lakes are more sensitive to phosphorus than streams and trout streams are more sensitive to increased temperature than non-trout streams.

Table 2.1 Nonpoint Sources and the Pollutants Associated with Them (Source: Adapted from *The Stormwater Pollution Prevention Handbook,* Conservation Toronto and Region, 2001)

Pollution Sources	Pollutants of Concern*
Vehicular traffic accounts for much of the build-up of contaminants on road surfaces and parking lots. Wear from tires, brake and clutch linings, engine oil and lubricant drippings, combustion products and corrosion, all account for build-up of sediment particles, metals, and oils and grease. Wear on road and parking surfaces also provides sediment and petroleum derivatives from asphalt. Spills from traffic accidents can occur on any street or highway.	Heavy metals (such as lead, zinc, copper, cadmium, and mercury), hydrocarbons (such as oil and grease, gasoline, cleaning solvents), salt (Na and Cl), sediment
Lawn and garden maintenance of all types of land uses including residential, industrial, institutional, parks, and road and utility right-of-ways accounts for additions of organic material from grass clippings, garden litter and fallen leaves. Fertilizers, herbicides and pesticides all can contribute to pollutant loads in runoff if not properly applied.	Phosphorus, nitrogen, fertilizers/ pesticides, organic debris, oxygen demand
Air pollution fallout of suspended solids from traffic, industrial sources and wind erosion of soils builds up contaminants in soil and on urban surfaces.	Organic pollutants such as polycyclic aromatic hydrocarbons (PAHs), pesticides, polychlorinated biphenyls (PCBs), and phenols, heavy metals, nitrogen and sulfur oxides, hydrocarbons, mercury
Municipal maintenance activities including road repair and general maintenance (road surface treatment, salting, dust control, etc.).	Sediment, hydrocarbons, salt
Industrial and commercial activities can lead to contamination of runoff from loading and unloading areas, raw material and by-product storage, vehicle maintenance and spills.	Any raw material exposed to runoff
Illicit connections of sanitary services, roof/sump drains or industrial process water to storm sewers can cause contamination with organic wastes, nutrients, heavy metals and bacteria.	Bacteria/virus, phosphorus, nitrogen, excess water, heavy metals
Improper disposal of household hazardous wastes can introduce waste oil and a multitude of toxic materials such as paint, solvents, auto fluids, and waste products to storm and sanitary sewers. Note that industrial and commercial hazardous materials are regulated under point source control programs.	Any household material deemed hazardous
Pet and wildlife feces and litter introduce organic contamination, nutrients and bacteria.	Bacteria/virus, phosphorus, nitrogen

Table 2.1 Nonpoint Sources and the Pollutants Associated with Them (Source: Adapted from ***The Stormwater Pollution Prevention Handbook,*** **Conservation Toronto and Region, 2001)**	
Construction activity can introduce heavy loads of sediment from direct runoff, construction vehicles and wind-eroded sediment. Sediment particles also: transport other pollutants that are attached to their surfaces including nutrients, trace metals and hydrocarbons; fills ditches and small streams and clogs storm sewers and pipes, causing flooding and property damage; and reduces the capacity of wetlands, reservoirs and lakes. Construction can also contribute construction debris, material spills and sanitary waste.	Sediment, phosphorus, nitrogen, debris, sanitary waste
Combined sewer overflows** (CSOs) and Sanitary Sewer Overflows (SSOs) contain a mixture of sanitary, commercial and often industrial waste, along with surface drainage.	Bacteria/virus, phosphorus, nitrogen, suspended solids, heavy metals, organic contaminants, oxygen demanding substances
Runoff from residential driveways and parking areas can contain driveway sealants, oil, salt, and car care products.	Salt, PAHs, hydrocarbons, increased temperature

* Representative list only; many additional pollutants can be associated with most of the activities listed.
** Combined sewers are very limited in Minnesota, with only a few remnants still existing in the metropolitan area. However, the same concerns apply for sewage spills and accidental overflows.

Potential water quality concerns resulting from stormwater include (among others):

- Beach closures and potential illness from bacteria/virus from fecal material in pet and wildlife litter and sanitary wastes;
- Nuisance algal growth in lakes and streams from nutrient enrichment (nitrogen and phosphorous compounds);
- Choking of aquatic life and elimination of suitable habitat from deposits of sediments, exacerbated if the sediments are also contaminated;
- Toxicity from ammonia, metals, organic compounds, pesticides and other contaminants, including potential endocrine disruption effects from certain organics and pesticides;
- Oxygen depletion potential or biochemical oxygen demand (BOD) of the water from biodegradable organic material, which can lead to oxygen deprivation of the organisms in the receiving water;
- Temperature changes due to an influx of water warmed by the ‘heat island’ effect of roads and buildings. Warm water can hold less dissolved oxygen than cold water, so this thermal pollution further reduces oxygen levels in depleted urban streams. Temperature changes can severely disrupt certain aquatic species, such as trout and stoneflies, which can survive only within a narrow temperature range;
- Aesthetic impacts from floatable matter and sediments (e.g., litter, grass clippings, sanitary items, and soil erosion); and
- Contamination of ground water with soluble organic chemicals, metals, nitrates and salt.

IV. The Challenges of Stormwater Management in Minnesota

Minnesota is a large and varied state. Physical elements such as climate, occurrence of water, ecology, geology, soils and topography, and cultural features such as land use vary dramatically from one end of the state to the other. Stormwater managers in Minnesota know that conditions in the state can complicate solutions that might be simple elsewhere in the country. The extreme weather conditions (cold and hot) and physiographic variability under which we operate makes it impossible to generalize a single accepted approach for the entire state under all conditions. Flexibility in approaching problems site by site is stressed in this Manual. The following section describes some of the statewide variability that can be addressed with variable techniques in the Manual. Appendix A contains a compilation of several additional graphics illustrating the differences in factors that can influence stormwater.

Climate

The climate of Minnesota is characteristic of a transition zone from the moist and temperate eastern U.S. to the dry and droughty western U.S. Minnesota's large size also means that much variation can occur within the state in any given year. Add to that extremes in temperature, and the difficulty in trying to describe Minnesota's climate can be appreciated. Although the temperature discussion is interesting, this Manual has been developed to address water, so other than the fact that we experience very cold winters, temperature will not be discussed.

The major factors to focus on for good statewide stormwater management are rainfall and snowfall (snowmelt). A complete picture of Minnesota stormwater runoff cannot be painted without a discussion of both. Issue Paper B in the Manual Sub-Committee series (see Appendix J) examined some questions associated with the frequency of precipitation in Minnesota. The discussion was oriented around which design events to use as a basis for unified sizing of stormwater facilities across the state.

Figure 2.4 depicts the normal average annual Minnesota precipitation (rain plus snow) pattern. The statewide variation from less than 20 inches in the northwest to about 35 inches in the southeast is evident on the map. Figure 2.5 is a similar representation showing the areal variability in snowfall, varying less regularly from about 40 to 64 inches.

Rainfall

The real impact of the precipitation that falls in the state is felt when it runs off either as rainfall or snowmelt. Issue Paper B (Appendix J) contains a substantial amount of discussion on the proper statistical representation of "design events" based on the relationship of precipitation to runoff. The discussion was intended to set the stage for selection of the unified sizing criteria contained in Chapter 10. Much of the discussion with the Manual Sub-Committee concerned the use of the US Weather Bureau's 1961 Technical Publication 40, commonly known as "TP 40". Even though this publication is generally considered out of date because it does not reflect recent climate changes, there is no acceptable substitute at

Figure 2.4 Average Annual Minnesota Precipitation (Source: MN State Climatology Office)

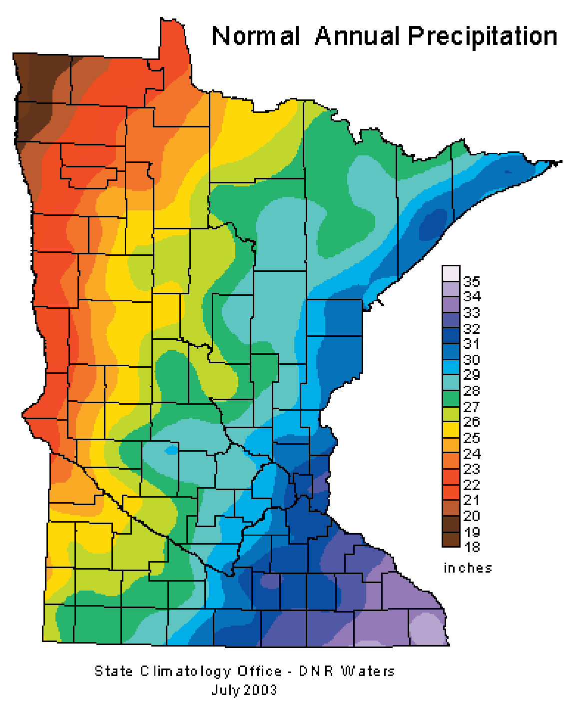


Table 2.2 Summary of TP 40 (USWB, 1961) Event Frequency Data for Minnesota		
Event Frequency (all for 24-hours)	**Minnesota Range (inches)**	**Twin Cities Approximate Average (inches)**
1-Year	1.8 – 2.6	2.4
2-Year	2.1 – 2.9	2.75
5-Year	2.8 – 3.7	3.65
10-Year	3.3 – 4.4	4.2
25-Year	3.9 – 5.0	4.8
50-Year	4.4 – 5.6	5.3
100-Year	4.8 – 6.2	5.95

this time (see Issue Paper B discussion). Until such time as an acceptable replacement exists, the graphics presented in Appendix B define design events that should be used in Minnesota. Appendix B (Supplemental Graphics B.1 – B.7) contains the TP 40 graphs showing the 1-year through 100-year, 24-hour rainfall events. Table 2.2 summarizes the TP 40 data for the state and the seven-county metro area. Further breakdown of aerial precipitation frequencies across the state are presented in Chapter 10 (see also Issue Paper B in Appendix J).

Snowmelt

The determination of snowmelt volumes is more complicated that rainfall because it depends on two factors – snowfall depth and the amount of moisture (or the equivalent water moisture) in the snow. Figure 2.5 shows the average annual snowfall amount for the state, but this graphic is somewhat misleading because it does not show the amount of moisture running off as snowmelt when the snowpack melts.

Initial determination of the average amount of snowmelt runoff can be determined using the information presented in Figure 2.6a. This shows the average snowfall depth on March 10th, an approximation of the initiation of melt in much of Minnesota, plus isolines that show the last occurrence of three-inches of standing snowpack. Figure 2.6b shows the average snow water equivalent for March. The total runoff is the product of the snowpack depth times the water equivalent. For example, St. Paul would be 7 inches (0.58 feet) times approximately 0.11 inches of equivalent water equals about 0.77 inches of water that will be available for runoff during a total melt of the snowpack. For Tower, the snow on the ground at melt is closer to 20 inches, but the snow water equivalent is only 0.09 inches, so the amount available for runoff is about 1.8 inches. Details on the data presented in Figures 2.6a and b and much more regarding Minnesota climate in general can be obtained at the Minnesota Climatology Working Group Web site.

Of course not all of the meltwater runs off. Figure 2.7 is based on research in Canada and illustrates that some of the meltwater enters the ground as infiltration. This graphic needs local adjustment based on knowledge of ground conditions, but it does give an approximation of the amount of melt that will soak into the ground and hence be removed from the total runoff volume. (See the equation describing this below).

Average snowmelt volume (depth/unit area)	=	Average snow pack depth at the initiation of the snowmelt period	X	Typical snow pack water equivalent at time of melt	—	Estimated infiltration volume likely during a 10-day melt period

Figure 2.5 Average Annual Minnesota Snowfall (Source: University of Minnesota, Department of Soil, Water, and Climate)

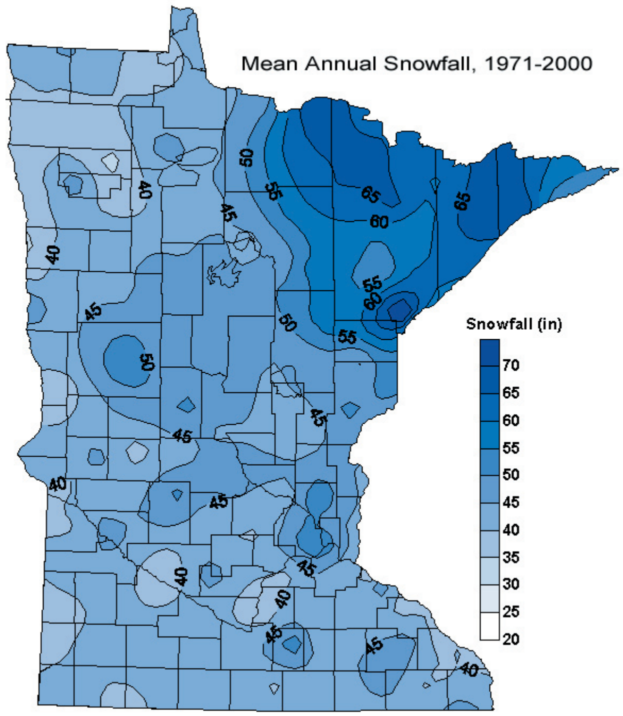


Figure 2.6a Snow Depth at Initiation of Melt (Source: Adapted from the Minnesota Climatology Working Group)

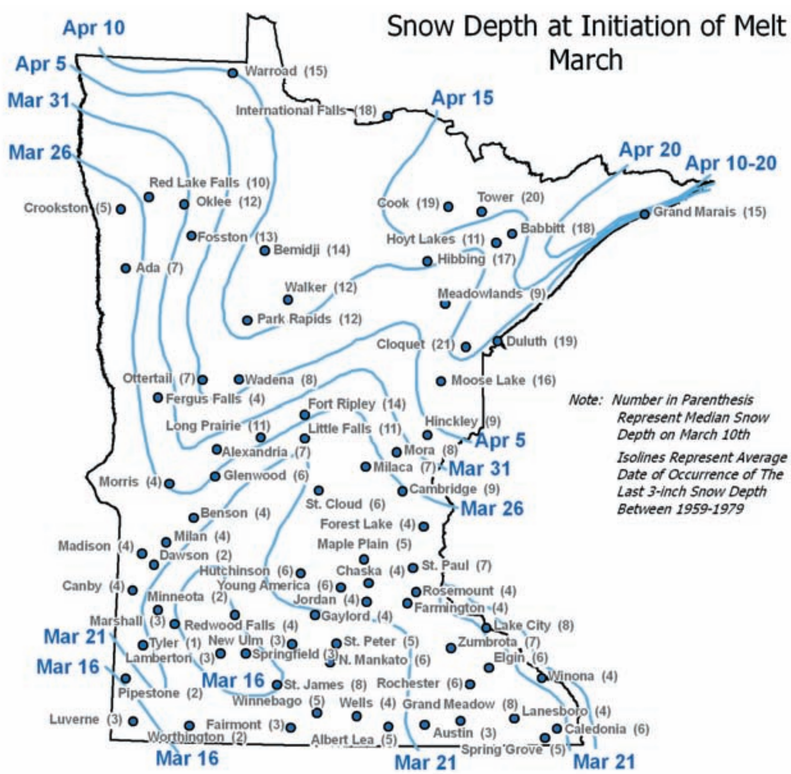


Figure 2.6b Snow Water Equivalent for March (Source: Adapted from the Minnesota Climatology Working Group)

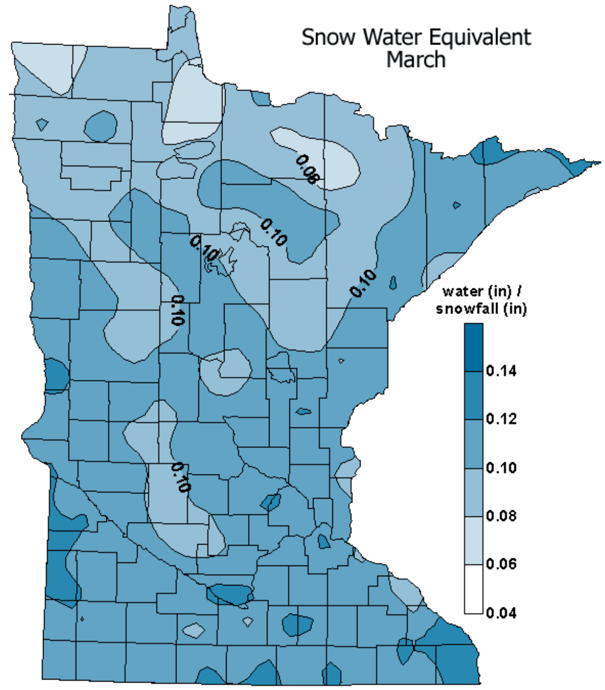
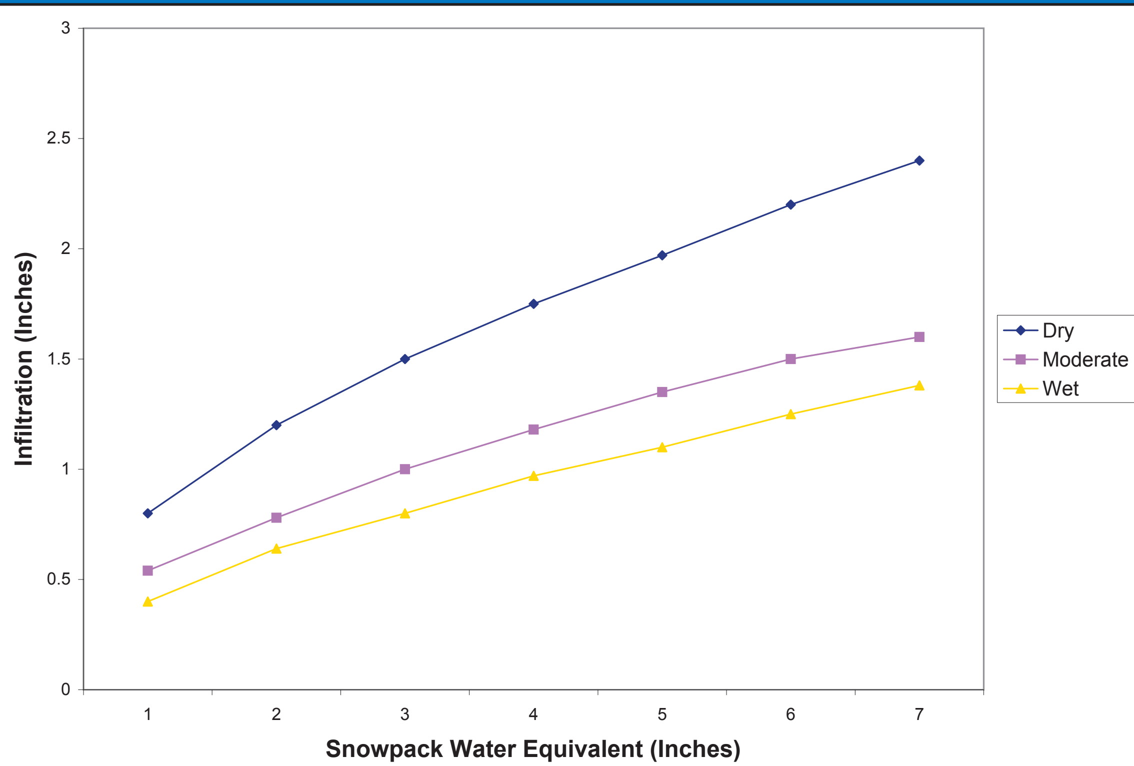


Figure 2.7 Snowmelt Infiltration Based on Soil Moisture Content (Source: Adapted from Granger *et al.* 1984)



Physical Features

Many of the physical features that influence the behavior of stormwater are not mapped at a level of sufficient enough detail for the state. This section will generally describe the features of importance and refer the user to sources of better information.

Minnesota Waters

The Manual Foreword listed some numbers describing the lakes, rivers, streams and wetlands in Minnesota (see also Figure 2.8). Illustrations of many of these features occur in Appendix A and Appendix F of this Manual. Due to the richness and variety of Minnesota's water resources, several classes of waters have been identified for special protections through legislation or programs designed to protect these unique resources (Table 2.3).

Special Waters,
Special Waters are designated in Appendix B.1-8 of the MN Construction General Permit (2003), include the following eight categories of receiving waters:

- Wilderness areas
- Mississippi River (Lake Itasca through Morrison County)
- Scenic or recreational river segments
- Lake Superior
- Lake trout lakes
- Trout lakes
- Scientific and natural areas
- Trout streams

Outstanding Resource Value Waters (ORVW)
ORVWs are designated in Minnesota Rules Chapter 7050 and include the following categories:

- Waters within the Boundary Waters Canoe Area Wilderness, Voyageur's National Park, and Department of Natural Resources designated scientific and natural areas
- Wild, scenic, and recreational river segments
- Lake Superior

Figure 2.8 Minnesota's Surface Water Resources

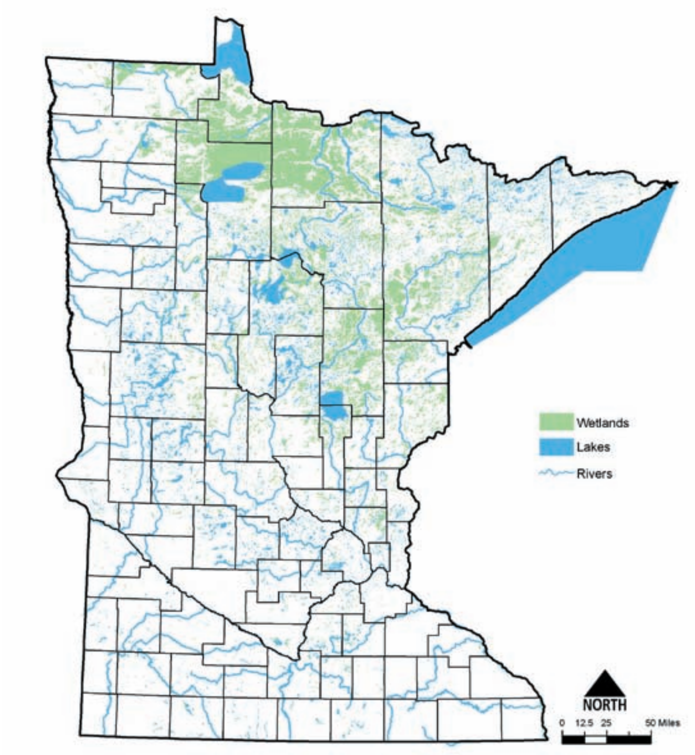


Table 2.3 Links to Special Waters, ORVWs, and Other Sensitive Receiving Waters	
Water	**Link**
Calcareous Fens	http://www.pca.state.mn.us/publications/wq-strm1-06.xls
Impaired Waters (303d List)	http://www.pca.state.mn.us/publications/reports/tmdl-list-2004.pdf
Metropolitan Council Priority Lakes	http://www.metrocouncil.org/planning/environment/WRMPP/WRMPPMay2005_Appendices2.pdf
Mississippi National River and Recreation Area (MNRRA)	http://www.dnr.state.mn.us/waters/watermgmt_section/mnrra/index.html
Mississippi River Critical Area	http://www.dnr.state.mn.us/waters/watermgmt_section/critical_area/index.html
Outstanding Resource Value Waters (ORVW)	http://www.revisor.leg.state.mn.us/arule/7050/0180.html
Public Waters	http://www.dnr.state.mn.us/waters/watermgmt_section/pwi/maps.html
Scientific and Natural Area	http://www.dnr.state.mn.us/snas/list.html
Special Waters List	http://www.pca.state.mn.us/publications/wq-strm1-05.xls
Trout Lakes	http://www.dnr.state.mn.us/fishing/trout_lakes/list.html
Trout Streams	http://www.dnr.state.mn.us/fishing/trout_streams/index.html
Wetlands	http://wetlands.fws.gov/mapper_tool.htm
Wild, Scenic, Recreational Rivers	http://www.dnr.state.mn.us/waters/watermgmt_section/wild_scenic/index.html

- Portions of the Mississippi River from Lake Itasca to the southerly boundary of Morrison County
- Other waters of the state with high water quality, wilderness characteristics, unique scientific or ecological significance, exceptional recreational value, or other special qualities which warrant stringent protection from pollution

Other Sensitive Receiving Waters

In addition to the Special Waters and ORVWs, there are several other classes of sensitive receiving waters, as defined by a variety of federal, state and local entities, that receive special protections and merit additional management attention. Recommended stormwater criteria for these waters are provided in Chapter 10. These other sensitive receiving waters can be broken down into five general classes:

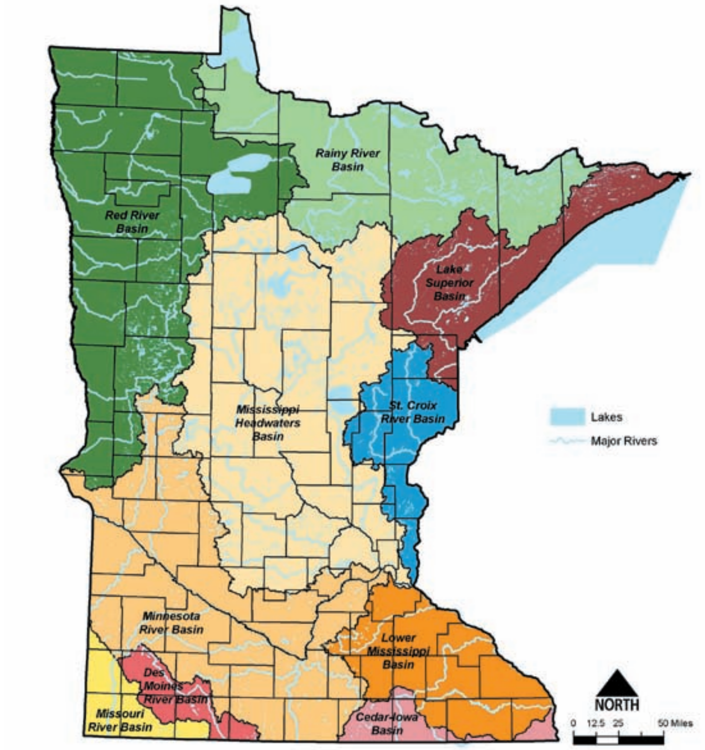
- Lakes
- Trout Resources
- Wetlands (Including Calcareous Fens)
- Drinking Water Source Areas
- Impaired Waters

Watersheds and Ecoregions

Watershed-based water management began in earnest in the state in the mid-1950s and has had several additional mandates put in place since then. Watershed districts, watershed management and watershed-based planning are all common terms within the state. Figure 2.9 shows the eight major watershed basins across the state. Details on local watersheds are available from local sources, the Minnesota Department of Natural resources at http://www.dnr.state.mn.us/watersheds/map.html or the Minnesota Association of Watershed Districts's "Where is my Watershed?" Web site.

The reality associated with so many watershed units occurring in the state is that a complex planning and regulatory framework exists for water management. Many of the sub-watersheds contained within the major watershed units have watershed management organizations that typically have some level of authority through a Watershed District or Watershed Management Organization. Information on the location and operations of these organizations can be obtained from the State Board of Water and Soil Resources at its Web site (http://www.bwsr.state.mn.us/) .

Figure 2.9 Minnesota's Major Basins (Source: Adapted from DNR)



Another primary watershed mapping unit for Minnesota waters is based on MPCA's ecoregion concept. These are geographic areas reflective of similar ecological character assembled to define causative factors for water behavior. Figure 2.10 illustrates the ecoregions as they are mapped for the state. Although not universally true, waters within each ecoregion should generally be similar in character, when all other factors (like rainfall, land use, and land cover) are similar. MPCA uses these as basic planning units for setting water quality standards and evaluating water quality variation. Keeping in mind the watershed and ecoregion within which water is being managed is an important part in structuring an effective management approach for stormwater.

The variable ecology across the state can be presented in many different ways. Figure 2.11 is one of those depictions from the DNR, but again it should be verified with local data when used as a consideration in stormwater design.

Geology

The geologic variability across Minnesota is reflective of billions of years of igneous and sedimentary history, plus geologically "recent" glaciation which is responsible for much of Minnesota's vast natural beauty and abundance of water related resources. In most cases, the debris left behind by the glaciers provides a thick cover between the land surface and the buried surface of the underlying bedrock. In other cases, this glacial material either by-passed a location or has been eroded away, exposing bedrock to material (and possibly pollution) that comes from the land surface.

Figures 2.12 and 2.13 are depictions of the bedrock and surficial (Quaternary) geology, respectively, within Minnesota. Manual users are referred to the Minnesota Geological Survey (MGS) Web site (http://www.geo.umn.edu/mgs) for details on the geology of the state.

Figure 2.10 Minnesota's Ecoregions (Source: MPCA)

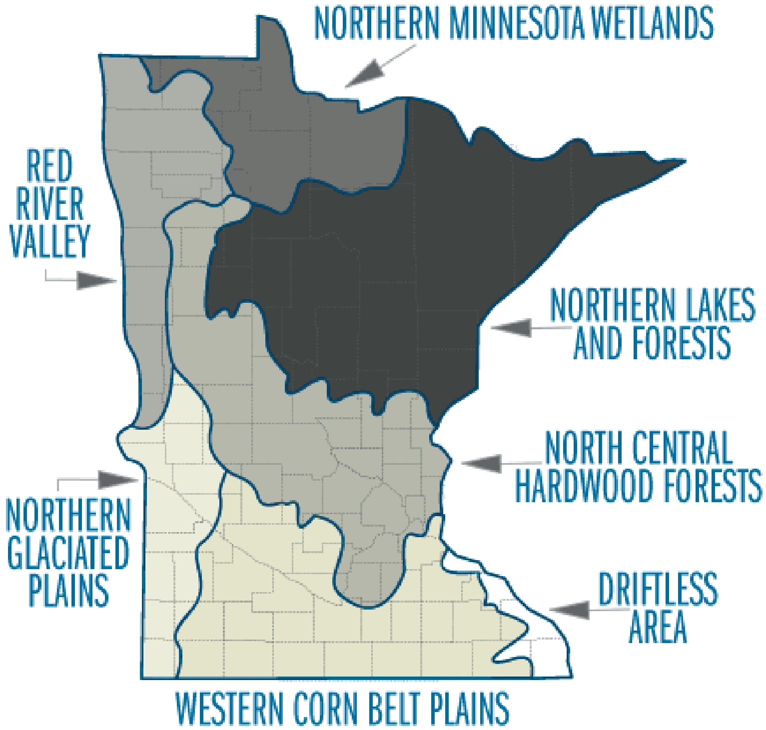


Figure 2.11 DNR Ecoregion Sections (Source: Adapted from DNR)

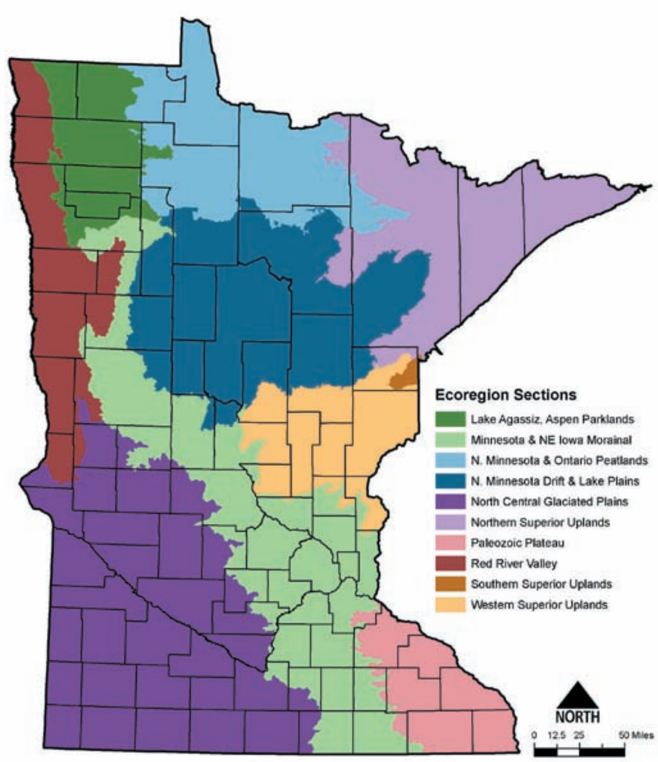


Figure 2.12 Bedrock Geology of Minnesota (Source: Minnesota Geological Survey)

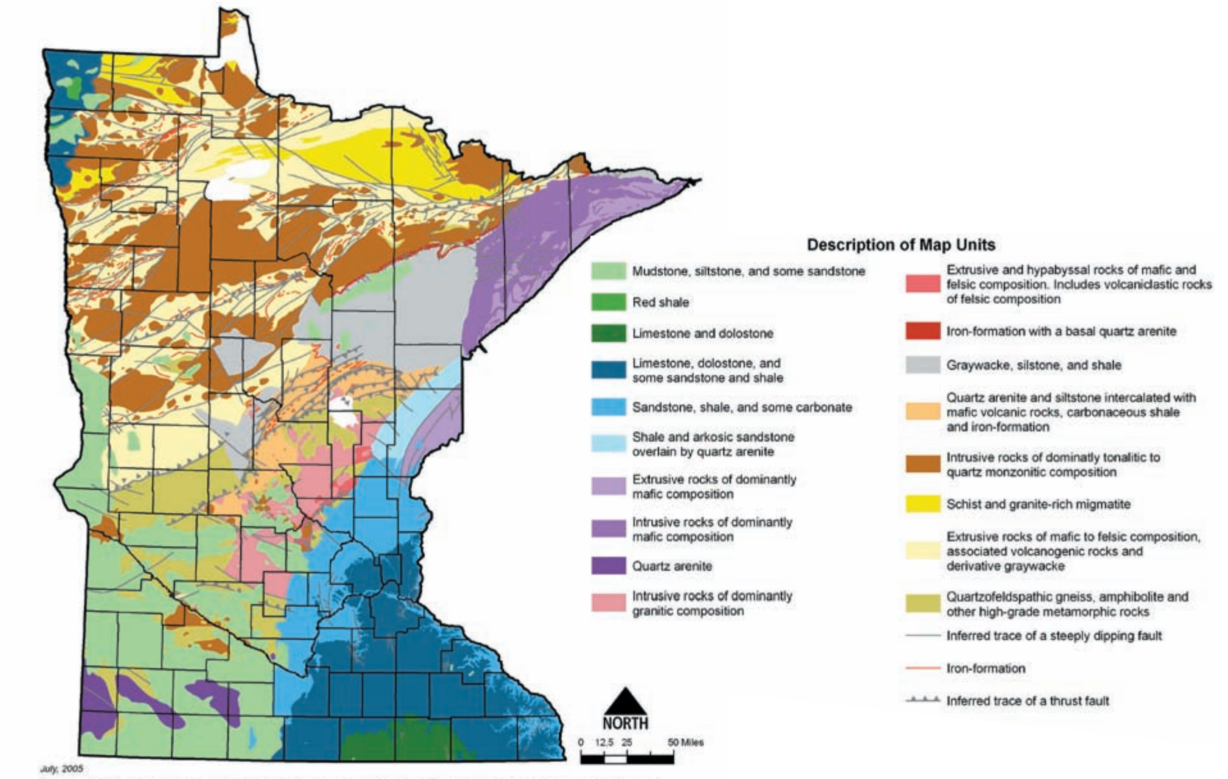
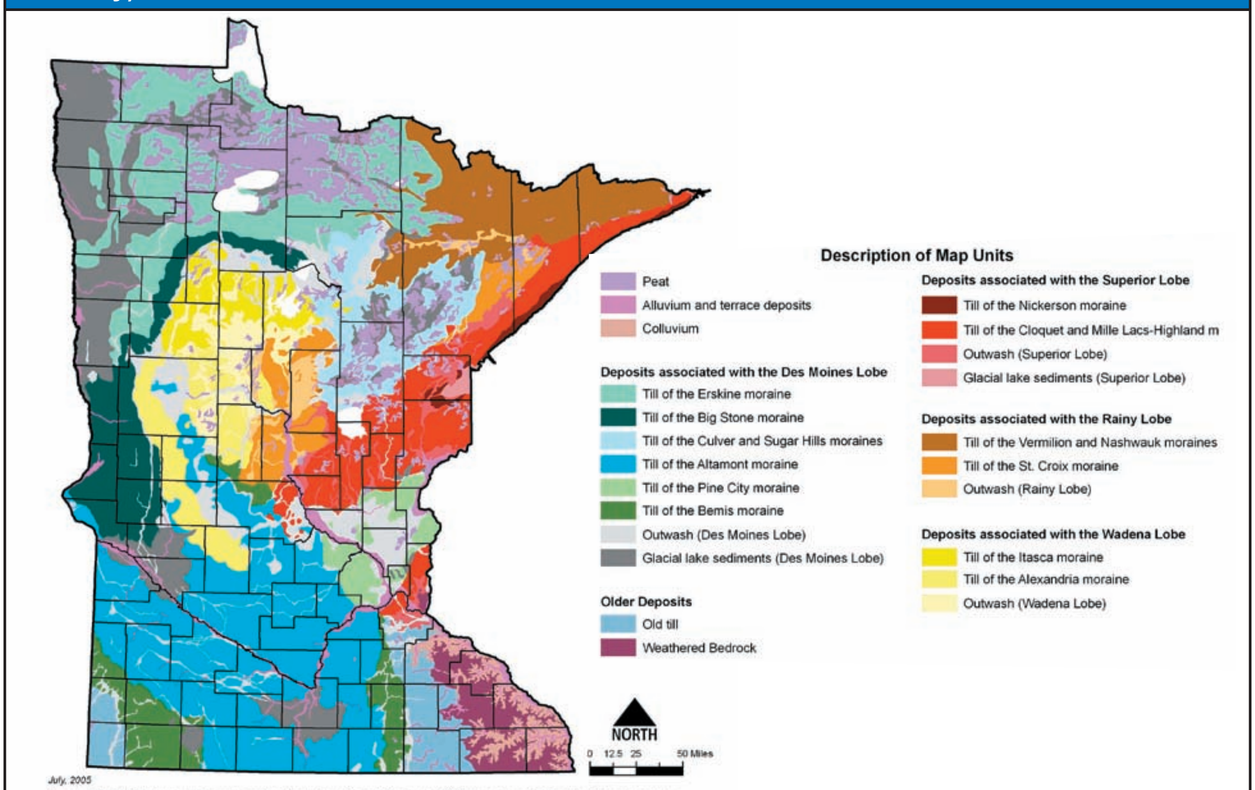


Figure 2.13 Surficial (Quaternary) Geology of Minnesota (Source: Minnesota Geological Survey)



Shallow Bedrock

In many portions of the state, bedrock occurs at or near the surface. The "red rocks" of the southwest, igneous intrusions along the St. Croix River and North Shore, and scattered sedimentary outcrops all around the state present some challenges in stormwater management because of their proximity to the surface. Among those difficulties are a lack of soil depth for use of infiltration techniques, structural impairment to best management practice (BMP) installation and steep slopes. The stormwater management implications of shallow bedrock affect infiltration, ponding depths, and the use of underground practices.

Figure 2.14 illustrates just one example of shallow bedrock along the North Shore. Again, details can be obtained from the MGS or a reliable local source, such as the county or a local well driller.

Karst

Carbonate and possibly other forms of bedrock can erode or dissolve in a manner that opens up pathways for movement of water into and through the rock. Such karst features, if sufficiently close to the land surface or to a ground water flow pathway, can present an opportunity for surface contaminants to enter the ground water system with very little or no treatment. This has important implications with respect to geotechnical testing, infiltration, pre-treatment and ponding of runoff.

Karst regions are predominantly found in the southeastern portion of the state, as shown in Figure 2.15 by Alexander and Gao (2002). A statewide map of karst regions is shown in Appendix A. These areas have important implications with respect to geotechnical testing, infiltration, pretreatment and ponding of runoff. Figure 2.16 shows that caution must be used in interpreting the geographic depiction of "Karst lands". The figure shows the difference between a generalized map (2.15) of active karst versus a county-scale map (2.16) of actual karstic features.

In karst settings where active karstic conditions (within 50 feet of the surface) are known to exist, additional constraints and considerations need to be evaluated prior to implementing most structural BMPs. Of particular concern in karst settings is

Figure 2.14 Shallow Bedrock in Northern Minnesota (Source: The Great Lakes Association)

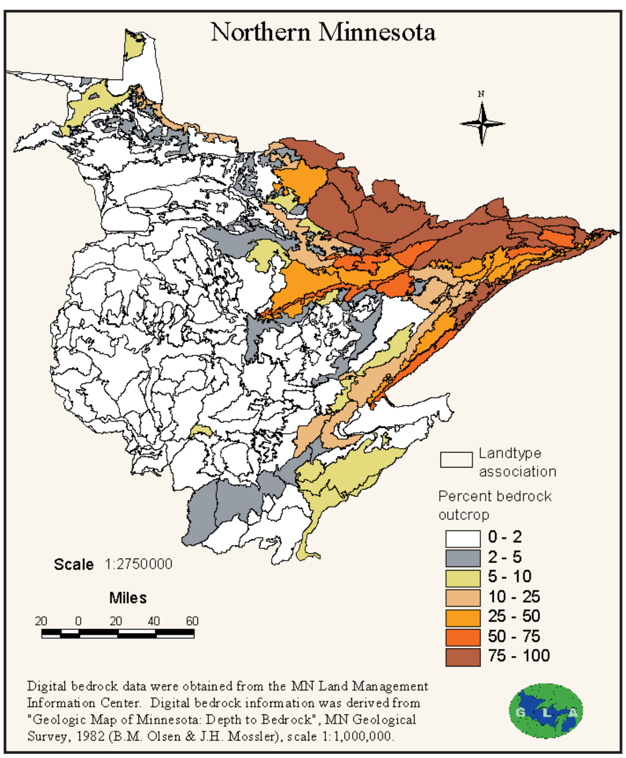


Figure 2.15 Minnesota Karst Lands (Source: Alexander and Gao, 2002-See Also Appendix A for Statewide Map)

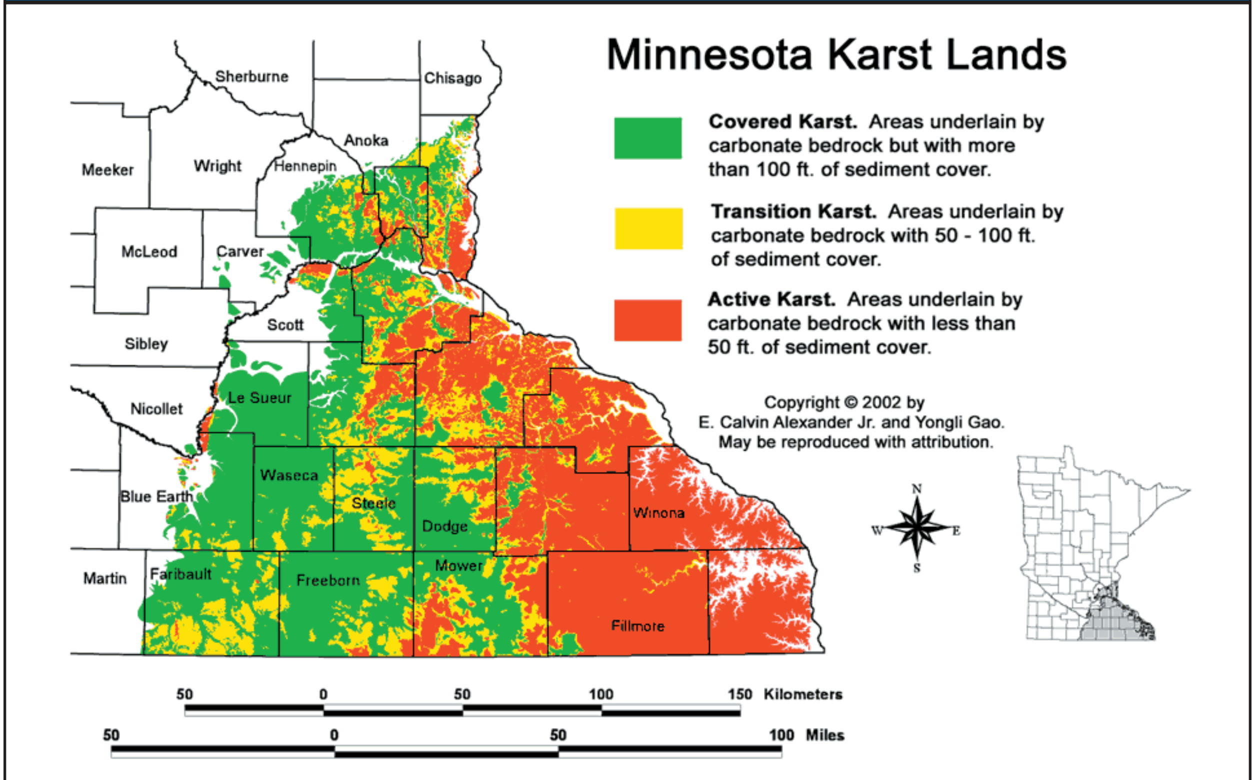
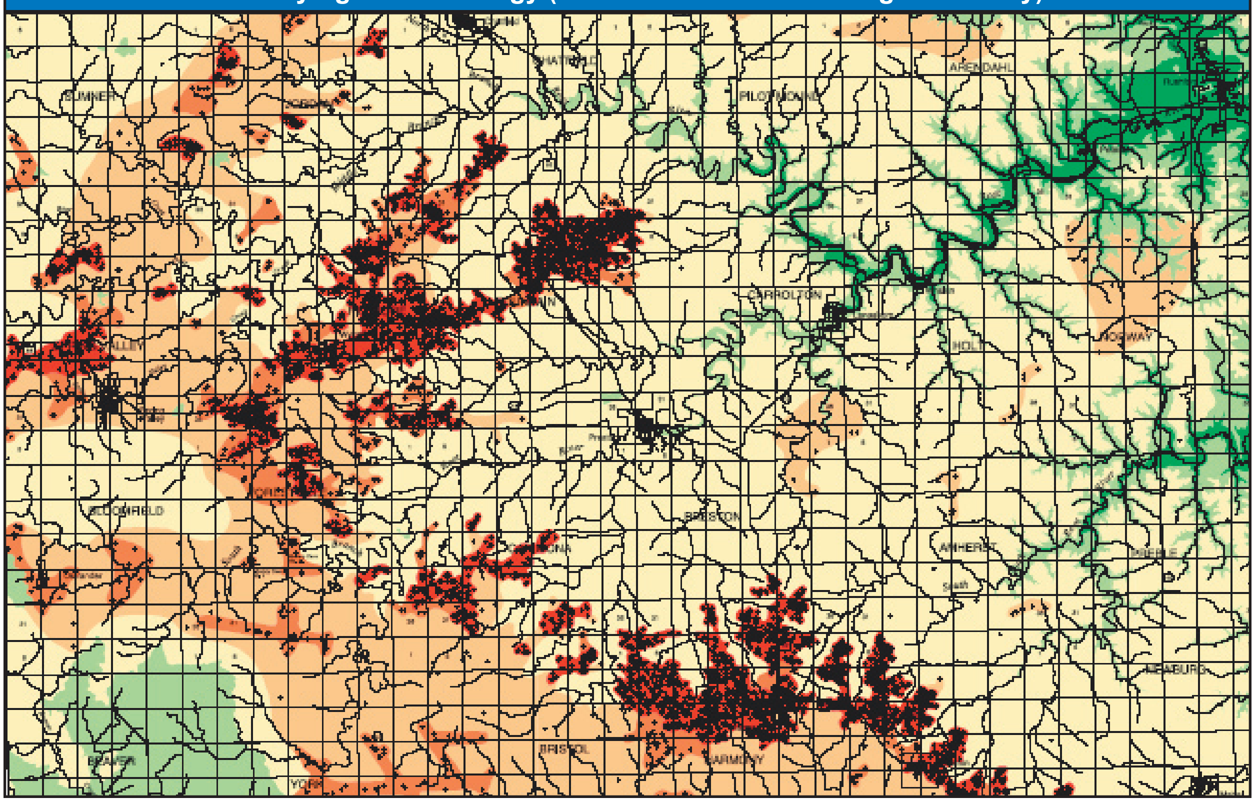


Figure 2.16 Fillmore County Geologic Atlas: Red and Orange Shades Indicate Varying Likelihood of Underlying Karst Geology (Source: Minnesota Geological Survey)



the formation of sinkholes as a result of hydraulic head build up and/or dissolution of rock present underneath or adjacent to BMPs. Concerns also exist for ground water flow interruption, interflow and recharge particularly as it relates to stormwater facility, location, and size and the relationship of ground water to surface water. Where karst conditions exist, there are no prescriptive rules of thumb or universally accepted management approaches because of the variability intrinsic to karst terrain. An adaptation of a familiar old saying is very appropriate: the only thing predictable about the behavior of water in a karst system is its unpredictability.

In general when underlying karst is known or even suspected to be present at the site, stormwater runoff should not be concentrated and discharged into known sinkholes, but should rather be dispersed, or soaked into the ground after adequate pre-treatment, or conveyed to a collection and transmission system away from the area. In other cases, it may be impossible to remove water from an area with sinkholes or away from karst geology, so common sense clean-up of the water and discharge into the karstic area is a reasonable management approach, especially if some filtering soil is available between the land surface and the karst formation.

More in-depth discussion of karst occurs in the Chapter 10 discussion of special stormwater management approaches and in Chapter 13.

Soils

One of the first steps in the selection of BMPs is an assessment of the type of soils present on a site and the inherent ability of those soils to soak-up water. Soils are extremely variable throughout the state, but fortunately good information on local soil conditions is usually available. Details on surficial soils (generally to a depth of about six feet) are contained in county soil surveys, which are available from the U.S. Department of Agriculture's Natural Resource Conservation Service (NRCS). Soil surveys for much of the state have been digitized to make electronic use practical. Figure 2.17 shows the early 2005 status of the digitizing effort. Note, however, that these surveys are not accurate enough to determine site specific characteristics suitable for many BMP applications, so a detailed site analysis is recommended. The primary reason for this is that soils can vary substantially with depth, and the county soil surveys depict only surficial mapped units.

Limited Infiltration Capacity

Soils with low infiltration capacity are found throughout the state. On a local scale the absence of good soils that can absorb runoff (i.e., infiltrate) can be a major detriment to good stormwater management. Stormwater management limitations in areas with "tight" soils generally preclude large-scale infiltration and ground water recharge (infiltration that passes into the ground water system). These soils will typically be categorized under Hydrologic Soil Group (HSG) D and have other characteristics as shown in Table 2.4. The infiltration rates noted in this table are conservative estimates of long-term, sustainable infiltration rates that have been documented in Minnesota. They are based on in-situ measurement within existing infiltration practices in Minnesota, rather than national numbers or rates based on laboratory columns.

Figure 2.17 Status of Soil Survey Digitizing in Minnesota (Source: NRCS)

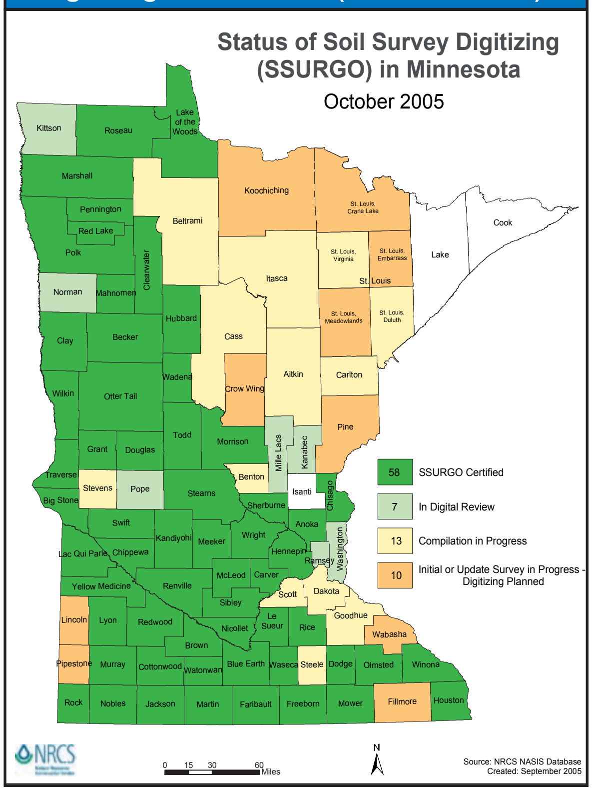


Table 2.4. Infiltration Rates of Hydrologic Soil Group Classifications (Source: Adapted From Brown's Creek Watershed District)			
Hydrologic Soil Group	**Infiltration Rate [inches/ hour]**	**Soil Textures**	**Corresponding Unified Soil Classification**
A	1.6 – 0.6	Sand, loamy sand or sandy loam	**GW** - Well-graded gravels, sandy gravels **GP** – Gap-graded or uniform gravels, sandy gravels **GM** - Silty gravels, silty sandy gravels **SW** - Well-graded, gravelly sands **SP** - Gap-graded or uniform sands, gravelly sands
B	0.6 – 0.3	Silt loam or loam	**SM** - Silty sands, silty gravelly sands **MH** – Micaceous silts, diatomaceous silts, volcanic ash
C	0.3 – 0.1	Sandy clay loam	**ML** - Silts, very fine sands, silty or clayey fine sands
D	< 0.1	Clay loam, silty clay loam, sandy clay, silty clay or clay	**GC** – Clayey gravels, clayey sandy gravels **SC** – Clayey sands, clayey gravelly sands **CL** – Low plasticity clays, sandy or silty clays **OL** – Organic silts and clays of low plasticity **CH** – Highly plastic clays and sandy clays **OH** – Organic silts and clays of high plasticity

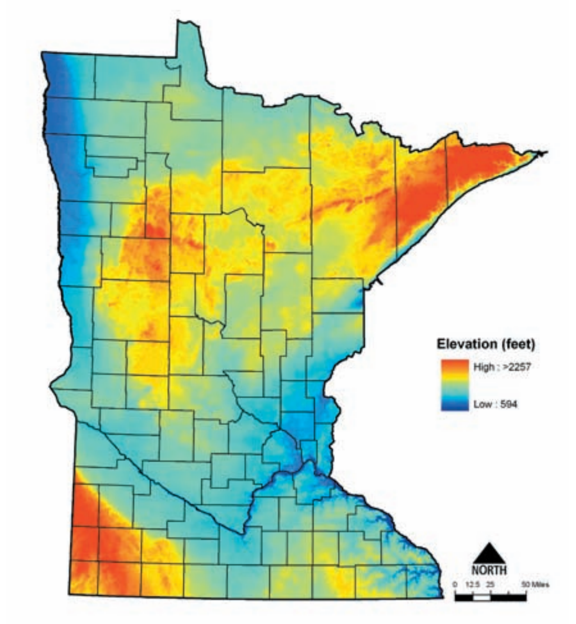
Use of HSG C or D soils for BMPs that rely on infiltration is generally not recommended unless a pre-development condition is trying to be simulated. That is, these soils can certainly be used in a system that relies only on a small amount of infiltration similar to the small amount that inherently exists on site. If a manager wants to match pre-development volume for all soils, it is apparent that D soils will continue to yield low infiltration. More details on these systems are found in the Chapter 6 and Chapter 12 discussions of BMPs. Pre-development condition is defined in Table 10.1.

Rapidly Infiltrating Soils

On the opposite side of the infiltration spectrum are those soils that rapidly infiltrate water from the surface. Soils with large percentages of sand and separate from the water table transmit water very quickly and might work extremely well for infiltration practices provided precautions are taken to protect the ground water from the introduction of polluting materials. The level of treatment in sandy soils is quite variable. Although the sands can act similar to a sand filter for particulate material, soluble pollutants generally move through the soil quite rapidly and unattenuated. Figure 2.18 shows an example of a large-scale sandy soil condition in the Anoka Sand Plain. Similar large expanses of sandy soils exist elsewhere in Minnesota and

Figure 2.18 Anoka Sand Plain (Source: Adapted from DNR)

Figure 2.19 Minnesota Elevation Schematic (Source: Adapted from MGS)



should be recognized when planning a BMP strategy.

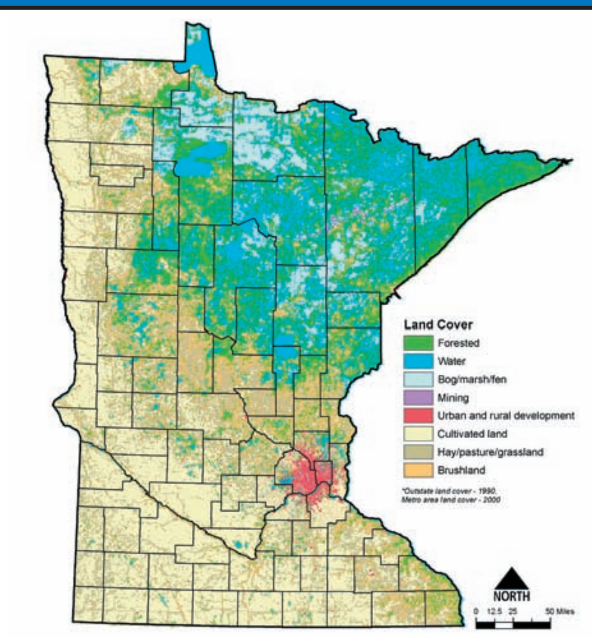
Topography

The elevation and topographical changes evident in Minnesota also present variable challenges to local stormwater managers. For example, the steep slopes along the North Shore and along many major river banks requires a far different approach than those practices where a deep soil cover exists on a flat plain or slowly rolling hills. Figure 2.19 illustrates the state variation in elevation, but again, local attention is required when information on slope, topography and physiographic character is part of the stormwater management deliberation.

Cultural Features

Most of the cultural variation in the state relates to the land uses that have developed. Figure 2.20 illustrates the statewide differences in land use that have resulted as the state developed over the past 100+ years. Although the major focus of this Manual is on urbanized land uses, many urbanizing type activities, such as road building, transcend a single land use and apply throughout the state. Also in many cases urbanization occurs on land that was previously altered by agricultural, silvicultural, or pre-development activity.

Figure 2.20 Minnesota Land Use (from DNR, 1990 Statewide and Metropolitan Council, 2000 Metro Area)



V. How This Manual Will Help

The above scenario points out the many challenges faced as Minnesota develops, but there is a positive side. The citizens of Minnesota long ago realized the potential for worsening water quality as the state grew. The solution they discovered was not to stop growth, but rather to plan for how it happens and to institute protective actions to prevent many of the negative impacts. It is virtually impossible to prevent all negative impacts, but there is a realistic expectation that efforts to minimize the impact should occur. This is the basis for the stormwater regulatory program in place in the state.

There are also many new and ever-evolving ways to manage the runoff and eliminate some of the pollution associated with it. These best management practices are proven effective measures that are readily available in both structural and non-structural ways. There are no "best" solutions that apply universally to all situations across the state. There are best solutions that can be chosen for specific applications to solve specific problems, hence the name best management practice.

The *Minnesota Stormwater Manual* provides insight for Minnesota stormwater managers on the nature of the stormwater problem in the state, as well as guidance on how to manage it using many available tools. We do not have to accept the situation portrayed in Figure 2.3, for example; instead, we can protect our valuable receiving waters through a reasonable set of practices applied equitably across the state. This is a major objective of this Manual.

VI. General Principles for Stormwater Management

Awareness of the potential for pollution of Minnesota's water is an important beginning, but action must follow. A performance based approach to action means that a management plan is put together focused on achieving or maintaining a certain goal. The methods used to achieve the goal are not entirely prescriptive. This allows the stormwater manager the flexibility to be innovative.

There are several principles consistent with integrated stormwater management and the treatment train approach that this Manual uses to promote proper runoff management. They are:

- Think watershed by evaluating where the water from your land comes from and where it will go when it leaves.
- Preventing the potential for a pollutant to be washed-off is always the first step in a treatment train approach to runoff management.
- Unless there is a good reason not to, such as a source of toxic material in the watershed, try to soak in as much water as possible - the treatment train (Figure 1.1) starts here.
- Don't forget that winter is a season in Minnesota and that all of that snow will eventually melt and need to be managed.
- A vegetative cover is always better than bare soil, and native vegetation is always better than decorative grass.
- The less active management a BMP requires to properly operate, the better.
- Simple is okay. Performance based means the outcome is important, not necessarily the complexity of the BMP(s).
- Thoughtful design and sound construction can reduce the level of maintenance required for effective operation and performance of BMPs.
- Proper maintenance will prolong the life and sustain an optimum level of pollution removal from a BMP.
- Each site in Minnesota requires its own unique characterization to best address its stormwater management needs and coordination with all affected parties is essential to success.
- Management designs should consider all impacts, including secondary environmental factors, health and human safety, maintenance, and financial burden.

VII. References

Alexander, E.C. Jr. and Y. Gao, 2002. Copyrighted map of Minnesota Karst Lands.

Conservation Toronto and Region, 2001. The Storm Water Pollution Prevention Handbook. Copublished with the Ontario Ministry of the Environment. Available at http://www.ene.gov.on.ca/envision/water/stormwaterpph.htm.

Georgia (State of), 2001. Stormwater Management Manual. Available at http://www.georgiastormwater.com/ .

Granger, R.J., D.M. Gray, and G.E. Dick, 1984. Snowmelt Infiltration to Frozen Soils. Canadian Journal of Earth Science, 21:669-677.

Great Lakes Association. Percent Bedrock Outcrop of Landtype Associations of Northern Minnesota Map.

Minnesota State Climatology Office and Minnesota Department of Natural Resources. 2003. Normal Annual Precipitation.

Natural Resource Conservation Service. 2005. Status of Soil Survey Digitizing (SSURGO) Minnesota.

Schueler, T.R., 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban Best Management Practices. Metropolitan Washington Council of Governments, Washington, D.C.

U.S. Weather Bureau (D.M. Hershfield), 1961. Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. USWB Technical Publication 40 (TP 40).

Chapter 3

Integrating Stormwater Management Into Site Design

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VOLUME 1 - INTEGRATED STORMWATER MANAGEMENT

Chapter 3

Integrating Stormwater Management Into Site Design

This chapter provides a definition of "Integrated Stormwater Management" and discusses its multi-faceted approach. It discusses rate and volume control, ground water and surface water interaction, pollution prevention, and the definition of "BMP."

Contents

I. What Is Integrated Stormwater Management?

Integrated stormwater management is simply thinking about all of the factors that somehow affect precipitation as it moves from the land surface to an eventual receiving water. It is the process of accounting for all of these factors (e.g. rate, volume, quality, ground water impact) in a logical process so that inadvertent mistakes are not made that could eventually harm a resource. The treatment train approach to runoff management mimics the sequence as the stormwater manager looks at the runoff problem and determines how best to address it, starting with the most basic of questions and increasing in complexity only if needed, since simple methods of management are often the most practical. A regulator might view it as a check to see if a simple approach could replace something more complicated and expensive.

Project Scope

The first step in integrated stormwater management is determining the scope of the project and the likely solutions that will be needed. If on-site, simple practices will solve the problem, a non- or minimum-structural approach can be pursued. If problems extend off-site and impact a major regional water body, then a broader scale will need to be pursued and commensurate BMPs chosen.

The decisions will always be influenced by the regulatory requirements associated with the action. That is, a project that creates new impervious surfaces over one acre or is part of a common plan of development will need to comply with the requirements of the State's Construction General Permit. Additional local or watershed requirements may also be required (Chapter 5). Retrofits or actions not creating new impervious area can introduce creative or innovative solutions, such as supplemental sub-grade infiltration, proprietary filters or wetland polishing. Note that these can also be part of the regulated treatment train.

Watershed Approach

Minnesota has a long-standing tradition of approaching water management on a watershed system basis. Landmark legislation in the state has mandated watershed-based planning and management for over 50 years. Figure 2.8 from the previous chapter illustrated the large-scale watersheds within the state, but local or watershed agencies should be contacted to obtain fine-scale watershed boundaries, even on a parcel-by-parcel basis.

For every project, the question that should always be asked is "Where does water come from that enters my site and where does it ultimately go when it leaves?" This single question becomes the basis for a future management approach. For example, if the water leaving the site discharges to a trout stream rather than a lake, a different set of BMPs that focuses on temperature control rather than phosphorus removal will be pursued. Proper operation of the watershed as a "system" should always be part of a stormwater manager's thought process.

Use and Restoration of Natural Resources

The occurrence of natural features, such as wetlands, forest, natural drainage features, original topography, undisturbed soils, and open space on a site should be viewed as a positive thing. These features can be preserved to minimize the impact of development, used as an integral part of the treatment train, or even enhanced to improve site hydrology or the quality of runoff leaving the site.

Many of the basic tenets of "low impact development," "better site design," and "sustainable development" are rooted in the preservation, restoration and enhancement of the natural drainage system. Following this approach can lead to cost savings, as well as added environmental protection.

Water Quantity and Quality

Integrated stormwater management requires a complete look at both the movement and content of runoff water. Focusing exclusively on one or the other might meet a specific regulatory requirement, but will not result in effective overall stormwater management. Discussion of the quality impacts occurred in Chapter 2 and will not be repeated here. However further discussion of quantity impacts is warranted.

Integrated Stormwater Design Principles
(Source: Center for Watershed Protection)

Effective stormwater practices are integrated into the urban landscape to improve their function and performance. Twelve principles that help define the successful integration of a stormwater practice in the landscape include:

1. Provides Reliable Pollutant Removal Performance. The practice should be sized so that it captures sufficient volume of runoff and employs a sequence of pollutant removal mechanisms via a treatment train approach to maximize the removal of key pollutants of concern.

2. Mimics Pre-development Hydrology. The practice should operate in a manner so as to replicate pre-development hydrology for a range of storm events such that it safely recharges ground water, protects downstream channels and reduces off-site flood damage.

3. Integrates the Practice into Overall Site Design. The overall design of the site should support the function and performance of the practice, by minimizing or disconnecting impervious cover, implementing source controls, and utilizing better site design practices that reduce the quantity and adverse quality effects of runoff generated by the site.

4. Has a Sustainable Maintenance Burden. Both routine and long–term maintenance tasks should be carefully considered throughout the design process to reduce life cycle maintenance costs and promote longevity of the practice.

5. Is Accepted by the Public. The practice should be viewed as an attractive community amenity by adjacent residents or business owners, as measured by interviews, surveys, testimonials, increased property values and other yardsticks.

6. Creates Attractive Landscape Features. The practice should be an integrated practice designed to be highly visible within the site and serve as an attractive and inviting landscape feature.

7. Confers Multiple Community Benefits. An integrated practice should also contribute to other community benefits such as promoting neighborhood revitalization, expanding recreational opportunities, and educating residents about stormwater.

8. Creatively Uses Vegetation. An integrated practice not only greens up the site, but also uses vegetation to effectively promote cooling, shading, screening, habitat and enhanced pollutant removal functions. The design should also explicitly consider how vegetation will be managed over time to maintain functions and minimize maintenance costs.

9. Provides a Model for Future Improvement. An integrated practice is inspected, evaluated, or monitored so that lessons can be learned to improve the performance and integrate future designs.

10. Realizes Additional Environmental Benefits. The design of an integrated practice maximizes other environmental benefits at the site, such as the creation of aquatic or terrestrial habitat, protection of existing natural areas, reduction of urban heat island effects and other urban amenities.

11. Reduces Infrastructure Costs. An integrated practice reduces the amount of paving, curbs, storm drain pipes and other infrastructure that would have otherwise been employed in a traditional stormwater practice design within the community.

12. Acceptable Life Cycle Costs. An integrated practice will not result in high life cycle costs over its useful life.

Rate and Volume Control

In its early stages, stormwater management was primarily concerned only with quantity control. Urban hydrology techniques focused mostly on peak flow rate control and addressed volume in terms of flood control. The standard approaches for rate control have been greatly refined over the years, with more attention on mimicking pre-development or natural conditions (See discussion in Chapter 10). Volume control, on the other hand, has been something more difficult to achieve. The following section addresses the techniques that should be considered when a need exists to address stormwater quantity leaving a site.

Rate Reduction Techniques

In the past, rate control was primarily used to prevent downstream flooding. Relying solely on rate reduction for stormwater control led to many system failures as volume and quality factors were left uncontrolled. Although not universally true, advancement in the state of the art for rate control practices generally came about as urbanization increased and greater protection from water leaving these largely impervious places was needed.

Chapters within this Manual take the stormwater manager beyond flood protection to hydrograph frequency matching, downstream channel protection and control techniques designed to maximize water quality improvement from the commonly occurring events that account for most of the runoff. Reference to this chapter and Chapters 4, 8, 9 and 10, as well as Issue Papers B, D, E, F, and G, found in Appendix J, provides some insight to the reasons for rate control and tools available to accomplish it.

Volume Reduction Techniques

The importances of volume reduction become apparent as more and more urban surfaces developed and more stormwater overwhelmed receiving waters. Clearly stormwater management needs to include volume control.

The term volume reduction can be easily confused with infiltration. One does not, however, necessarily equate to the other. There are many additional techniques and BMPs that can be applied to yield volume reductions.

Any technique that soaks water into the ground, makes water available for evaporation and/or transpiration, stores water for re-use, or in any way diverts stormwater away from the drainage system can be considered a volume reduction practice. Infiltration is certainly one of these practices, but it is only one of many. In circumstances where soils are too tight or where infiltration would endanger ground water, alternatives are available (Table 3.1) to reduce volume.

The following categorical methods for volume reduction, while certainly not all-inclusive, can provide some ideas for how a stormwater manager could reduce the volume of runoff leaving a parcel of land. The specific BMPs that use these methods are discussed in Chapter 6 and Chapter 12.

Infiltration

The most commonly used method to reduce site volume is to soak it into the soil. The result of this action is a direct reduction in volume running off of the land surface. The biggest requirement for use of infiltration is the ability of the soil and the shallow ground water system to accept the water.

The distinction between infiltration and recharge is a narrow one that can usually be ignored. Commonly, infiltration is the process of soaking water into the ground, while recharge is the movement of water into the ground water system. Recharge occurs to both shallow and deep ground water systems.

Low impact development (LID), better site design (BSD) and sustainable development are all variations of an approach that mimics natural conditions by soaking water into the ground close to where it falls. Use of these methods along with reduction of impervious areas reduces overall runoff volume and may be a component in many, but certainly not all runoff management plans. Reduction of connected impervious area and retention of natural drainage patterns and surfaces are the heart of these methods. Chapters 12 and 13 address the caution that should be followed whenever infiltration is used as a management technique.

Evapotranspiration

The combined process of evaporating and/or transpiring (vegetative uptake and release of water) is called evapotranspiration or simply "ET." This process typically results whenever water is held in storage (evaporation, or sublimation of snow in the winter) and allowed to be taken up by roots and released through leaves (transpiration). In areas with tight soils, holding water in wetlands, depressions, swales or any similar land feature that exposes water to the air will result in evaporation of that water. In addition, allowing it to come in contact with roots either in standing water (wetland) or by soaking into the root zone, will yield volume reduction through transpiration. In fact, this and reforestation can be used as stormwater management techniques.

Where soils provide a constraint, under-drains can provide a means through which water can be routed through the root zone for root uptake, but excess can be captured after filtration and drained to a collection system. This option results in some net reduction in volume and adds filtration as a supplemental treatment. Many bioretention treatment techniques take advantage of this method of volume reduction.

The combined infiltration plus ET rates for Minnesota can vary across the state from 11 inches in the northeast to 23 inches in the south. The complex relationship among precipitation, runoff, infiltration, and ET is discussed by Baker *et al.* (1979). They discuss the details and methods used to divide the water that falls as precipitation into several categories reflective of where it ends up. Obviously, routing water to areas where it can soak into the ground or to areas with vegetation that can take it up through root action are two very good ways to reduce overall stormwater volume if adequate space is available.

Storage

Retaining water somewhere along the path from where it falls to where it enters a drainage system is another way to limit volume. Simple contained storage directly connected to buildings or impervious areas are effective volume reducers and provide an opportunity for water re-use, such as irrigation. A rain barrel, cistern, sub-grade storage device, or even a yard ornamental pond can hold enough water to contain much of the volume coming from a home. A green roof can reduce annual runoff by up to 75% because it soaks and stores water that falls on it, then transpires it away.

Even a pond or a wetland can reduce overall volume because they provide a quiescent area where water can collect and evaporate. Pan evaporation in Minnesota can reach as high as 40+ inches (Baker *et al.*, 1979). This is possible even when rainfall is much less because water is routed to these holding areas from a much larger watershed.

Conveyance

Getting rid of water was the common way to deal with stormwater before the results of that action were realized. Rushing water to a drain pipe, then into a receiving water is now considered a last resort. Using pervious approaches such as vegetated drainage swales and native grass filter strips, in combination with check dams give water a chance to soak into the ground or be filtered before it reaches a location where damage takes place. As with the practices above, volume reduction is an outcome of exposing stormwater to a pervious surface even while it is moving. See Chapter 12 for filtration and infiltration BMPs that would fit in this category.

Landscaping

Many of the previous practices could also be included in a general category that stresses the importance of stable landscapes with native vegetation. In many respects, this is LID/BSD with an added emphasis on structuring the land surface to handle moving water from impervious surfaces. Routing water to low-lying (sump) areas where it can soak in, placing planter boxes or grated inlets for watering trees, and contouring slopes to reduce runoff velocity are all variations on the landscaping theme.

Tying low impact drainage features together via corridors or designed natural treatment trains can further enhance overall site volume reduction by creating a string of reduction possibilities. Safety can always be assured by placing an overflow or even an under-drain to capture any excess flow and route it to the next BMP catchment area.

Cautions for Volume Control Techniques

As with all stormwater management techniques, some caution is advised when applying them under certain circumstances. Following are some advisory cautions that would apply:

- Techniques using any infiltration should abide by the cautionary statements made in the Chapter 12 guidance sheet for infiltration practices and avoid such things as introduction of runoff from potential stormwater hotspots and use of infiltration practices that could influence drinking water wells.
- A hydrologic analysis should be undertaken to determine the impact of excessive water (flooding) on the installation; that is, where excess water would go and any problems that would result. Similarly, an assessment should be done on whether additional ground water volume is likely to cause any local problems, for example with flooded basements.
- Evapotranspiration values go down dramatically in the cold weather. Consideration is needed on how this may impact operation assumptions for installation.
- Chapter 6 contains mosquito breeding cautions and recommendations for minimization of mosquito breeding habitat for any system in Minnesota that results in standing water.

List of Volume Reduction BMPs

Table 3.1 lists many, but not all, BMPs that can be used to reduce overall runoff volume. Reference is made in the table to a more complete description of the BMP later in this Manual.

The Interaction Between Ground Water and Surface Water

Integrated stormwater management often takes advantage of the interaction that takes place between ground water and surface water. For example, the slow infiltration and movement of surface water into the shallow ground water system results in peak and volume reduction, filtration through cleansing soil and continuation of baseflow to streams. Although stormwater management is often interpreted as a surface water program, many of the BMPs identified in this Manual rely on the ground water system to make them effective. Infiltration BMPs, for example, rely on the soil's capacity to soak in water and transmit it downward to the ground water system. Soil cleansing via filtration, adsorption and microbial uptake can be a very effective removal process for some of the more difficult to treat runoff pollutants.

For the above reason, there must be caution used when pollution is "removed" through a system that affects ground water. For example, although soil adsorption is an effective scavenger of some soluble pollutants, one could argue that the introduction of chloride-laden water into any system that discharges to the ground is merely trading pollution in one water for another. The same could be said for ground water pump-outs that discharge contaminated ground water into any surface water or onto any land surface.

The Manual will note several instances when the interaction between ground water and surface water could be problematic. Specific cautions are raised in Chapter 13 for active karst areas and other shallow or fractured bedrock, high ground water table, tight soils, source water (wellhead) protection areas, and potential stormwater hotspots (PSHs).

Pollution Prevention

The old adage "*An ounce of prevention is worth a pound of cure*" is never more appropriate than when used to describe integrated stormwater management. All of the previous elements have described the physical processes involved, but preventing pollution from coming into contact with runoff is a common sense element. A fact sheet presented in Chapter 12 describes some of the ways in which pollution prevention can be formalized, but keeping in mind the simple separation of runoff and those materials that cause pollution, such as oil, fertilizer, salt and sediment, will go a long way toward controlling urban pollution problems at a very low cost.

Pollution prevention methods are far too numerous to cover in their entirety, but include such common-sense practices as keeping yard and animal waste off of impervious surfaces, preventing soil erosion at all construction sites, disposing of household products properly, repairing leaky automotive parts, and careful storage and use of any polluting chemicals. Following these simple precautions

Table 3.1 Volume Reduction Practices			
Process	BMP*	Comments	Location in Manual
Infiltration	Low impact development/better site design/sustainable development	Includes such things as reduced street and sidewalk width, less curb and gutter drainage, scattered bioretention, shared pavement	Chapter 4
	Trench or basin	Must be properly engineered in adequate soils; proper maintenance essential	Chapter 12, Infiltration BMPs
	Perforated sub-surface pipes, tanks and storage systems	Expensive but effective and space-saving	Chapter 12, Infiltration Supplemental BMP sections
	Disconnected imperviousness	Includes primarily rooftop drains and roadway/parking surfaces	Chapter 12, Runoff Volume Minimization
	Pervious (porous) pavement	Includes a number of paving and block methods, or simple parking on reinforced grassed surfaces	Chapter 12, Runoff Volume Minimization
	Bioretention (if contains infiltration element)	Some bioretention facilities are designed to infiltrate	Chapter 12, Bioretention BMPs
Evapotranspiration	Bioretention (rain gardens)	Exposes runoff water to plant roots for uptake; can be under-drained and still effective	Chapter 12, Bioretention BMPs
	Vegetated swales	Provides water a chance to soak into the ground and be filtered as it flows	Chapter 12, Filtration BMPs
	Wetland/pond storage	Combination of standing water surface and vegetative root exposure yields volume reductions	Chapter 12, Ponds and Wetland BMP sections
	Vegetated drainage corridor	Connecting numerous features increases opportunities	Chapter 4
	Recessed road/parking drainage	Routing paved surface runoff to vegetated sump areas keeps it out of receiving waters	Chapter 12, Bioretention BMPs

Table 3.1 Volume Reduction Practices			
Process	BMP*	Comments	Location in Manual
Storage	Rain barrel/cistern	Small-scale runoff collectors keep water around for later re-use or slow release	Chapter 12, Runoff Volume Minimization
	Rooftop (green roof)	Storage on a roof prevents water from leaving the site; combining with vegetation (engineered green roof) makes it even better	Chapter 12, Runoff Volume Minimization
	Wetland/pond storage	Combination of standing water surface and vegetative root exposure yields dramatic volume reductions	Chapter 12, Pond and Wetland BMP sections
Conveyance	Vegetated swale	Provides water a chance to soak into the ground and be filtered as it flows	Chapter 12, Bioretention BMPs
	Filter strips/buffers	Variation on vegetated swale with side slope protection	Chapter 12, Temporary Construction Erosion Control and Bioretention BMP sections
Landscaping	Low impact development/better site design	Includes such things as scattered bioretention, shared pavement; native or prairie plantings	Chapter 4
	Bioretention (rain gardens)	Exposes runoff water to plant roots for uptake; can be under-drained and still effective	Chapter 12, Bioretention BMPs

*Note that some BMPs occur in more than one reduction practice

can make a dramatic difference in the type and amount of polluting material available for wash-off or aerial mobilization.

II. Non-Structural vs. Structural BMPs

The selection of a proper management approach is a key factor in the success of an integrated stormwater management approach. Knowing which BMP(s) to apply under certain conditions could make the difference between success and failure, or between a low-cost and high-cost project. As pointed out in the principles listed in Chapter 2, the simpler the approach to an effective solution, the better.

The definition of BMP can vary significantly depending upon the individual or entity. While some only use BMP to define a practice that improves water quality, this Manual uses the term for both quantity and quality. That is, Chapter 12 includes many BMPs that reduce runoff rate or volume, but might have little direct effect on water quality. For example, dry ponds reduce runoff volume by allowing infiltration to occur as water flows and temporarily accumulates over a vegetated pervious layer. Some water quality improvement certainly occurs as the volume of water, and hence the load of any pollutant it carries, is decreased. However, dry ponds are not recognized by the MPCA as a water quality BMP because settled material is easily resuspended when the next big flow occurs.

Chapters 4, 6, 7, and 12 all contain discussion of BMPs, techniques for runoff management and selection criteria. These are all tools to assist with choosing structural or non-structural approaches. This Manual does not contain many additional non-structural practices that could be considered as institutional management approaches. Details on such things as zoning, ordinances, plan and permit review, public education, training, and others are not contained in this Manual. However, they have been referenced throughout with links often included if the user would like further information. The Manual is designed to present physical BMPs only to keep the scope manageable

III. Link to Better Site Design

More detail on integrated stormwater management is part of the discussion in Chapter 4 on better site design. Better site design is used as an all-inclusive term that includes low impact development, sustainable development, design with nature or any other approach to consistent with the treatment train design philosophy.

IV. References

Baker, D.G., W.W. Nelson and E.L. Kuehnast, 1979. *Climate of Minnesota: Part XII – The Hydrologic Cycle and Soil Water.* University of Minnesota, Agricultural Experiment Station, St. Paul, MN.

Chapter 4

Better Site Design Techniques

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VOLUME 1 - INTEGRATED STORMWATER MANAGEMENT

Chapter 4

Better Site Design Techniques

This chapter provides guidance to designers on how to plan and apply better site design practices at new development projects, including a series of techniques that reduce impervious cover, conserve natural areas, and use pervious areas to more effectively treat stormwater runoff.

Contents

I. Introduction

This chapter provides guidance to designers on how to plan and apply better site design practices at new development sites. Better site design includes a series of techniques that reduce impervious cover, conserve natural areas, and use pervious areas to more effectively treat stormwater runoff (Center for Watershed Protection, 1998a) and promote the treatment train approach to runoff management. The goal of better site design is to reduce runoff volume and mitigate site impacts when decisions are being made about proposed layout of a development site. These techniques are known by many different names, such as low impact development, design with nature, sustainable development and conservation design. Better site design techniques have been promoted in earlier state and regional stormwater manuals (MPCA, 2002 and Metropolitan Council 2001). As always, state and local regulations and design standards should be checked to assure that all requirements have been met.

When applied early in the design and layout process, better site design techniques can sharply reduce stormwater runoff and pollutants generated at a development site, and also reduce the size and cost of both the stormwater conveyance system and stormwater management practices (Center for Watershed Protection, 1998b).

More than a dozen different better site design techniques can be applied early in the design process at development sites. While not all of the better site design techniques will apply to every development site, the goal is to apply as many of them as possible to maximize stormwater reduction benefits, as shown below:

- ► **Preserving Natural Areas**
    - Natural Area Conservation*
    - Site Reforestation*
    - Stream and Shoreline Buffers*
    - Open Space Design

- ► **Disconnecting and Distributing Runoff**
    - Soil Compost Amendments
    - Disconnection of Surface Impervious Cover*
    - Rooftop Disconnection*
    - Grass Channels*
    - Stormwater Landscaping

- ► **Reducing Impervious Cover in Site Design**
    - Narrower Streets
    - Slimmer Sidewalks
    - Smaller Cul-de-sacs
    - Shorter Driveways
    - Smaller Parking Lots

*Better site design techniques denoted by an asterisk above may be worked into a program for stormwater credit which reduces the water quality volume that must be treated at a site. More information on how to compute stormwater credits can be found in Chapter 11 of this Manual.

II. Preserving Natural Areas

From a stormwater standpoint, it is desirable to maintain as much natural vegetative cover such as forest, prairie or wetland as possible. Natural areas generate the least amount of stormwater runoff and pollutant loads and establish and maintain the desired pre-development hydrology for the site. One of the first steps in the site planning involves identifying, conserving and restoring natural areas present at the development site. The overall strategy is to maximize natural area conservation beyond what is required under local or state resource requirements. Normally, an inventory of natural areas is conducted at the site, along with an assessment of potential areas for reforestation or restoration. Next, designers modify the layout of the development project to take advantage of natural features, preserve the most sensitive areas, and mitigate any stormwater impacts. Open space design is one of the most effective better site design techniques for preserving natural areas at residential sites without losing developable lots.

Natural Area Conservation

Natural area conservation protects natural resources and environmental features that help maintain the pre-development hydrology of a site by reducing runoff and promoting infiltration (Figure 4.1). Examples include any undisturbed vegetation preserved at the development site, such as forests, prairies, and riparian areas, ridge tops and steep slopes, and stream, wetland and shoreline buffers. Designers should also place a particular priority on preserving natural drainage pathways, intermittent and perennial streams, and floodplains and their associated wetlands. Buildings and roads should be located around the

Figure 4.1 Residential Subdivision Illustrating Preservation of Undisturbed Natural Areas (Source: Arendt, 1997).

Figure 4.2 Potential Planting Areas at a Development Site (Source: Cappiella *et al.*, 2005) .

natural topography and drainage so as to avoid unnecessary disturbance of vegetation, soils and natural drainage ways.

The undisturbed soils and vegetation of natural areas promote infiltration, runoff filtering and direct uptake of pollutants. Forested areas intercept rainfall in their canopy, reducing the amount of rain that reaches the ground. Vegetation also pumps soil water back into the atmosphere which increases storage available in the soil. Native vegetation also prevents erosion by stabilizing soil, filtering sediment and pollutants from runoff, and nutrient uptake. Preserving natural areas creates many economic benefits including decreased heating and cooling costs, higher property values and improved habitat (Cappiella, 2005). Generally a natural grassland area would have to be five acres or larger to approach *full* ecological function, and a forested site would have to be in the range of 20-40 acres (DNR written correspondence, 2005).

Two resource tools for identifying natural forest or prairie areas include native plant community and biodiversity site polygons form the DNR Data Deli and natural element occurrences from the Natural Heritage Information System. Native plant communities can also be identified using the DNR plant community keys: Minnesota Department of Natural Resources , 2003; Minnesota Department of Natural Resources , 2005; Minnesota Department of Natural Resources , 2006. These guides also provide information on plant species to include in restoration efforts.

Site Reforestation or Restoration

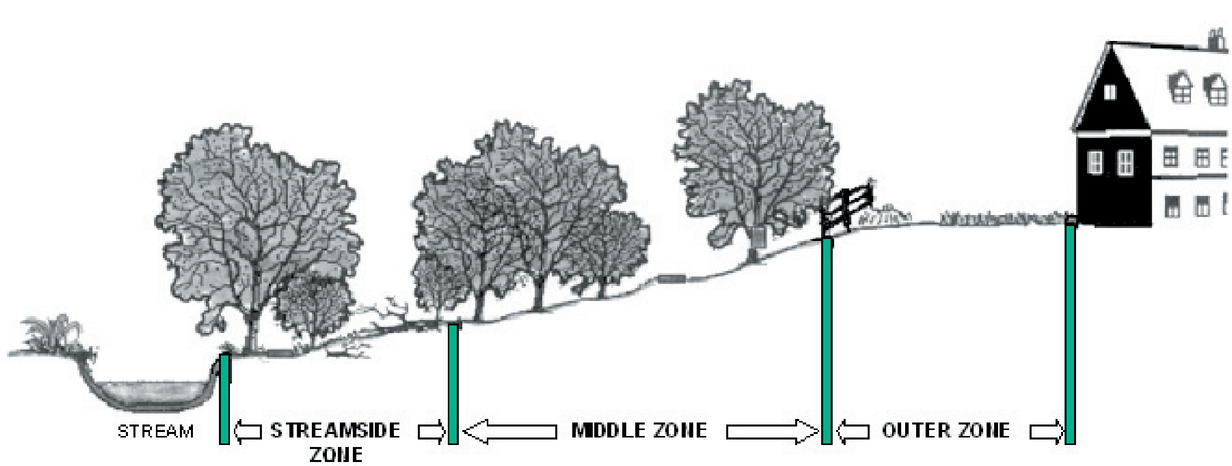
Site reforestation involves planting trees on existing turf or barren ground at a development site with the goal of establishing a mature forest canopy that can intercept rainfall, maximize infiltration and increase evapotranspiration (Figure 4.2). In some parts of the state, prairie is the desired vegetative community, and prairie restoration can provide similar hydrological benefits.

Reforestation is accomplished through active replanting or natural regeneration of forest cover. Cappiella (2005) reviewed a range of research that demonstrated the runoff reduction benefits associated with forest cover compared to turf cover. The benefits include reduced annual runoff volumes, higher rates of infiltration, reduced soil erosion, and greater uptake removal of stormwater pollutants. Forest soils actively promote greater infiltration rates due to surface organic matter and macro pores created by tree roots. Forests also intercept rainfall in their canopy, reducing the amount of rain that reaches the ground and increasing potential water storage in forest environments.

Stream and Shoreline Buffers

Many communities require buffers at development sites to provide a vegetative setback between development and streams, lakes or wetlands. The portions of a site reserved for buffers can present an excellent opportunity to practice better site design. The primary function of buffers is to

Figure 4.3 Three-Zone Stream Buffer System (Source: Adapted from Schueler, 1995).



physically protect a stream, lake or wetland from future disturbance or encroachment; however, with careful design they can also be used to capture and filter stormwater runoff from upland areas of the site. To optimize stormwater treatment, the outer boundary of the buffer (Figure 4.3) should have a stormwater depression area and a grass filter strip. Runoff captured within the stormwater depression is spread across a grass filter designed for sheet flow conditions, and discharges to a wider forest or shrub buffer in the middle or streamside zones that can fully infiltrate and/or further treat stormflows.

Buffers can provide many different environmental and economic benefits, including:

- Reduced small drainage problems and complaints
- Reduced risk of flood damage
- Reduced stream bank erosion
- Increased adjacent property values
- Enhanced pollutant removal
- Location for greenways and trails
- Sustained integrity of stream ecosystems and habitat
- Protection of wetlands associated with the stream corridor
- Prevention of disturbance of steep slopes
- Mitigation of stream warming
- Protection of important stream corridor habitat for wildlife

Open Space Design

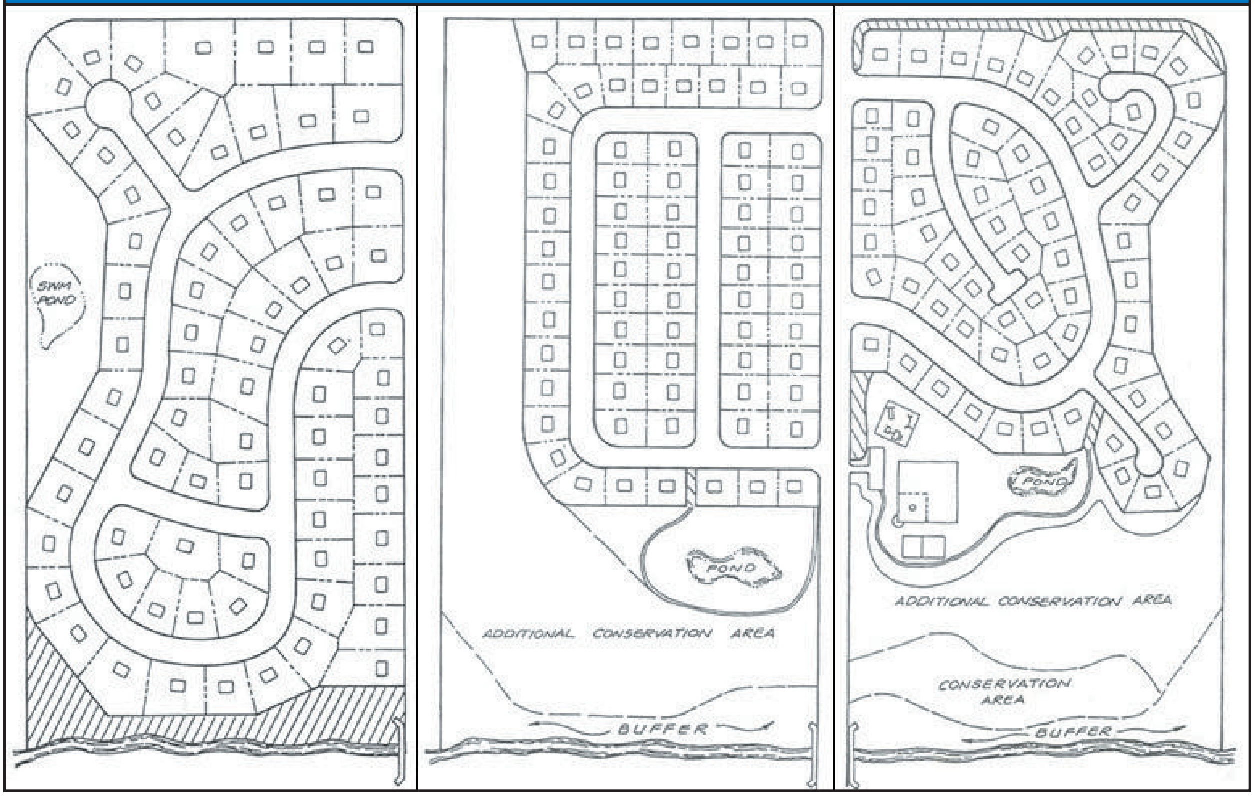
Open space design is a form of residential development that concentrates lots in a compact area of the site to allow for greater conservation of natural areas (Figure 4.4). Minimum lot sizes, setbacks and frontage distances are relaxed so as to maintain the same number of dwelling units at the site. This form of development may also be called cluster design or conservation design. If open space design is available as an option under local zoning codes, it can be an excellent tool to conserve more natural areas beyond the minimum required under local and state water resource protection ordinances. Open space design can also be used to reduce or disconnect impervious cover and provide for greater on-site stormwater treatment. The natural areas conserved are protected by easement and managed by a community or homeowners association.

Research has shown that open space designs can reduce overall site impervious cover compared to conventional subdivisions, and command higher prices and more rapid sales, as well (Zielinski, 2001). Other benefits include lower costs for grading, erosion control, stormwater and site infrastructure, as well as greater land conservation without the loss of developable lots.

III. Disconnecting and Distributing Stormwater

A better site design strategy seeks to maximize the use of pervious areas at the site to help filter

Figure 4.4 Conventional Subdivision (left) with 72 Lots, an Alternative Layout (center) Using Open Space Design with the Same Number of Lots, and Another Alternative Layout (right) Using Open Space Design with 66 Lots (Source Schueler, 1995)



and infiltrate runoff generated from impervious areas and to spread excess runoff from these surfaces over pervious areas. Most development sites have extensive areas of grass or landscaping where runoff can be treated close to the source where it is generated. Designers should carefully look at the site for pervious areas that might be used to disconnect or distribute runoff.

Compost and Amended Soils

Compost amended soils are used to recover soil porosity lost due to compaction as a result of past construction, soil disturbance and ongoing human traffic. The amendment process seeks to recover the porosity and bulk density of soils by incorporating soil amendments or conditioners into the lawn, such as compost, top soil, lime and gypsum (McDonald, 1999).

Soils can also be amended through the addition of fibers for structural support to prevent compaction, as well as the simple addition of sand to improve permeability or organic material other than compost (e.g. peat).

Soils are the foundation for successful planting, and the water holding capacity of soils can significantly reduce the volume of runoff from a site. What constitutes a "good" soil depends on the purpose it is to serve. For example, if you are planting prairie plants a high organic content in the soil is required. However, if you are planting Kentucky Bluegrass a lower organic content soil can be used.

In addition to successful plant growth, soils can be engineered to improve water holding capacity. The humus materials or compost created from the compost process has a water holding capacity of up to 80 percent by weight. This quality is very significant when trying to decrease runoff and increase filtration. On-site soils can be amended by incorporating compost into the soils or by laying a one to three inch "blanket" of compost on top of the soils. Fiber amendments can assist in maintaining soil structure even with heavy surface loads. The method chosen depends on site

Table 4.1 Environmental Factors to Consider When Integrating Stormwater and Landscaping	
Factor	**Problem Addressed**
Duration and depth of inundation	Invasive plants
Frequency of inundation	Pollutants and toxins
Available moisture during dry weather	Soil compaction
Sediment loading	Susceptibility to erosion
Salt exposure	Browsers (deer and beavers)
Nutrient loading	Slope
Adapted from Shaw and Schmidt (2003)	

characteristics and the purpose it is intended to serve, such as promoting infiltration or reducing nutrient and sediment loading to surface waters.

Disconnection of Surface Impervious Cover

Surface disconnection spreads runoff from small parking lots, courtyards, driveways and sidewalks into adjacent pervious areas where it is filtered or infiltrated into the soil. Designers look for areas of the site where flow can be diverted into turf, lawns or a vegetated filter strip. When many small areas of impervious cover are disconnected from the storm drain system, the total volume and rate of stormwater runoff can be sharply reduced. Disconnections may be restricted based on the length, slope, and soil infiltration rate of the pervious area in order to prevent any reconnection of runoff with the storm drain system. In some cases, minor grading of the site may be needed to promote overland flow and vegetative filtering.

Rooftop Disconnection

Disconnection of rooftops offers an excellent opportunity to spread runoff over lawns and other pervious areas where it can be filtered and infiltrated. Downspout disconnection can infiltrate runoff, reduce runoff velocity, and remove pollutants. Alternately, downspouts can be directed to a dry well, rain garden or surface depression. The stormwater benefits associated with rooftop disconnection can be significant, particularly when residential lot size is large and soils are relatively permeable. Note that building sub-drains generally intercept water from entering a building and do not lend themselves to the impervious disconnection category.

Grass Channels

Curbs, gutters and storm drains are all designed to be hydraulically efficient in removing stormwater from a site. However, they also increase peak runoff discharge, flow velocity, and pollutant delivery to downstream waters. From a better site design perspective, grass channels are preferable to curb and gutters as a conveyance system, where development density, topography, soils and slopes permit their use. Grass channels provide on-site runoff storage, lower peak flows, reduce runoff velocities, and filter or infiltrate some portion of storm flows. While research has indicated that grass channels cannot remove pollutants reliably enough to qualify as a BMP (Winer, 2000), they have been shown to reduce runoff volumes during smaller storms when compared to curbs and gutters.

Stormwater Landscaping

Traditionally, landscaping and stormwater management have been treated separately in site planning. In recent years, engineers and landscape architects have discovered that integrating stormwater into landscaping features can improve the function and quality of both. The basic concept is to adjust the planting area to accept stormwater runoff from adjacent impervious areas and utilize plant species adapted to the modified runoff regime (Table 4.1). Excellent guidance on how to match plant species to stormwater conditions can be found in the MPCA publication *Plants for Stormwater Design: Species Selection for the Upper Midwest* (Shaw and Schmidt, 2003) and in Cappiella *et al.* (2005).

Figure 4.5 Examples of the Use of Landscaped Islands for Stormwater Treatment in a Suburban Parking Lot (left), the Parking Lot of a Government Office Building (right top), and a Highly Urban Parking Lot (right bottom)

A landscaping area may provide full or partial stormwater treatment, depending on site conditions. An excellent example of the use of landscaping for full stormwater treatment is bioretention (Figure 4.5). In other cases, landscaping can provide supplemental treatment such as green rooftops and stormwater planters. Even small areas of impervious cover should be directed into landscaping areas since stormwater or melt water help to reduce irrigation needs. More specific recommendations on the use of landscaping in BMP design can be found in Chapter 12 and Appendix E.

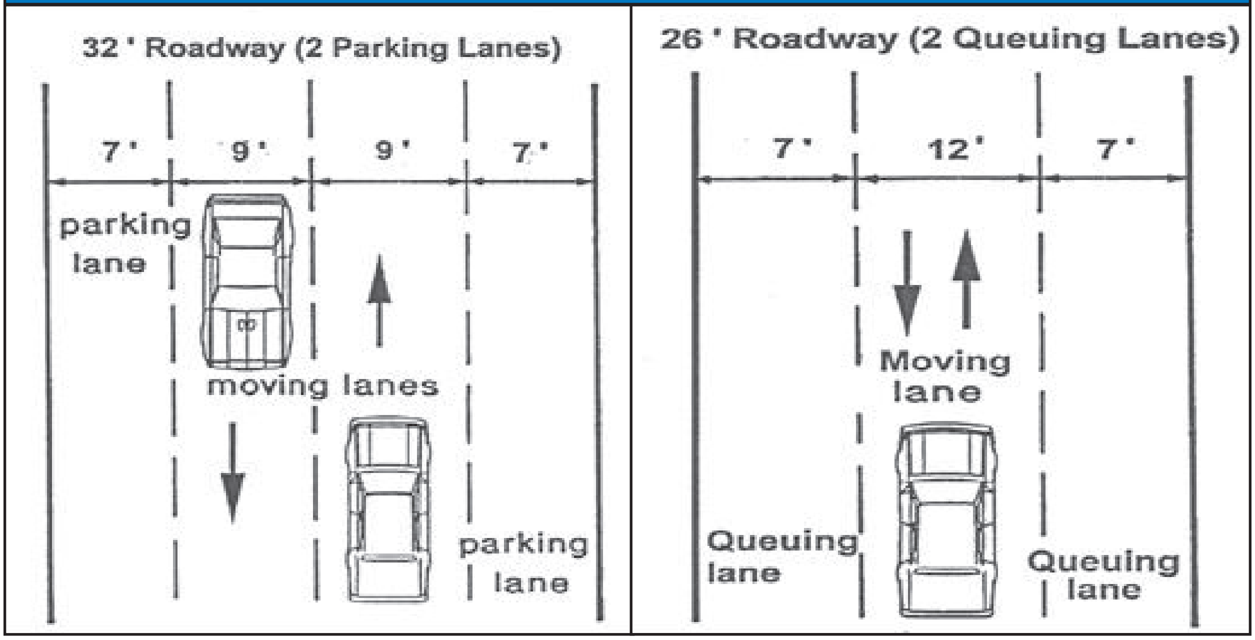
IV. Reducing Impervious Cover in Site Design

This strategy relies on several techniques to reduce the total area of rooftops, parking lots, streets, sidewalks and other types of impervious cover created at a development site. The basic approach is to reduce each type of impervious cover by downsizing the required minimum geometry specified in current local codes, keeping in mind that there are minimum requirements that must be met for fire, snowplow and school bus operation. Less impervious cover directly translates into less stormwater runoff and pollutant loads generated at the site. In most communities, local codes must be changed to allow the use of this group of better site design techniques.

Narrower Streets

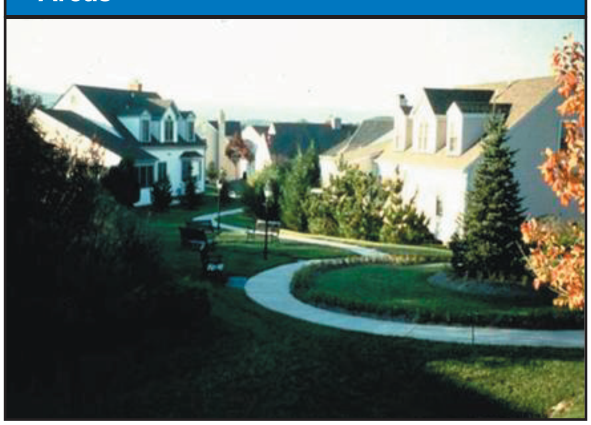
Many communities require residential streets that are much wider than needed to support travel lanes, on-street parking, and emergency access. Some communities currently require residential streets as wide as 32 to 40 feet and which provide two parking lanes and two moving lanes (Figure 4.6). Local experience has shown that residential streets can have pavement widths as narrow as 22 to 26 feet, and still accommodate all access and parking needs (ITE, 1997). Even narrower access streets or shared driveways can be used when only a handful of homes are served. Narrower streets help reduce impervious cover and associated runoff and pollutant generation.

Figure 4.6 Example of a Traditional Road Design (left) and a Road that was Narrowed Through the Use of "Queuing" Lanes (right)



Significant cost savings occur in both road construction and maintenance. Narrower streets also help reduce traffic speeds in residential neighborhoods which, in turn, improve pedestrian safety. Snow stockpiles on narrow streets can be accommodated if parking is restricted to one side of the street or alternated between the sides. Alternatively, the right-of-way may be used for snow storage. Narrow snowplows are available. Snowplows with 8' width, mounted on a pick-up truck are common. Some companies manufacture alternative plows on small bobcat-type machines.

Figure 4.7 Sidewalk that Drains to Adjacent Vegetation and Provides Common Walkways Linking Pedestrian Areas



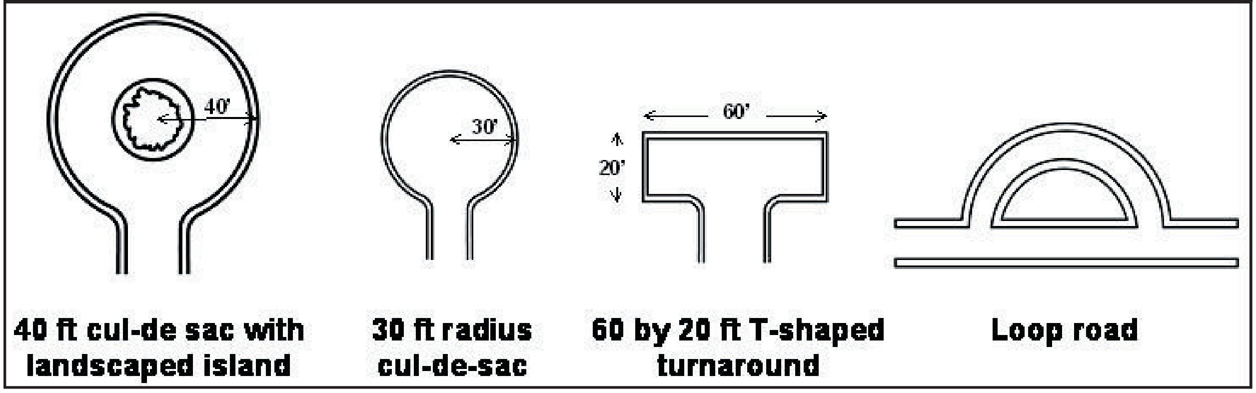
Slimmer Sidewalks

Many communities require sidewalks that are excessively wide or are located adjacent to the street where the pedestrians are at risk from vehicles. A better site design technique modifies the width and location of sidewalks to promote safer pedestrian mobility (Figure 4.7). Impervious cover is reduced when sidewalks are required on only one side of the street, reduced in width and are located away from the street. Sidewalks can also be disconnected so they drain to lawns or landscaping instead of the gutter and storm drain system. Slimmer sidewalks reduce and/or disconnect impervious cover, and thus reduce the generation of runoff. Other benefits include greater pedestrian safety, lower construction and maintenance costs, and reduced individual homeowner responsibility for snow clearance.

Smaller Cul-de-Sacs

The large cul-de-sacs that enable vehicles to turn around at the end of a residential street provide a great opportunity for better site design. Impervious cover can be reduced by minimizing the diameter of residential street cul-de-sacs and incorporating landscaped areas into them. Many communities require cul-de-sacs that have a

Figure 4.8 Turnaround options for residential streets (Source: Adapted from Schueler, 1995)



greater diameter than needed to allow emergency and large vehicles to adequately turn around. Alternatives to the traditional 80 foot diameter cul-de-sac include 60 foot diameter cul-de-sacs, hammerhead turnarounds and loop roads (Figure 4.8). In addition, the inside of the turnaround can be landscaped as a bioretention area to further reduce impervious cover and improve stormwater treatment. Trees and vegetation planted in landscaped islands can be used to intercept rain water and treat stormwater runoff from surrounding pavement (Figure 4.9). Each of these alternative turnaround options produces a more attractive and safe environment for residents.

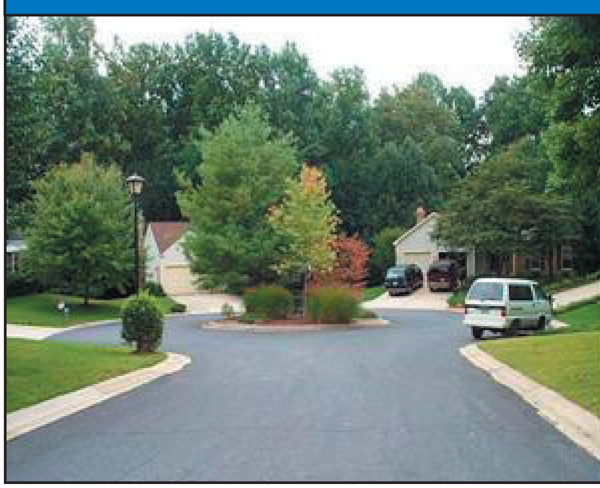
Shorter Driveways

Driveways present another opportunity to practice better site design. Most local codes contain front yard setback requirements that dictate driveway length. In many communities, front yard setbacks for certain residential zoning categories may extend 50 or 100 feet or even longer, which increases driveway length well beyond what is needed for adequate parking and access to the garage. Shorter setbacks reduce the length and impervious cover for individual driveways. In addition, driveway width can be reduced, and more permeable driveway surfaces allowed. Another way to reduce impervious cover is to allow shared driveways that provide street access for up to six homes (Figure 4.10). Shorter driveways help reduce infrastructure costs for developers since they reduce the amount of paving or concrete needed.

Smaller Parking Lots

The parking lot is an excellent place to apply better site design. In many communities, parking lots are

Figure 4.9 Trees and Vegetation Planted in the Landscaped Island of a Cul-de-sac (left) and a Loop Road (right)



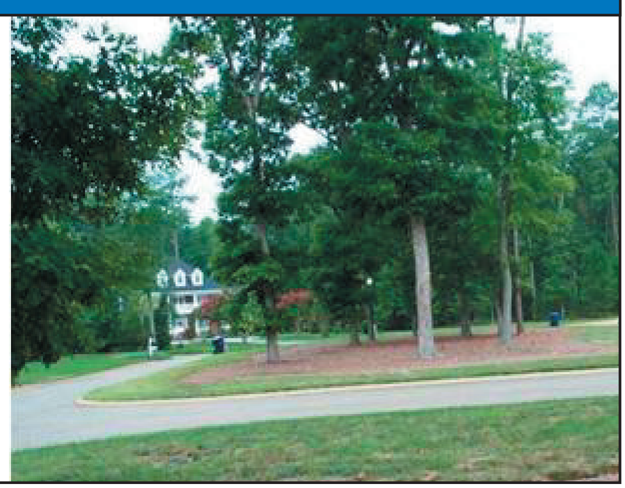


Figure 4.10 Example of a Shorter Driveway (left) and a Shared Driveway (right)

over-sized and under-designed. Local parking and landscaping codes can be modified to allow the following better site design techniques to be applied within parking lots:

- Minimize standard stall dimensions for regular spaces
- Provide compact car spaces
- Use of pervious pavement (asphalt, concrete, blocks, sand amendments)
- Incorporate efficient parking lanes
- Reduce minimum parking demand ratios for certain land use
- Treat the parking demand ratio as a maximum limit
- Create stormwater "islands" in traffic islands or landscaping areas to treat runoff using bioretention, filter strips or other practices
- Encourage shared parking arrangements

Smaller parking lots can sharply reduce impervious cover and provide more effective treatment of stormwater pollutants. In addition, smaller parking lots reduce both up front construction costs and long term operation and maintenance costs, as well as the size and cost of stormwater practices. Parking lot landscaping makes the lot more attractive to customers, and promotes safety for both vehicles and pedestrians. In addition, trees and other landscaping help screen adjacent land uses, shade people and cars, reduce summertime temperatures and improve air quality and bird habitat. Example wetlands to incorporate into large-scale commercial/institutional parking lots are shown in Section VII.

V. The Benefits of Better Site Design

Several researchers have employed redesign comparisons to demonstrate the benefits of better site design over a wide range of residential lot sizes and commercial applications. For example, Center for Watershed Protection (1998b) demonstrated that better site design techniques could reduce impervious cover and stormwater runoff by 7 to 70%, depending on site conditions. Figure 4.11 illustrates a redesign analysis for a medium density residential subdivision. The analysis suggested that better site design techniques could reduce impervious cover and annual runoff volume by 24%, cut phosphorus loadings by half, and increase site infiltration by 55%, compared to a traditional subdivision.

Each better site design technique provides environmental and economic benefits to both the developer and the community at large. When techniques are applied together at a development site, they can result in tangible savings for the developer in the form of:

- Reduced infrastructure costs (e.g., paving and piping)
- Reduced clearing and grading costs during construction

Figure 4.11 Center for Watershed Protection (1998) Comparative Analysis of Stonehill Estates in the Pre-development Conditions (top), the Conventional Design (middle), and the Open Space Design (bottom)

- ► Smaller and less costly structural stormwater BMPs
- ► Faster sales and lease rates
- ► Easier compliance with wetland and other resource protection regulations
- ► More land available for building since fewer structural BMPs are needed

Cost savings really start to add up when many better site design techniques are applied together. Research indicates that infrastructure savings alone can range from 5 to 65%, depending on site conditions, lot size and the extent that better site design techniques are applied (Cappiella *et al,* 2005; Center for Watershed Protection, 1998b; Liptan and Brown, 1996; Dreher and Price, 1994; and Maurer, 1996).

Better site design techniques continue to provide benefits to the community long after the developer has sold the lots. Some examples of these benefits include:

- ► Reduced operation and maintenance costs for roads and stormwater system
- ► Increased property values for homes and businesses
- ► Increased open space available for recreation
- ► More pedestrian friendly neighborhoods
- ► Reduced annual cost for mowing
- ► More pleasing and attractive landscaping
- ► Improved air quality (more forest cover)
- ► Less temperature fluctuation from paved surfaces

Table 4.2 compares the economic and environmental benefits that can be expected for individual better site design techniques.

VI. Overcoming Barriers to Better Site Design

Despite the clear benefits of better site design techniques, it may be difficult to apply some of them in many communities across the state at the present time. The primary reason is that the geometry, location, and design of development projects is largely dictated by local subdivision codes and zoning ordinances. In some cases, these codes discourage or even prohibit better site design techniques. In other cases, development review authorities are hesitant to approve innovative better site design techniques because of fears they may create real or perceived problems. While potential barriers differ in every community, some frequently cited problems are that better site design techniques may:

- ► Restrict access for fire trucks and emergency vehicles
- ► Increase future municipal maintenance costs
- ► Drive up construction costs
- ► Make it more difficult to plow snow
- ► Generate future problems or complaints (e.g. inadequate parking, wet basements, etc.)
- ► Interfere with existing utilities

These real or perceived local problems must be directly addressed in order to gain widespread adoption of better site design techniques. Communities may also need to carefully reevaluate their local codes and ordinances to overcome barriers to better site design. At the end of the chapter there is an example of how better site design principles can be applied, in this case for "big box" commercial design. This example shows how such features as bioretention, reduced impervious area, and pervious pavement can be used.

An effective method for promoting code change is a local site planning roundtable (http://www.cwp.org/site_planning.htm). Roundtables involve key stakeholders from the local government, development, and environmental communities that influence the development process.

The roundtable approach is but one of many different approaches that can be used for public participation in the development of improved local ordinances. The development of a good comprehensive plan that involves a local water or watershed component that includes an inventory of natural amenities and a stormwater management plan is another. The roundtable discussion is included here as an option that might not be as familiar as the comprehensive planning approach. The roundtable is a consensus process to negotiate new development guidance in the context of local conditions. A site planning roundtable is normally conducted in five steps, as shown below:

Table 4.2 Comparison of Benefits Provided by Better Site Design Techniques *

Better Site Design Technique	Minimizes Land Disturbance	Preserves Vegetation & Habitat	Lowers Capital Costs	Lowers O&M** Costs	Raises Property Value
Natural Area Conservation	●	●	●	●	◐
Site Reforestation	◐	●	○	●	●
Stream and Shoreline Buffers	●	●	●	●	◐
Open Space Design	●	●	●	●	◐
Soil Compost Amendments	◐	●	○	◐	○
Surface IC Disconnection	◐	◐	●	◐	○
Rooftop Disconnection	◐	◐	●	●	◐
Grass Channels	◐	◐	●	◐	◐
Stormwater Landscaping	◐	●	○	◐	●
Narrower Streets	●	◐	●	●	◐
Slimmer Sidewalks	◐	◐	●	●	◐
Smaller Cul-de-sacs	◐	◐	●	●	◐
Shorter Driveways	●	◐	●	●	◐
Smaller Parking Lots	◐	◐	●	●	◐

Key:

● = often provides indicated benefit

◐ = sometimes provides a modest benefit

○ = does not provide benefit

*Comparison is intended for general purposes; and will vary on a site-by-site basis.
**O&M = Operation and Maintenance

Step 1. Conduct Research on Local Development Codes and Ordinances

In the first step in a local roundtable, existing development codes and ordinances are assessed and then compared with the principles of better site design to identify which ones may need changing. Communities may use the codes and ordinances worksheet to facilitate this assessment (Center for Watershed Protection (1998a). The worksheet helps communities systematically compare their existing development rules to the better site design techniques by asking specific questions on how development actually happens in the community. To use the worksheet, communities assemble all of the local, watershed, state, and federal codes and regulations that collectively govern how development occurs in the community, including documents such as:

- Zoning ordinances
- Subdivision codes
- Street standards and road design manuals
- Building and fire codes
- Septic and sewer regulations
- Environmental regulations
- Stormwater drainage criteria
- Tree protection/landscaping ordinances
- Erosion and sediment control and grading requirements
- Public safety and access requirements
- Other documents that influence how development occurs

Table 4.3 Potential Members to Invite to a Roundtable	
Planning Agency or Commission	Engineering Consultants
Department of Public Works	Homeowner Associations
Road or Highway Department	Chamber of Commerce
Developers	Elected Officials
Land Trusts	Urban Foresters
Realtors	Site Plan Reviewers
Real Estate Lenders	Stormwater Management Authority
Civic Associations	Municipal Insurance
Fire Official	Watershed Organization
Health Department	Residents and Owners
Land Use Lawyers	State Agencies

In some cases, information on a particular development rule may not be explicitly articulated in local code or may be hidden in supporting design manuals, review checklists, or as an unwritten review policy. Once current development rules and regulations are identified, the codes and ordinances worksheet can be completed. The worksheet consists of 66 questions that compare local development rules against 22 national better site design benchmarks, as outlined in Center for Watershed Protection (1998a). Each question focuses on a specific site design practice, such as the minimum diameter of cul-de-sacs, the minimum width of streets, or the minimum parking ratio for a certain land use. Points are awarded if local development rules agree with the benchmark for a particular site design practice. In some instances, local codes and ordinances might not explicitly address a particular practice. In these cases, roundtable members should use appropriate judgment based on standard community practices.

Step 2. Identify Stakeholders That Will Participate in the Roundtable Process

The next step involves assembling the stakeholders that will participate in the roundtable process, which should include representatives from all sectors that influence development in a community. The diversity of potential members to invite to a local site planning roundtable is shown in Table 4.3. For example, every local agency with development review authority should participate in the roundtable. Elected officials should also be invited since they must ultimately vote to adopt the proposed changes. The development industry including developers, realtors, homebuilders, design engineers and others who will be responsible for implementing better site design techniques, should also be actively involved. Finally, community input from environmental organizations and homeowners associations should be solicited, since they contribute an important perspective on what local residents would like to see in future development.

Step 3. Introduce Stakeholders to the Roundtable Process

The first meeting of a roundtable focuses on educating stakeholders to ensure they have a firm grasp of its purpose and goals. The initial meeting introduces stakeholders to three key topics:

1. ***Education on better site design techniques.*** Stakeholders initially may have different levels of understanding about better site design techniques, stormwater impacts or the development process. Stakeholders need to be educated on each topic so everyone starts off on a level playing field.

2. ***Introduce them to the roundtable process.*** Roundtables are a structured process that consists of numerous facilitated meetings. Since participation entails a significant time commitment, stakeholders should clearly understand how the roundtable process works and the expectations for their participation.

3. ***Review of the codes and ordinance analysis***. Stakeholders should get a chance to review the codes and ordinances worksheet and help identify the real and perceived barriers that impede adoption of better site design techniques.

Step 4. Conduct the Roundtable and Facilitate Consensus

The roundtable process may extend over an entire year. Subcommittee meetings are often used to focus the efforts of a smaller group of stakeholders on a limited number of topics, such as road and parking lot design. Several subcommittees work on their topics concurrently, and then report their recommendations during full roundtable meetings. An independent third party is often needed to manage stakeholders through the process and guide them toward consensus.

Step 5. Implement Code and Ordinances Changes

The product of a roundtable is a list of specific recommendations on local code change that promote adoption of better site design techniques in new development projects. In addition, the roundtable may also recommend incentives, training, education or other measures to encourage greater use of better site design techniques. The full package of consensus recommendations is then presented to local elected officials and the larger community as well. In most cases, additional education of elected officials is needed to ensure that changes to local code and ordinance change are adopted or enacted.

VII. Thinking Outside of the Big Box: An Example of Parking Lot Surplus and Retrofit Opportunities

Excess parking lot stalls add a tremendous amount of impervious surface that is unnecessary for almost every day of the year except the day after Thanksgiving. This is just one of many situations where Minnesota stormwater managers can make a difference. This insert provides an example for one of many land uses that substantially increase the amount of impervious area within a watershed. It provides some example alternatives that are possible to those who want to “think outside of the big box” and create resource oriented solutions.

Figure 4.12 illustrates the typical metro area shopping center on almost any day of the year. Figure 4.13 shows the excess at several places that experience more frequent filling, but still remain unfilled for large portions of the year.

Alternative designs are available to reduce the impervious areas associated with seldom used parking lots. Figure 4.14 shows some alternative designs for commercial parking lots that introduce either pervious elements or tree cover that provides some canopy interception of rainfall. Figure 4.15 illustrates some pervious pavement alternatives that can be used for overflow or seldom used parking areas. Figure 4.16 shows some low impact parking lot BMPs that can minimize the impact of impervious surface runoff through filtration and infiltration.

The use of some simple solutions can reduce the amount of runoff and the pollution it carries. If every city in Minnesota approached stormwater with these ideas in mind, just think of the runoff we could reduce! For every ten acres of impervious parking lot replaced with a pervious surface, runoff is reduced by about eight million gallons of water.

Figure 4.12 Empty Metro Area Shopping Center Parking Lots (Source: University of Minnesota Metropolitan Design Center)

Figure 4.13 Infrequently Filled Parking Lots at the University of Minnesota (left), Grace Church in Eden Prairie (top right) and the Minnesota Zoo in Apple Valley (bottom right) (Source: University of Minnesota Metropolitan Design Center)

Figure 4.14 Alternative Commercial-scale Parking Lot Design (Source: University of Minnesota Metropolitan Design Center)

Figure 4.15 Alternatives for Overflow and Seldom-used Parking Areas

Figure 4.16 Alternative Parking Lot Collection and Treatment Systems

*Netlon amended soil

VIII. References

Arendt, R. 1997. Designing Open Space Subdivisions. Natural Lands Trust. Media, PA

Cappiella, K. 2005a. Urban Watershed Forestry Manual Part 1: Conserving Trees at the Watershed Scale. Prepared for: USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.

Cappiella, K., T. Schueler, and T. Wright. 2005b. Urban Watershed Forestry Manual Part 2: Conserving and Planting Trees at Development Sites. Prepared for: USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 1998a. Better Site Design: A Handbook for Changing Development Rules in Your Community. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 1998b. Nutrient Loading From Conventional and Innovative Site Development. Prepared for: Chesapeake Research Consortium. Center for Watershed Protection. Ellicott City, MD.

Chicago Wilderness and Northeastern Illinois Planning Commission, 2003. Conservation Design Resource Manual. Available at http://www.chicagowilderness.org/

Delaware Department of Natural Resources and Environmental Conservation (DE DNREC). 1997. Conservation Design for Stormwater Management. Dover, DE.

Dreher, D, and T. Price. 1994. Reducing the Impact of Urban Runoff: The Advantages of Alternative Site Design Approaches. Northeastern Illinois Planning Commission. Chicago, IL.

Illinois Conservation Foundation and Chicago Wilderness, 2005. Changing Cost Perceptions: An Analysis of Conservation Development. Prepared by the Conservation Research Institute. http://www.nipc.org/environment/sustainable/conservationdesign/cost_analysis/

Institute of Transportation Engineers Transportation Planning Council Committee 5P-8 (ITE). 1997. Traditional Neighborhood Development Street Design Guidelines. Institute of Transportation Engineers. Washington, DC.

Liptan, T. and C. Brown. 1996. A Cost Comparison of Conventional and Water Quality-based Stormwater Designs. City of Portland. Portland OR.

Maurer, G. 1996. A Better Way to Grow: For More Livable Communities and a Healthier Chesapeake Bay. Chesapeake Bay Foundation. Annapolis, MD.

McDonald, F. 1999. Ecologically Sound Lawn Care for the Pacific Northwest: Findings from the Scientific Literature and Recommendations from Turf Professionals. City of Seattle Public Works. Seattle, WA.

Metropolitan Council. 2001. Urban Small Sites Best Management Practice Manual. St. Paul, MN.

Minnesota Department of Natural Resources. 2003. Field Guide to the Native Plant Communities of Minnesota: The Laurentian Mixed Forest Province. Ecological Land Classification Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program, MNDNR St. Paul, MN.

Minnesota Department of Natural Resources. 2005. Field Guide to the Native Plant Communities of Minnesota: The Eastern Broadleaf Forest Province. Ecological Land Classification Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program, MNDNR St. Paul, MN.

Minnesota Department of Natural Resources. 2006. Field Guide to the Native Plant Communities of Minnesota: The Prairie Parkland and Tallgrass Aspen Parklands Province. Ecological Land Classification Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program, MNDNR St. Paul, MN.

Minnesota Pollution Control Agency. 2000. Protecting Water Quality in Urban Areas: Best Management Practices for Dealing with Storm Water Runoff from Urban, Suburban, and Developing Areas of Minnesota. St. Paul, MN.

Schueler, T. 1995. Site Planning for Urban Stream Protection. Center for Watershed Protection. Ellicott City, MD

Shaw, D. and R. Schmidt, 2003. Plants for Stormwater Design - Species Selection for the Upper Midwest. Edited by S. Brungardt, Designed by R. Harrison, Minnesota Pollution Control Agency, St. Paul, MN.

Winer, R. 2000. National Pollutant Removal Performance Database for Stormwater Treatment Practices, 2nd Edition. Prepared for: U.S. EPA Office of Science and Technology. Center for Watershed Protection. Ellicott City, MD.

Zielinski, J., 2001. The Benefits of Better Site Design in Residential Subdivisions. Watershed Protection Techniques, 3(2):633-646. Center for Watershed Protection. Ellicott City, MD.

Minnesota Regulations, Rules, and Programs

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VOLUME 1 - INTEGRATED STORMWATER MANAGEMENT

Chapter 5

Minnesota Regulations, Rules, and Programs

This chapter outlines the major stormwater programs in Minnesota that are implemented at federal, state, and local levels and provides links for the user to obtain more information about each program.

Contents

I. Relationship of Manual to Regulatory Programs

Many agencies at the federal, state, watershed, and local levels have jurisdiction over surface and ground waters in Minnesota. Figure 5.1 illustrates how the jurisdictions can vary and overlap. Mulitiple agencies involved in managing the same jurisdictional water lead to complex regulations and permitting programs. This complexity is documented in the 2002 report by the Minnesota Planning Department titled: Charting a Course for the Future: Report of the State Water Program Reorganization Project.

This chapter focuses solely on those programs and permits that are specifically tied to stormwater management, though many other programs may exist that have an indirect stormwater connection. Examples include federal and state hazardous waste managment, abovegournd and underground storage tanks, solid waste managment, oil handling and spill prevention, pesticide management, and facility planning and construction. (See also Issue Paper C in Appendix J)

This section focuses primarily on description/ interpretation of programs and permits at the federal and state levels. Most of the decisions about development and land use however are made at the local level. It is also at the local level that the effects of runoff problems become most apparent and the responsibility for implementing and maintaining the stormwater infrastructure and stormwater management resides. Because of this, many of the federal and state regulatory programs have a large impact on stormwater management responsibilities at the local level. Counties, watershed organizations, regional agencies (ie. Metropolitan Council), municipalities, and townships are all examples of local government groups that may have responsibility for stormwater management.

The implementation vehicle for many local stormwater management programs is through local ordinances. Stormwater management activities may be addressed through specific stormwater ordinances, zoning ordinances or development ordinances and may contain requirements for water quantity, water quality, erosion and sediment control, nonpoint source pollution control, channel protection, and natural area protection. Appendix G contains links to model ordinances for local stormwater management.

While the Manual has no regulatory authority in and of itself, it seeks to provide a sound technical basis for stormwater management design and implementation. This can be coordinated on a statewide level through existing laws and regulations. Table 5.1 provides a summary

Figure 5.1 Federal and State Agencies and Jurisdictional Waters

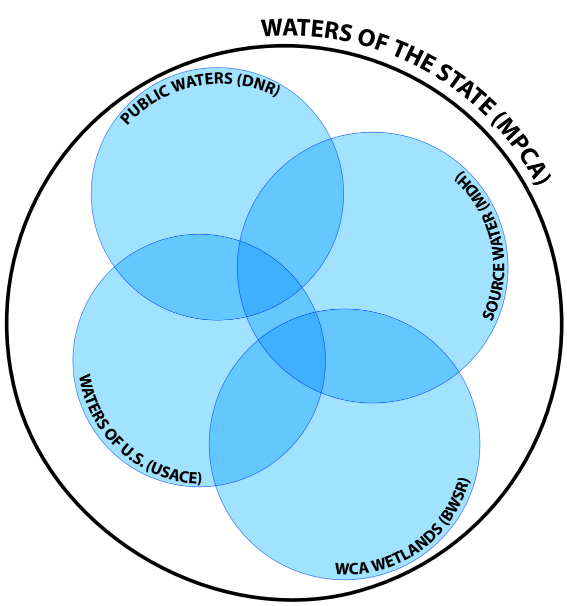


Table 5.1 Regulatory Authorities for Selected Actions									
Action Classes	**Federal**			**State**				**Local***	
	USEPA	USACE	FEMA	MPCA	DNR	BWSR	MDH	Met Council	Local Government Units
Erosion and Sediment Control	◐/E			●/E	E			○	●/E
Lake, Stream, River Protection	◐/E	●/E	○	●/E	●/E		○	○	◐/E
Wetland Protection	○/E	●/E	○	●/E	●/E	○		○	●/E
Ground Water Protection	◐/E			●/E	●/E		○	○	●/E
Surface Water Quality Protection	◐/E			●/E	◐/E		○	○	◐/E
Construction Stormwater Discharge	◐/E			●/E	◐/E			○	◐/E
Municipal Stormwater Discharge	◐/E			●/E				○	◐/E
Industrial Stormwater Discharge	◐/E			●/E				◐/E	◐/E
Agricultural Stormwater Discharge	◐/E			●/E				○	◐/E
Flood Control		●/E	●		◐/E			○	◐/E

Key:

- ● Represents an agency/organization with primary permitting authority in this area
- ◐ Represents an agency/organization that has permitting authority in this area under specific circumstances (i.e., if they are designated as LGU, if the receiving water falls under more than one jurisdiction, etc.)
- ○ Represents an agency or organization with review authority on permits that are not issued by their agency/ organization or an agency/organization with the authority to set standards.
- E Represents an agency/organization with enforcement authority.

* Depending upon location in the state, the local jurisdictions may be administered at the county, watershed organization (if one exists), city/township/village, or tribal level or a combination of these. Contact the local zoning authority for more information on local regulations.

of regulatory authorities for some common stormwater management activities. It outlines the agencies with permitting or review authority and those with the ability to set standards or provide enforcement for those programs.

II. Stormwater Programs and Permit Requirements

This section is intended to serve as guidance to assist stormwater practitioners and the regulated community in identifying and complying with existing federal, state, and local regulations. Local programs can vary considerably and go beyond the scope of this document to address individually, though several of the major programs implemented at a local level have been summarized here. Contact the local zoning authority for more specific information on requirements for the project area. Table 5.2 provides an overview of the federal and state stormwater permitting programs. This is followed by summaries of the major stormwater programs at all levels of government. At the end of this section is Table 5.3 which is a worksheet that can be used by stormwater managers or applicants to help identify programs and permits they may need for a particular type of project. The abbreviations contained within these tables are defined in Appendix H.

Table 5.2 Federal and State Stormwater Related Permits

Permit Title	Regulatory Agency	Enforcement Authority	Implementation Authority	Applicability	Stormwater Regulated Activities
NPDES/SDS Construction Site Permit (Phase II)	MPCA	MPCA USEPA	USEPA - Clean Water Act M.S. 115.01-115.09 Mn. Rules 7090	Applies to all construction disturbing one or more acres of land, areas less than one acre if that activity is part of a “larger common plan of development or sale” that is greater than one acre, and MPCA designated construction activities disturbing less than one acre that have the potential for contribution to a violation of a water quality standard or for significant contribution of pollutants to water resources.	Stormwater discharge associated with road building, landscaping, clearing, grading, excavation, and construction of homes, office buildings, industrial parks, landfills and airports.
NPDES/SDS Municipal Separate Storm Sewer System Permit (Phase II)	MPCA	MPCA USEPA	USEPA - Clean Water Act M.S. 115.01-115.09 Mn. Rules 7001 and 7090	Applies to municipal separate storm sewer systems located in state and federal designated areas.	On going site management and maintenance activities. Site management must include at a minimum the Six Minimum Control Measures: 1. public education and outreach, 2. public participation and involvement, 3. illicit discharge detection and elimination, 4. construction site storm water runoff control, 5. post construction storm water management, and 6. pollution prevention / good house keeping.

Table 5.2 Federal and State Stormwater Related Permits

Permit Title	Regulatory Agency	Enforcement Authority	Implementation Authority	Applicability	Stormwater Regulated Activities
NPDES/SDS Industrial Site Permit (Phase II)	MPCA	MPCA USEPA	USEPA - Clean Water Act M.S. 115.01-115.09 Mn. Rules 7001 and 7090	Applies to public (municipal) and private operators of industrial facilities included in one of the 11 categories of industrial activity defined in the federal regulations by an industry's Standard Industrial Classification (SIC) code or a narrative description of the activity found at the industrial site are required to apply for a permit	On going site management and maintenance activities. Site management may include BMPs such as oil and grease separators, designated wash out locations, site sweeping, and storing materials indoors.
NPDES/SDS Feedlot Permit	MPCA	MPCA USEPA	USEPA - Clean Water Act M.S.115.076 and 116.07 Mn. Rules 7001, 7020, 7050, and 7060	Applies to owners and operators of feedlots capable of holding 1,000 animal units or more or Concentrated Animal Feeding Operations (CAFOs) meeting criteria in 40 CFR § 122.23(b)(4).	Stormwater discharge associated site location and expansion activities; construction activities; manure application, storage (stockpiling) location, and management; phosphorus management, pollutions prohibitions; and process wastewater and milk house wastes.
401 Water Quality Certification	MPCA	MPCA USEPA	USEPA – Clean Water Act (33 U.S.C. 1341) M.S. 115.03 Mn. Rules 7001	Applies to all activities requiring a federal permit that may have discharge to state waters.	Water quality impacts that may be generated from the structure, siting, or runoff management.
Section 404 Permit	USACOE	USACOE USEPA	USEPA - Clean Water Act Section 404 (33 U.S.C. 1344)	Applies to territorial seas; all navigable waters and adjacent wetlands; tributaries to navigable waters and adjacent wetlands; Interstate waters and adjacent wetlands; and all waters not identified above in which the destruction or degradation could affect interstate commerce	Discharge of dredged or fill material into waters of the United States.

Table 5.2 Federal and State Stormwater Related Permits

Permit Title	Regulatory Agency	Enforcement Authority	Implementation Authority	Applicability	Stormwater Regulated Activities
Section 10 Rivers and Harbors Act Permit	USACOE	USACOE	Rivers and Harbors Act Section 10	Applies to all Navigable Waters of the U.S. Navigable Water designation is based on past, present or potential use for transportation or interstate commerce.	Any work in, over or under a Navigable Water of the U.S or work that affects the course, location, condition or capacity of such waters.
Class V Injection Well Inventory and Permit	USEPA	USEPA	Safe Drinking Water Act	Applies to all potential underground sources of drinking water.	Installation, operation, or abandonment of shallow disposal systems that are used to place stormwater below the land surface through a shaft or hole that is deeper than it is wide.
Public Waters Work Permit	DNR	DNR	M.S. 103G.245 Mn. Rules 6115	Development activities below the ordinary high water level (OHWL) in public waters and public waters wetlands	Filling, excavation, shore protection, bridges and culverts, structures, docks, marinas, water level controls, dredging, and dams.
Water Appropriations Permit	DNR	DNR	103G.255 Mn. Rules 6115.0600	Regulates surface and ground water appropriations and use of water	Construction dewatering permits (erosion control and discharge conditions).
Calcareous Fen Management Plan	DNR	DNR MPCA	103G.223 Mn. Rules 8420.1010	Regulated drain, fill, otherwise alter or degrade calcareous fen	Discharges that affect the quantity, quality, or chemistry of waters supporting the fen.
Utility Crossing License	DNR	DNR	M.S. 84 Mn Rules 6135	Applies to utility crossing of any state land or public waters.	Discharges or adverse effect to the water resource resulting from passage of any utility over, under, or across state land or public waters.

Table 5.2 Federal and State Stormwater Related Permits

Permit Title	Regulatory Agency	Enforcement Authority	Implementation Authority	Applicability	Stormwater Regulated Activities
Water/Wetlands Project Permit (WCA)	LGU (as designated in WCA)*	DNR	Wetland Conservation Act M.S. 103G Mn. Rules 8420	Applies to all jurisdictional wetlands.	Draining, filling, and in some cases excavation, degradation of water quality due to untreated stormwater runoff.
Industrial Discharge Permit	Met Council (Twin Cities Area Only)	MPCA USEPA	Mn. Rules 473	Applies to industrial users of the Metropolitan Disposal System (public sanitary sewers)	Stormwater discharge, leachate, and groundwater where there is no prudent or feasible disposal alternatives .
Drainage Permit or Permission	Drainage Authority	Drainage Authority LGU*	M.S. 103D M.S. 103E	Applies to the public drainage system.	Introduction of stormwater into the system, conveyance of stormwater through the system, and discharge of stormwater from the system.
Other Local Permits	LGUs*	LGU* DNR MPCA	Various	Applies to any additional local regulations which may include resources in the above categories, shoreland management, floodplain management, lake improvement districts, landfills, wastewater, sand and gravel operations, hot mixing, dewatering, TMDLs, etc.	Various.

C.F.R. - Code of Federal Regulations
M.S. - Minnesota Statute
U.S.C. - United States Code

* LGU = local governmental unit (Counties, Soil and Water Conservation Districts, Water Management Organizations, Watershed Districts, Metropolitan Council, Lake Associations, Municipalities, Townships, Villages, etc.)

Federal Level Implementation

Section 404 Permit Program

This program applies to all waters of the United States, including lakes, rivers, ponds, streams, and wetlands. The Section 404 program regulates the discharge of dredged or fill material into waters of the U.S.

There are several categories of permits and approvals:

- non-reporting general permit
- statewide general permits
- letters of permission
- individual permits

An individual permit is required if the proposed work does not meet the requirements of one of the specific general permits or letter of permission.

Enabling Legislation:
Section 404, Clean Water Act (Appendix G)

Required Permit:
Section 404 Permit

Regulatory Authority:
U.S. Army Corps of Engineers (Appendix G)
U.S. Environmental Protection Agency (Appendix G)

Applicability:
Waters of the U.S.

Stormwater Relationship:
Discharge of dredged or fill material into waters of the U.S.

Rivers and Harbors Act, Section 10 Permit Program

This program applies to all Navigable Waters of the U.S. Navigable Water designation is based on past, present or potential use for transportation or interstate commerce. The Section 10 program regulates any work in, over or under a Navigable Water of the U.S or work that affects the course, location, condition or capacity of such waters.

There are several categories of permits and approvals:

- non-reporting general permit
- statewide general permits
- nationwide general permits
- letters of permission
- individual permits

An individual permit is required if the proposed work does not meet the requirements of one of the specific general permits or letter of permission.

Enabling Legislation:
Section 10, Rivers and Harbors Act (Appendix G)

Required Permit:
Section 10 Permit

Regulatory Authority:
U.S. Army Corps of Engineers (Appendix G)

Applicability:
Navigable Waters of the U.S. (Appendix G)

Stormwater Relationship:
Work in, over, under, or affecting the course, location, condition or capacity of a Navigable Water of the U.S.

Underground Injection Control Program (Class V Injection Wells)

This program applies to shallow disposal systems that are used to place a variety of fluids, including stormwater, below the land surface. Class V injection wells are defined as any bored, drilled, driven shaft, or dug hole that is deeper than it is wide; any improved sinkhole; or any subsurface fluid distribution system.

The purpose of the program is to prevent the contamination of any underground sources of drinking water. Inventory information must be submitted for any existing Class V injection wells and before installation of new Class V injection wells. However, a permit is not required if it is determined that the well does not endanger underground sources of drinking water.

The program has two requirements:

1. Submitting basic inventory information about the stormwater drainage wells to the EPA
2. Constructing, operating, and closing the drainage well in a manner that does not endanger underground sources of drinking waters (USDWs)

Enabling Legislation:
Safe Drinking Water Act (Appendix G)

Required Permit:
Class V Injection Well Inventory (Appendix G)

Regulatory Authority:
U.S. Environmental Protection Agency (Appendix G)

Applicability:
Underground sources of drinking water

Stormwater Relationship:
Shallow stormwater disposal systems (eg. dry wells, sumps, drain tile, certain infiltration practices) placing stormwater below the land surface.

Mississippi National River and Recreation Area (MNRRA) Program

This is a joint federal, state, and local program, overseen by the National Park Service which provides coordination for 72 miles of the Mississippi River, four miles of the Minnesota River, and 54,000 acres of adjacent corridor lands. The MNRRA Comprehensive Management Plan adopts and incorporates by reference the state Critical Area Program, Shoreland Management Program, and other applicable state and regional land use management programs that implement the plan's visions.

Enabling Legislation:
Minnesota Statutes, Section 116G (Appendix G)
Minnesota Rules, Chapter 4410 (Appendix G)

Required Permits:
NA

Regulatory Authority:
National Park Service (oversight) (Appendix G)
DNR, Division of Waters (Appendix G)
Local Government (Appendix G)

Applicability:
Sections of the Mississippi and Minnesota River and designated corridor

Stormwater Relationship:
Activities within the national river and recreation area

State Level Implementation

Stormwater Program

The Stormwater Program is a comprehensive state stormwater program based on the Federal NPDES program and administered by the MPCA with oversight by the USEPA. The program is based on federal Clean Water Act requirements for addressing polluted stormwater runoff. Stormwater disposal is regulated nationally through the National Pollutant Discharge Elimination System (NPDES) and Minnesota regulates the disposal of stormwater through the State Disposal System (SDS). MPCA issues combined NPDES/SDS permits.

A 1987 amendment to the federal Clean Water Act required implementation of a two-phase comprehensive national program to address stormwater runoff. Phase I regulated large construction sites, 11 categories of industrial facilities, and major metropolitan municipal separate storm sewer systems (MS4s), including Minneapolis and St. Paul. Phase II includes smaller construction sites, municipally owned or operated industrial activity, and many more municipalities.

Stormwater permits require permittees to control polluted discharges. Regulated parties must develop stormwater pollution prevention plans (or stormwater pollution prevention programs, for MS4s) to address their stormwater discharges. Each regulated party determines the appropriate best management practices (BMPs) to minimize pollution for their specific site. The three permit types - construction, industrial, and MS4 - have distinct requirements and some regulated parties may require more than one permit.

There are two types of NPDES/SDS permits: general permits and individual permits. If work meets the requirements of a specific general permit, an individual permit is not required. Currently there are three categories for stormwater permitting as follows:

1. **Construction Stormwater Permitting Program.** The Construction Stormwater Permitting Program is designed to reduce the amount of sediment and pollution entering surface and ground water bassociated with construction projects. Prior to applying for permit coverage, the owner is required to develop a Stormwater Pollution Prevention Plan (SWPPP) that incorporates specific best management practices applicable to their site. Construction activities requiring a permit include road building, landscaping clearing, grading, excavation, and construction of homes, office buildings, industrial parks, landfills and airports. Permits are required from owners and operators for any construction-re;ated activity disturbing one acre or more of land. In some cases, smaller sites may require permit coverage if they are part of a larger common plan for development.

2. **Industrial Stormwater Permitting Program.** The Industrial Stormwater Permitting Program is designed to reduce the amount of pollution that enters surface and ground water from industrial facilities in the form of stormwater runoff. Stormwater discharges associated with 11 categories of industrial activities are regulated. Industrial facilities require that a permit must develop and implement a SWPPP designed to eliminate or minimize stormwater contact with significant materials that may result in polluted stormwater discharges from the industrial site.

3. **Municipal Stormwater Permitting Program.** The Municipal Separate Storm Sewer System Stormwater (MS4) Permitting Program is designed to reduce the amount of sediment and pollution that enters surface and ground water from storm sewer systems to the maximum extent practicable. Stormwater discharges associated with MS4s are regulated and the owners or operators of these systems are required to develop a SWPPP that incorporates best management practices applicable to their MS4. The MS4 general permit is scheduled for adoption in early 2006.

Enabling Legislation:

Section 402, Clean Water Act (Appendix G)
Minnesota Statutes, Chapter 115 (Appendix G)
Minnesota Rules, Chapter 7001 (Appendix G)
Minnesota Rules, Chapter 7050 (Appendix G)
Minnesota Rules, Chapter 7090 (Appendix G)

Required Permit(s):
NPDES/SDS General Stormwater Permit for Construction
NPDES/SDS General Stormwater Permit for Industrial
NPDES/SDS General Stormwater Permit for Municipal Separate Storm Sewer Systems
NPDES/SDS Individual Stormwater Permit

Regulatory Authority:
Minnesota Pollution Control Agency
U.S. Environmental Protection Agency

Applicability:
Stormwater

Stormwater Relationship:
Stormwater discharge

Feedlot Program

The feedlot program regulates the collection, transportation, storage, processing and disposal of animal manure and livestock processing activities, and provides assistance to counties and the livestock industry. The rules apply to all aspects of livestock production areas including the location, design, construction, operation and management of feedlots, feed storage, stormwater runoff, and manure handling facilities.

There are two NPDES/SDS permits for feedlots: general permits for livestock production and individual permits for an animal feedlot or manure storage area. If the proposed facility meets the requirements of the general permit, an individual permit is not required. An individual permit is required if the proposed project does not meet the requirements of a specific general permit due to size or past infractions.

Enabling Legislation:
Clean Water Act (Appendix G)
Minnesota Statutes, Chapter 115 (Appendix G)
Minnesota Rules Chapter 7020 (Appendix G)

Required Permits:
NPDES/SDS General Permit for Livestock Production
NPDES/SDS Permit for an Animal Feedlot or Manure Storage

Regulatory Authority:
Minnesota Pollution Control Agency
Counties
U.S. Environmental Protection Agency (oversight)

Applicability:
Feedlots

Stormwater Relationship:
Location, design, construction, operation and management of feedlots, feed storage, stormwater runoff, and manure handling facilities

Minnesota Impaired Waters and Total Maximum Daily Load (TMDL) Program

In compliance with Section 303 of the Clean Water Act, this program publishes an updated list of impaired waters every two years. An impaired water does not meet the water quality standards established to protect the designated use (ie. fishing, swimming, irrigation, etc.) of those waters due to pollutants. The MPCA is required to conduct a TMDL study which identifies both point and nonpoint sources of each pollutant in and impaired water that fails to meet water quality standards. A TMDL specifies the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, and allocates pollutant loadings among point and nonpoint pollutant sources.

Enabling Legislation:
Clean Water Act, Section 303 (Appendix G)
Minnesota Statutes, Chapter 115 (Appendix G)
Minnesota Rules, Chapter 7052 (Appendix G)

Required Permit(s):
Compliance with a TMDL plan, once adopted by MPCA

Regulatory Authority:
Minnesota Pollution Control Agency
U.S. Environmental Protection Agency (oversight)

Applicability:
Impaired waters
Stormwater Relationship:
Discharges to impaired waters

Stormwater Relationship:
Stormwater discharge to an impaired water or a water with a TMDL.

Section 401, Water Quality Certification

Anyone who wishes to obtain a federal permit for any activity that may result in a discharge to a navigable water must first obtain a state 401 water quality certification. This program requires the applicant to demonstrate that a proposed activity will not violate Minnesota's water quality standards or result in adverse long-term or short-term impacts on water quality. Such impacts can be direct or cumulative with other indirect impacts. Because MPCA staff are no longer assigned to evaluate 401 applications for conformance with water-quality standards, the MPCA has decided to waive its 401 authority in most, but not all, cases. However, this should not be viewed as a waiver from the requirements of MN Rule, Chapter 7050. This action does not waive MPCA's authority to take necessary enforcement actions to ensure that the applicant and the project's construction, installation, and operation comply with water quality standards, statutes and rules.

Enabling Legislataion:
Clean Water Act, Section 401 (Appendix G)
Minnesota Statutes, Chapter 115 (Appendix G)
Minnesota Rules, Chapter 7001 (Appendix G)

Required Permit:
Section 401 Water Quality Certification or Waiver

Regulatory Authority:
Minnesota Pollution Control Agency
U.S.Environmental Protection Agency (oversight)

Applicability:
Waters of the U.S.
Waters of the State

Stormwater Relationship:
Discharge of stormwater or alteration of wetland in violation of state water quality standards

Nonpoint Source Management Program and Coastal Nonpoint Source Pollution Control Program

Section 319 of the Clean Water Act requires each state to address nonpoint pollution by developing nonpoint source assessment reports that identify nonpoint source pollution problems and the nonpoint sources responsible for the water quality problems. States also adopt management programs to control nonpoint source pollution and then implement the management programs. States, Territories, and Indian Tribes can receive Section 319 grant money which supports a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects, and monitoring to assess the success of specific nonpoint source implementation projects.

Minnesota became part of the national Coastal Management Program after receiving federal approval in July 1999. Minnesota's Lake Superior Coastal Nonpoint Pollution Control Program is designed to reduce nonpoint pollution in the Lake Superior Basin.

Enabling Legislataion:
Section 319, Clean Water Act (Appendix G)

Required Permit(s):
NA

Regulatory Authority:
Minnesota Pollution Control Agency
U.S. Environmental Protection Agency (oversight)

Applicability:
Waterbodies, streams, and associated uplands
Lake Superior Basin

Stormwater Relationship:
Nonpoint sources of pollution

Drinking Water Protection Program

This program's mission is to protect the public health by ensuring a safe and adequate supply of drinking water at all public water systems (community and non-community drinking water systems). The program reviews plans for water system improvements, conducts on-site inspections and sanitary surveys, provides training and technical assistance, ensures that water systems are tested for contaminants, and takes action against water systems not meeting standards.

Enabling Legislation:
Safe Drinking Water Act (Appendix G)
Minnesota Statutes, Chapter 103H (Appendix G)
Minnesota Rules Chapter 4720 (Appendix G)

Required Permit:
NA

Regulatory Authority:
Minnesota Department of Health (Appendix G)

Applicability:
Public drinking water systems and their source areas

Stormwater Relationship:
Source water contamination

Source Water Protection Program

This program applies to drinking water and its sources, which includes rivers, lakes, reservoirs, springs, and ground water wells. The Source Water Protection Program's purpose is to help prevent contaminants from entering public drinking water sources. There are three different classifications of public water systems: communities, transient noncommunities, and nontransient noncommunities. For groundwater supply areas, each of the public water system categories maintains an inner wellhead management zone, which is a 200-foot radius around wells. In addition, communities and nontransient noncommunities must also identify capture zones for their wells (wellhead protection areas) and create a formal wellhead protection plan.

The Source Water Protection Program consists of three primary parts:

1. **Wellhead Protection Program.** The purpose of the Wellhead Protection Program is to prevent contamination of public drinking water supplies by identifying water supply recharge areas and implementing management practices for potential pollution sources found within those areas.

2. **Source Water Assessment Program.** The purpose of the Source Water Assessment Program is to develop reports that provide a concise description of the water used by a public water system and identify susceptibility to contamination.

3. **Surface Water Intake Protection**. Protection for surface water intakes is not required, but many of Minnesota's community water supply systems that use surface water have expressed interest in developing protection plans. The Minnesota Department of Health is currently developing guidelines for protection plans.

Enabling Legislataion:
Minnesota Statutes, Chapter 103H (Appendix G)
Minnesota Statutes, Chapter 103I (Appendix G)
Minnesota Statutes, Chapter 144 (Appendix G)
Minnesota Rules, Chapter 4720 (Appendix G)
Minnesota Rules, Chapter 4725 (Appendix G)

Required Permit:
NA

Regulatory Authority:
Minnesota Department of Health

Applicability:
Source waters for public drinking water systems

Stormwater Relationship:
Source water contamination

Public Waters Work Permit Program

This program, begun in 1937, regulates water development activities below the ordinary high water level (OHWL) in public waters. The Public Waters Work Permit Program applies to those lakes, wetlands, and streams identified on DNR Public Water Inventory maps. Proposed projects affecting the course, current, or cross-section of these water bodies may require a Public Waters Work Permit from the DNR.

There are two types of Public Waters Work Permits: general permits and individual permits. If work proposed in public waters or public waters wetlands meets the requirements of a specific general permit, an individual permit is not required. Currently there are five categories of general permits as follows:

- Emergency Repair of Public Flood Damages
- Multiple Purposes
- Bridge and Culvert Projects
- Dry Hydrants
- Bank/Shore Protection or Restoration

An individual permit is required if the proposed work does not meet the requirements of a specific general permit. There are also deregulated activities for which no permit is required.

Enabling Legislataion:
Minnesota Statutes 103G.245 (Appendix G)
Minnesota Rules Chapter 6115 (Appendix G)

Required Permit(s):
Public Waters Work Permit

Regulatory Authority:
DNR, Division of Waters (Appendix G)

Applicability:
Activities below the ordinary high water level (OHWL) in designated public waters

Stormwater Relationship:
Filling, excavation, shore protection, bridges, culverts, structures, docks, marinas, water level controls, dredging, dams or other activities affecting the course, current or cross section.

Water Appropriations Permit Program

This program was created in response to legislation requiring DNR to balance competing management objectives that include both development and protection of Minnesota's water resources. The Water Appropriations Permit Program applies to all users withdrawing more than 10,000 gallons of water per day or 1 million gallons per year. Proposed projects withdrawing this amount of water or more may require a Water Appropriations Permit from the DNR.

There are several types of water appropriations permits including general permits and individual permits for both irrigation and non-irrigation purposes. Several exemptions apply for domestic uses serving less than 25 people, test pumping of a groundwater source, reuse of water already authorized by a permit, and for certain agricultural drainage systems. If appropriations meet the requirements for one of the general permits then an individual permit is not required.

Currently there are two categories of general permits:

1. **Temporary Projects:** authorizes temporary water appropriations for construction dewatering, landscaping, dust control, and hydrostatic testing of pipelines, tanks, and wastewater ponds.

2. **Animal Feedlots and Livestock Operations:** authorizes groundwater appropriations up to 5 million gallons per year for livestock watering and sanitation purposes.

If the proposed appropriation does not meet the requirements of a specific general permit or is not exempt, an individual permit is required.

Enabling Legislation:
Minnesota Statutes, Section 103G.265 (Appx. G)
Minnesota Rules Chapter 6115 (Appendix G)

Required Permits:
Water Appropriations Permit

Regulatory Authority:
DNR, Division of Waters (Appendix G)

Applicability:
Surface and ground water withdrawals greater than 10,000 gallons of water per day or 1 million gallons per year

Stormwater Relationship:
Discharge of water withdrawals

Calcareous Fen Protection

Calcareous fens are classiied as oustanding resource value waters (ORVWs) and are protected under the restricted discharge provisions of the MPCA water quality standards in Minnesota Rule 7050.0180 Subp. 6. In addition, calcareous fen protections were also put in place in 1991 with the passing of the Wetland Conservation Act and regulate activities that may alter or degrade calcareous fens. Calcareous fens are the rarest wetland community in Minnesota and may not be drained or filled or otherwise altered or degraded except as provided for in a management plan approved by the commissioner.

Enabling Legislation:
Clean Water Act, Section 401 (Appendix G)
Minnesota Statutes, Section 103.G.223 (Appx. G)
Minnesota Statutes, Section 115 (Appendix G)
Minnesota Rules Chapter 7001 (Appendix G)
Minnesota Rules Chapter 7050 (Appendix G)
Minnesota Rules Chapter 8420 (Appendix G)
Commissioner's Order No. 05-001 (Appendix G)

Required Permits:
Approved Calcareous Fen Management Plan
NPDES/SDS General Stormwater Permit

Regulatory Authority:
Minnesota Department of Natural Resources
Minnesota Pollution Control Agency

Applicability:
Calcareous fens

Stormwater Relationship:
Drainage, fill, alteration, or degradation of a calcareous fen

Dam Safety Program

This program was created in 1978 in response to the federal Dam Safety Act and regulates the repair, operation, design, construction, and removal of public and private dams. The program sets minimum standards for dams regarding safety, design, construction, and operation and it classifies dams into three dam hazard classes. Proposed projects for construction, alteration, repair, removal or transfer of ownership of a regulated dam may require a Public Waters Work Permit.

Enabling Legislation:
Dam Safety Act (Appendix G)
Minnesota Statutes, Section 103G.515 (Appx. G)
Minnesota Rules, parts 6115.0300 through 6115.0520 (Appendix G)

Required Permits:
Public Waters Work Permit

Regulatory Authority:
DNR, Division of Waters (Appendix G)

Applicability:
Structures that pose a potential threat to public safety or property. Dams 6 feet high or less and dams that impound 15 acre-feet of water or less are exempt from state dam safety rules as are dams that are less than 25 feet high and impound less than 50 acre-feet, unless there is a potential for loss of life due to failure or misoperation.

Stormwater Relationship:
Repair, operation, design, construction, and removal of regulated dams

Mississippi River Critical Area Program

The Mississippi River Critical Area Program is a joint local and state program that provides coordinated planning and management for 72 miles of the Mississippi River, four miles of the Minnesota River, and 54,000 acres of adjacent corridor lands.

Enabling Legislation:
Minnesota Statutes, Section 116G (Appendix G)
Minnesota Rules, Chapter 4410 (Appendix G)

Required Permits:
NA

Regulatory Authority:
DNR, Division of Waters (Appendix G)
Local Government (Appendix G)

Applicability:
Sections of the Mississippi and Minnesota River and designated corridor

Stormwater Relationship:
Activities within the critical area

Wild and Scenic Rivers Program

In Minnesota, the Department of Natural Resources maintains the state Wild and Scenic River Program and cooperates with the Wisconsin Department of Natural Resources and the National Park Service for management of the lower St. Croix River, which is part of the National Wild and Scenic Rivers Program. The purpose of the Wild and Scenic Rivers Programs is to preserve select rivers with outstanding scenic, recreational, geologic, fish and wildlife, historic, cultural or other important values in a free-flowing condition.

Six rivers in Minnesota have segments, which are designated as wild, scenic, or recreational under the state program in addition to the federally designated lower St. Croix River. These seven rivers are also designated as Outstanding Resource Value Waters (ORVWs) in Minnesota. Each of the seven designated river segments in Minnesota has a management plan, which outlines the rules and goals for that waterway. These rules work together with local zoning ordinances to protect the rivers from pollution, erosion, over-development, and degradation factors, which undermine the wild, scenic, and recreational qualities for which they were designated.

Enabling Legislataion:
National Wild and Scenic Rivers Act (Appx. G)
Minnesota Statutes, Chapter 103F (Appendix G)
Minnesota Rules, Chapter 6105 (Appendix G)

Required Permit:
Compliance with management plan for the river

Regulatory Authority:
DNR, Division of Waters (Appendix G)
National Park Service (Appendix G)
Local Government (Appendix G)

Applicability:
Portions of the St. Croix River, Mississippi River, Kettle River, Rum River, North Fork of the Crow River, Minnesota River, and Cannon River

Stormwater Relationship:
Restrictions on activities adversely affecting the river or its designated corridor.

Lake Superior Coastal Program

Minnesota participates in the federal Coastal Zone Management program through the Lake Superior Coastal Program. Local issues that the program helps to address include: shoreline erosion, inadequate sewage and stormwater systems, local watershed and land use planning, habitat restoration, waterfront revitalization, and water access. The program was developed to encourage greater cooperation, to encourage simplification of governmental processes, and provide tools to implement existing policies, authorities and programs within the area defined by the program boundary. Lake Superior is designated as an ORVW in Minnesota.

Enabling Legislataion:
Coastal Zone Management Act of 1990, Section 6217 (Appendix G)

Required Permit(s):
NA

Regulatory Authority:
DNR, Division of Waters (Appendix G)
US Environmental Protection Agency
National Oceanic and Atmospheric Administration

Applicability:
Coastal Zone of Lake Superior

Stormwater Relationship:
Discharges adversely impacting land and water resources within the designated coastal zone

National Flood Insurance Program

The National Flood Insurance Program (NFIP) enables property owners in participating communities to purchase insurance protection against losses from flooding. Participation in the NFIP is based on an agreement between local communities and the federal government that states if a community will adopt and enforce a floodplain management ordinance to reduce future flood risks to new construction in Special Flood Hazard Areas, the federal government will make flood insurance available within the community as a financial protection against flood losses. In Minnesota, the National Flood Insurance Program is administered by the Minnesota Department of Natural Resources. By state law, all flood prone communities in the state are required to participate in the program.

Enabling Legislataion:
National Flood Insurance Act of 1968 (Appx. G)

Required Permit(s):
NA

Regulatory Authority:
DNR, Division of Waters (Appendix G)
Federal Emergency Management Agency
Local Government

Applicability:
Floodprone communities

Stormwater Relationship:
Restrictions on activities and structures in floodplain

Utility Crossing License Program

This is a licensing program for the passage of any utility over, under or across any state land or public waters.

Enabling Legislation:
Minnesota Statutes, Chapter 84 (Appendix G)
Minnesota Rules, Chapter 6135 (Appendix G)

Required Permit:
Utility Crossing License

Regulatory Authority:
DNR, Department of Land and Minerals (App. G)

Applicability:
public waters or state land

Stormwater Relationship:
Utility crossings of public waters or state land

Comprehensive Local Water Management

The Board of Water and Soil Resources (BWSR) oversees the adoption and implementation of comprehensive local water management plans, which are voluntary plans created by counties outside the seven-county metropolitan area. The Act, passed in 1985 encourages counties outside the metropolitan area to protect water resources through the adoption and implementation of local water management plans that are based on local priorities.

Enabling Legislation:
Minnesota Statutes 103B.301 (Appendix G)

Required Permit(s):
NA

Regulatory Authority:
Board of Water and Soil Resources (Appendix G)
Local Government

Applicability:
Counties outside the seven-county metro area

Stormwater Relationship:
Erosion and sedimentation reduction, storm water design standards, wetland protection

Comprehensive Surface Water Management

The Board of Water and Soil Resources oversees the adoption and implementation of comprehensive surface water management plans, which are created by watershed districts, watershed management organizations, or county/city/township joint powers organizations within the seven-county metropolitan area.

After local, regional, and agency review, plans are approved by the Board of Water and Soil Resources. The WMO/WD/JPO then formally adopts the plan and requires each city or township within the WMO/WD/JPO to create and implement their own local water management plan consistent with the WMO/WD plan. Updates are required every 5-10 years.

Enabling Legislation:
Minnesota Statutes 103B (Appendix G)
Minnesota Rules Chapter 8410 (Appendix G)

Required Permit(s):
NA

Regulatory Authority:
Board of Water and Soil Resources (Appendix G)
Local Government

Applicability:
Watershed Districts, Water Management Organizations, or Joint Powers Organizations in seven-county metro area

Stormwater Relationship:
Erosion and sedimentation reduction, storm water design standards, wetland protection

Local Level Implementation

Wetland Conservation Act

This program, begun in 1991, regulates drainage, fill, or excavation of wetlands in the state. Proposed projects are required to demonstrate through sequencing requirements that the project first seeks to avoid disturbing the wetland; second try to minimize any impact on the wetland; and finally, when impact is unavoidable, replaces any lost wetland acres, functions, and values. Certain wetland activities are exempt from the act, allowing projects with minimal impact or projects located on land where certain pre-established land uses are present to proceed without regulation.

There are two categories for WCA permits:

1. Water/Wetland Projects
2. Water/Wetland Projects: Public Transportation and Linear Utility Projects

Projects disturbing wetlands may also require permits or approvals from the Department of Natural Resources, U.S. Army Corps of Engineers, and Minnesota Pollution Control Agency. A joint application form has been developed that may be used for application to all of these agencies.

Enabling Legislation:
Minnesota Statutes 103G (Appendix G)
Minnesota Rules Chapter 8420 (Appendix G)

Required Permit:
Water/Wetland Projects

Regulatory Authority:
Local Government Unit
Board of Water and Soil Resources (oversight)

Applicability:
Jurisdictional wetlands (meeting the criteria for soil, hydrology, and vegetation outlined in the 1987 Army Corps of Engineers Wetland Delineation Manual)

Stormwater Relationship:
Drainage, fill, or excavation of wetlands

Industrial Discharge

This program regulates and monitors industrial discharges into the Metropolitan Disposal System (public sanitary sewer system) to ensure compliance with local and federal regulations. Industrial users discharging wastewater into public sewers are required to apply for an industrial waste permit.

There are three categories for industrial waste permits:

1. standard discharge permits
2. special discharge permits
3. liquid waste hauler permits

Enabling Legislation:
Minnesota Statutes, Chapter 473 (Appendix G)

Required Permit:
Industrial Discharge Permit

Regulatory Authority:
Metropolitan Council
Minnesota Pollution Control Agency
Environmental Protection Agency

Applicability:
Metropolitan Disposal System (public sanitary sewers in Twin Cities Metropolitan area)

Stormwater Relationship:
Industrial discharges of wastewater or contaminated stormwater into public sanitary sewer system

Drainage

Public drainage administrative oversight is provided by designated Drainage Authorities. Drainage Authorities may be a County Board, a Joint Ditch Authority composed of representatives from multiple counties, a Watershed District or a Water Management Organization. Drainage law applies to public ditches and conveyance systems and consists of four elements; legal, engineering, environmental, and economic. The Drainage Authority has general authority for regulating and maintaining the public drainage system as it was designed. In accordance with M.S. 103E.411 Subp 2, the MPCA must approve any plan for connection or outlet of a municipal drainage system to a county drainage system.

Enabling Legislation:
Minnesota Statutes 103E (Appendix G)
Minnesota Statutes 103D (Appendix G)

Required Permit:
Local drainage permit

Regulatory Authority:
Drainage Authority (Appendix G)

Applicability:
Public drainage system components

Stormwater Relationship:
Conveyance of stormwater

Shoreland Management Program

This program was created in 1969 in response to the Shoreland Management Act and applies to all land within a Shoreland District. Shoreland Districts are defined as lands within 1,000 feet of a lake which is greater than 25 acres (10 acres in municipalities) or within 300 feet of a river with a drainage area two square miles or greater and its designated floodplain defined from the ordinary high water level (OHWL). Local units of government are required to adopt the DNR minimum or stricter standards into their zoning ordinances and permit programs for the use and development of shoreland property. This includes a sanitary code, minimum lot size, minimum water frontage, building setbacks, building heights, land use, BMPs, shoreland alterations, subdivision, and PUD regulations.

Enabling Legislation:
Minnesota Statutes, Section 103.F.201-221 (Appendix G)
Minnesota Rules Chapter 6120 (Appendix G)

Required Permit:
Local government permits for building construction, installation of sewage treatment systems, and grading and filling

Regulatory Authority:
Local Government Unit
DNR, Division of Waters (oversight)

Applicability:
All lakes greater than 25 acres (10 acres in Municipalities) and rivers with a drainage area two square miles or greater and their associated floodplains

Stormwater Relationship:
Activities on all land within 1,000 feet of a designated lake and 300 feet of a designated river and its designated floodplain

Floodplain Management Program

This program was created in 1969 in response to the State Floodplain Management Act and regulates the construction of structures, roads, bridges or other facilities located within the 100-year floodplain areas.

Local units of government for flood prone communities are required to adopt the DNR minimum standards, or stricter, for floodplain management into their ordinances and permit programs. They are also required to enroll and maintain eligibility in the DNR administered National Flood Insurance Program (NFIP), to protect new development and modifications to existing development from flood damages when locating in a flood prone area cannot be avoided.

Enabling Legislation:
Minnesota Statutes, Section 103.F.101-165 (Appendix G)
Minnesota Rules Chapter 6120 (Appendix G)

Required Permit:
Local government permits for construction of structures, roads, bridges or other facilities within the floodplain

Regulatory Authority:
Local Government Unit
DNR, Division of Waters

Applicability:
All areas mapped within the 100-year floodplain

Stormwater Relationship:
Construction of structures, roads, bridges or other facilities on any lands within the 100-year floodplain

Lake Improvement District Program

Local citizen initiatives can petition counties to create lake improvement districts in order to address specific concerns within a lake watershed that cannot be addressed under normal governmental actions. Citizens and counties willing to undertake such initiatives gain greater local involvement in the management of their own lakes.

Enabling Legislation:
Minnesota Statutes, Section 103B.501 - 103B.581 (Appendix G)
Minnesota Rules Chapter 6115 (Appendix G)

Required Permit:
Local government permits

Regulatory Authority:
Local Government Unit
DNR, Division of Waters

Applicability:
lakes

Stormwater Relationship:
Activities affecting lakes and associated resources within a lake improvement district

III. Related Information

Table 5.3 is a permitting worksheet that is designed to aid the user in determining which permits they may need for a specific project and which agencies to contact for more information. This worksheet should not be viewed as a definitive list but rather as a resource to point the user in the right direction. This worksheet is provided as a means of organization and information gathering. Applicants should always check with their local zoning authority for more information on local requirements.

Appendix F includes a links to more information about Special Waters in Minnesota. If a project is in, near, or draining to a Special Water then additional permit conditions designed to preserve and protect the quality and character of these unique waters will apply.

Appendix G includes additional regulatory information that may be useful:

► A general list of agencies and contacts with a brief description of the agency, address, telephone, and website contact information.

► A brief summary of the major federal and state enabling legislation that mandates or supports the above programs.

► Links to model ordinances for a number of stormwater management activities.

The Manual Sub-Committee prepared an "Overlaps and Gaps Analysis: Stormwater Regulatory Framework Supplement" as part of its work on assessing the regulatory programs in Minnesota. This report in Appendix J contains information from regulated parties and regulatory agencies and should be used when future regulatory updates are considered.

Table 5.3 Permitting Worksheet

Step 1: Determine if your project entails a regulated activity:

Is the project:	Yes	No	Not sure?	Primary Agency to Contact	Related Permits You May Need
disturbing > 1 acre?			Check project plans	MPCA, MS4	NPDES/SDS Construction Permit
dewatering?			Check project plans	DNR	Water Appropriations Permit
appropriating water?			Check project plans	DNR	Water Appropriations Permit
an industrial discharge?			Check project plans	MPCA Met Council	NPDES/SDS Industrial Permit Industrial Waste Disposal Permit
a feedlot operation?			Check project plans	MPCA MDA	NPDES/SDS Feedlot Permit
discharging to Special Waters?			Check Special Waters list	MPCA	NPDES/SDS Permits
discharging to surface waters?			Check project plans	MPCA DNR	NPDES/SDS Permit Water Appropriations Permit
disposing/injecting stormwater into the shallow subsurface?			Check project plans	USEPA	Class V Injection Well Inventory Class V Injection Well Permit
draining wetland?			Check NWI Check wetland delineation	USACE DNR MPCA BWSR, LGU	Section 404 Permit Public Waters Permit Section 401 Water Quality Certification Waters/Wetlands (WCA) Permit
filling wetland?			Check NWI Check wetland delineation	USACE DNR MPCA BWSR, LGU	Section 404 Permit Public Waters Permit Section 401 Water Quality Certification Waters/Wetlands (WCA) Permit
excavating wetland?			Check NWI Check wetland delineation	USACE DNR MPCA BWSR, LGU	Section 404 Permit Public Waters Permit Section 401 Water Quality Certification Waters/Wetlands (WCA) Permit
innundating wetland?			Check NWI Check wetland delineation	USACE DNR MPCA BWSR, LGU	Section 404 Permit Public Waters Permit Section 401 Water Quality Certification Waters/Wetlands (WCA) Permit
affecting a calcareous fen?			Check calcareous fens list	DNR MPCA	Calcareous Fen Management Plan Individual NPDES/SDS Permit

Table 5.3 Permitting Worksheet					
working below the ordinary high water level or in a Public Water?			Check OHWL Check PWI	DNR	Public Waters Permit
a utility crossing (e.g. pipe, transmission line, etc.)?			Check project plans	DNR, public owner of land	Utility Crossing License, State/ Public Landowner Permission
Step 2: Determine the receiving water					
Is the project area is in, near, or draining directly to:	**Yes**	**No**	**Not Sure?**	**Primary Agency to Contact**	**Considerations and Related Permits You May Need**
a trout lake or lake trout lake?			Check trout lakes	DNR	Special Permit Conditions Apply
DNR public waters?			Check PWI	DNR	Public Waters permit
a water of the US?			Check Waters of US	USACE	Section 404 or Section 10 Permit and Section 401 Water Quality Certification
a trout stream?			Check trout streams	DNR	Special Permit Conditions Apply
a wild, scenic, or recreational river?			Check WSR Rivers	DNR	Special Permit Conditions Apply
the Upper Mississippi River?			Check Special Waters	DNR	Special Permit Conditions Apply
a public drainage ditch?			Contact Drainage Authority	Drainage Authority	Drainage permit/permission
wetland?			Check NWI Check wetland delineation	BWSR, LGU	WCA Permit, Section 404 Permit, Public Waters Permit, and/or Section 401 Water Quality Certification
DNR public waters wetlands?			Check PWI	DNR	WCA Permit, Section 404 Permit, Public Waters Permit, and/or Section 401 Water Quality Certification
a calcareous fen?			Check Calcareous Fens list	DNR, MPCA	Approved calcareous fen management plan and individual NPDES/SDS permit
an impaired water or TMDL listed water?			Check 303d list	MPCA	Special Permit Conditions Apply
outstanding resource value waters (ORVWs)?			Check ORVWs	MPCA	Special Permit Conditions Apply

Table 5.3 Permitting Worksheet

Step 3: Determine if your project area is in, near, or draining to special areas:

Is the project area in, near, or draining directly to:	Yes	No	Not Sure?	Primary Agency to Contact	Considerations and Related Permits You May Need
a MS4?			Check with MS4 (City, Watershed, Mn/DOT)	MPCA, LGU	NPDES/SDS MS4 Permit
a construction site?			Check with LGU	MPCA, LGU	NPDES/SDS Construction Permit
an industrial site?			Check with LGU	MPCA Met Council	NPDES/SDS Industrial Permit or Industrial Waste Disposal Permit
a feedlot operation?			Check with LGU	MPCA	NPDES/SDS Feedlot Permit
a coastal zone (Lake Superior)?			Check Coastal Zone	DNR	Special Permit Conditions Apply
the Mississippi River Critical Area (MRCA)?			Check MRCA	DNR	Special Permit Conditions Apply
a shoreland district?			Check with LGU	LGU	Special Permit Conditions Apply
a floodplain, floodway, or flood zone?			Check FEMA maps	LGU	Special Permit Conditions Apply
a wilderness area?			Check Wilderness Areas	NPS, USFS, BLM, USFWS	Special Permit Conditions Apply
a scientific or natural area?			Check SNAs	DNR	Special Permit Conditions Apply
a lake improvement district?			Check with LGU	LGU	Special Permit Conditions Apply
a dewatering site?			Check project plans	DNR	Water Appropriations Permit
a watershed district or water management organization?			Check WD/WMOs	WD/ WMO,BWSR	Watershed Permits
an Indian Reservation?			Check Reservations	Tribal government	Tribal Permits
federally protected land?			Check with LGU	NPS, USFS, BLM, USFWS	Special Permit Conditions Apply
a source water protection area?			Check with LGU	LGU, MDH	Special Permit Conditions Apply
a drinking water protection area?			Check with LGU	LGU, MDH	Special Permit Conditions Apply
a karst area?			Check Karst	DNR, LGU	Special Permit Conditions Apply

Table 5.3 Permitting Worksheet

a wellhead protection area?			Check with LGU	LGU, MDH	Special Permit Conditions Apply

Step 4: Compile a list of agencies to consult and permits you may need (from lines marked “yes” above):

Agency to consult:	Permits which may be required:

Step 5: Consult your local zoning authority and watershed organization for more information on local regulations/requirements/permits

Local Zoning Authority:	Local Watershed Organization:
Contact Name:	Contact Name:
Address:	Address:
City, State, Zip:	City, State, Zip:
Telephone:	Telephone:
Email:	Email:
Web:	Web:

Local Permits which may be required:	Watershed Permits which may be required:

IV. References

Federal Emergency Management Agency (FEMA)

FEMA's Introduction to NFIP
http://www.fema.gov/nfip/intnfip.shtm.

Metropolitan Council (Met Council)

Met Council Environmental Services: Industrial Waste Forms
http://www.metrocouncil.org/environment/IndustrialWaste/forms.htm.

Met Council Environmental Services: Industrial Wastes http://www.metrocouncil.org/environment/IndustrialWaste/.

Met Council Environmental Services: Watershed planning http://www.metrocouncil.org/environment/Watershed/planning/inde.g.htm.

Met Council Home Page
http://www.metrocouncil.org/.

Minnesota Board of Water and Soil Resources (BWSR)

BSWR 404 Permit (joint state and federal permit) Application Forms
http://www.bwsr.state.mn.us/wetlands/wcaforms/inde.g.html.

BWSR and SWCD Supervisors Handbook
http://www.bwsr.state.mn.us/aboutbwsr/publications/supervisorshandbook.pdf.

BWSR Comprehensive Local Water Management
http://www.bwsr.state.mn.us/watermgmt/complocalwatermgmt/inde.g.html.

BWSR Home Page
http://www.bwsr.state.mn.us/inde.g.html.

BWSR Metropolitan Area Surface Water Management
http://www.bwsr.state.mn.us/watermgmt/metroareasurface.html.

BWSR Permit Application Forms
http://www.bwsr.state.mn.us/wetlands/wcaforms/inde.g.html.

BWSR Wetland Conservation Act
http://www.bwsr.state.mn.us/wetlands/wca/inde.g.html.

Minnesota Cities and Local Government

League of Minnesota Cities Home Page
http://www.lmnc.org/.

Minnesota North Star Local Government
http://www.state.mn.us/cgi-bin/portal/mn/jsp/content.do?subchannel=-536879913&id=-8494&agency=NorthStar.

Minnesota Counties

Minnesota Association of Counties Home Page
http://www.mncounties.org/.

Minnesota Department of Agriculture (MDA)

Minnesota Department of Agriculture: Ask MDA
webinfo@mda.state.mn.us.

Minnesota Department of Health (MDH)

MDH Addresses, Phone Number and Directions
http://www.health.state.mn.us/about/direct.html.

MDH Drinking Water Protection About Our Programs
http://www.health.state.mn.us/divs/eh/water/org/programdesc.html.

MDH Drinking Water Protection
http://www.health.state.mn.us/divs/eh/water/inde.g.html.

MDH Drinking Water Protection Contact List
http://www.health.state.mn.us/divs/eh/water/org/contactlst.html.

MDH Health Risk Limits for Groundwater
http://www.health.state.mn.us/divs/eh/groundwater/hrlrule.html.

MDH Source Water Assessments of Public Water Systems
http://www.health.state.mn.us/divs/eh/water/swp/swa/inde.g.htm.

MDH Source Water Protection General Information
http://www.health.state.mn.us/divs/eh/water/swp/inde.g.htm.

MDH Surface Water Intake Protection
http://www.health.state.mn.us/divs/eh/water/swp/surfaceguide.pdf.

MDH Well Head Protection
http://www.health.state.mn.us/divs/eh/water/swp/whp/inde.g.htm.

Minnesota Department of Natural Resources (DNR)

DNR Coastal Nonpoint Pollution Control Program
http://www.dnr.state.mn.us/waters/lakesuperior/cnp/inde.g.html.

DNR Dam Safety Permits
http://www.dnr.state.mn.us/permits/water/inde.g.html#dam_safety.

DNR Dam Safety Program
http://www.dnr.state.mn.us/waters/surfacewater_section/damsafety/safety.html.

http://ww.dnr.state.mn.us/waters/surfacewater_section/damsafety/inde.g.html.

DNR Division of Waters
http://www.dnr.state.mn.us/waters/orgchart.html.

DNR Do I Need a Permit
http://www.dnr.state.mn.us/permits/water/needpermit.html.

DNR Floodplain Management Program
http://www.dnr.state.mn.us/waters/watermgmt_section/floodplain/inde.g.html.

DNR Floodplain Management Program history
http://www.dnr.state.mn.us/waters/watermgmt_section/floodplain/history.html.

DNR Forms related to Division of Waters programs
http://www.dnr.state.mn.us/waters/forms.html.

DNR Guide for Buying and Managing Shoreland
http://www.dnr.state.mn.us/shorelandmgmt/guide/standards_tables.html.

DNR Lake Management Program
http://www.dnr.state.mn.us/waters/watermgmt_section/lake/inde.g.html.

DNR Lake Superior Coastal Program
http://www.dnr.state.mn.us/waters/lakesuperior/inde.g.html.

DNR List of Known Calcareous Fens
http://files.dnr.state.mn.us/publications/waters/Calcareous_Fen_List.pdf.

DNR Ordinary High Water
http://www.dnr.state.mn.us/waters/surfacewater_section/hydrographics/ohw.html.

DNR Minimum Shoreland standards
http://www.dnr.state.mn.us/shorelandmgmt/guid/standards_tables.html.

DNR Mississippi National River & Recreation Area
http://www.dnr.state.mn.us/waters/watermgmt_section/mnrra/inde.g.html.

DNR Mississippi River Critical Area Program
http://www.dnr.state.mn.us/waters/watermgmt_section/critical_area/inde.g.html.

DNR Mississippi River Management – Navigation
http://www.dnr.state.mn.us/waters/watermgmt_section/river/miss_mgmt.html.

DNR National Flood Insurance Program
http://www.dnr.state.mn.us/waters/watermgt_section/nfip/inde.g.html.

DNR Public Waters Works Permit Programs
http://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/inde.g.html.

DNR River Resource Management Program
http://www.dnr.state.mn.us/waters/watermgmt_section/river/inde.g.html.

DNR Shoreland Management Program
http://www.dnr.state.mn.us/waters/watermgmt_section/shoreland/inde.g.html
http://www.dnr.state.mn.us/waters/watermgmt_section/shoreland/references.html.

DNR Utility Crossing License
http://www.dnr.state.mn.us/permits/utility_crossing/inde.g.html.

DNR Water Appropriations Permit Program
http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/inde.g.html.

DNR Water Use Permits
http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/permits.html.

DNR Wild and Scenic Rivers Program
http://www.dnr.state.mn.us/waters/watermgmt_section/wild_scenic/inde.g.html.

Minnesota Department of Transportation (Mn/DOT)

MnDOT: Contact Mn/DOT
http://www.dot.state.mn.us/information/talk.html.

Minnesota Pollution Control Agency (MPCA)

MPCA Clean Water Partnership Section 319 Combined Application http://www.pca.state.mn.us/publications/wq-cwp7-02.doc.

MPCA Coastal Nonpoint Pollution Program
http://www.pca.state.mn.us/water/basins/superior/coastalnp.html.

MPCA Feedlots program
http://www.pca.state.mn.us/hot/feedlots.html#forms.

MPCA Home Page
http://www.pca.state.mn.us/.

MPCA Minnesota 2001 - 2005 Nonpoint Source Management Program Plan (NSMPP), http://www.pca.state.mn.us/water/nonpoint/mplan.html.

MPCA Minnesota's Impaired Waters and Total Maximum Daily Loads (TMDL)
http://www.pca.state.mn.us/water/tmdl/inde.g.html.

MPCA), last updated March 10, 2003
http://www.pca.state.mn.us/water/319.html.

MPCA More about the Clean Water Partnership Program CWP
http://www.pca.state.mn.us/water/cwp.html.

MPCA Nonpoint Source Issues
http://www.pca.state.mn.us/water/nonpoint/inde.g.html.

MPCA Section 401 Certification
http://www.pca.state.mn.us/water/401.html.

MPCA Stormwater Program
http://www.pca.state.mn.us/water/stormwater/inde.g.html.

MPCA Stormwater Program for Construction Activity
http://www.pca.state.mn.us/water/stormwater/stormwater-c.html.

MPCA Stormwater Program for Industrial Facilities NPDES
http://www.pca.state.mn.us/water/stormwater/stormwater-i.html.

MPCA Stormwater Program for MS4s
http://www.pca.state.mn.us/water/stormwater/stormwater-ms4.html.

MPCA Water Quality Standards
http://www.pca.state.mn.us/water/standards/inde.g.html.

MPCA Water Quality Standards: Beneficial use designations
http://www.pca.state.mn.us/water/standards/inde.g.html#beneficial.

MPCA Water Quality Standards: Non-degradation policy
http://www.pca.state.mn.us/water/standards/inde.g.html#nondegradation.

MPCA Water Quality Standards: Numerical and narrative standards and criteria
http://www.pca.state.mn.us/water/standards/inde.g.html#nnstandards.

Minnesota Soil and Water Conservation Districts (SWCD)

Minnesota Association of Soil and Water Conservation Districts (MASWCD) Home http://www.maswcd.org/inde.g.htm.

SWCD directory, retrieved April 4, 2005, http://www.bwsr.state.mn.us/directories/SWCDs.pdf.

Minnesota Watershed Districts and Water Management Organizations

Minnesota Association of Watershed Districts
http://mnwatershed.govoffice.com/inde.g.asp?Type=B_BASIC&SEC={1F1ACEE4-3C71-468E-8830-469FA9E1C8CE.

National Oceanic and Atmospheric Administration (NOAA)

NOAA
http://www.noaa.gov/.

NOAA's Coastal Nonpoint Pollution Control Program
http://www.ocrm.nos.noaa.gov/czm/6217/.

NOAA's Minnesota Coastal Zone
http://www.ocrm.nos.noaa.gov/czm/czmminnesota.html.

NOAA's NFIA
http://www.csc.noaa.gov/opis/html/summary/nfia.htm.

National Park Service (NPS)

History of Critical Area
http://www.nps.gov/miss/programs/critical/cahist.htm.

National Park Service MNRRA website
http://www.nps.gov/miss/inde.g.html.

National Park Service Program at a glance, Partnership Wild and Scenic Rivers
http://www.nps.gov/nero/rivers/wildandscenic.htm.

National Wild and Scenic Rivers Act
http://www.nps.gov/rivers/wsract.html.

National Wild and Scenic Rivers Act Enabling Legislation
http://www.nps.gov/rivers/wsract.html.

National Wild and Scenic Rivers System home page
http://www.nps.gov/rivers/.

U.S. Army Corps of Engineers (USACOE)

Sacramento District Regulatory Branch
http://www.spk.usace.army.mil/organizations/cespk-co/regulatory/inde.g.html.

Overview of the Corps' Permit Programs
http://www.mvp.usace.army.mil/regulatory/default.asp?pageid=799.

U.S. Army Corps of Engineers' Permit
http://www.nwp.usace.army.mil/op/g/Regs/Permit_req.htm.

U.S. Army Corp of Engineers' Recognizing Wetlands an informational pamphlet
http://www.sac.usace.army.mil/permits/rw-bro.html.

U.S. Army Corps of Engineers' Section 404 Regulations
http://www.usace.army.mil/inet/functions/cw/cecwo/reg/33cfr323.htm.

U. S. Army Corp of Engineers, St. Paul District
http://www.mvp.usace.army.mil/.

U.S. Army Corp of Engineers' wetland information
http://www.sac.usace.army.mil/permits/wet.html.

U.S. Environmental Protection Agency (USEPA)

USEPA's Underground Injection Control Program
http://www.epa.gov/region5/water/uic/.

USEPA's Class V Injection Wells
http://www.epa.gov/safewater/uic/c5fin-fs.html.

USEPA's Class V Injection Wells and Stormwater
http://www.epa.gov/safewater/uic/pdfs/fact_class5_stormwater.pdf.

USEPA's Clean Water Act
http://www.epa.gov/region5/water/cwa.htm.

USEPA's Clean Water Act module
http://www.epa.gov/watertrain/cwa/inde.g.htm.

USEPA's Clean Water Act module Section 319 page
http://www.epa.gov/watertrain/cwa/cwa52.htm.

USEPA's Clean Water Act module Section 401 page
http://www.epa.gov/watertrain/cwa/cwa58.htm.

USEPA's Clean Water Act module Section 402 page
http://www.epa.gov/watertrain/cwa/cwa37.htm.

USEPA's Clean Water Act module Section 404 page
http://www.epa.gov/watertrain/cwa/cwa55.htm.

USEPA's Coastal Zone Act Reauthorization Amendments Section 6217
http://www.epa.gov/owow/nps/czmact.html.

USEPA's Current TMDL Program and Regulation
http://www.epa.gov/owow/tmdl/overviewfs.html

USEPA's NPDES
http://cfpub.epa.gov/npdes/inde.g.cfm.

USEPA's Region 5
http://www.epa.gov/Region5/.

USEPA's Safe Drinking Water Act 30th Anniversary Understanding the Safe Drinking Water Act
http://www.epa.gov/safewater/sdwa/30th/factsheets/understand.html.

USEPA's Source Water Assessment Page
http://www.epa.gov/ogwdw/protect/assessment.html.

USEPA's TMDL definition
http://www.epa.gov/owow/tmdl/intro.html#definition.

Source Water Assessment Program
http://www.epa.gov/safewater/protect/swap.html.

U.S. Fish and Wildlife Service (FWS)

U.S. Fish and Wildlife Service, Great Lakes-Big Rivers Region Regional Office
http://www.fws.gov/midwest/regionaloffice/.

US Forest Service

U.S. Forest Service Eastern Region
http://www.fs.fed.us/r9/.

US Forest Service Mississippi National River & Recreation Area
http://www.nps.gov/miss/inde.g.html.

Other Web References

Minnesota Shoreland Management Resource Guide
http://www.shorelandmanagement.org/.

Minnesota Statutes 2004 Table of Chapters
http://www.revisor.leg.state.mn.us/stats/103E/.

University of Minnesota Extension
http://www.extension.umn.edu/inde.g.html.

Chapter 6

Introduction to Best Management Practices

VOLUME 1 - INTEGRATED STORMWATER MANAGEMENT

Chapter 6

Introduction to Best Management Practices

This chapter provides an introduction into the selection of best management practices or "BMPs". It provides some insight into selection of a BMP suite or specific practice, and provides some advice on how to retrofit and respond to mosquito concerns.

Contents

I. Using the Treatment Train Approach to BMP Selection

Introduction

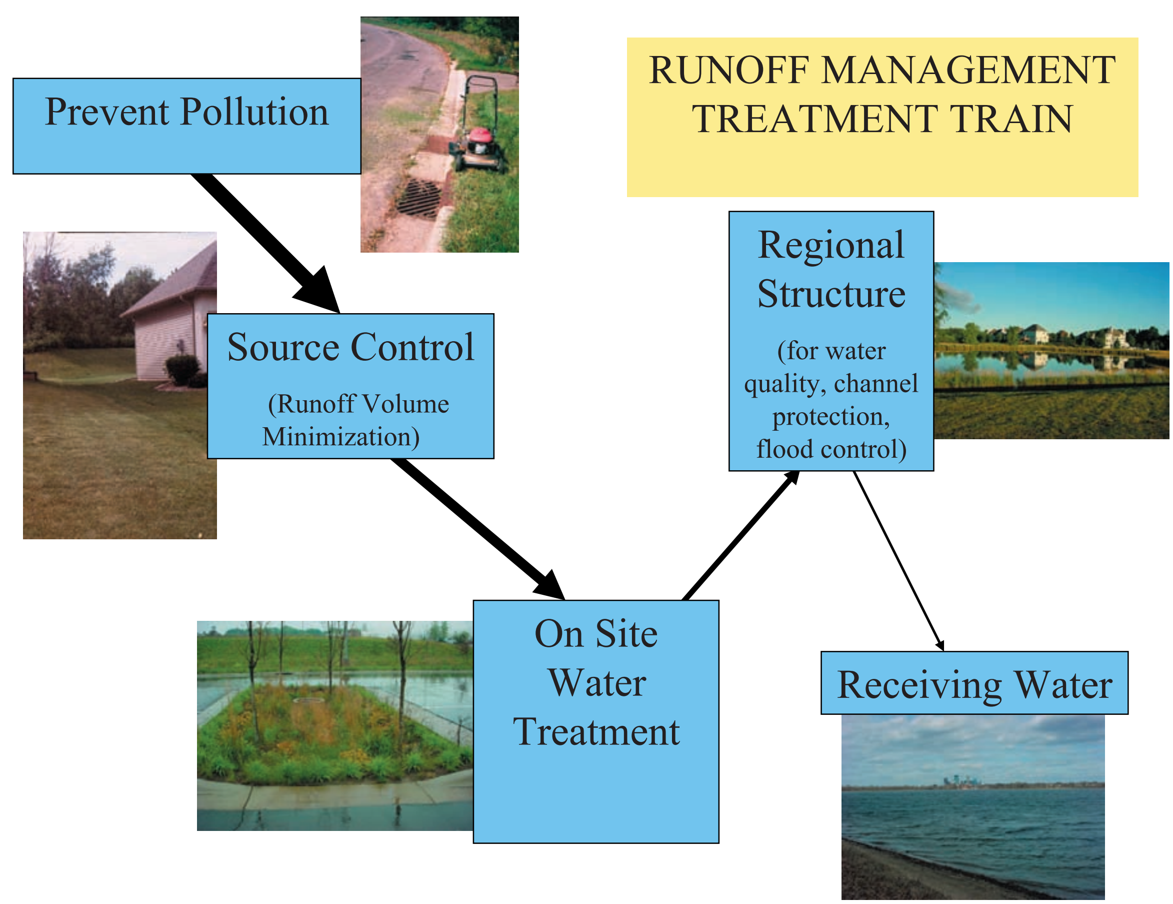
The basic premise for selection of a Best Management Practice (BMP) or group of BMPs is to follow the treatment train approach introduced in Chapter 1 (Figure 6.1). Under the treatment train strategy, stormwater management begins with simple methods that minimize the amount of runoff that occurs from a site and methods that prevent pollution from accumulating on the land surface and becoming available for wash-off. Even though we know that we will never be able to fully accomplish either of these goals, we can make substantial progress using the better site design techniques shown in Chapter 4 and the pollution prevention, volume minimization, temporary construction erosion control and supplemental techniques in Chapter 12.

After all of the efforts possible are made to minimize runoff and surface wash-off, we must recognize that some potential for runoff will occur. The next major BMP then becomes collection and treatment of runoff locally and regionally, either as stand-alone practices or in treatment train combinations. Some of the available BMPs are best used to reduce runoff volume, while others focus on water quality improvement. Some BMPs will be easy to implement, while others involve serious engineering and sophisticated design. Chapter 12 presents detailed design guidance for categories of structural BMPs: bioretention devices, filtration practices, infiltration practices, stormwater ponds and stormwater wetlands.

Pollutant Removal Mechanisms

The key to proper selection of a single or series of BMPs is to match the pollutant to be controlled against the pollutant removal mechanism of a specific BMP. For example, it is not appropriate to

Figure 6.1 Treatment Train Approach to Runoff Managment



use a stormwater pond when temperature control is necessary; however it is very appropriate to use a pond for purposes of rate control. The definition of pollutant being utilized by the *Minnesota Stormwater Manual* includes both the traditional pollutants (nutrients, solids, etc.) plus the negative effects caused by thermal increases and excessive rate/speed of stormwater flows. Stormwater planners and designers will first need to understand the pollutant(s) of concern that may be generated at their sites. At the early stages of design, stormwater managers should be contacting local water management agencies (watershed districts, watershed management organizations, soil and water conservation districts, counties and/or cities) to learn which pollutants are necessary to control prior to discharge of new stormwater runoff to local waterbodies.

The guidance fact sheets contained in Chapter 12 discuss the pollutant removal mechanisms of each BMP in greater detail. However, the key mechanisms for each group of structural BMPs are presented in Table 6.1 and can be used by stormwater managers as a preliminary screening tool. Further tools for BMP selection are presented in Chapter 7.

Water Quality Pollutant Removal Mechanisms

- **Screening/Filtration**

  The capture of solid pollutants through screens and/or filters which use a media such as sand. Effective for removal of suspended solids.

- **Infiltration/Ground Water Recharge**

  A technique to discharge stormwater runoff to ground water. Effective when runoff volume controls are required and surface water temperatures must be controlled.

Table 6.1 Primary and Secondary Pollutant Removal Mechanisms

BMP Group	Pollutant Removal Mechanisms									
	Water Quality						Water Quantity			
	Screening/ Filtration	Infiltration/ Recharge	Settling	Biological Uptake	Temperature Control	Soil Adsorption	Volume Control	Rate Control	Velocity Control	Evapo-transpiration
Pollution Prevention	Not applicable – pollutants not exposed to stormwater									
Runoff Volume Minimization		◐			◐		●	◐		
Temporary Construction Sediment Control			●					●	◐	
Bioretention	●	◐	◐	◐	◐	◐	◐	◐		◐
Filtration	●	◐		◐		◐		◐		◐
Infiltration	◐	●		◐	●	◐	◐	◐		
Stormwater Ponds		◐	●	◐				●	●	◐
Constructed Wetlands	◐	◐	●	●		◐		●	●	◐
Supplemental Treatment	Each supplemental and proprietary device should be carefully studied to learn the primary and secondary pollutant removal functions.									

● = Primary Pollutant Removal Mechanism
◐= Secondary Pollutant Removal Mechanism

- ▶ **Settling**

  Deposition of solids in a water column, usually in a pond, wetland or hydrodynamic device. Typically a minimum of 12 hours of detention is needed to effectively settle solids in stormwater ponds and stormwater wetlands.

- ▶ **Biological Uptake**

  Vegetative and microbial uptake of nutrients. Usually accomplished in biofiltration devices and stormwater wetlands.

- ▶ **Temperature Control**

  Techniques to reduce the heating effects when runoff flows across hot pavements. Most effective technique is for groundwater to cool treated runoff.

- ▶ **Soil Adsorption**

  The physical attachment of a particle, usually nutrients and heavy metals, to the soil.

Water Quantity Control Mechanisms

- ▶ **Volume Control**

  Methods to limit the net increase in stormwater runoff volume caused by the creation of new impervious surfaces. Most common techniques include limitation of new surface areas, infiltration, and re-use by vegetation.

- ▶ **Rate Control**

  Detention of stormwater runoff to slow the discharge of runoff to surface waters to rates comparable with pre-development conditions (see Chapter 10). Effective for peak rate control, but can significantly increase the time period of the peak flows.

- ▶ **Velocity Control**

  Similar to rate control; intentional restriction of stormwater runoff such that velocity of discharged runoff through downstream channels does not cause channel erosion.

- ▶ **Evapotranspiration**

  Specific volume control technique that utilizes evaporation from water surfaces and/or transpiration by vegetation.

BMP Organization

The following sections describe the BMPs that are recommended for Minnesota. The selection criteria are included in Chapter 7 and the specific information on each category is included in Chapter 12. Some additional support information occurs in Appendix D. Note that the order of the BMP presentation follows the treatment train sequence illustrated in Figure 6.1.

Non-Structural or Planning Level BMPs

The first level of BMP application occurs at the planning stage and is intended to minimize the impact of development. These practices are intended to prevent pollution and minimize the increase in stormwater volume and are considered prior to initiation of construction or land altering activity.

1. **Pollution Prevention Practices (Water Quality Focus).**
   - ▶ Residential, municipal and industrial/ commercial practice categories
   - ▶ Specific recommended practices include such things as:
     - Housekeeping including landscaping, street sweeping, pavement maintenance, catch basin maintenance, yard waste reduction and litter control
     - Atmospheric controls including wind erosion and dust, as well as regulatory emission regulations
     - Chemical control of hazardous waste and salt, fertilizer/pesticides, spills (including prevention), swimming pool drainage
     - Animal waste management
     - Streambank stabilization
     - Public works activities including chemical and sanitary wastes, and sewer maintenance

2. **Better Site Design.** Refer to Chapter 4.

3. **Runoff Volume Minimization (Water Quantity Focus; See Also Table 7.1).** Note that many typical runoff volume reduction techniques are included in the Chapter 4 discussion of better site design, including:
   - Green roofs/rooftop gardens
   - Pervious pavement/lattice blocks
   - Rainwater harvesting (barrels/cisterns, evaporative and irrigation systems)

3. **Temporary Construction Sediment Control (Water Quality Focus; See Also Table 7.2; Reference MS4, NPDES, and Local References and Ordinances).** These practices are described in terms of perimeter, slope, drainageway and "other" criteria, and include:
   - Vegetated buffers
   - Silt fence
   - Access/egress and drainage inlet protection
   - Soil and slope stabilization
   - Exposed soil covers and reinforcement

Structural BMPs

These BMPs have design guidance describing the engineering details for the BMP category. This design guidance is used, for example, to determine storage volume and physical configuration that best meet the objectives of the BMP application. Also note that some of these BMPs, such as filtration, can be either a primary treatment technique or used for pre-treatment into another BMP.

4. **Bioretention.** This BMP suite includes vegetated systems that provide a combination of filtration and infiltration into a bio-system consisting of plants and soil, including:
   - Rain gardens
   - Depressed parking lot/traffic islands
   - Road medians
   - Tree pits/stormwater planters

5. **Filtration.**
   - Media (sand) filters (surface, underground, perimeter/Delaware filter)
   - Surface (vegetative) flow (grass channels, dry or wet swales, filter strips)
   - Combination media/vegetative filters

6. **Infiltration.**
   - Trenches
   - Basins
   - Dry wells
   - Underground systems

7. **Stormwater Ponds.** Design based upon components needed to fulfill the desired function.
   - Components include forebay/pre-treatment, various storage volumes, physical configuration
   - Functions include water quality (including thermal impact) and flow control (rate and volume), which determine whether they are wet/dry or some combination

8. **Constructed Wetlands.** Selection criteria is similar to stormwater ponds.
   - Components include pre-treatment, various storage volumes (detention needed), biologic character
   - Functions include primarily water quality and flow control, but could also include ecological factors

Supplemental Pre- and Post-Treatment BMPs

The final category of BMPs present those that are generally, but not always, included in the stormwater treatment train as a supplement to the primary treatment device. Although this is not generally recommended, there is the possibility that these devices could be the only BMP used. These are described in less detail than the previous sections. The designer will be guided through a process of determining the function a generic device serves within the treatment train and evaluating the proposed device against the needed function and manufacturer claims. Proprietary devices are generically described rather than listed as individual companies to avoid risking some omissions and claims of certification in the Manual.

9. **Supplemental Pre- and Post-Treatment.**
   - Hydrodynamic

- Proprietary sediment and oil/grease removal devices
- Wet vaults
- Sorbents
- Skimmers

► Filtration

- Catch basin inserts
- Sorbents
- Proprietary filtration devises

► Chemical/biological treatment

- Chemical treatment * (ferric chloride, alum, polyacrylamides)
- Biological additives (ex. chitosan)

* Note that these chemical treatments could be limited in the State of Minnesota because of the potential toxic effects associated with them; care will be taken to assess these impacts in the BMP discussion.

Using the Manual to Select BMPs

The approach used in this Manual is slightly different from many other manuals. The proposed concept uses a "functional components approach" wherein basic BMP components are selected and pieced together to achieve a desired outcome. For example, if a BMP is needed to reduce peak discharge and remove sediment, the "Stormwater Ponds" BMP detailed in Chapter 12 is selected and the actual design components are then assembled based upon the material presented in the design guidance. In this case, a pond with a specific outflow rate(s) and sufficient water quality storage is designed to meet both functions according to state design criteria. This approach limits the inclusion of numerous individual BMP sheets in favor of categorical sheets with design variations included on each sheet. This should be a more user-friendly way of defining how BMPs can be designed to solve a particular problem.

The BMP lists follow a simple-to-more complex treatment train sequence, one that starts with on-site pollution prevention and works upward in complexity to wetland systems. The final section on treatment supplements is a compilation of additional measures that could be used to enhance treatment either before or after more complex BMP use.

Chapter 12 includes detailed BMP fact sheets on bioretention, filtration, infiltration, ponds and wetlands. Pollution prevention, runoff minimization and temporary construction runoff control practices will include some descriptive language for the numerous practices listed via "fact sheets," but will not contain engineering details. The final section on treatment supplements will similarly not contain detailed engineering, but will describe a process that designers should follow when considering the use of proprietary devices, inserts and chemical/biological treatment.

The beginning stormwater manager or a designer unfamiliar with the many BMPs available might have some questions on which BMP or group of BMPs to include in a treatment scheme. Table 6.2 is a screening tool to get the user going on BMP selection. It contains the list of BMPs contained in this Manual and a corresponding list of use assessment parameters to help narrow the wide range of potential BMPs for a particular project. A user will need to have some objectives in mind to extract information from the matrix, but once into the matrix, selection of BMPs based on either positive or negative factors will be possible.

Table 6.2 Best Management Practices Matrix

	BMP from Minnesota Stormwater Manual [1]																													
	Better Site Design	Pollution Prevention			Runoff Minimization		Temporary Construction Sediment Control						Bioretention				Filtration		Infiltration				Stormwater Ponds		Constructed Wetlands			Supplemental Treatment		
Use Assessment Parameter (see Chapter 7 for details of parameter)	See Chapter 4 for Techniques	Residential	Municipal	Industrial/Commercial	Runoff Volume Reduction	Capture and Re-use	Pre-Construction	Perimeter	Slope	Drainageway	Other [2]	Inspect/maintain	Infiltration/recharge	Filtration/partial recharge	Infiltration/filtration/recharge	Filtration	Media (sand)	Vegetative	Infiltration Basin	Infiltration Trench	Dry Well	Underground System	With Extended Detention	Without Extended Detention (ex. Walker Pond)	Shallow Wetland	ED Shallow Wetland	Pond/wetland System	Chem./Biological Treatment	Filtration devices	Hydrodynamic Devices
Pollution Prevention	●		●	●	●	●	●	●	●	●	●	●				◐		◐												
Minimize Runoff [3]																														
- Reduce volume	●				●	●							●	●	●	◐	◐	◐	●	●	●	●			◐	◐	◐			
- Increase recharge	●				●	●			◐				●	●	●	◐	●	◐	●	●	●	●	◐	◐	◐	◐	◐			
- Improve WQ	●	●	●	●	◐	◐		●	●	●	●	●	◐	◐	◐	◐	◐	●	◐	◐	◐	◐	●	●	●	●	●	◐	◐	◐
- Reduce costs	●	◐	◐	◐	◐	◐	●					◐	◐	◐	◐	◐		◐												
- Local feasibility	●	●	●	◐				●	●	●	●																			
- Cold climate	●	◐	●	●	◐			◐	◐	◐			◐	◐	◐	◐	●	●	◐	◐	◐	◐	●	●	●	●	●		●	●
- Land use									●				◐	◐	◐	◐		◐											◐	◐
Temporary Construction Sediment Control			●	●	◐	◐	●	●	●	●	●	●	◐	◐	◐	●	●	●	○	○	○	○	●	●	◐	◐	●	◐	●	●
Watershed Factors																														
- Lakes	●	●	●	●	●			●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	◐	◐	●	●		
- Trout resources	●				●	◐		●	●	●	●		●	●	●	●	●	●	●	●	●	●	○	○	◐	◐	●			
- Drinking water	●	●	●	◐	●	◐				●	◐		●	●	●			◐	●	●	●	●	●	●			●			
- Wetlands (calcareous fens)	●				◐			●	●	●	●		◐	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		

Table 6.2 Best Management Practices Matrix

	BMP from Minnesota Stormwater Manual [1]																													
	Better Site Design	Pollution Prevention			Runoff Minimization		Temporary Construction Sediment Control						Bioretention				Filtration		Infiltration				Stormwater Ponds		Constructed Wetlands			Supplemental Treatment		
Use Assessment Parameter (see Chapter 7 for details of parameter)	See Chapter 4 for Techniques	Residential	Municipal	Industrial/Commercial	Runoff Volume Reduction	Capture and Re-use	Pre-Construction	Perimeter	Slope	Drainageway	Other [2]	Inspect/maintain	Infiltration/recharge	Filtration/partial recharge	Infiltration/filtration/recharge	Filtration	Media (sand)	Vegetative	Infiltration Basin	Infiltration Trench	Dry Well	Underground System	With Extended Detention	Without Extended Detention (ex. Walker Pond)	Shallow Wetland	ED Shallow Wetland	Pond/wetland System	Chem./Biological Treatment	Filtration devices	Hydrodynamic Devices
- Impaired waters	●	●	●	◐	●	◐		●	●	●	◐		◐	◐	●	●	●	●	◐	◐	◐	◐	●	●	●	●	●			
Climate & Terrain																														
- Active karst	◐				●	●			●	◐	◐		○	◐	○	●	●	●	○	○	○	○		◐	●	●	◐			
- Fractured bedrock/shallow soil	◐												○																	
- Low infiltration soil	◐				●	●		●	●				○	○	○	◐	◐	◐	○	○		○	●	●	●	●	●			
- High snowfall	◐		●	◐	●	●			●	●		●	◐	●	●	●	◐	◐	◐	●	●	●	●	●	●	●	●		●	●
- Low rainfall																●	●	●						◐	●	●	●			
SW Treatment Suitability																														
- Recharge	●				●	●			◐	◐	◐		●	●	●	◐		◐	●	●	●	●								
- Water quality	●	●	●	●	◐	◐		●	●	●	●	●	◐	◐	◐	◐	●	●	◐	◐	◐	◐	●	●	●	●	●	◐	◐	◐
- Channel protection	●		●		●			●	●	●	◐		◐	◐	◐	◐		◐	◐	◐	◐	◐	●	●	●	●	●			
- Peak discharge			●		●				●		◐		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			
- PSH [4]	◐	●	●	●									○	○	○	◐	●	●	○	○	○	○	◐	◐	◐	◐	◐			
Physical Feasibility																														
- Surface area																							○	○					◐	◐

Table 6.2 Best Management Practices Matrix

	BMP from Minnesota Stormwater Manual [1]																													
	Better Site Design	Pollution Prevention			Runoff Minimization		Temporary Construction Sediment Control						Bioretention				Filtration		Infiltration				Stormwater Ponds		Constructed Wetlands			Supplemental Treatment		
Use Assessment Parameter (see Chapter 7 for details of parameter)	See Chapter 4 for Techniques	Residential	Municipal	Industrial/Commercial	Runoff Volume Reduction	Capture and Re-use	Pre-Construction	Perimeter	Slope	Drainageway	Other [2]	Inspect/maintain	Infiltration/recharge	Filtration/partial recharge	Infiltration/filtration/recharge	Filtration	Media (sand)	Vegetative	Infiltration Basin	Infiltration Trench	Dry Well	Underground System	With Extended Detention	Without Extended Detention (ex. Walker Pond)	Shallow Wetland	ED Shallow Wetland	Pond/wetland System	Chem./Biological Treatment	Filtration devices	Hydrodynamic Devices
- Drainage area																									○	○	○			
- Soils								●	●	●						●	●	●	○	○	○	○			◐	◐				
- Elevation difference									◐							●														
- Depth to rock	●												○	○	○	●	●	●	○	○	○	○	○	○	●	●				●
-Depth to water table	●					●							◐	◐	◐	●	●	●	○	○	○	○			●	●				●
- Site slope	●							●	●	●			◐	◐	◐	◐														
- Ultra-urban	●	●	●			●		●	●				●	●	●	●	●	●				●	○	○	○	○	○		●	●
Community and Environment																														
- Ease of maintenance	●	●	●	◐				●	●		◐					◐	○	●	○	○	○	○	◐	◐	●	●	◐		●	◐
- Community acceptance	●	●	●	◐				●	●	●			○		○	●		●					●	●	●	●	●		●	
- Const. cost	●						●	●									○	●		○		○						○		
- Habitat quality	●												●	●	●	●	○	●		○	○	○	◐	◐	●	●	●		○	○
- Nuisance (including mosquitoes)																			●	●	●	●	◐	◐	◐	◐	◐			

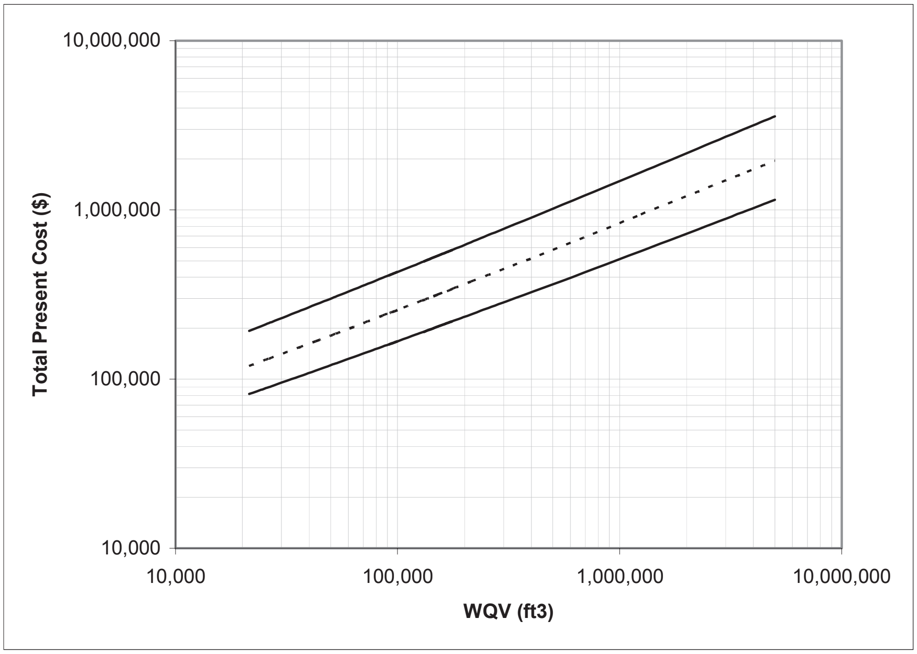
Table 6.2 Best Management Practices Matrix

	BMP from Minnesota Stormwater Manual [1]																													
	Better Site Design	Pollution Prevention			Runoff Minimization		Temporary Construction Sediment Control						Bioretention				Filtration		Infiltration				Stormwater Ponds		Constructed Wetlands			Supplemental Treatment		
Use Assessment Parameter (see Chapter 7 for details of parameter)	See Chapter 4 for Techniques	Residential	Municipal	Industrial/Commercial	Runoff Volume Reduction	Capture and Re-use	Pre-Construction	Perimeter	Slope	Drainageway	Other [2]	Inspect/maintain	Infiltration/recharge	Filtration/partial recharge	Infiltration/filtration/recharge	Filtration	Media (sand)	Vegetative	Infiltration Basin	Infiltration Trench	Dry Well	Underground System	With Extended Detention	Without Extended Detention (ex. Walker Pond)	Shallow Wetland	ED Shallow Wetland	Pond/wetland System	Chem./Biological Treatment	Filtration devices	Hydrodynamic Devices
Location-specific Restrictions and Setbacks	◐		●			◐				●																				
Knowledge of Performance and Reliability[5]	●	●	●	●	●	◐		●	●	●	◐	●	◐	◐	◐	●	●	●	◐	◐	◐	◐	●	●	●	●	●	◐	◐	◐
Sensitivity to Improper Construction and Poor Maintenance [5]	◐				○	◐		○	○	○			○	○	○	◐		◐	○	○	○	○	◐	◐						○

● = Recommended
◐ = Recommended with conditions (see Chapter 12)
○ = Not recommended;
Empty space = neutral

[1] See Chapter 12 descriptions
[2] Other includes drainage inlets, trees, and waterbodies
[3] Chapter 7 addresses only BSD techniques
[4] PSH = "potential stormwater hotspot"
[5] Not included in Chapter 7

Figure 6.2 Total Construction and Maintenance Cost for Water Quality Volumes of a Wet Basin (Source: Mn/DOT, 2005)



Using Cost Factors to Select BMPs

Stormwater managers are reluctant to make a final BMP selection without having some basic information on the construction and maintenance costs. Chapter 12 and Appendix D contain guidance on the preparation of construction and maintenance costs for specific BMPs. However, this technique is not always practical or even feasible at the BMP selection stage. Stormwater managers who wish to learn the relative cost effectiveness between two specific BMPs are encouraged to use information prepared by the Minnesota Department of Transportation in a May, 2005 report titled *The Cost Effectiveness of Stormwater Management Practices.* As part of their research, the authors incorporated both historical construction costs and 20 years of expected annual maintenance costs. The result is a series of graphs that present total present cost (construction plus maintenance) plotted against water quality volume. Figure 6.2 can be used to determine the total present worth value of construction plus maintenance costs for wet basins. Similar graphs are available for dry detention basins, constructed wetlands, infiltration trenches, bioinfiltration filters, sand filters, and 1,000-foot long vegetated swales in the Mn/DOT report. This simple technique can then be used to estimate the total present cost of a BMP under consideration. For purposes of establishing a specific budget for construction and maintenance, stormwater managers are encouraged to follow the procedures outlined in Chapter 12.

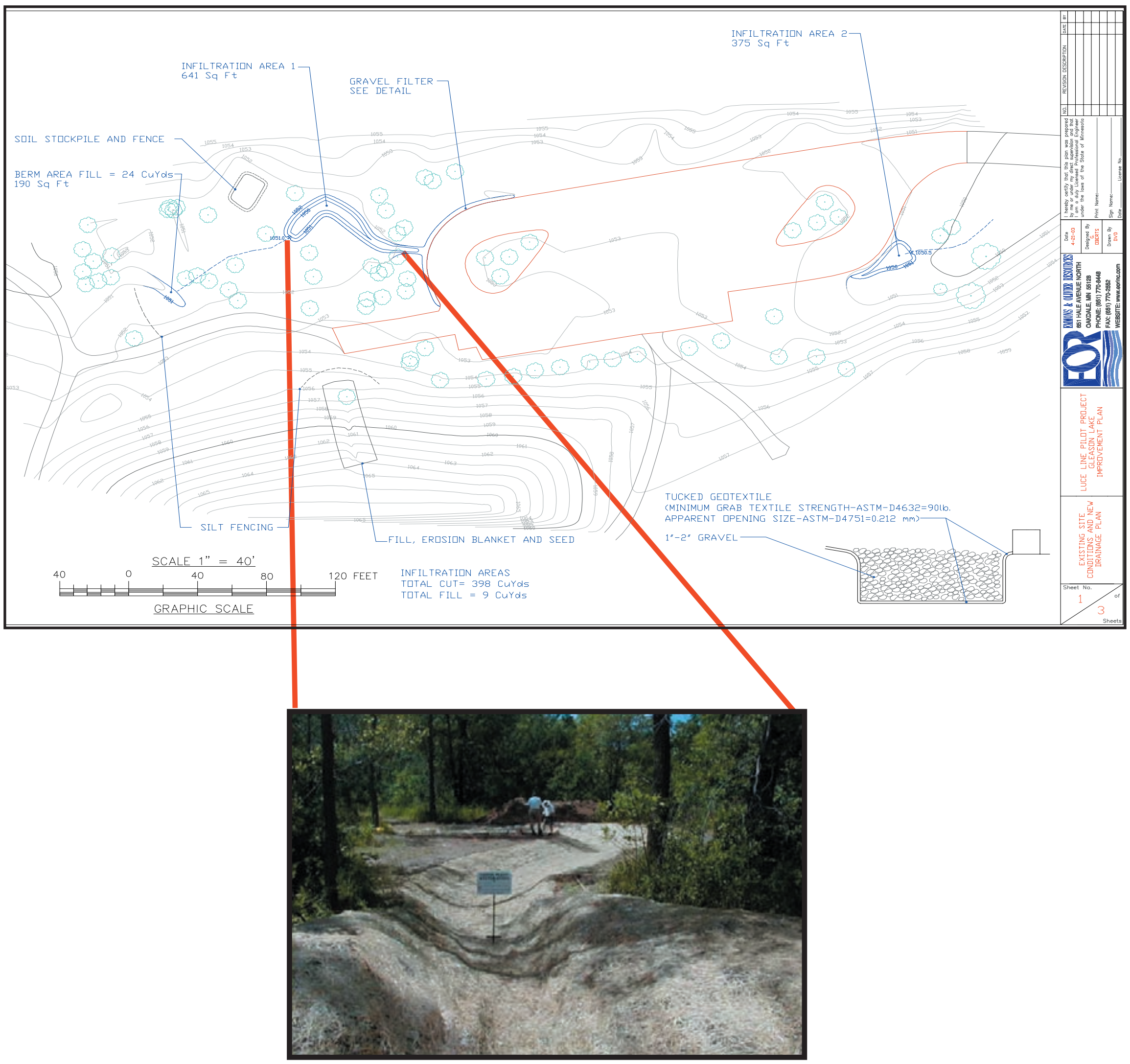
II. Retrofitting To Achieve Better Stormwater Management

Retrofitting is the introduction of a new or improved stormwater management element where it has either never existed or where it did not operate effectively. A golden opportunity for retrofitting exists every time re-development takes place, a road repair is done, or a major water project occurs. Every time a retrofit is installed, the stormwater leaving a site should be improved. Even if the improvement is very small in scope, the net result is positive.

Two examples of retrofits with very different scales are the Ames Lake project in St. Paul (Figure 6.3) and the Luce Line project in Plymouth (Figure 6.4). The Ames Lake project involved the

Figure 6.3 Restored Ames Lake in St. Paul (Source: Metropolitan Council)

Figure 6.4 Luce Line Parking Lot Infiltrating Rain Garden.



demolition of a 1950s-era shopping center and the re-introduction of a wetland where it once stood. Figure 6.3 shows the before and after condition of restored Ames Lake.

Small-scale improvements can also be made, such as the installation of an infiltration rain garden at the DNR's Luce Line Trail parking lot in Plymouth. A cooperative venture among the Gleason Lake Improvement Association, Minnehaha Creek Watershed District, Metropolitan Council, City of Plymouth, DNR and Luce Line Trail Association led to the installation of the system shown in Figure 6.4, which infiltrates essentially all of the parking lot rainfall and snowmelt runoff.

These are just two of many examples that show how retrofits can improve stormwater handling in situations that have not ever been treated or were altered so that no trace remains.

The BMP design guidance in Chapter 12 is suitable to retrofit situations. Often stormwater retrofits are considered supplemental to on-site stormwater systems, and therefore may not be subject to design requirements set by the Minnesota Pollution Control Agency and local stormwater management agencies. Stormwater designers are encouraged to confirm local retrofit design requirements.

III. Mosquito Control and Stormwater Management

Background

Because stormwater management usually deals with the transmission, storage and treatment of water, there is much concern about the proliferation of mosquito breeding habitat associated with BMPs. This is a well-founded concern because mosquitoes may colonize any source of standing water provided there is a source of organic material to provide sustenance to larvae (Messer, 2003). Although this basic fact often means that BMPs will result in more mosquitoes, there are many design and management measures that can be followed to minimize this increase.

The primary threat to Minnesotans from mosquitoes, besides the nuisance, is the transmission of serious disease. West Nile Virus (WNV) and various forms of encephalitis are the major concerns. In spite of this threat, the U.S. Department of Health and Human Services Centers for Disease Control and Prevention (CDC) and Minnesota Department of Health both point out that a very small percentage of mosquitoes are vectors for disease and many of those bitten by carriers will not experience major health consequences, although minor difficulties could develop. Both organizations advise avoidance of outside activity, use of repellents and good integrated pest management programs (see next section) to avoid disease problems related to mosquitoes.

Mosquitoes in Minnesota

Minnesota is fortunate to have a major mosquito research and management agency, the Metropolitan Mosquito Control District (MMCD), in the Twin Cities metropolitan area, as well as research in other parts of the state by the University of Minnesota and the Minnesota Department of Health. They have been able to characterize the occurrence of mosquitoes and the problems they cause in the state.

Information provided by Nancy Read of the MMCD via education material (ex. Minnesota Erosion Control Association Annual Conference, 2004) included the following basic facts:

- There are about 50 varieties of mosquito in the state, but only a few are efficient transmitters of diseases such as WNV.
- All mosquitoes need water for the larval and pupal stages of development. The larval stage lasts anywhere from 5-7 days, so holding water for less than five days will prohibit the progression of life past the larval stage. Standing water for over two weeks can easily breed mosquitoes if not treated.
- *Aedes vexans* is the most common Minnesota mosquito. It is a "floodwater" mosquito that lays its eggs on moist surfaces near water and relies on periodic submersion for eggs to hatch into larvae. Eggs can remain viable on moist surfaces for years before hatching once inundated. It is a vector (or carrier) of heartworm disease and may have a small role in WNV transmission.

- *Ochlerotatus triseriatus* is a "treehole" variety floodwater mosquito that lays eggs in containers that periodically fill with water, such as tires, bird baths, or holes in a tree. This variety is a vector for LaCrosse encephalitis, which affects primarily children.
- *Culex tarsalis* is a standing-water species that is principally responsible for the spread of WNV in the western US. It lays eggs in "rafts" in standing water. The ideal habitat for *Culex* species are areas that will remain wet for about two weeks, contain vegetation for shelter and nourishment, and have few predatory fish.
- *Culex pipiens and restuans* are species often found in stormwater catch basins, rip-rapped areas and ponds with vegetative debris. MMCD treats 50,000 water-holding catch basins in the Twin Cities metropolitan area to control these species.
- The larvae of the cattail mosquito, *Coquillettidia perturbans,* attach themselves to cattails and breathe through the inner air tube. Eggs are laid in late summer, with larvae able to over-winter under the ice. These varieties emerge as adults in large quantities around mid-summer.
- MMCD uses an integrated pest management (IPM) approach to controlling mosquitoes that targets primarily the larval stage through the use of bacteria (Bti or *Bacillus thuringiensis* var *israelensis*) toxic to larvae and growth regulators (methoprene) that inhibit larval development. Some limited spraying with synthetic pyrethoids is done for adults. IPM also includes good site design for BMPs and encourages biological control agents like predators (especially fish).

Methods to Limit Mosquito Breeding in Stormwater Facilities

The presence and behavior of water is the most important element to the continuing life cycle of the mosquito. Controlling standing and stagnant water, and adapting design and habitat conditions are the ways stormwater managers can avoid a proliferation of mosquito breeding in association with stormwater BMPs.

A number of technical publications, articles and fact sheets on mosquitoes (Aichinger, 2004; Commonwealth of Virginia, 2003; Messer, 2003; Metzger, 2003; Nancy Read, MMCD, personal communications; Stanek, brochure with no date; USEPA, brochure with no date; Wass, 2003) were evaluated to come up with the following advisory material for homeowners (possible public information for SWPPPs) and stormwater managers.

Homeowner Actions

- Eliminate standing and stagnant water around the home, such as in abandoned tires, boat covers, wheelbarrows, flower pots, or other containers. Change the water in wading pools, birdbaths, or dog dishes frequently.
- Protect family members from mosquito contact via such measures as house screening, avoidance during hours of maximum exposure, repellents, clothing coverage.
- Chlorinate, clean and cover swimming pools, and prevent water from collecting on cover.
- Unclog roof drains and downspouts.
- Aerate water gardens or use fish to prevent larval mosquito development.
- Screen rain barrels to keep adult mosquitoes from laying eggs.

Stormwater Managers Actions

See next section for additional information on items marked with an asterisk (*).

- Use BSD/LID development techniques to reduce the amount of stormwater that needs to be conveyed and managed.
- Do not allow water to collect in "temporary" facilities for longer than five days, preferably less than three.
- Adhere to Minnesota Construction General Permit requirement to drain infiltration/filtration BMPs within 48 hours.

- Avoid allowing standing water to collect in inlets and outlets and in conveyance pipes; avoid corrugated pipe without constant flow and sumps in catch basins.
- Maintain and clean-out sediment traps/basins and all drainage structures, inlets, outlets and orifices (use only openings >3” to prevent clogging) to keep positive water drainage.
- Screen inlet and outlet pipes or place under water if no other control available (prevents fly-in.
- Eliminate standing stagnant water as part of any BMP appurtenance, including forebays, sediment traps, sump areas and pumps. (*)
- Avoid the use of rip-rap that can catch and hold organic debris in a wet area. (*)
- Design de-watering capability into every BMP for routine dry-down and maintenance.
- Minimize installation of BMPs that will collect stormwater for only brief periods then stagnate until the next event; this could include a water budget analysis to make sure some baseflow will occur through the BMP.
- Minimize shallow depths (less than one-foot) as part of ponds and wetlands (*); if this cannot be done, make sure flow continually occurs over the shallow area.
- Design facilities to minimize vegetation overgrowth floating organic debris, algae, trash, sediment dead grass/clippings, and cattails. (*)
- Avoid the use of mulch that will wash into any BMP (use geotechnical material or secured mats instead).
- Avoid vegetation cutting operations that leave debris, blow into standing water, or leave ruts for water accumulation.
- Keep dense emergent vegetation limited to narrow (<1m) bands around areas with standing water and prevent the development of cattail stands. (*)
- Keep permanent pool embankments steep to prevent emergent vegetation, especially cattails, from growing; carefully plan plant species for aquatic/access benches to avoid cattail intrusion. (*)
- Fall draw-down on cattail marshes can be a very effective control for cattail mosquitoes, which overwinter as larvae in the water.
- Design healthy natural systems that encourage mosquito predators to thrive and have access to mosquito larvae; this includes open water (over four-feet deep) as part of wetland design (preferably oriented perpendicular to flow-through), minimization of stagnant, non-flowing water, creation of diverse vegetation along periphery of ponds.
- For stormwater wetlands, maintain a constant water table just below the ground surface (or above ground <5 days) to minimize mosquito production.
- Require a written inspection and maintenance plan that addresses stagnant water, water quality, and vegetation and debris management.
- Consider including mosquito control as a potential annual maintenance cost in some situations.
- Work with vector control agencies on integrated pest management approach to larval control.
- Always design access for vector control staff to reach entire BMP, not just the inlet or outlet.
- Properly design and maintain all stormwater BMPs.

Compatibility with Common BMP Design

A cursory consideration of the list of commonly used Minnesota BMPs relative to the above list would seem to indicate that some BMPs might be more desirable than others when mosquitoes are concerned. The practices that would seem to be the best for preventing mosquitoes would be permanent pools with steep slopes below the water line, infiltration devices that drain effectively in 48 hours, bioretention that infiltrates or filters water then dries at the surface, dry ponds, ponds with a water quality volume that is fully treated and discharged within three days, and healthy pond/

wetland systems (those with diverse vegetation, open water areas over three-feet in depth, fairly steady water levels and low nutrient loads).

Practices that would seem to cause mosquito breeding to proliferate would include water basins or holding areas that hold water in a stagnant condition for longer than three days, sub-grade treatment systems that include sumps and are not properly sealed, poorly maintained water holding areas that contain substantial amounts of vegetative debris, wet meadows with less than one-foot of standing water, and storage areas that bounce up and down repeatedly. Not all of these systems need to be dropped from the list of suitable BMPs, but their use should be supplemented with IPM techniques (ex. biological larvicides), physical sealing, or adequate maintenance.

The recommendations listed with a (*) above could be designs that appear to conflict with common BMP use. Careful consideration of these practices can avoid the mosquito impact, as follows:

- Avoiding excessive vegetative growth does not mean minimizing vegetation, rather it means keeping a healthy mix that thrives and does not overwhelm the BMP or an (upland) area adjacent to a BMP. The same applies for emergent vegetation that is planted as part of an overall planting scheme.
- Shallow vegetated benches are part of the recommended access design for ponds, as outlined in Chapter 12. Although a recommendation above suggests that "shallow" water less than one-foot be avoided in standing water situations, it might be necessary, depending upon access needs, to construct such a bench. In addition, a recommendation above suggests that dense periphery vegetation be limited to about 1m in width, whereas Chapter 12 recommends bench width at 10 feet. Designers are advised to use their judgment on the mix of recommendations for edge-of-pond depth, depending upon priorities for access relative to mosquito control. Care should be taken in plant selection, particularly if bench depths less than one-foot are anticipated.
- Rip-rap or similar structural armor for bank stabilization are options that are sometimes needed in erosive situations. The tendency for these materials to capture vegetative debris and to create small pools of water make them ideal mosquito breeding sites. If mosquito breeding is a concern at these installations, smoothing with a grout material or size grading can be used to minimize edges and pools that promote mosquito habitat, or alternative materials can be used.
- The required wet basin design in the MPCA CGP contains a water quality volume that is temporarily detained above the permanent pool. Although there are no CGP requirements for the amount of time this should be held, a minimum of 12 hours is recommended in Chapter 10 and trying to get the extended detention pool to recede within three days is a good goal to minimize possible mosquito breeding. Floodwater mosquito egg-laying on the moist side slopes above the permanent pool is almost impossible to control in this situation because the eggs remain viable for up to five years and could hatch with the resulting larvae inhabiting the pool whenever water levels rise. Standing water mosquito varieties can be minimized with a management plan that allows these areas to fully dry out between events. If conditions cannot be improved to minimize breeding habitat, biologic larvicides should be used.
- Forebays, sediment traps and treatment sumps could all be part of a well designed treatment train. The recommendation above to keep these from becoming stagnant is consistent with good design principles and should not preclude their use. The essential elements in keeping them "fresh" are to either drain them fully after use or keep baseflow moving through them. MMCD began a monitoring program in underground structures in 2005 and has found evidence of mosquito breeding in half of the structures tested through mid-summer of 2005. Studies in California outline more details of which structures are most likely to provide habitat for mosquitoes (Metzger, *et al., 2002).*

In summary, there are many ways in which stormwater BMPs can become mosquito breeding grounds if caution is not followed in their design, operation and maintenance. The means exist to install BMPs that minimize the creation of mosquito habitat and/or to biologically attack the larvae that result even under the best designs.

IV. References

Aichinger, C., 2004. Understanding the West Nile Virus. Woodbury Bulletin (newspaper opinion page), August 11, 2004. Contact Ramsey-Washington Metro Watershed District, North St. Paul, MN.

Commonwealth of Virginia, 2003. Vector Control: Mosquitoes and Storm Water Management. Stormwater Management Technical Bulletin No 8.

Messer, D.F., 2003. Mosquitoes in Structural Stormwater BMPs: A Case Study. In Proceedings of the StormCon Conference of 2003, San Antonio, Texas. Published by Forester Communications, Santa Barbara, CA.

Metzger, M.E., 2003. Mosquito Control Challenges Presented by Stormwater Treatment Devices in the United States. In Proceedings of the StormCon Conference of 2003, San Antonio, Texas. Published by Forester Communications, Santa Barbara, CA.

Metzger, M.E., D.F. Messner, C.L. Beitia, C.M. Meyers, and V.L. Kramer, 2002. The Dark Side of Stormwater Runoff Management: Disease Vectors Associated with Structural BMPs. Stormwater, 3(2):24-39.

Minnesota Department of Transportation, 2005. The Cost and Effectiveness of Stormwater Management Practices. Report 2005-23, St. Paul, MN. http://www.lrrb.org/pdf/200523.pdf

Stanek, S. (no date). West Nile Virus and Stormwater Management. Brochure prepared for the Minnehaha Creek Watershed District, Deephaven, MN.

U.S. EPA (no date). Wetlands and West Nile Virus brochure.

Wass, R.D., 2003. Mosquito Management Do's and Don'ts in an Engineered Arizona Treatment Wetland System. In Proceedings of the StormCon Conference of 2003, San Antonio, Texas. Published by Forester Communications, Santa Barbara, CA.

Links to Information on Mosquito Control

American Mosquito Control Assoc.
http://www.mosquito.org/

BMPs and Mosquitoes National Information by Marco Metzger
http://www.forester.net/sw_0203_dark.html - 71k - 28 Oct 2003

California IPM for Mosquito Series, UC ANR Communication Services
http://www.ipm.ucdavis.edu/

CDC statement on stormwater and mosquitoes
http://www.cdc.gov/nceh/ehs/Docs/Stormwater-Factsheet.pdf

"Managing Mosquitoes in Surface-flow Constructed Treatment Wetlands" by William Walton
http://anrcatalog.ucdavis.edu/pdf/8117.pdf

"Management of Mosquitoes in Stormwater Treatment Devices" by Marco Metzger
http://anrcatalog.ucdavis.edu/pdf/8125.pdf

Metropolitan Mosquito Control District
http://www.mmcd.org/wnvfaq.html

Rutgers University Mosquito Links
http://www-rci.rutgers.edu/~insects/links.htm

U.S. Department of Health and Human Services, Centers for Disease Control and Prevention
http://www.cdc.gov/ncidod/dvbid/westnile/index.htm

USEPA Mosquito Factsheet
http://www.epa.gov/pesticides/factsheets/mosquito.htm

USEPA Publication, How Specific Changes in Wetlands Changed Mosquito Populations
http://www.epa.gov/owow/wetlands/pdf/WestNile_pr.pdf

Willott, E. 2004. "Restoring nature, without mosquitoes?" Restoration Ecology 12(2): 147-153.
http://research.biology.arizona.edu/mosquito/Willott/Pubs/Restore.html

Chapter 7

Choosing Best Management Practices (BMPs)

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VOLUME 1 - INTEGRATED STORMWATER MANAGEMENT

Chapter 7

Choosing Best Management Practices (BMPs)

This chapter guides designers through nine key factors involved in BMP selection, and features a series of tables that present comparative BMP information. Beginning designers may wish to go sequentially through all nine factors when screening BMP options, while more experienced designers may only want to consult the individual factors they need to review.

Contents

I. Process for Selecting Best Management Practices

Designers need to carefully think through many factors to choose the most appropriate, effective and feasible practice(s) at a development site that will best meet local and state stormwater objectives. This chapter presents a flexible approach to BMP selection that allows a stormwater manager to select those BMPs most able to address an identified problem. Selecting an inappropriate best management practice (BMP) for a site could lead to adverse resource impacts, friction with regulators if a BMP does not work as anticipated, misperceptions about stormwater control success, and wasted time and money. Careful selection of BMPs will prevent negative impacts from installing the wrong BMP at the wrong location. Regulators can similarly use these matrices to check on the efficiency of proposed BMPs.

Nine factors should be evaluated in the BMP selection process, as follows:

1. **Investigate Pollution Prevention Opportunities.** Evaluate the site to look for opportunities to prevent pollution sources on the land from becoming mobilized by runoff.

2. **Design Site to Minimize Runoff.** Assess whether any better site design techniques can be applied at the site to minimize runoff and therefore reduce the size of structural BMPs.

3. **Select Temporary Construction Sediment Control Techniques.** Check to see what set of temporary sediment control techniques will prevent erosion and minimize site disturbance during construction.

4. **Identify Receiving Water Issues.** Understand the regulatory status of the receiving water to which the site drains. Depending on the nature of the receiving water, certain BMPs may be promoted, restricted or prohibited, or special design or sizing criteria may apply.

5. **Identify Climate and Terrain Factors.** Climate and terrain conditions vary widely across the state, and designers need to explicitly consider how each regional factor will influence the BMPs proposed for the site.

6. **Evaluate Stormwater Treatment Suitability.** Not all BMPs work over the wide range of storm events that need to be managed at the site, so designers need to choose the type or combination of BMPs that will provide the desired level of treatment.

7. **Assess Physical Feasibility at the Site.** Each development site has many physical constraints that influence the feasibility of different kinds of BMPs; designers confirm feasibility by assessing eight physical factors at the site.

8. **Investigate Community and Environmental Factors.** Each group of BMPs provides different economic, community, and environmental benefits and drawbacks; designers need to carefully weigh these factors when choosing BMPs for the site.

9. **Determine Any Site Restrictions and Setbacks.** Check to see if any environmental resources or infrastructure are present that will influence where a BMP can be located at the development site.

> ***Regulators:***
>
> ***Tables 7.3 through 7.8 may be used to check whether a proposed BMP is suitable for a specific site or receiving water.***

II. Investigate Pollution Prevention Opportunities

Pollution prevention should be the first consideration during any development or redevelopment project. This step involves looking for opportunities to reduce the exposure of soil and other pollutants to rainfall and possible runoff.

Examples of pollution prevention practices include keeping urban surfaces clean, proper storage and handling of chemicals, and preventing exposure of unprotected soil and pollutants. More information on pollution prevention practices can be found in Chapter 12 of this Manual, and a description of the treatment train approach in Chapter 1 and Chapter 6.

III. Design Site to Minimize Runoff

A range of better site design (BSD) techniques are described in Chapter 4 of this Manual. These can provide non-structural stormwater treatment, improve water quality and reduce the generation of stormwater runoff. These techniques reduce impervious cover and reduce the volume of stormwater runoff at a site, which can save space and reduce the cost of structural BMPs. Designers should review Table 7.1 to understand the comparative benefits and drawbacks of BSD techniques that could potentially be applied to the site. All of the techniques shown are suitable for cold climate conditions in the State of Minnesota.

- ► **How well does the technique reduce stormwater runoff volume?**
  Each BSD technique is rated as having a high, medium, or low capability to reduce the volume of stormwater runoff generated at a development site. The ability to promote infiltration of runoff, preserve natural hydrology or filter pollutants are main reasons why these techniques vary in their volume reduction capability.

- ► **Is the technique eligible for a possible stormwater credit?**
  While all better site design techniques can reduce the size and cost of structural BMPs needed at the site, six techniques may be eligible as a stormwater credit during the design phase. Specific details on how stormwater credits are computed and reviewed are provided in Chapter 11. Check with your local review authority to see which credits may be offered in your community. Stormwater credits can reduce required water quality volumes by as much as 10% to 40%, and even more if multiple credits are applied.

- ► **What are the potential cost savings for developers?**

  Many BSD techniques can result in significant cost savings for developers during construction, in the form of reduced infrastructure costs, more available land for development, higher and faster sales, and lower long-term maintenance costs. Table 7.1 ranks the potential cost savings for each technique, as being high, medium, or low.

- ► **How easy is it to implement the technique in most communities?**
  Some BSD techniques are standard practice in many communities, while others are newer and more difficult to adopt. Table 7.1 rates how easy it is to implement each technique given typical local codes or design guidelines in the State. Techniques denoted as *experimental* are not included in current local design guidelines and may involve a time-consuming and uncertain approval process. *Required* techniques are allowed under most local design guidelines; whereas *promoted* techniques are actively encouraged in most communities. *Constrained* techniques are harder to implement since current local codes impede or even prohibit their use in some communities. Designers should always check with their local reviewing authority to confirm which techniques can be used.

- ► **What is the most appropriate land use for the technique?**
  The nature of the proposed land use at a site often influences the kinds of BSD techniques can be applied. Table 7.1 presents a general indication of the most appropriate land use for each technique, using the following codes:

  - **Residential** - Appropriate for residential development, any density.
  - **HDR** - Best for high density residential development.
  - **C/O** - Best for commercial/office, including institutional uses.
  - **I-PSH -** Industrial development that may be a potential stormwater hotspot (PSH).
  - **I** - Industrial development not considered to be a PSH.

Table 7.1 Techniques to Reduce Runoff During Site Design and Layout

Better Site Design Technique	Reduce Stormwater Runoff Volume	Possible Stormwater Credit	Cost Savings	Local Feasibility*	Appropriate Land Use
Natural Area Conservation	High	Yes	High	Promoted	All
Site Reforestation & Prairie Restoration	High	Yes	Medium	Promoted	All
Stream and Shoreline Buffers	High	Yes	High	Required	All
Soil Amendments	High	Yes	Low	Experimental	All
Surface IC Disconnection**	High	Yes	High	Experimental	Residential, C/O, I Caution w/ I-PSH
Rooftop Disconnection	High	Yes	High	Experimental	All
Open Space Design	High	No	High	Constrained	Residential, C/O, I
Grass Channels	Low	Yes	High	Constrained	Residential, C/O, I Caution w/ I-PSH
Reduced Street Width	High	No	High	Constrained	Residential, C/O
Reduced Sidewalks	High	No	High	Constrained	Residential, C/O
Smaller and Vegetated Cul-de-sac	High	No	High	Constrained	Residential
Shorter Driveways	High	No	High	Constrained	Residential
Green Parking Lots	Medium	No	Low	Experimental	HDR, C/O, I

Residential- appropriate for residential development at any density
HDR- best for high density residential development
C/O- best for commercial/office (including institutional uses)
I-PSH- industrial development that may be a potential stormwater hot spot (PSH)
I- Industrial development not considered to be a PSH
*varies greatly among communities, consult local reviewing authority to determine ease of implementation
** IC = impervious cover

IV. Select Temporary Construction Sediment Control Techniques

Construction sites can be a major source of sediment and nonpoint source pollutants if soils are exposed to erosion. Effective application of temporary sediment controls is an essential element of a stormwater management plan and helps preserve the long-term capacity and function of permanent stormwater BMPs. Designers should recognize that they will need to revisit and refine the erosion and sediment control plan throughout the design and construction period as more information on site layout and the type and location of BMPs becomes available.

Table 7.2 lists the range of temporary sediment control techniques that could be considered in the erosion and sediment control plan for a site. The table indicates how each technique reduces erosion, when it is applied in the construction process, and provides some additional comments. More information on how to integrate erosion and sediment control in the context of site design is discussed in Chapter 4 of this Manual. More detailed design guidance on sediment control techniques can be found in Chapter 12 and *Protecting Water Quality in Urban Areas* (MPCA, 2000).

V. Identify Receiving Water Issues

Designers should understand the nature and regulatory status of the waters that will receive runoff from the development site. The type of receiving water strongly influences the preferred BMP to use, and in some cases, may trigger increased treatment requirements. The many different kinds of Special Waters and other sensitive receiving waters in Minnesota are described in Chapter 2, Chapter 5, and Chapter 10 and listed in Appendix F. For purposes of this Manual, receiving waters fall into five categories: lakes, trout resources, drinking waters, wetlands and impaired waters. More information on BMP restrictions and special stormwater sizing criteria for the five receiving water categories is summarized in the latter part of Chapter 10.

The full spectrum of BMPs can be applied to sites that drain to receiving waters that are not designated as special or sensitive in Minnesota. If the receiving water falls into one of the special or sensitive water categories, the range of BMPs that can be used may be reduced. For example, only BMPs that provide a higher level of phosphorus removal may be encouraged for sensitive lakes. In trout streams, use of ponds may be discouraged due to concerns over stream warming. The full range of BMP restrictions for the five categories of receiving water are presented in Table 7.3 and described below.

- **Does the site drain to a sensitive lake?**
  BMPs differ in their ability to remove phosphorus, which is the key stormwater pollutant managed to protect sensitive lakes (Note: this category also includes trout lakes and surface water drinking supplies). The comparative phosphorus removal ability of BMPs is compared in Table 7.4. Communities may require greater water quality treatment, a specific phosphorus removal rate or even load reduction at the development site to protect their most sensitive lakes. In general, higher phosphorus removal requirements result in shorter list of acceptable BMP designs that can be used at the site.

- **Does the site drain to a trout stream protection?**
  Trout streams merit special protection, which strongly influences the choice of BMPs. Some BMPs are preferred because they promote baseflow, protect channels from erosion or achieve high rates of sediment removal. Other BMPs, such as ponds, may be discouraged because they cause stream warming.

- **Is the site within a ground water drinking water source area?**
  Sites located in aquifers used for drinking water supply require BMPs that can recharge aquifers at the same time they prevent ground water contamination from polluted stormwater, particularly when it is generated from potential stormwater hotspots (PSH). Table 7.3 indicates the kinds of BMPs that can meet these ground water protection challenges.

Table 7.2 Temporary Construction Sediment Control Techniques

Technique	Practice	How it Works	When to Apply	Comments
Pre-construction planning	Site planning and grading	Minimizes soil disturbance and unprotected exposure	Planning	Expose only as much area as needed for immediate construction
	Sequencing	Limits amount of soil exposed	Planning	
Resource protection	Forest conservation and water resource buffers	Establishes protective zone around valued natural resources	Early	Buffer variable from a few feet to 100' depending upon resource being protected and local regulations
Perimeter control	Access and egress control	Minimizes transport of soil off-site	Early	Must be in place prior to commencement of construction activities
	Inlet protection	Stops movement of soil into drainage collection system	Early	
Slope stabilization	Grade breaks	Minimizes rill and gully erosion	Early	No unbroken slopes > 75 ft. on 3:1 or steeper slopes
	Silt curtain	Stops sediment from moving	Early	
Runoff control	Stabilize drainageways	Minimizes increased erosion from channels	All construction phases	Possible to convert these into permanent open channel systems after construction
	Sediment control basins	Collects sediment that erodes from site before it leaves site or impacts resource	All construction phases	Possible to convert these into post construction practices after construction
Rapid stabilization of exposed soils	Seeding and mulch	Immediately establishes vegetative cover on exposed spoil	All construction phases	Apply seed as soils are exposed
	Blankets	Provides extra protection for exposed soil or steep slopes	All construction phases	Apply blanket as exposed soil cover until plants established
Inspection and maintenance	Formalized I&M program	Assures that BMPs are properly installed and operating in anticipated manner	All construction phases	Essential to proper BMP implementation

Table 7.3 Receiving Water Factors

BMP Group	Receiving Water Management Category[a]				
	Lakes	Trout Resources	Drinking Water [b]	Wetlands [d]	Impaired Waters
General Location	Outside of Shoreline Buffer	Outside of Stream Buffer	Setbacks from wells, septic systems	Outside of Wetland Buffer	Selection based on Pollutant Removal for Target Pollutants
Bioretention	PREFERRED	PREFERRED	OK with cautions for PSHs	PREFERRED	PREFERRED
Filtration	Some variations RESTRICTED due to limited P removal, combined with other treatments	PREFERRED	PREFERRED	OK	PREFERRED
Infiltration	PREFERRED	PREFERRED	RESTRICTED if potential stormwater hotspot (PSH)	PREFERRED	RESTRICTED for some target TMDL pollutants
Stormwater Ponds	PREFERRED	Some variations RESTRICTED due to pool and stream warming concerns	PREFERRED	PREFERRED but no use of natural wetlands	PREFERRED
Constructed Wetlands	Some variations RESTRICTED due to seasonally variable P removal, combined with other treatments	RESTRICTED except for wooded wetlands	PREFERRED	PREFERRED but no use of natural wetlands	PREFERRED
Supplemental BMPs[c]	RESTRICTED due to poor P removal, must combine with other treatments	RESTRICTED must combine with other treatments	RESTRICTED must combine with other treatments	RESTRICTED must combine with other treatments	RESTRICTED must combine with other treatments

[a] Outstanding Resource Value Waters (ORVW) is not included since it falls within Categories A-D.
[b] Applies to ground water drinking water source areas only; use the sensitive lakes category to define BMP design restrictions for surface water drinking supplies.
[c] Listed in Chapter 12
[d] including calcareous fens

Table 7.4 Comparative BMP Phosphorus Removal Performance [a]				
BMP Group	BMP Design Variation	Average TP Removal Rate [b]	Maximum TP Removal Rate [c]	Average Soluble P Removal Rate [d]
Bioretention	Under-drain	50%	65%	60%
	Infiltration	60%	75%	70%
Filtration	Media	50%	60%	0%
	Vegetative	65%	75%	70%
Infiltration	Infiltration Trench	65%	90%	80%
	Infiltration Basin	65%	90%	80%
Stormwater Ponds	Wet Pond	50%	65%	70%
	Multiple Pond	60%	75%	75%
Constructed Wetlands	Shallow Wetland	45%	65%	50%
	Pond/Wetland	55%	75%	65%

[a] Removal rates shown in table are a composite of four sources: Caraco (2001), MDE (2000), Winer (2000) and P8 (William Walker, http://wwwalker.net/p8/) modeling. Note that the numbers are reflective of treatment only for the water that actually reaches the BMP. That is, bypass of flow will occur at times and not be treated.
[b] Average removal efficiency expected under MPCA CGP Sizing Rules 1 and 3 (see Chapter 10)
[c] Upper limit on phosphorus removal with increased sizing and design features, based on national review
[d] Average rate of soluble phosphorus removal in literature

IMPORTANT NOTE: Removal rates shown here are composite averages intended solely for use in comparing performance between BMP designs and for use in calculating load reduction in site-based TP models. They have been adapted, rounded and slightly discounted from statistical values published in BMP performance databases.

- **Does the site drain to a wetland?**
  Wetlands can be indirectly impacted by upland development sites, so designers should choose BMPs that can maintain wetland hydroperiods and limit phosphorus loads. As shown in Table 7.3, several BMPs provide infiltration and extended detention storage that protect natural wetlands from increased stormwater runoff and nutrient loads from upland development.

- **Does the site drain to an "impaired water"?**
  BMP selection becomes very important when a development site drains to a receiving water that is not meeting water quality standards and is subject to a TMDL. The designer may need to choose BMPs that achieve a more stringent level of removal for the listed pollutant(s) of concern. Table 7.5 compares BMP removal capability for a range of common pollutants that cause water quality impairment in the State.

VI. Identify Climate and Terrain Factors

Climate and terrain conditions vary widely across the State, and designers need to explicitly consider each of these regional factors in the context of BMP selection (see also Chapter 2 and Appendix A). The proposed BMPs for the site should match the prevailing climate and terrain; preferred BMPs and design modifications are outlined in Table 7.6.

- **Is the site within an active karst region?**
  Active karst is defined as karst features within 50 feet of the surface of the site and poses many challenges to BMP design. It is safe to assume that any treated or untreated runoff that is infiltrated will reach the drinking water supply in karst areas. In addition, some BMPs can promote sinkhole formation that may threaten the integrity of the practice. Table 7.6 reviews the most feasible BMPs in active karst regions, and the type of geotechnical

Table 7.5 Median Pollutant Removal (%) of Stormwater Treatment Practices for Possible Use in Impaired Waters						
BMP Group	Impaired Waters					
	TSS	TN	Hydro-carbons	Bacteria[4]	Metals	
					Cu	Zn
Bioretention[1]	85[3]	45	80[3]	N/A	95	95
Filtration[2]	85	35	80[1]	35[2]	45	85
Infiltration	95[1]	50	N/A	N/A	N/A	95+[1]
Stormwater Ponds	80	30	80[1]	70	55	65
Constructed Wetlands	75	30	85[1]	75[1]	40	40

Source: Winer, 2000
[1] Data based on fewer than five monitoring studies
[2] Excludes vertical sand filters and filter strips
[3] Filtration values used.
[4] Bacteria data include fecal streptococci, enterococci, fecal coliform, E. coli, and total coliform
NOTES: N/A indicates that no data available
TSS = Total Suspended Solids
TN = Total Nitrogen
Cu = Copper
Zn = Zinc

investigations needed. Reference is also made to a Chapter 13 discussion of karst features.

- **Does the site have exposed bedrock or shallow soils?**
Portions of the State have exposed bedrock or extremely shallow soils that may preclude the use of some BMPs. For example, infiltration practices may be impractical in shallow soils due to the limited soil separation distance between the bottom of the practice and bedrock. Other BMPs, such as ponds and wetlands may be feasible, but may be more difficult or costly to design and construct (e.g., may require liners to prevent rapid drawdown).

- **Will the site experience high snowfall or require melt water treatment?**
Table 7.6 presents guidance on how to choose BMPs for high snowfall areas that can withstand snow and ice cover (consult Figure 2.5 in Chapter 2 to check if your development site is within this zone). Frozen conditions will inhibit performance throughout the winter and generate a significant volume of melt water and pollutant loads in the spring.

- **Is the site located in a region with low annual rainfall?**
Development sites in the southwest part of the State get much less annual rainfall, which plays a strong role in BMP selection. Frequent rainfall is often important to maintain water balance in ponds and wetlands. BMP function could decline when there is not enough runoff to sustain a normal pool elevation.

VII. Evaluate Stormwater Treatment Suitability

Not all BMPs work over the wide range of storm events that need to be managed at a site. Designers first need to determine which of the recommended unified sizing criteria apply to the development site (i.e., recharge, water quality, channel protection, peak discharge), and then

Table 7.6 Climate, Terrain, and Soil Factors

BMP		Karst	Bedrock and Shallow Soils	High Snowfall - Meltwater Treatment	Low Rainfall
Bioretention	Infiltration	NOT RECOMMENDED Extensive pre-treatment required.	NOT RECOMMENDED due to separation distance	OK Use salt-tolerant vegetation and pre-treatment. Chlorides will move through untreated.	OK Use appropriate vegetation.
	Under-drain	OK Use under-drain and impermeable liner.	RECOMMENDED Use under-drain.		
Filtration		OK Use Impermeable Liner	RECOMMENDED	OK Place below frost line. Use pre-treatment. Chlorides will move through untreated.	RECOMMENDED
Infiltration		NOT RECOMMENDED Extensive pre-treatment required.	LIMITED Due to minimum separation requirement.	OK BUT COULD BE LIMITED Active management needed to prevent infiltration of chlorides and soluble toxics.	RECOMMENDED
Stormwater Ponds		OK Use impermeable liner; limit depth; geotechnical investigation needed.	LIMITED Due to available depth and large surface area requirement.	RECOMMENDED Limit depth to avoid stratification. Adapt outlet structure.	LIMITED Water budget calculations may show this to be unsuitable.
Constructed Wetlands		OK Use impermeable liner; limit depth; geotechnical investigation needed.	OK Large surface area.	OK Use salt-tolerant vegetation	LIMITED Water budget calculations may show this to be unsuitable.

choose the type or combination of BMPs from Table 7.7 that can achieve them.

This is the stage in BMP selection process where designers often find that a single BMP may not satisfy all stormwater treatment requirements. The alternative is to use a combination of BMPs arranged in a series or treatment train, or add supplemental practices to the primary BMP that provide additional pre- or post-treatment.

► **Can the BMP provide ground water recharge?**
BMPs that infiltrate runoff into the soil are needed when a site is subject to a recharge requirement. If infiltration is impractical, designers may want to use some of the better site design techniques profiled in Table 7.1 to make up the difference and provide full treatment.

<table>
<tr><th colspan="7">Table 7.7 Stormwater Treatment Suitability</th></tr>
<tr><th colspan="2">BMP Group</th><th>Recharge</th><th>Water Quality</th><th>Channel Protection</th><th>Peak Discharge</th><th>Hot Spot Runoff</th></tr>
<tr><td colspan="2">Bioretention</td><td>Varies</td><td>Yes</td><td>Possible[4]</td><td>No</td><td>Yes
Needs under-drain</td></tr>
<tr><td rowspan="2">Filtration</td><td>Media</td><td>No</td><td rowspan="2">Yes</td><td>No</td><td rowspan="2">No</td><td rowspan="2">Yes</td></tr>
<tr><td>Vegetative</td><td>Varies[1]</td><td>Possible[4]</td></tr>
<tr><td rowspan="2">Infiltration</td><td>Trench</td><td rowspan="2">Yes</td><td rowspan="2">Yes</td><td>No</td><td>No</td><td rowspan="2">No</td></tr>
<tr><td>Basin</td><td>Yes</td><td>Yes</td></tr>
<tr><td colspan="2">Stormwater Ponds</td><td>No[2]</td><td>Yes</td><td>Yes</td><td>Yes</td><td>Yes</td></tr>
<tr><td colspan="2">Constructed Wetlands</td><td>Varies[2]</td><td>Yes</td><td>Yes</td><td>Yes</td><td>Yes
Needs Pre-treatment</td></tr>
<tr><td colspan="2">Supplemental BMPs</td><td>Varies</td><td>No[3]</td><td>Possible[4]</td><td>No</td><td>No[3]</td></tr>
<tr><td colspan="7">[1] May be provided by infiltration
[2] When impermeable liners are required or pool intercepts ground water
[3] Can be included as part of the treatment train.
[4] Can be incorporated into the structural control in certain situations</td></tr>
</table>

- **Can the BMP treat the water quality volume?**
  All of the BMPs in this Manual, with the exception of supplemental BMPs, can meet the water quality volume (Vwq) requirement stipulated in construction general permit, so this is seldom a major factor in BMP selection.

- **Can the BMP provide channel protection?**
  BMPs must provide extended detention for long periods at sites where channel protection (Vcp) is required to protect streams, which means that only a short list of BMPs can meet this criterion (see Table 7.7). BMPs that cannot meet the channel protection requirement as stand alone practices should not be discarded, as they may still be needed to meet other sizing criteria (e.g., water quality).

- **Can the BMP effectively control peak discharges from overbank floods?**
  Generally, only ponds, wetlands and infiltration basins have the capacity to control peak discharge events that cause flooding at the site (e.g., Vp10 and Vp100 storm events). Once again, if a BMP cannot meet peak discharge requirements, it can be used in combination with one that does to meet all sizing criteria.

- **Can the BMP accept runoff from potential stormwater hotspots (PSHs)?**
  Designers need to be careful choosing BMPs at sites designated as PSHs to minimize the risk of ground water contamination. BMPs that rely on infiltration should be avoided and other design modifications may be needed for other practices that send runoff into the soil (Table 7.7).

VIII. Assess Physical Feasibility at the Site

By this point, the list of possible BMPs has been narrowed and now physical factors at the site are assessed to whittle it down even further. Table 7.8 indicates eight physical factors at the site that can constrain, restrict or eliminate BMPs from further consideration.

- **Is there enough space available for the BMP at the site?**
  BMPs vary widely in the amount of surface area of the site they consume, which can be an important factor at intensively developed sites where space may be limiting and land prices are at a premium. In some instances, underground BMPs may be an attractive option in highly urban areas. Some general rules of thumb on BMP surface area needs are presented in Table 7.8, expressed in terms of contributing impervious area or total area.

- **Is the drainage area at the site suitable for the proposed BMP?**
  Table 7.8 shows the minimum or maximum recommended drainage areas for each group of BMPs. If the drainage area of the site exceeds the maximum, designers can always use multiple smaller BMPs of the same type, or modify the design. The minimum drainage area thresholds for ponds and wetlands are not quite as flexible, although smaller drainage areas can work if designers can confirm the presence of ground water or baseflow that can sustain a normal pool and incorporate design features to prevent clogging.

- **Will soils limit BMP options at the site?**
  Low infiltration rates limit or preclude the use of infiltration practices and certain kinds of bioretention designs. By contrast, soils with low infiltration rates are preferred for ponds and wetlands since they help to maintain permanent pools without need for a liner. Designers should consult the design guidance in Chapter 12 to determine minimum soil infiltration rates and testing procedures for each kind of BMP. Table 7.8 references USDA-NRCS Hydrologic Soil Groups A to D. Further geotechnical testing may be needed to confirm soil permeability and ground water depth.

- **Is enough head present at the site to drive the BMP?**
  Head is defined as the elevation difference between the inflow and outflow point of a BMP that enables gravity to drive the BMP. BMP choices are constrained at flatter sites that have less than three or four feet of available head.

- **Will depth to bedrock or the water table constrain the proposed BMP?**
  Bioretention, infiltration and some filtering practices need a minimum separation distance from the bottom of the practice to bedrock (or the water table) to function properly. The Minnesota Pollution Control Agency's Construction General Permit (CGP) requires a minimum distance of three feet between the bottom of an infiltrating BMP and the seasonally saturated water table. Other BMPs do not require as much separation distance, although the cost and complexity of construction of most BMPs increases sharply at development sites where the bedrock or water table are close to the surface.

- **Is the slope at the proposed BMP site a design constraint?**
  Sites with extremely steep slopes can make it hard to locate suitable areas for BMPs. Table 7.8 outlines maximum slope recommendations for BMPs, which refers to the gradient where the BMP will actually be installed. Designers will need to carefully scrutinize site topographic and grading plans to find suitable locations, and if this does not work, the grading plan may need to be changed to meet slope thresholds.

- **Is the BMP suitable for ultra-urban sites?**
  BMP selection for ultra-urban development and redevelopment sites is challenging, since space is extremely limited, land is expensive, soils are disturbed, and runoff volumes and pollutant loadings are

Table 7.8 Physical Feasibility at the Site

BMP Group		Surface Area[1]	Drainage Area	Soils Infiltration Rate	Head	Separation from Bedrock	Depth to Seasonally High Water Table	Max. Slope[3]	Ultra-Urban
Bioretention		7-10% Min 200 ft^2	5 ac max 0.5-2 ac preferred	Any soil. Use under-drain in C, D [4]	4-6 ft	3 ft	3 ft	20%	Yes
Filtration	Media	Negligible, except for access	5 ac max 0.5-2 ac preferred	media part of design[4]	2-6 ft	0 ft if enclosed	3 ft for vegetated; 0 ft if enclosed	20%	Yes
Filtration	Vegetative	Varies based on depth	10 ac max	media part of design[4]	2-6 ft	0 ft if enclosed	3 ft for vegetated; 0 ft if enclosed	20%	Possible
Infiltration	Trench	Varies based on depth	5 to 10 ac max	Native soils with f>=0.2 in/hr	2-12 ft	3 ft	3 ft	15%	Possible
Infiltration	Basin	Varies based on depth	5-50 ac max	Native soils with f>=0.2 in/hr	2-12 ft	3 ft	3 ft	15%	No
Stormwater Ponds		1-3%	25 ac min[2]	A or B soils may require liner	3-10 ft	0 ft (shallow soil limits design)	0 ft (except if hotspot or aquifer)	25%	No
Constructed Wetlands		2-4%	25 ac min[2]	A or B soils may require liner	3-10 ft	0 ft	0 ft (except if hotspot or aquifer)	25%	No

[1] Surface area as a function of contributing impervious area, except for ponds and wetlands, where it is a function of entire drainage area.
[2] 10 acres may be feasible if ground water is intercepted and/or if water balance calculations indicate a wet pool can be sustained.
[3] Slope is defined as the slope across the proposed location of the practice
[4] Infiltration gallery could be designed to provide limited recharge

great. These sites do, however, present a great opportunity for making progress in stormwater management where it has not previously existed. Table 7.8 compares the general suitability of BMPs for ultra-urban sites.

IX. Investigate Community and Environmental Factors

Some BMPs can provide positive economic and environmental benefits for the community, while others can have drawbacks or create nuisances. Table 7.9 presents general guidance on how to choose the most economically and environmentally sustainable BMPs for the community. Readers should note that rankings in this table are fairly subjective, and may vary according to community perceptions and values. A poor score should not mean the BMP is discarded; rather, it signals that attention should be focused on improving that element of the BMP during the design phase.

- **Ease of Maintenance.** All BMPs require routine inspection and maintenance throughout their life cycle, although some are easier to maintain than others. This screening factor looks at each major BMP from the standpoint of the frequency and cost of scheduled maintenance, chronic maintenance problems, reported failure rates, and inspection needs. Designers should try to prevent or reduce maintenance problems during the design

Table 7.9 Community and Environmental Factors*						
BMP Group		**Ease of Maintenance**	**Community Acceptance**	**Construction Cost**	**Habitat Quality**	**Nuisances**
Bioretention		Medium	High	Medium	Medium	Mosquitoes Overgrown vegetation
Filtration	Media	Difficult	High	High	Low	Filter media replacement. Underground practices not seen, not maintained.
	Vegetative	Medium	Medium			
Infiltration	Trench	Difficult	High	High	Low	Susceptible to failure if poorly installed or maintained.
	Basin	Medium	Low	Medium		
Stormwater Ponds		Easy-Medium	Medium-High	Low	Medium	Geese, Odors Mosquitoes, Floatables
Constructed Wetlands		Medium	Medium-High	Medium	Medium	Overgrown vegetation. Mosquitoes
Supplemental BMPs	Hydro-dynamic Devices	Medium	High	High	Low	Underground practices not seen, not maintained.
	Filtration Devices	Difficult (expensive)	High	High	Low	Underground practices not seen, not maintained.

* Note that values in this table are fairly subjective and may differ according to local perceptions. Some adjustment might be needed.

phase for BMPs that are rated as difficult to maintain.

- **Community Acceptance.** Community acceptance involves a great deal of subjective perception, but a general sense can be gleaned from market surveys, reported nuisance problems, visual preference, and vegetative management. BMPs rated as having low or medium community acceptance can often be improved through better landscaping or more creative design. Note that while underground BMPs enjoy high community acceptance, this is solely due to the fact they are "out of sight, out of mind," which substantially reduces their ease of maintenance.

- **Construction Cost.** Table 7.9 presents a very general comparison of BMP construction costs, based on the average cost per impervious acre treated. More specific techniques to estimate construction and O&M costs for individual BMPs are provided in Chapter 6, Chapter 12, and Appendix D.

- **Habitat Quality.** BMPs have the potential to create aquatic and terrestrial habitat for wildlife and waterfowl, which can be an important community amenity. Potential habitat quality is ranked as low, medium or high depending on BMP-specific factors such as surface area, water and wetland features, vegetative cover, and buffers. Habitat quality is not automatic, and requires proper installation, landscaping, and vegetative management at the BMP.

- **Nuisances.** Nearly all BMPs can create nuisance conditions, particularly if they are poorly designed or maintained. BMP nuisances reduce community acceptance and generate complaints, but seldom affect the pollutant removal performance of the BMP. Common nuisances include mosquitoes, geese, overgrown vegetation, floatable debris and odors. A more expanded discussion on design considerations to manage mosquitoes is provided in Chapter 6. If a BMP is prone to nuisance conditions, designers should focus attention on preventing or minimizing the problem. For example, distance to residences could be a factor in determining the impact of mosquito breeding, so an analysis of BMP placement relative to residences could result in some impact mitigation.

X. Determine any Site Restrictions and Setbacks

The last step in BMP selection checks to see if any environmental resources or infrastructure are present that will influence where a BMP can be located on the site (i.e., setback or similar restriction). Table 7.10 presents an overview of ten site-specific conditions that impact where a BMP can be located on a site. A more extensive discussion of the relevant Minnesota rules and regulations that influence BMP design can be found in Chapter 5 and Appendix G.

XI. References

Caraco, D. 2001. "Managing Phosphorus Inputs Into Lakes III: Evaluating the Impact of Watershed Treatment." Watershed Protection Techniques. 3 (4): 791-796. Center for Watershed Protection. Ellicott City, MD.

Maryland Department of the Environment (MDE). 2000. 2000 Maryland Stormwater Design Manual. MDE. Baltimore, MD.

Walker Jr., W. W., 2000. P8 Urban Catchment Modal (Version 2.4), IEP, Inc. and Narragansett Bay Project USEPA/RIDEM. http://wwwalker.net/p8/

Winer, R. 2000. National Pollutant Removal Performance Database for Stormwater Treatment Practices. 2nd Edition. Center for Watershed Protection. Ellicott City, MD.

Table 7.10 Location-Specific Restrictions and Setbacks	
Factor	**Considerations**
Jurisdictional Wetland U.S Army Corps of Engineers (USACE) Section 404 Permit Minnesota Department of Natural Resources Public Waters Permit Minnesota Pollution Control Agency 401 Water Quality Certification and NPDES Permit Local Governments Under the Wetland Conservation Act	► Wetlands should be delineated prior to siting stormwater BMPs ► Demonstrate that the impact to a wetland complies with all of the following principles in descending order of priority: avoid direct or indirect impacts, minimize impact by limiting the degree or magnitude of activity, mitigate unavoidable impacts through restoration or creation. ► Always check with local, state and federal jurisdictions for appropriate regulations. ► Natural wetlands should not be used for stormwater treatment, unless they are severely impaired, and construction would enhance or restore wetland functions. ► Direct pipe outfalls to wetlands should be restricted. The discharge of untreated stormwater to a wetland should be avoided. ► BMPs are restricted in the wetland buffer. ► For sensitive bogs and fens, BMPs should be designed for site-based nutrient load reduction.
Stream Channel U.S Army Corps of Engineers Section 404 Permit Minnesota Department of Natural Resources Public Waters Permit Minnesota Pollution Control Agency 401 Water Quality Certification and NPDES Permit	► All waterways (including streams, ponds, lakes, etc) should be delineated prior to design. ► Use of any Waters of the U.S. for stormwater quality treatment is contrary to the goals of the Clean Water Act and should be avoided. ► BMPs should not be placed on-line (in-stream) under most conditions. ► If in-stream BMPs are used, justification of no existing practical upland treatment alternatives must be made. Implement measures that reduce downstream warming. ► Activities such as excavation, shore protection, structures, dams, and water level controls are regulated. ► State water quality standards apply.
Shoreland Management DNR and Local Governments State Floodplain Management Act	► Check state and local shoreland development ordinances regarding BMP setbacks from the shoreline and any required buffers.
Stream Buffer	► Consult local authority for stormwater policy regarding buffers. ► Outstanding Resource Value Waters (ORVWs) require a 100-foot buffer. ► Structural BMPs are strongly discouraged in the stream-side zone (within 25 feet of streambank). BMP may be allowed within the outer portion of a buffer. ► Consider how the outfall channel will cross the buffer to the stream.

Table 7.10 Location-Specific Restrictions and Setbacks	
Factor	**Considerations**
Sinkholes (see also discussion in Chapter 13)	▶ Existing known sinkholes should be identified with a 100 foot buffer and delineated on site plans. ▶ Sinkholes should be remediated and stormwater directed away from these areas during and after construction. Whenever possible, discharges from BMPs or impervious surfaces should not be routed within 100 feet of the edge of any existing un-remediated sinkhole, and runoff should not be directed to an area underlain by known active karst conditions. ▶ Sinkholes occurring within BMPs should be repaired as soon as feasible after the first observation. ▶ BMPs should be designed off-line to limit volumes and flow rates managed by individual practices. Sinkhole formation is less likely when practices such as swales, bioretention, and vegetated filters are used.
100-year Floodplain	▶ Grading and fill for BMP construction is strongly discouraged within the ultimate 100-year floodplain, as delineated on FEMA flood insurance rate maps, FEMA flood boundary and floodway, or more stringent local maps. ▶ Floodplain fill cannot raise the 100-year water surface elevation by more than 0.5 feet (local regulations may be more stringent).
Water Wells (private and municipal)	▶ Observe local wellhead protection zones and minimum setbacks. ▶ Consult the Minnesota Department of Health (MDH), County health department and local water utility. ▶ Mn.Rule 4725.4350 requires a 50-foot setback between stormwater ponds and water supply wells ▶ If not otherwise regulated, a similar 50-foot setback for infiltration BMPs is advisable ▶ No infiltration of confirmed stormwater hotspot runoff. Infiltration of potential stormwater hotspot (PSH) runoff should be restricted and have suitable pre-treatment
Septic Systems	▶ Recommended setback is 35 feet minimum from a drain field. ▶ Consult the MDH and County health department.
Utilities	▶ Call **Gopher State One Call** (800-252-1166) to locate existing utilities prior to design. ▶ Consider the location of proposed utilities to serve the development. ▶ Structural controls are discouraged within utility easements or the right of way for public or private utilities.
Roads	▶ Consult local/county highway or public works department for any setback requirement from local/county roads. ▶ Consult Mn/DOT guidelines for setback from State roads. ▶ Approval may be needed to discharge stormwater to a local, county or state owned storm drain or channel.
Structures	▶ Consult the local review authority for the BMP setback from structures. ▶ Recommended setbacks for each BMP group are provided in Chapter 12 of this Manual.

Chapter 8

Hydrologic, Hydraulic, and Water Quality Evaluation Methods and Models

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VOLUME 2 - TECHNICAL AND ENGINEERING GUIDANCE

Chapter 8

Hydrologic, Hydraulic, & Water Quality Evaluation Methods & Models

This chapter provides an overview of computer models most frequently used to analyze the hydrology, hydraulics, and water quality factors for best management practices. It also includes recommendations for model input parameters.

Contents

I. Introduction

Purpose of Stormwater Modeling

The foundation of stormwater management is an understanding of how a particular land area and drainage system can affect, and can be affected by, the stormwater passing through it. In particular, when (or preferably before) alterations are made to the land area or drainage network, stormwater managers need to understand and anticipate how the alteration is likely to affect the volume, flow rate, and quality of runoff moving through the system, and in turn, how the stormwater is likely to impact the people, property, and natural resources of the area. Modeling is a tool that can be used to understand and evaluate complex processes.

Some kind of stormwater model is needed whenever an estimate of the expected volume, rate, or quality of stormwater is desired. Modeling is also often necessary for the design of BMPs and hydraulic structures and for evaluation of the effectiveness of water quality treatment by BMPs. If monitoring data exists for the specific combination of precipitation and site conditions under consideration, modeling may not be necessary. However, in many cases the conditions to be analyzed do not fit precisely with the conditions monitored in the past and modeling will be necessary.

In general, there are two types of models: physical and numerical. A physical model is a constructed replica of the system whereas a numerical model is based on equations that approximate the processes occurring in the system. Typically, it is not realistic to construct a physical model that would provide reliable hydrologic predictions for a watershed or drainage system, so numerical (nearly always computer-based) models are the standard tool for stormwater management.

Note that this Manual cannot possibly contain a thorough analysis of modeling. Instead, the purpose of this chapter is to introduce a stormwater manager to the terms of modeling and some cursory assessment of model calibration. Those interested in model details are encouraged to follow the links in Appendix B or to locate model manuals.

In practice, stormwater models are most commonly used either as planning and decision making aids for water management authorities, or as tools for developers who wish to design for and demonstrate compliance with regulations and principles governing protection of water and waterways. They are used, for example, to predict:

- water quality effects of various land management scenarios
- effects of water control structures on water surface elevations in a channel
- performance of stormwater management structures such as ponds, wetlands, trenches, etc.
- wetland impacts resulting from channel excavation
- lateral extents of a floodplain along a channel

These examples show some of the potential uses of modeling, but the list is by no means exhaustive. Modeling in general is a versatile tool that can be applied to any number of situations.

Types of Models

The most commonly used stormwater models can generally be classified as either hydrologic, hydraulic, or water quality models.

- Hydrologic models are used to estimate runoff volumes, peak flows, and the temporal distribution of runoff at a particular location resulting from a given precipitation record or event. Essentially, hydrologic models are used to predict how the site topography, soil characteristics, and land cover will cause runoff either to flow relatively unhindered through the system to a point of interest, or to be delayed or retained somewhere upstream. Many hydrologic models also include relatively simple procedures to route runoff hydrographs through storage areas or channels, and to combine hydrographs from multiple watersheds.

- Hydraulic models are used to predict the water surface elevations, energy grade lines, flow rates, velocities, and other flow characteristics throughout a drainage network that result from a given runoff hydrograph or steady flow input. Generally, the output (runoff) from a hydrologic model is used in one way or another as the input to a hydraulic model. The hydraulic model then uses various computational routines to route the runoff through the drainage network, which may include channels, pipes, control structures, and storage areas.

- Combined hydraulic and hydrologic models provide the functions of both hydraulic models and hydrologic models in one framework. A combined model takes the results from the hydrologic portion of the model and routes it through the hydraulic portion of the model to provide the desired estimates.

- Water quality models are used to evaluate the effectiveness of a BMP, simulate water quality conditions in a lake, stream, or wetland, and to estimate the loadings to water bodies. Often the goal is to evaluate how some external factor (such as a change in land use or land cover, the use of best management practices, or a change in lake internal loading) will affect water quality. Parameters that are frequently modeled include total phosphorus, total suspended solids, and dissolved oxygen.

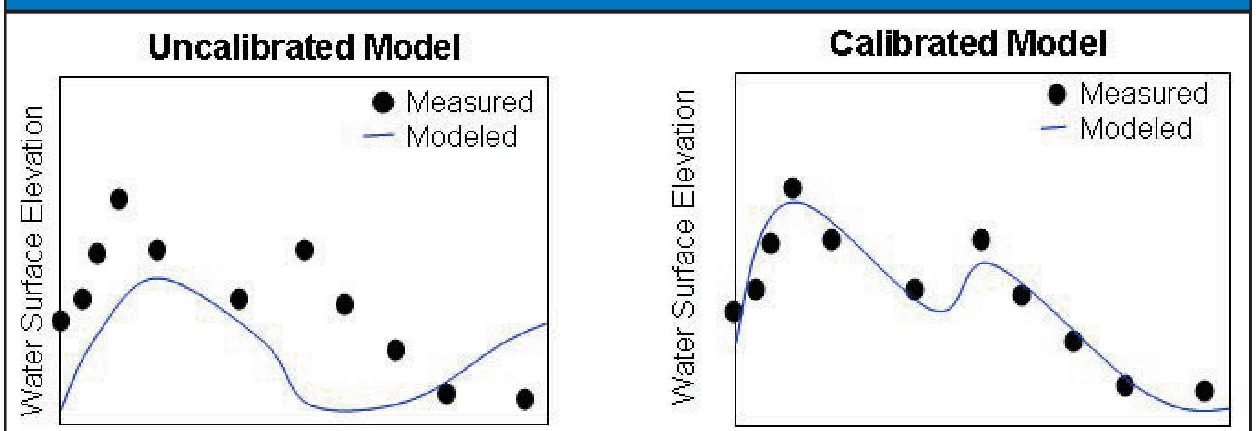
Limitations of Modeling and the Importance of Calibration

Hydrologic, hydraulic, and water quality models are not exact simulations of the processes occurring in nature. Rather, they are approximate representations of natural processes based on a set of equations simplifying the system and making use of estimated or measured data. The accuracy of a model, therefore, is limited by the quality of the simplifications made to approximate the system processes and the quality of the input data. In some cases, the impact of these limitations can be reduced by using a more complex model or paying to acquire more or better input data. However, it is also important to recognize that oftentimes, it is simply not possible to significantly increase accuracy with such means, because the necessary computational and data collection technology does not exist, and in any case the climatic forces driving the simulation can only be roughly predicted. There also could be time and funding constraints.

Recognizing the high degree of error or uncertainty inherent in many aspects of stormwater modeling can help to focus efforts where they do the most good. Generally, the goal of stormwater modeling is to provide a reasonable prediction of the way a system will respond to a given set of conditions. The modeling goal may be to precisely predict this response or to compare the relative difference in response between a number of scenarios. The best way to verify that a model fulfills this need (to the required degree of accuracy) is to check it against actual monitoring data or observations (Figure 8.1).

The process of model calibration involves changing the estimated input variables so that the output variables match well with observed results under similar conditions. The process of checking the model against actual data can vary greatly in complexity, depending on the confidence needed and the amount of data available. In some cases,

Figure 8.1 Importance of Model Calibration



the only feasible or necessary action may be a simple "reality check," using one or two data points to verify that the model is at least providing results that fall within the proper range. In other cases, it may be necessary to perform a detailed model calibration, to ensure the highest possible accuracy for the output data. For some models, calibration is unnecessary due to the design of the model.

Calibration should not result in the use of model parameters that are outside a reasonable range. Additionally, models should not be calibrated to fit so tightly with observed data that the model loses its flexibility to make estimates under other climatic conditions.

II. Selecting a Stormwater Modeling Tool

Hydrologic, hydraulic, and water quality models all have different purposes and will provide different information. Table 8.1 summarizes some of the commonly used modeling software and modeling techniques and the main purpose for which they were developed. The table shows the relative levels of complexity of necessary input data, indicates whether the model can complete a continuous analysis or is event based, and lists whether the model is in the public domain. For hydraulic models, Table 8.1 indicates whether unsteady flow calculations can be conducted. For water quality models, the table indicates whether the model is a receiving waters model, a loading model, or a BMP analysis model.

The selection of a stormwater modeling tool is based on the modeling objectives and on the available resources. When evaluating the modeling objectives, the modeler should consider:

- the type of information desired from the modeling effort.
- the specific conditions to be modeled.
- the required level of accuracy and reliability of the model.
- the further use of the model and model results.

For example, estimating peak runoff rates is a different problem than estimating the peak elevation of a water body and could require the use of a different model. A model able to estimate phosphorus loading from a network of detention ponds may not be able to model the phosphorus loading from an infiltration pond.

When evaluating the resources available, the modeler should consider:

- the general limitations of modeling which include imperfect approximations of natural processes, uncertainty and variability in results, and uncertainty and error in the input parameters.
- availability of existing models used for site analysis.
- familiarity with the specific model.
- modeling expertise available.

III. Minnesota Model Input Guide

Chapter 10, Unified Stormwater System Sizing Criteria, outlines recommendations for sizing best management practices. The following sources of information will allow designers to use the above referenced models for estimating hydrologic, hydraulic, or water quality parameters.

Data Resources

Precipitation

The most commonly referenced precipitation frequency study in Minnesota is the U.S. Weather Bureau's 1961 Technical Publication 40 (TP-40, Hershfield, 1961). Despite potential doubts regarding the adequacy of TP-40, which is viewed by some as outdated and not reflective of recent climate trends, use of newer studies has not taken hold. As a result, TP-40 remains the dominant source for Minnesota precipitation magnitude and return frequency (see also Issue Paper B in Appendix J).

Isopluvial maps showing precipitation depths corresponding to the following 24-hour return events over the entire state are included in TP-40 and reproduced in Appendix B of this Manual:

- 1-Year design storm
- 2-Year design storm
- 5-Year design storm
- 10-Year design storm
- 25-Year design storm
- 100-Year design storm

Table 8.1 Modeling Tool Selection					
Model or Tool*	**Input Complexity**	**Continuous Modeling**	**Public Domain**	**Unsteady Flow**	**Type of Water Quality Model**
Rainfall-Runoff Calculation Tools	*peak flow, runoff volume, and/or event hydrograph calculations only*				
TR-55 (original or DOS)	Low	No	Yes	--	--
Rational Method (equation)	Low	No	Yes	--	--
Hydrologic Models	*rainfall-runoff simulation, reservoir & channel routing*				
HEC-1	Medium	No	Yes	--	--
HEC-HMS	Medium	Yes	Yes	--	--
WinTR-20 (or TR-20)	Medium	No	Yes	--	--
WinTR-55	Low	No	Yes	--	--
HydroCAD	Medium	No	No	--	--
Hydraulic Models	*water surface profile determination along waterways & through structures*				
HEC-RAS	Medium	Yes	Yes	Yes	--
HEC-2	Medium	No	Yes	No	--
WSPRO	Medium	No	Yes	No	--
CULVERTMASTER	Low	No	No	No	--
FLOWMASTER	Low	No	No	No	--
Combined Hydraulic & Hydrologic Models	*rainfall-runoff results automatically input into hydraulic calculation module*				
PondPack	Medium	No	No	No	--
EPA-SWMM	Medium / High	Yes	Yes	Yes	--
XP-, PC-, MIKE- SWMM	Medium / High	Yes	No	Yes	--
Water Quality Models					
SLAMM	Medium	Yes	No	--	Loading
P8	Medium	Yes	Yes	--	BMP, Loading
BASINS **					
QUAL2E/QUAL2K	Medium	No	Yes	--	Receiving Waters
WinHSPF	High	Yes	Yes	--	Receiving Waters
SWAT	Medium / High	Yes / No	Yes	--	Loading
PLOAD	Low	No	Yes	--	Loading
PondNet	Low	No	Yes	--	BMP, Loading
WiLMS	Low	No	Yes	--	Receiving Waters
Bathtub	Medium	No	Yes	--	Receiving Waters
WASP	High	Yes	Yes	--	Receiving Waters
EPA-SWMM	Medium / High	Yes	Yes	--	Loading
XP-SWMM	Medium / High	Yes	No	--	Loading

*Further information on each of the above models is available in Appendix B
** BASINS is a group of models, with each of the model having different characteristics

Design engineers typically make use of precipitation excedence probability to calculate the risks of design failure for channel protection, over-bank flooding, and extreme flooding. A storm magnitude of a return period (T) has the probability of being equaled or exceeded in any given year is equal to 1/T. For example a “100-year” event at a given location has a chance of 1/100 or 0.01 or 1% of being equaled or exceeded in *any* given year.

The complete TP-40 document is available on line through the National Weather Service Web site at: http://www.nws.noaa.gov/ohd/hdsc/temp_currentpf.htm#TP40 .

More recent work by others to update, test and/or validate the TP-40 findings include precipitation frequency studies conducted by the Midwest Climate Center (Huff and Angels’ 1992 Bulletin 71), Metropolitan Council’s Precipitation Frequency Analysis for the Twin Cities Metropolitan Area (study updates in 1984, 1989, and 1995), and Mn/DOT’s November 1998 study (Intensity of Extreme Rainfall over Minnesota) in coordination with Richard Skaggs from the University of Minnesota.

In addition to the frequency analysis studies, an impressive source of historical (and current) precipitation data and other climate data for Minnesota exists at the Minnesota Climatology Working Group Web site at: http://www.climate.umn.edu/.

Climate Trends

According to Dr. Mark Seeley, University of Minnesota, sufficient data exist to support recently observed trends of climate change in Minnesota. Notable changes over the last 30 years include:

- warmer winters.
- higher minimum temperatures.
- increased frequency of tropical dew points.
- greater annual precipitation with:
  - more snowfall.
  - more frequent heavy rainstorm events.
  - more days with rain.

The increasing precipitation and snowfall trends suggest the need for an updated Minnesota precipitation study.

Topographic Data

General topographic information can be obtained from USGS topographic maps. The USGS topographic maps display topographic information as well as the location of roads, lakes, rivers, buildings, and urban land use. Paper or digital maps can be purchased from local vendors or ordered on the USGS Web site: http://store.usgs.gov/. Counties often have more detailed topographic information available in a format suitable for use in GIS. Additionally, topographic data suitable for GIS use for the metro area and statewide may be available from MetroGIS http://www.datafinder.org/index.asp, and the DNR: http://deli.dnr.state.mn.us/data_catalog.html. To acquire detailed topographic data for a site, a local survey may need to be completed. Appendix A contains a general elevation map for Minnesota.

Soils / Surficial Geology

Data on soils can be obtained from county soil surveys completed by the USDA Natural Resources Conservation Service (NRCS). These reports describe each soil type in detail and include maps showing the soil type present at any given location. A list of soil surveys available for Minnesota can be found on the NRCS Web site: http://soils.usda.gov/survey/printed_surveys/minnesota.html. Soils information could also be obtained by conducting an onsite soil survey, by conducting soil borings, and by evaluating well logs. Other sources of soils information (for example, dominant soil orders as shown in Appendix A) may be found in this list from the Land Management Information Center, http://www.lmic.state.mn.us/chouse/soil.html, from the DNR http://deli.dnr.state.mn.us/data_catalog.html, or from MetroGIS http://www.datafinder.org/index.asp.

Land Cover / Land Use

Land cover and land use information (see example in Appendix A) can be obtained from the local planning agency such as the county or city of interest but may also be available in the sources listed by the Land Management Information Center http://www.lmic.state.mn.us/chouse/land_use.html, the DNR http://deli.dnr.state.mn.us/data_catalog.html, and MetroGIS http://www.datafinder.org/index.asp.

Monitoring Data

Monitoring data can be used as model input and for model calibration. Data on lake levels, ground water levels, stream flow, and water quality can be obtained from local monitoring studies or from such agencies as the Department of Natural Resources (DNR) http://www.dnr.state.mn.us/lakefind/index.html, United States Geologic Survey (USGS) http://www.usgs.gov/state/state.asp?State=MN,, Minnesota Pollution Control Agency (MPCA) http://www.pca.state.mn.us/data/edaWater/index.cfm, and the Metropolitan Council for the Twin Cities metro area http://www.metrocouncil.org/environment/Riverslakes/.

Input Guidance

Rainfall Distribution

Storm distribution is a measure of how the intensity of rainfall varies over a given period of time. For example, in a given 24 hour period, a certain amount of rainfall is measured. Rainfall distribution describes where that rain fell over that 24 hour period; that is, whether the precipitation occurred over a one hour period or over the entire 24 hours.

The standard rainfall distribution used for urban areas in Minnesota for sizing and evaluation of BMPs (Chapter 10) is the Natural Resource Conservation Service's (NRCS) recommended SCS Type II rainfall distribution for urban areas. This is a synthetic event, created by the SCS (now the NRCS), of a 24-hour duration rainfall event in which the peak intensity falls in the center of the event (at 12 hours).

The advantage of using the synthetic event is that it is appropriate for determining both peak runoff rate and runoff volume. Drawbacks of using a synthetic event are that they rarely occur in nature and are difficult to explain. Observed precipitation data can be used if analysis with a natural distribution is desired.

Further information regarding rainfall distribution can be found in the Minnesota Department of Transportation's *Drainage Manual* and in the *Hydrology Guide for Minnesota* prepared by the Soil Conservation Service (now the NRCS).

Water Quality Event

Small storms are often the focus of water quality analysis because research has shown that pollution migration associated with frequently occurring events accounts for a large percentage of the annual load. This is because of the "first flush" phenomenon of early storm wash-off and the large number of events with frequent return intervals. Rain events between 0.5 inches and 1.5 inches are responsible for about 75% of runoff pollutant discharges (MPCA, 2000).

The rainfall depth corresponding to 90% and 95% of the annual total rainfall depth shows surprising consistency among six stations chosen to represent regional precipitation across the State. The six stations analyzed were Minneapolis/St. Paul International Airport, St. Cloud Airport, Rochester Airport, Cloquet, Itasca, and the Lamberton SW Experiment Station. The rainfall depth which represents 90% and 95% of runoff producing events was 1.09 inches (+/- 0.04 inches) and 1.46 inches (+/- 0.08 inches), respectively. This rainfall depth can be used for water quality analysis throughout the state.

Larger events such as the spring snowmelt, however, can be the single largest water and pollutant loading event in the year. In Minnesota, this spring snowmelt occurs over a comparatively short period of time (i.e., approximately two weeks) in March or April of each year – depending on the region of the state. The large flow volume during this event may be the critical water quality design event in much of the state. See Chapter 2 for a further discussion of snowmelt runoff variation across the state and Chapter 9 for the problems associated with snowmelt.

Technical Bulletin 333: Climate of Minnesota (Kuehnast, 1982) (http://www.climate.umn.edu/pdf/climate_of_minnesota/comXIII.pdf) shows that the average annual date of snowmelt can be represented by the last date of a 3 inch snow cover. This document also includes figures that allow estimation of the average depth of snowpack at the start of spring snowmelt plus the water content of the snowpack during the month of March (see also Chapter 2).

The estimated infiltration volume can be determined from research in cold climates by Baker (1997), Buttle and Xu (1988), Bengtsson (1981), Dunne and Black (1971), Granger *et al.*

(1984) and Novotny (1988). This research shows that infiltration does in fact occur during a melt at volumes that vary considerably depending upon multiple factors including: moisture content of the snow pack, soil moisture content at the time the soil froze, plowing, sublimation, vegetative cover, soil properties, and other snowpack features. For example, snowmelt investigations by Granger *et al*. (1984) (see Chapter 2, Figure 2.7) took measurements from 90 sites, located in Saskatchewan Canada, representing a wide range of land use, soil textures, and climatic conditions. From this work, general findings showed that even under conservative conditions (wet soils, ~35% moisture content, at the time of freeze) about 0.4 inches of water infiltrated during the melt period from a one-foot snowpack with a 10% moisture content (1.2 inches of equivalent moisture) in areas with pervious cover. This would not apply to impervious surfaces.

The average snowmelt volume can then be estimated using the equation below (see Chapter 2, Figures 2.6 and 2.7 for input variables):

$$\begin{array}{c} \text{Average} \\ \text{snowmelt} \\ \text{volume} \\ \text{(depth/unit area)} \end{array} = \begin{array}{c} \text{Average snow pack} \\ \text{depth at the} \\ \text{initiation of the} \\ \text{snowmelt period} \end{array} \times \begin{array}{c} \text{Typical snow} \\ \text{pack water} \\ \text{equivalent at} \\ \text{time of melt} \end{array} - \begin{array}{c} \text{Estimated infiltration} \\ \text{volume likely} \\ \text{during a 10-day} \\ \text{melt period} \end{array}$$

Other procedures for estimating water quality treatment volume based on annual snow depth are described by the Center for Watershed Protection (CWP) (Caraco and Claytor, 1997), which is available as a free download from the CWP Web page at http://www.cwp.org/cold-climates.htm.

More snowfall and snowmelt data can be found in the following report sponsored by the Minnesota Department of Transportation: http://www.climate.umn.edu/snow_fence/Components/SWE/marswe.htm#

For purposes of determining the volume of runoff or snowmelt that should be managed by the site BMPs, designers must make two water quality volume computations: snowmelt and rainfall runoff. The BMP would then be sized for the larger of the two results. Areas with low snowfall will likely find that the rainfall based computations are the larger value, while those areas with greater snowpack will find that snowmelt is larger.

In some cases snowmelt would be selected as the design parameter for computing the volume, whereas other options lead to rainfall as the critical design parameter. More discussion on the various options for selection criteria is contained in Chapter 10, Unified Stormwater System Sizing Criteria.

Extreme Flood Events

Because a spring melt event generates a large volume of water over an extended period of time, evaluation of the snowmelt event for channel protection and over-bank flood protection is generally not as important as the extreme event analysis. This warrants attention because of the possibility that a major melt flooding event could, and sometimes does, happen somewhere in the state.

Conservative design for extreme storms can be driven by either a peak rate or volume event depending upon multiple hydraulic factors. Therefore, depending upon the situation, either the 100-yr, 24-hr rain event or the 100-yr, 10-day snowmelt runoff event can result in more extreme conditions. For this reason, both events should be analyzed. Chapter 9 contains further discussion of the need for special design considerations for snowmelt.

Protocol for simulation of the 100-yr, 24-hr rainfall event is well established in Minnesota. High water elevations (HWL) and peak discharge rates are computed with storm magnitudes based on TP-40 frequency analysis and the SCS Type II storm distribution.

Protocol has been established for the analysis of HWL and peak discharge resulting from a 7.2 inch 100-yr, 10-day snowmelt runoff event. However, this event has received a considerable amount

Table 8.2 Runoff Coefficients for 5- to 10-Year Storms* (Source: Haan et al., 1994)

Land Use Description	Runoff Coefficient
Forest*	
< 5% slope	0.30
5% - 10% slope	0.35
> 10% slope	0.50
Open Space	
< 2% slope	0.05 – 0.10
2% - 7% slope	0.10 – 0.15
> 7% slope	0.15 – 0.20
Industrial	0.50 – 0.90
Residential	
Multi-Family	0.40 – 0.75
Single Family	0.30 – 0.50
Impervious Areas	0.7 – 0.95
Row Crops**	
< 5% slope	0.50
5% - 10% slope	0.60
> 10% slope	0.72
Pasture*	
< 5% slope	0.30
5% - 10% slope	0.36
> 10% slope	0.42

*For use in the Rational Method (see Appendix B for use of the Rational Method

**For clay and silt loam soils

of criticism. Although not well documented, it is thought that the theoretical snowmelt event was devised by assuming a six inch 100-yr, 24-hr rainfall event occurs during a 10-day melt period in which one foot of snow (with a 10% moisture content) exists at the onset. A typical assumption accompanying the event is that of completely frozen ground (no infiltration) during the melt period for which the result is 100% delivery of volumes. So what do we use? Climate records show that the highest rain event during this common melt period over the past 100+ years was 4.75 inches. An alternative method to consider is to add 4.75 inches of precipitation to the site's snowmelt volume (including infiltration). Designers should compare this to the 7.2 inch, 10-day snowmelt volumes and then determine which is best for the site.

Protocols for computation of extreme snowmelt events should be established as part of a state-wide precipitation study that has been discussed to update TP-40.

Runoff Coefficient

The Rational Method is used to estimate peak runoff rates for very small sites. The simple equation for peak discharge is $Q=C_iA$.Table 8.2 gives runoff coefficient (*C)* values for use in the Rational Method with, *i* in inches per hour, *A* in acres, and *Q* in cfs. The chosen value of *C* must represent losses to infiltration, detention, and antecedent moisture conditions. Additionally, *C* varies with the frequency of the rainfall event.

Curve Numbers

Curve numbers are used in the SCS Method to represent the runoff expected after initial abstractions and infiltration into the soil. Curve numbers are based on land use and hydrologic soil group. The SCS (now the NRCS) developed tables with curve numbers appropriate for urban, agricultural, arid and semiarid rangeland, and undisturbed land uses. Hydrologic soil group can be determined from soil surveys. Curve number tables are published in TR-55: Urban Hydrology for Small Watersheds (ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf) but are also available in textbooks and within modeling software. Curve numbers vary for smaller storms (see discussion in SLAMM documentation: http://www.unix.eng.ua.edu/~rpitt/SLAMMDETPOND/WinSlamm/Ch2/Ch2.html.) A short summary of some more commonly used curve numbers is given in Table 8.4.

The selection of appropriate curve numbers is of great importance when using the SCS Method. Sizing of facilities and comparisons of existing or pre-development conditions to proposed developed conditions can depend highly on the selected curve numbers. MPCA uses the land

What is the Pre-Development Condition?

When a requirement exists to match runoff rate or volume to "pre-development conditions," there is a range of options that could be applied to define land cover conditions. This range goes from pre-settlement, which assumes land is in an undeveloped condition, to the land use condition immediately prior to the project being considered, which assumes some level of disturbance in the natural landscape has already occurred. Interpretations of this variation from Scott County, Project NEMO, Dane County (WI), and the USDA-NRCS were used to lay out the range of approaches that local units can use when applying this criterion.

Pre-Settlement Conditions

The most conservative assumption for pre-development conditions is the assumption that the land has undergone essentially no change since before settlement. In this case, a meadow or woodland in good condition is commonly used to portray a "natural" condition. Table 8.3 shows the curve numbers used when this situation is applied using TR-55. Similar hydrologic characteristics would be applied when using other models

Table 8.3 Curve Number for Use with Pre-Settlement Conditions

	Runoff Curve Number*	
Hydrologic Soil Group (HSG)	**Meadow**	**Woods**
A	30	20
B	58	55
C	71	70
D	78	77

* Curve numbers from USDA-NRCS, Technical Release 55

Conditions Immediately Preceding Development

On the other end of the pre-development definition is the assumption that land disturbance has previously occurred with the land use in place at project initiation. This is the definition used by the MPCA in the Construction General Permit (CGP). Under this scenario, runoff assumptions after construction need to match those of the land use prior to the development using matching curve numbers or runoff coefficients. The new project could possibly improve runoff conditions, if the prior land use did not accommodate any runoff management. That is, implementation of good runoff management to an area that had previously developed without it would likely reduce total runoff amount compared to existing development.

The immediately preceding definition could include agricultural activity. Heavily disturbed agricultural sites should be lowered one permeability class for hydrologic calculations to account for the compaction that likely occurred. Lightly disturbed areas require no modification. Where practices have been implemented to restore soil structure, no permeability class modification is recommended.

Table 8.4 Curve Numbers for Antecedent Moisture Condition II (Source: NRCS)

Land Use Description	Hydrologic Soil Group			
	A	B	C	D
Meadow				
Good condition	30	58	71	78
Forest				
Poor	45	66	77	83
Fair	36	60	73	79
Good	30	55	70	77
Open Space				
Poor	68	79	86	89
Fair	49	69	79	84
Good	39	61	74	80
Commercial				
85% impervious	89	92	94	95
Industrial				
72% impervious	81	88	91	93
Residential				
1/8 ac lots (65% impervious)	77	85	90	92
1/4 ac lots (38% impervious)	61	75	83	87
1/2 ac lots (25% impervious)	54	70	80	85
1 acre lots (20% impervious)	51	68	79	84
Impervious Areas	98	98	98	98
Roads (including right of way)				
Paved	83	89	92	93
Gravel	76	85	89	91
Dirt	72	82	87	89
Row Crops				
Straight row – Good	67	78	85	89
Contoured row – Good	65	75	82	86
Pasture				
Good	39	61	74	80
Open Water	99	99	99	99

cover in place immediately before the proposed project as the “pre-development condition”. Many other regulators use a more natural condition to reflect change from pre-European settlement times (See box on previous page). The hydrologic soil group of the native soils should be used for pre-development conditions, but developed conditions may alter the soil condition by compaction, fill, or soil amendments. In the more conservative, natural definition of pre-development condition, land use would be meadow or woods in good condition as appropriate to the natural state of the site. Chapter 10 contains further discussion of the option for defining pre-development conditions. Special care should be taken to identify areas of soil group D and areas of open water as these areas have high

Table 8.5 Design Infiltration Rates*

Hydrologic Soil Group	Infiltration Rate [inches/hour]	Soil Textures	Corresponding Unified Soil Classification
A	1.63	Gravel, sandy gravel and silty gravels	**GW** - Well-graded gravels, sandy gravels **GP** – Gap-graded or uniform gravels, sandy gravels **GM** - Silty gravels, silty sandy gravels **SW** - Well-graded, gravelly sands
	0.8	Sand, loamy sand or sandy loam	**SP** - Gap-graded or uniform sands, gravelly sands
B	0.6	Silt loam	**SM** - Silty sands, silty gravelly sands
	0.3	Loam	**MH** – Micaceous silts, diatomaceous silts, volcanic ash
C	0.2	Sandy clay loam	**ML** - Silts, very fine sands, silty or clayey fine sands
D	< 0.2	Clay loam, silty clay loam, sandy clay, silty clay or clay	**GC** – Clayey gravels, clayey sandy gravels **SC** – Clayey sands, clayey gravelly sands **CL** – Low plasticity clays, sandy or silty clays **OL** – Organic silts and clays of low plasticity **CH** – Highly plastic clays and sandy clays **OH** – Organic silts and clays of high plasticity

*Thirty guidance manuals and many other stormwater references were reviewed to compile recommended infiltration rates. All of these sources use the following studies as the basis for their recommended infiltration rates: Rawls, Brakensiek and Saxton (1982); Rawls, Gimenez and Grossman (1998); Bouwer and Rice (1989); and *Urban Hydrology for Small Watersheds* (NRCS). The rates presented in this infiltration table use the information compiled from these sources as well as eight years of infiltration rates collected in various infiltration practices located in the Twin Cities metropolitan area.

levels of runoff. Care must also be taken when selecting curve numbers for agricultural land as its use can change considerably annually and even over the course of a season.

Antecedent Moisture Conditions

Antecedent moisture conditions (AMC) describe the moisture already present in the soil at the time of the rain event. AMC level I represents dry conditions, level II represents normal conditions, and level III represents wet conditions. Normal conditions are defined as 1.4 to 2.1 inches of rainfall in the growing season in the five days preceding the event of interest. Most evaluations of expected future site conditions use the curve numbers appropriate to AMC II. However, if the specific conditions of interest are expected to differ, curve numbers appropriate to AMC I or III should be used.

Infiltration Rates

Infiltration is the process of water entering the soil matrix. The rate of infiltration depends on soil properties, vegetation, and the slope of the surface, among other factors. Discussions of infiltration often include a discussion of hydraulic conductivity. Hydraulic conductivity is a measure of ease with which a fluid flows through the soil, but it is not the infiltration rate. The infiltration rate

Table 8.6 Infiltration Rates Observed in Infiltration Practices Operating in Minnesota

Source of Data	Range of Infiltration Rates [inches/ hour]	Number of Monitoring Sites	Brief Description of Site	Monitoring Dates
South Washington Watershed District	0.14 – 3.10*	1	Monitoring data collected at regional basin CD-P85.*	1999 - 2005
South Washington Watershed District	0.03 – 0.6	4	Monitoring data collected at 4 natural infiltration basins. Soils in the basins consist of silt loams underlain by sands and gravel interspersed with clayey-silty sediments.	1999 - 2005
South Washington Watershed District	0.02 – 5.0	1	Infiltration trench located at the Math and Science Academy in Woodbury, MN. In order to intersect more permeable material, trench is 15 feet deep for a portion of the practice. Underlying material is variable: till and sand/ gravelly sand. Trench receives pretreatment of stormwater prior to infiltration.	1999 - 2005
South Washington Watershed District	0.02 – 3.02	1	Infiltration trench located in regional basin CD-P85. These trenches are an average of 13 feet deep. Underlying material is sand and gravelly sand.	1999 - 2005
Rice Creek Watershed District	0.03 – 0.59	4	Monitoring data collected at 3 rain gardens and an infiltration island located at Hugo City Hall. Soils in the basins consist of silty fine sand with a shallow depth to the water table. Trench receives significant pretreatment of stormwater prior to infiltration.	2002 - 2003
Brown's Creek Watershed District	0.01 – 0.20	2	Monitoring data collected at two infiltration basins. Soils in the basins consist of silty sand and sandy silt interspersed with clayey sandy silt.	2000 - 2005
Field's of St. Croix, Lake Elmo, MN	0.02 - 0.14	3	Monitoring data collected at 3 infiltration basins located in a residential development. Soils in the basins consist of sandy loam and silt loam (HSG B).	2001 - 2003
Bradshaw Development, Stillwater, MN	0.26 – 0.28	1	Monitoring data collected in one infiltration basin located in a commercial development. Soils in the basin consist of silty sand.	2005

*The high end of this rage (3.1 iph) is not representative of typical rates for similar soil types. This facility is periodically subject to 25 foot depths of water, is underlain by more than 100 feet of pure sand and gravel without any confining beds and the depth to the water table is greater than 50 feet below the surface. In addition, two infiltration enhancement projects have been constructed in the bottom of the facility to promote infiltration: five dry wells and two infiltration trenches have been operating in CD-P85 at various periods of the monitoring program.

Table 8.7 Typical Event Mean Concentrations for Total Phosphorus

Land Cover/Land Use	Total Phosphorus (mg/L)
Cropland[1]	0.32
Forest/Shrub/ Grassland[1]	0.04
Open Water[1]	0.01
Wetlands[1]	0.01-0.04*
Freeways[2]	0.25
Commercial[1,2]	0.22
Farmsteads[1]	0.46
Industrial[1,2]	0.26
Residential[2]	0.30
Multi-Family Residential[1,2]	0.27-0.32
Park and Recreation[1]	0.04
Open Space[1,2]	0.31
Public/Semi Public (Institutional)[1,2]	0.18

[1] Minnehaha Creek Watershed District, 2003
[2] Robert Pitt *et al*., 2004
* Average for large wetlands and wetland complexes. Individual wetlands should be monitored to determine source/sink behavior.

Modeling Recommendations

Pre-development conditions land use can vary from land use composed of meadow or woods in good condition as appropriate to the natural state of the site to the condition of the site immediately preceding development.

Most evaluations of expected future site conditions should use the curve numbers appropriate to AMC II.

Event mean concentrations can range by an order of magnitude for a given land use, therefore, it is best to have local data for calibration purposes.

can be determined using the hydraulic conductivity through the use of the Green-Ampt equation. The Green-Ampt equation relates the infiltration rate as it changes over time to the hydraulic conductivity, the pressure head, the effective porosity, and the total porosity. Typical values used in the Green-Ampt equation can be found in Rawls, *et al.* (1983).

A simple estimate of infiltration rates can be made based on the hydrologic soil group or soil texture (Table 8.5). These infiltration rates represent the long-term infiltration capacity of a constructed infiltration practice and are not meant to exhibit the capacity of the soils in the natural state. The recommended design infiltration rates fit within the range of infiltration rates observed in infiltration practices operating in Minnesota (Table 8.6). The length of time a practice has been in operation, the location within the basin, the type of practice, localized soil conditions and observed hydraulic conditions all affect the infiltration rate measured at a given time and a given location within a practice. The range of rates summarized in Table 8.6 reflects the variation in infiltration rate based on these types of factors. Information on measuring infiltration rates and the use of the numbers presented in Table 8.5 can be found in the infiltration section in Chapter 12 of this manual.

Event Mean Concentrations

Event mean concentrations (EMCs) of a particular pollutant (i.e. total phosphorus, total suspended solids) are the expected concentration of that pollutant in a runoff event. Along with runoff volume, EMCs can be used to calculate the total load of a pollutant from a specific period of time. EMCs are frequently based on land use and land cover, with different predicted pollutant concentrations based on the land use and/or land cover of the modeled area. Table 8.7 lists EMCs for total phosphorus (TP) that were reported in Pitt *et al.* (2004). EMCs can range by an order of magnitude for a given land use, an it is therefore best to have site-specific or comparable local data for calibration purposes. The EMCs in the Pitt *et al*. study were from the National Stormwater Quality Database (NQSD, Version 1.1). Note also that

EMCs are concentration data, which are only part of the overall loading equation. Although some land uses might have a high EMC, for example open space at 0.27-0.31 mg/l, little runoff occurs from this land so overall phosphorus loading is low.

IV. References

Baker, J.M., 1997. Vanishing Ponds Not a Sure Sign of Spring. Agricultural Research, April, p.9.

Bengtsson, L., 1981. Snowmelt-Generated Runoff in Urban Areas. In Proceedings, Second International Conference on Urban Storm Drainage, Urbana, Illinois, June 14-19, 1981, pp.444-451.

Bouwer, H. and R. C. Rice. 1989. Effect of Water Depth in Ground-water Recharge Basins on Infiltration. Journal of Irrigation and Drainage Engineering, Vol. 115, No. 4, pp. 556-567.

Buttle, J.M. and F. Xu, 1988. Snowmelt Runoff in Suburban Environments. Nordic Hydrology, 19:19-40.

Caraco, D. and R. Claytor, 1997. Stormwater BMP Design Supplement for Cold Climates. Center for Watershed Protection, Ellicott City, Maryland.

Dunne, T. and R.D. Black, 1971. Runoff Processes during Snowmelt. Water Resources Research, 7(5): 1160-1172.

Granger, R.J., D.M. Gray and G.E. Dick, 1984. Snowmelt Infiltration to Frozen Soils. Canadian Journal of Earth Science, 21:669-677.

Haan, C., B. Barfield, J. Hayes, 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press, San Diego.

Hershfield, D.M., 1961. Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. U.S. Weather Bureau, Technical Publication 40.

Huff and Angels, 1992. Bulletin 71. Midwest Climate Center.

Metropolitan Council, 1995. Precipitation Frequency Analysis.

Minnehaha Creek Watershed District, 2003. Hydrologic, Hydraulic, and Pollutant Loading Study.

Minnesota Department of Transportation, Drainage Manual, 2000. http://www.dot.state.mn.us/bridge/Hydraulics-Internet-Web site/Hydraulics-Internet-DrainageManual.html

Minnesota Department of Transportation, 1998. Intensity of Extreme Rainfall over Minnesota.

Minnesota Pollution Control Agency, 2000. Protecting Water Quality in Urban Areas. Best Management Practices for Dealing with Storm Water Runoff from Urban, Suburban, and Developing Areas of Minnesota. St. Paul, MN.

Natural Resources Conservation Service, 1986. Urban Hydrology for Small Watersheds, Technical Release 55 (TR-55). ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

Natural Resources Conservation Service. 1975. Minnesota Hydrology Guide. http://www.mn.nrcs.usda.gov/technical/eng/pdf/mhgweb.pdf

Novotny, V., 1988. Modeling Urban Runoff Pollution during Winter and Off-Winter Periods. In Advances in Environmental Modeling, A. Marani (Editor), Elsevier Publishing, Amsterdam, pp.43-58.

Pitt, R., A. Maestre, and R. Morquecho, 2004. The National Stormwater Quality Database (NSQD, Version 1.1). Department of Civil and Environmental Engineering. University of Alabama, Tuscaloosa.

Rawls, W., D. Brakensiek, and N. Miller, 1983. Green-Ampt infiltration parameters from soils data. Journal of Hydraulic Engineering. Vol. 109, No. 1, pp. 62 – 70.

Rawls, W., D. Brakensiek, and K. Saxton, 1982. Estimation of Soil Water Properties. Transactions of the American Society of Agricultural Engineers. Vol. 25, No. 5, pp. 1316 – 1320 and 1328.

Rawls, W., D. Giminez, and R. Grossman, 1998. Use of Soil Texture, Bulk Density and Slope of water Retention Curve to Predict Saturated Hydraulic Conductivity. ASAE. Vol. 41(2), pp. 983 – 988.

Soil Conservation Service, 1975. Hydrology Guide for Minnesota.

Chapter 9

Cold Climate Impact on Runoff Management

VOLUME 2 - TECHNICAL AND ENGINEERING GUIDANCE

Chapter 9

Cold Climate Impact on Runoff Management

This chapter provides a summary of the considerations that should be made in adapting stormwater management practices to Minnesota's cold climate conditions.

It provides guidance on the following topics:

- ***cold climate BMP design adaptations***
- ***developing snow management plans***
- ***implementing a management sequence***
- ***providing effective pollutant removal and runoff control in winter***

Contents

I. Background

This section introduces national and international research and experience on stormwater practices maintained in cold climate regions, and presents principles for adapting BMPs to provide effective pollutant removal and runoff control during cold-weather months. It also introduces some recent findings from within Minnesota on the impact of climate change on stormwater and meltwater runoff. This information supplements information currently contained in **Chapter 5 of MPCA's Protecting Water Quality in Urban Areas (2000 update).**

Minnesota stormwater managers must recognize that runoff from snowmelt has characteristics different than those of rainfall runoff, and that BMP design criteria addressing only rainfall runoff might not work well during cold periods. This becomes a major problem because a substantial percentage of annual runoff volume and loading can come from snowmelt in years when snowfall is high.

An expanded discussion is contained in Issue Paper G in **Appendix J**.

II. Nature of the Cold Climate Problem

Hydrology of Melt

The heart of the problem with snowmelt runoff is that water volume in the form of snow and ice builds for several months and suddenly releases with the advent of warm weather in the spring or during short interim periods all winter long. The interim melts generally do not contribute a significant volume of runoff when compared to the large spring melt. Note that snowmelt peaks are substantially less than those from rainfall, but the total event volume of a snowmelt, although it occurs over a much longer period, can be substantially more. Ignoring the contribution of these large spring melts to the annual runoff and pollution loading analysis could be a major omission in a watershed analysis. This type of comparison also shows why facility design is critical to the proper quantity and quality management of this meltwater.

This behavior of seeing a major portion of the annual runoff occur during the relatively short period in the year when the snowpack melts is typical of cold climates. Factors influencing the nature of this melt and the speed with which it occurs include solar radiation, the distribution of snow cover, the addition of de-icing chemicals to the pack, and the amount of freeze-thaw cycling.

The source area for snowmelt plays a critical role in both the hydrologic and water quality character of snowmelt runoff, as shown in Figures 9.1a-c. Roadways and large paved surfaces (Figure 9.1a) like commercial parking lots are the direct recipients of fast and efficient snow removal. This can occur by plowing, which can include total site removal or relocation off of the surface, and/or chemical-induced (salt) melting. Because of the need to promote safety, obtaining an ice- and snow-free surface is a focal point for winter management of these surfaces. As a result, these surfaces generate numerous loading events every time it snows or even in anticipation of a snowfall, since pre-icing application of salt can be a common practice. By the time the major spring melt occurs, many of these surfaces are free of snow and ice. However, in many instances the snow that has been removed is piled or plowed close to the surface and flows onto it. At this time it becomes part of the urban drainage system or is stored in a location where it immediately enters the drainage system upon melt. These road and parking surfaces can be a significant source of many of the most contaminating pollutants associated with urban runoff.

Figure 9.1b shows the second category of importance to snowmelt runoff and the area that is generally the most significant source of poor water quality during a melt. This is the area immediately adjacent to the roadway or parking surface. Because snow is plowed and piled in these areas, they accumulate both equivalent water volume and pollutants for an extended period of time over the winter. This material is then available for release and migration over a several week period in the spring. This critical area is usually contained within about 25 feet of the paved surface and easily flows to the storm drain system as it melts. Sometimes, as in commercial parking or roadside piles, the snow is actually sitting on an impervious surface.

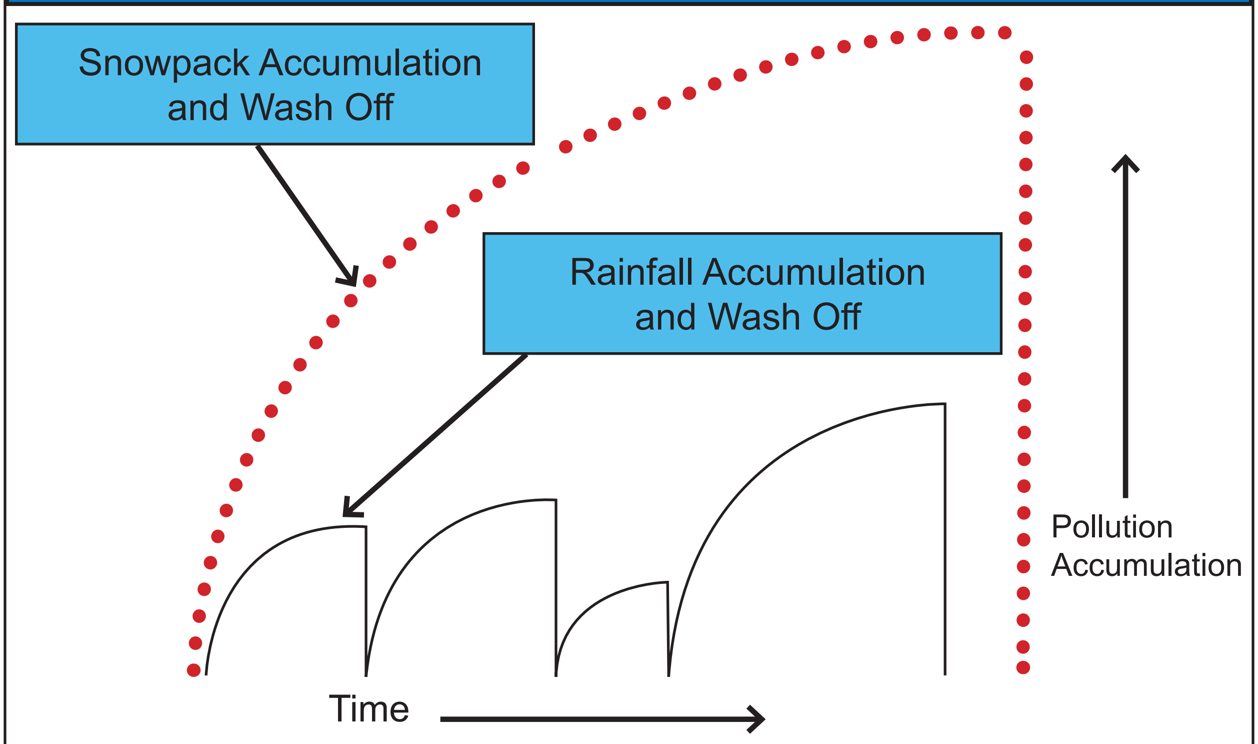
The final contributing area to meltwater runoff is the less developed residential, open space, low density area typical of suburban watersheds (Figure 9.1c). Snowmelt from these areas can

Figure 9.1a Direct Paved Surface with Heavy Traffic

Figure 9.1b Nearby Areas of Snow Accumulation from Distribution/Plowing

Figure 9.1c Areas Well Removed from Roadways and High Traffic

Figure 9.2 Snowpack Accumulation and Wash off as Compared to Rainfall



be large contributors of meltwater volume, but the quality of the melt is better than from roadways and parking areas. Typically a fair amount of the initial meltwater soaks into the ground and can continue to do so as long as the rate of melt does not exceed the infiltration capacity of the soil. If sufficient snowpack is available, saturation can occur, leading to this portion of the watershed acting as an impervious surface.

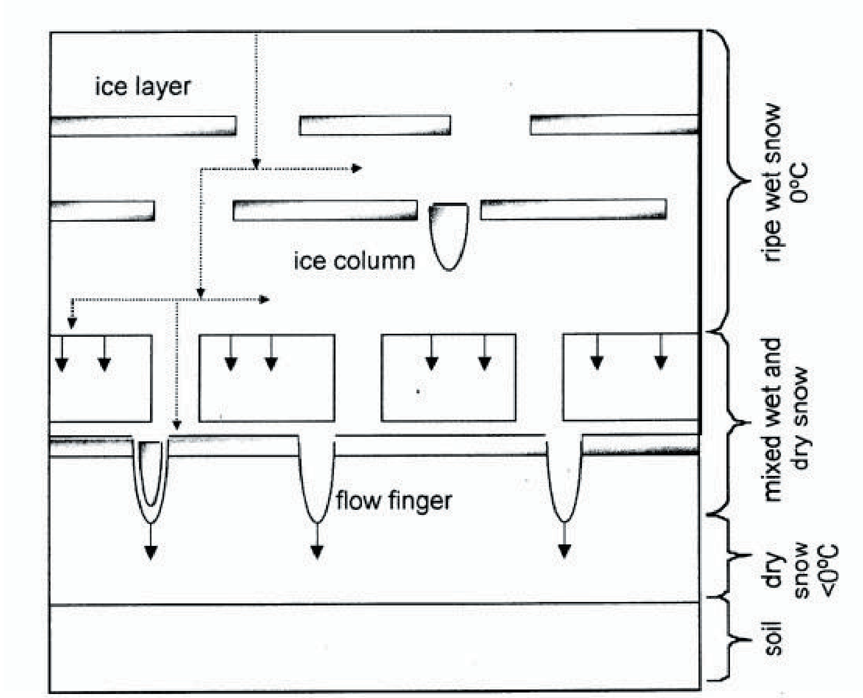
The relative contributions of the three principal areas shown in Figures 9.1a-c cannot be generalized because of the mix that occurs within any watershed. However, the characteristics of a specific watershed and the management approach needed as a result can be estimated from the mix. That is, a densely developed urban area will have more roadways and impervious parking surfaces typical of Figure 9.1a, whereas a suburban neighborhood or rural setting will be a larger source of volume as one could imagine from the snowpacks shown in Figure 9.1c.

Snowpack builds throughout the winter and increases in moisture content as the winter season draws toward melt. When meltwater exits the snowpack, it moves into the ground or over the land surface. A very important part of snowmelt management for both quantity and quality depends upon this behavior and the variations it takes. It is very common for the first part of the melt to soak into the ground. However, at some point in the melt sequence, particularly when there is a deep snowpack at the on-set, the ground can become saturated and turn a pervious, non-contributing part of the watershed into an essentially impervious surface from which all additional melt runs off. Hydrographs from melt events will typically show a period of little to no runoff, even though the melt rate might be high, followed by accelerating flow as the ground no longer soaks in the melting snowpack. Recognizing this behavior could be important for early runoff and quality management.

Quality of Melt

The water quality problems associated with melt occur because the large volume of water released during melt and rain-on-snow events not only carries with it the material accumulated in the snowpack all winter, but also material it picks up as it flows over the land's surface. Figure 9.2 illustrates the accumulation of surface material on a snowpack compared to that occurring on the same urban surface during the rainfall season.

Figure 9.3 Percolation of Water Through a Snowpack (Source: UNESCO 2000, Chapter 2 of Semadeni-Davies and Bengtsson, as Adapted from Marsh and Woo, 1984)



The winter accumulation can occur directly on a standing snowpack or on the side of a roadway where it is plowed. In either case, the material builds for several months prior to wash-off. Since snow is a very effective scavenger of atmospheric pollutants, literally any airborne material present in a snow catchment will show up in meltwater when it runs off. Add to this the material applied to, or deposited upon the land surface, for example to melt snow or prevent cars from sliding, and the wide range of potential pollutants becomes apparent. As with the volume of meltwater, a major portion of annual pollutant loading can be associated with spring melt events.

The conventional pollutants of concern for most urban runoff situations are supplemented in meltwater runoff by additional contaminants added during the winter. The solids, nutrients, and metals present during the summer are joined by increased polynuclear aromatic hydrocarbons (PAHs) and hydrocarbons from inefficient and increased fuel combustion; by salt and increased solids from anti-skid application; and by cyanide that has been added as an anti-caking additive to salt. Pesticide and fertilizer runoff and organic debris (leaves, grass clippings, seeds) are less of a concern during the winter.

The complex melting pattern that occurs within a snowpack results in the release of pollutants at different times during the melt, further complicating an already difficult management scenario. The variability of snow character and the repeated freeze-thaw cycles that occur throughout a long winter create a very heterogeneous snowpack, with many different flow paths available for melt water to move along (Figure 9.3). The freeze-thaw cycles also result in the re-crystallization of snow and the subsequent exclusion of "impurities" to the outside edge of the crystals, whereupon they become available for wash-off by the melting front as it passes. The process has been called by many different names, including "preferential elution," "freeze extraction," and "first flush." This melting sequence becomes a very important part of snowmelt quality management because the practices used may or may not come close to treating a particular target pollutant depending upon where in the sequence it is captured.

Figure 9.3 shows how melt water can move downward in a snowpack through different flowpaths around “dry” snow and ice layers caused by repeated freeze-thaw cycles. As this water moves through, it picks up or mobilizes soluble ions that have pushed to the edge of ice crystals. Through this process, the snowpack cleanses itself of soluble contaminants that become available in the first phases of the melt, yielding a highly soluble, acidic and perhaps toxic (to animal and plant-life) runoff volume. Later in the event, melt water from the snowpack is depleted in these soluble contaminants, but water flow can be at its highest. Energy levels are only high enough to move fine- to medium-grained particulates when the snowpack allows their passage, leaving behind the coarser-grained material. The coarser material is available for wash-off during the higher energy spring rainfall events, and becomes a major source of contamination at that time. Alert sweeping can pick this coarse material up from paved surfaces if there is an opportunity between the departure of snow and the first rains.

The management implication of the preferential elution (or chemical dissolution) process is illustrated in Figure 9.4. The graphic shows that the early part of the melt involves the very efficient elution of soluble constituents (ex., Cl, dissolved metals and nutrients, dissolved organics) at the crystal edges, resulting in a substantial release of the soluble component of a snowpack, often resulting in a “shock” effect as these pollutants reach a receiving water body. Following the release of solubles is a period when much of the liquid volume of the snowpack releases (skewed toward the earlier part of the mid-melt event) and carries with it the remaining solubles along with the beginning portion of finer-grained solids and associated contaminants (ex. hydrophobic PAHs). This mid-melt period generally has the largest portion of water runoff associated with the melt, and the mobilization of solids begins and continues as long as sufficient energy is available to move the finer particles, leaving behind the larger particles.

Part of the severity of the water quality problem associated with melt is that it occurs when the hydrologic system is least able to deal with it. Routine assumptions on biological activity, aeration, settling, and pollutant degradation are altered by the cold temperatures, cold water and ice covered conditions that prevail for many months. An end of the season rain-on-snow event often presents the worst-case scenario when rain falls onto a deep, possibly saturated snowpack. The movement of a well defined, rapidly moving wetted front through the snowpack results in the mobilization of soluble constituents, plus the energy associated with the rainfall is sufficient to mobilize the fine-grained or possibly larger solids and associated contaminants. This wave of melt also washes over urban surfaces and picks up material that has been deposited on these surfaces all winter. Comprehensive reviews of the quality of snowmelt are presented in many of the references at the end of this chapter.

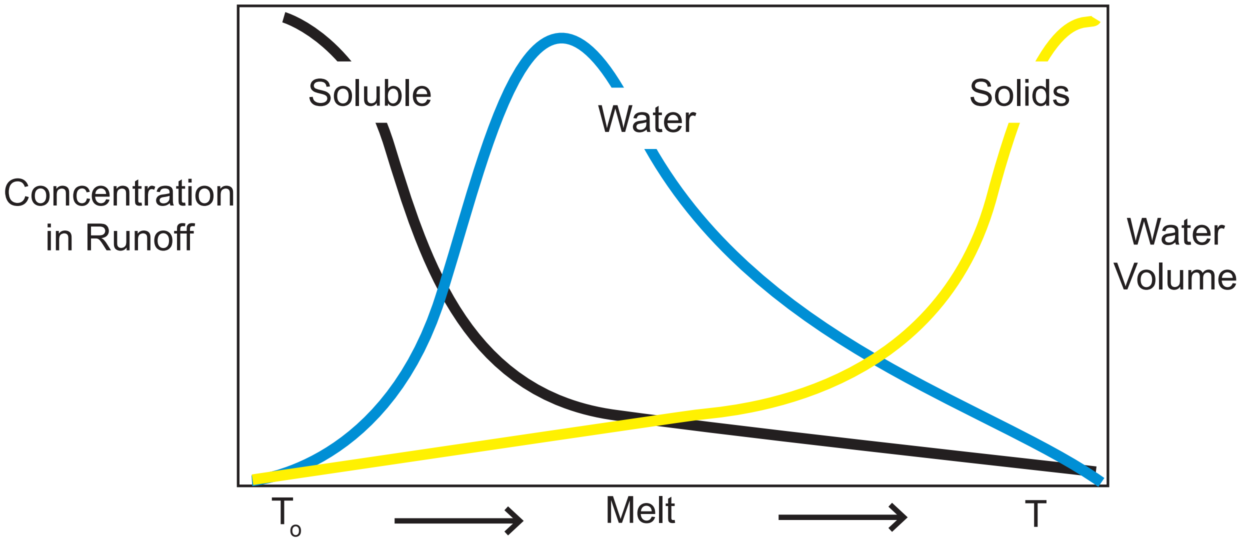
The toxicity of the meltwater and the effects that these chemicals have on various receiving waters and related biological resources is still poorly understood. It is understood that meltwater can be extremely concentrated in many different toxic substances (metals, PAHs, organics, free cyanide, chloride). However, little is known about the impact of these substances on streams, lakes, ground water and wetlands, and even less about their impact on plants, invertebrates, fish and other biological life.

The effects of road salting, especially the conservative element chloride (Cl), becomes increasingly important as the number of vehicles in the state dramatically increases. With the increased number of vehicles comes a need to provide ever safer traffic-ways, which translates into ice-free roads for several months in cold climates. The increase in road salt has even led the Government of Canada to recommend the inclusion of Cl as a toxic substance because of the impact of this chemical on ground and surface waters. Associated with Cl is the anti-caking salt additive, sodium ferrocyanide, which is used commonly in Minnesota. Although not toxic itself, ferrocyanide can break down to free cyanide, which is extremely toxic at low levels. Recent data collected in Minnesota has shown that chemicals associated with salting operations (Na, Cl and cyanide) can reach very high levels in runoff from sites where salt is stored and handled, even if recommended handling procedures are followed.

Ground Water Impact

The most damaging meltwater component affecting ground water appears to be the two elements associated with the most commonly used road salt - Na and Cl. The damage begins at the soil interface where Na can displace Ca and Mg and disrupt the physical structure of the soil

Figure 9.4 General Pollutant Movement from a Snowpack



Early	Middle	Late
Character		
High soluble content	Remaining solubles, beginning of fine- to medium-solids	High solids content
Low runoff volume, early infiltration	Large runoff volume	Large runoff volume (especially if rain-on-snow occurs), saturated soils
Initiated by chemical addition and/or solar radiation	Largely driven by solar radiation, aided by salt	Solar driven
Land Use Where Important		
Low density	High density	High density
Residential/neighborhood	Roads, parking lots	Roads, highways
Open space	Snow storage sites	Commercial
BMP Focus		
Infiltration	Pre-treatment (settling)	Pre-treatment (settling)
Dilution	Volume control	Filtration
Pollution prevention (salt, chemical application)	Detention/settling	Volume control
Retention		Pollution prevention (surface sweeping)
Wetlands/vegetation (infiltration, biological and soil uptake)		Detention/settling
Diffuse runoff paths		Wetlands/vegetation (filtration, settling)

column. Chloride can lower pH and dissociate heavy metals into more soluble and mobile forms. Although both of these chemicals can continue to migrate downward, it is mostly the Cl that presents a major threat. Much more data are needed before the complexity of the Cl threat can be fully understood. Although the threat is very real and has been documented with ground water data in many places, in other places even within the same region, the threat is variable. An example of this is presented in Issue Paper G (Appendix J) for two metro area watersheds.

Wetland, Open Space and Biological Impacts

There are scant data available on the impact of meltwater on wetland systems and associated open space areas. This information is critical when the use of "natural systems" for runoff management is increasingly promoted. Among the impacts are species shifts to less desirable species, increased toxicity to various biota, and decreased diversity. Appendix E contains a list of recommended vegetative species for use in various surface water management approaches in Minnesota. A very good resource on the topic has been produced through MPCA, entitled *Plants for Stormwater Design - Species Selection for the Upper Midwest* (Shaw and Schmidt, 2003).

Effects of Climate Change

According to University of Minnesota Professor and Extension Climatologist/Meteorologist Dr. Mark Seeley, sufficient data exist to support recently observed trends of climate change in Minnesota. These trends, as well as others collected from the global climate research community (ie. the National Academy of Sciences "U.S. Global Change Research Programs," the World Meteorological Organization and the United Nations "International Panel on Climate Change," and numerous national and international universities) indicate that the following changes are likely to occur in the state:

- Warmer winters.
- Higher minimum temperatures.
- Greater annual precipitation with:
  - more snowfall, but faster melting and smaller snowpacks
  - more days with rain (possibly when snow present)
- Local weather less predictable and forecast less accurate
- Local weather more variable with longer periods of drought and wetness
- Local weather more severe (more "storms of the century")
- Stormwater and flood design criteria changes to reflect new conditions more accurately
- Less annual runoff, frequent summer droughts
- Lack of ice cover or thinning of cover, decreased annual freshet (high spring flows), warmer water temps, loss of wetlands, poorer water quality

The results of this phenomenon on the character of snow accumulation and melt could be substantial in the long-term. It seems clear that snow will fall in changed patterns and that which falls will accumulate less; that snowfall terminus lines will shift northward, and upward in elevation; that the mix of ice storms and rain-on-snow will increase; that the timing and rate of snowmelt will vary from current conditions; and that the likelihood of flooding events associated with rainfall during spring melt will increase. This is a future that could also imply more chemical use to provide road safety, less chance for effective storage of snowmelt for later use, and altered annual water balances. It is also assured that any scenario for the future will include a substantial amount of uncertainty in both climatic factors and social factors as solutions to perceived and real problems are implemented.

Based on this evidence, techniques for managing stormwater under these changing conditions should be considered:

- Managers should address cold climate conditions and the pollutants associated with them.
- Higher levels of treatment (i.e., pollutant removal) for meltwater, perhaps in an SWPPP, based on land use, snow management plans, and anticipated pollutant loads of priority pollutants (sediment, chlorides, nutrients) and the waters to which they discharge should be considered.
- Implementation of a "snow management plan" should be considered.

III. Key Challenges in Engineering and Design

List of Complicating Factors for Cold Climate Design

The physical and chemical processes under way in a snowpack present an extremely complicated and variable set of phenomena. The freeze-thaw cycle and the elution of chemicals that it drives have been understood for many years, but details on the migration and management of the many chemicals of concern from the snowpack are seldom pursued by runoff managers. In 1997, the Center for Watershed Protection produced a design manual intended to address many of these problems. One of the items reported in that manual was a survey of cold climate stormwater managers asking what the challenges were that they faced. Table 9.1 is a reproduction of a table from the CWP report.

A special session was held at the 2003 Maine Cold Climate Conference during which practitioners were asked the same question. Also, a public input meeting during the development of this Manual noted the basic problems in Table 9.1 were still of concern to managers. While no magic new practices exist to treat this runoff, some adaptation of our existing approach to design and snow management could be the key to addressing this situation in cold climates.

Table 9.1 Challenges to the Design of Runoff Management Practices in Cold Climates (Source: Caraco and Claytor, 1997)

Climatic Condition	BMP Design Challenge
Cold Temperatures	▶ Pipe freezing ▶ Permanent pool ice covered ▶ Reduced biological activity ▶ Reduced oxygen levels during ice cover ▶ Reduced settling velocities
Deep Frost Line	▶ Frost heaving ▶ Reduced soil infiltration ▶ Pipe freezing
Short Growing Season	▶ Short time period to establish vegetation ▶ Different plant species appropriate to cold climates than moderate climates
Significant Snowfall	▶ High runoff volumes during snowmelt and rain-on-snow ▶ High pollutant loads during spring melt ▶ Other impacts of road salt/deicers ▶ Snow management may affect BMP storage

IV. Management Approaches

Meltwater Management

Special management of cold weather runoff is usually required because of the extended storage of precipitation and pollutants in catchment snowpack, the processes occurring in snowpack, and the changes in the catchment surface and transport network by snow and ice. The discharges that come from urban meltwater may cause physical, chemical, biological and combined effects in receiving waters and thereby limit their quality, ecosystems and beneficial uses.

For many years the old adage "one size fits all" was tried for the management of all runoff management. Once the effects of this approach were scrutinized, however, it became apparent that applying traditional rainfall runoff BMPs was not working for meltwater in spite of their success with rainfall. The problem is usually not the large volume resulting from a significant event, although serious flooding certainly can occur. Rather, it is that the BMPs are prevented from working as intended because of ice, cold water, highly concentrated pollution and lack of biological activity. Complications encountered in cold climates simply work against many of the commonly used warm weather BMPs, reinforcing the need for the development or adaptation (e.g. revised criteria and specifications) of existing treatment practices to better address melt runoff. Additionally, the usually poorer performance exhibited during cold weather is generally not considered when management approaches are designed because of the perceived uselessness in trying to overcome the items in Table 9.1. The problems cannot be entirely negated, but any improvement in the quantity and quality of runoff will be a step forward.

Typical results of the conditions listed above include flow by-passing and flooding, lack of reaeration in the water column, pond stratification, decreased settling and biological uptake, flushing of previously settled material, and reduced infiltration capacity.

Management Sequence

The manner in which meltwater runs off of different contributing surfaces was previously addressed. This behavior suggests that a sequence be followed to intercept and treat variable quantities and qualities of runoff as they emerge. The following general, idealized approach should be used in planning a strategy for optimizing treatment effectiveness when it is possible to implement (see sidebar). Specific BMP adaptations to account for these strategies will be discussed later in this section.

Pollution Prevention

Keeping contaminating materials away from paved surface and out of accumulated or dumped snow is the key to minimizing the pollution associated with meltwater runoff. Management approaches that help accomplish this include:

The 5 Steps for Management

Step 1 - Pollution Prevention

Pollution prevention is always the best way to manage the quality of runoff from urban and rural surfaces (see next section).

Step 2 - Infiltration

The highly soluble and perhaps toxic "first flush" should be infiltrated to the extent possible provided the source area is not concentrated in Cl or other toxic pollutants. This can be done on-site in areas with a high degree of pervious surfaces, or perhaps routed to an area where short-term detention and infiltration can occur. For source areas high in Cl and soluble toxics or near drinking water sources, infiltration should be avoided in favor of storage and slow release once sufficient flow occurs in the receiving water to dilute the effects. Note also that snow deposits should not be located directly over a designed infiltration facility because of the possibility of clogging from debris in the snow.

Step 3 - Meltwater Storage

Excess flow that cannot be infiltrated because of preventive (frozen) or pollution conditions should be collected in a meltwater storage area with excess capacity to hold it for the later influx of water volume and particulates. These particulates can adsorb solubles and settle, thus removing a portion of the more toxic soluble load (see **Ponds** section).

Step 4 - Filtration

When fine- and medium-grained solids begin to move, settling BMPs can be incorporated starting with local application, and moving to regional storage as the need dictates. Some adaptations will be needed to incorporate storage around ice layers that might be present.

Step 5 - Housekeeping

Much of the remaining solids are too heavy to be moved by melt so they remain near the roadside, in gutters, or in the location they were dumped as part of a snow pile, available for wash-off when spring rains come. After the snowpack has totally melted and before the first rainfall (if possible) preventive measures such as street and parking lot sweeping should be pursued. Note that Step 5 could occur after Step 1 for those communities or commercial/industrial facilities that practice cleaning activities during the winter.

The sequence above is an optimal approach and ideal conditions seldom occur. See the "Management Sequence" section for more details.

- Judicious use of de-icing and anti-skid chemicals, which then indirectly control secondary effects like heavy metal speciation and soil character changes from Cl
- Less additives like cyanide (CN) to salt
- Better chemical storage and mixing (covered storage and mix areas, mix only needed amount)
- Improved application technology with trucks, such as weather monitoring (RWIS or “road weather information systems”), direct application to roadway, and brine wetting
- Snow removal and meltwater routing to less sensitive receiving waters or treatment facilities
- Design of Cl dilution system to lower its direct impact
- Rapid sweeping as soon as snow gone from paved surfaces
- Litter control
- Erosion control
- Disconnection of impervious surfaces/ reduced pavement (such as narrow roads, fewer parking spaces)

Chloride is the cause of many problems associated with snowmelt runoff. Chloride is a very soluble, conservative chemical that migrates easily through treatment systems and soil. High Cl levels decrease sorption of heavy metals and mobilize them. This leads to release of these polluting materials from storage areas with high Cl levels, as density stratification leads to the build-up of Cl to very high levels if not properly flushed from bottom waters. Methods to prevent this are discussed in the ponding section.

Infiltration

After some basic pollution prevention is practiced, the next phase of runoff management should be to soak in as much of the meltwater as possible, provided the source area does not contribute high Cl or soluble toxic pollutants.

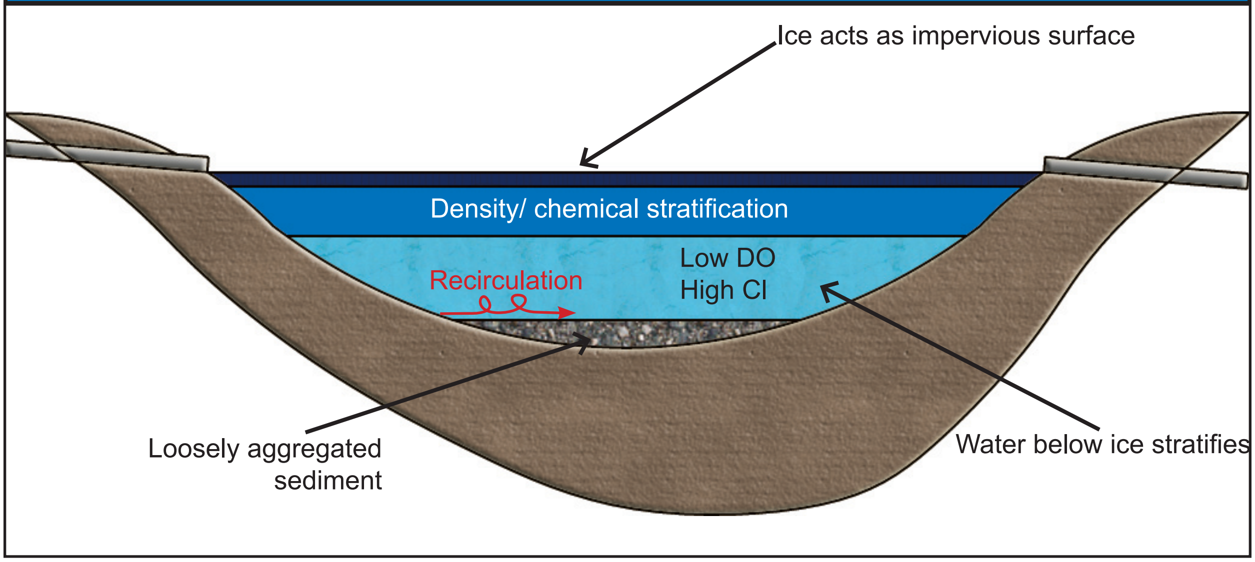
The treatment available from infiltrating meltwater through soil (filtration, ion exchange, adsorption, and biological decomposition/transformation) will remove many of the most polluting contaminants typical of low density urban areas. These practices are, therefore, most appropriate for residential and open space areas within a watershed. Local infiltration systems, like bioretention (rain gardens, swales) and dry ponds are a good approach to route water for infiltration or filtration. All flows to infiltration practices should be pre-treated to remove particulate material that could clog the pore interstices and lead to system failure.

The problems that Cl-laden runoff can cause in both surface water and ground water were previously discussed. However, in addition to Cl, early runoff can include other soluble pollutants. The degree to which soluble contaminants will be pervasive is a function of the source load and the amount of particulates available to possibly adsorb them. Sansalone and Buchberger (1996) found that when a high level of particulate material is present in meltwater that a fair amount of adsorption occurs, negating some of the mobilization of this otherwise potentially toxic material. For source areas where runoff is a possibility, routing the runoff to a facility where an opportunity exists for this sorption to take place is a management option. Similarly, some sorption from these areas might naturally occur, so routing to a storage facility is again advisable for settling of the particulates and adsorbed material.

Although infiltration has not been a commonly used meltwater BMP in Minnesota, studies from many similar climates show that it is a feasible practice when used with precautions. Specific BMPs that involve infiltration include such practices as trenches and basins, permeable pavement and paving blocks, vegetated swales and biofilters.

Snow deposits should not be located directly over a designed infiltration facility because of the possibility of clogging from debris in the snow.

Figure 9.5 Character of Water Under Ice



Criteria for infiltration are contained in the BMP sheet for infiltration practices in Chapter 12.

Routing meltwater into or away from an infiltration system is also an active meltwater management decision that can be made depending upon conditions. For example, highly Cl-laden water can be routed away from an infiltration system that might operate during three seasons, but not the winter. On the other hand, meltwater from a residential area could be routed to an infiltration system to take advantage of early melt infiltration into a dry infiltration basin.

Stormwater Ponds

The most commonly used rainfall runoff BMP has been various versions of detention ponding. Difficulties in applying warm weather detention concepts to cold weather meltwater treatment occur with higher runoff volumes and increased pollutant loads, ice layers and frozen/sand-plugged conduits, anaerobic conditions, greatly enriched under-ice accumulation of pollutants, circulation problems and resuspension.

Figure 9.5 graphically summarizes the many processes that work to limit the effectiveness of ponding during meltwater events, including:

- Densimetric stratification caused by accumulation of road salt in runoff
- Anaerobic conditions evolving once ice prevents reaeration and baseflow ceases
- Release of pollutants, once thought to be permanently removed, from both bottom sediment and interstitial waters
- Displacement and flushing of highly polluted under-ice pond water with the first waves of meltwater that sink below the ice layer in ice-free areas near the inflow

To better understand the dynamics of sedimentation and resuspension necessary for building better cold climate detention systems in the future, and for retro-fitting the thousands in place already in Minnesota, better data collection will be needed. Such data collection should include meltwater treatment adaptations, such as seasonal detention, variable outlets, under-ice circulation, and first melt diversion into or around a treatment system.

In spite of the fact that detention systems often do not work well under typical designs in cold weather, they play a prominent role in treatment of meltwater. In the areas draining the paved areas and accumulating snow and ice near paved areas, particulate content can become extremely high because of a winter's accumulation of anti-skid sand and urban debris. Routing this runoff to a detention facility prior to release to a receiving water is a reasonable thing to do. This large mass of particulates near these surfaces also plays an important role in adsorbing soluble pollutants that otherwise might escape further treatment. For both of these reasons, an adapted ponding system is among the list of recommended treatment methods for meltwater management.

Ponds also provide an opportunity to store, mix and slowly release pollutants mobilized during a melt event. Oftentimes, pollutants like Cl in meltwater can rise to toxic levels defined by MPCA water quality standards (Mn. Rules 7050) as beginning to show chronic toxicity at 230 mg/l. If routed into a storage facility and slowly released when sufficient water is, for example, flowing in a receiving stream, the toxic effects can be minimized. Ponds can also be used to accumulate all or a substantial part of the meltwater volume for later release when biological and physical constraints are less apparent.

It is important to recognize the potential pollution problems that Cl and toxic contaminant build-up in a pond can cause when released. A delicate balance needs to be pursued in deciding whether to adjust pond level to pass Cl-laden runoff downstream or retain as much as possible for later release when flows are higher. Retaining polluted water all winter long only to discharge it all at once in the spring is not in the best interest of receiving waters, but this is what can happen in a pond not managed for seasonally changing conditions. In no case should ponds be drained in the spring following a winter's long accumulation of under-ice contaminants. If lowering is done, it should be done in the late fall before freeze-up.

Adaptations to commonly designed ponding systems are discussed later and as part of the design sheets in Chapter 12.

Wetland and Biological-Based Systems

In Minnesota, wetlands often act as modified detention facilities by virtue of their sheer numbers and the location they occupy in the drainage landscape. Most of the constraints listed above for ponds also apply to the proper operation of wetland treatment systems. In addition, however, is the sparse biological activity during the cold weather season. Vegetative uptake, filtering and microbial activity are all effective mechanisms to reduce pollution related to biological activity during warm weather that are much reduced when the weather is cold. Although sedimentation might continue to play a role in meltwater treatment, provided an ice layer does not prevent it, decomposition, chemical adsorption and biological transformation will all likely be reduced.

The impacts of Cl-laden meltwater on vegetation were previously discussed. Greatly reduced germination and growth of seeds, reduced community biomass, taxa and productivity, and a shift to less desirable species are all the effect of pollution loading to wetlands.

Other biological systems that are commonly used for rainfall runoff also suffer a drop in effectiveness in winter weather. For example, water draining to vegetated swales and bioretention (rain gardens) systems experience a drop in water quality because of reduced pollution removal.

Even though the pollutant removal effectiveness of biological systems is less during cold weather, these systems certainly have their place in an overall runoff management program. Low-lying wetlands and bioretention areas are the first place that soluble-laden first meltwater will migrate and soak into the ground. Standing vegetation, although not green and vibrant, still provides a measure of filtration as meltwater flows through. Soil microbes still live and consume nutrients even in the dead of winter. Accumulation of Cl is generally not a problem in shallow biological systems, as long as very highly concentrated levels are not routed directly to them. Even when this does occur, salt tolerant vegetation can survive. The best salt tolerant plant species for use in Minnesota are contained in Appendix E of the Manual.

Filtration, Hydrodynamic Structures and Treatment Trains

Filtration was to some degree addressed in the previous section on wetlands. Filtration also plays a role as part of a treatment train, or sequence of treatment steps designed to remove incrementally greater pollution as runoff water flows through. Filtration through a granular inorganic (sand, perlite) or organic (compost, leaf pellet) medium can be a fairly effective way to treat many of the pollutants associated with meltwater. The organic materials are less attractive in Minnesota because of the potential for phosphorus leaching into our lake dominated receiving waters.

Filtration is usually one of the last stages of a treatment train, typically preceded by processes such as screening, settling, floatable skimming, aeration, and chemical addition. Filtration is usually the final process before system infiltration or discharge to an outflow pipe connected to a storm sewer.

These systems can be particularly effective when placed as a sub-grade unit below the frostline. Sub-grade construction also allows for surface land to be used for other things, such as parking or open space.

Many new proprietary management systems are on the market today with promises of year-round effectiveness. Perhaps the most promising practices for meltwater are the treatment trains that incorporate settling, floatables skimming, and filtration through some kind of organic or synthetic media. Theoretically, these systems should be able to settle the solids associated with anti-skid grit added over the winter, then remove a fair portion of the soluble toxics also washing off in a melt. Unfortunately, conservative elements like Cl will move through these systems unchanged. The Environmental Technology Verification (ETV) program of USEPA has begun to test the claims of many proprietary units. Available results from this program are incorporated into BMP design sheets in Chapter 12, especially if field data on cold weather performance have been part of the testing procedure on the effectiveness of these systems.

Other Considerations

Alternatives to Sodium Chloride (NaCl)

Perhaps the most vexing problem facing cold climate water managers today in many parts of the world is the accumulation of Cl from the ever-increasing application of road salt. As a conservative element, Cl moves readily through all commonly used treatment devices and into both ground and surface waters. The only effective means to remove Cl is through reverse osmosis, which does not lend itself to the large volume of runoff associated with a melt runoff event. Other treatments, like evaporation, do not work well during critical cold periods and only serve to concentrate the pollutant for later attention. The treatment approaches that seem to have some likelihood of success are:

- Wiser and less use (the focus of most transportation managers as long as safety is not compromised)
- Dilution (mix high load runoff with low load runoff)
- Detention and slow release to avoid toxic shock.

Alternative chemicals have shown some promise in the past, but each alternative seems to bring associated impacts once scrutinized. Yet, the search for, and evaluation of alternative chemicals or artificial substances for deicing or anti-icing continues. "Smart salting" is the preemptive application of deicer to prevent ice from forming (anti-icing). In Minnesota, the use of liquid $MgCl_2$ spray on bridge decks has proven to be an effective way to avoid repeated NaCl application at high doses. Continued data collection on the presence of Cl in receiving waters is essential to the development of a reasonably protective Cl strategy. Other routinely mentioned alternatives to NaCl use are calcium chloride ($CaCl_2$), calcium magnesium acetate (CMA), potassium formate (KFo), potassium acetate (KAc) and urea (used almost exclusively at airports). Until such time as these alternative sources are shown to be effective in controlling ice, environmentally suitable and economically affordable, NaCl will continue to be the chemical of choice by those responsible for keeping roads safe. However, Minnesota (primarily through Mn/DOT programs) will continue to explore alternatives to the use of NaCl and ways to lower the impact of salt on our receiving waters.

Many new proprietary management systems are on the market today with promises of year-round effectiveness. Many of these systems are promising, yet most are untested in cold climates.

Typical Snow Management Techniques

Figure 9.6a Snow Plowed Off the Road and Left Piled on the Roadside

Figure 9.6b Snow Plowed Off Commercial Parking Lot and Piled in Corner

Winter Construction Season

A recent trend in Minnesota as the winters have seemed to be more mild and construction techniques improve is to continue or even initiate building during the winter. Going into a winter building season means all too often that soil and slopes are left bare all winter and exposed to snowmelt and early spring rainfall events with little protection in place.

Under the Phase II NPDES permit provisions, a Stormwater Pollution Prevention Plan (SWPPP) must be produced for each construction site over one acre, but often the provisions of the SWPPP and local ordinances are ignored during the winter because of the infeasibility, for example, of getting vegetation started or of placing material over a frozen surface and having it blow away. A small amount of planning before cold conditions set in could prevent the serious erosion and pollution problems associated with these sites in the spring.

Following is a list of practices and options to consider <u>before</u> the cold weather construction season. Many of these elements are currently required as part of the NPDES Construction Permit, but unfortunately are often overlooked or considered infeasible during cold weather. Effective implementation of <u>all</u> permit requirements during cold weather is important.

- Terminate activity until warm weather returns, if construction not required over winter.
- Sequence work such that all earth-moving and soil impacting activities occur prior to freeze-up.
- Stabilize all exposed soil surfaces with vegetation, mulch or synthetic cover before the ground surface freezes and sprays become inoperable.
- Seed before October 1st to assure germination and adequate growth before cold conditions prevent growth.
- Establish stable access/egress points and stockpiling some gravel on site to maintain these routes during the winter season.
- Install roads to keep all vehicles off of exposed soil.
- Open limited new soil exposures (if any at all) and stabilize them immediately.
- Establish perimeter controls and inspect them weekly throughout the winter for structural integrity (use surface bags or rolls when posts and staples cannot be driven into the ground).
- Maintain a stockpile of sandbags and other erosion and sedimentation controls (ex. rock bags, erosion blankets) to address problems that need immediate attention.

Snow Management

The plowing, relocation and collection of snow presents some very real management questions in need of support data.

In most urban areas, a number of approaches are followed depending upon the level of urban density. In residential areas, snow is generally plowed to the side of the road and allowed to accumulate there all winter long. However, in commercial/industrial zones, snow is often plowed to a corner of a parking lot, and in densely-developed urban centers, snow is often removed to a totally different, often remote area, where it is dumped for an entire winter season (Figures 9.6 a and b in sidebar). Local practices seem to vary considerably based on tradition, expectations and the cost of removal operations. Assuming snow is collected, the design of "snow dumps" must take into account the fact that snow eventually melts and will need somewhere to flow, either off of the land surface or into the ground. Of particular need is data on the impact of these facilities on both ground and surface waters. Until adequate data are available, commonly accepted snow dump guidelines include:

- If possible, collect snow on an impervious pad and divert melt for treatment (ex. detention, routing to a wastewater treatment facility).
- If runoff collection and treatment is not an option, locate on a flat slope well away from surface water bodies, outside of the floodplain and well above the ground water table.
- Place the collected snow over well-drained soil to allow filtration, adsorption and microbial activity.
- Clean-up of debris left after the snowmelt and before the first spring rains fall, and restore the soil if needed.
- Monitor the quality of snowmelt and of the receiving water, especially if it is the local ground water system.

Collecting and treating snow dump meltwater should become more important if a sensitive receiving water is at stake.

Low Impact Development

The movement in runoff management toward less structural, "low impact" development techniques shows a great deal of promise for snowmelt management. The effectiveness of this approach to runoff management relies to a great extent on the biological and soil systems within a watershed. The ability of these systems to operate in an acceptable manner could mean they are propelled to common practice or doomed to failure. Much of the discussion in this section stresses the role that low impact approaches can have in meltwater management. Research on this topic will be entered into the BMP design sheets. Practices such as porous pavement, ground water recharge by local infiltration, use of grass swales, and road drainage infiltration systems have been found to be effective under cold climate conditions, as long as they are adequately maintained to assure their effective performance.

Planning and Education

All of the design and evaluation assistance that will be contained in the Minnesota Manual will be meaningless if the results do not get properly interpreted and distributed, both to the local officials making decisions and to the public that must live with those decisions. For example, a public clamoring for ice-free roads could be in direct conflict with a reduced salt strategy. Local officials also need data and technical assistance to make good decisions on meltwater management. The *Minnesota Stormwater Manual* is intended to fulfill at least some of this need. Preparation of more of this kind of "on-the-ground" technical information in the hands of everyday managers is essential to improve water management in cold climate areas.

V. Design Adaptations for Cold Climates

Unified Sizing

How can design criteria be recommended such that everyone uses the same approach? Part of the material presented in Issue Paper G (Appendix J) addressed the inclusion of snowmelt runoff into the calculations. A methodology for determining the snowmelt volume to add into the runoff calculations is suggested as input independent of whatever method is used for defining "water quality volume." The unified sizing criteria for ponding (Chapter 10) includes adaptations that would account for less effective cold weather treatment, if possible. This may be achieved through initial design or through retrofit of existing facilities. This runoff volume should also be considered in other BMPs besides ponding and in the use of any kind of credit for meltwater design.

Water Quality Sizing of Snowmelt

Minnesota climatology data supports a common rule of thumb that most of the snowpack disappears in the spring over a period of about ten days. The question can be raised as to why this volume should be important if BMP facilities are generally designed for treating a runoff event lasting only 24-hours. That is, why would on average 1/10 of a snowmelt runoff volume going into a facility designed to treat a much larger volume be a problem? This is a very valid comment. Clearly, if the systems are built to store a large volume of rainfall runoff, there will be no problem. The difficulty arises when complicating factors in cold weather prevent the full storage volume for a pond, or infiltration capacity of an infiltration device, or conveyance for a diversion to be available during the period of time when they are designed to operate. Suddenly snowmelt could receive less than adequate treatment or by-pass any treatment whatsoever.

Various methods to deal with the conditions experienced in cold climate BMPs were suggested previously. But the question remains, should adaptations or sizing changes be part of the recommended criteria or simply recognize the need to change our approach to get the same treatment as the facility was intended to achieve during warm weather? Should we instead think in terms of the entire snowmelt volume over ten days and compare it with the daily value used for warm weather runoff events because the treatment levels will not be the same?

Water Quality Credits for Onsite Snow Management

Credits for snowmelt management should be considered when management decisions need to be made. For example, if there is an approved and enforceable snow management plan for a fully developed urban commercial site that dictates plowed snow will be hauled to a suitable on-site snow storage area (e.g., pervious soils, sump area sized to certain design specifications, spring clean-up plan), then the stormwater BMPs can be sized according to the baseline (rainfall runoff) criteria. However, if the same site merely plows the snow to a corner of a parking lot and lets it enter a storm sewer that empties to a nearby pond with a thick ice cover, then maybe the applicable SWPPP needs more attention.

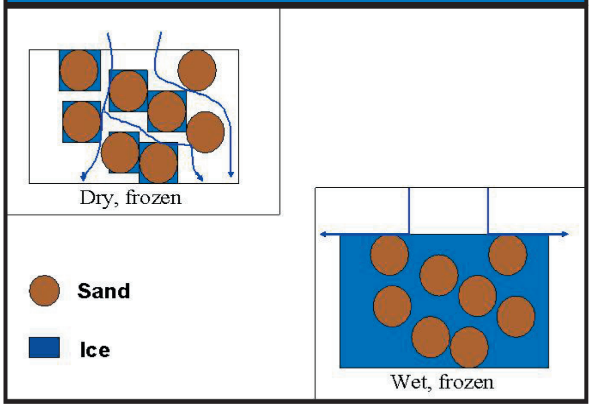
Another opportunity to incorporate credits could be possible if it is presumed that the snowmelt sizing approach showed that the snowmelt water quality volume (Vwq) is greater than the rainfall runoff Vwq. If this is the case, certain measures could lead to a reduction in that volume to the point where it approached or equaled the rainfall Vwq. Credits such as considering subtracting out roof areas that drain to pervious surfaces could be applied to adjust the snowmelt volumes. If chloride loads are of particular concern, a credit could be given for residential streets that have a “reduced salt” covenant. The street area could be subtracted out of the snowmelt Vwq computation.

Perhaps the level of inclusion of a snow management plan should be a function of whether a community is covered under an NPDES MS4 permit. That is, are there exemptions that should be considered such as waiving snowmelt criteria for sites outside of MS4 jurisdictions? Another example might involve waiving snowmelt criteria for direct discharges to streams where the ratio of site drainage area to upstream drainage areas is less than some fraction (e.g., 5%). This argument would be loosely founded on the dilution principle, which has been previously identified as one of the limited management approaches for Cl, but might not send a positive message (that is, using dilution to solve a water quality problem).

Snow Management Plan Guidelines

Perhaps the best approach for incorporating cold climate considerations into a community stormwater plan is through a “Snow Management Plan”. This plan could be implemented a number of different ways. The most obvious would be incorporation into the SWPPPs developed by MS4 communities or as part of a construction or industrial site permit. There currently are no requirements for snow management plans in state regulations. For large-scale operational agencies, such as Mn/DOT, it could be adopted in its standards of practice. The plan could also be part of an ordinance that a community requires be applied for specific types of land use, such as commercial or multi-family buildings.

Figure 9.7 Applicability of BMPs for Cold Climate Use



This section in part addresses the need for guidance, but not fully. It does not, for example, provide fact sheets for small landscaping companies that plow snow at commercial facilities, which could be produced as part of the MS4 technical information assistance effort.

The following elements (Table 9.2) are guidelines for the preparation of a Snow Management Plan. Each of these categorical discussions also has a recommendation(s) on the proper approach.

BMP Design Modifications

Another option originally proposed in the CWP Cold Climate BMP Supplement (Caraco and Claytor, 1997) is to incorporate additional storage or treatment volume into typical designs. For example, the CWP proposed the addition of an extra 25% Extended Detention (ED) storage to ponds for winter use. This approach could also be accommodated under the seasonal designs presented in this chapter. It is clear that the problems associated with the collection, routing and treatment of snowmelt runoff will continue to occur unless the shortcomings of using our warm weather techniques to treat a cold weather problem are addressed.

VI. Preliminary Considerations for Design Sheets Based on Cold Climate Performance

Applicability of BMPs for Cold Climate

It is necessary to look at the list of BMPs identified in Chapter 5 and assess their applicability for cold climates. Details on specific BMP design and maintenance are part of the design sheets that follow in Chapter 12.

Adaptation Concepts

Each of the design sheets for the BMPs (Chapter 12) addresses adaptations needed to properly operate in cold climates. Following in this section, however, are some select summary adaptations for some of the engineered systems.

Infiltration Basin/Surface Filter

Various options for use of infiltration and filtration are available for treating meltwater. Some of the installations are built below the frost-line (trenches, sub-grade proprietary chambers) and do not need further adaptation for the cold. Surface systems, however, do need some special consideration.

The problem with infiltration or filtration in cold weather is the ice that forms both over the top of the facility and within the soil interstices (Figure 9.7). To avoid these problems to the extent possible, the facility must be actively managed to

Do not introduce flow into an infiltration area that originates in a potential stormwater hotspot or high traffic area where large amounts of salt are added. Flow from these source areas should be diverted away from infiltration systems.

Table 9.2 Recommended Elements of a Community Snow Management Plan	
Plan Element	**Recommended Practices**
Snow Removal and Disposal Approach	
Formalize snow removal and disposal goals and objectives (action steps)	Adopt community snow removal and disposal goals and objectives so citizens know what to expect under certain conditions; clarify intent of wiser salt use
Develop plowing and removal/ redistribution plan	Formalize goals and objectives into an action plan that clearly delineates steps that will be taken under different snow and ice scenarios; target problem areas (such as ice formation)
Salt/Mixed Sand-Salt Storage	
Characterization of storage areas	Identify areas where both public and private salt and salt-sand mixes are accumulated and stored, and the characteristics of these areas, such as: ► surface of storage area ► containment and cover ► method of operation ► drainage pattern
Cover exposed chemicals	Provide a small containment shelter with full coverage and a 3” lip to stop small flow from even leaving the storage pile. For larger operations, full coverage of both storage and mixing areas, and removal of unused pre-mixed sand/salt back into covered storage is recommended.
Chemical Application Practices	
Identify the amount and manner of salt use	Determine the volume of salt being used, by whom, and where they are storing and applying it
Identify training programs for salt handlers	Institute formal training program for all loaders and applicators
Specify methods used to minimize salt application rate	Develop protocol for promotion of less salt use through driver training, equipment calibration and maintenance, pre-wetting techniques, anti-icing, sand mixing
Initiate record keeping system to track application rates by route and driver	Develop log system to track the amount of salt applied by each driver
Opportunities for BMP Adaptation	
Map surface water drainage system and BMPs designed to handle runoff	Examine existing drainage maps to determine where chloride-laden meltwater runoff will go; identify sensitive water bodies; and assess the effectiveness of BMPs to treat snowmelt runoff
Upgrade BMPs if needed	Identify problem BMPs that could be preventing adequate runoff treatment and program to manage them better

Table 9.2 Recommended Elements of a Community Snow Management Plan	
Plan Element	**Recommended Practices**
Winter Construction Control	
Assess current practices used in your community	As part of SWPPP, are there any limits on construction or special BMPs required during the winter season
List special provisions	Identify possible protective measures that could be adopted to prevent problems associated with winter conditions
Method of Addressing New Site Versus Existing Site	
Assess need for construction control program	Notify new sites covered under NPDES construction permit process that they are required to address snow in a site SWPPP
Assess need for MS4 program under post-construction elements	Address existing sites covered under the umbrella of the MS4 SWPPP or any re-development permitting
Pollution Prevention Efforts	
Develop pollution prevention program focused on winter activities	List program elements that could be used to prevent runoff problems from occurring during the winter construction season; adopt ones most appropriate to your community
Identify any measures that show effectiveness	Identify other methods that could be used, although not part of previous element

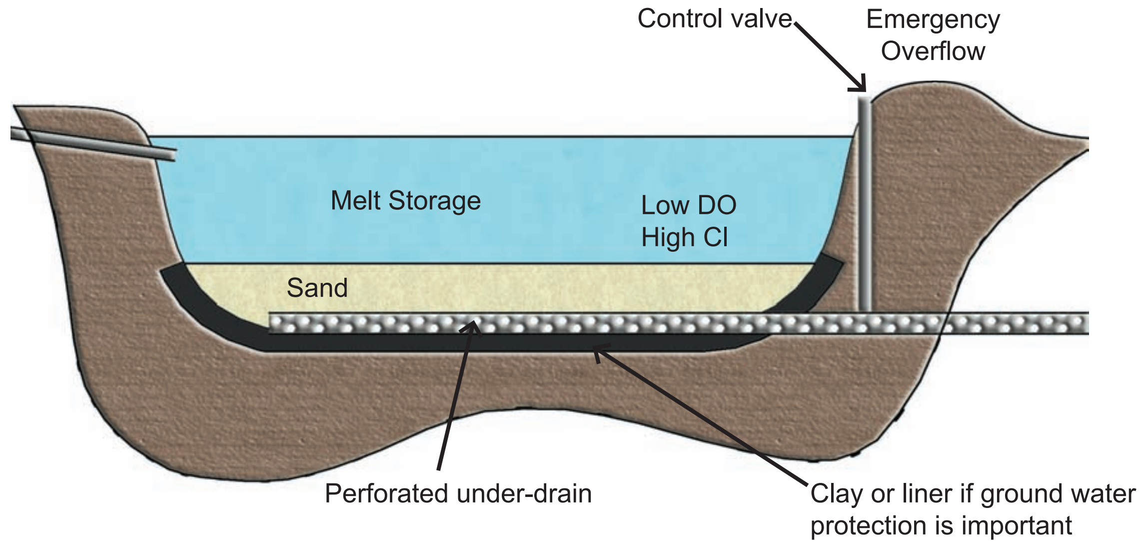
keep it dry before it freezes in the late fall. This can be done by various methods including limiting inflow, under-drainage and surface disking. Even if the infiltration properties of an infiltration basin are marginal for melt, the storage available in the facility will provide some storage if it is dry entering the melt season. Routing the first highly soluble portions of melt to an infiltration facility provides the opportunity for soil treatment (filtration, adsorption, microbial activity) of these solubles. Figure 9.8 is a general graphic portrayal of an infiltration basin adapted for handling spring meltwater runoff. The adaptation in this graphic is a sub-drain installed to dewater the basin of any water heading into the freeze-up. This drain can be closed just prior to meltwater inflow and during the non-winter seasons to allow infiltration to continue downward. Also note that a clay liner can be added if the need to protect local ground water from infiltrating meltwater is important. If this adaptation is made, the basin is no longer an infiltration system, but instead becomes a filtration system or dry pond.

Proprietary, sub-grade infiltration systems provide an alternative to standard surface based systems. These systems, in essence, provide an insulated location for *pre-treated* meltwater to be stored and slowly infiltrated, or simply filtered and drained away if ground water sensitivity is an issue. The insulating value of these systems adds to their appeal as low land consumption alternatives to ponds and surface infiltration basins.

In cold climates, stormwater filtering systems need to be modified to protect the systems from freezing and frost heaving. Physical design and operational considerations to keep in mind for filtration systems are included in Chapter 12.

Note that although filtering systems are not as effective during the winter, they are often effective at treating storm events in areas where other BMPs are not practical, such as in highly urbanized regions. Thus, they may be a good design option, even if winter flows cannot be treated. It is also important to remember that these BMPs are designed for highly impervious areas. If the snow from the contributing areas is transported to another area, such as a pervious infiltration area, their performance during the winter season is less critical to obtain water quality goals.

Figure 9.8 Seasonal Infiltration Basin (or Filtration Basin if Liner Installed)



Seasonal Ponds

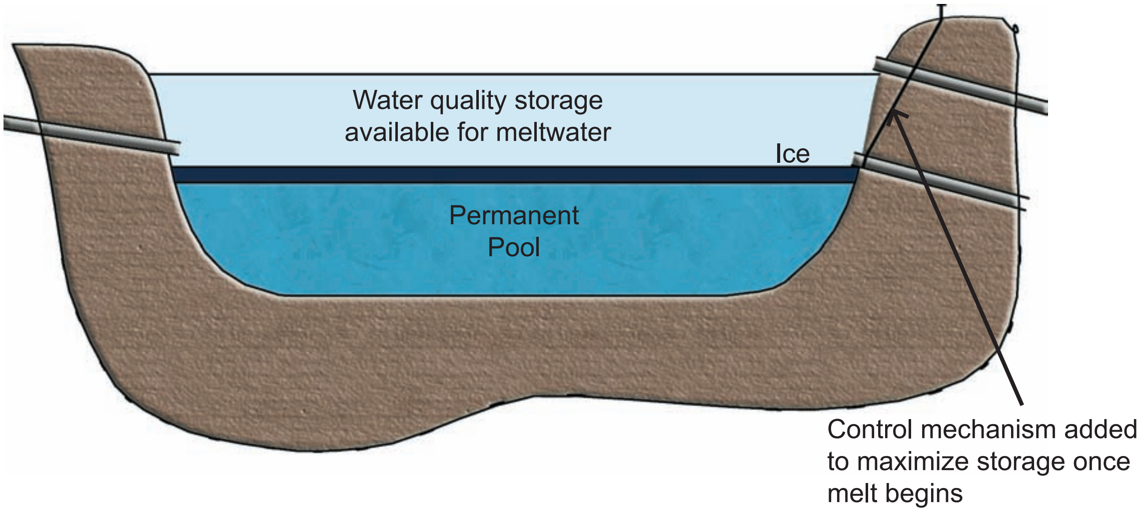
The difficulties of operating an effective storage and treatment pond in a cold climate were discussed previously. Problems exist with the thick ice cover (lack of reaeration, "impervious" cover for settling purposes, reduced storage volume) and under the ice (anaerobic conditions, resuspension of settled material, concentration of Cl and toxic material, dissolution and density stratification).

To overcome these difficulties, some seasonal adjustments can be made to account for winter conditions. The obvious need in this situation is to eliminate the effect of the ice layer. This layer can be up to several feet thick during a hard winter and can greatly reduce the availability of the designed storage volume. The result is usually a small amount of the initial melt diving under the ice in a somewhat pressurized manner forcing out water that might have sat stagnant all winter long. When the available capacity provided by limited uplift of the ice cover is filled, meltwater begins to flow over the top of the ice, which usually means outflow at the other end after very limited exposure to settling due to the "impervious" ice cover.

Minimizing the effect of the ice cover can be done passively through the design of surplus storage or actively through the management of water levels before ice has a chance to form and after meltwater inflow begins. The first suggested adaptation is shown in Figure 9.9. In this system, the normal design storage volumes are maintained, but a control mechanism (valve, weir, stop-log) is installed to reduce or even eliminate outflow for the normal water quality volume. This volume is then made available for meltwater, which can be held and slowly released. This approach provides for some settling time and could be used to capture high Cl flow for later slow release. The problems with under-ice build-up of anaerobic conditions and poor water quality will likely not be avoided under this adaptation.

The second adaptation is one that should be used when concern over the quality of water associated with a pond is paramount. The adaptations in Figure 9.10 require more active management, but they will result in improved performance and fewer downstream water quality problems. This adaptation is especially recommended when sensitive receiving waters are a concern, or if additional treatment effectiveness is needed to achieve a TMDL requirement. The significant change made in Figure 9.10 is the addition of a controlled outlet mechanism for the permanent storage pool. Lowering this pool to a lower level will minimize the effect of an ice layer and maximize the storage available once the lower control is closed and the large spring melt occurs. The poor under-ice water quality concerns will be minimized. The "reclaimed" storage volume will equal most of the permanent pool and all of the water quality volume. The storage of all phases of the melt sequence means that solubles will be

Figure 9.9 Simple Meltwater Storage



held, volume will be stored, and particulates will have a chance to both adsorb soluble pollutants and settle.

One caution for this system is that the permanent pool could completely freeze or possibly disappear entirely if the drawdown is complete. Since maintaining a healthy biological system is part of a successful detention system, it is recommended that the permanent pool not be drawn too far down such that total freeze-up or elimination occurs.

The Importance of Baseflow, Inlet and Outlet Design in Ponds

Baseflow

The problems that develop under ice could be overcome in situations where baseflow is sufficient to keep the water refreshed enough to avoid anaerobic conditions and pollutant build-up. An assessment (in most cases a visual estimate) of the rate of inflow from baseflow expected over

Figure 9.10 Lowered Permanent Pool Control

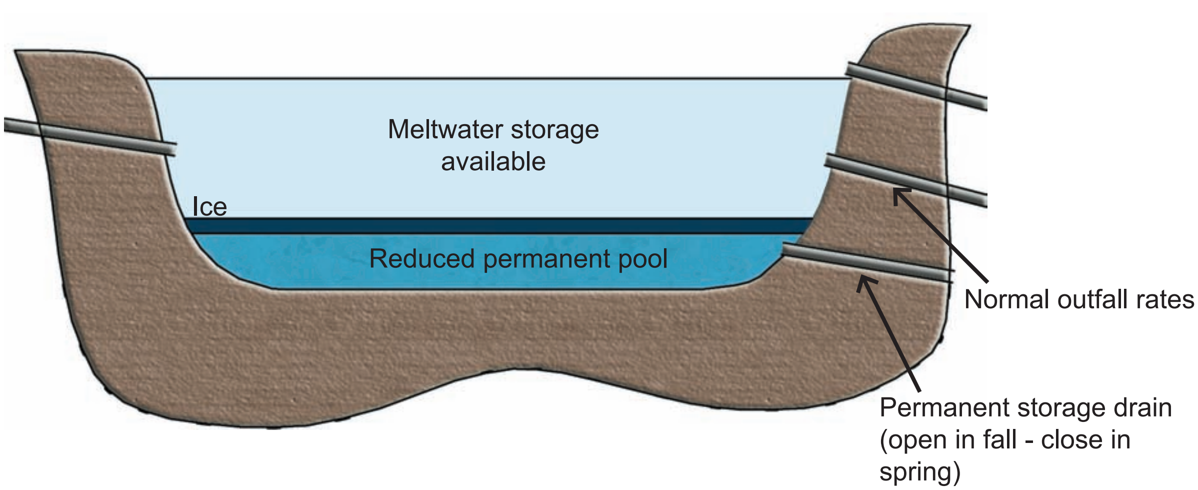
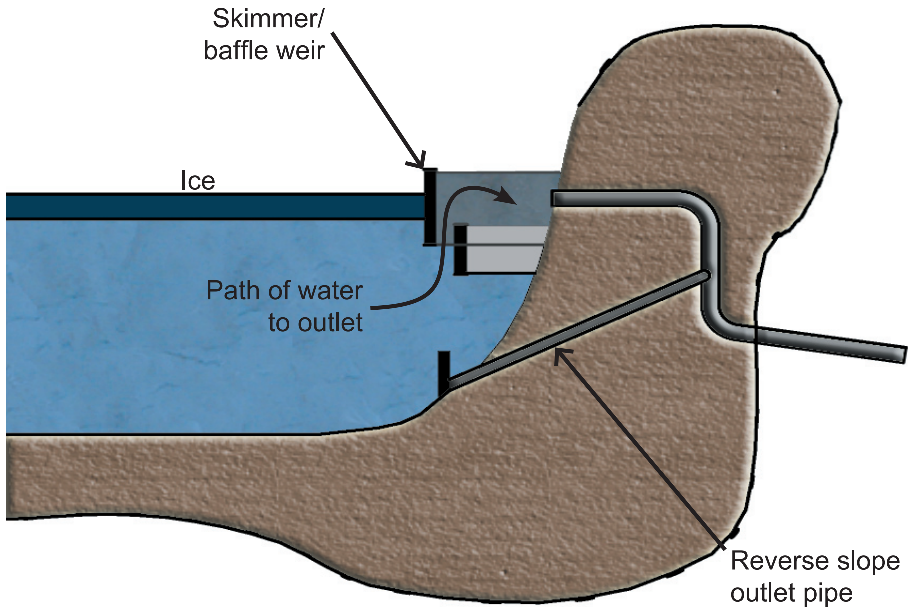


Figure 9.11 Drawing Outflow Water from Below the Ice



a winter could form the basis for establishing a drawdown level for the permanent pool. That is, the volume could be designed to be replaced on a frequency determined to avoid the depletion of oxygen and keep pollutant levels below toxic levels. Information on the source and characteristics of the inflow can also be important to pond design levels.

The total absence or occurrence of intermittent baseflow should favor a very low permanent pool level if an active management approach can be pursued.

Inlet and Outlet Design

One of the biggest problems associated with proper pond operation during cold weather is the freezing and clogging of inlet and outlet pipes. Some general design suggestions to avoid these problems are listed in Chapter 12.

Details on various outlet configurations are also suggested in the design sheets in Chapter 12. Some basic outlet concepts, however, should be mentioned. Perhaps as important as the layer of ice over the permanent pool is the blockage or hindrance of outflow from a pond because of a frozen outlet. There is a need to get water from under an ice layer to exit in a manner that does not cause splashing or gradual freezing of layer after layer of outflow. Drawing water from below the ice via a reverse sloped outlet pipe and installation of a skimmer device (baffle weir) that draws water from below the ice are two options shown in Figure 9.11.

Bioretention

Table 9.3 notes that bioretention can be of marginal effectiveness for treating meltwater because of the dormancy of the vegetation during the cold season. However, the incorporation of some sump storage into the design of any bioretention system will provide an opportunity to route and collect meltwater and begin the filtration and infiltration processes. The only adaptation then that should be needed is the incorporation of some storage as part of the system. Once relatively “warm” meltwater begins to accumulate in a bioretention system, some downward migration will likely begin and the system will activate.

Vegetated Conveyance

Routing runoff over pervious drainage surfaces is a management method to promote the infiltration

Table 9.3 Applicability of BMPs for cold climate use			
BMP Family	BMP	Classification	Notes
Pollution Prevention	Housekeeping practices	Yes	Focus on rapid clean-up of paved surfaces after snowmelt
	Atmospheric control	Marginal	Control of auto emissions and industrial output usually not under local control, but exposed winter soils are controllable
	Chemical controls	Yes	Salt management and chemical spill control can be local programs
	Animal waste management	Yes	Strict waste control can be covered in local ordinance
	Streambank stabilization	Yes	Attention to local erosion sites can reduce ice damage and sediment load from high spring flows
Runoff Volume Minimization	Natural area conservation	Yes	Preserving pervious areas for meltwater to infiltrate is effective way to control volume
	Soil amendments	Yes	Enhancing soil permeability will increase infiltration of meltwater
	Reduction of impervious surface	Yes	Preserving pervious areas for meltwater to infiltrate is effective way to control volume and to minimize mobilization of pollutants
	Grass drainage channel	Yes	Routing meltwater over a pervious surface will yield some reduction in flow and improved water quality
	Rain barrel/ cistern	Marginal	Capturing meltwater from a building will reduce volume but ice build-up could be a problem unless collection occurs below frostline
	Permeable pavement/ blocks	Yes	Recent research has shown this approach to be successful in cold climates when properly installed and maintained, and when sanding kept to a minimum
	Soakaway pit/ drywell (designed so as not to qualify as a Class V injection well)	Yes	Effective as long as system is installed below the frostline to avoid ice build-up
	Stormwater planter	Marginal	These are designed more for the growing season, but they do provide a sump area for runoff to collect and will infiltrate some of the volume
	Rooftop garden	Yes	Recent research has shown that slow melting in the spring reduces the volume running off of roof surfaces

Table 9.3 Applicability of BMPs for cold climate use

BMP Family	BMP	Classification	Notes
Temporary Construction Sediment Control	Pre-construction planning	Yes	Focus on sequencing to avoid open soils during winter and on limited grading prior to freeze-up
	Resource protection	Yes	Buffers reduce runoff by providing infiltration potential
	Runoff control	Yes	Stable drainageways and sediment basins assure erosion control and provide storage opportunities for spring meltwater
	Perimeter control	Yes	These practices are especially effective during winter construction
	Slope stabilization	Yes	These must be installed prior to freeze-up to be effective; they must be checked often and maintained all winter
	Stabilized soil	Marginal	Seeding, blankets and sprayed stabilizers must all be in place and working before freeze-up; if necessary, blankets can be laid and held in place with sandbags or rock logs
	Inspection and maintenance	Yes	Essential for proper operation all winter
Bioretention	Rain garden	Marginal	By definition, these are growing season practices, but they do provide a sump area for storage and some infiltration during a melt
	Depressed parking islands	Yes	These can provide needed storage during the cold season and for spring runoff events; vegetation will not be a factor during winter
Filtration	Media filter	Yes-to-marginal	Surface systems need to be fully dry before freeze-up for these to work properly; sub-grade systems can be very effective for meltwater treatment
	Surface vegetative filter	Marginal	Vegetative filtering is reduced once vegetation dies back in the fall; some physical filtering will occur if vegetation density and depth are sufficient
	Combination filter	Yes-to-marginal	See comments above
Infiltration	Trench	Yes with caution	Effective when designed, installed and maintained properly; caution applies to limitations on source area to avoid high concentrations of Cl and toxics
	Basin	Yes with caution	See above comment
Stormwater Ponds	Forebay	Yes	Effective if designed with enough available volume to accommodate meltwater in the spring

Table 9.3 Applicability of BMPs for cold climate use			
BMP Family	BMP	Classification	Notes
Stormwater Ponds (continued)	Storage components	Yes	Adaptations must be made to allow meltwater runoff to receive appropriate amount of treatment (see discussion following in this section); treatment effectiveness usually lower than warm weather
	Outlet	Yes	Proper design of the outlet structure can be the key to ponding effectiveness
Constructed Wetlands	Forebay	Yes	See comment for forebay above
	Storage components	Yes-to-marginal	Volume will be less than typical pond, but provide location for storage, some infiltration, filtration and some microbial activity; biological activity at a minimum
Supplemental Treatment	Proprietary sediment removal	Yes	These devices are typically installed below ground and below the frostline, and can be effective in treating sediment-laden spring runoff
	Catch basin insert	Marginal	The location of these in a very cold location often leads to icing conditions; can be marginally effective for solids even if frozen
	Wet vault	Yes	See comment for proprietary devices
	Chemical treatment	Yes	These systems are designed to inject treatment chemicals for all flows
	Floatable skimmer	Yes-to-marginal	Proper installation of a floatable skimmer or baffle weir will allow water to pass even when thick ice is present; draws water from below ice layer
	Sorbents	Yes	These absorb chemicals usually in sub-grade systems
	Thermal protection	No	Do not apply to winter conditions
	Biological additives	Yes	See comment for chemical treatment

of water and reduce runoff volumes. Previous discussion in this paper described both the promise and the problems associated with these systems in cold weather. In essence, any infiltration should be considered an extra benefit, but the systems should not be relied upon during winter conditions to operate as well as they do during warmer weather.

Some considerations to keep in mind for these systems are included in Chapter 12.

Snow and Ice Management

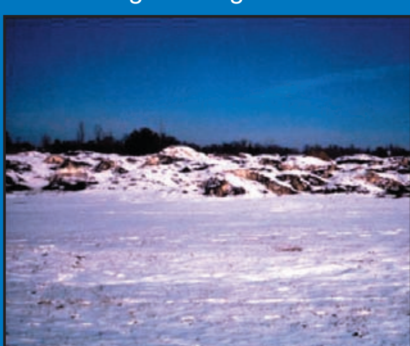
Dealing with the accumulation, removal and disposal of snow and ice is not a stand-alone BMP, but rather it encompasses many public works practices that potentially impact on the quantity and quality of meltwater runoff. Practices are as variable as the number of governmental public works departments and commercial maintenance companies providing services. Local snow

Examples of Proper Snow Management Practices

Figure 9.12a Snow Plowed Off Parking Area Onto Flat Grassed Area

Figure 9.12b Snow Plowed Off Parking Lot Over Curb and Onto Grassy Depression

Figure 9.12c Snow Collected, Removed, and Transported Off-Site to Large Storage Area



removal does not usually involve collection and removal to a remote site. Rather, it is typically a matter of plowing to the side of the road or the far ends of the parking facility. Little thought is given to the fact that this snow will melt in the spring and flow into a receiving water or into a conveyance line that will flow to a receiving water.

Options for disposal of snow removed via neighborhood street and major roadway plowing are usually quite limited. The common Minnesota practice of pushing piles back from the paved surface as far as possible is encouraged. Research has shown that up to 90% of the pollution accumulated next to roadsides over the winter is deposited within about 25 feet of the road surface. Keeping the melt from this area off of the paved surface to the maximum extent possible is a positive water quality management strategy. Allowing it to soak into the ground is a good first step, followed by exposure of the melt to particulates in the roadside area so adsorption can occur.

Commercial and industrial areas that plow their parking and paved areas into big piles on top of the pavement could greatly improve the management of runoff if instead they dedicated a pervious area within their property for the snow. Even pushing the plowed snow up and over a curb onto a pervious grassed area will provide more treatment than simply allowing it to melt on a paved surface and run off into a storm sewer. (See sidebar Figures 9.12a-c)

As mentioned previously, alternatives to NaCl for road salting are not currently feasible because of cost (high relative to NaCl) and secondary environmental effects (like high BOD). Until such alternatives become available, a wise-use ethic should be the goal of every salt user. Adaptations in equipment are always being evaluated by Mn/DOT, which continually updates its statewide fleet with improved equipment. Passing down its experience and knowledge on these improvements is an important role for Mn/DOT. Adequate driver training on application methods and monitoring of driver salt use are other approaches to wiser salt use.

There has been a shift in recent years by many public works departments to reduction in anti-skid sand and greater use of salt. This shift has been propelled by the high cost of removing sand from street surfaces and stormwater conveyance and treatment systems. If this trend continues, the adverse impact of salt on Minnesota's receiving waters is likely to increase. As difficult as sand is to deal with, it is generally inert and can be easily removed. Salt is a conservative substance that readily migrates into soil, ground water, lakes and streams, causing problems at each step along the way. A continued state program to reduce use, keep storage areas covered, educate salt handlers and improve equipment is essential to keep salt loads down as we change to greater application percentages of pure salt.

Finally, reduction in overall salt use has always been perceived as competing with driver safety. The progress made in more effective salt application techniques will hopefully be adopted by all applicators and show how the two important goals of environmental protection and driver safety can co-exist. The ultimate approach must balance safety, economics, and environmental considerations.

High Sediment Load

The addition of sand as an anti-skid agent to roads and parking lots can lead to the accumulation of sand in conveyance systems and pond inlets, as well as the plugging of infiltration and filtration systems. Frequent inspection of these facilities is essential, particularly in the early spring when large amounts of sand are washed from paved surfaces into runoff conveyance and treatment systems. Examining the need for clean-out of conveyance lines, dredging of forebays and ponds, and debris removal from infiltration/filtration systems should be a part of an annual inspection and maintenance program.

Many of the newly available proprietary sediment removal devices (see Chapter 12) are intended to be installed below the frostline and, therefore, operate as designed under all weather conditions. These systems come with many different design approaches, but as a group they provide a very good method of pre-treating inflow into primary runoff treatment devices during the winter and spring runoff seasons.

Secondary Practices

There are some BMPs that are not generally recommended for water quantity or quality improvement because they are not as effective as other available techniques. There are situations, however, when these less used BMPs could have a possible cold climate role. One example of this is the use of dry detention ponds. These ponds have a limited long-term water quality benefit, although there is some benefit from the fact that a portion of the stormwater infiltrates while it awaits outletting. A secondary benefit could be achieved by routing overflow meltwater from a non-functioning practice into a dry detention pond to obtain even a small amount of infiltration and settling.

VII. References and Annotated Bibliography

References

Andrews, W.J., J.R. Stark, A.L. Fong and P.E. Hanson, 1999. Ground-water quality along a flowpath in surficial outwash aquifer in the Upper Mississippi River Basin The influence of land use. Hydrological Science and Technology, 15(1-4):66-75. Special Issue: 4thUSA/CIS Joint Conference, November 7-10, 1999, San Francisco. American Institute of Hydrology.

Bäckström, M., 1999. Series of Papers in Licentiate Thesis, Luleå University of Technology.

Bäckström, M., 2002. Series of Papers in Doctorate Thesis, Luleå University of Technology.

Buttle, J.M., 1990. Effect of suburbanization upon snowmelt runoff. Hydrol. Sci. Jour.,35(3):285-302.

Caraco, D. and R. Claytor, 1997. Stormwater BMP Design Supplement for Cold Climates. Center for Watershed Protection, Ellicott City, Maryland, USA.

Colbeck, S.C., 1978. Physical aspects of flow through snow. Advances in Hydroscience,11: 165-206.

Colbeck, S.C., 1981. A simulation of the enrichment of atmospheric pollutants in snow cover runoff. Water Res. Research, 17(5): 1383-1388.

Colbeck, S.C., 1991. The layered character of snow covers. Rev. Geophys., 29(1): 81-96.

Granger, R.J., D.M. Gray and G.E. Dick, 1984. Snowmelt Infiltration to Frozen Soils. Canadian Journal of Earth Science, 21:669-677.

Isabelle, P.S., L.J. Fooks, P.A. Kenny and S.D. Wilson, 1987. Effects of roadside snowmelt on wetland vegetation: An experimental study. Jour. of Envir Management, 25:57-60.

Jeffries, D.S., 1988. Snowpack release of pollutants. National Water Research Institute (Burlington, Ontario, Canada), Report No. 88-06.

Marsalek, J., 2003. Road salts in urban stormwater: An emerging issue in stormwater management in cold climate. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.65-74.

Marsalek, J., G.L. Oberts, K. Exall and M. Viklander, 2003. Review of the operation of urban drainage systems in cold weather: Water quality considerations. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.1-11.

Marsalek, P.M., W.E. Watt, J. Marsalek, and B.C. Anderson, 2000. Winter flow dynamics on an on-stream stormwater management pond. Water Qual.Res. Jour. Canada,35(3): 505-523.

Marsh, P. and M-K. Woo, 1984. Wetting front advance and freezing of meltwater within a snow cover - 1. Observations in the Canadian Arctic. Water Res. Research,20(12): 1853-1864.

Matheussen, B.V. and S.T. Thorolfsson, 2003. Estimation of snow-covered area for an urban catchment using image processing and neural networks. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.315-326.

Natural Resources Conservation Service (NRCS), 1984. Engineering Field Manual for Conservation Practices. U.S. Department of Agriculture, Washington, D.C.

Novotny, V., D.W. Smith, D.A. Kuemmel, J. Mastriano and A. Bartošová, 1999. Urban and Highway Snowmelt: Minimizing the Impact on Receiving Water. Water Environment Research Foundation (WERF), Project 94-IRM-2.

Oberts, G.L., 2003. Cold climate BMPs: Solving the Management Puzzle. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.13-31.

Oberts, G.L., P.J. Wotzka and J.A. Hartsoe, 1989. The Water Quality Performance of Select Urban Runoff Treatment Systems, Metropolitan Council, Publication No.590-89-062a, 170 p.

Sansalone, J.J. and S.G. Buchberger, 1996. Characterization of metals and solids in urban highway winter snow and spring rainfall-runoff. Trans. Res. Record, 1523:147-159.

Semadeni-Davies, A., 2003. Response surfaces for climate change impact assessments in urban areas. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.269-279.

Shaw, D. and R. Schmidt, 2003. Plants for Stormwater Design. Minnesota Pollution Control Agency, 369 p.

UNESCO, 2000. Urban Drainage in Specific Climates: Vol.II. Urban Drainage in Cold Climates. ed. by S. Saegrov, J. Milina and S.T. Thorolfsson. IHP-V, Technical Documents in Hydrology, No. 40, Vol. II, Paris.

Westerström, G., 1984. Snowmelt runoff from Porsön residential area, Luleå, Sweden. In Proceedings of the Third International Conference on Urban Storm Drainage, Gothenburg, Sweden, June 4-8, 1984, pp. 315-324.

Wheaton, S.R. and W.J. Rice, 2003. Siting, design and operational controls for snow disposal sites. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.85-95.

Annotated Bibliography

Eastern Snow Conference Series
Research into cold climate hydrology began in earnest in the U.S. with the activities of the Eastern Snow Conference (ESC - http://www.easternsnow.org/) in the early 1940s. This long and successful series of annual conferences continues today. This series has produced a myriad of papers that began the modern era of research into snow build-up and melt models.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL)
CRREL(http://www.crrel.usace.army.mil/) also has a long history of studying the physical processes associated with snow, including the classic works of S.C. Colbeck and many others, helped to define the physics of snow accumulation and the movement of water and its contents from that snowpack after it melts. In 1966, a CRREL publication (Bates and Bilillo, 1966) noted that nearly half of the land mass in the Northern Hemisphere, and essentially everything north of 40˚N latitude can be classified as “cold regions” based upon air temperature, snow depth, ice cover and frozen ground.

International Association of Hydraulic Engineering and Research
Meltwater runoff management has been the topic of several sessions at IAHR/IAWQ international conferences on urban storm drainage, including those in Banff in 1972, Gothenburg in 1984 and Niagara Falls in 1993. A 2005 cold climate session is planned at the August conference in Copenhagen.

International Conference on Urban Hydrology Under Wintry Conditions, March 19-21, 1990, Narvik, Norway
Proceedings from this conference are generally not available. Gary Oberts has a set of papers delivered at the conference, but a proceedings was not published. This was the first conference dedicated strictly to cold climate hydrology and water management. It brought together researchers from Europe, Japan, Canada and the US to present ideas on meltwater management.

Center for Watershed Protection's Stormwater BMP Design Supplement for Cold Climates (Caraco and Claytor, 1997) and revision session in Maine (2003)
This CWP publication was the product of a workshop held in St. Paul in the fall of 1997. The document is available from CWP at http://www.cwp.org/cold-climates.htm .

Water Environment Research Foundation's Urban and Highway Snowmelt: Minimizing the Impact on Receiving Water, by V. Novotny, D.W. Smith, D.A. Kuemmel, J. Mastriano, and A. Bartošová, 1999. WERF Project 94-IRM-2.
This WERF publication is a collection and synopsis of many pieces of cold climate research and data, primarily from the US and Canada. The focus is on highways, but the report is very informative on all aspects of urban cold climate runoff behavior.

UNESCO International Hydrological Programme, Urban Drainage in Specific Climates - Volume II Urban Drainage in Cold Climates, Edited by S. Saegrov, J. Milina and S.T. Thorolfsson, 2000. IHP-V, Technical Documents in Hydrology, No. 40, Vol. II.
This UNESCO report has a decidedly European focus, but in doing so, it collects many important research summaries and indications of the current state-of-the-art on cold climate hydrology and water management.

First International Conference on Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden and follow-up journal series in Water Science and Technology, Vol. 48, No. 9, 2003.
Researchers from predominantly the Scandinavian countries, Canada and the US presented a series of papers on cold climate water management. Many of the papers were published in the referenced WST periodical from 2003.

An International Conference - Stormwater Management in Cold Climates, November 3-5, 2003, Portland, Maine
This conference was a US version of the Riksgränsen conference referenced above. There was a markedly New England tone to the papers, but speakers from Canada and Scandinavia also presented. The CWP held a special session to receive input on revising its Cold Climate BMP Supplement, but funding for the reissuance has not been sufficient as yet. Although not all speakers prepared a paper, many are available for viewing and download at http://www.cascobay.usm.maine.edu/proceed.html

Unified Stormwater Sizing Criteria for General and Sensitive Receiving Waters

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VOLUME 2 - TECHNICAL AND ENGINEERING GUIDANCE

Chapter 10

Unified Stormwater Sizing Criteria for General and Sensitive Receiving Waters

This chapter outlines revised and suggested procedures for sizing stormwater practices for regular and special waters of the state.

Contents

I. Introduction

A unified framework is presented for addressing stormwater sizing criteria in the context of the 2003 MPCA Construction General Permit (CGP) and local stormwater management requirements, if chosen by the local community. The unified approach addresses five different sizing criteria, as shown below:

- recharge
- water quality
- channel protection
- overbank flooding
- extreme storms

Once the basic stormwater sizing criteria are defined for regular waters, the chapter then describes how they can be adapted to provide greater protection for special and other sensitive waters of the state.

The goal of the unified framework is to develop a consistent approach for sizing stormwater practices that can:

- **Perform Effectively**
  Manage enough runoff volume to actually solve the stormwater problem it is intended to address.

- **Perform Efficiently**
  Manage just enough runoff volume to address the problem but not over-control it. More storage is not always better, and can greatly increase construction costs.

- **Be Simple to Administer**
  Be understandable, relatively easy to calculate with current hydrologic models, and workable over a range of development conditions and intensities. In addition, criteria should be clear and straightforward to avoid needless disputes between design engineers and plan reviewers when they are applied to development sites, while also eliminating any competitive disadvantages that are created when uniform regulations do not exist.

- **Promote Better Site Design**
  Be structured in a manner so that property owners have real incentives to reduce storage volumes (and costs) by applying better site design techniques (Chapter 4) to receive stormwater credits (Chapter 11).

- **Be Flexible to Respond to Special Site and Receiving Water Conditions**
  Be expanded to adequately protect unique receiving waters, and to be reduced or eliminated in certain development situations where they are inappropriate or infeasible.

A unified framework for sizing stormwater practices provides greater consistency and integration among the many city, county, watershed organization, regional and statewide stormwater requirements and ordinances adopted over the years. It also establishes a common framework to address all stormwater problems caused by development sites over the entire spectrum of rainfall events. The unified approach still provides communities with flexibility to develop stormwater criteria adapted for local conditions, within overall context of the 2003 MPCA CGP. In addition, Chapter 8 presents more detailed guidance on the appropriate design assumptions for accepted hydrologic models used in design.

II. Overview of the Unified Stormwater Sizing Framework

This section reviews the key stormwater sizing concepts and terminology used in the chapter and presents an overview of the unified framework for managing stormwater in Minnesota. The terminology and abbreviations associated with various stormwater sizing criteria can be confusing at times, as the state and local reviewing authorities often define or interpret them in a slightly different manner. The specific meanings of important terms used in this chapter are described in Table 10.1.

In the course of a year, anywhere from 35 to 50 precipitation events fall on Minnesota. Most events are quite small but a few can be several inches in depth. A rainfall frequency spectrum describes the average frequency of the depth of precipitation events (adjusted for snowfall) that occur during a normal year. Figure 10.1 provides an example of a typical rainfall frequency spectrum for Minnesota (MSP airport) which shows the percent of rainfall events that are equal to or less than an indicated rainfall depth. Similar graphs for other locations are contained in Appendix B. As can be seen, the majority of storms are relatively small but a sharp

Table 10.1 Review of Key Stormwater Sizing Terminology	
Term	**Definition**
Better Site Design (BSD)	Better site design refers to the application of non-structural practices at new development sites to reduce site impervious cover, conserve natural areas, and use pervious areas to more effectively treat stormwater runoff. Also known as low impact development. See also Chapter 4.
Channel Protection (V_{cp}) Volume	Refers to the recommended runoff storage volume needed to control post-development bankful and sub-bankful flow velocities so they do not increase erosion in downstream channels. Typically, detention and/or extended detention of intermediate sized storms (0.5 to 2.0 inches of rainfall) are used for this purpose. The channel protection volume is denoted as V_{cp}.
Design Storm	An engineering term for a single rainfall event with a defined intensity, duration and statistical recurrence interval commonly ranging from 0.5 years up to 100 years. These single event storms are based on long-term rainfall data, and are used in hydrologic models to predict the peak discharges and runoff volumes associated with each type of storm. Unless otherwise indicated, all design storms in this chapter have a 24-hour duration and a Type II distribution.
Detention Time	Various definitions for detention time exist in hydraulic manuals and in help screens in computer models. For this Manual, a simple method of computing detention time is recommended. Detention time is equal to the length of time starting at basin full (for a specific design storm) and ending when either the basin is dry (filtration or infiltration) or the basin has attained normal water level (stormwater ponds or constructed wetlands).
Extreme Storm Volume (V_{p100})	The greatest runoff storage volume is used to detain the peak discharges of infrequent but very large storm events to pre-development levels. The 100-year design storm, which has a statistical recurrence interval of occurring once in a hundred years, is used by most communities. Extreme floods can cause catastrophic damage and even loss of life. The storage volume needed to store and detain them is denoted as $V_{p100.}$ Note that storms more "extreme" than the 100-year event do occur in Minnesota. The extreme term is used relative to other volume terms for perspective.
Hydrologic Soil Group (HSG)	HSG is an USDA-NRCS designation given to different soil types to reflect their relative surface permeability and infiltrative capability. Group A soils have low runoff potential and high infiltration rates; Group B soils have moderate infiltration rates; Group C soils have low infiltration rates; and Group D soils have high runoff potential with very low infiltration rates and consist chiefly of clay soils (TR-55, 1986). See Chapter 8 and Chapter 12 for further discussion and numbers for A-D soils.

Table 10.1 Review of Key Stormwater Sizing Terminology	
Term	**Definition**
Other Sensitive Receiving Waters	In addition to the special waters defined above in the CGP, there are other receiving waters that merit additional management attention because of their sensitivity, as defined by various state and local entities. Recommended stormwater criteria for these waters are provided later in this Chapter, including specific stormwater criteria to protect: ► Lakes (most-sensitive and sensitive) ► Wetlands (susceptible and non-susceptible) ► Drinking Water Source Areas (ground and surface water) ► Impaired Waters (computable and non-computable)
Overbank Flood Volume (V_{p10})	Refers to the runoff storage volume needed to prevent an increased frequency of floods that spill out of the channel and onto the floodplain where they may cause damage to conveyance systems, property and infrastructure. Overbank flooding is normally controlled by detention of post-development 10-year storm so that pre-development (see entry following in table) peak discharge rates (as defined by state or local agencies) are maintained, and is denoted by V_{p10} , (assuming that the local review authority requires control of the 10-year storm event).
Permanent Pool Volume (V_{pp})	The CGP requires that all wet sedimentation basins contain a permanent pool with a volume of 1,800 cubic feet of storage for each acre that drains to the basin. This equates to 1/2 inch of runoff per acre. The permanent pool must reach a minimum depth of three feet, stay below 10 feet, and be configured to minimize scour and resuspension of solids.
Pre-Development Conditions	The term pre-development conditions can be interpreted in many different ways. The MPCA uses land cover conditions immediately preceding the current development project as the CGP pre-development condition, whereas many other local and watershed managers use a more natural definition, such as meadow or woodlands in good shape (stated in a manner to help in CN selection). Obviously the CGP version will usually result in a smaller net runoff increase for most land that has anything but a natural cover. It is recommended that the CGP definition be used for its intended purpose as part of state permit issuance, but that the more natural pre-development condition be used if a stormwater manager wants to assume a more conservative condition. See also the discussion in Chapter 8.
Recharge Volume (V_{re})	Refers to the recommended volume of runoff which should be spread over pervious areas and otherwise infiltrated into the soil to promote ground water recharge. The recharge volume is denoted as V_{re} and is normally included as part of the water quality volume.

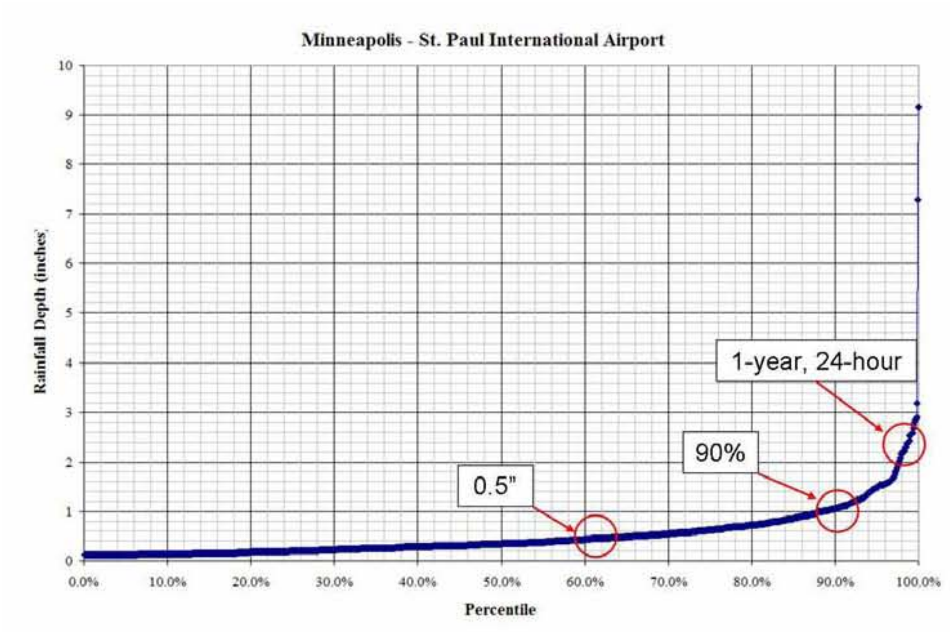
Table 10.1 Review of Key Stormwater Sizing Terminology	
Term	**Definition**
Special Waters	A list of eight categories of receiving waters are specifically designated as "special waters" in Appendix B.1-8 of the MN Construction General Permit (2003). Additional BMPs and enhanced runoff controls are required for discharges to the following special waters defined in the CGP: ▶ Wilderness areas ▶ Mississippi River (Lake Itasca through Morrison County) ▶ Scenic or recreational river segments ▶ Lake Superior ▶ Lake trout lakes ▶ Trout lakes ▶ Scientific and natural areas ▶ Trout streams
Total Storage Volume (V_{ts})	For ponds built under the requirements of the CGP, the total storage volume required is the sum of the permanent pool volume (V_{pp}) plus the water quality volume (V_{wq})
Water Quality (V_{wq}) Volume	Generic term for the storage volume used to capture, treat and remove pollutants in stormwater runoff. It is normally expressed as a volume (watershed-inches or acre-feet) and is denoted by V_{wq} . For ponds and wetlands, the MCPA CGP defines it as the volume of live storage above the permanent pool (above the dead storage) used for water quality. For non-pond BMPs, MPCA defines the water quality volume in the same manner as the general definition above.

upward inflection point occurs at about one-inch of rainfall.

The unified sizing approach seeks to manage the entire frequency of rainfall events that are anticipated at development sites. The runoff frequency spectrum is divided into five management zones, based on their relative frequency, as follows:

- **Recharge**: targets rainfall events that create little or no runoff but produce much of the annual ground water recharge at the site.
- **Water Quality**: targets rainfall events that deliver the majority of the stormwater pollutants at the site.
- **Channel Protection**: targets storms that generate bankful and sub-bankful floods in the stream that cause channel enlargement.
- **Overbank Floods:** targets large and infrequent storm events that spill over to floodplain and cause damage to infrastructure,
- **Extreme Storms**: controls the largest, most infrequent and most catastrophic floods that threaten property and public safety (e.g., commonly known as the 100-year storm).

The goal of stormwater management is to provide effective control over each management zone in order to produce post-development hydrology that most closely resembles state or locally defined pre-development conditions at the development site. Each criterion defines a unique storage volume that should be managed at the site. They are best understood visually as a layer cake that has progressively larger layers from bottom to top, with recharge volume being the narrowest layer at the bottom and extreme storm control comprising



the thickest layer at the top. Figure 10.2 shows how the five storage volumes interact in a stormwater BMP.

The unified approach proposes to standardize the basic approach to stormwater design for regular waters of the state, while also defining certain site conditions or development scenarios where individual stormwater sizing criteria may be relaxed or waived. The unified framework also clearly indicates when sizing criteria need to be enhanced to provide a higher degree of water

Table 10.2 Overview of Unified Stormwater Sizing Criteria	
Target	**Current State or Local Sizing Criteria**
Recharge (V_{re}) or Infiltration	**Regular Waters:** None required, although recharge and infiltration are strongly encouraged through better site design and stormwater credits. **CGP Special Waters:** Full infiltration of the excess runoff volume from the two year-24 hour storm event is one option contained in the CGP to meet the requirement for temperature control for trout streams. **Other Sensitive Receiving Waters:** Recharge recommended as a local option. Recharge may be restricted or prohibited in certain settings, as outlined in Section III of this chapter (Recharge and Infiltration Criterion)
Water Quality (V_{wq})	**Regular Waters:** Apply MPCA Sizing Rule 1 or 3 (see Section IV of this chapter) in 2003 GCP, depending on BMP used. **CGP Special Waters:** Apply MPCA Sizing Rule 2 or 4 in 2003 GCP, depending on BMP used. Additional BMPs required under CGP Appendix A (B) for special waters. **Other Sensitive Receiving Waters:** Recommend expanded sizing criteria for most-sensitive lakes, trout streams (in CGP), susceptible wetlands and impaired waters, as described later in this chapter.
Channel Protection (V_{cp})	**Regular Waters:** No current state requirement. Some local reviewing authorities do require 24-hour extended detention of the 1-year, 24-hour design storm. It is recommended that communities adopt this criterion when revising or adopting local stormwater ordinances (and eliminate two-year peak discharge requirements). **CGP Special Waters:** One- and two-year design storm peak discharge and volume control required in four special water categories (wilderness, trout lakes, lake trout lakes, and scientific and natural areas). **Other Sensitive Receiving Waters:** 12-hour extended detention of the 1-year, 24- hour design storm is highly recommended for trout streams, with other sensitive receiving waters recommended at a 24-hour detention time.
Overbank Flood (V_{p10})	**Current Local Requirement:** Varies, but typically involves either 10-year design storm peak discharge control, or a combination of 10- and 25-year design storm peak discharge control. **CGP Special Waters and Other Sensitive Receiving Waters:** No additional requirements.
Extreme Storm (V_{p100})	**Current Local Requirement:** Varies, but frequently involves 100-year design storm peak discharge control. In other cases, peak discharge control is waived if development is excluded from ultimate 100-year floodplain, or an acceptable downstream hydrologic analysis indicates it is not needed. Stormwater BMPs must be designed to provide safe overflow of the 100 year-peak discharge even if extreme storm control is not required at the site. **CGP Special Waters and Other Sensitive Receiving Waters:** No additional requirements.

resource protection for special or other sensitive waters. Table 10.2 profiles the recommended or required sizing criteria for each of the five stormwater management zones for both regular and special waters. The next five sections of the chapter describe each of the standard stormwater sizing criteria, including how they are calculated and the conditions where they may be relaxed or waived. This chapter is a general guide, and designers should always check with their local review authority and the MPCA to determine the appropriate sizing criteria used in their community.

III. Recharge and Infiltration Criterion (V_{re})

The intent of this sizing criterion is to maintain ground water recharge rates at development sites to preserve existing water table elevations and support natural flows in streams and wetlands. Under natural conditions, the amount of recharge that occurs at a site is a function of slope, soil type, vegetative cover, precipitation and evapotranspiration. Sites with natural ground cover, such as forest and meadow, typically exhibit higher recharge rates, less runoff and greater transpiration losses than sites dominated by impervious cover. Since development increases impervious cover, a net decrease in recharge rates is inevitable.

Recharge and/or infiltration criteria offer additional benefits, as they promote more on-site infiltration/filtration of stormwater runoff, and enable communities to offer stormwater credits that reduce the water quality storage volume. Recharge credits provide real incentives to apply better site design techniques at development sites that can reduce the size and cost of stormwater BMPs needed at some sites. To maximize recharge, designers should explore how to use pervious areas for infiltration early in the site layout process.

The recharge volume is considered to be part of the total water quality volume provided at a site and is not an additional CGP requirement (e.g., V_{re} is contained within V_{wq}). Recharge can be achieved either by a structural BMP (e.g., infiltration, bioretention, filter), better site design techniques, or a combination of both.

There are currently no statewide recharge sizing requirements for regular waters in the state of Minnesota, although previous stormwater guidance has strongly promoted recharge and infiltration (MPCA, 2000 and MC, 2001). Also, infiltration can be used as one way to meet the state CGP requirement for permanent stormwater management. Recharge and infiltration are strongly encouraged through better site design and stormwater credits. There are three readily available options for how a community or stormwater manager could determine the amount of runoff to include as the Re_v factor. The three methods for determining recharge volumes are included in the boxes on the following page.

Since there are no current required state infiltration requirements, any of the three approaches that follow could be used. Stormwater managers are cautioned to review local conditions and select a method according to what can logically be expected, keeping in mind that the goal is to match pre-development volumes of infiltration as closely as possible in most cases. However, if the potential for using site development to enhance or increase local infiltration exists, for example through an infiltration basin, managers might choose another method to increase infiltration expectations. The Manual Sub-Committee (MSC) noted infiltration as an area for needed discussion during the next CGP update.

Modifications to Recharge Criteria

Infiltration and recharge of polluted stormwater runoff is not always desirable or even possible at some development sites. Therefore, most communities qualify their recharge and/or infiltration requirements to reflect special site conditions, protect ground water quality, and avoid common nuisance issues. For example, the local review authority may require:

- some form of special pre-treatment of stormwater runoff prior to infiltration for some land cover types and pollution source areas (e.g. parking lots).
- recharge be restricted or prohibited at specific industrial, commercial and transport-related operations designated as potential stormwater hotspots (PSH). Chapter 13 defines the range and type of

Recharge Option 1: CGP Method for Providing Recharge and Infiltration

First, while the state has no explicit recharge requirements, the state CGP does suggest infiltration as one option for temperature control for trout streams and their tributaries. This option is defined as infiltration of the excess pre-project runoff volume up to the two-year, 24-hour event (see Chapter 5 for more information). Recharge and/or infiltration are strongly recommended as part of an effective stormwater strategy to protect trout streams and other sensitive receiving waters, as discussed later in this chapter.

Recharge Option 2: Hydrologic Soil Group Method for Providing Recharge and Infiltration

The objective of this approach is to mimic the average annual recharge rate for the prevailing hydrologic soil group(s) (HSG) present at a development site. Therefore, the recharge volume is calculated as a function of annual pre-development recharge for a given soil group, average annual rainfall volume, and amount of impervious cover at a site. This approach usually requires a detailed hydrologic and soils study of the site to determine appropriate infiltration numbers to match conditions before the project.

Recharge Option 3: Wisconsin Method for Providing Recharge and Infiltration

Several states have recently established significant requirements for on-site infiltration of stormwater runoff. One of the most notable examples is the recent Wisconsin NR-151 runoff management rule (State of Wisconsin, 2004) which mandates that between 10 to 25% of the runoff volume produced from the two-year, 24-hour design storm be infiltrated, depending on the land use. In rough terms, the new Wisconsin rule requires from 0.1 to 0.75 watershed-inches of infiltration, depending on site land use and impervious cover.

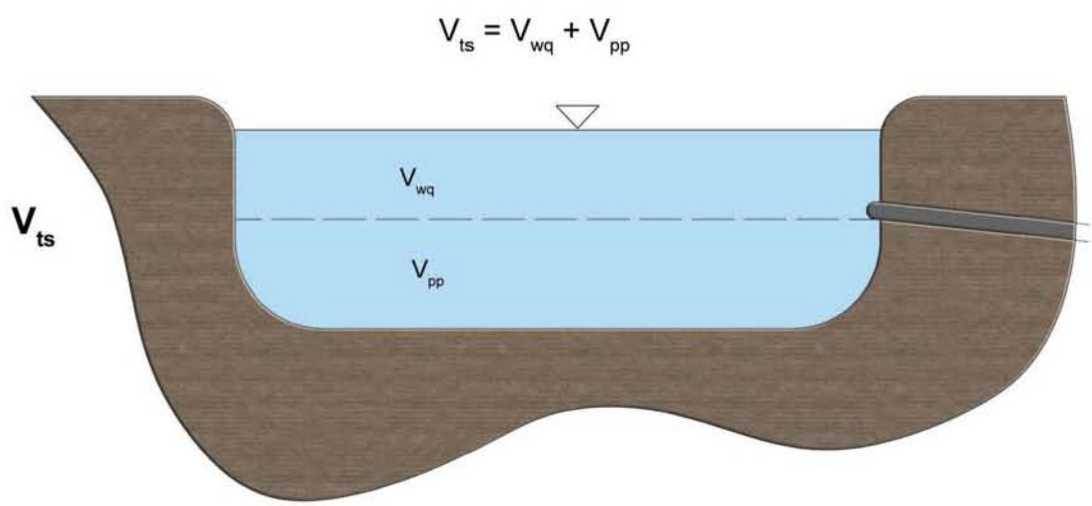
development sites designated as potential stormwater hotspots within Minnesota.

- recharge be prohibited or otherwise restricted within the vicinity of ground water aquifers, wellhead protection areas, individual wells, structures and basins.
- recharge be discouraged within certain geological zones such as active karst and bedrock, and adjacent to steep or unstable slopes.
- recharge be reduced or waived for minor redevelopment projects that have previously compacted soil structures.

IV. Water Quality Criteria

Treatment of stormwater runoff is needed to meet in-stream water quality standards and protect aquatic life and water resources. Extensive monitoring has revealed high concentrations of sediments, nutrients, bacteria, metals, oxygen-demanding substances, hydrocarbons and other pollutants in untreated stormwater runoff (Pitt *et al.,* 2004) and demonstrated their impact on stream and lake quality (CWP, 1999 and CWP, 2003). A range of BMPs can provide a high degree of removal for stormwater pollutants (ASCE, 2004 and Winer, 2001). The 2000 state manual (MPCA, 2000) established a performance goal that BMPs provide a minimum degree of pollutant removal for a defined fraction of stormwater runoff events, which has been operationally defined as 90% sediment removal. A 50% total phosphorus removal can be assured to accompany this removal. Parts of the state CGP reference the 80% Total Suspended Solids (TSS) standard.

The state has defined how to compute the water quality volume for projects that must meet the requirements in the 2003 Construction General Permit. The current MPCA water quality volume criteria is referred to as the “hybrid rule” because it actually encompasses four different rules, depending on the type of BMP used and whether the development drains to regular or special waters.



*V_{wq} equals 1/2" for normal receiving water and 1" for CGP special waters

Designers in the state have traditionally relied on ponds for water quality treatment, so the first water quality rule applies to ponds that drain to regular waters. As illustrated in Figure 10.3, the total storage volume (V_{ts}) has two additive components: dead (or permanent) storage of a half-inch per acre (also stated as 1800 cubic feet per acre) and live (or temporary) water quality storage of one-half inch times the fraction of new impervious cover (IC) for the site. Mathematically, the acre feet of storage needed for basic pond sizing in regular waters is computed as:

Rule 1:

$$V_{ts} = V_{pp} + V_{wq}$$

$$V_{pp} = 0.5\, inches * A * \frac{1}{12}$$

$$V_{wq} = 0.5\, inches * IC * \frac{1}{12}$$

Where:

V_{ts} = *total storage volume in acre - feet*

V_{pp} = *required permanent pool (dead storage) in acre - feet* - *or* - = 1800 *cubic feet of storage per acre draining to pond*

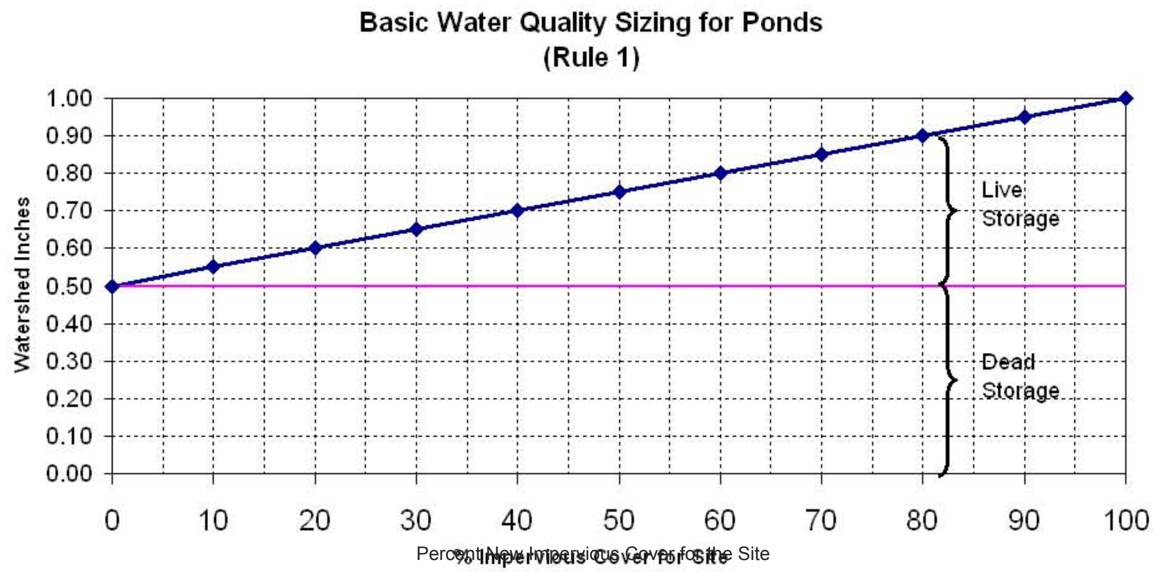
V_{wq} = *required water quality volume (live storage) in acre - feet*

IC = new *site impervious cover, in acres*

A = *total watershed area (in acres) draining to pond*

Figure 10.4 shows the relationship of the two water quality storage components (dead and live) in a pond sized according to Rule 1. In addition, ponds are also required to have a live storage release rate no greater than 5.66 cubic feet per second (cfs) per surface acre of pond area (as measured from the top of the live water quality storage bounce above the permanent pool). For example, if the maximum surface area of the pond created by the V_{wq} is three acres, the allowable maximum discharge rate from the pond would be 16.98 cfs (3 * 5.66). It is important to note that this is a geometrical requirement to achieve an overflow rate that ensures that a five-micron (5μ) sediment particle can be effectively settled within the pond, based on prior work by Pitt (1989). Designers are encouraged to ensure that at least 12 hours of extended detention are provided for the live storage in the pond BMP (using an acceptably sized and protected outlet at the orifice) to ensure an acceptable level of pollutant removal.

The second water quality sizing rule pertains to ponds located within the special waters of the State (Chapter 2) as defined in the CGP. These ponds must have a greater live storage component (V_{wq}) -- one-inch times the fraction of new IC for the site.. The required acre-feet of total storage volume (V_{ts}) needed for ponds draining to special waters is computed as:



Rule 2:

$$V_{ts} = V_{pp} + V_{wq}$$

$$V_{pp} = 0.5\,inches * A * \frac{1}{12}$$

$$V_{wq} = 1.0\,inches * IC * \frac{1}{12}$$

Where:

V_{ts} = *total storage volume in acre - feet*

V_{pp} = *required permanent pool (dead storage) in acre - feet* - *or* -

= 1800 *cubic feet of storage per acre draining to pond*

V_{wq} = *required water quality volume (live storage) in acre - feet*

IC = new *site impervious cover, in acres*

A = *total watershed area (in acres) draining to pond*

The live storage in ponds draining to special waters must also conform to the maximum 5.66 cfs required release rate and should allow for a recommended minimum 12 hour extended detention time.

A third water quality sizing rule contained in the 2003 GCP applies to non-pond BMPs such as infiltration, bioretention and filtering practices. These practices are not explicitly required to have permanent pool storage, although some dead sediment storage is recommended for pre-treatment before discharging into the practice. The basic sizing equation for non-pond BMPs located in regular waters is shown below:

Rule 3:

$$V_{wq} = 0.5\,inches * IC * \frac{1}{12}$$

Where:

V_{wq} = *required water quality volume*

IC = new *site impervious cover, in acres*

The minimum pre-treatment volume recommended (not required in CGP) to protect non-pond BMPs from clogging and increase their longevity is 0.10 watershed inches, as shown in Figure 10.5.

Non-pond BMPs located in special waters must have additional live storage (V_{wq}), as shown below:

Rule 4:

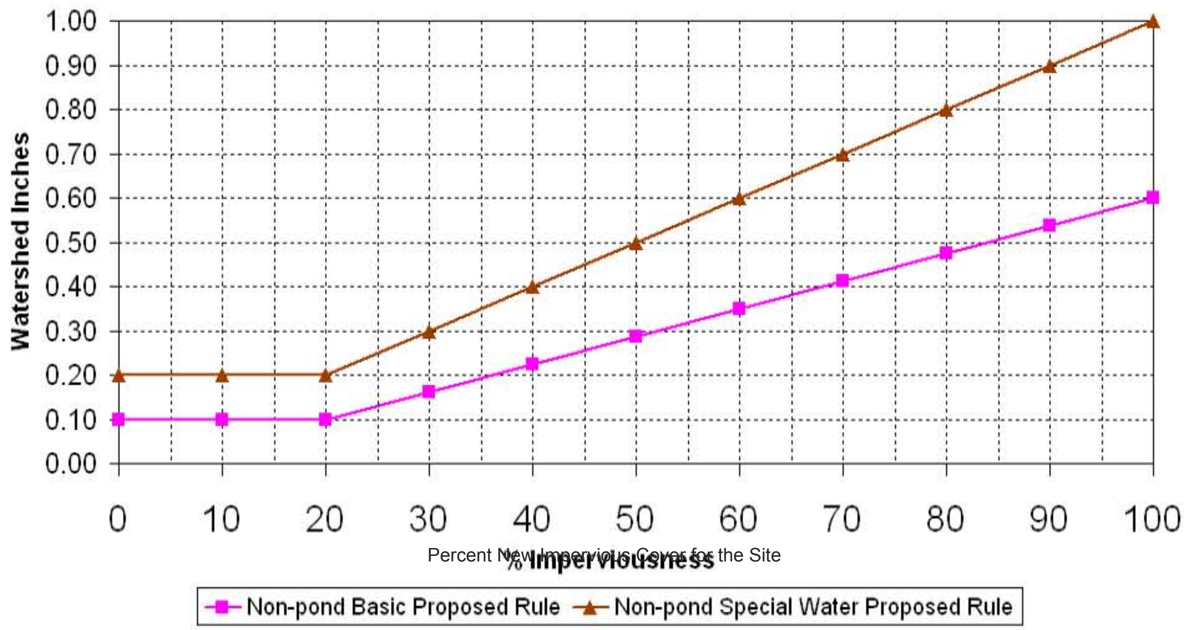
$$V_{wq} = 1.0\,inches * IC * \frac{1}{12}$$

Where:

V_{wq} = *required water quality volume*

IC = new *site impervious cover, in acres*

These non-pond BMPs should have a minimum water quality storage volume of 0.2 watershed inches reserved for pre-treatment, regardless of site impervious cover, as shown in Figure 10.5.



The four water quality sizing rules are compared against each other in Figure 10.6. An even higher degree of phosphorus removal may be needed to protect the most sensitive lakes and susceptible wetlands. Recommended guidance on sizing BMPs for these special receiving waters is provided in Sections IX Lakes and XII Wetlands, respectively.

Modifications to Water Quality Criteria

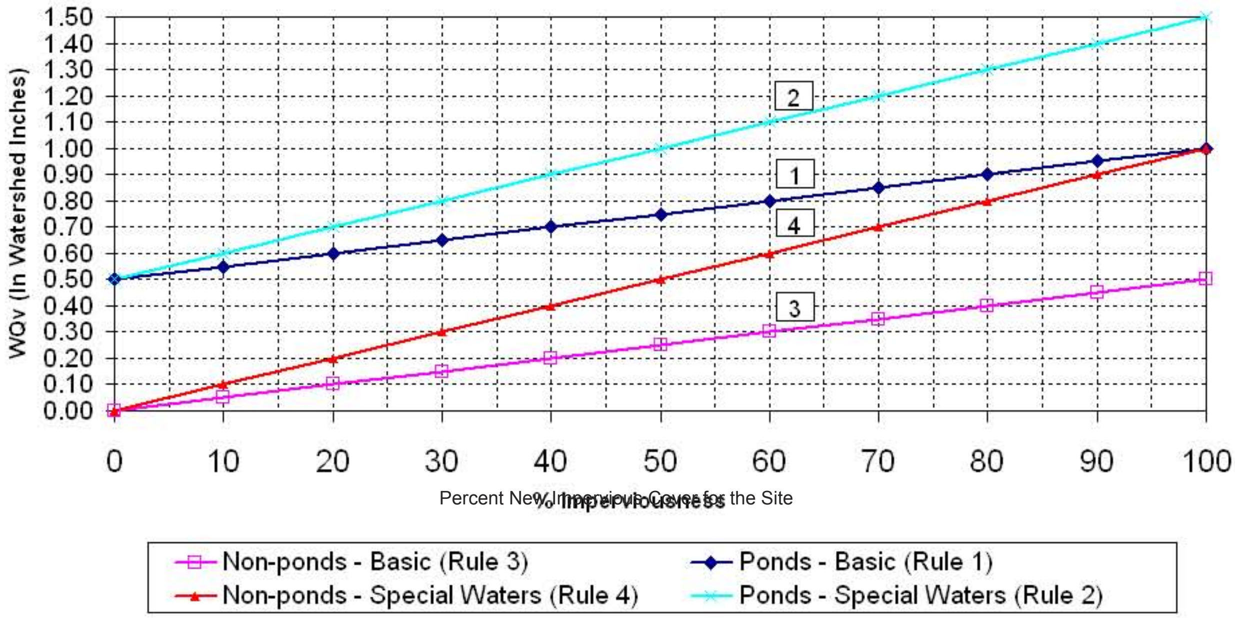
Most communities do not allow many exemptions to their basic water quality sizing criteria, although they may choose to reduce or exempt certain redevelopment and infill projects. Some guidance on handling water quality sizing in redevelopment situations is provided in Section XIV, Stormwater Sizing for Redevelopment Projects.

Water quality sizing criteria can be modified upward or downward. The first occurs when stormwater credits are offered to reduce water quality sizing when acceptable better site design techniques are applied on the site (Chapter 11). The second occurs when sizing criteria are increased to provide an enhanced level of treatment to protect special waters, such as a nutrient sensitive lake or when local criteria exceed the state minimum. Guidance on these potential modifications is provided later in this chapter.

V. Channel Protection Criteria (V_{cp})

The purpose of channel protection criteria is to prevent habitat degradation and erosion in urban streams caused by an increased frequency of bankful and sub-bankful stormwater flows. Channel protection criteria seek to minimize downstream channel enlargement and incision that is a common consequence of urbanization (Schueler and Brown, 2004). As fields and forests are converted to impervious surfaces, the volume and frequency of runoff is increased significantly. Research indicates that urbanization causes channels to expand two- to ten-times their original size to adjust to the increased volume and frequency of runoff caused by impervious cover, as well as the increased conveyance efficiency of curbs, gutters and storm drains (CWP, 2003 and 2004).

Urban stream channel enlargement significantly impacts stream habitat, water quality and public infrastructure. Bank erosion sharply increases



total annual sediment yield and nutrient loads as nutrient-rich floodplain soils are eroded and transported downstream. In addition, channel erosion degrades and simplifies stream habitat structure, which diminishes aquatic biodiversity. Lastly, channel erosion can cause severe damage to bridge, culvert and sewer infrastructure and loss of private property.

Historically, two-year peak discharge control has been the most widely applied local criteria to control channel erosion in Minnesota, and many communities continue to use it today. More specifically, two-year peak control seeks to keep the post-development peak discharge rate for the 2-year, 24-hour design storm at pre-development rates. The reasoning behind this criterion is that the bankful discharge for most streams has a recurrence interval of between 1 and 2 years, with approximately 1.5 years as the most prevalent (Leopold, 1964 and 1994), and maintaining this discharge rate should act to prevent downstream erosion.

Recent research, however, indicates that two-year peak discharge control does not protect channels from downstream erosion and may actually contribute to erosion since banks are exposed to a longer duration of erosive bankful and sub-bankful events (MacRae, 1993 and 1996, McCuen and Moglen, 1988). Consequently, two-year peak discharge control may have some value for overbank flood control, but is not effective as a channel protection criterion, since it may actually extend the duration of erosive velocities in the stream and increase downstream channel erosion. Communities may wish to drop two-year peak discharge control if they also need 10-year peak discharge control for overbank flooding when they adopt or revise stormwater ordinances as part of NPDES Phase II MS4 permits.

There are currently no state requirements to provide channel protection for regular waters, although a few local reviewing authorities have recently adopted channel protection criteria. Communities are encouraged to adopt new channel protection criteria (and eliminate two-year peak discharge control requirements) when they revise or adopt local stormwater ordinances to comply with municipal NPDES permits.

The state CGP references an “enhanced runoff control” criterion wherein the post-development runoff rate and volume need to be maintained for both the one-year 24-hour and two-year 24-hour storm. This criterion could have some channel protection applicability. The criterion only applies to a very restricted subset of special waters designated in the CGP permit, including:

- Wilderness Areas
- Trout Lakes
- Lake Trout Lakes
- Scientific and Natural Areas

The options suggested in the CGP for controlling temperature could also help reduce channel volume by infiltrating or otherwise controlling discharges to trout streams.

The recommended channel protection criteria described next should satisfy the CGP channel protection criterion. Channel protection is also highly recommended for trout streams and certain discharge situations to lakes and wetlands.

The recommended channel protection criterion is to provide 24 hours of extended detention for the runoff generated from the 1-year 24-hour design storm. This runoff volume generated is stored and gradually released over a 24-hour period so that critical erosive velocities in downstream channels are not exceeded over the entire storm hydrograph. As a very rough rule of thumb, the storage capacity needed to provide channel protection is about 60-65% of the one-year storm runoff volume. The rainfall depth for the one-year, 24-hour storm varies across the State, but can be inferred from intensity-duration-frequency [IDF] curves. The one-year, 24-hour rainfalls range between 1.8 and 2.5 inches across the State of Minnesota (Appendix B). Maximum extended detention time should be limited to 12 hours in trout streams to minimize stream warming, provided erosive velocities can be avoided. Channel protection has recently been adopted by the States of Maryland, New York, Vermont, and Georgia, and is relatively easy to compute at most development sites using existing hydrologic design models. The recommended criterion reduces the magnitude and duration of highly erosive stream channel velocities which should help to reduce downstream channel erosion.

For those wishing more in-depth analysis of channel protection flows, the following option could be used. The State of Washington (2004) has adopted an extremely stringent channel protection criterion that requires the duration of post-development peak stormwater discharges match pre-development durations for the entire range of storms between 50% of the one-year storm and the 50-year event. Designers must use a continuous hydrologic simulation model (e.g. HSPF) to demonstrate compliance. As of 2004, hydrologic models such as TR-55 or P-8 that employ single event design storms are no longer allowed in Washington for design purposes. The goal of the peak duration matching criteria is to exactly replicate the pre-development frequency of peak discharge rates for all storm events that should provide a high level of channel protection. This approach was considered by the Manual Sub-Committee, but recommended only as an option because of the high cost of implementation.

Channel Protection Methods

For information about Channel Protection Methods, see Appendix M.

Modifications to Channel Protection Criteria

There are some practical limitations in applying channel protection criteria to small development sites because orifice diameters or weir sizes become extremely small and are prone to clogging. As a result, it is recommended that localities waive the channel protection requirements at small sites that have less than three acres of impervious cover. Channel protection need not be applied at sites that have a discharge condition that will not likely cause a local channel erosion problem, such as sites that directly discharge to:

- 4th order or higher streams and rivers (data on stream order is available from DNR or the USGS from the National Hydrography Dataset at http//nhd.usgs.gov.)
- lakes and reservoirs where the development area is less than 5% of the watershed area upstream of the development site.

VI. Overbank Flood Protection Criteria (V_{p10})

The goal of this criterion is to prevent flood damage to conveyance systems and infrastructure and reduce minor flooding caused by overbank floods. Overbank floods are defined as floods which exceed the bankful capacity of the channel and spill over to the floodplain where they can damage property and structures. The key management objective is to protect downstream structures (houses, businesses, culverts, bridge abutments, etc.) from increased flows and velocities from upstream development.

Most local reviewing authorities establish an overbank design storm that is matched with the same design storm used to design open channels, culverts, bridges, and storm drain systems. Most localities in Minnesota require that post-development peak discharge rates from the 10-year and/or 25-year, 24-hour design storm event be controlled to pre-development rates.

In general, the storage volume needed to manage the 25-year return design storm is much greater than the 10-year design storm. Modeling has shown that control of the 10-year storm coupled with control of the 100-year storm effectively attenuates storm frequencies between these two events (e.g., the 25-year storm). Even without attenuation of the 100-year event, 10-year control provides a significant control for the 25-year storm (approximately 70 to 80%).

Consequently, most communities across the state have adopted the 10-year design storm control for overbank protection, since it requires less storage volume and provides some de-facto control for the 25-year storm. The choice of what design storm(s) to target for overbank control is always a local decision, and normally depends on whether the 10- or 25-year design storm has historically or currently been used as the basis for the design of conveyance systems and culverts.

VII. Extreme Flood Control Criteria (V_{p100})

The goal of extreme flood criteria is to maintain the boundaries of the pre-development 100-year floodplain, reduce risk to life and property from infrequent but very large floods and protect the physical integrity of a stormwater BMPs and downstream infrastructure.

The accepted design storm to manage extreme storms in most communities in Minnesota is the 100-year, 24-hour event. Designers are required to control the post-development 100-year, 24-hour peak discharge rate to locally defined pre-development levels. Communities should carefully reassess extreme flood criteria since it requires the largest storage volume and greatest cost of any stormwater sizing criteria

Communities may elect to waive 100-year peak discharge criteria in certain situations. The most common situation is when they have a buffer or floodplain ordinance that effectively excludes development from ultimate 100-year floodplain. Designers may also need to demonstrate that no downstream structures exist within the 100-year floodplain and that bridges and other infrastructure can safely pass the storm using an acceptable downstream analysis. This approach accomplishes the goal of extreme flood control by protecting the downstream ultimate 100-year floodplain rather than providing expensive upstream storage. Hydrologists have often noted that extreme flood criteria may not always provide full downstream control from the out-of-bank events, due to differences in timing of individual peak discharges in the downstream portion of the watershed. Depending on the shape and land use of a watershed, it is possible that upstream peak discharge may arrive at the same time a downstream structure is releasing its peak discharge, thus increasing the total discharge. As a result of this "coincident peaks" problem, it is often necessary to evaluate conditions downstream from a site to ensure that effective out-of-bank control is being provided. Hydrologic and hydraulic models that can be used for analysis of downstream effects are provided in Appendix B.

Debo and Resse (1992) proposed the concept of the "10% rule" as the point to which a downstream analysis should extend. This is operationally defined as the downstream point where the development site represents 10% of the total contributing drainage area of a watershed. They contend that the hydrologic effects of flooding stabilize and remain constant further downstream. A typical downstream analysis will need a hydrologic investigation of the site area draining to a proposed detention facility and of the contributory watershed to the location of the 10% rule for the 10- and 100-year storms. As a minimum, the analysis should include the hydrologic and hydraulic effects of all culverts and/or obstructions within the downstream channel and assess whether an increase in water surface elevations will impact existing buildings or other structures. The analysis should compute flow rates and velocities for pre-developed conditions and proposed conditions both with and without the detention facility.

While the 10% rule is useful in establishing a limit for assessment, stormwater program managers still have some basic issues that need to be addressed. For example,

- Is a downstream analysis always required?
- Should a downstream analysis be required on a case-by-case basis?
- Is a certain site size threshold required to trigger the analysis?
- What should the analysis include (culverts, channel erosion, flooding, etc.)?
- What data requirements are necessary for the analysis and what methods should be employed?

The following recommendations are provided to help answer these questions.

A downstream analysis is probably warranted for projects over 50 acres that posses more than 25% impervious cover or when deemed appropriate by the reviewing authority when existing conditions are already causing a problem (e.g., known drainage or flooding conditions documented in a regional plan or existing channel erosion is evident).

A typical downstream analysis will require a hydrologic investigation of the site area draining to a proposed detention facility and of the contributory watershed to the location of the 10% rule for the 10- and 100-year storms. A hydraulic analysis of the stream channel below the facility to the location of the 10% rule will also be necessary (e.g., a HEC-RAS water surface profile analysis). Depending on the magnitude of the impact and the specific conditions of the analysis, additional information and data may be necessary such as collecting field run topography, establishing building elevations and culvert sizes or investigating specific drainage concerns or complaints.

If the hydrologic investigation shows that flow rates and velocities (for Vp_{10} and Vp_{100}) with the proposed detention facility increase by less than 5% from the pre-developed condition, and no existing structures are impacted, then no additional analysis is necessary. If the flow rates and velocities increase by more than 5%, then the designer should either redesign the detention structure, evaluate the effects of no detention structure, or propose corrective actions to the impacted downstream areas. Additional investigations may be required by the approving authority on a case-by-case basis depending on the magnitude of the project, the sensitivity of the receiving water resource, or other issues such as past drainage or flooding complaints. Special caution should be employed where the analysis shows that no detention structure is required. Stormwater designers should be able to demonstrate that runoff will not cause downstream flooding within the stream reach to the location defined by the 10% rule.

A local community may elect to waive the V_{p100} criteria when a development project:

- Directly discharges to a large reservoir or lake,
- Directly discharges to a 4th order or larger stream or river
- Is smaller than five acres in area
- Is a redevelopment or infill project
- Is within an area where a regional flood model indicates that 100-year control is not needed at a particular site.

Some Minnesota communities base their extreme storm design on a rain-on-snow scenario, rather than a specific design storm approach. Under this scenario, communities may define the effective 100-year event as having as much as 7.2 inches of equivalent rainfall that needs to be controlled to pre-development levels. There is little basis for this approach in Minnesota based on rainfall records or experience, and it clearly results in costly over-control (Chapter 9), although some communities chose to continue its use for conservative design in land-locked basins.

VIII. Adapting Stormwater Criteria for Receiving Waters

This section begins by reviewing the diversity of "special" watershed and receiving water resource designations in Minnesota, and then presents recommendations for adapting the standard stormwater sizing criteria described earlier in the chapter to better protect these important receiving waters.

The State of Minnesota has many different kinds of mandated special watershed and water resource designations that directly influence how stormwater is managed at a site (Chapter 2 and Appendix F). When these are combined with the even more numerous water resource designations created by localities and watershed organizations (see for example, WCWC, 2003 and EOR, 2000), there is a great deal of potential for overlap and confusion. Indeed, in many regions of the state there can be more area designated and managed for specially protected waters than for regular ones. The remainder of this chapter presents a condensed framework for managing stormwater when these sensitive waters need additional protection. Please note that this section focuses on additional stormwater management practices that can be used to supplement protection of sensitive receiving waters. Some of these waters currently have limited protections under state or local programs, while others do not. The material in this section is offered as guidance when further stormwater management is deemed necessary or desirable by state or local decision makers.

In addition to the eight specific "special waters" mentioned in the state CGP and listed in Table 10.1, there are several specifically protected waters that may warrant supplemental protection relative to stormwater. These include calcareous fens, all DNR designated Public Waters, many kinds of wetlands, shoreland/floodplain areas, areas with active karst, drinking water source areas, impaired waters and the Mississippi River Critical Area. Appendix A and Appendix F present a directory of on-line maps and lists to help designers and reviewers determine if their development project is located in a special water of the state.

The many different local and state receiving waters noted above that could be addressed by supplemental stormwater management fall into five basic groups:

- Lakes
- Trout Resources
- Drinking Water Source Areas
- Wetlands
- Impaired Waters

Some of these groups may be further divided into management subcategories, as shown in the right column of Table 10.3. These subcategories will each be discussed in the remainder of this chapter.

Table 10.4 compares the main stormwater management criteria and considerations for all five groups in Table 10.3 The text following the table discusses the details of application for each of the receiving water classes.

Table 10.3 Classification of Receiving Waters Used in this Manual

Group Name	Stormwater Management Subcategory
Lakes	Most-Sensitive
	Sensitive
Trout Resources	Trout Protection
Drinking Water	Ground Water
	Surface Water
Wetlands	Susceptible
	Non-Susceptible
Impaired Waters	Computable Pollutants
	Non-Computable

IX. Lakes

Research has shown that development can increase eutrophication, bacteria and turbidity levels in lakes. According to a national survey of 3,700 urban lakes, more than 80% were found to be either eutrophic or hyper-eutrophic (U.S. EPA, 1980). Urban and urbanizing lakes receive higher phosphorus loads than non-urban lakes because urban watersheds, particularly those under construction, produce higher unit area phosphorus loads from stormwater runoff, compared to other watersheds (Caraco and Brown, 2001). A summary of the impacts of eutrophication on lakes is provided in Table 10.5.

From a stormwater management standpoint, lakes can be divided into three management categories based on their current trophic status and sensitivity to additional phosphorus loads. *Most-Sensitive Lakes* are normally defined as being oligotrophic, whereas *Sensitive Lakes* are considered to be mesotrophic or slightly eutrophic. A third category of all other lakes would include eutrophic and highly eutrophic lakes that are not generally categorized as sensitive because of their relatively poor quality. These lakes should be treated under regular stormwater programs. The lake designation is normally made by the local

Table 10.4 Summary of Suggested Stormwater Criteria for MN Receiving Waters	
Group Name	**Suggested Stormwater Sizing Criteria***
Most-Sensitive Lakes	**Recharge (V_{re})**: HIGHLY RECOMMENDED if lake is fully or partially ground water dependent **Water Quality (V_{wq}):** *Site-Based Phosphorus Load Reduction*: To apply this HIGHLY RECOMMENDED criteria for the most sensitive lakes, a manager would compute pre- and post-development phosphorus load at the development site using Simple Method (Appendix L), P8, SLAMM or an equivalent water quality model (Chapter 8). A TP load reduction is then calculated for the site based on a range of no change to a 25% reduction in post-development load, if additional load reduction is warranted. Designers document load reduction achieved using a list of BMP removal efficiencies (Chapter 7 and Chapter 12). If on-site compliance is not possible, an offset fee can be charged which is equivalent to cost of removing similar mass of phosphorus elsewhere in the watershed. The offset may be applied at time of permit application in the form of bond held by the issuing agency **Channel Protection (V_{cp}):** HIGHLY RECOMMENDED if site drains to tributary stream to a lake
Sensitive Lakes	**Recharge (V_{re}):** HIGHLY RECOMMENDED if lake is fully or partially ground water dependent **Water Quality (V_{wq}):** *Increased Water Quality Sizing*: RECOMMEND MPCA pond rule 2 or 4 for "special waters", depending on the BMP used. (Section IV). For sites with more than 30% Site IC, the Walker Rule (Section IX) presents another option that will result in similar TP removal **Shorter BMP List:** Only BMP designs or combination with a TP removal capability exceeding 50% should be used (Table 10.7) **Channel Protection (V_{cp})**: RECOMMENDED if site drains to tributary stream to a lake
Trout Streams	**Recharge (V_{re}):** HIGHLY RECOMMEND recharge of additional runoff that occurs over pre-development conditions from 2-year, 24- hour storm event, where soils allow **Water Quality (V_{wq}):** HIGHLY RECOMMEND applying MPCA rule 4 for special waters (Section IV), infiltrate and/or filter the entire V_{wq} at the site to the extent possible. Use of ponds or wetlands with standing water is discouraged, but if they are used, they should be sized according to MPCA Sizing Rule 2, incorporate temperature controls, and have an extended detention time of no more than 12 hours **Channel Protection (V_{cp}):** If soils do not permit full infiltration then provide 12 hour extended detention of 1-year 24-hour runoff volume is HIGHLY RECOMMENDED
Ground Water Drinking Water Source Areas	**Recharge (V_{re}):** RECOMMENDED in certain situations **Water Quality (V_{wq}):** RECOMMEND apply MPCA Sizing Rules 2 and 4, depending on BMP used. Comply with SWPPP requirement in CGP, as well as prohibited industrial discharges into infiltration systems. No infiltration of stormwater without pre-treatment. If site is designated as a potential stormwater hotspot, no infiltration of runoff should be allowed. Special precautions are advised for karst areas (Chapter 13).

Table 10.4 Summary of Suggested Stormwater Criteria for MN Receiving Waters	
Group Name	**Suggested Stormwater Sizing Criteria***
Surface Water Drinking Supplies	**Recharge (V_{re}):** RECOMMENDED for watersheds, with caution for ground water functioning as a surface water source **Water Quality (V_{wq}):** RECOMMEND apply the same sizing criteria as Sensitive Lakes Comply with SWPPP requirement in CGP
Susceptible Wetlands	**Maintain Wetland Hydroperiods:** For wetlands identified as HIGHLY or moderately susceptible in Table 10.12, meet the storm bounce and inundation duration limits set forth in Table 10.13. This may be done through infiltration, extended detention, or diversion **Recharge (V_{re}):** HIGHLY RECOMMENDED **Water Quality (V_{wq}):** RECOMMEND site-based phosphorus load reduction as described for Most Sensitive Lakes to control nutrients. **Channel Protection (V_{cp})**: RECOMMENDED if channel is direct tributary to the wetland No use of natural wetlands for stormwater treatment (REQUIRED) No constrictions at wetland outlets (RECOMMENDED)
Non-Susceptible Wetlands	**Recharge (V_{re})** *:* RECOMMENDED **Water Quality (V_{wq})***:* No untreated stormwater discharges to wetlands (REQUIRED) which is operationally defined as providing V_{wq} via MPCA Rules 1 and 3 **Channel Protection (V_{cp}):** RECOMMENDED only if channel is direct tributary to the wetland
Impaired Waters for Computable Pollutants	**Water Quality (V_{wq}):** If new development site is located in a watershed subject to a TMDL that has no remaining stormwater allocation, designer may need to document no net increase in pollutant load; RECOMMEND using the general method proposed for the Most Sensitive Lakes but using the appropriate pollutant. Currently, sufficient data are only available to perform this calculation for sediment, phosphorus, nitrogen, ammonia, and bacteria **Channel Protection (V_{cp}):** RECOMMENDED when water body impaired for sediment or sediment related pollutant
Impaired Waters for Non-Computable Pollutants	**Water Quality (V_{wq}):** For the remaining ten pollutants which may be subject to a TMDL but have no remaining stormwater allocation, designers should satisfy appropriate MPCA sizing rules. **Channel Protection (V_{cp}):** RECOMMENDED when water body impaired for sediment related pollutant
* REQUIRED- CGP requirement HIGHLY RECOMMENDED- Essential to provide adequate management and good engineering RECOMMENDED- Suggested for good management and engineering	

Table 10.5 Impacts of Eutrophication on Lake and Reservoir Quality (Brown and Simpson, 2001)

- Nuisance algal blooms in the summer
- Reduced dissolved oxygen in the bottom of the lake
- Fish kills due to low dissolved oxygen
- Taste and odor problems with drinking water
- Formation of THMs (trihalomethanes) and other disinfection byproducts in water supplies
- Increased cost to treat drinking water
- Reduced water clarity
- Decline in fish community (more rough fish, fewer game fish)
- Blockage of intake screens by algal mats
- Reduced quality of boating, fishing and swimming experience
- Decline in lakefront property values
- Floating algal mats and/or decaying algal clumps
- Increased density of aquatic weeds in shallow areas

or regional lake management authority, although the state may do so for certain special waters such as trout lakes or lake trout lakes (Table 10.1). Often, the lake management designation has already been made by the local, watershed, regional or state agencies, or perhaps even by a university or local educational institution. If no designation has been made, the local review authority should consult available data on water clarity, phosphorus content and algal abundance (using Chlorophyll-*a* as a surrogate measure). If none of these data exist, the local review authority may want to collect lake monitoring data to make a designation. Future phosphorus loadings should also be considered when making a stormwater management designation for a lake.

As a general rule, all surface water drinking supplies, such as water supply reservoirs and river intakes should be managed using the same stormwater sizing criteria as Sensitive Lakes, given the importance of controlling bacteria, toxic pollutants and turbidity that can threaten drinking water quality. The ensuing section presents stormwater guidance for most-sensitive and sensitive lakes, including enhanced sizing criteria and recommendations for BMP design and selection.

Most-Sensitive Lakes

The following adjustments to the basic sizing criteria are recommended for lakes designated as most-sensitive:

Recharge: Highly recommended

Water Quality: Highly recommend a site-based phosphorus load reduction if the lake in question is a state-designated "special water" under the CGP or falls under a similar local regulatory designation; also highly recommended for non-designated lakes with documented oligotrophic quality.

Under this criterion, designers would demonstrate that no increase in total phosphorus (TP) loads will occur at a site from pre-development to post-development conditions using a site-based TP load calculation. The designer could use the Simple Method (Schueler, 1987) or equivalent to compute pre-development and post-development TP loads at the site and determine the pollutant removal requirement (in pounds; Appendix L). The designer would then propose a series of BMPs that maximize the amount of phosphorus removal at the site to reach the desired condition. This criterion provides a major incentive to design for maximum phosphorus removal which is essential for managing most-sensitive lakes. Site-based phosphorus reductions have been adopted by several communities in Minnesota, which vary between no change in phosphorus load to as much as a 25% reduction from pre-development conditions. The step-wise computational approach is described in detail in Appendix L and is outlined below:

1. Calculate site imperviousness before and after development
2. Calculate the pre-development phosphorus load
3. Calculate the expected post-development pollutant load
4. Calculate the pollutant removal requirement

BMP Group[e]	BMP Design Variation	Average TP Removal Rate	Maximum TP Removal Rate[c]	Average Soluble P Removal Rate[d]
Bioretention	Underdrain	50%	65%	60%
	Infiltration	60	75	70
Filtration	Media Filters	50	60	0
	Vegetative Filters (dry)	65	75	70
Infiltration	Infiltration Trench	65	90	80
	Infiltration Basin	65	90	80
Stormwater Ponds[f]	Flow-Through (Wet) Pond	50	70	60
	Wet ED Pond[b]	55	70	70
	Micropool ED Pond	40	75	30
Constructed Stormwater Wetlands	Shallow Wetland	45	65	50
	Pond/Wetland	55	75	65
	ED Shallow Wetland	40	75	30

[a] Removal Rates Shown in this Table are a composite of four sources: Caraco (2001), MDE (2000), and Winer (2001). They apply only to the volume of water that passes through the BMP and does *not i*nclude water that bypasses the practice.
[b] Average removal efficiency expected under MPCA V_{wq} sizing Rules 1 and 3
[c] Upper limit on phosphorus removal with increased sizing and design features, based on national review
[d] Average rate of soluble phosphorus removal in literature
[e] See Issue Paper A (Appendix J)
[f] Does not include dry ponds as a water quality BMP

⚠ IMPORTANT NOTE: Removal rates shown here are composite averages intended solely for use in comparing performance between BMP designs and for use in calculating load reduction in site-based TP models. They have been adapted, rounded and slightly discounted from statistical values published in BMP performance databases.

5. Identify feasible BMPs and calculate load removed (using standard BMP removal efficiencies, Table 10.6)
6. Select off-site mitigation option, if needed.

If a designer cannot meet the total removal requirement, they could be allowed to pay an offset fee that is equivalent to the cost of removing an equivalent amount of phosphorus elsewhere in the watershed.

Channel Protection: Highly recommended if the site drains to a direct tributary stream to a lake.

BMP Selection: The following BMP design and selection guidance is recommended for lakes designated as most-sensitive.

The foremost concern is to choose BMPs with a proven ability to reliably remove high levels of phosphorus. Table 10.6 summarizes the total and soluble phosphorus removal capabilities of common BMPs. Soluble phosphorus is of particular interest since it is most readily available for algal uptake. Therefore, any BMP employed to protect most-sensitive lakes protection should have a moderate to high capability to remove total *and* soluble phosphorus.

Infiltration practices tend to have the highest phosphorus removal, but are not always be feasible due to soil constraints or lack of the three-foot separation distance between the bottom of the infiltration device and the seasonally saturated water table. Pond systems are generally a reliable removal option for both soluble and total phosphorus. Filters are fairly effective at removing total phosphorus, but exhibit little or no capability to remove soluble phosphorus. This can be explained by the fact that most sand filters have no biological or chemical processes to bind soluble phosphorus. The addition of organic matter or binding agents to sand filters may show promise in boosting removal, but early monitoring of experimental filters have yet to demonstrate this result conclusively (Schueler, 2000a).

Wetlands have a highly variable capability to remove both soluble and particulate forms of phosphorus. The variability can be explained in part by internal phosphorus cycling within the wetland, sediment release, and vegetative dieback during the non-growing season (Schueler, 1992). Factors such as soil pH, oxygen conditions, nutrient saturation and presence of Ca, Mg or Fe in the soil can also make a big difference in whether phosphorus is removed or released. The best design variation for phosphorus removal in the stormwater wetland group is the pond-wetland system (e.g., wetland with a relatively large portion of its storage devoted to a deep pool -- Chapter 12).

Sensitive Lakes

The following recommends that stormwater ponds and constructed wetlands discharging to sensitive lakes be sized larger to increase the retention time for additional phosphorus removal. These designs are more conservative than the MPCA sizing rule and could be considered by local authorities interested in greater protection for sensitive lakes. Recommended adjustments to the standard stormwater sizing criteria for Sensitive Lakes are:

Recharge: Highly recommended

Water Quality: Adjusted pond sizing

The MPCA water quality sizing Rule 2 should be applied to size stormwater ponds (e.g., ponds located within special waters). If the site has more than 30% impervious cover, the Walker Rule presents a size option that should result in similar TP load reductions in ponds. Users interested in the details on the development of this relationship are referred to Issue Paper D (Figure 13) via Appendix J. The Walker Rule was developed in the upper Midwest to maximize retention time needed within a pond to promote maximum algal uptake of phosphorus and subsequent settling between storm events. The Walker Rule seeks to attain an average pond retention time of about two weeks. Based on the distribution of storm events in the upper Midwest, Walker (1987) recommended all storage via a permanent pool storage volume equivalent to 2.5 inches multiplied by the site runoff coefficient. Based on the Minnesota rainfall frequency spectrum, the Walker Rule would capture about 98% of all runoff producing events each year, resulting in very little bypass of untreated runoff. In addition, runoff from many storm events is retained within the pond over several storm cycles to help improve phosphorus uptake. The pond designer should allocate total storage to the permanent pool under the Walker Rule. The total storage in acre-feet needed under the Walker Sizing Rule is provided using the following equation:

$$V_{wq} = R * A * \frac{1}{12}$$

Where:

V_{wq} = *required water volume*

$$R = 2.5 * FI + \left[\frac{(2.5 - 0.2S)^2}{2.5 + 0.8S}\right] * (1.0 - FI)$$

(*Runoff for design storm*)

A = *area, in acres*

FI = *Fraction of total impervious cover of site*

$$S = \frac{1{,}000}{CN} - 10$$

CN = *curve number*

Walker Rule:

The MPCA water quality sizing Rule 4 should be applied if the designer is using a BMP other than a pond (e.g., non-BMPs draining to special waters), keeping in mind that a minimum water quality storage volume of 0.2 watershed inches is recommended for pre-treatment, regardless of site impervious cover.

Channel Protection: Limited application

Table 10.7 Recommended BMPs for Sensitive Lakes		
BMP Group	BMP Design Variation	Recommended for Lake Watersheds
Bioretention	Underdrain or Infiltration	Yes
Filtration	Media	No
	Vegetative Filter (dry)	Yes
	Vegetative Filter (wet)	No
Infiltration	Infiltration Trench	Yes
	Infiltration Basin	Yes
Stormwater Ponds	Flow-Through (Wet) Pond	Yes
	Wet ED Pond	Yes
	Micropool ED Pond	No
Constructed Stormwater Wetlands	Shallow Wetland	Yes
	Pond/Wetland	Yes
	ED Shallow Wetland	No

Channel protection is recommended if a development site drains to a tributary stream to a lake. Channel protection is not needed if the site discharges directly to the lake.

BMP Selection: The following guidance on BMP design and selection is offered for Sensitive Lakes:

Designers should only apply BMPs that have a total phosphorus removal rate exceeding 50%. Based on Table 10.7, four kinds of BMPS are not recommended in sensitive lakes: media filters, wet vegetated swales, micropool extended detention ponds, and extended detention wetlands. If these BMPS are used, they need to be combined with more effective BMPs in a treatment train. By contrast, infiltration, wet ponds, and bioretention have high phosphorus removal rates, and are strongly encouraged in Sensitive Lakes.

In addition, designers and plan reviewers should evaluate every BMP to look for ways to maximize phosphorus removal. For example, the use of multiple treatment pathways is encouraged (e.g., directing runoff to a filtering or infiltration BMP, and then routing it a wet pond). Additional tips on maximizing phosphorus reduction in BMP design are provided in Table 10.8.

Also, as a general rule, no BMPs should be located inside the shoreline buffer, as defined by the local reviewing authority.

X. Trout Streams

Trout populations are threatened by stream habitat degradation, stream warming, possible chloride toxicity, and other impacts associated with upland development. Trout are very sensitive to increases in water temperature. The optimal temperature range for adult trout is from about 57°F to 65°F. Generally, adult trout can survive warmer temperatures if cool water refuge is present in the form of ground water upwelling or springs. Juvenile trout, fry and eggs are much more susceptible to warm water temperatures and are not able to tolerate temperatures much above 68°F (Emmons & Olivier Resources, 2000). Stream warming also harms trout by reducing dissolved oxygen available for fish and aquatic life. Increased temperatures can also increase the metabolic rates of aquatic organisms and increase their sensitivity to other pollutants, parasites, and diseases (SSL SWCD, 2001).

The reduction in streamside forest cover removes much of the mechanisms that keep a stream cool. The heating of impervious surfaces by solar radiation also warms precipitation that runs over them and potentially into a stream. A series of

Table 10.8 Stormwater Design Recommendations to Enhance Phosphorus Removal	
BMP Design	Design Criteria
Bioretention	▶ Bioretention are preferred practices.
Filtration	▶ Organic filters are a source of soluble phosphorus and should not be used. ▶ Employ finer-grained media in the filter bed with a small diameter (15 microns), or provide a finer-grained layer at mid-depth in the filter profile. ▶ The process for pre-treatment and/or filtration should extend from 36 to 48 hours, where possible. ▶ Filters should be oriented to provide maximum solar exposure. ▶ Wet swales are not recommended. ▶ Open channels should be designed to be either self-cleansing or promote maximum sediment retention. ▶ Open channels should not be relied on as the only BMP to remove phosphorus at a site, with the exception of an engineered dry swale.
Stormwater Ponds	▶ Design wet ponds with a depth no greater than 10 feet to prevent stratification and potential release of phosphorus from bottom sediments. ▶ Avoid the use of dry or dry extended detention ponds ▶ Designers should consider the snowmelt runoff volume and design ponds for seasonal operation ▶ Use a surface or mid-depth release from the pond. ▶ Landscape pond to discourage geese. ▶ Add shallow benches and wetland areas to enhance the plankton community. ▶ Follow mosquito advisories in Chapter 6.
Constructed Stormwater Wetlands	▶ Pond/ wetland system is the preferred wetland design. ▶ Use a surface or mid-depth release from the wetland. ▶ Maximize surface micro-topography. ▶ Landscape wetland to discourage geese. ▶ Follow mosquito advisories in Chapter 6.
Infiltration	▶ Infiltration BMPs are preferred practices. ▶ Provide a minimum 3-foot separation from the seasonally-high water table, bedrock or impervious soil layer.

monitoring studies have documented the stream warming effect in urban trout streams (Roa-Espinosa *et al*. 2003; SSL SWCD, 2001; Johnson, 1995; Galli, 1990).

Sedimentation is also a major concern for trout. Construction runoff, channel erosion and road sand all increase sediment loads which can impair streambed habitat in trout streams. Excess sediment can affect the productivity of a trout stream in several ways. Sediment can impede trout respiration by clogging gill plates. In addition, sediment deposition can destroy spawning habitat and harm the benthic organisms upon which the trout feed.

Road salt may also significantly impact trout habitat. Chloride is one of the main components of road salt, and is extremely soluble in water. As a result, there is virtually no way to remove chloride once it gets into either surface or ground water. Chloride levels are the highest in late winter as initial melting occurs from snow containing significant amounts of road salt and stream flows are lowest. The chloride from the salt can be toxic in trout streams during some meltwater events (Chapter 9).

The following adjustments to the basic sizing criteria are recommended to protect trout streams.

Recharge: Highly recommend infiltration as part of stormwater control

It is highly recommended that all excess runoff volume above that produced from the pre-development 2- year, 24-hour storm event should be infiltrated for designated trout streams, where soils conditions permit. The state CGP contains this method as one option to meet mandated temperature control for designated trout streams.

Water Quality: Discourage use of ponds/ wetlands

Use MPCA water quality sizing rule 4 for non-pond BMPs volume determination for special waters, and infiltrate and/or filter this volume at the site regardless of soil conditions (e.g., bioretention, dry swales, infiltration, and better site design practices). Discharge from ponds or wetlands with standing water to trout streams is discouraged. If they are used, they should be sized according to MPCA Sizing Rule 2, incorporate temperature controls, and have an extended detention time no longer than 12 hours.

Channel Protection: Highly recommended.

Given the importance of trout habitat, it is highly recommended that channel protection criteria be applied to all trout streams. If soils do not permit infiltration of the channel protection volume, then designers should provide 12 hour extended detention of 1-year, 24-hour runoff volume in a thermally acceptable pond option. Note that CGP allows up to 24 hours, but 12 is recommended in the Manual.

BMP Selection: There are quite a few do's and don'ts when it comes to BMP design for trout streams.

Designers should look for ways to incorporate the following design features into their BMPs:

- Consider using forested wetland design (see Capiella 2005b).
- Maximize use of better site design techniques
- Use infiltration and bioretention to the maximum extent possible
- Construct BMPs "off-line"
- Shade pilot and outflow channels and micropools by planting trees and shrubs
- Plant trees to the maximum extent possible in the stormwater practices and buffers
- Manage buffers to maximize forest cover and shading in riparian areas
- Pre-treat roadway runoff to reduce sediment and road sand discharges to streams
- Develop and test roadway spill management plans

Designers should ensure that each BMP does not have:

- A large, unshaded permanent pool or shallow wetland
- Extensive and unshaded pilot and outflow channels within the BMP
- An extended detention time longer than 12 hours
- Extensive exposed riprap or concrete channel
- An on-line or in-stream location
- A location within the forested buffer
- Infiltration practices that are undersized or lack pre-treatment.

XI. Drinking Water Source Areas

Ground Water

This group includes any ground water recharge areas that supply water used for drinking water supply. The management goal is to maintain ground water recharge while preventing the possibility of ground water contamination. Ground water is a critical water resource, as many residents depend on ground water for their drinking water, and the health of many aquatic systems depends on steady recharge to maintain surface water bodies throughout the year. For example, during periods of dry weather, ground water sustains flows in streams and helps to maintain the hydrology of wetlands. Because development creates impervious surfaces that prevent natural recharge, a net decrease in ground water recharge rates can be expected in urban watersheds. Thus, during prolonged periods of dry weather, stream flow sharply diminishes. In smaller headwater streams, the decline in stream flow can cause a perennial stream to become seasonally dry.

Urban land uses and activities can also degrade ground water quality if stormwater runoff is directed into the soil without adequate treatment. Certain land uses and activities are known to produce higher loads of metals and toxic chemicals and are designated as potential stormwater hotspots or "PSHs" (see Chapter 13 for definitions and further discussion). Soluble pollutants, such as chloride, nitrate, copper, dissolved solids and some hydrocarbons can migrate into ground water and potentially contaminate wells. Stormwater runoff should never be infiltrated into the soil from sites designated as a PSH (Table 10.9).

Stormwater hotspots commonly occur as commercial, industrial, institutional, municipal, or transportation-related operations that produce higher levels of stormwater pollutants, and/ or present a higher potential risk for spills, leaks or illicit discharges (Table 10. 9). Runoff from these operations may contain soluble pollutants which cannot be effectively removed by current BMPs and can contaminate ground water quality.

Typical sources of nutrients, metals, hydrocarbons, toxins and other pollutants that can be generated from PSH are summarized in Table 10.10. It should be noted that not all of these operations or activities will actually generate pollution at an individual stormwater hotspot. In fact, many industrial operations are highly regulated under state and federal programs. There are, however, many small or unregulated facilities (such as gas stations or auto salvage yards) that are of concern because of the potential for release of toxic material to stormwater.

The management goal in ground water drinking water source areas is to prevent possible ground water contamination by preventing infiltration of untreated hotspot runoff. At the same time, recharge of unpolluted stormwater is needed to maintain flow in streams and wells during dry weather. As such, structural BMPs alone should not be relied upon as a sole stormwater management strategy at a PSH. A stormwater pollution prevention plan for a PSH should also incorporate a combination of:

- Good housekeeping
- Preventive maintenance
- Spill prevention and clean-up
- Employee training
- Inspections
- Record-keeping
- Chemical use restrictions

More information on how to prepare an effective pollution prevention plan for a site can be found in Chapter 12 and Chapter 13.

The following adjustments to the standard stormwater sizing criteria are recommended to protect the quality of ground water drinking water source areas:

Water Quality: Enhanced sizing and pre-treatment

MPCA water quality sizing Rules 2 or 4 should be applied to development sites within ground water drinking water source areas, depending on

Table 10.9 Business Operations at Potential Stormwater Hotspots (adapted from MDE, 2000)

▶ Vehicle salvage yards and recycling facilities	▶ Outdoor liquid container storage
▶ Vehicle service and maintenance facilities	▶ Outdoor loading/unloading facilities
▶ Vehicle and equipment cleaning facilities	▶ Public works storage areas
▶ Fleet storage areas (bus, truck, etc.)	▶ Facilities that generate or store hazardous materials
▶ Industrial sites	▶ Commercial container nursery
▶ Marinas (service and maintenance)	▶ Large parking lots
▶ Transportation routes* and fueling areas	▶ Large chemically managed turf areas

* Note that road surfaces are not always considered PSHs unless a history of contaminated water has occurred.

Table 10.10 Stormwater Pollutants Associated With Common Operations at Potential Stormwater Hotspots (Schueler *et al*., 2004)

Operation or Activity	Nutrients	Metals	Oil / Hydrocarbons	Toxics	Others
Vehicle Repair	◔	●	●	●	
Vehicle Fueling	◔	●	●	●	(MTBE not used in MN)
Vehicle Washing	●	◐	◐	●	Water Volume
Vehicle Storage	○	◐	●	◔	Trash
Outdoor Loading	◐	◐	◔	◔	Organic Matter
Outdoor Storage	◐	◐	◐	◐	
Liquid Spills	◐	◐	●	●	
Dumpsters	◐	◐	◐	●	Trash
Building Repair	◔	◐	◐	◐	Trash
Building Maintenance	○	●	◔	◐	
Parking Lot Maintenance	◔	◐	●	◐	Chloride
Turf Management	●	○	○	●	Pesticides
Landscaping	●	○	○	●	Pesticides
Swimming Pool Discharges	○	○	○	○	Chlorine
Golf Courses	●	◔	○	●	Pesticides
Hobby Farms/Race Tracks	◐	○	○	○	Bacteria
Construction	◐	◔	◔	◐	Trash, Sanitary Waste, Sediment
Marinas	◐	◐	◐	●	Bacteria
Restaurants	◐	○	●	○	Grease

Key:
- ● major contributor
- ◐ moderate contributor
- ◔ minor contributor
- ○ not a pollutant source

whether a pond or non-pond BMP option is being considered. A minimum of 0.2 watershed-inches of effective pre-treatment is recommended for non-pond BMPs to remove pollutants prior to any infiltration or soil filtration.

Recharge: Encouraged in limited situations

Infiltration is encouraged at residential subdivisions to increase ground water recharge through rooftop disconnections and other better site techniques. Commercial and institutional rooftops can also be disconnected as long as they are not a potential stormwater hotspot. No infiltration or recharge of runoff from potential stormwater hotspot operations should be allowed to reduce the risk of ground water contamination. Caution on the source of infiltrating water should be exercised in all cases.

BMP Selection: The following guidance on BMP design and selection is offered to protect ground water drinking water source areas.:

- In general, infiltration of clean runoff from residential and non-residential rooftops is encouraged with acceptable pre-treatment.
- Stormwater ponds, wetlands, bioretention, and filters are effective surface treatment

- ▶ No infiltration from PSHs, especially those with potentially high chloride levels and/or vulnerable ground water resources
- ▶ Minimum setbacks from wells, septic systems, sinkholes and wellhead protection zones in conformance with state and local regulations (contact Minnesota Department of Health) and plans
- ▶ Avoid pooling or infiltrating stormwater in active karst areas (Chapter 13)

Additional BMP design criteria for ground water protection are presented in Table 10.11.

Surface Water

There is a large portion of Minnesota residents served by drinking water obtained from a surface water source. The supplies for the St. Cloud, Minneapolis and St. Paul metropolitan areas are obtained mostly from the Mississippi River; St. Paul's supply is supplemented by both small stream flow and ground water. Several other cities throughout the state are also supplied by smaller rivers such as the Minnesota/Blue Earth, Red Lake and Red Rivers, by Lake Superior or by large abandoned quarries in the Iron Range. In each of the river source areas, protection of the surface water source reaches far beyond the local border to the entire watershed feeding the supply intake. For the quarries, inflow occurs primarily from ground water sources that must be protected as noted in the previous section. Lake Superior itself requires attention, as do the tributary streams that feed it.

Each of the surface water sources is preparing or has prepared a source water protection plan in which they identify potential pollutants of interest and the likely source of those pollutants. They also must put together a plan to protect the source of water. This plan, as is the case for the Mississippi River communities, can stretch far upstream (or up-gradient for ground water) to areas not under the control of the served communities. This severely limits the direct control that the supplied communities have over pollution generating activities. Fortunately, a willingness to help protect these drinking water source areas has led to multi-community cooperative protection efforts.

The pollutants mentioned in the previous ground water section certainly all apply to surface water sources. In addition, surface water suppliers have to be concerned about such things as sediment, phosphorus, nuclear waste (Mississippi River suppliers), any cargo hauled through the watersheds on rail or roads, or on the water in barges, PSHs, fire-fighting runoff and a myriad of other potential surface water contaminants. All of the precautions mentioned in the previous

Table 10.11 BMP Design Considerations for Ground Water Aquifer Protection

BMP Group	Design Consideration
Bioretention	▶ OK with proper caution for PSH
Filtration	▶ OK with proper caution for PSH ▶ Open channels are OK, but polluted runoff must be adequately pre-treated
Infiltration	▶ Provide a 100-foot horizontal separation distance from wells and three-foot vertical distance from the water table ▶ No PSH runoff, unless treated by another practice, such as a filtering system ▶ Needed pre-treatment of all runoff except rooftop
Stormwater Ponds	▶ Needed liner if A soils or active karst are present ▶ Pre-treat PSH runoff ▶ Provide a separation distance from well or water table to BMP
Constructed Stormwater Wetlands	▶ May needed liner if A soils or active karst are present ▶ Pre-treat PSH runoff ▶ Provide a separation distance from well or water table to BMP

section for ground water source areas should also be applied to surface waters that provide drinking water.

The management goal in surface water drinking water source areas is to prevent possible source contamination by preventing any potential contaminant from reaching either the stream or river providing the water or any ground water inflow that will eventually feed a surface water source. Pollution prevention and emergency response become primary BMP approaches for source waters. Information on how to prepare an effective pollution prevention plan for a site can be found in Chapter 12 and Chapter 13. The list of focal BMPs remains similar to the ground water list noted previously with the addition of good watershed management to control pollutants associated with nonpoint sources.

The following adjustments to the standard stormwater sizing criteria are recommended to protect the quality of surface water drinking water source areas:

Water Quality: Enhanced sizing and pre-treatment

MPCA water quality sizing Rules 2 or 4 should be applied to development sites within surface water drinking water source areas that are determined in a source water protection plan to be critical to maintaining the quality of the source water. A minimum of 0.2 watershed-inches of effective pre-treatment is recommended for non-pond BMPs to remove pollutants prior to any infiltration or soil filtration.

Recharge: Encouraged for watersheds, with caution for ground waters feeding a surface water source

Infiltration is encouraged within watersheds upstream of drinking water intakes from surface water. Protective measures consistent with the previous ground water supply section are encouraged for ground waters feeding surface water sources.

BMP Selection: Supplemental BMPs should follow those suggested for Sensitive Lakes. The following guidance on BMP design and selection is offered to protect surface water source areas:

- A pollution prevention plan is essential for the entire area draining to the surface water intake;
- Stormwater ponds, wetlands, bioretention, and filters are effective surface treatment;
- No infiltration or direct runoff in the vicinity of the intake from PSHs, especially those with potentially high chloride levels and/or vulnerable ground water resources; and
- An emergency response plan should be prepared for spill response in areas critical to supply protection.

Additional BMP design criteria for ground water protection are presented in Table 10.12.

Table 10.12 BMP Design Considerations for Surface Water Source Protection (see also Table 10.8)

BMP Group	Design Considerations
Bioretention	▶ OK with proper caution for PSH
Filtration	▶ OK with proper caution for PSH ▶ Open channels are OK, but polluted runoff must be adequately pre-treated
Infiltration	▶ No PSH runoff, unless treated by another practice, such as a filtering system. ▶ Need pre-treatment of all runoff except rooftop.
Stormwater Ponds	▶ Need liner if A soils or active karst are present ▶ Pre-treat PSH runoff ▶ Prepare response plan to capture and remove spills in pond
Constructed Stormwater Wetlands	▶ Pre-treat PSH runoff

XII. Wetlands

For a long time, wetlands were viewed as wastelands that were better drained or filled. It is estimated Minnesota has lost nearly 42 percent of its original wetland acreage (MN SWAG, 1997). Wetlands are now recognized as performing many important watershed functions and services, and their direct disturbance is closely regulated. Chapter 5 of this Manual reviews state, local and federal aspects of wetland regulation and management.

Naturally occurring quantities of runoff with seasonal fluctuations are essential for the maintenance of a wetland, and moderate amounts of nutrients and sediment in the runoff can increase a wetland's productivity. However, excessive stormwater runoff has the potential to alter the hydrology, topography, and the vegetative composition of a wetland (U.S. EPA, 1993). For example, an increased frequency and duration of inundation can degrade native wetland plant communities or deprive them of their water supply.

Stormwater inputs can also cause changes in water or soil chemistry that can degrade wetlands. This is a particular concern for wetlands with a narrow pH range such as acidic sphagnum bogs and alkaline calcareous fens (MN SWAG, 1997). Calcareous fens are the rarest wetland plant community in Minnesota, and as such are specially protected (Chapter 5 and Appendix F). These fens are peat-accumulating wetlands dominated by distinct ground-water inflows having specific calcium carbonate chemical characteristics. Flows are circum-neutral to alkaline, with high concentrations of calcium and low dissolved oxygen content. The water chemistry creates a unique environment for a disproportionately large number of rare, threatened, and endangered wetland plant species compared to other plant communities in the Great Lakes region (MN SWAG, 1997). Changes in wetland water quality can alter the nature of the plant community, encouraging invasive species, and reducing sensitive species that are preferred by fish, mammals, birds, and amphibians for food and shelter (U.S. EPA, 1993).

Stormwater runoff inputs can exceed the water depths and frequency/duration of inundation prevalent in natural wetlands. Deposition of sediment carried by urban stormwater can have the same effect, causing replacement of diverse species with monotypes of reed-canary grass or cattails, which are much more tolerant of sedimentation and fluctuating water levels. Schueler (2000b) reported that invasive or aggressive plant species are favored when water level fluctuation (WLF) is high (e.g., reed-canary grass). The result is low vegetative diversity and lower quality wildlife habitat values (MN SWAG, 1997). A modest change in WLF sharply decreases plant species richness, and amphibian species richness a study in the Pacific Northwest (Horner, *et al*., 1996). Some communities have used existing wetlands for stormwater treatment by increasing the depth of ponding on a permanent or temporary basis. The end result is the transformation of a natural wetland into a stormwater wetland, with the attendant loss of diversity and functional values

Not all wetlands respond in the same way to the impact of stormwater runoff. In the context of this Manual, wetlands can be defined as Susceptible or Non-Susceptible to stormwater runoff, based on the MN SWAG (1997) wetland classification scheme. This classification provides a useful framework for managing stormwater inputs to different types of wetlands.

Highly susceptible wetland communities can be composed of dozens of plant species. Table 10.13 presents the MN SWAG classification of wetland types according to their presumed susceptibility to degradation by stormwater. Given this diversity of wetland types, it is not surprising that wetlands have a broad range of tolerance to stormwater runoff. Some wetlands (e.g. calcareous fens) are sensitive to any disturbance and will show signs of degradation with even low-level inputs of urban stormwater. Note that Susceptible Wetlands are defined as highly and moderately susceptible in Table 10.13 and Non-Susceptible Wetlands are defined as slightly and least in the table.

The following adjustments to the standard stormwater sizing criteria are recommended to protect wetlands from the indirect impact of stormwater runoff. Note that wetlands are highly regulated within the state (Chapter 5) and that all federal, state and local/watershed authorities should be consulted before any activity is initiated on any parcel of land that appears to be a wetland.

Recharge: Highly recommended for Susceptible Wetlands

Table 10.13 Susceptibility of Wetland Types to Degradation by Stormwater Input (Source: State of Minnesota Storm-Water Advisory Group, 1997)			
Susceptible		**Non-Susceptible**	
Highly Susceptible Wetland Types[1]	**Moderately Susceptible Wetland Types[2]**	**Slightly Susceptible Wetland Types[3]**	**Least Susceptible Wetland Types[4]**
▶ Sedge Meadows ▶ Open Bogs ▶ Coniferous Bogs ▶ Calcareous Fens ▶ Low Prairies ▶ Coniferous Swamps ▶ Lowland Hardwood Swamps ▶ Seasonally Flooded Basins	▶ Shrub-carrs[a] ▶ Alder Thickets[b] ▶ Fresh (Wet) Meadows[c,e] ▶ Shallow Marshes[d,e] ▶ Deep Marshes[d,e]	▶ Floodplain Forests[a] ▶ Fresh (Wet) Meadows[b] ▶ Shallow Marshes[c] ▶ Deep Marshes[c]	▶ Gravel Pits ▶ Cultivated Hydric Soils ▶ Dredged Material / Fill Material Disposal Sites

1. Special consideration must be given to avoid altering these wetland types. Inundation must be avoided. Water chemistry changes due to alteration by stormwater impacts can also cause adverse impacts. Note: All scientific and natural areas and pristine wetlands should be considered in this category regardless of wetland type.
2a, 2b, 2c. Can tolerate inundation from 6 inches to 12 inches for short periods of time. May be completely dry in drought or late summer conditions.
2d. Can tolerate +12" inundation, but adversely impacted by sediment and/or nutrient loading and pro- longed high water levels.
2e. Some exceptions.
3a. Can tolerate annual inundation of 1 to 6 feet or more, possibly more than once/year.
3b. Fresh meadows which are dominated by reed-canary grass.
3c. Shallow marshes dominated by reed-canary grass, cattail, giant reed or purple loosestrife.
4. These wetlands are usually so degraded that input of urban stormwater may not have adverse impacts.

Notes:
There will always be exceptions to the general categories listed above. Use best professional judgment.
Pristine wetlands are those that show little disturbance from human activity.

Many Susceptible Wetlands are dependent on ground water to maintain their natural hydrology so it is important to maintain recharge at a consistent rates in the contributing source area to the wetland. Recharge is also recommended for Non-Susceptible Wetlands that are dependent on ground water.

Water Quality: Recommend site based phosphorus load reduction

Site-based phosphorus load reduction for Susceptible Wetlands using the method described for Most-Sensitive Lakes (Section IX) are recommended to control nutrients. Site-based nutrient load reduction should be used for nutrient sensitive bogs and calcareous fens. No untreated stormwater discharges should be allowed to Non-Susceptible Wetlands, which are operationally defined as providing water quality volume according to MPCA sizing Rules 2 and 4 (depending on the type of BMP chosen). Currently, the MPCA interprets the CGP as requiring a permanent pool in constructed stormwater wetland systems. While this seems appropriate for a pond/wetland system, it does detract from the bioretention character of the other wetland BMPs described in Chapter 12. The application of a permanent pool to constructed stormwater wetland systems that behave as bioretention systems should be considered for change in the next CGP update.

In addition, Susceptible Wetlands should not be used for stormwater treatment. A Non-Susceptible Wetland should only be used for stormwater treatment if designers can demonstrate that it will restore wetland functional value, and only when approved by the local government unit acting as approving agency under the Minnesota Wetland Conservation Act.

Channel Protection: Limited

Channel Protection is recommended only when a channel is a direct tributary to a wetland.

Other: Maintain wetland hydroperiod

Designers should maintain the hydroperiod of Susceptible Wetlands following development to prevent detrimental impacts. Any wetlands present at the site should be investigated in the field to determine their wetland type and contributing hydrologic source area, and then determine if any additional runoff will be delivered to the wetland as a result of the proposed project. Based on this determination, a wetland will be classified as either Susceptible or Non-Susceptible, using the criteria outlined in Table 10.13.

Table 10.14 presents hydroperiod guidelines for wetlands, developed by MN SWAG (1997) for use unless better site-specific data are available. The term "existing" in this chart means the existing hydrologic conditions. If there have been recent significant changes in conditions, it means the conditions that established the current wetland. Designers then model the effect of runoff discharge from the site on the wetland to ensure they conform to the storm bounce and inundation duration guidelines standards set forth in Table 10.14 using infiltration, extended detention, diversion or other methods.

BMP Selection: Additional guidance on BMP design to protect wetlands is offered below:

- BMPs such as stormwater wetlands, infiltration systems, and bioretention are encouraged to treat runoff prior to discharge to a wetland.
- Direct pipe outfalls to wetlands should be restricted (e.g., not allowed, allowed if energy dissipated, or routed through a pre-treatment system).

Table 10.14 Recommended Hydroperiod Standards for Wetlands (Source: State of Minnesota Storm-Water Advisory Group, 1997)

	Susceptible		**Non-Susceptible**	
Hydroperiod Standard	Highly Susceptible Wetlands	Moderately Susceptible Wetlands	Slightly Susceptible Wetland	Least Susceptible Wetlands
Storm Bounce	Existing	Existing plus 0.5 ft	Existing plus 1.0 ft	No limit
Discharge Rate from Wetland	Existing	Existing	Existing or less	Existing or less
Inundation Period* for 1- & 2-Year Precipitation Event	Existing	Existing plus 1 day	Existing plus 2 days	Existing plus 7 days
Inundation Period for 10-Year Precipitation Event & Greater	Existing	Existing plus 7 days	Existing plus 14 days	Existing plus 21 days
Run-Out Control Elevation (Free Flowing)	No change	No change	0 to 1.0 feet above existing run out	0 to 4.0 feet above existing run out
Run-out Control Elevation (Landlocked)	Above delineated wetland	Above delineated wetland	Above delineated wetland	Above delineated wetland

* Inundation period is the time above the normal water level (NWL)

- Stormwater should be routed around sensitive wetlands using a diversion or bypass system.
- Constrictions at wetland outlets should be avoided.
- Natural wetlands should not be used for stormwater treatment, unless they are severely impaired and construction would enhance or restore wetland functions; if natural wetlands are used in this manner, MN Rules 7050 establishes the sequence of avoid, minimize and compensatory replacement.
- The discharge of untreated stormwater to a wetland is prohibited.

XIII. Impaired Waters

Under the Clean Water Act, Minnesota administers water quality standards which consist of numeric and narrative criteria that protect the physical, chemical and biological integrity of surface waters in the state. These criteria are set to maintain seven designated or beneficial uses of water in the state. The state routinely monitors the quality of its waters to determine if they are meeting their designated uses. If monitoring indicates that water quality standards are not being met and/or designated uses are not being achieved, the state lists the water as being "impaired". This, in turn, triggers the Total Maximum Daily Load (TMDL) provisions of the Clean Water Act.

A TMDL consists of an analysis to determine what pollutant reduction is needed to achieve water quality standards, and is normally conducted at the watershed scale. A TMDL determines the amount of pollutants that a waterbody can receive from both point and nonpoint sources and still meet water quality standards (e.g., no impairment). Water quality sampling and computer modeling determine how much each pollutant source needs to be reduced to assure the water quality standard is met. More discussion on how TMDLs are developed in Minnesota can be found at http://www.pca.state.mn.us/water/tmdl/index.html.

Impaired waters include streams and lakes that do not meet their designated uses because of excess pollutants or identified stressors. As of 2004, 916 lakes and 199 river and stream segments were listed as impaired waters for Minnesota (MPCA, 2004). Each listed water will ultimately require a TMDL based on the assessment. Currently, there are 14 pollutants causing water quality standard violations in some part of the state as shown in Table 10.15. To date (fall 2005), only four final TMDLs and their corresponding implementation plans have been completed in Minnesota, so many listed waters currently lack a TMDL or are in the process of developing one.

While none of the completed TMDL implementation plans currently contain stormwater requirements, they may eventually be included if stormwater pollution is determined to be a significant source of the listed pollutant. Therefore, development projects that occur in a listed watershed may require a higher level of stormwater treatment, regardless of whether a TMDL has been completed or not. The main reason is that both municipal NPDES Phase I or II stormwater permits and individual construction general permits must be consistent with the load allocations and pollutant reductions contained in an approved TMDL. If stormwater runoff is likely to be a significant pollutant source within a listed watershed, the local review authority may elect to require higher levels of stormwater treatment to restore the impaired water.

Table 10.15 Listed Pollutants* in Minnesota (MPCA, 2004)	
▶ **Sediment** ▶ **Phosphorus** ▶ **Nitrogen** ▶ **Ammonia** ▶ **Fecal Coliform** ▶ Oxygen Demand ▶ Turbidity	▶ Chloride ▶ DDT ▶ Dieldrin ▶ Mercury ▶ PCBs ▶ Toxaphene * ▶ Dioxin *
*Pollutants in **bold** are considered computable (see discussion below), whereas pollutants in normal typeface are considered non-computable at this time. An asterisk indicates that monitoring data suggests that the pollutant is normally not found in urban stormwater runoff.	

Some general guidance on how to deal with stormwater pollutant loads at development sites located within listed waters is provided below.

In the first step, the local review authority should check with MPCA to determine:

- Whether any local waters as listed as impaired;
- Which pollutant(s) is causing the impairment to be listed;
- The estimated watershed area to the receiving water;
- The timeframe under which the water will fall under the TMDL program; and
- Whether stormwater is expected to be a significant source of the impairment for the indicated pollutant.

If an impairment exists, the local reviewing authority should determine whether the indicated pollutant is considered computable or non-computable. In the context of stormwater, "computable" is defined as a pollutant for which enough data exist to perform a site-based pollutant load calculation that documents no increase or even a reduction in pollutant loading. By contrast, "non-computable" pollutants lack enough data to perform a reliable site based pollutant reduction calculation. Issue Paper E outlined the process for determining pollutant computability. Computable pollutant must pass four tests:

1. Enough stormwater EMC data is available to characterize its average level in stormwater;
2. Stormwater concentrations are high enough to constitute a major source in the stormwater load allocation;
3. Sufficient BMP performance data are available to estimate expected removal for a range of stormwater practices; and
4. Stormwater removal rates are high enough to warrant performing the calculation.

Currently, only five pollutants meet all four criteria -- sediment, phosphorus, nitrogen, ammonia, and fecal coliform bacteria (Table 10.15). A stormwater strategy to deal with computable and non-computable pollutants within listed is offered below:

***Water Quality*:** Computable pollutants

If a new development site is located in a watershed subject to a TMDL that has no remaining stormwater allocation, the local review authority may wish to adopt a "no net increase" policy for the listed computable pollutant (e.g., sediment, phosphorus, nitrogen, ammonia or fecal coliform). Pollutant removal calculations should be conducted on a site-by-site basis, using the general method proposed for the Most-Sensitive Lakes, adapted for the listed pollutant. An example of an approach for calculating phosphorus removal is provided in Appendix L.

***Water Quality*:** Non-computable pollutants

Since non-computable pollutants lack enough data to perform a site-based load reduction calculation, they can only be managed by increasing the V_{wq} assuming that a higher level of pollutant reduction will occur within the BMP. In these situations, the local review authority may wish to require that development sites satisfy MPCA water quality volume sizing Rules 2 or 4, depending on the type of BMP employed.

Channel Protection: Recommend for waters listed for sediment or sediment related pollutant:

Given the importance of channel erosion in the sediment budget of urban streams, it is advisable to require channel protection criteria in watersheds that are listed for sediment. In all cases, the local review authority should check with MPCA to determine what, if any, water quality or channel protection requirements need to be addressed as part of TMDL implementation.

BMP Selection: The selection and design of specific BMPs to address impaired water pollutant reductions will be determined through the TMDL process. Chapter 12 can be used to construct an effective BMP implementation strategy.

XIV. Stormwater Sizing for Redevelopment Projects

Small redevelopment sites can pose special challenges for stormwater design, given their small size, intensive use, and compacted soils. Redevelopment projects are also not covered under the CGP unless they created more than one acre of new impervious surface or are part of a larger related planned development. Communities may wish to develop special sizing criteria for smaller redevelopment so that the cost to comply with stormwater requirements does not become a barrier to smart growth.

The following guidance is offered for handling redevelopment projects. It has been adapted from several recent manuals that represent a balanced approach to stormwater management for these sites.

The first issue is how to define what is meant by infill and redevelopment, which may be different in each locality. One accepted definition is that redevelopment is “any construction, alteration, or improvement that disturbs greater than or equal to 5,000 square feet of existing impervious cover performed on sites where the existing land use is commercial, industrial, institutional, or residential.” Note that this definition does not fall under the purview of the CGP.

The second issue is to provide some greater flexibility in how redevelopment projects can comply with basic stormwater sizing criteria. This is done by proposing stormwater management guidance that a redevelopment will:

a. Provide a reduction in impervious area; or
b. Implement stormwater management practices; or
c. A combination of both (a) and (b) to result in an improvement to water quality.

More specifically, redevelopment projects introduce a chance to reduce existing site impervious area. Where site conditions prevent the reduction of impervious area, stormwater management practices could be implemented to provide water quality control for at least 20 percent of the site’s impervious area as a general guideline.

When a combination of impervious area reduction and stormwater management practice implementation is used for redevelopment projects, the combination of impervious area reduction and the area controlled by a stormwater management practice should equal or exceed 20 percent coverage of the project size.

The MPCA may allow practical alternatives where conditions prevent impervious area reduction or on-site stormwater management. Practical alternatives include, but are not limited to:

- Fees paid in an amount specified by the approving agency and then dedicated to stormwater management;
- Off-site stormwater treatment practice implementation for a drainage area comparable in size and impervious cover to that of the project;
- Watershed or stream restoration; or
- Stormwater retrofitting.

The recharge, channel protection storage volume, overbank, and extreme flood protection volume requirements specified in the Manual do not apply to redevelopment projects unless specified in an approved and adopted basin plan.

XV. References

American Society of Civil Engineers (ASCE). 2003. International Database on Pollutant Removal Performance of Stormwater Best Management Practices.

Booth, D. and P. Henshaw. 2001. Rates of channel erosion in small urban streams. Water Science and Application 2:17-38.

Brown, T. and J. Simpson. 2001. “Managing Phosphorus Inputs Into Lakes I: Determining the Trophic State of Your Lake.” Watershed Protection Techniques. 3 (4): 771-781. Center for Watershed Protection, Ellicott City, MD.

Cappiella, K., Schueler, T.R. and T. Wright. 2005. Urban Watershed Forestry Manual. Part 1: Methods for Increasing Forest Cover in a Watershed. USDA Forest Service, Northeastern Area State and Private Forestry, Newtown Square, PA.

Cappiella, K., Schueler, T.R. and T. Wright. 2005. Urban Watershed Forestry Manual. Part 2: Conserving and Planting Trees at Development Sites. USDA Forest Service, Northeastern Area State and Private Forestry, Newtown Square, PA.

Caraco, D. 2001. “Managing Phosphorus Inputs Into Lakes III: Evaluating the Impact of Watershed Treatment.” Watershed Protection Techniques. 3 (4): 791-796. Center for Watershed Protection, Ellicott City, MD.

Caraco, D. and T. Brown. 2001. “Managing Phosphorus Inputs Into Lakes II: Crafting an Accurate Phosphorus Budget for Your Lake.” Watershed Protection Techniques. 3 (4): 782-790. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 1999. Nutrient Loading from Conventional and Innovative Site Development. Chesapeake Research Consortium. Center for Watershed Protection, Ellicott City, MD.

Center for Watershed Protection (CWP). 2001. Special Issue on Urban Lake Management: Watershed Protection Techniques 3(4): 745-820.

Center for Watershed Protection (CWP). 2003. The Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research Monograph No. 1. Center for Watershed Protection, Ellicott City, MD. 142 pp.

Center for Watershed Protection. (CWP). 2004. An Integrated Framework to Restore Urban Small Urban Watersheds. Manual 1. Urban Subwatershed Restoration Manual Series. Center for Watershed Protection, Ellicott City, MD.

Debo, T. and A. Reese. 1992. Determining downstream analysis limits for detention facilities. Proceedings from International Conference on Innovative Technologies in the Domain of Urban Stormwater Drainage.

Emmons & Olivier Resources, Inc. (EOR). 2000. Brown's Creek Second Generation Watershed Management Plan.

Galli, J. 1990. Thermal Impacts Associated with Urbanization and Stormwater Management Best Management Practices. Metropolitan Washington Council of Governments, Washington, D.C.

Horner, R., D. Booth, A. Azous, and C. May. 1996. Watershed Determinants of Ecosystem Functioning. In L. A. Roesner (ed.), Effects of Watershed Development and Management on Aquatic Ecosystems: Proceedings of an Engineering Foundation Conference. Snowbird, UT: American Society of Civil Engineers.

Johnson, K. 1995. Urban Storm Water Impacts on a Coldwater Resource. Presentation to the Society of Environmental Toxicology and Chemistry (SETAC) Second World Congress. Vancouver, B.C., Canada.

Leopold, L. B. 1994. A View of a River. Harvard University Press. Cambridge, MA.

Leopold, L., M. Wolman, and J. Miller. 1964. Fluvial Processes in Geomorphology. W.H. Freeman and Company. San Francisco, CA.

MacRae, C. 1993. An alternate design approach for the control of instream erosion potential in urbanizing watersheds. pp. 1086-1091. In Proceedings of the Sixth International Conference on Urban Storm Drainage. Niagra Falls, Ontario. Marsalek and Torno (eds.).

MacRae, C. 1996. Experience from morphological research on Canadian streams: is control of the two-year frequency runoff event the best basis for stream channel protection? In Effects of Watershed Development and Management on Aquatic Systems . L. Roesner (ed.) Engineering Foundation Conference. Proceedings. Snowbird, UT. August 4-9, 1996. pp. 144-160.

McCuen R. and G. Moglen. 1988. Multicriterion stormwater management methods. Journal of Water Resources Planning and Management. (114) 4.

Metropolitan Council (MC). 2001. Minnesota Urban Small Sites BMP Manual: Stormwater Best Management Practices for Cold Climates. Metropolitan Council Environmental Services. St. Paul. MN.

Minnesota Pollution Control Agency (MPCA). 2000. Protecting Water Quality in Urban Areas. St Paul. MN.

Minnesota Pollution Control Agency (MPCA). 2004. 2004 Final List of Impaired Waters. http://www.pca.state.mn.us/water/tmdl/index.html.

Pitt, R. 1989. Small Storm Hydrology: The integration of flow and water quality for management practices University of Alabama-Birmingham.

Pitt, R., A. Maestre and R. Morquecho. 2004. The National Stormwater Quality Database (NSQD, version 1.1). University of Alabama. Tuscaloosa, AL.

Roa-Espinosa, A., T. Wilson, J. Norman, and K. Johnson. 2003. Predicting the Impact of Urban Development of Stream Temperature using a Thermal Urban Runoff Model (TURM). National Conference on Urban Storm Water: Enhancing Programs at the Local Level. Proceedings. Chicago, IL.

Schueler, T. 1987. Controlling urban runoff: a practical manual for planning and designing urban best management practices. Metropolitan Washington Council of Governments.Washington, DC.

Schueler, T. 1992. Design of Stormwater Wetland Systems. Metropolitan Washington Council of Governments. Washington, D.C.

Schueler, T. 2000a. Further Developments in Sand Filter Technology. Watershed Protection Techniques. 3(3): 707-716. Center for Watershed Protection. Ellicott City, MD.

Schueler, T. 2000b. The Impact of Stormwater on Puget Sound Wetlands." In T. Schueler and H. Holland, eds. 2000. The Practice of Watershed Protection. Center for Watershed Protection. Ellicott City, MD.

Schueler, T. and K. Brown. 2004. Manual 4: Urban Stream Repair Practices. Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

South St. Louis Soil and Water Conservation District. 2001. Miller Creek Diagnostic Study and Implementation Plan: Clean Water Partnership Phase I Report.

State of Maryland. 2000. Maryland Stormwater Design Manual. Volume I and II. Maryland Department of Environment. Baltimore, MD.

State of Minnesota Storm-Water Advisory Group. 1997. Storm-Water and Wetlands: Planning and Evaluation Guidelines for Addressing Potential Impacts of Urban Storm-Water and Snow-Melt Runoff on Wetlands.

State of Wisconsin. 2004. NR-151: Runoff management: Non-agricultural Performance Standards. Wisconsin Department of Natural Resources. July, 2004. No. 583.

USDA. 1986. TR-55 Urban Hydrology for Small Watersheds.

U.S. Environmental Protection Agency (US EPA). 1993. Natural Wetlands and Urban Storm water: Potential Impacts and Management.

United States Environmental Protection Agency (US EPA). 1980. Our Nation's Lakes. Office of Water. Washington, D.C. EPA-440-5-80-009.

Walker, 1987. Design calculations for Wet Ponds. Prepared fro St. Paul Water Utility and Vadnais Lake Area Water Management Organization, St Paul, MN.

Washington County Water Consortium (WCWC). 2003. Comparative review of watershed district rules and recommendations for standardization. Washington County Office of Administration.

Winer, R. 2000. National Pollutant Removal Database for Stormwater Treatment Practices: 2nd Edition. Center for Watershed Protection. Ellicott City, MD.

Winer, R. and J. Zielinski. 2003. Critical Area 10% Rule Guidance Manual: Maryland Chesapeake and Atlantic Coastal Bays. Center for Watershed Protection. Critical Area Commission, Annapolis, MD.

Chapter 11

Applying Stormwater Credits to Development Sites

VOLUME 2 - TECHNICAL AND ENGINEERING GUIDANCE

Chapter 11

Applying Stormwater Credits to Development Sites

This chapter reviews the purpose of stormwater credits, which could reduce required water quality volume in a BMP, outlines the specific procedures for computing them, and recommends a process for local adoption of a credit system.

Contents

I. Stormwater Credits

Stormwater credit is a tool for local stormwater authorities who are interested in providing incentives to site developers to encourage the preservation of natural areas and the reduction of the volume of stormwater runoff being conveyed to a best management practice (BMP).

Stormwater credits are simple to calculate, easy to review and delineate on site plans and quickly verified in the field. The main body of the chapter describes each stormwater credit, indicates how it is computed, outlines site conditions and restrictions that apply, and concludes with a numerical example. The six better site design approaches that could be eligible for water quality volume reduction stormwater credits include:

- Natural Area Conservation
- Site Reforestation or Prairie Restoration
- Drainage to Stream or Shoreline Buffers
- Surface Impervious Cover Disconnection
- Rooftop Disconnection
- Use of Grass Channels

For consistency with other sections of this Manual, the formulas for computing water quality volumes and related credits are based on the requirements contained in the MPCA Construction General Permit (CGP). These formulas provide just one option for local authorities to consider. The approach used in these examples subtracts the credit volume from the water quality volume (V_{wq}); the volume of a permanent pool (V_{pp}) in a stormwater pond or wetland is not adjusted. Other options that could be considered include applying credits to V_{pp}, or proportional application of a credit to both V_{pp} and V_{wq}.

It is not the intention of this system of credits to eliminate the need for a water quality volume. It is possible that the area proposed for conservation exceeds the area proposed as impervious surface. In this circumstance, it is recommended that a minimum water quality volume equal to 0.2 watershed inches be maintained, as further described in Chapter 10.

Local authorities should keep in mind that the current MPCA CGP, which expires in 2008, does not incorporate a technique for application of these credits. This CGP does allow up to a maximum of 1% of a site, up to three acres to drain untreated to natural areas, in sites where any BMP is not feasible.

Although stormwater credits are not currently used under the Minnesota Pollution Control Agency Construction General Permit (CGP), they can be applied at the local and watershed levels to supplement the CGP or be used for projects not covered under the CGP. Credits can also be used as part of the financial evaluation under a local stormwater utility program, similar to the Minneapolis approach. Further evaluation of the use of credits in the CGP process will occur as part of the permit update process over the next year.

Although not explicitly allowed under the current MPCA CGP, there are situations where a local authority could create a water quality credit system which does not conflict with the CGP. For example, a local authority that requires a water quality volume that is greater than the CGP water quality volume, could apply credits against the difference between the two volumes. Another situation appropriate for credits could be retrofit projects that do not create new impervious surfaces. These projects are not subject to permanent stormwater management requirements of the CGP. Local authorities interested in establishing a credit system prior to expiration of the CGP in 2008, are encouraged to contact the MPCA to explore if the local proposal is compatible with the CGP.

The last section presents tips on how to establish and administer a local stormwater credit system, with an emphasis on review and verification during concept design, final design and construction.

The decision to offer some, all or no stormwater credits solely rests with the local reviewing authority and should reflect local stormwater management goals and design review capability.

Table 11.1 Summary of Stormwater Credits Function		
Stormwater Credit	**Adjusted Water Quality Volume**	**Channel Protection & Overbank Storms**
Natural Area Conservation	Subtract CA from site IC when computing V_{wq}	Adjust CN for CA to woods in good condition
Site Reforestation Prairie Restoration	Subtract ½ RA from site IC when computing V_{wq}	Adjust CN for RA to woods or prairie in fair condition
Stream and Shoreline Buffers	Subtract ADB from site IC when computing V_{wq}	Adjust CN for ADB to woods in good condition
Surface Impervious Cover Disconnection	Subtract DIA from site IC when computing V_{wq}	Adjust CN for DIA to grass in good condition Adjust Tc
Rooftop Disconnection	Subtract DRA from site IC when computing V_{wq}	Adjust CN for DIA to grass in good condition Adjust Tc
Grass Channels	Subtract GA from site IC when computing V_{wq}	Adjust Tc

Note: Unless otherwise noted, all units below measured in acres
CA – Combined area of all natural areas conserved at site
RA – Total area of site reforestation or prairie restoration
ADB – Total area draining to buffer with appropriate flow path distance
DIA – Total area of surface impervious cover that can be effectively disconnected
DRA – Aggregate rooftop area that can be effectively disconnected
GA - total non-roadway area draining to swale (rooftop, yard and driveway)
CN – Runoff curve number for area (units: dimensionless) (see Ch.8 and App. B)
T_c – Time of Concentration (units: time)
V_{wq} – Water quality volume, as defined by relevant MPCA sizing rule
IC - Impervious area of site (acres)

II. Better Site Design and Stormwater Credits

Chapter 4 described more than a dozen better site design techniques that can be applied at development sites. When applied early in the design process, these techniques can dramatically reduce stormwater runoff and pollutants generated from development sites (CWP, 1999). In recent years, several states have sought to encourage greater use of better site design techniques by allowing for computation of stormwater credits that reduce the required water quality volume that must be provided at a development site.

Agencies that utilize stormwater credits can sharply reduce water quality and stormwater management BMP size requirements and recommendations. This translates directly into cost savings for developers since the size and cost of stormwater conveyance and treatment systems needed for the site are reduced, and less land area is needed for BMPs. The use of credits by developers is strictly voluntary, although they do offer a meaningful incentive to reduce the cost of stormwater compliance.

Stormwater credits are tied directly to the water quality volume requirements (V_{wq} and V_{pp}) outlined in Chapter 10. In addition, credits can be used to reduce the storage volumes needed to manage larger storm events, such as any locally-required channel protection and overbank floods (by increasing times of concentrations and reducing curve numbers in post-development hydrological modeling). Not all credits will be available for each site, and certain site-specific conditions should be met to receive each credit. These minimum conditions include site factors such as maximum flow length or contributing area that avoid situations that could lead to runoff concentration and erosion. Stormwater credits do not relieve designers from the normal standard of engineering practice of safe conveyance and drainage design. Multiple credits can be used at a development site, although two credits cannot be taken for the same physical area of the site. A brief summary of how stormwater credits work is presented in Table 11.1, and further explained with examples in the narrative that follows.

III. Stormwater Credit Categories

Credit 1. Natural Area Conservation Credit

Natural area conservation protects natural resources and environmental features that help maintain the pre-development hydrology of a site by reducing runoff, promoting infiltration and preventing soil erosion. Natural areas should be eligible for stormwater credit if they remain undisturbed during construction and are protected by a permanent conservation easement prescribing allowable uses and activities on the parcel and preventing future development. Examples of conservation areas include any areas of undisturbed vegetation preserved at the development site, such as forests, prairies (native grasslands), floodplains and riparian areas, ridge tops and steep slopes, and stream, wetland and shoreline buffers. Floodplain credits should not be issued to areas that cannot be developed due to existing floodplain ordinance restrictions.

The undisturbed soils and native vegetation of conservation areas promote rainfall interception and storage, infiltration, runoff filtering and direct uptake of pollutants. Portions of the site devoted to natural area conservation are eligible for two credits, such as the addition of a buffer credit.

Water Quality

The total combined area of all conservation areas can be subtracted from total site area when computing the water quality volume (V_{wq}) portion of the total storage volume. In the context of the

Natural Area Conservation Credit Example

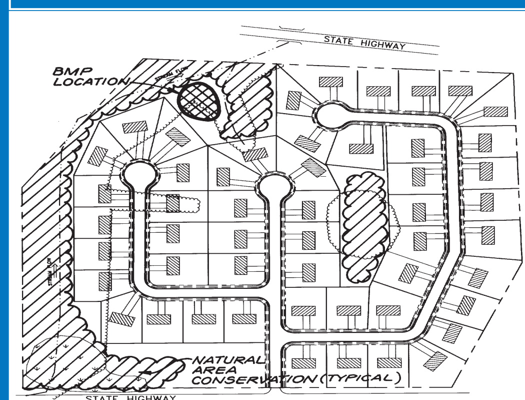
An example of how to compute the natural area conservation credit is provided for a hypothetical subdivision depicted in Figure 11.1. The 35 acre residential site consists of 50 ½-acre lots, and contains 12.25 acres of impervious cover and 2.89 acres of conservation area in the form of protected forests and stream buffers. The impervious cover (IC) for the residential site is calculated as: IC = 12.25 acres

The designer plans on using a wet pond for treatment, and the site discharges to a special water, so MPCA Sizing Rule 2 applies. In this case, the required water quality volume before and after the credit was calculated as:

$$V_{wq}\ Before\ Credit = [1.0\ inches * (12.25)] * \frac{1}{12}$$
$$= 1.02\ acre - feet$$
$$V_{wq}\ After\ Credit = [1.0\ inches * (12.25 - 2.89)] * \frac{1}{12}$$
$$= 0.78\ acre - feet$$

In this example, the credit reduces the required water quality volume by about 23% (0.24 acre-feet).

Figure 11.1 Application of Natural Area Credit to a Hypothetical Subdivision (Cross-Hatched Areas are Deducted from Total Site Area)



four MPCA V_{wq} sizing rules (see Chapter 10), the credit is numerically expressed as:

Rule 1 (Stormwater Ponds and Constructed Wetlands) and Rule 3 (Non-Ponds):

$$V_{wq} = [0.5\,inches * (IC - CA)] * \frac{1}{12}$$

$$\begin{aligned} &Where: \\ &V_{wq} = required\ water\ quality\ volume \\ &IC = new\ site\ impervious\ cover,\ in\ acres \\ &CA = total\ natural\ area\ conserved\ at\ site,\ in\ acres \end{aligned}$$

Rule 2 (Stormwater Ponds and Construction Wetlands Draining to Special Waters) and Rule 4 (Non-Ponds Draining to Special Waters):

$$V_{wq} = [1.0\,inches * (IC - CA)] * \frac{1}{12}$$

$$\begin{aligned} &Where: \\ &V_{wq} = required\ water\ quality\ volume \\ &IC = new\ site\ impervious\ cover,\ in\ acres \\ &CA = total\ natural\ area\ conserved\ at\ site,\ in\ ac \end{aligned}$$

Larger Storm Events

The post-development curve number (CN) used to compute the V_{cp}, V_{p10}, and V_{p100} for all natural conservation areas can be assumed to be "woods or prairie in good condition" when calculating the total site CN (Chapter 8 and Appendix B).

Conditions for Credit

It is HIGHLY RECOMMENDED that proposed conservation areas meet all of the conditions outlined below to be eligible for credit:

- The minimum combined area of all natural areas conserved at the site must exceed one acre. As referenced in Chapter 4, full ecological function for natural grassland (prairie) begins at 5 acres and for forested land starts at 20-40 acres. Credits could be increased beyond 1:1 for acreages that approach and exceed these values.
- No disturbance may occur in the conservation area during or after construction (i.e., no clearing or grading except for temporary disturbances associated with incidental utility construction or restoration operations, or removal of nuisance vegetation).
- The limits of disturbance around each conservation area should be clearly shown on all construction drawings.
- A long-term vegetation management plan must be prepared to maintain the conservation area in a natural vegetative condition. Managed turf is not considered an acceptable form of vegetation management, and only the passive recreational areas of dedicated parkland are eligible for the credit (e.g., ball fields and golf courses are not eligible).
- The conservation area must be protected by a perpetual easement that clearly specifies that no future development or disturbance can occur within the area.
- The credit cannot be granted for natural areas already protected by existing federal, state, or local law.
- Conservation areas should be preserved to maximize contiguous area and avoid habitat fragmentation.
- Credits should be considered for establishing native plant community corridors or naturally vegetated connections between sites.

Credit 2. Site Reforestation or Prairie Restoration Credit

Site reforestation involves planting trees on existing turf or barren ground at a development site with the explicit goal of establishing a mature forest canopy that will intercept rainfall and maximize infiltration. Reforested or restored sites that are protected and maintained under a perpetual conservation easement should be eligible for a stormwater credit.

Reforestation is accomplished through active replanting or natural regeneration of forest cover. Capiella (2005) reviewed a range of research that demonstrated the runoff reduction benefits associated with forest cover compared to turf cover. The runoff benefits include greater infiltration of stormwater, reduced soil erosion, and removal of stormwater pollutants. Forest soils actively promote greater infiltration rates through surface organic matter and macropores created by tree roots. Forests also intercept rainfall in their canopy, reducing the amount of rain that reaches the ground. Evapotranspiration by trees increases potential water storage in the soil.

In some parts of the State, a native grassland (prairie) community is the desired vegetative condition. Since native grasslands have the same hydrological benefits as forest, the same credit is also offered for any prairie restoration conducted at a development site. Two types of credit (water quality and CN adjustment) are available for site reforestation or grassland restoration, which are computed as follows:

Water Quality

The combined total of all reforested or restored areas is divided by two to determine net reforestation area (RA). This is due to the fact that it will take several decades for the replanted area to mature and provide full hydrologic benefits. RA is then subtracted from total site area when computing the water quality volume (V_{wq}) portion of the total storage volume (Chapter 10). In the context of the four MPCA V_{wq} sizing rules, the credit is numerically expressed as:

<u>Rule 1 (Stormwater Ponds and Constructed Wetlands) and Rule 3 (Non-Ponds):</u>

$$V_{wq} = [0.5\,inches * (IC - RA)] * \frac{1}{12}$$

Where:

V_{wq} = *required water quality volume*

IC = *new site impervious cover, in acres*

RA = *total area reforested or restored at site, in acres*

<u>Rule 2 (Stormwater Ponds and Construction Wetlands Draining to Special Waters) and Rule 4 (Non-Ponds Draining to Special Waters):</u>

$$V_{wq} = [1.0\,inches * (IC - RA)] * \frac{1}{12}$$

Where:

V_{wq} = *required water quality volume*

IC = *new site impervious cover, in acres*

RA = *total area reforested or restored at site, in acres*

Larger Storm Events

The post-development curve number (CN) used to compute the V_{cp}, V_{p10}, and V_{p100} for the reforested area can be assumed to be "woods or prairie in

Site Reforestation Credit Example

To illustrate an example of the reforestation credit, consider a 100-acre subdivision that has 15% impervious cover. The designer intends to reforest ten acres of land on the site. Since the forest will take years to grow to maturity, the reforestation area is divided by two.

RA = 10 acres / 2 = 5 acres

The designer plans on using a wet pond for treatment, but the site does not discharge to a special water, so MPCA Sizing Rule 1 applies. In this case, the required water quality volume before and after the credit was computed as:

$$V_{wq}\ Before\ Credit = [0.5\,inches * 15\,acres] * \frac{1}{12} = 0.625\ acre-feet$$

$$V_{wq}\ After\ Credit = [0.5\,inches * (15\,acres - 5\,acres)] * \frac{1}{12} = 0.42\ acre-feet$$

In this example, site reforestation produced a water quality volume that was 30% smaller (.205 acre-feet) than originally planned.

fair condition" when calculating the total site CN, even if it will be decades before the forest reaches maturity.

Conditions for Credit

It is HIGHLY RECOMMENDED that a proposed reforestation or prairie restoration project meet all of the conditions outlined below to qualify for credit:

- The minimum contiguous area of reforestation or prairie restoration must be greater than 20,000 square feet (i.e., no credit is granted for planting of individual street trees). As referenced in Chapter 4, full ecological function for natural grassland (prairie) begins at 5 acres and for forested land starts at 20-40 acres. Credits could be increased beyond 1:1 for acreages that approach and exceed these values.
- A long-term vegetation management plan must be prepared and filed with designated authority to maintain the conservation area in either a natural forest or prairie condition.
- The conservation area must be protected by a perpetual easement that clearly specifies that no future development or disturbance can occur within the area.
- The method used for reforestation or restoration must achieve 75% forest canopy or prairie cover within ten years.
- The planting plan must be approved by the appropriate local stormwater, watershed or forestry agency, including any special site preparation needs.
- The construction contract should contain a care and replacement warranty extending at least three growing seasons to ensure adequate survival and growth of the plant community.

Credit 3. Drainage to Stream, Wetland or Shoreline Buffer Credit

Buffers may be required at the development site to provide a vegetative setback between development and streams, lakes or wetlands. Portions of the site reserved as buffers and maintained in native vegetation can help filter stormwater runoff. While stream and shoreline buffers are already eligible for the natural area conservation credit, adjacent site area that directly contribute sheet flow to buffers may also be eligible for an additional credit.

In some cases, the outer boundary of the buffer may need to be modified to capture and treat overland flow from adjacent pervious and/or impervious areas by creating a shallow depression area or filter strip designed to maintain sheetflow conditions. The drainage to stream or shoreline buffer credit is computed as follows:

Water Quality

The total area draining by sheet flow into the buffer from adjacent areas can be subtracted from total site area in the V_{wq} calculation portion of the total storage volume (Chapter 10). The credit is numerically expressed for each of the four MPCA V_{wq} sizing rules using the following equations:

Rule 1 (Stormwater Ponds and Constructed Wetlands) and Rule 3 (Non-Ponds):

$$V_{wq} = [0.5\,inches * (IC - ADB)] * \frac{1}{12}$$

$$\begin{aligned} &Where:\\ &V_{wq} = required\ water\ quality\ volume\\ &IC = new\ site\ impervious\ cover,\ in\ acres\\ &ADB = total\ area\ draining\ to\ buffer,\ in\ acres \end{aligned}$$

Rule 2 (Stormwater Ponds and Construction Wetlands Draining to Special Waters) and Rule 4 (Non-Ponds Draining to Special Waters):

$$V_{wq} = [1.0\,inches * (IC - ADB)] * \frac{1}{12}$$

$$\begin{aligned} &Where:\\ &V_{wq} = required\ water\ quality\ volume\\ &IC = new\ site\ impervious\ cover,\ in\ acres\\ &ADB = total\ area\ draining\ to\ buffer,\ in\ acres \end{aligned}$$

Larger Storm Events

The post-development curve number (CN) used to compute the V_{cp}, V_{p10}, and V_{p100} for the contributing buffer area can be assumed to be "woods in good condition" when calculating the total site CN.

Conditions for Credit

Drainage to Stream, Wetland, or Shoreline Buffer Credit Example

Returning to the earlier 35-acre residential development example, the designer determined that 1.3 acres of the site drained to the stream buffer and met the contributing flow path conditions described above (Figure 11.2). Using MPCA Sizing Rule 2, the required water quality volume computed before and after the credit was:

$$V_{wq}\ \text{Before Credit} = [1.0\ \text{inches} * 12.25\ \text{acres}] * \frac{1}{12}$$

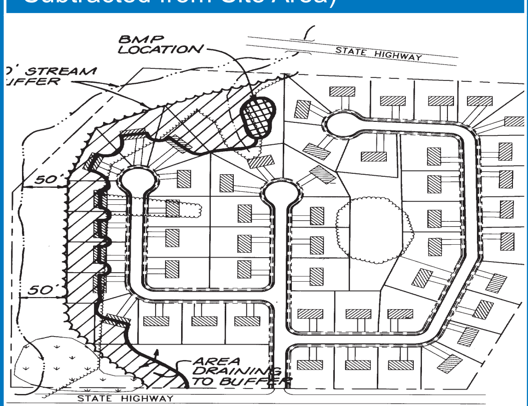
$$= 1.02\ \text{acre} - \text{feet}$$

$$V_{wq}\ \text{After Credit} = [1.0\ \text{inches} * (12.25\ \text{acres} - 1.3\ \text{acres})] * \frac{1}{12}$$

$$= 0.91\ \text{acre} - \text{feet}$$

Use of the buffer drainage credit resulted in a modest reduction of 0.11 acre-feet in the size of the water quality volume component of the total storage volume for a pond. However, when the credit was coupled with the 0.24 acre-foot natural area credit granted earlier, the size of the water quality volume was reduced by 34%.

Figure 11.2 Application of Buffer Drainage Credit to Hypothetical Subdivision (Cross-Hatched Areas Draining to Buffer Are Subtracted from Site Area)



It is HIGHLY RECOMMENDED that drainage to stream or shoreline buffers satisfy the following conditions to be eligible for credit.

- The minimum acceptable buffer width for effective stormwater treatment is an average of 50 feet (minimum 25 feet), measured perpendicular to the stream, lake or wetland (averaging over the length of the buffer boundary is allowed).
- The maximum contributing flow path to the buffer may be no more than 150 feet for adjacent pervious cover and no more than 75 feet for adjacent impervious cover.
- The average contributing overland slope to and across the buffer must be less than 3%.
- Runoff should enter the outer boundary of the buffer as sheet flow, although a depression or level-spreading device may be used to spread out concentrated flow.
- The buffer credit may not be taken if either the rooftop or surface impervious cover disconnection credit has already been taken for the same contributing area (i.e., no double counting).
- Buffers should not be graded or compacted during construction
- Buffers should be maintained in a natural vegetative condition, with a long-term vegetative management plan.
- The area of the buffer itself may qualify as natural area conservation credit.

Additional sources of information on buffers can be found in MCWD (2001) and Minnesota Forest Resources Council (1999)

Credit 4. Surface Impervious Cover Disconnection Credit

Surface disconnection spreads runoff from small parking lots, courtyards, driveways, sidewalks and other impervious surfaces into adjacent pervious areas where it is filtered or infiltrated. Note that rooftop disconnection is discussed in the next credits section. In most cases, the site is graded to divert sheet flow into a vegetated filter strip or pervious area for treatment. Disconnecting small areas of impervious cover from the storm drain system can greatly reduce the total volume and rate of stormwater runoff. Credits for surface disconnection are subject to numerous restrictions concerning the length, slope, soil characteristics of the pervious area which are designed to prevent any reconnection of runoff with the storm drain system. In some cases, minor grading of the site may be needed to promote overland flow and vegetative filtering. Two kinds of stormwater credit (water quality and CN adjustment) can be given for disconnecting surface impervious cover at a development site:

Water Quality

The total disconnected impervious area (DIA) is subtracted from the total site area when computing the V_{wq} portion of the total storage volume (Chapter 10). The following equations indicate how the credit is computed for the four MPCA sizing rules:

Rule 1 (Stormwater Ponds and Constructed Wetlands) and Rule 3 (Non-Ponds):

$$V_{wq} = [0.5\,inches * (IC - DIA)] * \frac{1}{12}$$

$$\begin{aligned} &Where: \\ &V_{wq} = required\ water\ quality\ volume \\ &IC = new\ site\ impervious\ cover, in\ acres \\ &DIA = total\ area\ of\ surface\ impervious\ cover \\ &\quad effectively\ disconnected, in\ acres \end{aligned}$$

Rule 2 (Stormwater Ponds and Construction Wetlands Draining to Special Waters) and Rule 4 (Non-Ponds Draining to Special Waters):

$$V_{wq} = [1.0\,inches * (IC - DIA)] * \frac{1}{12}$$

$$\begin{aligned} &Where: \\ &V_{wq} = required\ water\ quality\ volume \\ &IC = new\ site\ impervious\ cover, in\ acres \\ &DIA = total\ area\ of\ surface\ impervious\ cover \\ &\quad effectively\ disconnected, in\ acres \end{aligned}$$

Larger Storm Events (CN Adjustment)

The post-development curve number (CN) used to compute the V_{cp}, V_{p10}, and V_{p100} for the area of disconnected impervious cover area can be assumed to be "grass in good condition" when calculating the total site CN.

Conditions for Credit

The disconnection credit is subject to numerous conditions and restrictions, as outlined below:

- The contributing flow path from impervious

Surface Impervious Cover Disconnection Credit Example

An example of how the surface impervious cover credit could be applied to a small commercial site is shown in Figure 11.3. The commercial site is 3.17 acres in size, and contains 1.9 acres of impervious cover (IC = 60%). The site is not designated as a potential stormwater hotspot, does not drain to special waters, and, because of it small size, will be treated by a bioretention area. The designer realizes that 0.52 acres of parking lot can be disconnected to grassy areas at the bottom of the site. Based on these considerations, MPCA Sizing Rule 3 applies to the site, and the required water quality volume before and after the disconnection credit was calculated as:

$$\begin{aligned} V_{wq}\ Before\ Credit &= [0.5\,inches * 1.9\,acres] * \frac{1}{12} \\ &= 0.079\ acre-feet \\ V_{wq}\ After\ Credit &= [0.5\,inches * (1.9\,acres - 0.52\,acres)] * \frac{1}{12} \\ &= 0.066\ acre-feet \end{aligned}$$

In this example, the surface impervious cover credit reduced the size of the planned bioretention area for the site by about 16.5% (.013 acre-feet).

Figure 11.3. Application of Surface Impervious Cover Disconnection Credit to a Hypothetical Development (Shaded Areas are Deducted from Total Site Area.

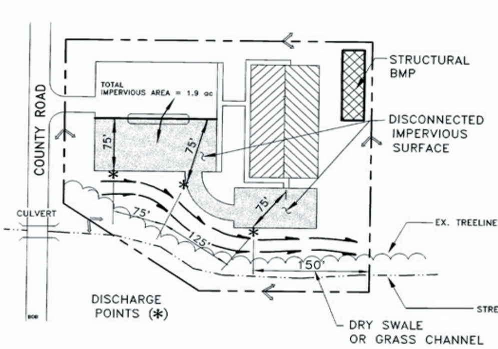


Table 11.2 Guidance on Storage-Compensation Rules for Shorter Disconnection Lengths						
Disconnection Length provided	**0 to 14 ft**	**15 to 29 ft**	**30 to 44 ft**	**45 to 59 ft**	**60 to 74 ft**	**75 ft**
% V_{wq} treated by disconnect	0%	20%	40%	60%	80%	100%
Runoff storage needed	100%	80%	60%	40%	20%	0%
Max Storage Volume*	40 cf	32 cf	24 cf	16 cf	8 cf	0 cf

* assuming 500 square feet roof area to each downspout disconnection.
cf = cubic feet

cover should not exceed 75 feet.

- The recommended minimum length of the pervious area over which runoff is spread is 75 feet, and, in all cases, the disconnection length must exceed the contributing flow path.
- Compensatory storage may be needed for shorter disconnection lengths, in the form of a dry well, rain garden or spreading device, following the guidance shown in Table 11.2.
- Pervious areas used for disconnection should have a slope no greater than 5%.
- The total surface impervious area contributing to any single discharge point shall not exceed 1,000 ft^2 and shall drain continuously through a pervious filter strip until it reaches the property line or drainage swale
- No on-site soil evaluations are needed if the NRCS Soil Survey indicates soils are relatively permeable (e.g., Hydrologic Soil Groups A and B).
- On-site soil evaluations by an engineer, geologist or soil scientist are needed for less permeable soils (HSG C and D). Soil amendments may be needed to restore

Table 11.3 Soil Amendments
Soil amendments refer to tilling, composting, or other amendments to urban soils to recover soil porosity, increase water holding capacity, and reduce runoff. Soils in many urban areas are highly compacted as a result of prior grading, construction traffic and ongoing soil disturbance. Amendments recover soil porosity by incorporating compost, top soil, and other soil conditioners to improve the hydrologic properties of lawns or landscaped areas. Soil amendments are often needed to obtain disconnection credits on sites with compacted or poorly infiltrating soils. Note that fibers added to soil can have a similar effect and should also be considered for credit if locally approved. ► Soil compost amendments may be required on pervious areas that will be utilized for either rooftop or surface disconnection that have soils in the C or D Hydrologic Soil Groups. ► Amendments can be applied to new lawns in residential subdivisions with lot sizes more than one-half acre in area , and at any other pervious area that is currently compacted or expected to become compacted in the future due to grading and construction activity. ► Soil amendment treatment used to enhance the disconnection properties of pervious areas should be a minimum of 5,000 square feet in surface area. ► Fiber type amendments are incorporated to maintain soil structure without compaction. These amendments are usually proprietary devices. Manufacturers should be contacted for specific recommendations. ► Soil amendments must meet minimum local specifications, such as Mn/DOT Technical Specifications #3890.

porosity of compacted pervious areas, as outlined in Table 11.3.

- If surface impervious cover ultimately drains to a stream buffer, the designer must choose either the surface disconnection credit or the stream buffer credit, but not both.
- The disconnection credit may not be used if the impervious cover is designated as a potential stormwater hotspot.

Credit 5. Rooftop Disconnection Credit

Disconnection of rooftops offers an excellent opportunity to spread rooftop runoff over lawns and other pervious areas where it can be filtered and infiltrated. Downspout disconnection can infiltrate runoff, reduce runoff velocity, and remove pollutants. Alternately, downspouts can be directed to a dry well, rain garden or surface depression. Stormwater credits could be offered for rooftop disconnections that effectively spread runoff over an acceptable pervious area that provides reasonable filtering and/or infiltration. In some cases, individual lots may need minor grading to meet minimum overland flow conditions. Two types of stormwater credits (water quality and CN adjusted) are possible for rooftop disconnections:

Water Quality

The combined area of disconnected rooftops are subtracted from the total site area when computing V_{wq} as shown in the equations below:

<u>Rule 1 (Stormwater Ponds and Constructed Wetlands) and Rule 3 (Non-Ponds):</u>

$$V_{wq} = [0.5\,inches * (IC - DRA)] * \frac{1}{12}$$

$$\begin{aligned} &Where: \\ &V_{wq} = required\ water\ quality\ volume \\ &IC = new\ site\ impervious\ cover,\ in\ acres \\ &DRA = total\ area\ of\ disconnected\ rooftops,\ in\ acres \end{aligned}$$

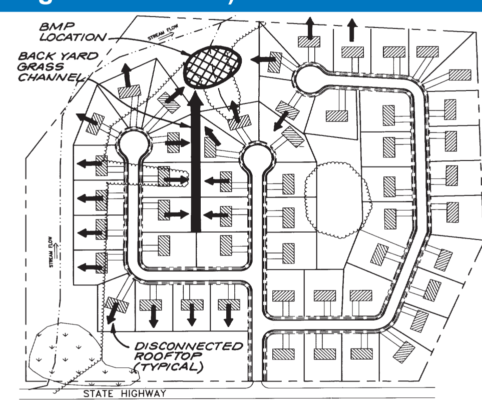
Rooftop Disconnection Credit Example

Returning once again to the 35-acre residential subdivision example, the designer determined that partial rooftop disconnection was feasible at 22 of the 50 lots. The average rooftop area was measured at 2500 square feet each, which results in a combined 1.26 acres of disconnected rooftop area (Figure 11.4). However, three rooftops were found to be ineligible for credit since they had already been used for the drainage to stream buffer credit. Therefore, the net disconnected rooftop area dropped to 1.09 acres. Using MPCA Sizing Rule 2 again, the required water quality volume before and after the credit was computed as:

$$\begin{aligned} V_{wq}\ Before\ Credit &= [1.0\,inches * 12.25\,acres] * \frac{1}{12} \\ &= 1.02\,acre-feet \\ V_{wq}\ After\ Credit &= [1.0\,inches * (12.25\,acres - 1.09\,acres)] * \frac{1}{12} \\ &= 0.93\,acre-feet \end{aligned}$$

Rooftop disconnection in this example produced a modest reduction of 0.09 acre-feet in the size of water quality volume. The benefits of applying multiple credits at the same site are evident when the rooftop credit was coupled with the 0.35 acre-feet of storage credits for natural area conservation and buffer drainage granted earlier, collectively reducing water quality volume by 0.44 acre-feet.

Figure 11.4. Application of Rooftop Disconnection Credit to Hypothetical Subdivision (Each Individual Rooftop Must be Assessed—Only Those with Black Arrows are Eligible for Credit)



Rule 2 (Stormwater Ponds and Construction Wetlands Draining to Special Waters) and Rule 4 (Non-Ponds Draining to Special Waters):

$$V_{wq} = [1.0\, inches * (IC - DRA)] * \frac{1}{12}$$

$Where:$

$V_{wq} = required\ water\ quality\ volume$

$IC = new\ site\ impervious\ cover,\ in\ acres$

$DRA = total\ area\ of\ disconnected\ rooftops,\ in\ acres$

Larger Storm Events (CN Adjusted)

The post-development curve number (CN) used to compute the V_{cp}, V_{p10}, and V_{p100} for the disconnected rooftops can be assumed to be grass in good condition when calculating the total site CN.

Conditions for Credit

It is HIGHLY RECOMMENDED that the rooftop disconnection credit is subject to the minimum conditions outlined below:

- The disconnections must address and adequately prevent any problems with basement seepage.
- Each individual rooftop must be assessed separately to determine if it can be effectively disconnected.
- The recommended length of pervious area over which rooftop runoff is spread should be at least 75 feet, and in all cases, the length of the disconnection should be equal to or greater than the contributing rooftop length.
- If shorter disconnection lengths are anticipated, then a runoff storage device such as a dry well or rain garden is needed, subject to the storage-compensation rules shown in Table 11.2.
- The contributing rooftop area to any single disconnected downspout cannot exceed 1,000 ft^2.
- Disconnections are only credited for residential lot sizes exceeding 6,000 ft^2.
- Pervious areas used for disconnection should have a slope no greater than 5%.
- Downspouts must be located at least 10 feet away from the nearest impervious surface to discourage re-connection with the storm drain system
- In cases where gutter/downspout system are not used, rooftop runoff should drain as either sheetflow from the roof or drain to a subsurface drain field not directly connected to the drainage network.
- No on-site soil evaluations are needed if the NRCS Soil Survey indicates site soils are relatively permeable (e.g., Hydrologic Soil Groups A and B).
- On-site soil evaluations by an engineer, geologist or soil scientist are needed for less permeable soils (Hydrologic Soil Groups C and D). Soil compost amendments may be needed to recover soil porosity for compacted pervious areas, as outlined in Table 11.3.
- If the disconnected rooftop also drains directly to a stream buffer, designers must choose the rooftop disconnection credit or the stream buffer credit, but not both.
- If a rooftop is designated as a potential stormwater hotspot, the disconnected rooftop runoff may not commingle with any other runoff from any paved surfaces at the site.

Credit 6. Grass Channel Credit

Curbs, gutters and storm drains are all designed to be hydraulically efficient in removing stormwater from a site. However, they also increase peak runoff discharge, flow velocity, and the pollutant delivery to downstream waters. Grass channels are preferable to curb and gutters as a conveyance system, where development density, topography, soils and slopes permit. While research has not demonstrated that grass channels remove pollutants reliably enough to qualify as a BMP (Winer, 2000), they have been shown to reduce runoff volumes during smaller storms when compared to curbs and gutters. Stormwater credits are provided for certain grass channel designs, based on their ability to reduce runoff volume through infiltration and soil filtration. Two credits (water quality and CN adjusted) can be applied when grass swales are used at a site:

Water Quality

The non-roadway portion of the area draining to the swale can be subtracted from the total site area when computing V_{wq} portion of the total storage volume ([Chapter 10)](#) using the following equations.

Rule 1 (Stormwater Ponds and Constructed Wetlands) and Rule 3 (Non-Ponds):

$$V_{wq} = [0.5\,inches * (IC - GA)] * \frac{1}{12}$$

$Where:$

$V_{wq} = required\ water\ quality\ volume$

$IC = new\ site\ impervious\ cover,\ in\ acres$

$GA = non-roadway\ area\ draining\ to\ the\ swale,\ in\ acres$

Rule 2 (Stormwater Ponds and Construction Wetlands Draining to Special Waters) and Rule 4 (Non-Ponds Draining to Special Waters):

$$V_{wq} = [1.0\,inches * (IC - GA)] * \frac{1}{12}$$

$Where:$

$V_{wq} = required\ water\ quality\ volume$

$IC = new\ site\ impervious\ cover,\ in\ acres$

$DRA = non-roadway\ area\ draining\ to\ the\ swale,\ in\ acres$

Larger Storm Events (CN Adjusted)

While the post-development curve number (CN) used to compute the V_{cp}, V_{p10}, and V_{p100} does not change, grass channels may increase the time of concentration and thereby reduce required storage volumes.

Conditions for Credit

It is HIGHLY RECOMMENDED that grass channels meet the following minimum conditions to be eligible for credit:

- Grass channel primarily serve low to moderate density residential development, with a maximum density no greater than 4 dwelling units per acre.
- The bottom width of the channel should be 2 feet minimum and 8 feet maximum.
- Swale side slopes should be no steeper than 3H:1V.
- The longitudinal slope of the grass channel should be less than or equal to 3%.
- The length of the grass channel should be equal to or greater than the roadway length.
- The dimensions of the swale should

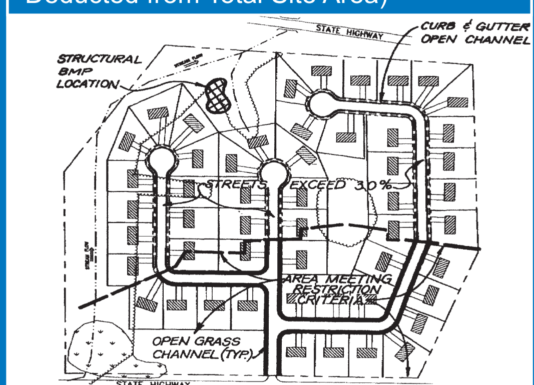
Grass Channel Credit Example

A network of grass swales served the entire 35-acre residential subdivision in our earlier example, but closer analysis revealed only about a quarter of the swale system met the 3% slope requirement. The non-roadway drainage area to the remaining eligible swales (sum of rooftop, front yard and driveways) were delineated and totaled 5.49 acres. The designer also found that 0.83 acres of swale drainage area had already been claimed for the drainage to buffer credit, so a net of only 4.66 acres were eligible for the swale credit. Using the MPCA Rule 2 sizing equation, the required water quality volume before and after the credit was calculated as:

$$V_{wq}\ Before\ Credit = [1.0\,inches * 12.25\,acres] * \frac{1}{12}$$
$$= 1.02\ acre-feet$$
$$V_{wq}\ After\ Credit = [1.0\,inches * (12.25\,acres - 4.66\,acres)] * \frac{1}{12}$$
$$= 0.63\ acre-feet$$

The water quality volume savings due to the grass swale credit alone was found to be about 0.39 acre-feet.

Figure 11.5 Assessing the Grass Channel Credit in a Hypothetical Subdivision (Drainage Area to Dark-Shaded Swales is Deducted from Total Site Area)



Total Allowable Credit Example

The minimum recommended water quality volume for any site is 0.2 inches per drained acre. For the 35-acre example site, the minimum V_{wq} is:

$$V_{wq} = 0.2\, inches * 35\, acres * \frac{1}{12} = .58\, acre - feet$$

When compared against the total credit computed for this site (Natural Area Conservation Credit, Buffer Credit, Rooftop Credit, and Grass Channel Credit), it was concluded that the total credits exceeded the available credit.

$$\begin{aligned} Total\ Computed\ Credit &= 0.85\, acre - feet \\ Total\ Allowable\ Credit &= (1.02\, acre - feet) - (0.58\, acre - feet) \\ &= 0.44\, acre - feet \end{aligned}$$

The excess credit equals 0.39 acre-feet, which is equal to the value of the grass channel credit. In this example, the design would have the option of proportionately reducing each credit, or eliminating the grass channel credit.

In the end, the total allowable credit for this site equals 0.44 acre-feet, or 43% of the required water quality volume -- a significant savings for the developer.

ensure that runoff velocity is non-erosive during the two-year design storm event.

- The grass channel credit cannot be taken for a front yard if the rooftop disconnection credit already been taken
- Grass channels that conform to the dimensions above qualify for the credit, unless the NRCS Soil Survey indicates the swale soils fall into Hydrologic Soil Group D. In these cases, designers must show that a maximum flow velocity of 1 fps (foot per second) and the average residence time of 10 minutes or more are maintained in the swale during a one-inch rainstorm.

IV. Establishing an Effective Local Stormwater Credit System

This section presents guidance to local reviewing authorities on how to establish and administer an effective stormwater credit system in the community.

Is My Community Ready for Credits?

Experience in other states has shown that it can take a while for both local plan reviewers and engineering consultants to understand and effectively use credits during stormwater design. Adoption of credits by a local regulator is particularly difficult in communities where stormwater design occurs long after final site layout, giving designers or plan reviewers little chance to apply the better site design techniques at the heart of the credit system.

Four ingredients appear to be important in establishing an effective local credit system:

- Strong interest and some experience in the use of better site design techniques
- A development review process that emphasizes early stormwater design consultations during and prior to initial site layout
- Effective working relationships between plan reviewers and design consultants

- A commitment by both parties to field verification to ensure that credits are not a paper exercise.

Adapting Credits for Local Use

If a community feels it has many of these ingredients in place, it is ready to decide whether to offer some or all of the credits described in this chapter. The first step in the adoption process is to review each stormwater credit to ensure whether it is appropriate given local conditions and review capability. Plan reviewers should pay close attention to how credit conditions and restrictions will be defined. It may be advisable to establish a team of local consulting engineers, plan reviewers and contractors to test out the proposed credits on some recently submitted site plans to make sure they are workable. Future plan review conflicts can be avoided when designers and plan reviewers agree on how credits will be handled in the local development review process.

Integrating Credits Into the *Local* Development Review Process

Stormwater credits need to be explicitly addressed during three stages of the local development review process, as shown below:

1. Feasibility during concept design
2. Confirmation in final design
3. Verification at final construction Inspection

The first stage where credits are considered is during initial stormwater concept design prior to site layout. The designer should examine topography and flow patterns to get a sense for how stormwater can be distributed and disconnected across the site, and explore opportunities to orient lots, grading or conveyance to maximize use of better site design techniques in the proposed site plan. While stormwater credits can be applied to any kind of site, they are ideally suited for low density residential development, particularly when open space or conservation designs are planned.

Communities may also elect to offer additional stormwater credits to promote adoption of innovative practices such as green rooftops, soil compost amendments, permeable pavements, and stormwater planters, using the same area-based computational approach outlined for the credits in this Chapter.

Once better site design techniques are incorporated into the site plan, the designer can delineate the approximate areas at the site that are potentially eligible for stormwater credits, making sure that credit areas do not overlap. Ideally, proposed credit areas are drawn directly on the stormwater element of the site plan. Next, the adjusted V_{wq} is computed, and the remaining elements of the BMP treatment system are sized and located. The local review authority then checks both the credit delineations and computations as part of the review of the stormwater concept plan.

The credits are reviewed a second time during final design to confirm whether they meet the site-specific conditions outlined earlier in this chapter (e.g., slope, contributing drainage area, flow path lengths, etc). The designer should be able to justify the precise boundaries of each credit area on the plan, and indicate in the submittal whether any grading or other site preparation are needed to attain credit conditions (this is particularly important for rooftop disconnection and grass channel credits). Designers should be encouraged to use as many credits as they can on different portions of the site, but plan reviewers should make sure that two or more credits are not claimed for the same site area (i.e., no double counting). Reviewers should carefully check the delineation of all credit areas, make sure flow paths are realistic, and then approve the adjusted V_{wq} for the site. In addition, the plan reviewer should check to make sure that any required easements or management plans associated with the credit have been secured prior to approval.

Field inspection is essential to verify that better site design techniques used to get the stormwater credits actually exist on the site and were installed properly. This is normally done as a site walk through as part of the final stormwater inspection at the end of construction. To ensure compliance, communities may want to set the value of performance bond for the stormwater system based on the unadjusted V_{wq} for the site (pre-credit) to ensure better site design techniques are installed properly.

V. References

Capiella, K, T. Schueler and T. Wright. 2005. Conserving and planting trees at development sites. USDA Northeastern Area State and Private Forestry. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 1998. Better Site Design: a handbook for changing development rules in your community. US EPA. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 1999. Nutrient loading from conventional and innovative site development. Chesapeake Research Consortium. Center for Watershed Protection. Ellicott City, MD.

Chang, M., M. McBroom, R. Beasley. 2004. Roofing as a source of nonpoint water pollution. Journal of Environmental Management. 73: 307-315.

Chollak, T and R. Rosenfield 1998. Guide for landscaping with compost amended soils. Department of Public Works. City of Redmond, WA.

City of Portland. 2004. Portland's Stormwater Management Manual. Bureau of Environmental Services. Portland Oregon. www.cleanrivers-pdx.org/tech_resources/2004_swmm.htm

City of Seattle, 2003 . How soil amendments and compost can aid in Salmon recovery. http://depts.washington.edu/cuwrm/publictn/s4s.pdf

Horsely, S. 1996. Memorandum dated July 10, 1996. Methods for Calculating Pre and Post-development Recharge Rates. Prepared for State of Massachusetts Stormwater Technical Advisory Group.

Metropolitan Council (MC). 2001. Minnesota urban small sites BMP Manual: Stormwater best management practices for cold climates. Metropolitan Council Environmental Services. St. Paul. MN.

Minnehaha Creek Watershed District (MCWD), 2001. Benefits of Wetland Buffers: A Study of Functions, Values, and Size. Prepared for MCWD by EOR. Oakdale, MN. 41pp.

Minnesota Forest Resources Council. 1999. Sustaining Minnesota Resources: Voluntary Site-Level forest Management Guidelines for Landowners, Loggers, and Resource Managers. (General Guidelines pp. 22-23). Minnesota Forest Resources Council, St. Paul, MN.

Minnesota Pollution Control Agency (MPCA). 2002. Protecting Water Quality In Urban Areas. St Paul. MN.

Pitt, R. 1989. Small Storm Hydrology: The integration of flow and water quality for management practices University of Alabama-Birmingham.

State of Maryland. 2000. Maryland Stormwater Design Manual. Volume I and II. Maryland Department of Environment. Baltimore, MD.

State of New York. 2003. Stormwater Management Design Manual. New York State Department of Environmental Conservation. Albany, NY.

State of Vermont, 2002. The Vermont Stormwater Management Manual-Final Draft. Vermont Agency of Natural Resources, Waterbury, VT.

USDA. 1986. TR-55 Urban Hydrology for Small Watersheds.

Winer, R. 2000. National Pollutant Removal Database for Stormwater Treatment Practices: 2nd Edition. Center for Watershed Protection. Ellicott City, MD.

Chapter 12

Details of Stormwater Best Management Practices (BMPs)

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VOLUME 2 - Technical Guidance

Chapter 12

Details of Stormwater Best Management Practices (BMPs) - Intro

This chapter provides a summary of guidance material for recommended BMPs, then provides the details in a series of Fact Sheets and Guidance Sheets. It contains some detail design factors, some necessary information for use of BMPs and the BMP sheets arranged in treatment train order.

Contents

I. Introduction

This part of the *Minnesota Stormwater Manual* creates a tool most requested by the stormwater community – information on the design, expected performance, and maintenance requirements of Best Management Practices (BMPs). Chapter 6 of the Manual introduced the various BMPs and a screening tool to narrow the possible choices to meet project objectives. Chapter 7 then took the user deeper into the selection process via a series of matrices that explore different decision elements. Chapter 12 follows-up those introductory BMP pieces with detailed information on how a particular BMP, once selected, is designed, constructed and maintained. The format of Chapter 12 is set to allow experienced designers to research specific questions, while providing complete information for people looking for an introduction to BMP design in Minnesota. Additional information on BMP cost, operation and maintenance, and construction is provided in Appendix D.

II. Fact Sheets and Design Guidance - General

This chapter presents a series of Fact Sheets and more detailed design Guidance Sheets for all BMPs discussed in this Manual. The information is presented in treatment train order, as defined in Chapters 1 and 6:

Pollution Prevention (PREV)

- Residential Practices Fact Sheet
- Municipal Practices Fact Sheet
- Industrial & Commercial Practices Fact Sheet

Better Site Design (BSD)

- Overview Fact Sheet
- Residential Streets and Parking Lots Fact Sheet
- Lot Development Fact Sheet

Runoff Volume Minimization (MIN)

- Green Roofs Fact Sheet
- Pervious Pavement Fact Sheet
- Rainwater Harvesting Fact Sheet

Temporary Construction Erosion and Sediment Control (CONST)

- Fact Sheet

Bioretention Practices (BIO)

- Fact Sheet
- Guidance Sheets

Filtration Practices (FIL)

- Fact Sheet
- Guidance Sheets

Infiltration Practices (INF)

- Fact Sheet
- Guidance Sheets

Stormwater Ponds (POND)

- Fact Sheet
- Guidance Sheets

Stormwater Wetlands (WETL)

- Fact Sheet
- Guidance Sheets

Supplemental BMPs (SUPP)

- Filtration Devices Fact Sheet
- Hydrodynamic Devices Fact Sheet
- Chemical & Biological Treatment Fact Sheet

The Fact Sheets are used as stand-alone education pieces and as introductions to more detailed design guidance sheets. These summary fact sheets present a description of the BMP, plus overview information on suitability, key design considerations (benefits and limitations), performance information, and site factors. Additional design Guidance Sheets are presented for the structural BMPs (Bioretention Practices, Filtration Practices, Infiltration Practices, Stormwater Ponds and Stormwater Wetlands). Each section of design guidance and the supporting details in Appendix D consists of discussions of BMP suitability, major design elements, design procedures, O&M procedures, cost determinations, graphics and references.

RESOLVING DESIGN CONFLICTS

When designing a BMP, it is possible that the site conditions will lead to conflicting regulatory or technical requirements. Designers and regulators that find themselves in such a situation should use the following guide to resolve these conflicts:

REQUIREMENT vs. REQUIREMENT: Contact local and state (of applicable) water management authorities to discuss solutions. Usually the strictest requirements will satisfy both regulations.

REQUIREMENT vs. TECHNICAL RECOMMENDATION: Follow regulatory requirement.

TECHNICAL RECOMMENDATION vs. TECHNICAL RECOMMENDATION: Use best professional judgment in consultation with local authorities.

III. Minnesota Design: Main Influences

Stormwater BMP design is governed by two fundamental influences: regulatory compliance and technical performance (indeed, regulations themselves are based on performance requirements). The *Minnesota Stormwater Manual* has added Minnesota - specific influences into design procedures recommended in other stormwater manuals. Stormwater designers may be familiar with BMP design manuals prepared by a technical organization or those written for other states (Vermont and Georgia are most recent). These manuals have excellent material which been used as a basis for this Manual, with important adjustments for Minnesota conditions, such as cold climate and mosquito habitat.

Regulatory

As previously indicated, throughout the State of Minnesota, minimum stormwater management requirements for most new construction are specified by the MPCA General Stormwater Permit for Construction Activities (MNR100001) commonly called the Construction General Permit (CGP).. Because this is a statewide regulation and is expected to affect the majority of users of this Manual, design criteria specifically required by the MPCA Permit (or other applicable regulations) are identified in the text of the following sections with the term REQUIRED. Of course, if the indicated rule does not apply in a given situation, neither do the associated requirements.

The MPCA Construction General Permit (CGP) allows specific permanent stormwater management BMPs, including wet detention ponds, infiltration/filtration areas, or regional ponds. These BMPs must meet the design requirements found in the CGP. Alternative stormwater treatment BMPs, defined as any BMP not contained in the list above, are allowed if they can demonstrate by calculation, design or other independent methods that they will achieve approximately 80% removal of total suspended solids on an annual average basis. The removal efficiency should be based on all particle sizes from the Midwest particle size distribution found in the National Urban Runoff Program (NURP) pond study completed in 1983. The permit application must include a mitigation plan, monitoring requirements, and performance goals for the proposed BMP. Permittees should expect an extended period of review, up to 90 days, from the MPCA. Information REQUIRED by the MPCA includes:

- Calculations, plans and specifications;
- Description of drainage area tributary to alternative BMP;

- Post construction monitoring plan, including samples from a minimum of 6 runoff producing events over a 2-year period.

- Mitigation plan for replacement of the alternative BMP in the event that the results of the monitoring plan show that the BMP fails to remove 80% of the Total Suspended Solids on an annual average basis from the site runoff.

Exceptions to alternative treatment procedures are allowed in areas where there is no feasible way to meet the treatment requirements, so long as the alternative BMP treats a cumulative maximum of 3 acres or 1% of the project site. Certain exemptions are also allowed in areas where bedrock precludes construction of a permanent BMP, so long as all BMP options are fully explored. Alternate methods are also allowed on road construction projects which lack adequate right-of-way. Permittees who are uncertain if a project has site limitations are encouraged to call the MPCA help desk at 651-297-2274 for assistance.

It must be understood that **additional local, watershed, state, or federal regulations may apply to a particular stormwater management practice**, although they are not specifically indicated in this Manual. These additional requirements (e.g., local rate control standards, more stringent water quality control requirements, regulations concerning BMP siting, etc.) must be identified and satisfied in all BMP construction projects. Chapter 5 and Appendices F and G can assist the reader with additional regulatory information.

Technical

In addition to the requirements outlined in applicable regulations, there are technical or engineering principles that are not specified in code but which can significantly affect BMP performance. Within this category of non-stipulated, performance-based design principles, a further distinction may be made between *essential design standards*, identified in this Manual with the term HIGHLY RECOMMENDED, which are critical for proper functioning, and *design recommendations*, identified as RECOMMENDED, which are valuable for enhancing BMP performance but not strictly crucial to the design.

IV. Design Guidance - Overview

BMP Suitability

This first section contains general suitability information for each BMP and its role in the treatment train. Information includes major features of each BMP "variant" or practice variation. In addition to the typical design elements, this guidance includes discussions of cold climate design modifications, retrofit feasibility, receiving water suitability and water quality treatment.

Design Elements

Site conditions often dictate the selection of BMPs. Therefore, this section allows site owners and designers to conduct a preliminary screening to learn if the BMP is feasible, based on specific site conditions. Major design elements of each BMP are described.

Construction Details and Specifications

Typical details for each structural BMP, and some variants, are included as AutoCAD Version 2000 DWG file format in Appendix D. Each document includes plan and profile views, plus important details, such as inlet structures, cross-sections and outlet structures. The notes section includes information that designers may wish to incorporate into their technical specifications.

These details and specs are focused on the BMPs contained in this Manual which are not available elsewhere. Designers are encouraged to research other excellent water resources related design documents prepared by Minnesota agencies:

Supplemental Environmental Design Documents for Public Watercourse Crossings, June, 2005. Minnesota Department of Natural Resources

CADD Standards, Minnesota Department of Transportation
CADD Standards Software LibrariesMn/DOT Standard Plans, English Subject Index - Mn/DOT

Mn/DOT Standard Specifications for Construction
[Mn/DOT Standard Specifications for Construction - 2000 and 1995 (Metric) Editions]

Mn/DOT Drainage Manual, 2005
[Hydraulics External Home]

Mn/DOT Specifications for Erosion Control (draft)
[Office of Environmental Services]

Erosion Control Handbook for Local Roads, 2003. Minnesota Local Technical Assistance Program (LTAP)

Best Practices Handbook on Roadside Vegetation, 2000. Minnesota Local Technical Assistance Program (LTAP)
[Publications - Minnesota LTAP]

Plants for Stormwater Design, Minnesota Pollution Control Agency
[Plants for Stormwater Design -- Minnesota Pollution Control Agency]

Operation and Maintenance

Long term performance of BMPs is ensured with proper operation and regular maintenance. Therefore, it is HIGHLY RECOMMENDED that site designers communicate how to maintain the BMP in an O&M Manual. Owners and maintenance staff will be able to reference this manual, for example, when they have questions about sediment removal, valve operation, or capacity for future site expansion. Contents of an O&M manual could include: as-built plans, operating instructions for weirs and valves, vegetation list, vegetation maintenance schedule, and maintenance checklists.

In this section operation and maintenance is discussed in terms of phasing:

- ► Design Phase Maintenance Considerations
- ► Construction Phase Maintenance
- ► Post-Construction Operation and Maintenance

Suggested checklists for construction phase maintenance and post-construction phase O&M are contained in Appendix D.

Construction and Maintenance Costs

The cost considerations section of the Guidance Sheets are set up to guide users through developing a cost to construct, operate and maintain the BMPs selected for their sites. In reports researched for this Manual, it was found that typically BMP construction cost is presented as a cost per unit area. Often it can be unclear whether the area is the size of the site or the size of the BMP. Such generic costs are useful for approximating the cost of stormwater management, but are not of adequate accuracy when creating a budget. Another disadvantage is that actual costs can be highly variable based on site specific conditions, such as site slopes or soil conditions. Other complications with overly simplified BMP costs include variability in unit prices due to inflation and/or regional differences in a state the size of Minnesota. Therefore, a more detailed cost estimation procedure, including both construction and O&M costs, is contained in the design guidance.

A design elements table includes major features of the specific BMP. The list does not include construction activities that are common to all aspects of a construction project, such as mobilization, traffic control and site erosion and sediment control. Estimators are encouraged to include these items for BMP construction projects that are not associated with a larger site development or redevelopment project. Appendix D contains BMP specific worksheets which could be used to prepare a detailed cost estimate. Designers who are seeking a preliminary comparison of overall BMP cost (incorporating both construction cost and long-term maintenance costs) are encouraged to use the tables prepared by the University of Minnesota, contained in Chapter 6.

The cost estimation worksheets contained in Appendix D are based on unit prices for St. Paul, Minnesota. However, a state the size of Minnesota does have regional variations in unit prices. An index factor was created for users to apply to the worksheet, which computes a regional based cost estimate. Users interested in other locations in the state should select the city closest to their site and multiply the St. Paul based cost by the recommended index. The following indices were based on “RSMeans” data for spring, 2005:

Bemidji	0.963
Brainerd	1.003
Detroit Lakes	0.962
Duluth	0.991
Mankato	0.990
Minneapolis	1.035
Rochester	0.983
St. Paul	1.000
St. Cloud	1.002
Thief River Falls	1.042
Willmar	0.961
Windom	0.935

Design Procedures

Detailed design guidance for each BMP includes step by step procedures, loosely based on the procedures in the *Georgia Stormwater Manual* (2001) and *The Vermont Stormwater Manual* (2002), with modifications appropriate for Minnesota. The steps refer the designer back to better site design procedures in Chapter 4 so that the space dedicated to stormwater management within any site is optimized for both location and size. Designers are encouraged to fit a stormwater practice into the space available, and then check the hydraulics to determine if the size is adequate for managing the water quality volume (see Ch. 10, Unified Sizing Criteria). This technique works well for infiltration, for example, since it may be advantageous to infiltrate as much runoff as the site allows. Bioretention and filtration guidance recommend sizing based on water quality volume. The Minnesota procedure is purposely intended to optimize the space available for BMPs on each site.

Figure 12.INTRO.1 lays out the general procedural steps recommended in this manual. Specific steps, based on this general procedure, are detailed in the design guidance sheets.

V. The Role of Pre-Treatment

A Matter of Necessity

The Manual user will notice that many of the stormwater practices discussed in this Manual recommend pre-treatment as an integral part of the BMP application. In fact, in many applications (ex. infiltration, stormwater ponds), the BMP would not be properly used if pre-treatment is ignored.

The simple reason for the use of pre-treatment techniques is the necessity to keep a BMP from being overloaded, primarily by sediment. Pre-treatment can also be used to dampen the effects of high or rapid inflow, dissipate energy, and provide additional storage. All of these ancillary benefits help BMP performance.

Methods of Pre-Treatment

Most stormwater managers would identify forebays or small sediment basins as the principal pre-treatment method. Although this is probably correct, there are many other ways to pre-treat runoff prior to discharging it into a BMP. Other methods that may under certain circumstances be a better approach than a forebay could include:

- Vegetated swale – soak up water and filter pollutants
- Street/parking lot sweeping – remove pollutants from an impervious surface draining to a BMP
- Proprietary settling/swirl chambers – remove particulates and litter prior to a BMP
- Rain gardens – filter pollutants and soak water into the ground

FIGURE 12.INTRO.1 Design Procedures Flow Chart

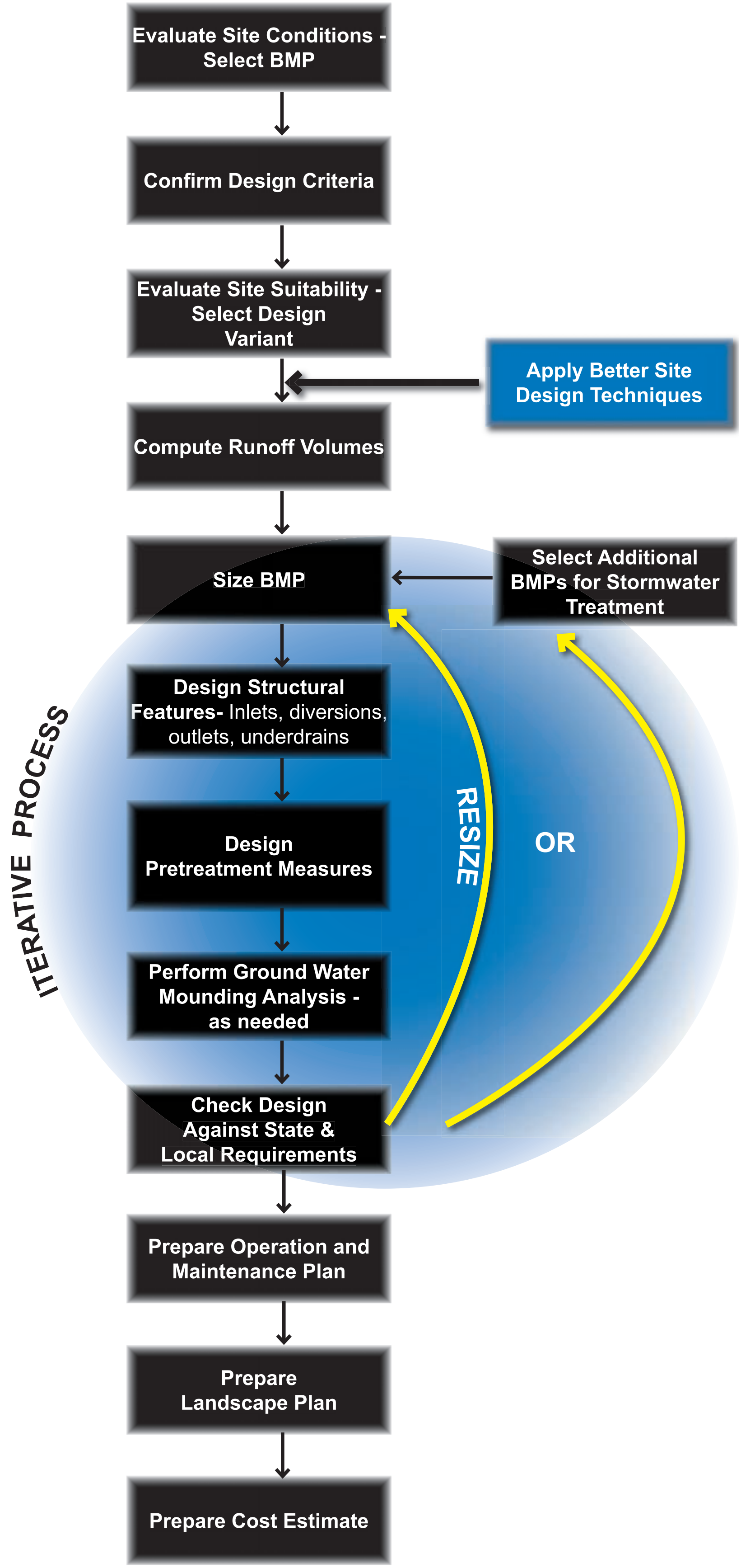
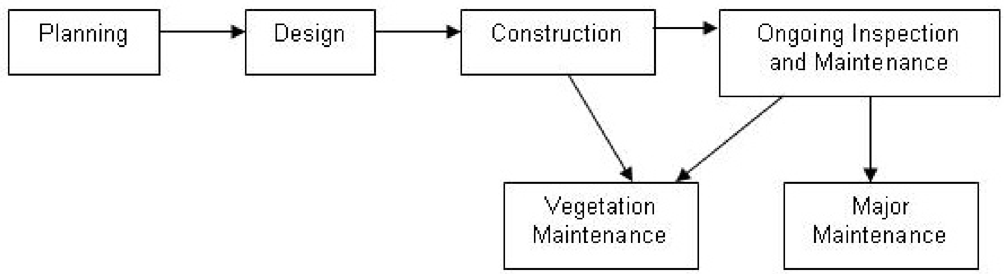


Figure 12.INTRO.2 The Pond/Wetland Life Cycle (adapted from CWP, 2004)



Although "pre-treatment" does not appear as a BMP group in this chapter, many of the listed BMPs can perform in such a role. The BMP designer is encouraged to go through a planning step in the BMP design that configures it in a treatment train with some kind of pre-treatment step.

VI. The Importance of Maintenance

Stormwater and watershed management in Minnesota began rapid growth in the mid 1980s, after the Minnesota Legislature adopted the Metropolitan Surface Water Management Act. Watershed districts and management organizations quickly began to require stormwater ponds on new development sites. At that time stormwater ponds were favored because of ease of operation. Over time, watershed organizations, homeowner associations and municipalities have learned that 20 years of ignoring routine maintenance can lead to expensive rehabilitation projects. The lesson learned for stormwater ponds is that "low maintenance" does not mean "no maintenance". Now that there are a number of successful alternatives to stormwater ponds, the pond maintenance lessons become even more important. Smaller BMPs will require a more frequent maintenance cycle, and native vegetation will require care to prevent invasion of non-native plant species.

The BMPs contained in the *Minnesota Stormwater Manual* are recommended because each has been proven effective in the removal of pollutants from stormwater runoff. Long term effectiveness of all BMPs requires the regular removal of these accumulated pollutants to ensure capacity for ongoing pollutant removal. The *Stormwater Pond and Wetland Maintenance Guide* (CWP, 2004) describes a life cycle for ponds and wetlands that could apply to all structural BMPs. Figure 12.INTRO.2 shows the Pond/Wetland Life Cycle adapted from CWP (2004).

Maintenance is necessary to prevent the following problems (CWP, 2004):

- ► Sediment accumulation, reduction in storage volume
- ► Debris blockage of structures
- ► Structural damage
- ► Invasive plants
- ► Loss of slope stabilization vegetation
- ► Reduced structural integrity of embankments, weirs or risers

This chapter of the *Minnesota Stormwater Manual* includes detailed maintenance recommendations, check lists and cost information. Stormwater managers seeking more detailed background information are encouraged to research information available from the Center for Watershed Protection, the Toronto SWAMP program, the US EPA; or a local source, such as the City of Plymouth Pond Maintenance Policy.

VII. References

Atlanta Regional Commission, 2001. *Georgia Stormwater Management Manual.*

Center for Watershed Protection (CWP). 1998. Better Site Design: a handbook for changing development rules in your community. US EPA. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP), 2004. *Stormwater Pond and Wetland Maintenance Guidebook* (draft). Prepared for Tetra Tech, Inc. and USEPA Office of Science and Technology.

City of Plymouth, 2005. *Pond Maintenance Policy.* Resolution No. 2005-102.

Northern Virginia Planning District Commission, Division of Environmental Services, 2000. *Maintaining Your BMP, A Guidebook for Private Owners and Operators in Northern Virginia.*

Toronto and Region Conservation Authority SWAMP Program. *Storm Water Management Facility Sediment Maintenance Guide.* Prepared by Greenland International Consulting Company.

Vermont Agency of Natural Resources, April, 2002. *The Vermont Stormwater Manual.*

Weiss, P.T., J.S. Gulliver and A.J. Erickson, 2005. *The Cost and Effectiveness of Stormwater Management Practices: Final Report.* University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, 99p.

RESIDENTIAL PRACTICES

Eagle Valley - Woodbury, MN

Definition:
Residential pollution prevention practices are household and neighborhood activities that prevent or reduce the contamination of stormwater.

KEY CONSIDERATIONS

Description:
Residential pollution prevention practices prevent or reduce stormwater contamination from residential sources such as yards, driveways, sidewalks, and household products. These practices are often simple, low cost behavioral changes that improve subwatershed water quality by minimizing the introduction of pollutants including sediment, nutrients, metals, bacteria, trash, oil, and toxins. Each of these practices are highly suitable and effective in cold climates. Table 12.PREV.1 indicates the pollutants controlled by various residential pollution prevention practices while Table 12.PREV.2 describes some of the methods used for each of these practices. See Photo Credits and References for further information.

Table 12.PREV.1 Residential Practices Pollutant Controls (Source: modified from the Center for Watershed Protection

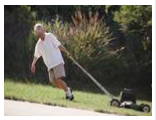
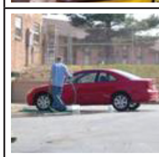
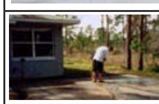
Practice	Stormwater Pollutants Controlled						
	Sediment	Nutrients	Metals	Bacteria	Trash	Oil	Toxins
Fertilizer and Pesticide Management	○	●	○	○	○	○	●
Litter and Animal Waste Control	○	●	○	●	●	○	○
Yard Waste Management	◑	●	○	◔	◔	○	○
Household Hazardous Waste Control	○	◔	●	○	○	●	●
Alternative Product Use	○	○	○	○	○	○	●
Better Car and Equipment Washing	◑	●	◑	○	○	◑	◑
Better Sidewalk and Driveway Cleaning	●	◑	◑	○	◑	◑	◔
Better Sidewalk and Driveway Deicing	◑	◔	◔	○	○	○	◑
Proper Pool Discharge	○	○	○	○	○	○	●
Septic Tank Maintenance	◔	●	○	●	○	○	◔
Exposed Soil Repair	●	◑	◔	◔	○	○	○
Native Landscaping	●	●	◔	◔	◔	○	○
Healthy Lawns	●	◑	◔	◔	○	○	○

Legend

○ = Uncontrolled ◑ = Moderately Controlled

◔ = Slightly Controlled ● = Significantly Controlled

Table 12.PREV.2 Residential Pollution Prevention Methods

Practice		Method
 [1]	Fertilizer and Pesticide Management	Reduce or eliminate the need for fertilizer and pesticides by practicing natural lawn care, planting native vegetation, and limiting chemical use; follow Minnesota Statutes Chapter 18C and federal regulatory requirements on fertilizer and pesticide storage and application if used.
 [1]	Litter and Animal Waste Control	Properly dispose of pet waste and litter in a timely manner and according to local ordinance requirements.
 [1]	Yard Waste Management	Prevent yard waste from entering storm sewer systems and water bodies by either composting or using curbside pickup services and avoiding accumulation of yard waste on impervious surfaces; keep grass clippings and leaves out of the street.
 [1]	Household Hazardous Waste (HHW) Control	Ensure that hazardous waste, including paints, stains, solvents, cleaning products, used motor oil, antifreeze, and pesticides, are disposed of properly by participating in a County household hazardous waste collection program; properly store hazardous waste items.
	Alternative Product Use	Use less harmful products including alternative cleaning solutions, pesticides, fertilizers, automotive and paint products to reduce the amount of toxic substances released into sewer systems.
 [1]	Better Car and Equipment Washing	Wash cars less often and on grassy areas using phosphorus-free detergents and non-toxic cleaning products or use commercial car washes to prevent dirty wash water from flowing to storm sewer systems and water bodies.
 [1]	Better Sidewalk and Driveway Cleaning	Sweep sidewalks and driveways and dispose of sweepings in the trash instead of using hoses or leaf blowers to clean surfaces.
 [1]	Better Sidewalk and Driveway Deicing	Reduce or eliminate the need for deicing products by manually clearing sidewalks and driveways prior to deicer use; use environmentally-friendly deicing products when possible, apply sparingly and store properly if used.
 [1]	Proper Pool Discharge	Check local ordinances for pool water discharge requirements; pool water should be discharged to sanitary sewer systems or held for a week or more without addition of chlorine prior to spreading over pervious areas to prevent stormwater contamination.
 [1]	Exposed Soil Repair	Use native vegetation or grass to cover and stabilize exposed soil on lawns to prevent sediment wash off.
	Native Landscaping	Reduce turf areas by planting native species to reduce and filter pollutant-laden runoff and prevent the spread of invasive, non-native plant species into the storm sewer system.
	Healthy Lawns	Maintain thick grass planted in organic-rich soil to a height of at least 3 inches to prevent soil erosion, filter stormwater contaminants, and absorb airborne pollutants; limit or eliminate chemical use and water and repair lawn as needed

Note: See page 7 for photo credits

MUNICIPAL PRACTICES

Salt delivery to a Washington County Salt Shed

Definition:
Municipal pollution prevention practices are public operation and maintenance activities and educational efforts implemented by municipal staff that prevent or reduce the contamination of stormwater.

KEY CONSIDERATIONS

Description:
Municipal pollution prevention practices prevent or reduce stormwater contamination from public sources such as streets, parking areas, maintenance vehicles, storm and sanitary sewers, dumpsters, swimming pools and other potential stormwater hotspots. These practices improve subwatershed water quality by minimizing the introduction of pollutants including sediment, nutrients, metals, bacteria, trash, oil, and toxins. Each of these practices is highly suitable and effective in cold climates. Table 12.PREV.3 indicates the pollutants controlled by various municipal pollution prevention practices while Table 12.PREV.4 describes some of the methods used for each of these practices. See Chapter 13 for further discussion of potential stormwater hotspots. See Photo Credits and References for further information.

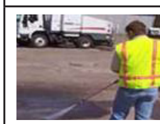
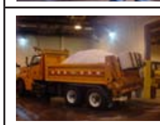
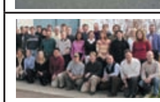
Table 12.PREV.3 Municipal Practices Pollutant Controls (Source: modified from the Center for Watershed Protection)

Practice	Stormwater Pollutants Controlled						
	Sediment	Nutrients	Metals	Bacteria	Trash	Oil	Toxins
Temp. Construction Sediment Control	●	◑	◔	○	◔	○	○
Wind Erosion Control	●	◑	◔	○	◔	○	○
Streambank Stabilization	●	◑	○	○	○	○	○
Material Storage Control	●	◑	◑	○	○	●	●
Dumpster and Landfill Management	◔	◑	◑	●	●	◑	●
Proper Pool Discharge	○	○	○	○	○	○	●
Better Turf Management	◑	●	○	○	○	○	●
Better Street and Parking Lot Cleaning	●	◑	◑	○	◑	◑	◔
Better Street and Parking Lot Deicing	◑	◔	◔	○	○	○	●
Proper Vehicle Management	●	●	●	○	◑	●	●
Storm Sewer System Maintenance	●	◑	◔	○	◑	○	○
Sanitary Sewer System Maintenance	◔	●	○	●	○	○	◔
Litter and Animal Waste Control	○	●	○	●	●	○	○
Public Education	◑	◑	◑	◑	◑	◑	◑
Staff and Employee Education	◑	◑	◑	◑	◑	◑	◑

Legend

○ = Uncontrolled ◑ = Moderately Controlled
◔ = Slightly Controlled ● = Significantly Controlled

Table 12.PREV.4 Municipal Pollution Prevention Methods

Practice		Method
	Temporary Construction Sediment Control	Implement and encourage practices to retain sediment within construction project area; see Temporary Construction Erosion and Sediment Control Factsheets for additional information.
	Wind Erosion Control	Institute a local program for wetting of open construction surfaces and other sources for windblown pollutants.
	Streambank Stabilization	Repair erosion occurring on a streambank of lakeshore in a timely manner; inspect bank areas for ice damage in the spring.
	Material Storage Control [1]	Reduce or eliminate spill and leakage loss by properly inspecting, containing, and storing hazardous materials and having a cleanup plan that can be quickly and efficiently implemented.
	Dumpster and Landfill Management	Ensure that contaminated material is contained to prevent solid and/or liquid waste from being washed into storm sewer systems or water bodies.
	Proper Pool Discharge [1]	Discharge pool water to sanitary sewer systems or hold for a week or more without the addition of chlorine prior to spreading over pervious areas instead of draining water directly to storm sewer systems. Follow local ordinances.
	Better Turf Management [1]	Ensure that mowing, fertilization, pesticide application, and irrigation are completed in ways that will prevent or reduce grass clippings, sediment, and chemicals from entering storm sewer systems; use native vegetation where possible.
	Better Street and Parking Lot Cleaning [1]	Maintain streets and parking lots frequently and especially in the spring by sweeping, picking up litter, and repairing deterioration; pressure wash pavement only as needed and avoid using cleaning agents.
	Better Street and Parking Lot Deicing	Properly store and conservatively apply salt, sand, or other deicing substances in order to prevent excessive and/or unnecessary contamination; implement anti-icing and prewet salt techniques for increased deicing efficiency.
	Proper Vehicle Management [1]	Ensure that vehicles are fueled, maintained, washed and stored in a manner that prevents the release of harmful fluids, including oil, antifreeze, gasoline, battery acid, hydraulic and transmission fluids, and cleaning solutions.
	Storm Sewer System Maintenance	Regularly clean debris from storm sewer inlets, remove sediment from catch basin sumps, and remove any illicit connections to storm sewer systems.
	Litter and Animal Waste Control [1]	Mandate litter and pet waste cleanup within the community and control waste-generating wildlife, such as geese; provide waste containers for litter and pet waste in public areas.
	Public Education	Label storm drains to indicate that no dumping is allowed and institute pollution prevention programs to educate and implement needed community practices.
	Staff, Employee, and Volunteer Education	Provide internal training for staff and provide direction to hired employees or volunteers regarding pollution prevention techniques to be used during work activites.

Note: See page 7 for photo credits

INDUSTRIAL & COMMERCIAL PRACTICES

Courtesy of the Center for Watershed Protection

Definition:
Industrial and commercial pollution prevention practices are private operation and maintenance activities implemented by owners or individuals responsible for industrial and commercial sites that prevent or reduce the contamination of stormwater. Note that certain industrial activities and sites could be covered under the NPDES Industrial Permit. See Chapter 5 for the Industrial Permit discussion.

KEY CONSIDERATIONS

Description:
Industrial and commercial pollution prevention practices prevent or reduce stormwater contamination from concentrated impervious surfaces and potential stormwater hotspots such as streets, parking areas, vehicles, smokestacks, and dumpsters. These practices improve subwatershed water quality by minimizing the introduction of pollutants including sediment, nutrients, metals, bacteria, trash, oil, and toxins. Table 12.PREV.5 indicates the pollutants controlled by various industrial and commercial pollution prevention practices while Table 12.PREV.6 describes some of the methods used for each of these practices. See Chapter 13 for further discussion of potential stormwater hotspots. See Photo Credits and References for further information.

Table 12.PREV.5 Industrial & Commercial Practices Pollutant Controls (Source: modified from the Center for Watershed Protection)

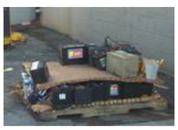
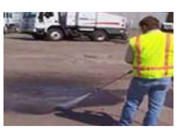
Practice	Stormwater Pollutants Controlled						
	Sediment	Nutrients	Metals	Bacteria	Trash	Oil	Toxins
Temp. Construction Sediment Control	●	◑	◔	○	◔	○	○
Wind Erosion Control	●	◑	◔	○	◔	○	○
Emission Regulation	◔	○	●	○	●	○	●
Material Storage Control	●	◑	◑	○	○	●	●
Dumpster and Landfill Management	◔	◑	◑	●	●	◑	●
Better Turf Management	◑	●	○	○	○	○	●
Better Parking Lot Cleaning	●	◑	◑	○	◑	◑	◔
Better Impervious Surface Deicing	◑	◔	◔	○	○	○	●
Proper Vehicle Management	●	●	●	○	◑	●	●
Storm Sewer System Maintenance	●	◑	◔	○	◑	○	○
Sanitary Sewer System Maintenance	◔	●	○	●	○	○	◔

Legend

○ = Uncontrolled ◑ = Moderately Controlled

◔ = Slightly Controlled ● = Significantly Controlled

Table 12.PREV.6 Industrial & Commercial Pollution Prevention Methods

Practice		Method
	Temporary Construction Sediment Control	Follow local, state, and federal regulatory requirements for control of erosion during construction activities.
	Wind Erosion Control	Institute a local program for wetting of open construction surfaces and other sources for windblown pollutants.
	Emission Regulation [1]	Follow local, state, and federal regulatory requirements for control of air emissions.
	Material Storage Control [1]	Reduce or eliminate spill and leakage loss by properly inspecting, containing, and storing hazardous materials and having a cleanup plan that can be quickly and efficiently implemented. Follow NPDES Industrial Permit requirements if permit authority applies.
	Dumpster and Landfill Management	Ensure that contaminated material is contained to prevent solid and/or liquid waste from being washed into storm sewer systems or water bodies.
	Better Turf Management [1]	Ensure that mowing, fertilization, pesticide application, and irrigation are completed in ways that will prevent or reduce grass clippings, sediment, and chemicals from entering storm sewer systems; use native vegetation where possible.
	Better Parking Lot Cleaning [1]	Maintain parking lots frequently and especially in the spring and fall by sweeping, picking up litter, and repairing deterioration; pressure wash pavement only as needed and minimize the use of cleaning agents.
	Better Impervious Surface Deicing [1]	Reduce or eliminate the need for deicing products by manually clearing sidewalks, driveways, and parking lots prior to deicer use; use environmentally-friendly deicing products when possible, apply sparingly and store properly if used.
	Proper Vehicle Management [1]	Ensure that vehicles are fueled, maintained, washed and stored in a manner that prevents the release of harmful fluids, including oil, antifreeze, gasoline, battery acid, hydraulic and transmission fluids, and cleaning solutions.
	Storm Sewer System Maintenance	Regularly clean debris from storm sewer inlets, remove sediment from catch basin sumps, and remove any illicit connections to storm sewer systems.
	Sanitary Sewer System Maintenance [2]	Regularly inspect and flush sanitary pipes to ensure that there are no leaks in the system and that the system is functioning properly

Note: See page 7 for photo credits

REFERENCES

Photo Credits

1. Courtesy of the Center for Watershed Protection
2. Courtesy of the Town of Amherst, New York
3. Courtesy of the United States Geological Survey
   All other photos from EOR.

References

Atlanta Regional Commission. *Georgia Stormwater Management Manual*.
http://www.georgiastormwater.com/

California Stormwater Quality Association. *Stormwater Best Management Practice Handbooks*.
http://www.cabmphandbooks.com

Center for Watershed Protection. *Urban Subwatershed Restoration Manual, Manual 8: Pollution Source Control Practices*.
http://www.cwp.org/

Center for Watershed Protection. *Fact Sheets on Residential Pollution Prevention Practices*
http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/residential.htm

Center for Watershed Protection. *Fact Sheets on Municipal Pollution Prevention Practices.*
http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/municipal.htm

Dakota County Environmental Education
http://www.co.dakota.mn.us/environ/education.htm

Government of Ontario, Canada. *Stormwater Pollution Prevention Handbook.*
http://www.ene.gov.on.ca/envision/water/stormwaterpph.htm

Hennepin County Environmental Education
http://www.co.hennepin.mn.us/vgn/portal/internet/hcchannelmaster/0,2324,1273_83263__2,00.html

Office of the Revisor of Statutes, State of Minnesota. *Minnesota Statutes 2004*.
http://www.revisor.leg.state.mn.us/stats/

University of Michigan Occupational Safety and Environmental Health. *Winter Maintenance: Snow and Ice Removal.*
http://www.oseh.umich.edu//salt.html

Math & Science Academy - infiltration trench
Woodbury, MN

KEY CONSIDERATIONS

Few watershed management practices simultaneously reduce pollutant loads, conserve natural areas, save money, and increase property values. Indeed, if such “wonder practices” were ever developed, they would certainly spread quickly across the nation. As it turns out, these practices have existed for years. Collectively called “better site design,” the techniques employ a variety of methods to reduce total paved area, distribute and diffuse stormwater, and conserve natural habitats.

Better Site Design is a fundamentally different approach to residential and commercial development. It seeks to accomplish three goals at every development site: to reduce the amount of impervious cover, to increase natural lands set aside for conservation, and to use pervious areas for more effective stormwater treatment. To meet these goals, designers must scrutinize every aspect of a site plan— its streets, parking spaces, setbacks, lot sizes, driveways, and sidewalks— to determine if any of these elements can be reduced in scale. At the same time, creative grading and drainage techniques reduce stormwater runoff and encourage more infiltration.

Fields of St. Croix - stormwater finishing pond
Lake Elmo, MN

BETTER SITE DESIGN

Use the following outline as a guide to better site design (early on and throughout the design process) for development, redevelopment and retrofits. The first goal should be to minimize stormwater runoff. Mitigating any generated stormwater should be the second goal.

MINIMIZE STORMWATER RUNOFF

USE HYDROLOGY AS THE INTEGRATING FRAMEWORK

- Reproduce predevelopment hydrology
- Create a multifunctional landscape, which incorporates stormwater features into the landscape
- Use surface water elements as the focal civic spaces

PRESERVE AND EMULATE NATURAL DRAINAGE

- Utilize existing flow paths
- Fit development to the terrain
- Restore the drainage and/ or biological capacity of damaged or lost soils through mechanical improvements or soil amendments

SITE FINGERPRINTING

- Incorporating smaller lot sizes to minimize total impervious
- Confine construction and development to least critical / sensitive areas
- Preserve open space / natural areas
- Reduce limits of clearing and grading
- Stage construction (limit area exposure of the site at any one time)
- Minimize soil compaction

IMPERVIOUS SURFACES

- Reduce
- Minimize
- Disconnect

MITIGATE STORMWATER RUNOFF

THINK MICROMANAGEMENT

- Control runoff at the source
- Minimize runoff by maximizing infiltration, evapotranspiration, and filtration
- Employ natural processes for water quality improvement

STORMWATER TREATMENT TRAIN

- Utilize simplistic, non-structural methods
- Use redundant runoff treatment systems
- Highy suitable for cold climates

BETTER SITE DESIGN

RESIDENTIAL STREETS & PARKING LOTS

KEY CONSIDERATIONS

Model development principles provide design guidance for economically viable, yet environmentally sensitive development. The key objective is to provide planners, developers, and local officials with benchmarks to investigate where existing ordinances may be modified to reduce impervious cover, conserve natural areas, and prevent stormwater pollution. These development principles are not national design standards. Instead, they identify areas where existing codes and standards can be changed to better protect streams, lakes and wetlands at the local level. These principles are also highly suitable and effective in cold climates.

Each principle is presented as a simplified design objective. Actual techniques for achieving the principle should be based on local conditions. Please consult **Chapter 4** for more detailed information on better site design.

EXAMPLES

Fields of St. Croix - Lake Elmo, MN

This residential conservation development uses minimum road widths and landscaped areas to reduce the amount of impervious surfaces and add to the rural character of the neighborhood. Vegetated channels and bioretention areas are used in the right-of-way to treat stormwater runoff.

H.B. Fuller - Vadnais Heights, MN

This parking lot incorporates bioretention strategies to treat stormwater runoff. The landscaped depressions provide stormwater treatment, snow storage, and improved parking lot aesthetics and climate. Low maintenance sedges are used in place of traditional turf grass to lower maintenance costs and pollution.

Use the following checklist as a tool to better site design (early on and throughout the design process) for street and parking lot development, redevelopment and retrofits. Place a check in the appropriate boxes if you think that this approach will work for your site.

RESIDENTIAL STREETS AND PARKING LOTS CHECKLIST

☐	Design residential streets for the minimum required pavement width needed to support travel lanes, on-street parking, and emergency, maintenance, and service vehicle access. These widths should be based on traffic volume.
☐	Reduce the total length of residential streets by examining alternative street layouts to determine the best option for increasing the number of homes per unit length.
☐	Wherever possible, residential street right-of-way widths should reflect the minimum required to accommodate the travel-way, the sidewalk, and vegetated open channels. Utilities and storm drains should be located outside of the BMPs section of the right-of-way wherever feasible.
☐	Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce impervious cover. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should be considered.
☐	Where density, topography, soils, and slope allow, vegetated open channels should be used in the street right-of-way to convey and treat stormwater runoff.
☐	Enforce the required parking ratio governing a particular land use or activity as both a maximum and a minimum, in order to curb excess parking space construction. Existing parking ratios should be reviewed for conformance, taking into account local and national experience to determine if lower ratios are warranted and feasible.
☐	Revise parking codes to lower parking requirements where mass transit is available or enforceable shared parking arrangements are made.
☐	Reduce the overall imperviousness associated with parking lots by providing compact car spaces, minimizing stall dimensions, incorporating efficient parking lanes, making use of vegetated parking islands, and using pervious materials in spillover parking areas where possible.
☐	Provide meaningful incentives to encourage structured and shared parking to increase economic viability.
☐	Provide stormwater treatment, wherever possible, for parking lot runoff using bioretention areas, filter strips, and/or other practices that can be integrated into required landscaping areas and traffic islands.

LOT DEVELOPMENT

KEY CONSIDERATIONS

Model development principles provide design guidance for economically viable, yet environmentally sensitive development. The key objective is to provide planners, developers, and local officials with benchmarks to investigate where existing ordinances may be modified to reduce impervious cover, conserve natural areas, and prevent stormwater pollution. These development principles are not national design standards. Instead, they identify areas where existing codes and standards can be changed to better protect streams, lakes and wetlands at the local level. These principles are also highly suitable and effective in cold climates.

Each principle is presented as a simplified design objective. Actual techniques for achieving the principle should be based on local conditions. Please consult **Chapter 4** for more detailed information on better site design.

EXAMPLES

Jackson Meadow - Marine on St. Croix, MN

Flexible design standards should be promoted that advocate open space design development. Design standards should encourage reductions of overall imperviousness, smaller lot sizes, preservation of natural areas, community open space, watershed protection, and unique neighborhood identity.

Lilydale - Inver Grove Heights, MN

Shared driveways in a development can significantly reduce the amount of overall imperviousness.

Use the following checklist as a tool to better site design (early on and throughout the design process) for street and parking lot development, redevelopment and retrofits. Place a check in the appropriate boxes if you think that this approach will work for your site.

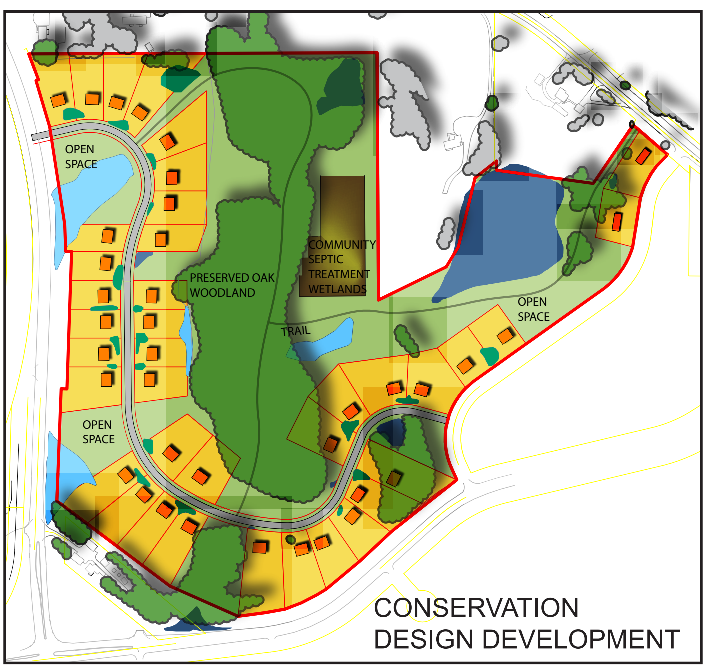
LOT DEVELOPMENT CHECKLIST

☐	Advocate open space design development incorporating smaller lot sizes to minimize total impervious area, reduce total construction costs, conserve natural areas, provide community recreational space, and promote watershed protection.
☐	Relax side yard setbacks and allow narrower frontages to reduce total road length in the community and overall site imperviousness. Relax front yard setback requirements to minimize driveway lengths and reduce overall lot imperviousness.
☐	Promote more flexible design standards for residential subdivision sidewalks. Where practical, consider locating sidewalks on only one side of the street and providing common walkways linking pedestrian areas.
☐	Minimize the number of residential street cul-de-sacs and incorporate landscaped areas to reduce impervious cover. The radius of cul-de-sacs should be the minimum required to accommodate emergency and maintenance vehicles. Alternative turnarounds should be considered.
☐	Reduce overall lot imperviousness by promoting alternative driveway surfaces and shared driveways that access two or more homes.
☐	Clearly specify how community open space will be managed, and designate a sustainable legal entity responsible for managing both natural and recreational open space.
☐	Direct rooftop runoff to pervious areas such as yards, open channels, or vegetated areas and avoid routing rooftop runoff to the roadway and the stormwater conveyance system.
☐	Restore the drainage and/ or biological capacity of damaged or lost soils through mechanical improvements or soil amendments.

KEY CONSIDERATIONS

Model development principles provide design guidance for economically viable, yet environmentally sensitive development. The key objective is to provide planners, developers, and local officials with benchmarks to investigate where existing ordinances may be modified to reduce impervious cover, conserve natural areas, and prevent stormwater pollution. These development principles are not national design standards. Instead, they identify areas where existing codes and standards can be changed to better protect streams, lakes and wetlands at the local level. These principles are also highly suitable and effective in cold climates.

Each principle is presented as a simplified design objective. Actual techniques for achieving the principle should be based on local conditions. Please consult **Chapter 4** for more detailed information on better site design.



COMPARISON

Traditional Residential Developments vs. Conservation Design Developments

Flexible design standards can allow for the conservation of a site's natural areas and ecological function. Conservation design developments advocate preserving a site's most distinguishing natural features and integrating them into the community of the new development. Open space should be consolidated to have the greatest recreational, aesthetic, and environmental benefit.

Smaller lot sizes allow the same densities as a traditional development, with more open space dedicated as a community amenity. Flexible lot design allows less roads and stormwater infrastructure to be built, reducing imperviousness and infrastructure costs.

Use the following checklist as a tool to better site design (early on and throughout the design process) for development, redevelopment and retrofits. Place a check in the appropriate boxes if you think this approach will work in your site.

CONSERVATION OF NATURAL AREAS CHECKLIST

☐	Create a variable width, naturally vegetated buffer system along all perennial streams and other water features that encompasses critical environmental features such as the 100-year floodplain, steep slopes and freshwater wetlands.
☐	Preserve or restore riparian stream buffers with native vegetation. Maintain the buffer system through the plan review delineation, construction, and post-development stages.
☐	Limit clearing and grading of forests and native vegetation at a site to the minimum area needed to build lots, allow access, and provide fire protection. Manage a fixed portion of any community open space as protected green space in a consolidated manner.
☐	Conserve trees and other vegetation at each site by planting additional vegetation, clustering tree areas, and promoting the use of native plants. Wherever practical, manage community open space, street rights-of-way, parking lot islands, and other landscaped areas.
☐	Encourage incentives and flexibility in the form of density compensation, buffer averaging, property tax reduction, stormwater credits, and open space development to promote conservation of stream buffers, forests, meadows, and other areas of environmental value. In addition, encourage off-site mitigation consistent with locally adopted watershed plans.
☐	Prevent the discharge of unmanaged stormwater from new stormwater outfalls into wetlands, sole-source aquifers, or ecologically sensitive areas.

GREEN ROOFS

Courtesy of The Green Institute - Minneapolis, MN

Definition:
Green roofs consist of a series of layers that create an environment suitable for plant growth without damaging the underlying roof system. Green roofs create green space for public benefit, energy efficiency, and stormwater retention/ detention.

KEY CONSIDERATIONS

Design Criteria:

- Structural load capacity, how much weight the roof can hold, is a major factor in determining whether the green roof is "extensive" or "intensive" (see next page).
- Vegetation selection is based on numerous factors including, growth medium depth, microclimate, irrigation availability and maintenance.
- A leak detection system is recommended to quickly detect and locate leaks.
- Modular products can increase installation and repair efficiency.

Benefits:

- Reduce, delay, and cool stormwater runoff.
- Insulate buildings and lower energy consumption and costs.
- Provide habitat for birds and insects.
- Increase longevity of traditional roofing systems by protecting from ultraviolet rays.
- Reduce carbon dioxide levels and heat island effect.

Limitations:

- Cost is higher than traditional roofing systems – can be significant for retrofits.
- Leaks can cause significant damage and can be hard to locate and repair without an electronic leak detection system.
- Conditions can be harsh for vegetation establishment.
- Maintenance needs can be higher than traditional roofing system.

MANAGEMENT SUITABILITY

High	Water Quality (V_{WQ})
Med.	Channel Protection (V_{CP})
Low	Overbank Flood Protection (V_{P10})
Low	Extreme Flood Protection (V_{P100})
Low	Recharge Volume (Re_V)

MECHANISMS

	Infiltration *with appropriate soil & conditions
X	Screening/ Filtration
X	Temperature Control
	Settling
X	Evaporation
X*	Transpiration *if vegetated
X	Soil Adsorption
X	Biological/ Micro. Uptake

POLLUTION REMOVAL

90%	Total Suspended Solids
100%/ 20%	Nutrients - Total Phosphorus/ Total Nitrogen
80%	Metals - Cadmium, Copper, Lead, and Zinc
65%	Pathogens - Coliform, Streptococci, E. Coli
NA	Toxins - Chloride, Hydrocarbons, Pesticides

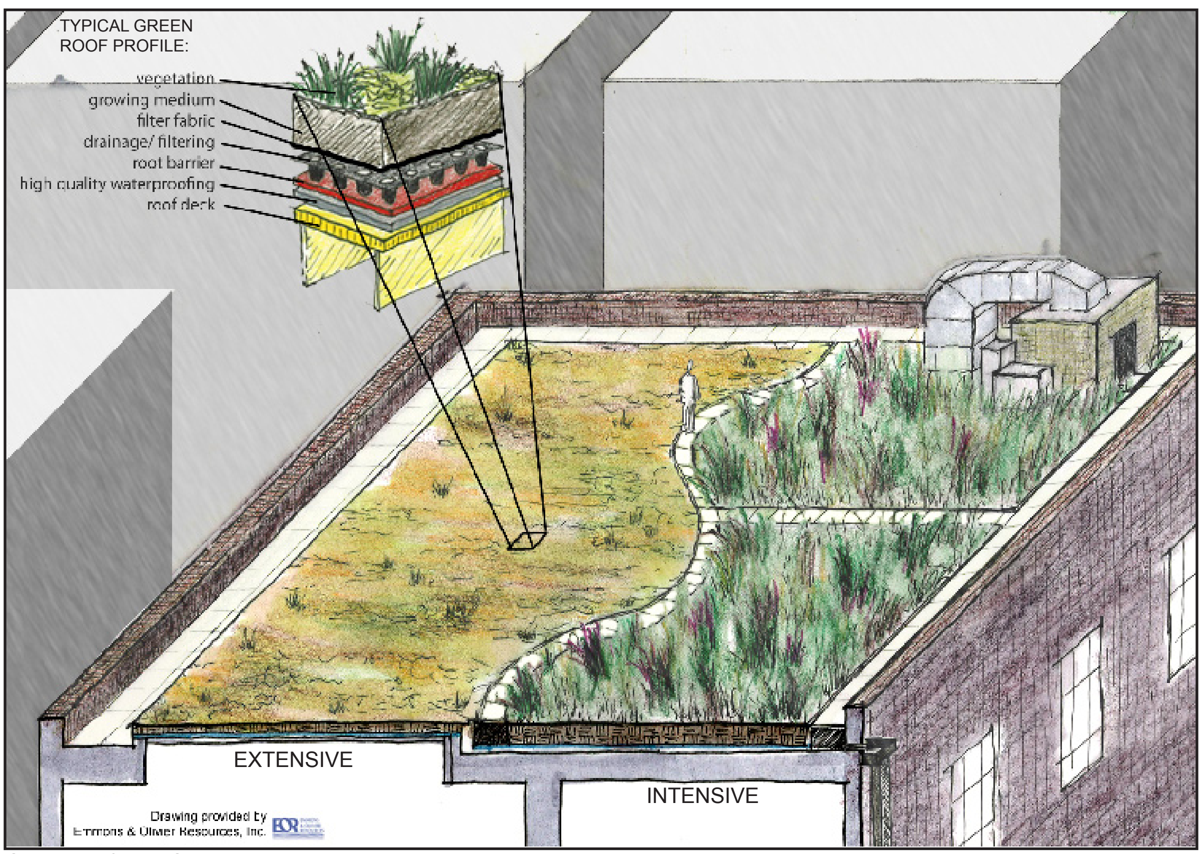
Note: Pollution removal percentages apply to volume of runoff treated, and not to volume bypassed

SITE FACTORS

ROOFTOP	Drainage Area
NA.	Max. Slope
NA	Min. Depth to Bedrock
NA	Min. Depth to Water Table
NA	SCS Soil Type *can be used in C&D soil types with modifications (e.g. underdrains)
GOOD	Freeze/ Thaw Suitability
SUITABLE	Potential Hotspot Runoff *requires impermeable liner

Description:
There are two systems of green roofs, extensive and intensive, composed of the same system of layers. Extensive systems are lighter, typically have 4 inches or less of growing medium, use drought tolerant vegetation, and can structurally support limited uses (such as maintenance personnel). Intensive systems are heavier, have a greater soil depth, can support a wider range of plants, and can support increased pedestrian traffic.

Rainfall is initially intercepted by vegetation, held on foliage, or soaked up by plant roots. Any remaining runoff filters through the growing medium and is drained away from the roof's surface by the drainage layer. Some drainage systems use small depressions to store excess water for uptake during drier conditions (RCWD 2005), while others provide an overflow for larger rainfall events.



Courtesy of Rice Creek Watershed District

PERVIOUS PAVEMENT

Grasspave® at Bradshaw Celebration of Life Center - Stillwater, MN

Definition:
Pervious pavements reduce the amount of runoff by allowing water to pass through surfaces that would otherwise be impervious. Water can either infiltrate into the ground, if soil permeability rates allow, or be conveyed to other BMPs or a storm water system by an under-drain.

KEY CONSIDERATIONS

Design Criteria:

- Pervious pavement is typically used in low traffic areas including overflow parking areas, emergency vehicle lanes, and pedestrian areas.
- In-situ soils should have field-verified minimum permeability rates greater than 0.3 in./hr. Contributing runoff from offsite should be limited to a 3:1 ratio of impervious area to pervious pavement area.
- The selected systems load bearing surface should be suited to maximum intended loads.
- Design storms should be infiltrated within 48 hours.

Benefits:

- Good for highly impervious areas – particularly parking lots.
- Reduces need for other storm water BMPs by reducing runoff.
- Construction costs of some systems are less than traditional paving.
- Soil-enhanced turf systems resist compaction, increase infiltration, and provide soils for healthier vegetation.

Limitations:

- Construction costs of some systems are more expensive than traditional paving
- Use depends on infiltration rates of underlying soils.
- Maintenance costs are higher than conventional paving.
- Not recommended for high traffic areas because of durability concerns.

MANAGEMENT SUITABILITY

High/ Med.	Water Quality (V_{WQ})
Med.	Channel Protection (V_{CP})
Low	Overbank Flood Protection (V_{P10})
Low	Extreme Flood Protection (V_{P100})
High/ Med.	Recharge Volume (Re_V)

MECHANISMS

X*	Infiltration *with appropriate site conditions
X	Screening/ Filtration
X	Temperature Control
	Settling
	Evaporation
X*	Transpiration *if vegetation present
X	Soil Adsorption
X	Biological/ Micro. Uptake

POLLUTION REMOVAL

NA*	Total Suspended Solids *pretreatment for TSS is recommended if adjacent areas drain to pervious pavement
80%/ 80%	Nutrients - Total Phosphorus/ Total Nitrogen
90%	Metals - Cadmium, Copper, Lead, and Zinc
NA	Pathogens - Coliform, Streptococci, E. Coli
NA	Toxins - Chloride, Hydrocarbons, Pesticides

Note: Pollution removal percentages apply to volume of runoff treated, and not to volume of runoff bypassed

SITE FACTORS

NA	Drainage Area
2% MAX.	Max. Slope
3 ft	Min. Depth to Bedrock
3 ft	Min. Depth to Water Table
A,B	SCS Soil Type *can be used in C&D soil types with modifications (e.g. underdrains)
GOOD	Freeze/ Thaw Suitability *with adequate sub-grade
YES	Potential Hotspot Runoff *requires impermeable liner if identified in hotspot area

Description:

Pervious pavements can be subdivided into three general categories: 1) **Porous Pavements** – porous surfaces that infiltrate water across the entire surface (i.e. porous asphalt and porous concrete pavements); 2) **Permeable Pavers** – impermeable modular blocks or grids separated by spaces or joints that water drains through (i.e. block pavers, plastic grids, etc.); 3) **Amended Soils** - Fiber or artificial media added to soil to maintain soil structure and prevent compaction. There are many different types of modular porous pavers available from different manufacturers.

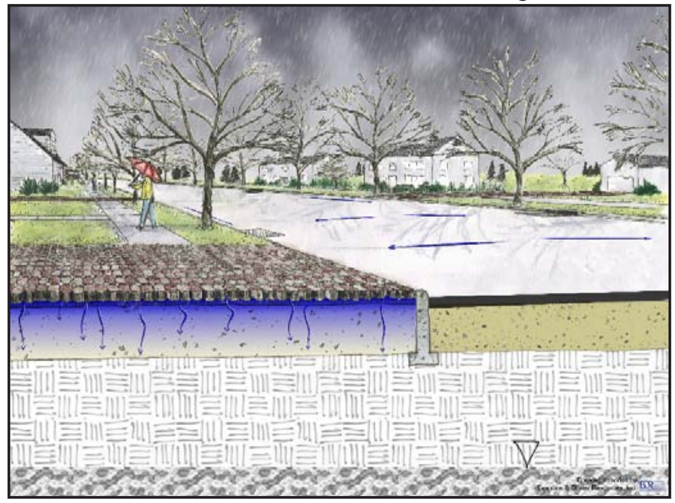
Pervious pavement systems reduce runoff from impervious surfaces by allowing storm water to pass through the load bearing surface and infill that are selected based upon the intended application and required infiltration rate. Runoff is stored in the stone aggregate base course/ storage layer, if present, and allowed to infiltrate into the surrounding soil (functioning like an infiltration basin), or collected by an under-drain system and discharged to the storm sewer system or directly to receiving waters (functioning like a surface sand filter).

Regular maintenance of pervious pavements is necessary to ensure long-term effectiveness. Annual or semi-annual sweeping or vacuuming of surface debris (litter, sediment, etc.) is STRONGLY RECOMMENDED for pavement or pavers. If clogging occurs, the filtration media below the surface may need to be replaced. Manufacturers should be consulted for specific maintenance requirements.

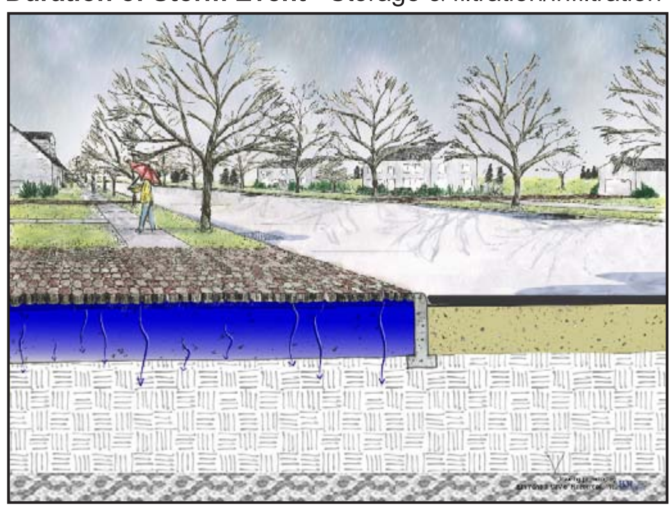
Currently, the MPCA will allow site designers to reduce the water quality volume sizing when using pervious pavement, up to a maximum of ½ acre of new impervious surface. The MPCA will not allow pervious pavements as a replacement for water quality treatment BMPs, such as infiltration or filtration practices.

STORM SEQUENCE

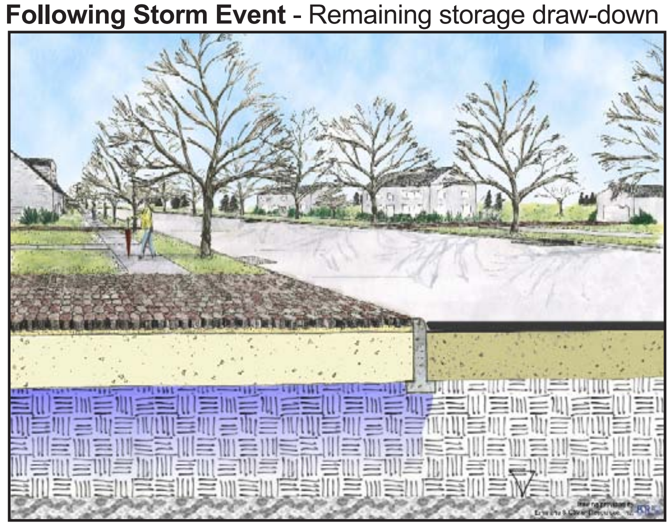
Start of Storm Event - Initial runoff & storage



Duration of Storm Event - Storage & filtration/infiltration



Following Storm Event - Remaining storage draw-down



Courtesy of Rice Creek Watershed District

RAIN WATER HARVESTING

Residential rain barrel - Stillwater, MN

Definition:
Rain water harvesting is the practice of collecting rain water from impermeable surfaces, such as rooftops, and storing for future use. There are a number of systems used for the collection, storage and distribution of rain water including rain barrels, cisterns, evaporative control systems, and irrigation.

KEY CONSIDERATIONS

Design Criteria:

- The system should be watertight, have a smooth interior surface, be located on level and stable ground, have a tight-fitting lid, good screens on the inlet and outlet and have an emergency overflow device.
- To prevent the breeding of mosquitoes, empty the water in less than 5 days or place a fine screen over all openings.
- Material can withstand the pressure of water over long periods of time.
- Disconnect and drain rain barrels and cisterns in the winter to prevent freezing and deformation of the rain water harvesting system.

Benefits:

- Protects water supplies by reducing use during peak summer months.
- Mimics the natural hydrology of the area by infiltrating a portion of the rain water falling on the site.
- Reduces volume of storm water being delivered to downstream waterbodies.
- Results in cost savings by reducing municipal water bill.

Limitations:

- Not suitable for the following roof types: tar and gravel, asbestos shingle and treated cedar shakes.
- Depending on the design, requires a certain amount of operation and maintenance.
- Proprietary systems can be expensive.

MANAGEMENT SUITABILITY

High*	Water Quality (V_{WQ})
Med.	Channel Protection (V_{CP})
Low	Overbank Flood Protection (V_{P10})
Low	Extreme Flood Protection (V_{P100})
High*	Recharge Volume (Re_V)

MECHANISMS

X*	Infiltration
X*	Screening/ Filtration
X	Temperature Control
X	Settling
X	Evaporation
X*	Transpiration
X*	Soil Adsorption
X*	Biological/ Micro. Uptake

POLLUTION REMOVAL

100%*	Total Suspended Solids
100%*	Nutrients - Total Phosphorus/ Total Nitrogen
100%*	Metals - Cadmium, Copper, Lead, and Zinc
100%*	Pathogens - Coliform, Streptococci, E. Coli
100%*	Toxins - Chloride, Hydrocarbons, Pesticides

**Assuming water is drained to a vegetated pervious area. Does not apply to volume of runoff that bypasses the system*

SITE FACTORS

ROOFTOP	Drainage Area
NA	Max. Slope
NA	Min. Depth to Bedrock
NA	Min. Depth to Water Table
NA	SCS Soil Type *can be used in C&D soil types with modifications (e.g. underdrains)
POOR	Freeze/ Thaw Suitability
SUITABLE	Potential Hotspot Runoff

Description:
Rain water harvesting can be accomplished using rain barrels and/or cisterns. Rain barrels are typically located at the downspout of a gutter system and are used to collect and store rainwater for watering landscapes and gardens. The simplest method of delivering water is by the force of gravity. However, more complex systems can be designed to deliver the water from multiple barrels connected in a series with pumps and flow control devices. Cisterns have a greater storage capacity than rain barrels and may be located above or below ground. Due to their size and storage capacity, these systems are typically used to irrigate landscapes and gardens on a regular basis reducing the strain on municipal water supplies during peak summer months. Again, cisterns may be used in series and water is typically delivered using a pump system. The storage capacity of a rain barrel or cistern is a function of the catchment area, the depth of rainfall required to fill the system and the water losses. A general rule of thumb in sizing rain barrels or cisterns is that one inch of rainfall on a 1,000 square foot roof will yield approximately 600 gallons of runoff.

TEMPORARY CONSTRUCTION EROSION AND SEDIMENT CONTROL

Site without temporary sediment control

Site with temporary sediment control

Definition:
Temporary construction erosion and sediment control is the practice of preventing or reducing the movement of sediment from a site during construction through the implementation of manmade structures, land management techniques, or natural processes. Note that this Fact Sheet does not contain detail on the use of specific BMPs. Because there are many good resources on erosion and sediment contol, this Fact Sheet merely discusses their use and refers the reader to other useful resources for detail.

DESCRIPTION

Temporary construction erosion and sediment control limits the amount of sediment that is carried into lakes, streams and rivers by storm water runoff. Sediment carries nutrients and pollutants that degrade water resources and harm aquatic wildlife. Proper planning of construction site activities greatly reduces the impact of soil disturbance activities on nearby resources and diminishes the need for costly restorations. A construction plan that limits sediment disturbance in potential problem areas and uses effective temporary sediment control practices will lessen negative impacts to local water resources and natural areas.

To establish a construction plan that will minimize sediment movement, designers will need information on existing site conditions and neighboring resources that require special consideration including water bodies, natural areas, bluffs and other highly erodible or sensitive areas. Construction activities should be designed in a manner that minimizes overall soil disturbance and phases areas of disturbance such that the amount of land disturbed at any one time is reduced. This type of planning will limit the need for larger structural sediment control solutions. Additionally, the designer should determine which local, state, and federal agencies require permits for the type of work planned. The site plan will need to account for the requirements of all agencies issuing permits.

Projects disturbing one acre or more of land or part of a commmon area that is disturbed will require a National Pollutant Discharge Elimination System (NPDES) Construction Stormwater Permit from the Minnesota Pollution Control Agency. The size threshold can be smaller if the site is a part of a “common plan of development or sale” and if the larger common plan will ultimately disturb more than one acre (see NPDES Construction General Permit). The permit requires the establishment of a Stormwater Pollution Prevention Plan (SWPPP) for the construction site.

Photo: MPCA

Other Minnesota agencies requiring permits typically might include watersheds, municipalities, and soil and water conservation districts.

The practices included in the site plan and SWPPP will need to control runoff, stabilize slopes and exposed soils, and limit the movement of soils into drainage systems and natural areas. A key factor in accomplishing these goals is the sequencing of construction activities such that the minimum possible area is disturbed at any one time. Initial site work should include establishing protective buffer zones adjacent to onsite resources that require protection and setting up perimeter sediment controls. During the course of construction, a variety of erosion prevention and sediment control practices may be necessary in order to stabilize slopes and drainageways, protect inlets to the storm water conveyance system, limit gully formation, and capture sediment. Table 12.CONST.1 summarizes some of the most common temporary erosion and sediment control practices, the on-site areas to use the practices, and the method of use for each of the practices. Table 12.CONST.2 indicates NPDES requirements and the temporary sediment control practices that can be used to fulfill these requirements. Temporary seeding is not erosion protection or sediment control until vegetation is established or until the area is protected with an erosion control blanket. Projects that are actively under construction in winter/frozen months should include additional inspection and clean-up activities. Temporary sediment basins should be sized to include extra storage for snowmelt, as discussed in Chapter 9.

A final key element to ensure effectiveness of the erosion and sediment control plan is the implementation of an inspection and maintenance program. Frequent inspection and maintenance activities ensure that the installed temporary sediment control practices are operating effectively throughout the course of the project.

References

Minnesota Department of Transportation, 2003. *2003 Seeding Manual*. http://www.dot.state.mn.us/environment/pdf_files/SeedingManual2003.pdf

Minnesota Department of Transportation, 2000. *Mn/DOT Standard Specifications for Construction*. http://www.dot.state.mn.us/tecsup/spec/

Minnesota Erosion Control Association and Minnesota Department of Transportation, 2001. *Erosion & Sediment Control Certification & ETeam Training Program 2001*. http://www.dot.state.mn.us/environment/pdf_files/TrnManCl.pdf

Minnesota Local Road Research Board, Federal Highway Administration, and Minnesota Department of Transportation, 2003. *Erosion Control Handbook for Local Roads*. Manual Number 2003-08. http://www.lrrb.gen.mn.us/pdf/200308.pdf

Minnesota Pollution Control Agency, 2005. NPDES General Permit for Storm Water Discharges From Construction Activities. http://www.epa.gov/npdes/pubs/cgp2003_entirepermit.pdf

Minnesota Pollution Control Agency, 2000. *Protecting Water Quality in Urban Areas*. http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html

Table 12.CONST.1 Temporary Sediment Control Practices

Temporary Sediment Control Practice		Erosion Protection	Sediment Control	Areas to Use: Perimeter	Slopes	Drainage-ways	Other	Method
	Vegetated Buffers Photo: MPCA	X		X	X	X	Around Trees, Water Bodies, Natural Areas	Vegetated buffers are areas designated to remain undisturbed in order to protect trees, lakes, bluffs, or natural areas. Buffers should be marked and maintained around all resources requiring protection.
	Silt Fence		X	X	X	X	Drainage System Inlets	Silt fence filters sediment from runoff by allowing water to pass through a geotextile fabric or by creating a pool to allow sediment to drop out of the water column. Silt fence is installed primarily at downslope boundaries of the work area but can also be used for inlet protection, and around the perimeter of stockpiles.
	Fiber Log		X	X	X	X	Drainage System Inlets	Fiber logs include straw, wood, or coconut fiber logs, compost logs, and rock logs that slow water and filter sediment. Fiber logs are used for inlet protection, ditch checks, and as perimeter control where silt fence is infeasible.
	Rock Construction Entrance		X	X				A rock construction entrance is a bed of rocks that helps to remove sediment from vehicle tires. Rock construction entrances should be placed at all site access points. The use of 1 1/2 inch - 3 inch clear aggregate is recommended. Periodic cleaning or replacement is recommended.
	Grade Breaks		X		X			Grade breaks are changes in slope that break up concentrated flow, preventing the formation of gullies. Grade breaks should be incorporated into long slopes.
	Temporary Seeding	X	X		X	X		Temporary seeding allows plants to stabilize the soil through vegetation and root growth. A large variety of plants are available for temporary seeding of different conditions; the most common are rye grass, winter wheat, and oats.
	Erosion Control Blanket	X	X		X	X		Erosion control blanket is a mat made of netting layered with straw, wood, coconut or man-made fibers that prevents erosion by sheltering the soil from rainfall and runoff while holding moisture for establishing plants. Blankets are installed in channels or on slopes where mulch would not be adequate.

Table 12.CONST.1 Temporary Sediment Control Practices

Temporary Sediment Control Practice		Erosion Protection	Sediment Contol	Areas to Use: Perimeter	Areas to Use: Slopes	Areas to Use: Drainageways	Areas to Use: Other	Method
	Mulch	X			X			Mulch is wood fibers, compost, wood chips, straw, or hay that is applied as a cover to disturbed soil. Mulch reduces erosion by absorbing energy from rainfall and runoff and provides protection and moisture for the establishment of vegetation, when properly disc anchored or spread.
	Hydraulic Mulch	X			X			Hydraulic mulches for erosion control are typically comprised of wood fibers and are applied by hydroseeding equipment. Hydraulic mulches are typically used in areas with steeper slopes or where equipment access would be difficult.
	Temporary Pipe Downdrains	X			X			A temporary pipe downdrain conveys runoff down slopes in a pipe so that runoff will not cause erosion. Pipe downdrains are installed where concentrated flow would drain onto a disturbed slope.
	Floatation Silt Curtain		X				Lakes, Wetlands, Streams	Floatation silt curtain is fabric fence installed in water bodies to contain sediment near the banks of the work area. Must be used in conjunction with other sediment control techniques
	Rock or Compost Bags		X		X	X	Drainage System Inlets	Rock and compost bags are filled bags that are used to filter water, control ditch grade, or to provide inlet protection.
	Rock Check Dam		X			X		Rock check dams are rocks piled across a ditch to slow flows and capture sediment. Rock checks are installed perpendicular to flow and should be wide enough to ensure that flow remains in the center.
	Riprap	X				X	Drainage System Outlets	Riprap is appropriately sized rocks that reduce the energy of fast moving flows. Riprap is used along channels and at outfalls.
	Temporary Sedimentation Basin		X				Throughout Site	Temporary sedimentation basins are depressions that capture runoff to slow the flow of water and allow sediment to settle out.
	Filter Bag Photo: Dandy Corp.		X				Drainage System Inlets	Filter bags are mesh bags that capture sediment but allow water to pass through. Filter bags are installed in storm drain inlets.

Table 12.CONST.2 NPDES Requirements and Associated Erosion Protection and Sediment Control Practices

NPDES General Construction Storm water Permit Requirement * *specific requirements may vary as specified in General Permit Appendix A	**Temporary Erosion Protection and/or Sediment Control Practice**															
	Vegetated Buffers	Silt Fence	Fiber Log	Rock Construction Entrance	Grade Breaks	Temporary Seeding	Erosion Control Blanket	Mulch	Hydraulic Mulch	Temporary Pipe Downdrains	Floatation Silt Curtain	Rockbags/Sandbags/ Compostbags	Rock Check Dam	Riprap	Sedimentation Basin	Filter Bag
Delineate areas of no disturbance before beginning site work.	X															
Sediment control must be established on all down gradient perimeters prior to commencement of land disturbing activities.		X	X								X					
Vehicle tracking of sediment must be minimized.				X												
All storm drain inlets must be protected.		X	X									X				X
Install energy dissipation measures at pipe outlets within 24 hours of connecting to a surface water.														X		
Drainage ditches within 200 feet of a surface water or the property edge must be stabilized within 24 hours of connection to a surface water.			X			X	X	X*	X*				X	X		
No unbroken slope of length greater than 75 feet for slopes of 3:1 or steeper. Slopes within 200 feet of a surface water must have temporary protection or permanent cover within the following timeframe based on slope: **Slope** — **Time** Steeper than 3:1 — 7 days 10:1 to 3:1 — 14 days Flatter than 10:1 — 21 days			X		X	X	X	X	X	X						
Install temporary basin where 10 acres or more drains to a common location.															X	

* Not recommended for areas of concentrated flow - such as channel bottoms

CHEMICAL & BIOLOGICAL TREATMENT

Tanners Lake alum injection facility - Oakdale, MN

Definition:
Chemical and biological treatment of stormwater enhances settling of suspended sediment by encouraging flocculation. Variations include aluminum sulfate, ferric chloride, chitosan, and polyacrylamide. Chemical and biological treatments are typically used as a final or polishing step in the treatment train.

KEY CONSIDERATIONS

Design Criteria:
- Properties of water to be treated (pH, sediment concentration, etc.)
- Level of treatment desired
- Requirements for discharge of treated water to receiving water bodies
- Type of facility required or present
- Pre-treatment or secondary treatment requirements
- Maintenance and monitoring requirements of the system

Benefits:
- Quickly removes suspended clays and silts
- Can be used as pre-treatment to remove suspended sediments prior to infiltration
- Can help project meet stringent water clarity and sediment-bound pollutant removal standards
- Suitable for cold climates

Limitations:
- Ongoing operation and maintenance of the chemical addition system may be required
- Monitoring may be required to determine the impact on downstream resources
- A pond or sediment collection area is necessary downstream of the treatment site for settling out the flocculants
- May require permit from DNR
- Expensive to build and operate

MANAGEMENT SUITABILITY

High	Water Quality (V_{WQ})
NA	Channel Protection (V_{CP})
NA	Overbank Flood Protection (V_{P10})
NA	Extreme Flood Protection (V_{P100})
NA	Recharge Volume (V_{RE})

MECHANISMS

	Infiltration
	Screening/ Filtration
	Temperature Control
X	Settling
	Evaporation
	Transpiration
X	Soil Adsorption
X	Biological/ Micro. Uptake

POLLUTION REMOVAL

X*	Total Suspended Solids
X*	Nutrients - Total Phosphorus/ Total Nitrogen
X*	Metals - Cadmium, Copper, Lead, and Zinc
	Pathogens - Coliform, Streptococci, E. Coli
	Toxins - Chloride, Hydrocarbon, Pesticide

* target pollutants - actual percentage of pollutant removal varies with each device and installation

Description:
Chemical and biological agents such as aluminum sulfate, polyacrylamide, ferric chloride, and chitosan can be added to stormwater to encourage the settling of smaller suspended particles. In a typical detention pond, suspended clays and other small particles are not well removed because they require long detention times to settle out. The addition of chemical or biological agents allows the small suspended particles to group together to form a larger conglomerate particle (or flocculent) that rapidly settles out of the water column.

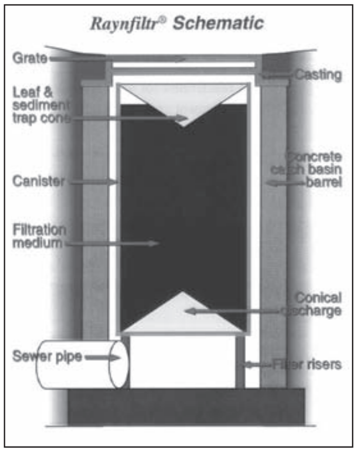
Chemical and biological treatment can be a passive system of flow through a solid form of the media, but it often requires the installation of monitoring and metering devices to ensure that the liquid agent is added at the proper dosage. Chemical or biological treatment can also be used as a temporary or one-time use product for construction or emergency situations.

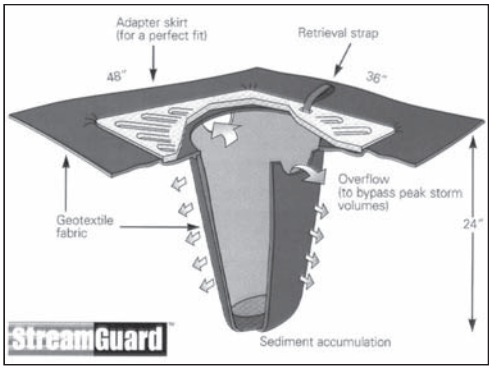
The MPCA Construction General Permit allows limited use of proprietary devices or "alternative methods". Use of the alternative method must be approved by the MPCA prior to installation. Approval is limited to those methods that achieve approximately 80% removal of total suspended solids. Additionally, the MPCA requires a two-year monitoring plan to measure the actual effectiveness of the method.

Selection:
When selecting or specifying a device that utilizes chemical or biological treatment processes, designers should research the following:

1. What are the minimum or maximum drainage areas recommended for the device or method?
2. What are the characteristics of the pollutants in the water used for testing? Review manufacturer's protocols for testing.
3. Are the pollutant removal tests verified by independent organizations such as USEPA, University of New Hampshire, University of Minnesota, Wisconsin Department of Natural Resources, or others?
4. Can the chemical or biological treatment agent be discharged into a natural water body?
5. What detention time is required for the chemical or biological treatment agent to cause flocculation?
6. How often must dosing rates be changed?
7. What are the construction costs? Does the cost include all materials, installation, and delivery?
8. What are the maintenance requirements? What are the costs of the required maintenance? Is there a standard operation and maintenance plan?
9. Will the manufacturer provide design computations and CADD details?

FILTRATION DEVICES





Proprietary systems used as an example only - NOT an endorsement

Definition:
Filtration devices (inserts_) allow stormwater to pass through filter media which are designed to reduce specific stormwater pollutants, but primarily solids and oils. Pollutants are captured physically or through sorption onto the filter media. Filters may either be inserts that are retrofitted into existing catch basins or manholes, or stand alone units supplied by a manufacturer.

KEY CONSIDERATIONS

Design Criteria:
- Pollutants of interest for reduction
- Desired removal efficiency
- Design flow or volume, site constraints on size, desired location of treatment unit
- Pre-treatment requirements
- Installation and maintenance costs, life of unit

Benefits:
- Units are typically underground or within existing structures and do not consume much site space
- Filtration devices can be customized to reduce a specific pollutant of concern
- Can often be easily incorporated into fully developed sites
- Can be used for pre-treatment prior to infiltration practices
- Relevant for use on industrial sites because filters can remove pollutants such as metals and oils

Limitations:
- Efficiency has not been widely tested
- Each type of unit has specific design constraints and limitations for use
- Can be more costly that other treatment methods
- Treatment may be greatly reduced if frequent maintenance is not conducted
- Subject to freezing in cold climates

MANAGEMENT SUITABILITY

X	Water Quality (V_{WQ})
NA	Channel Protection (V_{CP})
NA	Overbank Flood Protection (V_{P10})
NA	Extreme Flood Protection (V_{P100})
NA	Recharge Volume (V_{RE})

MECHANISMS

	Infiltration
X	Screening/ Filtration
	Temperature Control
	Settling
	Evaporation
	Transpiration
	Soil Adsorption
	Biological/ Micro. Uptake

POLLUTION REMOVAL

X*	Total Suspended Solids
	Nutrients - Total Phosphorus/ Total Nitrogen
X*	Metals - Cadmium, Copper, Lead, and Zinc
	Pathogens - Coliform, Streptococci, E. Coli
	Toxins - Chloride, Hydrocarbon, Pesticide

* target pollutants - actual percentage of pollutant removal varies with each device and installation

Description:
Filtration devices, depending on the design, can treat stormwater to reduce nutrients, sediment, floatables, metals, oil, and/or organic compounds. Different filtration media are used depending on the type of pollutant to be removed. Filter media may be a screen, fabric, activated carbon, perlite, zeolite, or other materials. Often a combination of filter media can be used to target the specific pollutants of interest.

These devices differ from the structural stormwater filters described in Chapter 12 in two aspects. First, these devices are proprietary and are designed to fit as an insert into the hydraulic infrastructure (eg. a catch basin). Second, the media material may have unique characteristics which are different from the soil/sand media recommended for general stormwater filtration.

Filtration devices have been developed for use in locations such as underground chambers, catch basins, trench drains, and roof drains. The manufacturer specifications should indicate key design parameters such as size, allowable flow rate, allowable pollutant concentrations, and removal efficiency. A bypass should be part of the system to allow high flows to circumvent the filtration device.

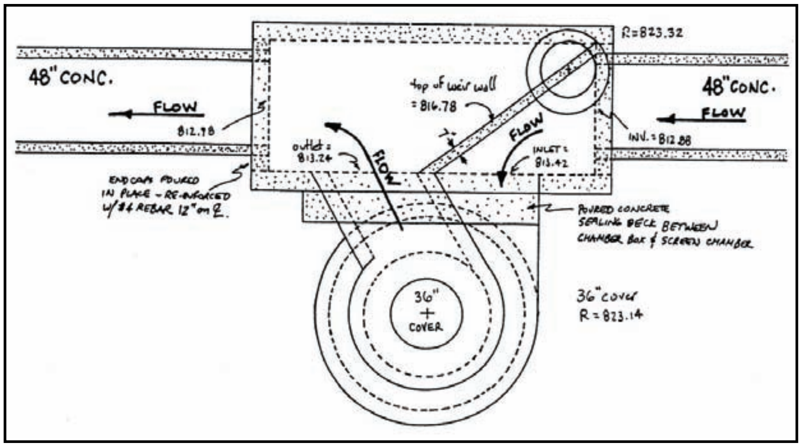
Performance data are often provided by the manufacturer. Users should review this information to ensure it was provided by an independent source.

The MPCA Construction General Permit allows limited use of proprietary devices or “alternative methods.” Use of the alternative device as a stand alone BMP must be approved by the MPCA prior to installation. Approval is limited to those devices that achieve approximately 80% removal of total suspended solids. Additionally, the MPCA requires a two-year monitoring plan to measure the actual effectiveness of the method. If a device does not meet this 80% total suspended solids removal requirement, then these devices could be used as pretreatment or supplemental to another stormwater practice.

Selection:
When selecting or specifying a filtration device, designers should research the following:

1. What are the minimum or maximum drainage areas recommended for the device or method?
2. What flow rates or volumes can the device accommodate? Will accessory structures be necessary to divert high flow around the filtration device?
3. What are the characteristics of the pollutants in the water used for testing? What particle size distribution was tested? Research protocols used for testing.
4. Are pollutant removal tests verified by independent organizations such as USEPA, University of New Hampshire, University of Minnesota, Wisconsin Department of Natural Resources, or others?
5. Does the device contain a by-pass for high flows? If so, then what is the percentage of flow is prior to by-pass.
6. What are the construction costs? Does the cost include all materials, installation, and delivery?
7. What are the maintenance requirements? What are the costs of the required maintenance? Is there a standard operation and maintenance plan? What is the typical life of the filtration unit?
8. Does the local regulatory authority approve the use of filtration devices?
9. Will the manufacturer provide design computations and CADD details?

HYDRODYNAMIC DEVICES



Courtesy of Minneapolis Public Works Department

Definition:
Hydrodynamic devices are designed to remove solids, oil/ grease, floatables and other debris from stormwater runoff through gravitational trapping of pollutants. Typically used in combination with other structural BMPs, such as a pre-treatment device.

KEY CONSIDERATIONS

Design Criteria:

- Expected flow rates
- Pollutants of concern
- Desired removal efficiencies
- Site constraints for size
- Installation and maintenance costs, life of unit
- Need for accessory structures

Benefits:

- Units are typically underground and do not consume much site space
- Can often be easily incorporated into fully developed sites
- Can be used for pre-treatment prior to other practices
- Suitable for cold climates if installed below frost line

Limitations:

- Each type of unit has specific design constraints and limitations for use
- Treatment may be reduced if frequent maintenance is not conducted
- May not meet local standards when used alone
- Generally good for solids and litter, but much less effective for other common pollutants.

MANAGEMENT SUITABILITY

X	Water Quality (V_{WQ})
NA	Channel Protection (V_{CP})
NA	Overbank Flood Protection (V_{P10})
NA	Extreme Flood Protection (V_{P100})
NA	Recharge Volume (V_{RE})

MECHANISMS

	Infiltration
X	Screening/ Filtration
	Temperature Control
X	Settling
	Evaporation
	Transpiration
	Soil Adsorption
	Biological/ Micro. Uptake

POLLUTION REMOVAL

X*	Total Suspended Solids
	Nutrients - Total Phosphorus/ Total Nitrogen
X*	Metals - Cadmium, Copper, Lead, and Zinc
	Pathogens - Coliform, Streptococci, E. Coli
	Toxins - Chloride, Hydrocarbon, Pesticide

* target pollutants - actual percentage of pollutant removal varies with each device and installation

Description:
Hydrodynamic devices are chambers that allow sediment to settle out of the water column. The devices often enhance the rate of sediment settling through the circular motion of stormwater within the chamber. The devices also capture oil, grease, and other floatables, most often through the use of baffles. Hydrodynamic devices are typically designed to provide optimal removal efficiency for smaller, more frequent storms with minimal removal in larger, less common storms. To maintain removal efficiency, the devices require regular removal of accumulated sediment and floatables.

These devices are proprietary and typically are designed and installed by a manufacturer. Performance data are often provided by the manufacturer. Users should review this information to ensure it was provided by an independent source.

The MPCA Construction General Permit allows limited use of proprietary devices or “alternative methods.” Use of the alternative device as a stand alone BMP must be approved by the MPCA prior to installation. Approval is limited to those devices that achieve approximately 80% removal of total suspended solids. Additionally, the MPCA requires a two-year monitoring plan to measure the actual effectiveness of the method. If a hydrodynamic device does not meet this 80% total suspended solids removal requirement, then the device could be used as pretreatment or supplemental to another stormwater practice. No single, stand alone device has been found to meet this criteria.

Selection:
When selecting or specifying a hydrodynamic device, designers should research the following:

1. What are the minimum or maximum drainage areas recommended for the device or method?
2. What flow rates or volumes can the device accommodate? Will accessory structures be necessary to divert high flow around the hydrodynamic device?
3. What are the characteristics of the pollutants in the water used for testing? Research protocols used for testing.
4. Are pollutant removal tests verified by independent organizations such as USEPA, University of New Hampshire, University of Minnesota, Wisconsin Department of Natural Resources, or others?
5. Does the device contain a bypass for high flows? If so, then what percentage of flow is treated prior to bypass?
6. What are the construction costs? Does the cost include all materials, installation, and delivery?
7. What are the maintenance requirements? What are the costs of the required maintenance? Is there a standard operation and maintenance plan?
8. Does the local regulatory authority allow the use of hydrodynamic devices?
9. Will the manufacturer provide design computations and CADD details?

Raingarden in a commercial development - Stillwater, MN

Definition:
Bioretention is a terrestrial-based (up-land as opposed to wetland), water quality and water quantity control process. Bioretention employs a simplistic, site integrated design that provides opportunity for runoff infiltration, filtration, storage and water uptake by vegetation.

KEY CONSIDERATIONS

Design Criteria:

- Infiltration requires suitable soils.
- Minimum 10' setback and located down grade from home foundations.
- Best applied to drainage areas with relatively flat slopes (5%).

Benefits:

- Can be very effective for removing fine sediment, trace metals, nutrients, bacteria and organics (Davis *et al*. 1998).
- Provides many additional environmental (*habitat, improves air quality, urban micro-climates*), social (*creates a unique sense of place*) and economic benefits (*reduces development and maintenance cost, greater lot yield, increases property values*).
- Well suited for high impervious areas.
- Reduces runoff volume.
- Flexible design, affording many opportunities for creativity.

Limitations:

- Susceptible to clogging by sediment; therefore maintenance and pretreatment is necessary to maintain effectiveness.
- Not effective for large drainage areas (use multiple structures, closer to source of runoff).
- Space consumption (5%-10% of drainage area).

MANAGEMENT SUITABILITY

Med/High	Water Quality (V_{WQ})
Med	Channel Protection (V_{CP})
Low/Med	Overbank Flood Protection (V_{P10})
Low	Extreme Flood Protection (V_{P100})
High	Recharge Volume (V_{RE})

MECHANISMS

X*	Infiltration *with appropriate soils & site conditions
X	Filtration
X	Temperature Control
X	Settling
	Evaporation
X	Transpiration
X	Soil Adsorption
X	Biological/ Micro. Uptake

POLLUTION REMOVAL

85%	Total Suspended Solids
60%/ 50%	Nutrients - Total Phosphorus/ Total Nitrogen
95%	Metals - Cadmium, Copper, Lead, and Zinc
35%*	Pathogens - Coliform, Streptococci, E. Coli *less than 5 independent studies
80%*	Toxins - Chloride, Hydrocarbon, Pesticide *less than 5 independent studies

Note: Average pollutant removal expected when sizing based on MPCA criteria. Values apply to treated runoff only.

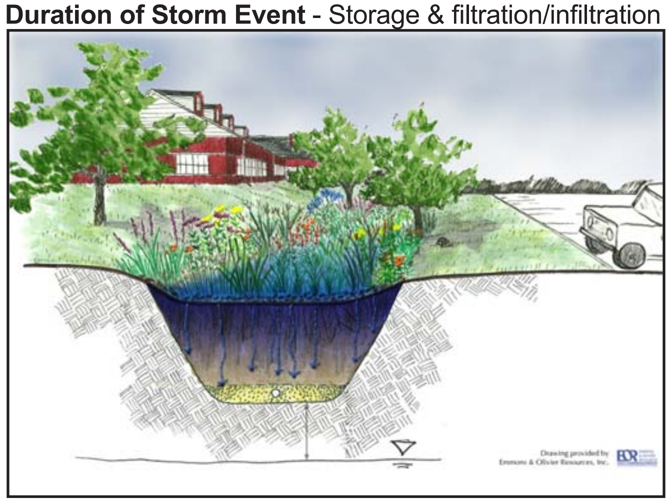
SITE FACTORS

2 AC Max; 1 AC Max Impervious	Drainage Area For Filtration Design (Per Practice)
2 AC Max; 1/2 AC Max Impervious	Drainage Area For Infiltration Design (Per Practice)
20%	Max. Slope of Site
3'	Min. Depth to Bedrock & Seasonally High Water Table
A,B - Normal	NRCS Soil Type *can be used in C&D soil types with modifications (e.g. under-drains)
Good	Freeze/ Thaw Suitability
Suitable	Potential Hotspot Runoff *requires impermeable liner

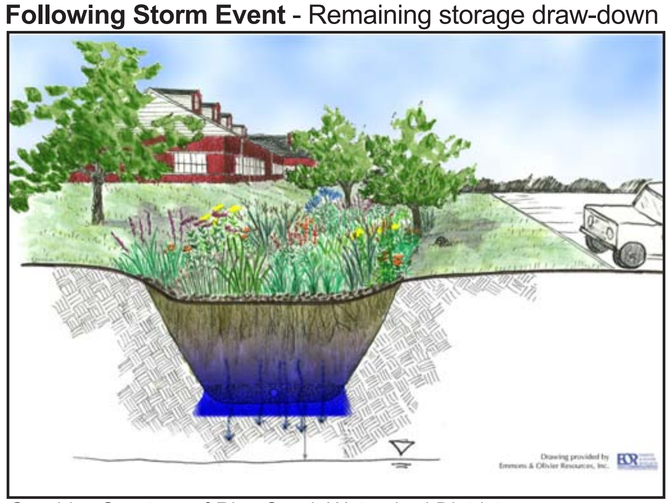
STORM SEQUENCE

Start of Storm Event - Initial runoff & storage

Duration of Storm Event - Storage & filtration/infiltration



Following Storm Event - Remaining storage draw-down



Graphics Courtesy of Rice Creek Watershed District

Description:

In general, bioretention systems can be described as shallow, landscaped depressions commonly located in parking lot islands or within small pockets in residential areas that receive stormwater runoff (Metropolitan Council Small Sites BMP Manual, 2001).

Bioretention facilities capture rainwater runoff to be filtered through a prepared soil medium. Once the soil pore space capacity of the medium is exceeded, stormwater begins to pool at the surface of the planting soil. Pollutants are removed by a number of processes including adsorption, filtration, volatilization, ion exchange and decomposition (Prince George's County, MD, 1993). Filtered runoff can either be allowed to infiltrate into the surrounding soil (functioning as an infiltration basin or rainwater garden), or collected by an under-drain system and discharged to the storm sewer system or directly to receiving waters (functioning like a surface sand filter). Runoff from larger storms is generally diverted past the area to the storm drain system (Metropolitan Council Small Sites BMP Manual, 2001).

Bioretention is a stormwater treatment practice that utilizes the chemical, biological and physical properties of plants, microbes and soils for capturing/reducing stormwater runoff and removing pollutants from runoff. This process is often incorporated into many different types of filtration and infiltration stormwater treatment practices.

BIORETENTION

I. Suitability

General

Bioretention areas are suitable stormwater treatment practices for all land uses, as long as the contributing drainage area is appropriate for the size of the facility. Common bioretention opportunities include landscaping islands, cul-de-sacs, parking lot margins, commercial setbacks, open space, rooftop drainage and street-scapes (i.e., between the curb and sidewalk). Bioretention, when designed with an under-drain and liner, is also a good design option for treating potential stormwater hotspots (PSHs). Bioretention is extremely versatile because of its ability to be incorporated into landscaped areas. The versatility of the practice also allows for bioretention areas to be frequently employed as stormwater retrofits.

Function Within Stormwater Treatment Train

Unlike end-of-pipe BMPs, bioretention facilities are typically shallow depressions located in upland areas. The strategic, uniform distribution of bioretention facilities across a development site results in smaller, more manageable subwatersheds, and thus, will help in controlling runoff close to the source where it is generated (Prince George's County Bioretention Manual, 2002).

Bioretention facilities are designed to function by essentially mimicking certain physical, chemical, and biological processes that occur in the natural environment. Depending upon the design of a facility, different processes can be maximized or minimized depending on the type of pollutant loading expected (Prince George's County, 2002).

MPCA Permit Applicability

One of the goals of this Manual is to facilitate understanding of and compliance with the MPCA Construction General Permit (CGP), which includes design and performance standards for permanent stormwater management systems. The permit and related documentation can be found online at http://www.pca.state.mn.us/water/stormwater/stormwater-c.html. Standards for various categories of stormwater management practices must be applied in all projects in which at least one acre of new impervious area is being created.

For regulatory purposes, bioretention practices fall under the "Infiltration / Filtration" category described in Part III.C.2 of the CGP. If used in combination with other practices, credit for combined stormwater treatment can be given as described in Part III.C.4. Due to the statewide prevalence of the MPCA permit, design guidance in this section is presented with the assumption that the permit does apply. Also, although it is expected that in many cases the bioretention practice will be used in combination with other practices, standards are described for the case in which it is a stand-alone practice.

The following terms are thus used in the text to distinguish various levels of bioretention practice design guidance:

REQUIRED:	Indicates design standards stipulated by the MPCA Construction General Permit (or other consistently applicable regulations).
HIGHLY RECOMMENDED:	Indicates design guidance that is extremely beneficial or necessary for proper functioning of the bioretention practice, but not specifically required by the MPCA CGP.
RECOMMENDED:	Indicates design guidance that is helpful for bioretention practice performance but not critical to the design.

Of course, there are situations, particularly retrofit projects, in which a bioretention practice is constructed without being subject to the conditions of the MPCA permit. While compliance with the permit is not required in these cases, the standards it establishes can provide valuable design guidance to the user. It is also important to note that **additional and potentially more stringent design requirements may apply for a particular bioretention practice**, depending on where it is situated both jurisdictionally and within the surrounding landscape.

Design Variants

Alternative Names

As bioretention becomes a more common tool in the stormwater management toolbox and as the number of design variants increases, so does the number of names for each of these variants.

As an example of the ongoing evolution of bioretention terminology, the terms "rain garden" and "rainwater garden" have recently caught on with the public and are being used interchangeably with bioretention. In most instances, rain garden designs are utilizing the processes of bioretention, but the term rain garden is also being loosely used to describe BMPs that are operating more as stormwater ponds (or as other BMPs) than as bioretention facilities.

Further confusion stems from the using the terms "process" and "practice" interchangeably. As mentioned earlier, bioretention is not a "practice" per se, but rather a process or group of processes that can be incorporated into many different practices.

This section is provided to clarify the more common bioretention terminology being used in the field of stormwater management today.

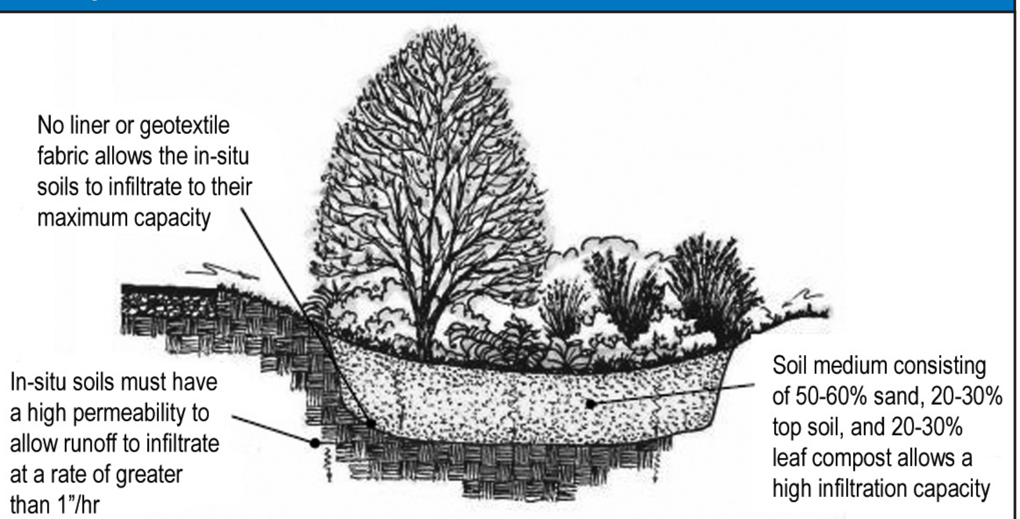
Performance Types (adapted from Prince George's County, 2002)

The following facility performance types have been slightly modified for Minnesota to optimize the expected or anticipated pollutant loadings based on the proposed land use. All of these facilities may be used as high-hydraulic-capacity filtration systems. High-hydraulic-capacity filtration systems are defined as systems that are composed of essentially a shallow sandy soil mix, thick layer of mulch and an under-drain/gravel discharge system.

Infiltration / Recharge Facility

This type of facility is suitable for areas where high recharge of ground water is possible and would be beneficial. Because there is no under-drain, the in-situ soils need to have a high infiltration rate to accommodate the inflow levels. The infiltration rate of the in-situ soils must be determined through proper soil testing/diagnostics. Preferably, facilities of this type should have infiltration rates of 1"/hr or greater. Facility filter media depth must be at least 2.5 feet deep to allow adequate filtration processes to occur. Siting of these facilities should be in areas where visibility is not a concern because hydraulic overload can cause extended periods of standing water conditions, although the CGP requires that the water quality volume (see Chapter 10) be drawn down within 48 hours. This

Figure 12.BIO.1 Infiltration / Recharge Facility (Source: Prince George's County Bioretention Manual, 2002



facility type is suitable for areas and land uses that are expected to generate nutrient runoff (i.e.; residential and business campuses) that can be infiltrated and captured by the facility. Fresh mulch rather then aged shredded bark mulch can be used to enhance denitrification processes.

Filtration/Partial Recharge Facility

This type of facility is suitable for areas where high filtration and partial recharge of runoff would be beneficial. This facility is designed with an under-drain at the invert of the planting soil mix to ensure that the facility drains at a desired rate. The facility allows for partial recharge, as an impervious liner is not used. The depth is also shallow (2.5') to allow the facility to handle high capacity flows if necessary. Siting of this performance type is suitable for visually prominent or gateway locations in a community. The facility type is suitable for areas and land uses that are expected to generate nutrient and metals loadings (residential, business campus, or parking lots). Attention to mulch type and amount will ensure the adequate treatment of the anticipated loadings. The facility shown in Figure 12.BIO.2 incorporates a filter material between the gravel blanket around the under-drain and the planting soil above. The filter fabric does not need to extend to the side walls. The filter fabric may be installed horizontally above the gravel blanket- extending just 1-2 feet on either side of the under-drain pipe below. Do ***not*** wrap the under-drain with filter fabric. Instead of using a filter fabric, the designer may opt to utilize a pea gravel diaphragm over the under-drain gravel blanket. This type of facility is also recommended for tight impermeable soils where infiltration is limited. Some volume reduction will be seen from evapotranspiration.

Infiltration/Filtration/Recharge

This type of facility (Figure 12.BIO.3) is recommended for areas where higher nutrient loadings (particularly nitrates) are anticipated. The facility is designed to incorporate a fluctuating aerobic/anaerobic zone below the raised under-drain discharge pipe. This fluctuation created by saturation and infiltration into the surrounding soils will achieve de-nitrification. With a combination of a fresh mulch covering, nitrates will be mitigated through the enhancement of natural denitrification processes. This type of facility would be suitable for areas where nitrate loadings are typically a problem (residential communities). The raised under-drain has the effect of providing a storage area below the invert of the under-drain discharge pipe. This area provides a recharge zone and quantity control can also be augmented with this storage area. The storage area is equal the void space of the material used.

Figure 12.BIO.2 Filtration / Partial Recharge Facility (Source: Prince George's County Bioretention Manual, 2002).

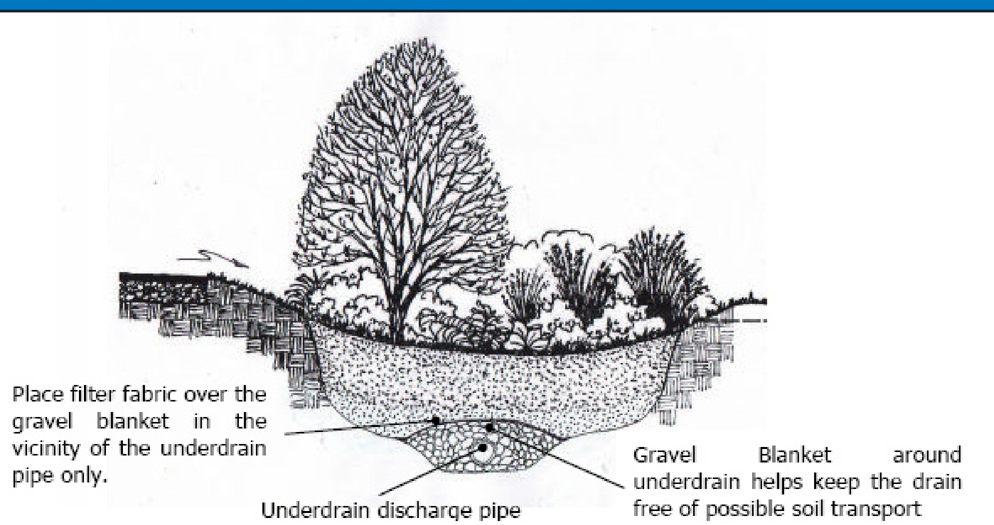


Figure 12.BIO.3 Infiltration / Filtration / Recharge Facility (Source: Prince George's County Bioretention Manual, 2002).

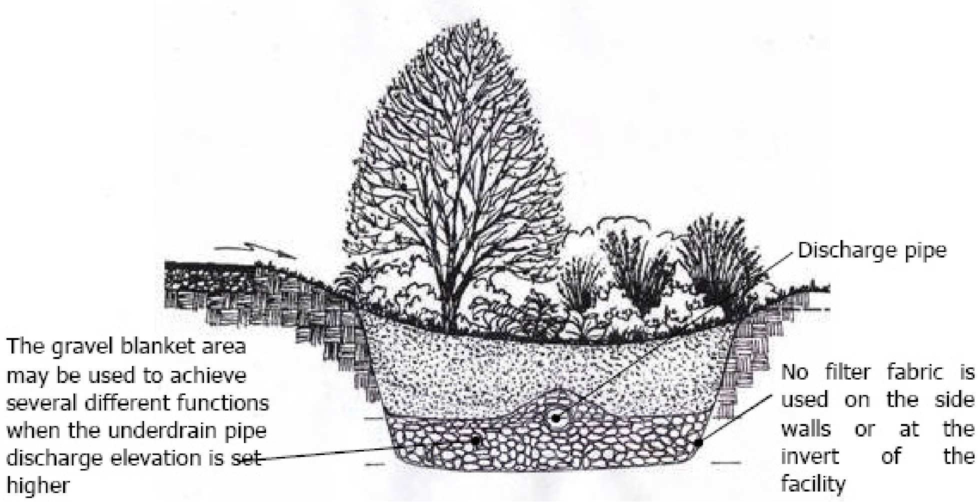
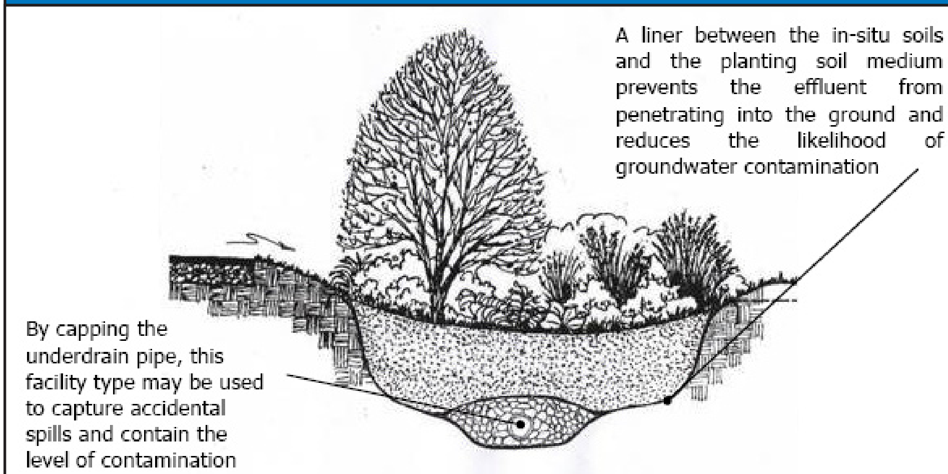


FIGURE 12.BIO.4 Filtration Only Facility (Source: Prince George's County Bioretention Manual, 2002).



Filtration Only

This type of facility is recommended for areas that are known as potential stormwater "hot-spots" (gas stations, transfer sites, and transportation depots). An important feature of this type of facility is the impervious liner designed to reduce or eliminate the possibility of ground water contamination. The facility provides a level of treatment strictly through filtration processes that occur when the runoff moves through the soil material to the under-drain discharge point. In the event of an accidental spill, the under-drain can be blocked and the objectionable materials siphoned through the observation well and safely contained.

Design Types for Various Land Uses

It should be noted that the layout of the bioretention area will vary according to individual sites, and to specific site constraints such as underlying soils, existing vegetation, drainage, location of utilities, sight distances for traffic, and aesthetics. Designers are encouraged to be creative in determining how to integrate bioretention into their respective site designs. With this in mind, the following conceptual illustrations are presented as alternative options.

- ► ***On-lot / Rain garden –*** Simple design that incorporates a planting bed in the low portion of the site. On-lot systems are designed to receive flows from gutters, and/or other impervious surfaces.

- ► ***Parking Lot Islands (Curbless)*** – In a paved area with no curb, pre-cast car-stops or a "ribbon curb" can be installed along the pavement perimeter to protect the bioretention area. This application of bioretention should only be attempted where shallow grades allow for sheet flow conditions over level entrance areas. Water may be pooled into the parking area where parking spaces are rarely used to achieve an element of stormwater quantity control beyond the confines of the bioretention surface area (Prince George's County, 2002).

- ► ***Parking Lot Islands (Curb-cut)*** – For curb-cut entrance approaches, the water is diverted into the bioretention area through the use of an inlet deflector block, which has ridges that channel the runoff into the bioretention area (Prince George's County, 2002). Special attention to erosion control and pre-treatment should be given to the concentrated flow produced by curb-cuts. Figure 12.BIO.5 features a parking lot island bioretention practice in context with other stormwater BMPs.

- ► ***Road Medians / Traffic Islands –*** A multifunctional landscape can be created by utilizing road medians and islands for bioretention. There is no minimum width recommended for traffic islands from street edge to edge. A buffer may be necessary along the outside curb perimeter to minimize the possibility of drainage seeping under the pavement section, and creating "frost heave" during winter months. Alternately, the installation of a geotextile filter fabric "curtain wall" along the perimeter of the bioretention island will accomplish the same effect.

Figure 12.BIO.5 Bioretention Parking Lot Island (Source: Minnehaha Creek Watershed District)

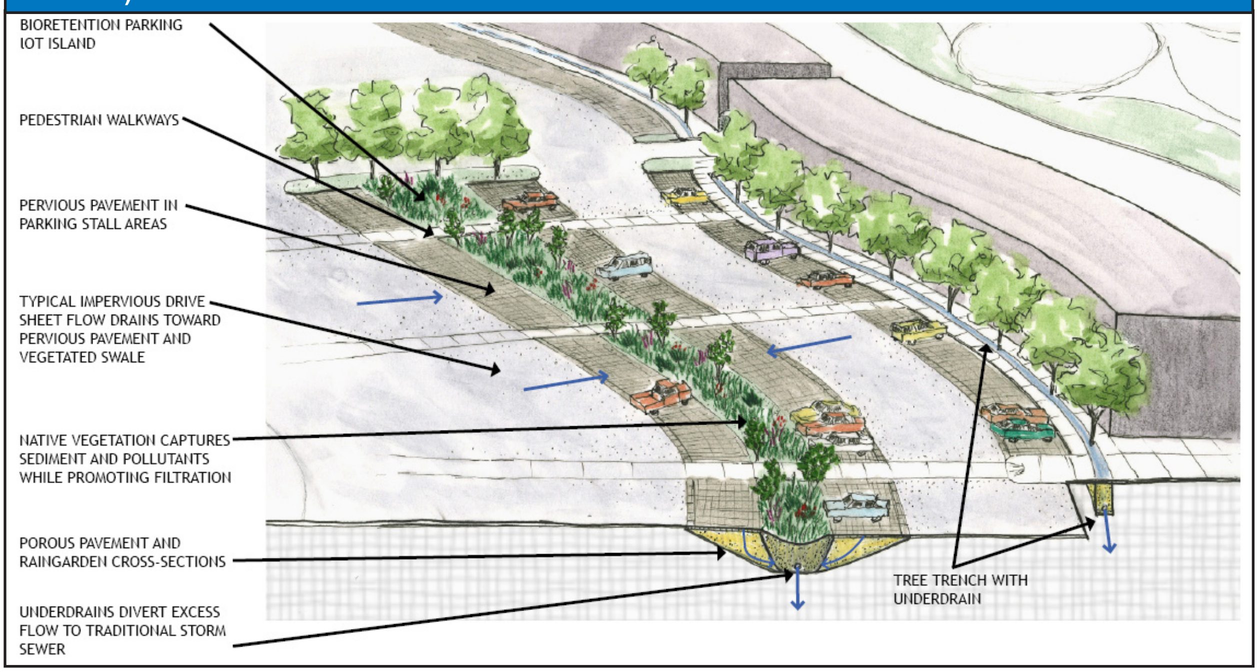
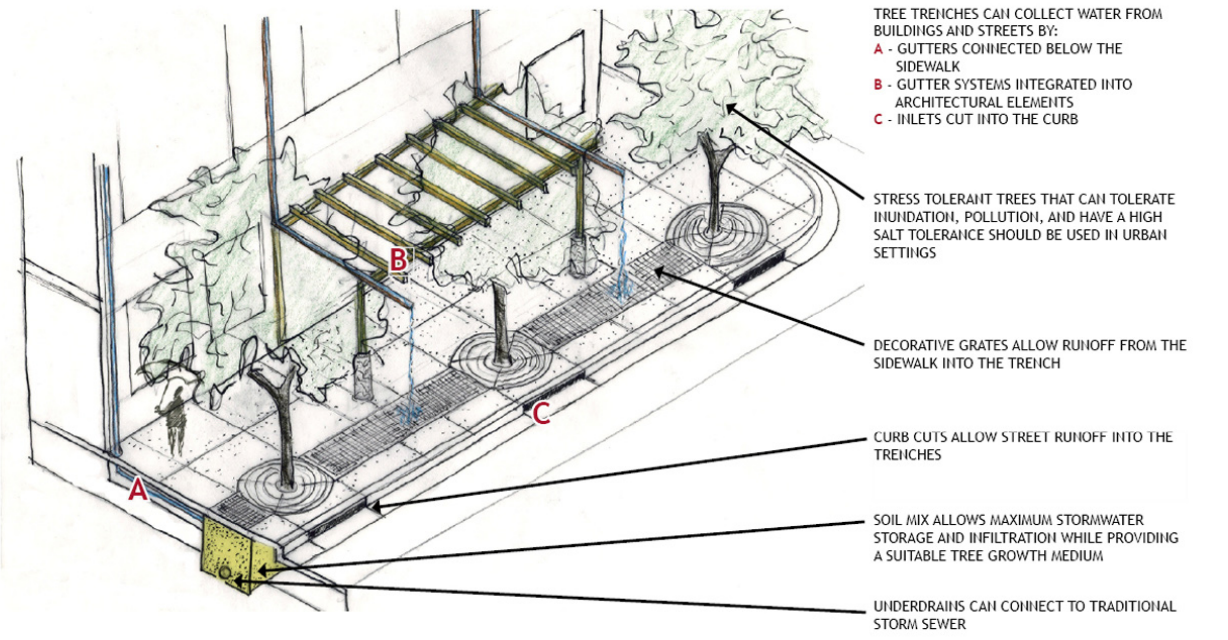


Figure 12.BIO.6 Tree Box Filter (Source: Minnehaha Creek Watershed District)



- ***Tree Pits / Tree Box Filters*** **–** tree Pits and tree box filters afford many opportunities for bioretention. Designs vary widely from simple “tree pits”, used for local drainage interception to more formal tree box filters, which are a useful tool for highly urbanized streetscapes.

  The tree pit technique provides very shallow ponding storage areas in a “dished” mulch area around the tree or shrub. Typically, the mulched area extends to the dripline for the tree and is similar to conventional mulching practices, except that the mulch area is depressed at least 2-3” rather than mounded around the tree (Low Impact Development Center, 2005).

  Tree box filters are bioretention areas installed beneath trees that can be very effective at controlling runoff, especially when distributed throughout the site. Runoff is directed to the tree box, where it is cleaned by vegetation and soil before entering a catch basin. The runoff collected in the tree-boxes helps irrigate the trees. The system consists of a container filled with a soil mixture, a mulch layer, under-drain system and a shrub or tree. Stormwater runoff drains directly from impervious surfaces through a filter media. Treated water flows out of the system through an under-drain connected to a storm drainpipe / inlet or into the surrounding soil. Tree box filters can also be used to control runoff volumes / flows by adding storage volume beneath the filter box with an outlet control device (Low Impact Development Center, 2005). Figure 12.BIO.6 details Tree box filters in a chain.

Retrofit Suitability

The ability to use bioretention as a retrofit often depends on the age of development within a subwatershed. Subwatersheds that have been developed over the last few decades often present many bioretention opportunities because of open spaces created by modern setback, screening and landscaping requirements in local zoning and building codes. However, not every open area will be a good candidate for bioretention due to limitations associated with existing inverts of the storm drain system and the need to tie the under-drain from the bioretention area (for practices requiring an under-drain) into the storm drain system. In general, four to six feet of elevation above this invert is needed to drive stormwater through the proposed bioretention area.

Table 12.BIO.1. BMP Design Restrictions for Special Water or Other Sensitive Receiving Waters

BMP	Watershed Management Category				
	Lakes	Trout Waters	Drinking Water [a]	Wetlands	Impaired Waters
Bioretention	PREFERRED	PREFERRED	OK with cautions for PSH	PREFERRED	PREFERRED

[a] Applies to ground water drinking water source areas only; use the sensitive lakes category to define BMP design restrictions for surface water drinking supplies
PSH – Potential Stormwater Hotspot

Special Receiving Waters Suitability

Table 12.BIO.1 provides guidance regarding the use of bioretention practices in areas upstream of special receiving waters. This table is an abbreviated version of a larger table in which other BMP groups are similarly evaluated. The corresponding information about other BMPs is presented in the respective sections of this Manual.

Cold Climate Suitability

Little research exists on the cold climate effectiveness of bioretention practices. Some believe that bioretention can be of marginal effectiveness for treating snowmelt runoff because of the dormancy of the vegetation during the cold season. However, the incorporation of some sump storage into the design of any bioretention system will provide an opportunity to route and collect snowmelt runoff and begin the filtration and infiltration processes. The incorporation of some storage as part of the system (for example, setting the outlet elevation 6” to 12” above the bottom of the bioretention practice) is necessary for this adaptation. Once relatively “warm” snowmelt runoff begins to accumulate in a bioretention system, some downward migration will usually begin and the system will activate. A system that is relatively dry when winter begins will respond more quickly and treat spring runoff more effectively once melt begins (see Chapter 9 Cold Climate discussions). To reduce freeze-up an 8” diameter (rather than the standard 6”) drain-tile is RECOMMENDED for practices requiring an under-drain.

Water Quantity Treatment

Bioretention practices are not typically suitable for providing water quantity control. It is HIGHLY RECOMMENED that bioretention practices be designed off-line. Off-line facilities are defined by the flow path through the facility. Any facility that utilizes the same entrance and exit flow path upon reaching pooling capacity is considered an off-line facility. However they may be designed to safely pass large storm flows while still protecting the ponding area, mulch layer and vegetation. In limited cases, a bioretention practice may be able to accommodate the channel protection volume, Vcp, in either an off-line or on-line configuration, and in general they do provide some (albeit limited) storage volume. Bioretention can help reduce detention requirements for a site by providing elongated flow paths, longer times of

It is HIGHLY RECOMMENDED that bioretention practices be designed off-line. Off-line facilities are defined by the flow path through the facility. Any facility that utilizes the same entrance and exit flow path upon reaching pooling capacity is considered an off-line facility.

concentration, and volumetric losses from infiltration and evapotranspiration. Experience and modeling analysis have shown that bioretention can be used for stormwater management quantity control when facilities are distributed throughout a site to reduce runoff and maintain the pre-existing time of concentration. This effort can be incorporated into the site hydrologic analysis (see also Chapter 8 and Appendix B). Generally, however, it is HIGHLY RECOMMENDED that in order to meet site water quantity or peak discharge criteria, another structural control (e.g., detention) be used in conjunction with a bioretention area.

Water Quality Treatment

Bioretention is an excellent stormwater treatment practice due to the variety of pollutant removal mechanisms including vegetative filtering, settling, evaporation, infiltration, transpiration, biological and microbiological uptake, and soil adsorption. Pollutant removal and effluent concentration data for select parameters are provided in Tables 12.BIO.2 and 3, respectively. Bioretention can also be designed as an effective infiltration / recharge practice, particularly when parent soils have high permeability (> ~ 0.5 in/hr). Where soils are not favorable, a rock infiltration gallery can be used to promote slow infiltration / recharge of stored water.

Early bioretention facilities were designed to provide water quality benefits by controlling the "first flush" event. Using highly permeable planting soils and an under-drain, however, creates a high-rate biofilter, which can treat 90-95% (or higher) of the total annual volume of rainfall/runoff. Furthermore, monitoring has shown the pollutant removal rates to be significantly above the estimates presented previously in the Prince George's County Manual (Prince George's County, 2002).

Limitations

The following general limitations should be recognized when considering installation of a bioretention practice:

- Emerging stormwater management technique with limited long-term experience available;
- Maintenance personnel may need additional instruction on routine Operation and Maintenance requirements; and
- Minimal long-term performance, operation and management information.

Table 12.BIO.2 Percent Removal of Key Pollutants by Bioretention (Source: Winer, 2000)

Practice	TSS [%]	Total Phosphorus [%]	Total Nitrogen [%]	Metals[2] [%]	Bacteria [%]	Hydro-carbons [%]
Bioretention	85[3]	65	50	95	35[3]	80[3]

1. Based on fewer than five data points (i.e., independent monitoring studies)
2. Average of zinc and copper
3. Assumed values based on filtering practice performance

Table 12.BIO.3 Typical BMP Best Achievable Effluent Concentrations (Source: Winer, 2000)

Practice	TSS	TP	TN	Cu[1]	Zn[1]
Bioretention	11	0.3	1.1[2]	7	40

1. Units for Zn and Cu are micrograms per liter
2. Assumed values based on filtering practice performance

II. Major Design Elements

Physical Feasibility Initial Check

Before deciding to use a bioretention practice for stormwater management, it is helpful to consider several items that bear on the feasibility of using such a device at a given location. The following list of considerations will help in making an initial judgment as to whether or not a bioretention practice is the appropriate BMP for the site.

- **Drainage Area** – Less than 1 acre maximum and ½ acre impervious maximum per infiltration design practice is RECOMMENDED. For larger sites, multiple bioretention areas can be used to treat site runoff provided appropriate grading is present to convey flows.

- **Site Topography and Slopes** – It is RECOMMENDED that sloped areas immediately adjacent to the bioretention practice be less than 33% but greater than 1%, to promote positive flow towards the practice.

- **Soils** – No restrictions; engineered media HIGHLY RECOMMENDED; under-drain is HIGHLY RECOMMENDED where parent soils are HSG C or D.

- **Depth to Ground Water and Bedrock** – A separation distance of 3 feet is REQUIRED between the bottom of the bioretention practice and the elevation of the seasonally high water table or bedrock.

- **Karst** – Under-drains and an impermeable liner may be desirable in some karst areas; specific site geotechnical assessment RECOMMENDED (See also Chapter 13).

- **Site Location / Minimum Setbacks** - It is HIGHLY RECOMMENDED that infiltration designed bioretention practices not be hydraulically connected to structure foundations or pavement, to avoid seepage and frost heave concerns, respectively. Table (12.BIO.4.) provides the minimum setbacks HIGHLY RECOMMENDED REQUIRED by the Minnesota Department of Health (MDH) for the design and location of bioretention practices for bioretention practices which are 1000 gallons (668 cubic feet) in volume or greater. The MDH is proposing to make this recommendation a requirement in future revisions to Minnesota Rule 4725.4350.The MDH is proposing revisions to Minnesota Rule 4725 that will decrease the setback for private wells from 50 feet to 35 feet and increasing the gallons from 1000 gallons to 5000 gallons.

Conveyance

It is HIGHLY RECOMMENDED that overflow associated with the 10-year or 25-year storm (depending on local drainage criteria) be controlled such that velocities are non-erosive at the outlet point (to prevent downstream slope erosion), and that when discharge flows exceed 3 cfs, the designer evaluate the potential for erosion to stabilized areas and bioretention facilities.

Common overflow systems within the structure consist of a yard drain inlet, where the top of the

Table 12.BIO.4. Minimum Setback Requirements (for bioretention practices that treat a volume of 1000 gallons or more)

Setback from	Minimum Distance [feet]
Property Line	10
Building Foundation*	10
Private Well	50
Public Water Supply Well	50
Septic System Tank/Leach Field	35

* Minimum with slopes directed away from the building.

yard drain inlet is placed at the elevation of the shallow ponding area. A stone drop of about twelve inches or small stilling basin could be provided at the inlet of bioretention areas where flow enters the practice through curb cuts or other concentrated flow inlets. In cases with significant drop in grade this erosion protection should be extended to the bottom of the facility.

It is HIGHLY RECOMMENDED that bioretention areas with under-drains be equipped with a minimum 8" diameter under-drain in a 1' deep gravel bed. Increasing the diameter of the under-drain makes freezing less likely, and provides a greater capacity to drain standing water from the filter. The porous gravel bed prevents standing water in the system by promoting drainage. Gravel is also less susceptible to frost heaving than finer grained media. It is also HIGHLY RECOMMENDED that a pea gravel diaphragm and/or permeable filter fabric be placed between the gravel layer and the filter media.

Pre-treatment

Pre-treatment refers to features of a bioretention area that capture and remove coarse sediment particles. Incorporating pretreatment helps to reduce the maintenance burden of bioretention, and reduces the likelihood that the soil bed will clog over time. Adequate pre-treatment for bioretention systems is REQUIRED.

For applications where runoff enters the bioretention system through sheet flow, such as from parking lots, or residential back yards, a grass filter strip with a pea gravel diaphragm is the preferred pretreatment method. The length of the filter strip depends on the drainage area, imperviousness, and the filter strip slope. For retrofit projects and sites with tight green space constraints, it may not be possible to include a grass buffer strip. For example, parking lot island retrofits may not have adequate space to provide a grass buffer. For applications where concentrated (or channelized) runoff enters the bioretention system, such as through a slotted curb opening, a grassed channel with a pea gravel diaphragm is the preferred pretreatment method.

In lieu of grass buffer strips, pretreatment may be accomplished by other methods such as sediment capture in the curb-line entrance areas. Additionally, the parking lot spaces may be used for a temporary storage and pretreatment area in lieu of a grass buffer strip. If bioretention is used to treat runoff from a parking lot or roadway that is frequently sanded during snow events, there is a high potential for clogging from sand in runoff. It is HIGHLY RECOMMENDED that grass filter strips or grass channels at least 10 or 20 feet long, respectively, convey flow to the system in these situations. Local requirements may allow a street sweeping program as an acceptable pre-treatment practice. It is HIGHLY RECOMMENDED that pre-treatment incorporate as many of the following as are feasible:

- ► Grass filter strip
- ► Gravel diaphragm
- ► Mulch layer
- ► Forebay
- ► Up Flow Inlet for storm drain inflow

Treatment

The following guidelines are applicable to the actual treatment area of a bioretention practice:

- ► ***Space Required*** – It is RECOMMENDED that approximately 5-10% of the tributary impervious area be dedicated to the practice footprint; with a minimum 200 square foot area for small sites (equivalent to 10 feet x 20 feet). The surface area of all infiltration designed bioretention practices is a function of MPCA's 48-hour drawdown requirement and the infiltration

Incorporating pretreatment helps to reduce the maintenance burden of bioretention, and reduces the likelihood that the soil bed will clog over time. Adequate pre-treatment for bioretention systems is REQUIRED.

capacity the underlying soils. The surface area of all filtration designed bioretention practices is a function of MPCA's 48-hour drawdown requirement and the filtration capacity of the soil medium and under-drain.

- ***Practice Slope*** **–** It is RECOMMENDED that the slope of the surface of the bioretention practice not exceed 1%, to promote even distribution of flow throughout.

- ***Side Slopes*** – It is HIGHLY RECOMMENDED that the maximum side slopes for an infiltration practice is 3:1 (h:v).

- ***Depth*** – Ponding design depths have been kept to a minimum to reduce hydraulic overload of in-situ soils/soil medium and to maximize the surface area to facility depth ratio, where space allows. Where feasible ponding depths should be no greater than 6 inches. The maximum allowable pooling depth is 18 inches. It is RECOMMENDED that the elevation difference from the inflow to the outflow be approximately 4-6 feet when an under-drain is used. The REQUIRED draw-down time for bioretention practices is 48 hours or less from the peak water level in the practice.

- ***Ground Water Protection*** – Exfiltration of unfiltered PSH runoff into ground water should never occur; the CGP specifically prohibits inflow from "designed infiltration systems from industrial areas with exposed significant materials or from vehicle fueling and maintenance areas".

It is HIGHLY RECOMMENDED that bioretention not be used on sites with a continuous flow from ground water, sump pumps, or other sources so that constant saturated conditions do not occur.

It is HIGHLY RECOMMENDED that soils meet the design criteria outlined later in this section, and contain less than 5% clay by volume. Elevations must be carefully worked out to ensure that the desired runoff flow enters the facility with no more than the maximum design depth. The bioretention area should be sized based on the principles of Darcy's Law, as follows:

Af = (Vwq) (df) / [(k) (hf + df) (tf)]

Where:

Af = surface area of device (ft^2)

V_{WQ} = water quality volume (ft^3)

df = filter bed depth (ft)

k = coefficient of permeability of filter media k = 0.5 ft/day is appropriate to characterize the planting medium / filter media soil. This value is conservative to account for clogging associated with accumulated sediment (Clayton and Schueler, 1996).

hf = average height of water above filter bed (ft) (Typically 1/2 hmax, where hmax is the maximum head on the filter media and is typically ≤6 feet)

tf = design filter bed drain time (days)

It is REQUIRED that the design permeability rate through the planting soil bed be high enough to fully drain the stormwater quality design storm runoff volume within 48 hrs. It is HIGHLY RECOMMENDED that this permeability rate be determined by field testing.

When using bioretention to treat PSHs, particularly in sensitive watersheds, it is HIGHLY RECOMMENDED that additional practices be incorporated as a treatment train for at least limited treatment during the winter when the bioretention area may be frozen.

Landscaping

It is REQUIRED that impervious area construction is completed and pervious areas established with dense and healthy vegetation prior to introduction of stormwater into a bioretention practice. Landscaping is critical to the performance and function of bioretention areas. Therefore, a landscaping plan is HIGHLY RECOMMENDED for bioretention areas. RECOMMENDED planting guidelines for bioretention facilities are as follows:

It is REQUIRED that impervious area construction is completed and pervious areas established with dense and healthy vegetation prior to introduction of stormwater into a bioretention practice.

- Vegetation should be selected based on a specified zone of hydric tolerance. *Plants for Stormwater Design* by the Minnesota Pollution Control Agency (Shaw and Schmidt, 2003) is a good resource.

- Native plant species should be specified over non-native species. Hardy native species that thrive in our ecosystem without chemical fertilizers and pesticides are the best choices.

- Many bioretention facilities feature wild flowers and grasses as well as shrubs and some trees.

- Woody vegetation should not be specified at inflow locations.

- Trees should not be planted directly overtop of under-drains and may be best located along the perimeter of the practice.

- Salt resistant vegetation should be used in locations with probable adjacent salt application, i.e. roadside, parking lot, etc. (see also Appendix E).

- Fluctuating water levels following seeding (prior to germination) can cause seed to float and be transported. Seed is also difficult to establish through mulch, a common surface component of bioretention. It may take up to two growing seasons to establish the function and desired aesthetic of mature vegetation via seeding. Therefore mature plantings are recommended over seed.

- If a minimum coverage of 50% is not achieved after the first growing season, a reinforcement planting is required.

- Bioretention area locations should be integrated into the site planning process, and aesthetic considerations should be taken into account in their siting and design.

Safety

Bioretention practices do not pose any major safety hazards. Trees and the screening they provide may be the most significant consideration of a designer and landscape architect. Where inlets exist, they should have grates that either have locks or are sufficiently heavy that they cannot be removed easily. Standard inlets and grates used by Mn/DOT and local jurisdictions should be adequate. Fencing of bioretention facilities is generally not desirable

III.. Construction Details

CADD based details for bioretention are contained in Appendix D. The following details, with specifications, have been created for bioretention systems:

- Bioretention Facilities General Plan

- Bioretention Facilities Performance Types Cross-Sections
  - Infiltration / Recharge Facility
  - Filtration / Partial Recharge Facility
  - Infiltration / Filtration / Recharge Facility
  - Filtration Only Facility

IV. Materials Specifications

Soil Medium / Filter Media Content

A well blended, homogenous mixture of 50-60% construction sand: 20-30% top soil; and 20-30%

organic leaf compost is necessary to provide a soil medium with a high infiltration/filtration capacity.

- ***Sand*** – Provide clean construction sand, free of deleterious materials. AASHTO M-6 or ASTM C-33 with grain size of 0.02”-0.04”
- ***Top Soil*** - sandy loam, loamy sand, or loam texture per USDA textural triangle with less than 5% clay content
- ***Organic Leaf Compost*** - (MnDOT Grade 2)

Soil Medium / Filter Media Depth

Field experiments show that pollutant removal is accomplished within the top 30” of soil depth with minimal additional removal beyond that depth (Prince George’s County, 2002). Therefore, the recommended depth of the prepared soil is 30 inches. However, if large trees are preferred in the design, a soil depth of 48”-52” should be utilized. The soil depth generally depends upon the root depth of the prescribed vegetation and content of underlying soils.

Gravel Filter Specifications - Under-drain gravel blanket shall be double washed stone, 1-1/2” in size. Pea Gravel shall be washed, river-run, round diameter, ¼ - ½ in size.

Mulch Content and Depth - Fresh shredded bark mulch (Mn/DOT Type 6) should be used when possible to maximize nitrogen retention. If aged mulch is used, use the shredded type instead of the “chip” variety to minimize floating action. The mulch layer should not exceed 3” in depth. Too much mulch can restrict oxygen flow to roots. In addition, mulch should not be mounded around the base of plants since this encourages damage from pests and diseases.

V. Construction Specifications

Given that the construction of bioretention practices incorporates techniques or steps which may be considered non-traditional; it is recommended that the construction specifications include the following format and information:

I. Temporary Erosion Control

- Install prior to site disturbance
- Protect catch basin/inlet
- It is HIGHLY RECOMMENDED that future bioretention locations not be used as temporary sedimentation basins. If used as temporary sedimentation basins, the bioretention practice should be over excavated a minimum of 18” below sedimentation basin grade.

II. Excavation, Backfill and Grading

- Timing of grading of infiltration practices relative to total site development
- Use of low-impact, earth moving equipment (wide track or marsh track equipment, or light equipment with turf-type tires)
- Do not over-excavate
- Restoration in the event of sediment accumulation during construction of practice
- Alleviate any compacted soil (compaction can be alleviated at the base of the practice by using a primary tilling operation such as a chisel plow, ripper or sub-soiler to a minimum 12” depth
- Gravel backfill specifications
- Gravel filter specifications
- Filter fabric specifications

III. Native Plants, Planting and Transplanting (MN Plant List in Appendix E of the Manual)

- Site preparation of planting areas
- Timing of native seeding and native planting
- Weed control
- Watering of plant material

IV. Construction Sequence Scheduling

- Temporary construction access
- Location of silt fence installation to protect BMPs and downstream receiving waters
- Removal and storage of excavated material
- Installation of underground utilities
- Rough grading
- Seeding and mulching disturbed areas
- Road construction
- Final grading
- Site stabilization
- Installation of semi-permanent and permanent erosion control measures
- Silt fence removal

V. Construction Observation

- Adherence to construction documents
- Verification of physical site conditions
- Erosion control measures installed appropriately

VI. Operation and Maintenance

Overview

The most frequently cited maintenance concern for bioretention is surface and under-drain clogging caused by organic matter, fine silts, hydrocarbons, and algal matter. Common operational problems include:

- standing water
- clogged filter surface
- inlet, outlet or under-drain clog

Recommendations described in this chapter are aimed at preventing these common problems.

Design Phase Maintenance Considerations

Implicit in the design guidance in the previous sections is the fact that many design elements of bioretention systems can minimize the maintenance burden and maintain pollutant removal efficiency. Key examples include: limiting drainage area, providing easy site access (REQUIRED), providing pre-treatment (REQUIRED), and utilizing native plantings.

Construction Phase Maintenance

Proper construction methods and sequencing play a significant role in reducing problems with operation and maintenance (O&M). In particular, with construction of bioretention practices the most important action for preventing operation and maintenance difficulties is to ensure that the contributing drainage area has been fully stabilized prior to bringing the practice on line (this is a REQUIRED practice).

Inspections during construction are needed to ensure that the bioretention practice is built in accordance with the approved design, standards and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is acceptable to the professional designer. An example construction phase inspection checklist is provided in Appendix D.

Post-construction Operation and Maintenance

A maintenance plan clarifying maintenance responsibility is REQUIRED. Effective long-term operation of bioretention practices necessitates a dedicated and routine maintenance schedule with clear guidelines and schedules. Proper maintenance will not only increase the expected life span of the facility, but will also improve aesthetics and property value. Some important post-construction considerations are provided below along with RECOMMENDED maintenance standards. A more detailed checklist of

A maintenance plan clarifying maintenance responsibility is REQUIRED. Effective long-term operation of bioretention practices necessitates a dedicated and routine maintenance schedule with clear guidelines and schedules. Proper maintenance will not only increase the expected life span of the facility, but will also improve aesthetics and property value.

maintenance activities and associated schedules is provided in Appendix D.

- ► A site specific O&M plan that includes the following considerations should be prepared by the designer prior to putting the stormwater filtration practice into operation:
  - Operating instructions for outlet component.
  - Vegetation maintenance schedule.
  - Inspection checklists.
  - Routine maintenance checklists.
- ► A legally binding and enforceable maintenance agreement should be executed between the practice owner and the local review authority.
- ► Adequate access must be provided for all bioretention facilities for inspection, maintenance, and landscaping upkeep, including appropriate equipment and vehicles.
- ► The surface of the ponding area may become clogged with fine sediment over time. Core aeration or cultivating of non-vegetated areas may be required to ensure adequate filtration.
- ► Bioretention areas should not be used as dedicated snow storage areas:

- Areas designed for infiltration should be protected from excessive snow storage where sand and salt is applied.

Table 12.BIO.5 Recommended Maintenance Activities For Bioretention Areas (Source: adapted from EPA, 1999)

Activity	Schedule
• Prune and weed to maintain appearance. • Mulch replacement when erosion is evident. • Remove trash and debris. • Mow filter strip.	As needed
• Inspect inflow points for clogging (off-line systems). Remove any sediment. • Inspect filter strip/grass channel for erosion or gullying. Re-seed or sod as necessary. • Trees and shrubs should be inspected to evaluate their health and remove any dead or severely diseased vegetation.	Semi-annually
• Inspect and remove any sediment and debris build-up in pre-treatment areas. • Inspect inflow points and bioretention surface for build up of road sand associated with spring melt period. Remove as necessary and replant areas that have been impacted by sand/salt build up.	Annually
• Replace mulch over the entire area. • Replace pea gravel diaphragm or filter fabric if warranted. • The planting soils should be tested for pH to establish acidic levels. If the pH is below 5.2, limestone should be applied. If the pH is above 7.0 to 8.0, then iron sulfate plus sulfur can be added to reduce the pH.	2 to 3 years

- Specific soil storage areas should be assigned that will provide some filtration before the stormwater reaches the infiltration areas.

- When used for snow storage, or if used to treat parking lot runoff, the bioretention area should be planted with salt tolerant, and non-woody plant species (see also Appendix C).

► Bioretention areas should always be inspected for sand build-up on the surface following the spring melt event.

► General maintenance activities and schedule are provided in Table 12.BIO.5.

VII. Construction and Maintenance Costs

Chapter 6 outlines a cost estimation method that site planners could use to compare the relative construction and maintenance costs for structural BMPs. These curves are excellent for purposes of comparison; however, it is recommended that construction and maintenance budgets should be based on site specific information. Once the construction plans are created, designers could

Table 12.BIO.6 Cost Components for Bioretention Practices

Implementation Stage	Primary Cost Components	Basic Cost Estimate	Other Considerations
Site Preparation	Tree & plant protection	Protection Cost ($/area) x Affected Area	Removal of existing structures, topsoil removal and stockpiling
	Clearing & grubbing	Clearing Cost ($/area) x Affected Area	
	Topsoil salvage	Clearing cost ($/area) x Affected Area	
Site Formation	Excavation / grading	4-ft Depth Excavation Cost ($/acre) x Area (acre)	Soil & rock fill material, tunneling
	Hauling material offsite	Excavation Cost x (% of Material to be hauled away)	
Structural Components	Under-drains	Under-drain cost ($/lineal foot) x length of device	Pipes, catch-basins, manholes, valves
	Inlet structure	($/structure) or ($/curb cut)	
	Outlet structure	($/structure)	
	Liner	Liner cost ($/square yard) x area of device	
Site Restoration	Filter strip	Sod cost ($/square foot) x filter strip area	Tree protection, soil amendments, seed bed preparation, trails
	Soil preparation	Topsoil or amendment cost ($/acre) x Area (acre)	
	Seeding	Seeding Cost ($/acre) x Seeded Area (acre)	
	Planting / transplanting	Planting Cost ($/acre) x Planted Area (acre)	
Annual Operation, Maintenance, and Inspection	Debris removal	Removal Cost ($/acre) x Area (acre) x Frequency	Vegetation maintenance, cleaning of structures
	Sediment removal	Removal Cost ($/acre) x Area (acre) x Frequency	
	Weed control	Labor cost ($/hour) x Hours per visit x Frequency	
	Inspection	Inspection Cost ($) x Inspection Frequency	
	Mowing	Mowing Cost ($) x Mowing Frequency	

use Table 12.BIO.6 and the cost estimation worksheet in Appendix D.

Table 12.BIO.6 lists the site components that are specific to bioretention practices. Not included in this table are those cost items that are common to all construction projects, such as mobilization, traffic control, erosion and sediment control, permitting, etc. A more detailed worksheet, utilizing 2005 construction prices, is contained in Appendix D.

VIII. Design Procedure

The following steps outline a recommended design procedure for bioretention practices in compliance with the MPCA Construction General Permit for new construction. Design recommendations beyond those specifically required by the permit are also included and marked accordingly.

Design Steps

Step 1. Make a preliminary judgment as to whether site conditions are appropriate for the use of a bioretention practice, and identify the function of the practice in the overall treatment system.

A. Consider basic issues for initial suitability screening, including:

- ► Site drainage area
- ► Site topography and slopes
- ► Soil infiltration capacity
- ► Regional or local depth to ground water and bedrock
- ► Site location/minimum setbacks
- ► Presence of active karst

B. Determine how the bioretention practice will fit into the overall stormwater treatment system.

- ► Decide whether the bioretention practice is the only BMP to be employed, or if are there other BMPs addressing some of the treatment requirements.
- ► Decide where on the site the bioretention practice is most likely to be located.

Step 2. Confirm design criteria and applicability.

- ► Determine whether the bioretention practice must comply with the MPCA Permit.
- ► Check with local officials, WMOs, and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Table 12.BIO.7 Summary of Bioretention Variants for Permeability of Native Soils and Potential Landuse Pollutant Loading

Bioretention Type	Variant	Underlying Soil Performance Criteria
Infiltration/Recharge Facility	No under-drain	Higher recharge potential (facility drain time without under-drain is < 48 hours)
Filtration/Partial Recharge Facility	Under-drain	Lower recharge potential (facility drain time without under-drain is > 48 hours)
Infiltration/Filtration/Recharge Facility	Elevated under-drain	Higher nutrient loadings and/or quantity control
Filtration Only Facility	Under-drain with liner	Hot Spot Treatment

Step 3. Perform field verification of site suitability.

- If the initial evaluation indicates that a bioretention practice would be a good BMP for the site, it is RECOMMENDED that soil borings or pits be dug (in the same location as the proposed bioretention practice) to verify soil types and infiltration capacity characteristics and to determine the depth to ground water and bedrock. The number of soil borings should be selected as needed to determine local soil conditions.

- It is RECOMMENDED that the minimum depth of the soil borings or pits be five feet below the bottom elevation of the proposed bioretention practice.

- It is HIGHLY RECOMMENDED that soil profile descriptions be recorded and include the following information for each soil horizon or layer (Source: Site Evaluation for Stormwater Infiltration, Wisconsin Department of Natural Resources Conservation Practice Standards, 2004):

  a. Thickness, in inches or decimal feet
  b. Munsell soil color notation
  c. Soil mottle or redoximorphic feature color, abundance, size and contrast
  d. USDA soil textural class with rock fragment modifiers
  e. Soil structure, grade size and shape
  f. Soil consistence, root abundance and size
  g. Soil boundary
  h. Occurrence of saturated soil, impermeable layers/lenses, ground water, bedrock or disturbed soil

- It is HIGHLY RECOMMENDED that the field verification be conducted by a qualified geotechnical professional.

Step 4. Compute runoff control volumes.

Calculate the Water Quality Volume (Vwq), Channel Protection Volume (Vcp), Overbank Flood Protection Volume (Vp10), and the Extreme Flood Volume (Vp100). Details on the Unified Stormwater Sizing Criteria are found in Chapter 10.

If the bioretention practice is being designed to meet the requirements of the MPCA Permit, the REQUIRED treatment volume is the water quality volume of ½ inch of runoff from the new impervious surfaces created from the project (or 1 inch for certain protected waterbodies). If part of the overall Vwq is to be treated by other BMPs, subtract that portion from the Vwq to determine the part of the Vwq to be treated by the bioretention practice.

The design techniques in this section are meant to maximize the volume of stormwater being infiltrated. If the site layout and underlying soil conditions permit, a portion of the Channel Protection Volume (Vcp), Overbank Flood Protection Volume (Vp10), and the Extreme Flood Volume (Vp100) may also be managed in the bioretention practice (see Step 7).

Step 5. Determine Bioretention Type and Size Practice (Note: Steps 5, 6, 7 and 8 are iterative)

A. Select Design Variant

After following the steps outlined above, the designer will presumably know the location of naturally occurring permeable soils, the depth to the water table, bedrock or other impermeable layers, and the contributing drainage area. While the first step in sizing a bioretention practice is selecting the type of design variant for the site, the basic design procedures for each type of bioretention practice are similar.

- Water Quality Volume (Vwq) – After determining the water quality volume for the entire site (Step 1), determine the portion of the total volume that will be treated by the bioretention practice.

Table 12.BIO.8 Design Infiltration Rates			
Hydrologic Soil Group	**Infiltration Rate** [inches/hour]	**Soil Textures**	**Corresponding Unified Soil Classification**
A	1.6*	Gravel, sandy gravel and silty gravels	**GW** - Well-graded gravels, sandy gravels **GP** – Gap-graded or uniform gravels, sandy gravels **GM** - Silty gravels, silty sandy gravels **SW** - Well-graded, gravelly sands
	0.8	Sand, loamy sand or sandy loam	**SP** - Gap-graded or uniform sands, gravelly sands
B	0.6	Silt loam	**SM** - Silty sands, silty gravelly sands
	0.3	Loam	**MH** – Micaceous silts, diatomaceous silts, volcanic ash
C	0.2	Sandy clay loam	**ML** - Silts, very fine sands, silty or clayey fine sands
D	< 0.2	Clay loam, silty clay loam, sandy clay, silty clay or clay	**GC** – Clayey gravels, clayey sandy gravels **SC** – Clayey sands, clayey gravelly sands **CL** – Low plasticity clays, sandy or silty clays **OL** – Organic silts and clays of low plasticity **CH** – Highly plastic clays and sandy clays **OH** – Organic silts and clays of high plasticity

* This rate is consistent with the infiltration rate provided for the lower end of the Hydrologic Soil Group A soils in the Wisconsin Department of Natural Resources Conservation Practice Standard: Site Evaluation for Stormwater Infiltration.

Source: Thirty guidance manuals and many other stormwater references were reviewed to compile recommended infiltration rates. All of these sources use the following studies as the basis for their recommended infiltration rates: (1) Rawls, Brakensiek and Saxton (1982); (2) Rawls, Gimenez and Grossman (1998); (3) Bouwer and Rice (1984); and (4) Urban Hydrology for Small Watersheds (NRCS). The rates presented in this infiltration table use the information compiled from these sources as well as eight years of infiltration rates collected in various infiltration practices located in the metro area.

► Based on the known Vwq, infiltration rates of the underlying soils and the known existing potential pollutant loading from proposed/existing landuse select the appropriate bioretention practice from Table 12.BIO.7. Note: the determination for under-drain is an iterative sizing process.

Information collected during the Physical Suitability Evaluation (see Step 2) should be used to explore the potential for multiple bioretention practices versus relying on a single bioretention practice. Bioretention is best employed close to the source of runoff generation and is often located in the upstream portion of the stormwater treatment train, with additional stormwater BMP following downstream.

B. Determine Site Infiltration Rates (for facilities with infiltration and/or recharge).

If the infiltration rate is not measured, Table 12.BIO.7 provides infiltration rates for the design of infiltration practices. These infiltration rates represent the long-term infiltration capacity of a practice and are not meant to exhibit the capacity of the soils in the natural state. Select the design infiltration rate from the table based on the least permeable soil horizon within the first five feet below the bottom elevation of the proposed infiltration practice.

The infiltration capacity and existing hydrologic regime of natural basins are inheritably different than constructed practices and may not meet MPCA Permit requirements for constructed practices. In the event that a natural depression is being proposed to be used as an infiltration system, the design engineer must demonstrate the following information: infiltration capacity of the system under existing conditions (inches/hour), existing drawdown time for the high water level (HWL) and a natural overflow elevation. The design engineer should also demonstrate that

Table 12.BIO.9 Guidelines for Filter Strip Pre-treatment Sizing								
Parameter	**Impervious Parking Lots**				**Residential Lawns**			
Maximum Inflow Approach Length (ft.)	35		75		75		150	
Filter Strip Slope	$\leq$2%	>2%	$\leq$2%	>2%	$\leq$2%	>2%	$\leq$2%	>2%
Filter Strip Minimum Length	10'	15'	20'	25'	10'	12'	15'	18'

operation of the natural depression under post-development conditions mimics the hydrology of the system under pre-development conditions. A discussion of "pre-development" definition occurs in Chapters 6 and 10.

If the infiltration rates are measured, the tests shall be conducted at the proposed bottom elevation of the infiltration practice. If the infiltration rate is measured with a double-ring infiltrometer the requirements of ASTM D3385 should be used for the field test.

C. Size Bioretention Area

a. Area sizing for facilities with and without an under-drain:

Without An Under-Drain

The bioretention surface area is computed using the following equation, for those practices that are designed **without an under-drain**:

A_f = $(Vwq \times d_f) / [i \times (h_f + d_f) \times t_f]$

Where:

A_f = surface area of filter bed (ft^2)

V_{WQ} = water quality volume (ft^3)

d_f = filter bed depth (ft)

i = infiltration rate of underlying soils (ft/day)

h_f = average height of water above filter bed (ft)

t_f = design filter bed drain time (days) (48 hours is the REQUIRED maximum t_f for bioretention under the CGP)

Use Table 12.BIO.8 to determine the infiltration rate of the underlying soils. Note that these numbers are intentionally conservative based on experience gained from Minnesota infiltration sites.

With An Under-Drain

The bioretention surface area is computed using the following equation, for those practices that are designed **with an under-drain**:

A_f = $(Vwq \times d_f) / [k \times (h_f + d_f) \times t_f]$

Where:

A_f = surface area of filter bed (ft^2)

d_f = filter bed depth (ft)

k = coefficient of permeability of filter media (ft/day)

h_f = average height of water above filter bed (ft)

t_f = design filter bed drain time (days) (48 hours is the REQUIRED maximum t_f for bioretention under the CGP)

The coefficients of permeability recommended for the planting medium / filter media soil is 0.5 ft/day (Claytor and Schueler, 1996). Note: the value is conservative to account for clogging associated with accumulated sediment.

Step 6. Size outlet structure and/or flow diversion structure, if needed (Note: Steps 5, 6, 7 and 8 are iterative).

It is REQUIRED that a secondary outlet be incorporated into the design of a bioretention practice to safely convey excess stormwater. Multi-stage outlet design procedures are detailed in Ponds section of this Chapter.

Step 7. Perform ground water mounding analysis (Note: Steps 5, 6, 7 and 8 are iterative).

Ground water mounding, the process by which a mound forms on the water table as a result of recharge at the surface, can be a limiting factor in the design and performance of bioretention practices where infiltration is a major design component. A minimum of 3 feet of separation between the bottom of the bioretention practice and **seasonally saturated soils** (or from bedrock) is REQUIRED (5 feet RECOMMENDED) to maintain the hydraulic capacity of the practice and provide adequate water quality treatment. A ground water mounding analysis is RECOMMENDED to verify this separation for infiltration designed bioretention practices.

The most widely known and accepted analytical methods to solve for ground water mounding is based on the work by Hantush (1967) and Glover (1960). The maximum ground water mounding potential should be determined through the use of available analytical and numerical methods. Detailed ground water mounding analysis should be conducted by a trained hydrogeologist or equivalent as part of the site design procedure.

Step 8. Determine pre-treatment volume and design pre-treatment measures.

Some form of dry or wet pre-treatment is REQUIRED prior to the discharge of stormwater into the bioretention practice, to remove any sediment and fines that may result in clogging of the soils in the sediment basin area. If a grass filter strip is used, it is HIGHLY RECOMMENDED that it be sized using the guidelines in Table 12.BIO.9.

Grass channel sizing

It is HIGHLY RECOMMENDED that grass channel pre-treatment for bioretention be a minimum of 20 feet in length and be designed according to the following guidelines:

- Parabolic or trapezoidal cross-section with bottom widths between 2 and 8 feet.
- Channel side slopes no steeper than 3:1 (horizontal:vertical).
- Flow velocities limited to 1 foot per second or less for peak flow associated with the water quality event storm (i.e., 0.5 or 1.0 inches depending on watershed designation).
- Flow depth of 4 inches or less for peak flow associated with the water quality event storm.

Step 9. Check volume, peak discharge rates and period of inundation against State, local and watershed management organization requirements (Note: Steps 5, 6, 7 and 8 are iterative)

Follow the design procedures identified in the Unified Sizing Criteria section of the Manual (Chapter 10) to determine the volume control and peak discharge recommendations for water

A minimum of 3 feet of separation between the bottom of the bioretention practice and seasonally saturated soils (or from bedrock) is REQUIRED (5 feet RECOMMENDED) to maintain the hydraulic capacity of the practice and provide adequate water quality treatment.

Bioretention practices shall discharge through the soil or filter media in 48 hours or less. Additional flows that cannot be infiltrated or filtered in 48 hours should be routed to bypass the system through a stabilized discharge point. The period of inundation is defined as the time from the high water level in the practice to 1 to 2 inches above the bottom of the facility.

quality, recharge, channel protection, overbank flood and extreme storm.

Model the proposed development scenario using a surface water model appropriate for the hydrologic and hydraulic design considerations specific to the site (see also Chapter 8 and Appendix B of the Manual). This includes defining the parameters of the bioretention practice defined above: sedimentation basin elevation and area (defines the pond volume), infiltration/permeability rate, and outlet structure and/or flow diversion information. The results of this analysis can be used to determine whether or not the proposed design meets the applicable requirements. If not, the design will have to be re-evaluated (back to Step 5).

The following items are specifically REQUIRED by the MPCA CGP:

Volume

Infiltration or filtration systems shall be sufficient to infiltrate or filter a water quality volume of ½ inch of runoff (1" is required for discharge to protected waters) from the new impervious surfaces created by the project. If this criterion is not met, increase the storage volume of the bioretention practice or treat excess water quality volume (Vwq) in an upstream or downstream BMP (see Step 5). Retrofit and supplemental systems do not need to meet this requirement, provided new impervious surfaces are not created.

Peak Discharge Rates

Since most bioretention systems are not designed for quantity control they generally do not have peak discharge limits. However outflow must be limited such that erosion does not occur down gradient.

Period of Inundation

Bioretention practices shall discharge through the soil or filter media in 48 hours or less. Additional flows that cannot be infiltrated or filtered in 48 hours should be routed to bypass the system through a stabilized discharge point. The period of inundation is defined as the time from the high water level in the practice to 1 to 2 inches above the bottom of the facility. This criterion was established to provide the following: wet-dry cycling between rainfall events; unsuitable mosquito breeding habitat; suitable habitat for vegetation; aerobic conditions; and storage for back-to-back precipitation events.

Other design requirements may apply to a particular site. The applicant should confirm local design criteria and applicability (see Step 2).

Step 10. Prepare Vegetation and Landscaping Plan

See Major Design Elements section for guidance on preparing vegetation and landscaping management plan.

Step 11. Prepare Operations and Maintenance (O&M) Plan

See Operations and Maintenance section for guidance on preparing an O&M plan.

Step 12. Prepare Cost Estimate

See Cost Considerations section for guidance on preparing a cost estimate that includes both construction and maintenance costs.

IX. Links to other Manuals

Price George's County Programs & Planning Division Department of Environmental Resources. 2002. *Bioretention Manual*. Landover, MD. http://www.co.pg.md.us/Government/AgencyIndex/DER/PPD/LID/bioretention.asp?h=20&s=40&n=50&n1=160

IX. References

Bouwer, H. and R. C. Rice. 1989. Effect of Water Depth in Ground-water Recharge Basins on Infiltration. Journal of Irrigation and Drainage Engineering, Vol. 115, No. 4, pp. 556-567.

Claytor, R.A., and T.R. Schueler. 1996. Design of Stormwater Filtering Systems. The Center for Watershed Protection, Silver Spring, MD.

Davis, A.P., M. Shokouhian, H. Sharma and C. Minani. 1998. Optimization of *Bioretention for Design for Water Quality and Hydrologic Characteristics.* n.p.

Georgia Stormwater Management Manual. 2001. Atlanta Regional Commission.

Glover, R., 1960. Mathematical Derivations as Pertain to Ground-water Recharge. Report CER60REG70. Agricultural Research Service, USDA, Fort Collins, Colorado. 81 pp.

Hantush, M., 1967. Growth and Decay of Ground-water-Mounds in Response to Uniform Percolation. Water Resources Research, 3(1): 227-234.

http://www.lid-stormwater.net

International Stormwater Best Management Practices (BMP) Database. http://www.bmpdatabase.org/ .

Low Impact Design Center, Inc. 2005. *Urban Design Tools*, Internet Resource. Beltsville, MD.

Metropolitan Council. 2001. *Minnesota Urban Small Sites BMP Manual, Stormwater Best Management Practice for Cold Climates*. St. Paul, MN.

Natural Resources Conservation Service, 1986. Urban Hydrology for Small Watersheds, Technical Release 55 (TR-55). ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

Price George's County, 2002. *Bioretention Manual*. Programs & Planning Division Department of Environmental Resources, Landover, MD.

Rawls, W., D. Brakensiek, and K. Saxton, 1982. Estimation of Soil Water Properties, Transactions of the American Society of Agricultural Engineers. Vol. 25, No. 5, pp. 1316 – 1320 and 1328.

Rawls, W., D. Giminez, and R. Grossman, 1998. Use of Soil Texture, Bulk Density and Slope of water Retention Curve to Predict Saturated Hydraulic Conductivity, ASAE. Vol. 41(4), pp. 983 – 988.

Shaw, D. and R. Schmidt. 2003. *Plants for Stormwater Design*. Minnesota Pollution Control Agency, St. Paul, MN.

South Washington Watershed District (SWWD), 2005. 2004 Infiltration Monitoring Program Final Report. Emmons and Olivier Resources, Inc.

State of New Jersey, Department of Watershed Management. 2004. *New Jersey Stormwater Best Management Practices Manual*. NJ.

Vermont Stormwater Management Manual. 2002. http://www.vtwaterquality.org/stormwater.htm.

Winer, R. 2000. National Pollutant Removal Performance Database.

Wisconsin DNR Bioretention for Infiltration Conservation Practice Standard 1004. 2004. http://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm#Post.

FILTRATION PRACTICES

Lino Lakes City Hall - Lino Lakes, MN

City of Woodbury, MN

Definition:

Structural Stormwater controls that capture, temporarily store, and route stormwater runoff through a filter bed to improve water quality.

KEY CONSIDERATIONS

Design Criteria:

- Ensure adequate space for filtration system
- Some installations require 2-6 feet of head
- Removal potential of the key pollutant
- Parent material and potential for ground water contamination

Benefits:

- Good for highly impervious areas with low sediment/high pollutant load (e.g. urban land use and retrofit scenarios)
- High pollutant removal rates
- May be used in a variety of soil types
- Good for the treatment of hotspots because it can be isolated from ground water if contamination concerns exist

Limitations:

- Higher maintenance requirements
- Some installations (media filters) have higher construction costs
- Potential to cause odor problems
- Minimal treatment of soluble nutrients
- Potential for nitrification in media filters where anaerobic conditions exist

MANAGEMENT SUITABILITY

High	Water Quality (V_{WQ})
Med.	Channel Protection (V_{CP})
Low	Overbank Flood Protection (V_{P10})
Low	Extreme Flood Protection (V_{P100})
Med./ Low	Recharge Volume (V_{RE})

MECHANISMS

X*	Infiltration *with appropriate soil & site conditions
X	Screening/ Filtration
	Temperature Control
	Settling
X	Evaporation
X*	Transpiration *if vegetated
X	Soil Adsorption
X	Biological/ Micro. Uptake

POLLUTION REMOVAL

85%	Total Suspended Solids
50%/35%	Nutrients - Total Phosphorus/ Total Nitrogen
50%	Metals - Cadmium, Copper, Lead, and Zinc
35%	Pathogens - Coliform, Streptococci, E. Coli
80%	Toxins - Chloride, Hydrocarbon, Pesticide

SITE FACTORS

5 AC Max	Drainage Area
20%	Max. Site Slope
3’	Min. Depth to Bedrock
3’	Min. Depth to Seasonally High Water Table
A,B,C,D	NRCS Soil Type
Poor - Good	Freeze/ Thaw Suitability
Suitable	Potential Hotspot Runoff *requires impermeable liner

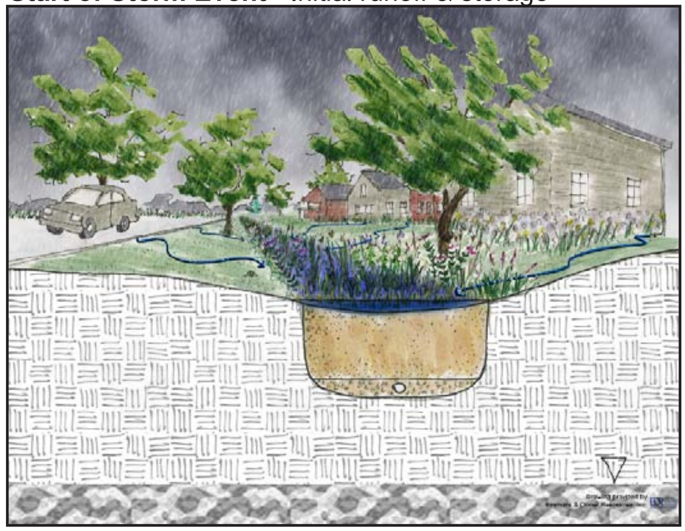
Description:

Filtration systems vary in their operation and applicability, but all can be described as structural BMPs that function mainly to enhance water quality by passing stormwater through a media. The media can be made of sand, peat, grass, soil, compost or vegetation and should be assigned on a case-by-case basis. Filters can be off-line systems or designed as pre-treatment before discharging to other stormwater features.

The two main categories of filtration systems include: media filters, and vegetated filters. Media filters can be located on the surface, underground, along the perimeter or an area, or in what is called a pocket design. Vegetated channels may be grass channels, dry or wet swales, submerged gravel wetlands, or filter strips.

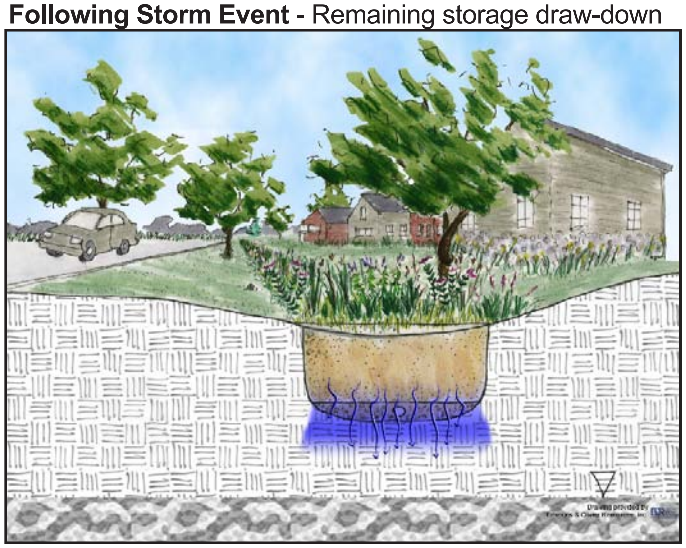
STORM SEQUENCE

Start of Storm Event - Initial runoff & storage



Duration of Storm Event - Storage & filtration/infiltration

Following Storm Event - Remaining storage draw-down



Courtesy of Rice Creek Watershed District

FILTRATION

I. Suitability

General

Filtering practices include media filters (surface, underground, perimeter), vegetative filters (filter strips, grass channels), and combination media/vegetative filters (dry swales). Media and media/vegetative filters operate similarly and provide comparable water quality capabilities as bioretention. Vegetative filters are generally more suitable as pre-treatment practices, but in some situations can be used on a stand alone basis.

Filtering practices have widespread applicability and are suitable for all land uses, as long as the contributing drainage areas are limited (e.g., typically less than 5 acres). Media filters are not as aesthetically appealing as bioretention, which makes them more appropriate for commercial or light industrial land uses or in locations that will not receive significant public exposure. Media filters are particularly well suited for sites with high percentages of impervious cover (e.g., greater than 50%). Media filters can be designed with an under-drain, which makes them a good option for treating potential stormwater hotspots (PSHs). They can also be installed underground to prevent the consumption of valuable land space (often an important retrofit or redevelopment consideration). Vegetative filters can be incorporated into landscaped areas, providing dual functionality.

Function Within Stormwater Treatment Train

Media filtration systems are designed primarily as off-line systems for stormwater quality and typically are used in conjunction with another structural control. Vegetative filters, designed as grass channels or swales, may be the main form of conveyance between or out of BMPs, as well as providing treatment for stormwater runoff.

MPCA Permit Applicability

One of the goals of this Manual is to facilitate understanding of and compliance with the MPCA Construction General Permit (CGP), which includes design and performance standards for permanent stormwater management systems. The permit and related documentation can be found online at http://www.pca.state.mn.us/water/stormwater/stormwater-c.html. These standards must be applied in all projects in which at least one acre of new impervious area is being created, and the permit stipulates certain standards for various categories of stormwater management practices.

For regulatory purposes, filtration practices fall under the "Infiltration / Filtration" category described in Part III.C.2 of the permit. If used in combination with other practices, credit for combined stormwater treatment can be given as described in Part III.C.4. Due to the statewide prevalence of the MPCA permit, design guidance in this section is presented with the assumption that the permit does apply. Also, although it is expected that in many cases the filtration practice will be used in combination with other practices, standards are described for the case in which it is a stand alone practice.

The following terms are thus used in the text to distinguish various levels of filtration practice design guidance:

REQUIRED:	Indicates design standards stipulated by the MPCA Permit (or other consistently applicable regulations).
HIGHLY RECOMMENDED:	Indicates design guidance that is extremely beneficial or necessary for proper functioning of the filtration practice, but not specifically required by the MPCA permit.
RECOMMENDED:	Indicates design guidance that is helpful for filtration practice performance but not critical to the design.

There are situations, particularly retrofit projects, in which a filtration practice is constructed without being subject to the conditions of the MPCA permit. While compliance with the permit is not required in these cases, the standards it establishes can provide valuable design guidance to the user. It is also important to note that **additional and potentially more stringent design requirements may apply for a particular filtration practice**, depending on where it is situated both jurisdictionally and within the surrounding landscape.

Design Variants

(Adapted from Georgia Stormwater Manual and Center for Watershed Protection)

As filtration becomes a more common tool in stormwater management, and as the number of design variants increases, so does the number of names for each of these variants. For example:

- Sand filters are also referred to as filtration basins, filter systems, first-flush filtration, or media filtration systems.
- Grass channels are also referred to as biofilters. (Seattle METRO, 1992 from CWP)
- Dry swales are also referred to as grassed or vegetated swales.

The following types of filtration systems are appropriate for Minnesota, depending upon project scale and site conditions:

Media Filters

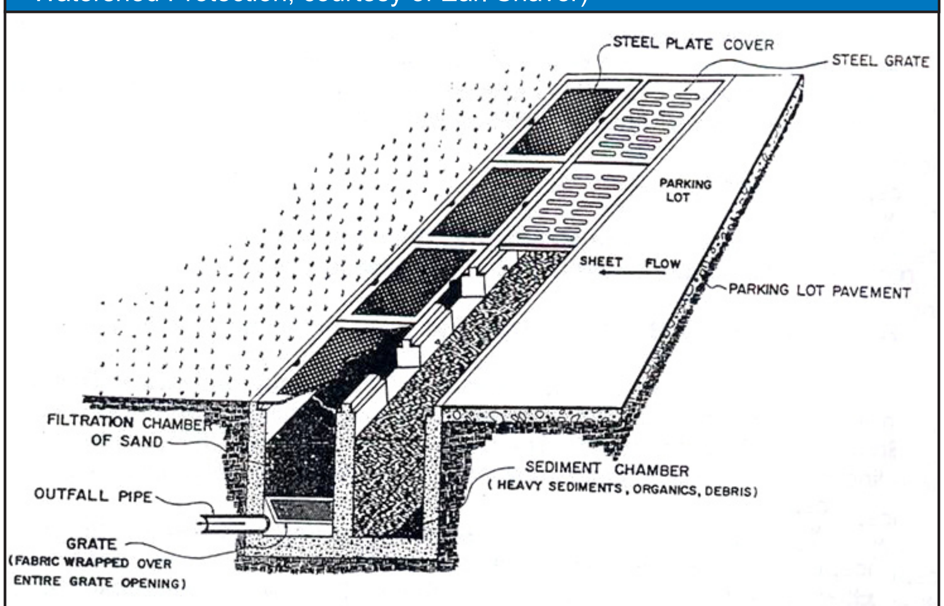
Surface Sand Filter

For a surface sand filter, a flow splitter is used to divert runoff into an off-line sedimentation chamber. The chamber may be either wet or dry, and is generally used for pre-treatment. Runoff is then distributed into the second chamber, which consists of a sand filter bed (~18") and temporary runoff storage above the bed. Pollutants are trapped or strained out at the surface of the filter bed. The filter bed surface may have a sand or grass cover. A series of perforated pipes located in a gravel bed collect the runoff passing through the filter bed, and return it to the stream or channel at a downstream point. If underlying soils are permeable, and ground water contamination unlikely, the bottom of the filter bed may have no lining, and the filtered runoff may be allowed to infiltrate. See Appendix D for design drawing.

Underground Sand Filter

The underground sand filter was adapted for sites where space is at a premium. In this design, the sand filter is placed in a three chamber underground vault accessible by manholes or grate openings. The vault can be either on-line or off-line in the storm drain system. The first chamber is used for pre-treatment and relies on a wet pool as well as temporary runoff storage. It is connected to the second sand filter chamber by an inverted elbow, which keeps the filter surface free from trash and oil. The filter bed is 18 inches in depth and may have a protective screen of gravel or permeable geotextile to limit clogging. During a storm, the water quality

Figure 12.FIL.1 Delaware Sand Filter (Source: Center for Watershed Protection, courtesy of Earl Shaver)



volume is temporarily stored in both the first and second chambers. Flows in excess of the filter's capacity are diverted through an overflow weir. Filtered runoff is collected, using perforated under-drains that extend into the third "overflow" chamber. See Appendix D for design drawing.

Perimeter Sand Filter

The perimeter sand filter consists of two parallel trench-like chambers that are typically installed along the perimeter of a parking lot (Figure 12.FIL.1). Parking lot runoff enters the first chamber, which has a shallow permanent pool of water. The first trench provides pre-treatment before the runoff spills into the second trench, which consists of a sand layer (12"-18"). During a storm event, runoff is temporarily ponded above the normal pool and sand layer, respectively. When both chambers fill up to capacity, excess parking lot runoff is routed to a bypass drop inlet. The remaining runoff is filtered through the sand, and collected by under-drains and delivered to a protected outflow point. See Appendix D for design drawing.

Figure 12.FIL.2 Vegetated Swale
(Wayzata, MN)

Vegetative Filters

Grass Channels

Grass channels are designed to meet a runoff velocity target for a water quality storm as well as the peak discharge from a 2-year design storm. The runoff velocity should not exceed 1.0 fps during the water quality storm. Grass channels can be designed to pass larger storms and serve as conveyance tools. Pre-treatment can be created by placing checkdams across the channel below pipe inflows, and at various other points along the channel. Grass channels do not provide adequate pollutant removal benefits to act as a stand-alone BMP.

Dry Swales

In dry swales, the entire water quality volume is temporarily retained by checkdams during each storm. Unlike the grass channel, the filter bed in the swale is 30 inches of prepared soil. Water is filtered through the sandy loam to under-drains and the swale is quickly dewatered. In the event that surface soils clog, the dry swale has a pea gravel window on the downstream side of each checkdam to route water to the under-drain. Dry swales are often preferred in residential areas because they prevent standing water. See Appendix D for design drawing.

Wet Swales

Wet swales occur when the water table is located very close to the surface. This wet swale acts as a very long and linear shallow wetland treatment system. Like the dry swale, the entire water quality treatment volume is stored within a series of cells created by checkdams. Cells may be planted with emergent wetland plant species to improve pollutant removal.

Filter Strips

Filter strips rely on the use of vegetation to slow runoff velocities and filter out sediment and other pollutants from urban stormwater (Figure 12.FIL.2). To be effective, however, filter strips require the presence of sheet flow across the entire strip. Once flow concentrates to form a channel, it effectively short-circuits the filter strip. In the most common design, runoff is directed from a parking lot into a long filtering system composed of a stone trench, a grass strip and a longer naturally vegetative strip. The grass portion of the filter strip provides pre-treatment for the wooded portion. In addition, a stone drop can be located at the edge of the parking lot and the filter strip to prevent sediments from depositing at this critical entry point. The filter strip is typically an on-line practice, so it must be designed to withstand the full range of storm events without eroding. Filter strips do not provide adequate pollutant removal benefits to act as a stand-alone BMP. See Appendix D for design drawing.

Other Filters Not Approved For Minnesota

The following filters are not recommended for use in Minnesota due to **high probability of failure** under cold climate conditions. They are included here for informational purposes only.

Organic Filter

The organic filter functions in much the same way as the surface sand filter, but uses leaf compost or a peat/sand mixture as the filter media instead of sand (peat should not be used when the target pollutant for removal is a dissolved nutrient). The organic material enhances pollutant removal by providing adsorption of heavy metals. In an organic filter, runoff is diverted with a flow splitter into a pre-treatment chamber, from which it passes into one or more filter cells. Each filter bed contains a layer of leaf compost or the peat/sand mixture, followed by a filter fabric and perforated pipe and gravel. Runoff filters through the organic media to the perforated pipe and ultimately to the outlet. The filter bed and subsoils can be separated by an impermeable polyliner to prevent movement into ground water.

Pocket Filter

Pocket sand filters are intended as an inexpensive variation of a sand filter where sediment loads do not warrant a sedimentation chamber and can suffice with a grass filter strip and a plunge pool. The filter bed is comprised of a shallow basin containing the sand filter medium. The filter surface is a layer of soil and a grass cover. In order to avoid clogging the filter has a pea gravel “window” which directs runoff into the sand and a cleanout and observation well. Typically the filtered runoff is allowed to exfiltrate to ground water, although under-drains may be needed if the soils are not suitably permeable.

Submerged Gravel Wetland

Submerged gravel filters consist of a series of cells that are filled with crushed rock or gravel. The standpipe from each cell is set at an elevation that keeps the rock or gravel submerged. Wetland plants are rooted in the media, where they can directly take up pollutants. The anaerobic conditions on the bottom of the filter can foster the de-nitrification process. Submerged gravel wetlands are not recommended for stormwater quality in cold climate conditions, although they do have been used in Minnesota for effluent polishing of wastewater.

Retrofit Suitability

The use of filters as a retrofit practice primarily depends on existing infrastructure and the compatibility of existing storm drain inverts that need to connect to the filter under-drain outflow. In general, four to six feet of elevation above the existing collection system invert is needed for media filter retrofits (2-3 feet is needed for perimeter filters). Underground media filters are excellent for ultra-urban settings where space is at a premium.

Special Receiving Waters Suitability

Table 12.FIL.1 provides guidance regarding the use of filtration practices in areas upstream of special receiving waters. This table is an abbreviated version of a larger table in which other BMP groups are similarly evaluated. The corresponding information about other BMPs is presented in the respective sections of this Manual.

Cold Climate Suitability

Various options for use of filtration are available for treating snowmelt runoff. Some of the installations are built below the frost line (trenches, sub-grade proprietary chambers) and do not need further adaptation for the cold. However, some special

Table 12.FIL.1 Design Restrictions for Special Waters					
BMP Group	**Stormwater Management Category**				
	A Lakes	**B Trout Waters**	**C Drinking Water**	**D Wetlands**	**E Impaired Waters**
Filtration	Some variations RESTRICTED due to poor P removal, combined with other treatments	PREFERRED	PREFERRED	OK	PREFERRED for non-nutrient impairments

consideration is HIGHLY RECOMMENDED for surface systems.

The problem with filtration in cold weather is the ice that forms both over the top of the facility and within the soil interstices. To avoid these problems to the extent possible, it is HIGHLY RECOMMENDED that the facility be actively managed to keep it dry before it freezes in the late fall. This can be done by various methods, including limiting inflow, under-drainage, and surface disking.

Proprietary, sub-grade filtration systems provide an alternative to standard surface based systems. Essentially, these systems provide an insulated location for **pre-treated** snowmelt to be stored and slowly filtered, or simply filtered and drained away if ground water sensitivity is an issue. The insulating value of these systems adds to their appeal as low land consumption alternatives to ponds and surface infiltration basins.

Water Quantity Treatment

Filters are not typically a primary practice for providing water quantity control. They are normally either designed off-line using a flow diversion or configured to safely pass large storm flows while still protecting the filter bed. In limited cases, filters may be able to accommodate the channel protection volume, **Vcp**, in either an off- or on-line configuration, and in general they do provide some (albeit limited) storage volume. Vegetative filters, in particular, can help reduce detention requirements for a site by providing elongated flow paths, longer times of concentration, and volumetric losses from infiltration and evapo-transpiration. Generally, however, to meet site water quantity or peak discharge criteria, it is HIGHLY RECOMMENDED that another structural control (e.g., detention) be used in conjunction with a filter.

Water Quality Treatment

Filters are an excellent stormwater treatment practice with the primary pollutant removal mechanism being filtering and settling. Less significant processes can include evaporation, infiltration, transpiration, biological and microbiological uptake, and soil adsorption. Pollutant removal and effluent concentration data for select parameters are provided in Tables 12.FIL.2 and 3, respectively. While it is possible to design media filters to discharge a portion of the effluent to the ground water, they are typically designed as enclosed systems (i.e., no "infiltration"). Vegetative filters, on the other hand, can readily be designed as an effective infiltration/recharge practice, particularly when parent soils have good permeability (> ~ 0.5 in/hr). Consult the Credits Chapter (Chapter 11) for more guidance on how to use filters to meet water quality and recharge criteria. All of the filtration practices discussed in detail meet the 80% TSS removal required by the NPDES Construction permit Part III.C.2.

It is HIGHLY RECOMMENDED that the facility be actively managed to keep it dry before it freezes in the late fall.

Table 12.FIL.2 Percent Removal of Key Pollutants by Practice Group (Source: Winer, 2000)						
Practice	**TSS [%]**	**Total Phosphorus [%]**	**Total Nitrogen [%]**	**Metals[1] [%]**	**Bacteria [%]**	**Hydro-carbons [%]**
Filtering Practices[2]	85	60	35[1]	50	35	80

Notes:
1. Based on fewer than five data points (i.e., independent monitoring studies)
2. Higher removal rates for dry swales with under-drains.

Removals represent median values

Table 12.FIL.3 Typical BMP Best Perfomance Effluent Concentrations (Source: ASCE BMP Database, Winer 2000)					
Practice	**TSS**	**TP**	**TN**	**Cu[1]**	**Zn[1]**
Filtering Practices	14	0.2	1.1	8	60

Notes
1. Units for Zn and Cu are micrograms per liter
2. Values from ASCE BMP database and Winer 2000 (shaded values)

Limitations

The following general limitations should be recognized when considering installation of a filtration practice:

- Nitrification of water in media filters may occur where aerobic conditions exist.
- Filtration offers limited water quantity control.
- The potential to create odors exists.

II. Major Design Elements

Physical Feasibility Initial Check

Before deciding to use a filtration device for stormwater management, it is helpful to consider several items that bear on the feasibility of using such a device at a given location. The following list of considerations will help in making an initial judgment as to whether or not a filtration device is the appropriate BMP for the site.

- **Drainage Area** – 5 acres maximum RECOMMENDED (0.5 to 2 acres is ideal). Surface sand filters can sometimes be sized for drainage areas up to 10 acres, but only with rigorous and committed maintenance schedules, among other design and O&M considerations.

- **Site Topography and Slopes** – It is RECOMMENDED that sloped areas immediately adjacent to practice be less than 20% but greater than 1%, to promote positive flow towards the practice.

- **Soils** – No restrictions for media filters with under-drain is needed. Vegetated filters should be sized assuming no losses to infiltration.

- **Depth to Water Table and Bedrock** – No minimum separation distance is needed if filter is fully enclosed (i.e., no exfiltration). A separation distance of at least 3 feet is REQUIRED under the state CGP between the bottom elevation of vegetative filters and the elevation of the seasonally high water table (does not apply to wet swales).

- **Site Location/Minimum Setbacks** – A minimum setback of 50’ between a stormwater pond and a water supply well is REQUIRED by the Minnesota Department of Health Rule 4725.4350. For purposes

  of this guidance, it is assumed that the definition of a stormwater pond includes a stormwater filtration system.

- **Karst** – It is HIGHLY RECOMMENDED that under-drains and an impermeable liner be used for sand filters in Karst terrain. It is RECOMMENDED that vegetative filters be designed such that concentration of flow and excessive flow depths are avoided.

Conveyance

It is HIGHLY RECOMMENDED that a flow splitter or diversion structure be provided to divert the Vwq to media filters and allow larger flows to bypass the practice. Where a flow splitter is not used, it is HIGHLY RECOMMENDED that contributing drainage areas be limited to approximately 0.5 acres and an overflow be provided within the practice to pass part of the Vwq to a stabilized watercourse or storm drain. It is also HIGHLY RECOMMENDED that overflow associated with the Vp_{10} or Vp_{100} storm (depending on local drainage criteria) be controlled such that velocities are non-erosive at the outlet point to prevent downstream slope erosion. Weirs are common overflow systems within media filters. It is HIGHLY RECOMMENDED that the flow splitter be designed such that 75% of the Vwq can enter the treatment system prior to flow bypass occurring at the flow splitter. The overflow weir between the sedimentation and filtration chambers may be adjusted to be lower in elevation than the flow splitter weir to minimize bypass of the filter system prior to inflow filling the 75% Vwq storage.

It is HIGHLY RECOMMENDED that media filters be equipped with a minimum 8” diameter under-drain in a 1’ gravel bed. Increasing the diameter of the under-drain makes freezing less likely. The porous gravel bed prevents standing water in the system by promoting drainage. Gravel is also less susceptible to frost heaving than finer grained media. It is also HIGHLY RECOMMENDED that a permeable filter fabric be placed between the under-drain and gravel layer but not extend laterally from the pipe more than two feet on either side.

Pre-treatment

Dry or wet pre-treatment is REQUIRED prior to media filter treatment (pre-treatment volume equivalent to at least 25% of the computed Vwq is HIGHLY RECOMMENDED). The typical method is a sedimentation basin with a RECOMMENDED minimum length to width ratio of 2:1. The Camp-Hazen equation is used to compute the target surface area for media filters requiring full sedimentation for pre-treatment (WSDE, 1992).

The RECOMMENDED pre-treatment for vegetative filters is a level spreader that allows coarse sediment to settle and evenly distributes flow across the full width of the filter.

The RECOMMENDED pre-treatment for media / vegetative filters such as dry swales is to install plunge pools where concentrated flows enter and to place level spreaders where lateral flows enter.

Additional pre-treatment measures include filter strips and street / parking lot sweeping. Street / parking lot sweeping may be considered pre-treatment in the case of a parking lot island or other area where spatial limitations make structural pre-treatment measures unfeasible.

When using media filters to treat runoff from potential stormwater hotspots (PSHs), particularly in sensitive watersheds, it is HIGHLY RECOMMENDED that additional practices be incorporated as partial treatment during the winter when the filter bed may be frozen.

Treatment

The following guidelines are applicable to the actual treatment area of a filtration facility:

- **Space Required** – Function of available head at site for surface filters. Underground filters generally have little or no surface space requirements except for access.

It is HIGHLY RECOMMENDED that media filters be equipped with a minimum 8” diameter under-drain in a 1’ gravel bed.

It is HIGHLY RECOMMENDED that vegetative filters have a maximum slope of 5% and a minimum slope of 1%.

- **Slope** – The surface slope of media filters should be level to promote even distribution of flow throughout the practice. It is HIGHLY RECOMMENDED that vegetative filters have a maximum slope of 5% and a minimum slope of 1%.

- **Depth** – The RECOMMENDED elevation difference at a site from the inflow to the outflow is 4-6 feet for most sand filters, and 2-3 feet for perimeter filters.

- **Ground Water Protection** – Infiltration of untreated PSH runoff into ground water is PROHIBITED. At confirmed hotspots, it is REQUIRED that filtered runoff be directed to the existing storm drain system or surface receiving waters.
- **Aesthetics** – Vegetative filters can be effectively integrated into the site planning process, and aesthetically designed as attractive green spaces. Media filters are less conducive to site aesthetics, but surface media filters can be designed with turf cover crops if desired.

Landscaping

It is REQUIRED that impervious area construction be completed and pervious areas established with dense and healthy vegetation (see Appendix E) prior to introduction of stormwater into a filtration practice.

Surface filters can have a grass cover to aid in pollutant adsorption. The grass should be capable of withstanding frequent periods of inundation and drought.

Safety

It is REQUIRED that underground media filters only be accessed by individuals with appropriate confined space entry training. No building structures should be constructed on top of underground filters.

The risk of creating mosquito breeding areas can be minimized by following the recommendations within the mosquito control section in Chapter 6.

It is HIGHLY RECOMMENDED that swale side slopes be set at 1:3 (V:H) or flatter.

It is HIGHLY RECOMMENDED that perimeter sand filter grates be sufficiently heavy that they cannot be removed easily.

Fencing may be desirable in surface sand filter designs with significant vertical walls for the sedimentation and/or filter chamber. Fencing can also protect the filter from vandalism and limit animal access.

If a dry well or infiltration trench is greater than five feet deep, it is REQUIRED that OSHA health and safety guidelines be followed for safe construction practices. Additional information on safety for construction sites is available from OSHA. Use the following link to research safety measures for excavation sites:

http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10930

III. Construction Details and Specifications

CADD based details for filtration systems are contained in Appendix D. The following details, with specifications, have been created for filtration systems.

- Underground Sand Filter
- Surface Sand Filter
- Perimeter Sand Filter

- Swale
- Outlet structure with drawdown valve
- Adjustable flow splitter

IV. *Operation and Maintenance*

Overview

The most frequently cited maintenance concern for filters is surface and under-drain clogging caused by organic matter, fine silts, hydrocarbons, and algal matter. Common operational problems include:

- standing water
- clogged filter surface
- clogged, inlet, outlet or under-drains

Design Phase Maintenance Considerations

Implicit in the design guidance in the previous sections is the fact that many design elements of filtering systems can minimize the maintenance burden and maintain pollutant removal efficiency. Key examples include: limiting drainage area, providing easy site access (REQUIRED), and providing adequate pre-treatment (REQUIRED).

Construction Phase Maintenance

Proper construction methods and sequencing play a significant role in reducing problems with operation and maintenance (O&M). In particular, with filter construction the most important action for

Table 12.FIL.4. Recommended Maintenance Activities for Media Filters (Sources: WMI, 1997; Pitt, 1997)

Activity	Schedule
• If filter bed is clogged or partially clogged, manual manipulation of the surface layer of sand may be required. Remove the top few inches of media, roto-till or otherwise cultivate the surface, and replace media with like material meeting the design specifications. • Replace any filter fabric that has become clogged.	As needed
• Ensure that contributing area, facility, inlets and outlets are clear of debris. • Ensure that the contributing area is stabilized and mowed, with clippings removed. • Remove trash and debris. • Check to ensure that the filter surface is not clogging (also check after storms greater than about 1”). • Ensure that activities in the drainage area minimize oil/grease and sediment entry to the system. • If permanent water level is present in pre-treatment chamber (e.g., perimeter sand filter), ensure that the chamber does not leak, and normal pool level is retained.	Monthly
• Check to see that the filter bed is clean of sediment and the sediment chamber is not more than 6 inches of sediment. Remove sediment as necessary. • Make sure that there is no evidence of deterioration, spalling or cracking of concrete. • Inspect grates (perimeter sand filter). • Inspect inlets, outlets and overflow spillway to ensure good condition and no evidence of erosion. • Repair or replace any damaged structural parts. • Stabilize any eroded areas. • Ensure that flow is not bypassing the facility. • Ensure that no noticeable odors are detected outside the facility.	Annually
• Remove and replace the top 2-5 inches of media every 3 to 5 years for low sediment applications, more often for areas of high sediment yield or high oil and grease.	3 to 5 years

preventing operation and maintenance difficulties is to ensure that the contributing drainage area has been fully stabilized prior to bringing the practice on line (this is a REQUIRED practice).

Inspections during construction are needed to ensure the filter practice is built in accordance with the approved design and standards and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction, to verify the contractor's interpretation of the plan is acceptable with the designer. An example construction phase inspection checklist is provided in Appendix D.

Post-construction Operation and Maintenance

Proper maintenance is critical to the successful operation of a filtration practice. Without regular maintenance, filtration system media can become clogged, losing its ability to conduct water at the designed rate. This can lead to stagnant water, mosquito breeding habitat, and reduction or elimination of pollutant removal capacity.

A maintenance plan clarifying maintenance responsibility is REQUIRED. Effective long-term operation of filtration practices necessitates a dedicated and routine maintenance schedule with clear guidelines and schedules. Some important post-construction considerations are provided below along with RECOMMENDED maintenance standards in Table 12.FIL.4. A more detailed checklist of maintenance activities and associated schedules is provided in Appendix D.

- ► A site specific O&M plan that includes the following considerations should be prepared by the designer prior to putting the stormwater filtration practice into operation:
  - Operating instructions for drawdown valves, gates and removable weirs (surface filters only).
  - Vegetation maintenance schedule.
  - Inspection checklists
  - Routine maintenance checklists
- ► A legally binding and enforceable maintenance agreement should be executed between the facility owner and the local review authority to ensure the following:
  - Sediment should be cleaned out of the sedimentation chamber when it accumulates to a depth equal to ½ the total depth to the outlet, or when greater than 1.5 feet, whichever is less. The sediment chamber outlet devices should be cleaned/repaired when drawdown times exceed 36 hours. Trash and debris should be removed as necessary.
  - Silt/sediment should be removed from the filter bed when the accumulation exceeds one inch. When the filtering capacity of the filter diminishes substantially (i.e., when water ponds on the surface of the filter bed for more than 48 hours), the top few inches of discolored material should be removed and replaced with fresh material. The removed sediments should be disposed in an acceptable manner (i.e., landfill).
- ► Media filters that have a grass cover should be mowed as needed during the growing season to maintain maximum grass heights less than 12 inches.

V. Construction and Maintenance Costs

Chapter 6 outlines a cost estimation method which site planners could use to compare the relative construction and maintenance costs for structural best management practices. These curves are excellent for purposes of comparison; however, it is recommended that construction and maintenance budgets should be based on site specific information. Utilizing Table 12.FIL.5 and the cost estimation worksheet in Appendix D, will allow designers to more accurately estimate the cost of a filtration BMP.

VI. Design Procedure: Media Filters

The following steps outline a recommended design

Table 12.FIL.5 Cost Components for Filtration Practices

Implementation Stage	Primary Cost Components	Basic Cost Estimate	Other Considerations
Site Preparation	Tree & plant protection	Protection Cost ($/acre) x Affected Area (acre)	Removal of existing structures, topsoil removal and stockpiling
	Topsoil salvage	Salvage cost ($/acre) x Affected Area (acre)	
	Clearing & grubbing	Clearing Cost ($/acre) x Affected Area (acre)	
Site Formation	Excavation / grading	X-ft Depth Excavation Cost ($/acre) x Area (acre)	Soil & rock fill material, tunneling
	Hauling material offsite	Excavation Cost x (% of Material to be hauled away)	
Structural Components	Under-drains	Under-drain cost ($/lineal foot) x length of device	Pipes, catchbasins, manholes, valves, vaults
	Vault structure (for media filters)	($/structure)	
	Media (for media filters)	Media cost ($/cubic yard) X filter volume (cubic yard)	
	Inlet structure (for vegetative filters	($/structure)	
	Outlet structure (for vegetative filters)	($/structure)	
Site Restoration	Filter strip	Sod cost ($/square foot) x filter strip area	Tree protection, soil amendments, seed bed preparation, trails
	Soil preparation	Topsoil or amendment cost ($/acre) x Area (acre)	
	Seeding	Seeding Cost ($/acre) x Seeded Area (acre)	
	Planting / transplanting	Planting Cost ($/acre) x Planted Area (acre)	
Annual Operation, Maintenance, and Inspection	Debris removal	Removal Cost ($/acre) x Area (acre) x Frequency (2x / 1yr)	Vegetation maintenance, cleaning of structures
	Sediment removal	Removal Cost ($/acre) x Area (acre) x Frequency (1x / 5yr)	
	Gate / valve operation	Operation Cost ($) x Operation Frequency (2x / 1 yr)	
	Inspection	Inspection Cost ($) x Inspection Frequency (6x / 1 yr)	
	Mowing (for some vegetative filters)	Mowing Cost ($) x Mowing Frequency (4x / 1 yr)	

procedure for media filters in compliance with the MPCA Permit for new construction. Design recommendations beyond those specifically required by the permit are also included and marked accordingly.

Design Steps

Step 1. Make a preliminary judgment as to whether site conditions are appropriate for the use of a surface or perimeter sand filter, and identify the function of the filter in the overall treatment system.

A. Consider basic issues for initial suitability screening, including:

- Site drainage area
- Site topography and slopes
- Regional or local depth to ground water and bedrock

- ► Site location/minimum setbacks
- ► Presence of active karst

B. Determine how the media filter will fit into the overall stormwater treatment system:

- ► Decide whether the filter is the only BMP to be employed, or if are there other BMPs addressing some of the treatment requirements.
- ► Decide where on the site the media filter is most likely to be located.

Step 2. Confirm design criteria and applicability.

A. Determine whether the media filter must comply with the MPCA Permit.

B. Check with local officials, watershed organizations, and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3. Select design variant based on Physical Suitability Evaluation

Once the Physical Suitability Evaluation is complete, apply the better site design principles in sizing and locating the filtration practice(s) on the development site. Given the drainage area, select the appropriate filtration practice for the first iteration of the design process.

Note: Information collected during the Physical Suitability Evaluation (see Step 2) should be used to explore the potential for multiple filtration practices versus relying on a single facility. The use of smaller filtration practices dispersed around a development is usually more sustainable than a single regional facility that is more likely to have maintenance problems (Source: Wisconsin Department of Natural Resources Conservation Practice Standards, 2004).

Step 4. Compute runoff control volumes

Calculate the Water Quality Volume (Vwq), Channel Protection Volume (Vcp), Overbank Flood Protection Volume (Vp_{10}), and the Extreme Flood Volume (Vp_{100}) where applicable.

If the media filter is being designed to meet the requirements of the MPCA Permit, the REQUIRED treatment volume is the water quality volume of ½ inch of runoff from the new impervious surfaces created from the project (or 1 inch for certain protected waterbodies). If part of the overall Vwq is to be treated by other BMPs, subtract that portion from the Vwq to determine the part of the Vwq to be treated by the filter.

Details on the Unified Stormwater Sizing Criteria are found in Chapter 10.

Step 5. Compute **Vwq** peak discharge (**Q_{wq}**)

The peak rate of discharge for water quality design storm is needed for sizing of off-line diversion structures. Details are found in Chapter 10.

Step 6. Size flow diversion structure, if needed

A flow regulator (or flow splitter diversion structure) should be supplied to divert the Vwq to the sand filter facility. This is generally accomplished by setting the bypass weir within the diversion to the elevation of the water quality volume within the practice. Please refer to the adjustable diversion detail in appendix D.

Size low flow orifice, weir, or other device to pass **Q_{wq}**.

Step 7. Size filtration basin chamber

The filter area is sized using the following equation (based on Darcy's Law):

Af = (Vwq) (df) / [(k) (hf + df) (tf)]

Where:

Af = surface area of filter bed (ft^2)

df = filter bed depth (ft) (typically 18 inches, no more than 24 inches)

k = coefficient of permeability of filter media (ft/day) (use 3.5 ft/day for

The filter media should consist of an 18-inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand) on top of the under-drain system.

sand)

hf = average height of water above filter bed (ft) (Typically 1/2 **hmax**, where **hmax** is the maximum head on the filter media and is typically ≤6 feet)

tf = design filter bed drain time (days) (Maximum of 2 days, 48 hours REQUIRED in CGP)

Set preliminary dimensions of filtration basin chamber. The following guidelines are HIGHLY RECOMMENDED:

- ► The filter media should consist of an 18-inch layer of clean washed medium sand (meeting ASTM C-33 concrete sand) on top of the under-drain system.
- ► For surface sand filters, three inches of topsoil are placed over the sand bed. Permeable filter fabric is placed both above and below the sand bed to prevent clogging of the sand filter and the under-drain system.
- ► The filter bed is equipped with an 8-inch perforated PVC pipe (AASHTO M 252) under-drain in a gravel layer. The under-drain must have a minimum slope of 1%. Holes should be 3/8-inch diameter and spaced approximately 6 inches on center. Gravel should be clean washed aggregate with a maximum diameter of 3.5 inches and a minimum diameter of 1.5 inches with a void space of about 40%. Aggregate contaminated with soil shall not be used.
- ► Underground sand beds should be protected from trash accumulation by a wide mesh geotextile screen to be placed on the surface of the sand bed. The screen is to be rolled up, removed, cleaned and re-installed during maintenance operations.

Step 8. Size sedimentation chamber

Sedimentation chamber size is dictated by volume requirements, maximum ponding depth, and the particle settling ability. It is HIGHLY RECOMMENDED that the sedimentation chamber be sized to at least 25% of the computed V_{WQ} for surface sand filters and 50% for perimeter sand filters and have a length-to-width ratio of 2:1. It is REQUIRED that the depth of settling basins be in the range of 3' to 10' (D_{max}), although site-specific requirements may apply. The Camp-Hazen equation is used to compute the surface area based on particle settling:

As = (Qo/w) * Ln (1-E)

Where:

As = sedimentation basin surface area (ft^2)

Qo = rate of outflow (cfs) = the Vwq over a 24-hour period

w = particle settling velocity (ft/sec)

E = trap efficiency (as decimal)

Assuming:

- 90% sediment trap efficiency (0.9)
- particle settling velocity (ft/sec) = 0.0004 ft/sec for imperviousness <75%
- particle settling velocity (ft/sec) = 0.0033 ft/sec for imperviousness ≥75%

Table 12.FILT.6 Settling Chamber Surface Area

Sand Filter		**Maximum Ponding Depth (feet)**	
		<4	**4 to 10**
Impervious	≥75%	$(0.25*\mathbf{Vwq})/\mathbf{D}_{max}$	$(0.25*\mathbf{Vwq})/\mathbf{D}_{max}$
	<75%	$(0.25*\mathbf{Vwq})/\mathbf{D}_{max}$	$0.066*\mathbf{Vwq}$
Perimeter Sand Filter		**Maximum Ponding Depth (feet)**	
		<7.5	**8 to 10**
Impervious	≥75%	$(0.5*\mathbf{Vwq})/\mathbf{D}_{max}$	$(0.5*\mathbf{Vwq})/\mathbf{D}_{max}$
	<75%	$(0.5*\mathbf{Vwq})/\mathbf{D}_{max}$	$0.066*\mathbf{Vwq}$

- average of 24 hour holding period

Then the equation reduces to:

As = (0.066) (Vwq) ft^2 for I < 75%

Or

As = (0.0081) (Vwq) ft^2 for I ≥ 75%

Where:

VWQ = water quality volume (ft3)

I = Percent Impervious

Use Table 12.FIL.6 to set the preliminary surface area of the settling chamber. Select the type of filter, imperviousness of the drainage area, and maximum ponding depth,

Step 9. Compute **Vmin** (minimum volume that can be stored within the filtration chamber)

$V_{MIN} = 0.75 * Vwq$

Step 10. Compute storage volumes within entire facility and sedimentation chamber orifice size

Surface sand filter:

$V_{MIN} = 0.75\ Vwq = Vs + Vf + Vf_{TEMP}$

(a) Compute Vf = water volume within filter bed/gravel/pipe = Af * df * n

Where: n = porosity = 0.4 for most applications

(b) Compute Vf_{TEMP}= temporary storage volume above the filter bed = 2 * hf * Af

(c) Compute Vs = volume within sediment chamber = $V_{MIN} - Vf - Vf_{TEMP}$

(d) Compute hs = height in sedimentation chamber = Vs/As

(e) Ensure hs and hf fit available head and other dimensions still fit – change as necessary in design iterations until all site dimensions fit.

(f) Size orifice from sediment chamber to filter chamber to release Vs within 24-hours at average release rate with 0.5 hs as average head.

(g) Design outlet structure with perforations allowing for a safety factor of 10.

Perimeter sand filter:

(a) Compute Vf = water volume within filter bed/gravel/pipe = Af * df * n

Where: n = porosity = 0.4 for most applications

(b) Compute Vw = wet pool storage volume As * 2 feet minimum

(c) Compute Vf_{TEMP} = temporary storage volume = V_{MIN} – (Vf + Vw)

(d) Compute h_{TEMP}= temporary storage height = Vf_{TEMP} / (Af + As)

(e) Ensure $h_{TEMP} \geq 2$ * hf, otherwise decrease hf and re-compute. Ensure dimensions fit available head and area – change as necessary in design iterations until all site dimensions fit.

(f) Size distribution slots from sediment chamber to filter chamber.

Step 11. Design inlets, pre-treatment facilities, under-drain system, and outlet structures

(a) Pre-treatment of runoff in a sand filter system is provided by the sedimentation chamber. Inlets to surface sand filters should be provided with energy dissipaters. Exit velocities from the sedimentation chamber must be non-erosive.
(b) Outlet pipe should be provided from the under-drain system to the facility discharge. Due to the slow rate of filtration, outlet protection is generally unnecessary (except for emergency overflows and spillways).
(c) An emergency or bypass spillway must be included in the surface sand filter to safely pass flows that exceed the design storm flows. The spillway prevents filter water levels from overtopping the embankment and causing structural damage. The emergency spillway should be located so that downstream buildings and structures will not be impacted by spillway discharges.
(d) Inlets to surface sand filters should be provided with energy dissipaters. Exit velocities from the sedimentation chamber must be nonerosive.

The allowable materials for sand filter construction are detailed in Table 12.FIL.7.

Step 12. Compute overflow weir sizes

Surface sand filter:

(a) Plan inlet protection for overflow from sedimentation chamber.
(b) Size overflow weir at elevation in filtration chamber above perforated stand pipe to handle surcharge of flow through filter system from 10-year storm.

Perimeter sand filter:

Size overflow weir at end of sedimentation chamber to handle excess inflow, set at Vwq elevation.

Step 13. Check volume, peak discharge rates and period of inundation against State, local and watershed organization requirements (Note: Steps are iterative)

Follow the design procedures identified in Chapter 10, Unified Sizing Criteria, to determine the volume control and peak discharge requirements for water quality, recharge (not required), channel protection, overbank flood and extreme storm. Adapt these values to local regulations, if any exist.

Model the proposed development scenario using a surface water model appropriate for the hydrologic and hydraulic design considerations specific to the site (see also Chapter 8 and Appendix B of the Manual). This includes defining the parameters of the filtration practice defined above: pond elevation and area (defines the pond volume), filtration rate and method of application (effective filtration area), and outlet structure and/or flow diversion information. The results of this analysis can be used to determine whether or not the proposed design meets the applicable requirements. If not, the design will have to be re-evaluated.

The following items are specifically REQUIRED by the MPCA Permit:

Volume

Filtration systems shall be sufficient to filter a water quality volume of ½ inch of runoff from the new impervious surfaces created by the project. If this criterion is not met, increase the storage volume of the filtration practice or treat excess water quality volume (Vwq) in an upstream or downstream BMP (see Step 5). The Vwq increases to 1 inch

Table 12.FIL.7 Sand Material Specifications (Adapted from Vermont Stormwater Manual prepared by CWP)			
Parameter	**Specification**	**Size**	**Notes**
Sand	clean AASHTO M-6 or ASTM C-33 concrete sand	0.02” to 0.04”	Sand substitutions such as Diabase and Graystone #10 are not acceptable. No calcium carbonated or dolomitic sand substitutions are acceptable. Rock dust cannot be substituted for sand.
Under-drain Gravel	AASHTO M-43	1.5” to 3.5”	
Geotextile Fabric (if required)	ASTM D-4833 (puncture strength - 125 lb.) ASTM D-1117 (Mullen Burst Strength - 400 psi) ASTM D-4632 (Tensile Strength - 300 lb.)	0.08” thick equivalent opening size of #80 sieve	Must maintain 125 gpm per sq. ft. flow rate. Note: a 4” pea gravel layer may be substituted for geotextiles meant to separate sand filter layers.
Impermeable Liner (if required)	ASTM D-4833 (thickness) ASTM D-412 (tensile strength 1,100 lb., elongation 200%) ASTM D-624 (Tear resistance - 150 lb./in) ASTM D-471 (water adsorption: +8 to -2% mass)	30 mil thickness	Liner to be ultraviolet resistant. A geotextile fabric should be used to protect the liner from puncture.
Under-drain Piping	ASTM D-1785 or AASHTO M-278	8” rigid schedule 40 PVC	3/8” perf. @ 6” on center, 4 holes per row; minimum of 3” of gravel over pipes; not necessary underneath pipes
Concrete (Cast-in-place)	See local Standards and Specs. f’c = 3,500 psi, normal weight, air-entrained; re-enforcing to meet ASTM 615-60	n/a	on-site testing of poured-in-place concrete required: 28 day strength and slump test; all concrete design (cast-in-place or pre-cast) *not using previously approved State or local standards* requires design drawings sealed and approved by a licensed professional structural engineer.
Concrete (pre-cast)	per pre-cast manufacturer	n/a	SEE ABOVE NOTE
non-rebar steel	ASTM A-36	n/a	structural steel to be hot-dipped galvanized ASTM A-123

Table 12.FIL.8. Open Vegetated Swale and Filter Strip Materials Specifications (Adapted from Vermont Stormwater Manual prepared by CWP)			
Parameter	**Specification**	**Size**	**Notes**
Dry swale soil	USCS; ML, SM, SC	n/a	soil with a higher percent organic content is preferred
Dry Swale sand	ASTM C-33 fine aggregate concrete sand	0.02” to 0.04”	
Check Dam (pressure treated)	AWPA Standard C6	6” by 6” or 8” by 8”	*do not* coat with creosote; embed at least 3’ into side slopes
Check Dam (natural wood)	Black Locust, Red Mulberry, Cedars, Catalpa, White Oak, Chestnut Oak, Black Walnut	6” to 12” diameter; notch as necessary	*do not* use the following, as these species have a predisposition towards rot: Ash, Beech, Birch, Elm, Hackberry, Hemlock, Hickories, Maples, Red and Black Oak, Pines, Poplar, Spruce, Sweetgum, Willow
Filter Strip sand/gravel pervious berm	sand: per dry swale sand gravel; AASHTO M-43	sand: 0.02” to 0.04” gravel: 1/2” to 1”	Mix with approximately 25% loam soil to support grass cover crop; see Bioretention planting soil notes for more detail.
Pea gravel diaphragm and curtain drain	ASTM D 448	varies (No. 6) or (1/8” to 3/8”)	use clean bank-run gravel
Under-drain gravel	AASHTO M-43	1.5” to 3.5”	
Under-drain	ASTM D-1785 or AASHTO M-278	6” rigid Schedule 40 PVC	3/8” perf. @ 6” o.c.; 4 holes per row
Geotextile	See local Standards and Specs	n/a	
Rip rap	per local criteria	size per requirements based on 10-year design flows	

for discharge to “special waters” (Appendix A of MPCA Permit).

Period of Inundation

Filtration practices shall discharge through the soil or filter media in 48 hours or less. Additional flows that cannot be infiltrated or filtered in 48 hours should be routed to bypass the system through a stabilized discharge point. This criterion was established to provide the following: wet-dry cycling between rainfall events; unsuitable mosquito breeding habitat; suitable habitat for vegetation; aerobic conditions; and storage for back-to-back precipitation events.

The period of inundation is defined as the time from the high water level in the practice to 3 to 6 inches above the invert of the outlet structure or drain tile or bottom of the facility. It is assumed that this range is less than 1/5 the bounce in the filtration practice.

Step 14. Prepare Vegetation and Landscaping Plan

See Major Design Elements section for guidance on preparing vegetation and landscaping management plan.

Step 15. Prepare Operations and Maintenance (O&M) Plan

See Operations and Maintenance section for guidance on preparing an O&M plan.

Step 16. Prepare Cost Estimate

See Cost Considerations section for guidance on preparing a cost estimate that includes both construction and maintenance costs.

VII. Design Procedure: Vegetative Filters

(Adapted from the Georgia Stormwater Management Manual)

Design Steps

Step 1. Make a preliminary judgment as to whether site conditions are appropriate for the use of a vegetative filter, and identify the function of the filter in the overall treatment system

A. Consider basic issues for initial suitability screening, including:

- Site drainage area
- Site topography and slopes
- Regional or local depth to ground water and bedrock

  Dry Swale: Bottom of facility to be at least three feet above the seasonably high water table.

  Wet Swale: The seasonally high water table may inundate the swale; but not above the design bottom of the channel.
- Site location/minimum setbacks.
- Presence of active karst.

B. Determine how the vegetative filter will fit into the overall stormwater treatment system:

- Decide whether the filter is the only BMP to be employed, or if are there other BMPs addressing some of the treatment requirements.
- Decide where on the site the vegetative filter is most likely to be located.

Step 2. Confirm design criteria and applicability.

A. Determine whether the vegetative filter must comply with the MPCA Permit.

B. Check with local officials, watershed organizations, and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3. Select design variant based on physical suitability evaluation

Once the physical suitability evaluation is complete, it is HIGHLY RECOMMENDED that the better site design principles be applied in sizing and locating the filtration practice(s) on the development site. Given the drainage area, select the appropriate filtration practice for the first iteration of the design process.

Note: Information collected during the physical suitability evaluation (see Step 1) should be used to explore the potential for multiple filtration practices versus relying on a single facility. The use of smaller filtration practices dispersed around a development is usually more sustainable that a single regional facility that is more likely to have maintenance problems (Source: Wisconsin Department of Natural Resources Conservation Practice Standards, 2004

Step 4. Compute runoff control volumes and other key design parameters.

Calculate the Water Quality Volume (Vwq), Channel Protection Volume (Vcp), Overbank Flood Protection Volume (Vp10), and the Extreme Flood Volume (Vp100).

If the vegetative filter is being designed to meet the requirements of the MPCA Permit, the REQUIRED treatment volume is the water quality volume of ½ inch of runoff from the new impervious surfaces created from the project (or 1 inch for certain protected waterbodies). If part of the overall Vwq is to be treated by other BMPs, subtract that portion from the Vwq to determine the part of the Vwq to be treated by the filter.

Details on the Unified Stormwater Sizing Criteria are found in Chapter 10.

For filter strips, compute the following design parameters:

(a) Calculate the maximum discharge loading per foot of filter strip width

$$q = \frac{0.00236}{n} Y^{\frac{5}{3}} S^{\frac{1}{2}}$$

Where:

q = discharge per foot of width of filter strip, from Manning's equation (cfs/ft)

Y = allowable depth of flow (inches) (3" - 4" maximum)

S = slope of filter strip (percent) (2% – 6%)

n = Manning's "n" roughness coefficient (use 0.15 for short prairie grass, 0.25 for dense grasses such as bluegrass, buffalo grass, blue grama grass and other native grass mixtures)

(b) Use a recommended hydrologic model from Chapter 8 to compute Q_{wq}

(c) Minimum Filter Width = Q_{wq} / q

Where:

Q_{wq} = the water quality peak discharge (cfs)

Qu = the unit peak discharge (cfs/mi²/inch)

A = drainage area (mi²)

Vwq = Water Quality Volume (inch)

Step 5. Determine pre-treatment method

Pre-treatment

Pre-treatment for vegetative filters is REQUIRED. One alternative is a level spreader that allows coarse sediment to settle and evenly distributes flow across the full width of the filter. Pre-treatment could be provided with plunge pools where concentrated flows enter and with level spreaders where lateral flows enter. Additional pre-treatment measures include filter strips and street/parking lot sweeping. Street/parking lot sweeping may be considered pre-treatment in the case of a parking lot island or other area where spatial limitations make structural pre-treatment measures unfeasible.

Storage volume created for pre-treatment counts toward the total Vwq requirement, and should be subtracted from the Vwq for subsequent calculations.

Step 6. Preliminary design

Wet and Dry Swales:

(a) Size bottom width, depth, length, and slope necessary to store Vwq with less than 18 inches of ponding at the downstream end.

(b) Slope should not exceed 5% (1 to 2% recommended)

(c) Bottom width should range from 2 to 8 feet

Slope should not exceed 5% (1 to 2% recommended)

(d) Ensure that side slopes are no greater than 3:1 (4:1 recommended)

If the system is on-line, channels should be sized to convey runoff from the overbank flood event (Vp10) safely with a minimum of 6 inches of freeboard and without damage to adjacent property. The peak velocity for the 2-year storm must be nonerosive for the soil and vegetative cover provided.

The channel and under-drain excavation should be limited to the width and depth specified in the design. The bottom of the excavated trench shall not be loaded in a way that causes soil compaction, and scarified prior to placement of gravel and permeable soil. The sides of the channel shall be trimmed of all large roots. The sidewalls shall be uniform with no voids and scarified prior to backfilling.

Step 7. Compute number of check dams (swales) or berms (filter strip)

Wet and Dry Swales: Checkdams

Design to contain entire Vwq.

Channel slopes between 1% and 2% are recommended unless topography necessitates a steeper slope, in which case 6- to 12-inch drop structures can be placed to limit the energy slope to within the recommended 1 to 2% range. Energy dissipation will be required below the drops. Spacing between the drops should not be closer than 50 feet. Depth of the Vwq at the downstream end should not exceed 18 inches.

Filter Strips: Berms

. (a) Size outlet pipes to ensure that the bermed area drains within 24 hours.

(b) Specify grasses resistant to frequent inundation within the shallow ponding limit.

(c) Berm material should be of sand, gravel and sandy loam to encourage grass cover (Sand: ASTM C-33 fine aggregate concrete sand 0.02”-0.04”, Gravel: AASHTO M-43 ½” to 1”).

(d) Size filter strip to contain the Vwq within the wedge of water backed up behind the berm.

(e) Maximum berm height should be 12 inches.

Pervious berms to be a sand/gravel mix (35-60% sand, 30-55% silt, and 10-25% gravel). Berms are to have overflow weirs with 6-inch minimum head.

Step 8. Calculate draw-down time.

Dry swale:

The bed of the dry swale consists of a permeable soil layer of at least 30 inches in depth, above an 8-inch diameter perforated PVC pipe (AASHTO M 252) longitudinal under-drain in a 12-inch gravel layer. The soil media should have an infiltration rate of at least 0.5 feet per day (fpd) with a maximum of 1.5 fpd and contain a high level of organic material to facilitate pollutant removal. A permeable filter fabric is placed between the gravel layer and the overlying soil.

Dry swale channels are sized to store and filter the entire Vwq and allow for full filtering through the permeable soil layer.

Step 9. Check 2-year and 10-year velocity erosion potential and freeboard.

Check for erosive velocities and modify design as appropriate based on local conveyance regulations. Provide 6 inches of freeboard.

Step 10. Design low flow control at downstream headwalls and checkdams.

Design control to pass Vwq in 48 hours.

Step 11. Design inlets, sediment forebay(s), and under-drain system (dry swale).

Inlets to swales must be provided with energy dissipaters such as riprap or geotextile reinforcement. Pre-treatment of runoff in both a dry and wet swale system is typically provided by a sediment forebay located at the inlet. Enhanced swale systems that receive direct concentrated runoff may have a 6-inch drop to a pea gravel diaphragm flow spreader at the upstream end of the control. A pea gravel diaphragm and gentle side slopes should be provided along the top of channels to provide pre-treatment for lateral sheet flows.

The under-drain system should discharge to the storm drainage infrastructure or a stable outfall. For a wet swale, do not use an under-drain system.

Step 12. Check volume, peak discharge rates and period of inundation against State, local and watershed organization requirements (Note: Steps are iterative).

Follow the design procedures identified in the Unified Sizing Criteria section of the Manual (Chapter 10) to determine the volume control and peak discharge requirements for water quality, recharge (not required), channel protection, overbank flood and extreme storm.

Model the proposed development scenario using a surface water model appropriate for the hydrologic and hydraulic design considerations specific to the site (see also Chapter 8 and Appendix B of the manual). This includes defining the parameters of the filtration practice defined above: pond elevation and area (defines the pond volume), filtration rate and method of application (effective filtration area), and outlet structure and/or flow diversion information. The results of this analysis can be used to determine whether or not the proposed design meets the applicable requirements. If not, the design will have to be re-evaluated.

The following items are specifically REQUIRED by the MPCA Permit:

Volume

Filtration systems shall be sufficient to filter a water quality volume of ½ inch of runoff from the new impervious surfaces created by the project. If this criterion is not met, increase the storage volume of the filtration practice or treat excess water quality volume (Vwq) in an upstream or downstream BMP (see Step 5). The Vwq increases to 1 inch for discharge to “special waters” (Appendix A of CGP; also referenced in Chapter 10 of the Manual)

Period of Inundation

Filtration practices shall discharge through the soil or filter media in 48 hours or less. Additional flows that cannot be infiltrated or filtered in 48 hours should be routed to bypass the system through a stabilized discharge point. This criterion was established to provide the following: wet-dry cycling between rainfall events; unsuitable mosquito breeding habitat; suitable habitat for vegetation; aerobic conditions; and storage for back-to-back precipitation events.

The period of inundation is defined as the time from the high water level in the practice to 3 to 6 inches above the invert of the outlet structure or drain tile or bottom of the facility. It is assumed that this range is less than 1/5 the bounce in the filtration practice.

Step 13. Prepare Vegetation and Landscaping Plan.

A landscaping plan for a dry or wet swale should be prepared to indicate how the enhanced swale system will be stabilized and established with vegetation. The recommended construction materials for open channels and filter strips are detailed in Table 12.FIL.7. Further information on plant selection and use occurs in Appendix E of the manual.

Landscape design should specify proper grass species and wetland plants based on specific site, soils and hydric conditions present along the channel.

Step 14. Prepare Operation and Maintenance (O&M) Plan.

See Operation and Maintenance section for guidance on preparing an O&M plan.

Step 15. Prepare Cost Estimate.

See Cost Considerations section for guidance on preparing a cost estimate that includes both construction and maintenance costs.

VIII. Links to Other Manuals

See Appendix C.

IX. References

American Society of Civil Engineers (ASCE). *International Stormwater Best Management Practices (BMP) Database*. Continually updated web-site at: http://www.bmpdatabase.org

Center for Watershed Protection, 1996. *Design of Stormwater Filtering Systems*.

Georgia Stormwater Management Manual, 2001. Atlanta Regional Commission.

Metropolitan Council. 2001. *Minnesota Urban Small Sites BMP Manual, Stormwater Best Management Practice for Cold Climates*. St. Paul, MN.

Vermont Stormwater Management Manual, 2002. Web-address: http://www.vtwaterquality.org/stormwater.htm.

Watershed Management Institute (WMI). 1997. Operation, Maintenance, and Management of Stormwater Management Systems. Prepared for: US EPA Office of Water. Washington, DC.

Washington State Department of Ecology (WSDE). 1992. Stormwater Management Manual for the Puget Sound Basin. Olympia, WA.

Haan, C.T., B.J. Barfield and J.C. Hayes, 1994. *Design Hydrology and Sedimentology for Small Catchments*.

Pitt, R., M. Lilburn, and S. Burian. 1997. *Storm Drainage Design for the Future: Summary of Current U.S. EPA Research.* American Society of Civil Engineers Technical Conference, Gulf Shores, AL.

Lino Lakes City Hall - Infiltration trench Lino Lakes, MN

Bradshaw Celebration of Life Center - underground storage & infiltration Stillwater, MN

Definition:

Natural or constructed depressions located in permeable soils that capture, store and infiltrate the volume of stormwater runoff associated with a particular design event.

KEY CONSIDERATIONS

Design Criteria:

- Contributing drainage area
- Underlying soil types
- Depth to the water table, bedrock or other impeding layer
- Proximity to buildings, drinking water supplies, karst features, etc…
- Source of stormwater runoff

Benefits:

- Reduces volume of stormwater runoff
- Increases groundwater recharge
- Improves surface water quality
- Provides thermal benefits (e.g. to cold water fisheries)
- Mimics pre-development hydrology

Limitations:

- Unusual construction considerations
- Potential for groundwater contamination
- Tendency to lose effectiveness over time due to clogging – if not properly constructed or maintained
- Not recommended for areas with steep slopes
- May require landscaping: consideration should be given to periods on inundation and drought

MANAGEMENT SUITABILITY

High	Water Quality (V_{WQ})
Med.	Channel Protection (V_{CP})
Low/Med.	Overbank Flood Protection (V_{P10})
Low	Extreme Flood Protection (V_{P100})
High	Recharge Volume (V_{RE})

MECHANISMS

X	Infiltration
X	Screening/ Filtration
X	Temperature Control
	Settling
	Evaporation
X*	Transpiration *if vegetated
X	Soil Adsorption
X	Biological/ Micro. Uptake

POLLUTION REMOVAL

95%	Total Suspended Solids
65%/ 50%	Nutrients - Total Phosphorus/ Total Nitrogen
95%	Metals - Cadmium, Copper, Lead, and Zinc
NA	Pathogens - Coliform, Streptococci, E. Coli
NA	Toxins - Chloride, Hydrocarbon, Pesticide

SITE FACTORS

1/ 5/ 50 AC Max	Drainage Areas: Dry Well/ Trench/ Basin
20%	Max. Site Slope
3'	Min. Depth to Bedrock
3'	Min. Depth to Seasonally High Water Table
A,B,C*,& D*	NRCS Soil Type *C & D soils have limited infiltration ability but can be used to match pre-development conditions
Poor - Good	Freeze/ Thaw Suitability

Description:

In general terms, infiltration systems can be described as natural or constructed depressions located in permeable soils that capture, store and infiltrate stormwater runoff within 48 hours. These depressions can be located at the surface of the ground (e.g. infiltration basin) or they can be designed as underground facilities (e.g. structural chamber or excavated pit filled with aggregate such as an infiltration trench). Typically, infiltration systems are designed with one or more pre-treatment facilities or they are designed as off-line facilities.

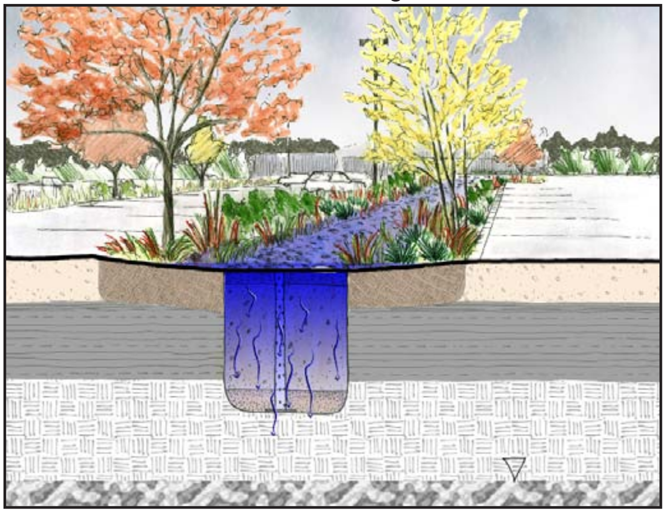
Infiltration systems should be located in permeable soils and a minimum 3-foot distance is REQUIRED from the bottom of the practice to the seasonally high water table, bedrock or other impeding layer per the Minnesota Pollution Control Agency Construction General Permit (CGP). Dry wells and Trenches should be designed to handle the smaller, more frequent rainfall events. Stormwater associated with the larger rainfall events should bypass these practices by a separate pipe or an overflow device. Infiltration basins and underground infiltration systems should be designed to handle both the water quality volume and as the water quantity volume.

Infiltration systems can be designed to address a number of stormwater management issues including: water quality, stormwater runoff reduction, flow attenuation, thermal impacts to cold water fisheries, and ground water recharge.

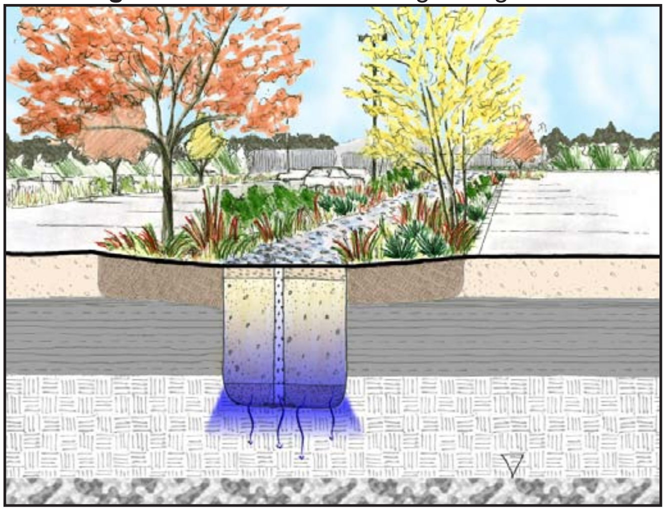
STORM SEQUENCE

Start of Storm Event - Initial runoff & storage

Duration of Storm Event - Storage & filtration/infiltration



Following Storm Event - Remaining storage draw-down



Courtesy of Rice Creek Watershed District

INFILTRATION

I. *Suitability*

General

Stormwater infiltration practices capture and temporarily store stormwater before allowing it to infiltrate into the soil. Design variants include; the infiltration basin, the infiltration trench, the dry well and the underground infiltration system. As the stormwater penetrates the underlying soil, chemical, biological and physical processes remove pollutants and delay peak stormwater flows. Infiltration practices are applicable to sites with naturally permeable soils and a suitable distance to the seasonally high ground-water table, bedrock or other impermeable layer. They may be used in residential and other urban settings where elevated runoff volumes, pollutant loads, and runoff temperatures are a concern. In applications where the stormwater runoff has a particularly high pollutant load or where the soils have very high infiltration rates, a significant amount of pre-treatment should be provided to protect the ground-water quality. Sources that include potential stormwater should not be introduced to infiltration systems. Sources that include potential stormwater hotsposts (PSH) should not be introduced to infiltration areas.

Function Within Stormwater Treatment Train

Infiltration practices may be located at the end of the treatment train or they can be designed as off-line configurations where the water quality volume is diverted to the infiltration practice. In any case, the practice may be applied as part of a stormwater management system to achieve one or more of the following objectives:

- reduce stormwater pollutants
- increase ground-water recharge
- decrease runoff peak flow rates
- decrease the volume of stormwater runoff
- preserve base flow in streams
- reduce thermal impacts of runoff.

MPCA Permit Applicability

One of the goals of this Manual is to facilitate understanding of and compliance with the MPCA General Stormwater Permit for Construction Activity (MN R100001), commonly called the Construction General Permit (CGP), which includes design and performance standards for permanent stormwater management systems. The permit and related documentation can be found online at http://www.pca.state.mn.us/water/stormwater/stormwater-c.html. These standards must be applied in all projects in which at least one acre of new impervious area is being created, and the permit stipulates certain standards for various categories of stormwater management practices.

For regulatory purposes, infiltration practices fall under the "Infiltration / Filtration" category described in Part III.C.2 of the permit. If used in combination with other practices, credit for combined stormwater treatment can be given as described in Part III.C.4. Due to the statewide prevalence of the MPCA permit, design guidance in this section is presented with the assumption that the permit does apply. Also, although it is expected that in many cases infiltration will be used in combination with other practices, standards are described for the case in which it is a stand alone practice.

The following terms are thus used in the text to distinguish various levels of stormwater pond design guidance:

REQUIRED:	Indicates design standards stipulated by the MPCA Permit (or other consistently applicable regulations).
HIGHLY RECOMMENDED:	Indicates design guidance that is extremely beneficial or necessary for proper functioning of the infiltration practice, but is not specifically required by the MPCA permit.
RECOMMENDED:	Indicates design guidance that is helpful for infiltration performance but not critical to the design.

Of course, there are situations, particularly retrofit projects, in which an infiltration facility is constructed without being subject to the conditions of the MPCA permit. While compliance

Note:

There is some concern that underground infiltration systems and dry wells meet the U.S. Environmental Protection Agency (EPA) definition of a Class V injection well. Class V injection wells are defined as any bored, drilled, or driven shaft, or dug hole that is deeper than its widest surface dimension, or an improved sinkhole, or a subsurface fluid distribution system (from U.S. Environmental Protection Agency, When Are Storm Water Discharges Regulated as Class V Wells, June 2003. http://www.epa.gov/safewater/uic/pdfs/fact_class5_stormwater.pdf.

Please consult MPCA with questions on th eapplicability of Class V injection well rules.

with the permit is not required in these cases, the standards it establishes can provide valuable design guidance to the user. It is also important to note that **additional and potentially more stringent design requirements may apply for a particular infiltration facility**, depending on where it is situated both jurisdictionally and within the surrounding landscape.

Design Variants

Infiltration Basin

An infiltration basin is a natural or constructed impoundment that captures, temporarily stores and infiltrates the design volume of water over several days. In the case of a constructed basin, the impoundment is created by excavation or embankment. Infiltration basins are commonly used for drainage areas of 5 to 50 acres with land slopes that are less than 20 percent. Typical depths range from 2 to 12 feet, including bounce in the basin. An infiltration basin construction detail is located in Appendix D.

Infiltration Trench (a.k.a. infiltration gallery)

An infiltration trench is a shallow excavated trench, typically 3 to 12 feet deep, that is backfilled with a coarse stone aggregate allowing for the temporary storage of runoff in the void space of the material. Discharge of this stored runoff occurs through infiltration into the surrounding naturally permeable soil. Trenches are commonly used for drainage areas less than 5 acres in size. An infiltration trench construction detail is located in Appendix D.

Dry Wells (a.k.a. infiltration tubes, french drains, soak-away pits or soak holes)

A dry well or soak away pit is a smaller variation of an infiltration trench. It is a subsurface storage facility (a structural chamber or an excavated pit backfilled with a coarse stone aggregate) that receives and temporarily stores stormwater runoff. Discharge of this stored runoff occurs through infiltration into the surrounding naturally permeable soil. Due to their size, dry wells are typically designed to handle stormwater runoff from smaller drainage areas, less than one acre in size (e.g. roof tops). A dry well construction detail is located in Appendix D.

Underground Infiltration Systems

Several underground infiltration systems, including pre-manufactured pipes, vaults, and modular structures, have been developed as alternatives to infiltration basins and trenches for space-limited sites and stormwater retrofit applications.

Table 12.INF.1. BMP Design Restrictions for Special Watersheds					
BMP Group	**Watershed Management Category**				
	A Lakes	**B Trout Waters**	**C Drinking Water** [1]	**D Wetlands**	**E Impaired Waters**
Infiltration	PREFERRED	PREFERRED	RESTRICTED if potential stormwater pollution sources evident	PREFERRED	RESTRICTED if target TMDL pollutant is a soluble nutrient or chloride

1. Applies to ground water drinking water source areas only; use the lakes category to define BMP design restrictions for surface water drinking supplies

These systems are similar to infiltration basins and trenches in that they are designed to capture, temporarily store and infiltrate the design volume of stormwater over several days. Underground infiltration systems are generally applicable to small development sites (typically less than 10 acres) and should be installed in areas that are easily accessible to routine and non-routine maintenance. These systems should not be located in areas or below structures that cannot be excavated in the event that the system needs to be replaced. An underground infiltration system construction detail is located in Appendix D.

Retrofit Suitability

The narrow and versatile shape of infiltration trenches and dry wells makes them well suited for retrofit projects. For example, infiltration practices can be situated along the margin or perimeter of a developed site or roadway in many cases. They are particularly desirable as retrofit practices in watersheds or catchments that are targeting volume reduction practices to help minimize channel erosion. Use of infiltration practices is PROHIBITED in the CGP for treatment of runoff from industrial areas with exposed significant materials or from vehicle fueling and maintenance areas. Generally, infiltration should not be used to treat runoff from manufacturing or industrial sites or other areas with high pollutant concentrations unless correspondingly high levels of pre-treatment are provided.

Special Receiving Waters Suitability

Table 12,INF.1 provides guidance regarding the use of infiltration practices in areas upstream of special receiving waters. This table is an abbreviated version of a larger table in which other BMP groups are similarly evaluated. The corresponding information about other BMPs is presented in the respective sections of this Manual.

Cold Climate Suitability

Various options for use of infiltration are available for treating snowmelt runoff. Some of the installations are built below the frost line (trenches, sub-grade proprietary chambers) and do not need further adaptation for the cold. However, some special consideration as described in Chapter 9 is HIGHLY RECOMMENDED for surface systems.

The problem with infiltration in cold weather is the ice that forms both over the top of the facility and within the soil interstices. To avoid these problems to the extent possible, it is HIGHLY RECOMMENDED that the facility be actively managed to keep it dry before it freezes in the late fall. This can be done by various methods, including limiting inflow, under-drainage, and surface disking.

Even if the infiltration properties of an infiltration practice are marginal for snowmelt runoff, the storage available in the facility will provide some storage if it is dry entering the melt season. Routing the first highly-soluble portions of snowmelt to an infiltration facility provides the opportunity for soil treatment (such as filtration, adsorption, microbial activity) of these solubles. Again, however, flow originating in an industrial area, a high traffic area where large amounts of salt are added, or another PSH should be diverted away from infiltration systems.

Proprietary, sub-grade infiltration systems provide an alternative to standard surface based systems. Essentially, these systems provide an insulated location for **pre-treated** snowmelt to be stored and slowly infiltrated, or simply filtered and drained away if ground-water sensitivity is an issue. The insulating value of these systems adds to their appeal as low land consumption alternatives to ponds and surface infiltration basins.

Water Quantity Treatment

The amount of stormwater volume infiltrated depends on the design variant selected. Smaller infiltration practices (e.g. infiltration trenches) should either be designed off-line using a flow diversion, or designed to safely pass large storm flows while still protecting the infiltration area. In limited cases (e.g. extremely permeable soils), these smaller infiltration practices can accommodate the channel protection volume, Vcp, in either an off- or on-line configuration.

In general, supplemental stormwater practices will be necessary to satisfy channel and flood protection requirements when smaller infiltration practices are used. However, these practices can help reduce detention requirements for a site through volume reduction.

Due to their size, the larger infiltration practices (e.g. infiltration basins and underground infiltration systems) have the potential to provide greater water quantity benefits. Surcharge storage above the practice bottom is available for detention. Outlet structures can be sized to partially or fully accommodate larger storm peak discharge control while allowing the volume below the outlet to infiltrate.

Water Quality Treatment

Infiltration practices can remove a wide variety of stormwater pollutants through chemical and bacterial degradation, sorption, and filtering. Surface water load reductions are also realized by virtue of the reduction in runoff volume. Due to the logistical challenges presented in structuring a study design, the number of scientific studies documenting the pollutant removal capability of infiltration practices is limited. However, pollutant removal and effluent concentration data for select parameters are provided in Tables 12.INF.2 and 3, respectively.

Table 12.INF.2. Percent Removal of Key Pollutants by Infiltration Practices (Source: Winer, 2000)

Practice	TSS [%]	Total Phosphorus [%]	Total Nitrogen [%]	Metals[1] [%]	Bacteria [%]	Hydro-carbons [%]
Infiltration Practices[3]	95	65	50	95[2]	ND	ND

Notes
1. Average of zinc and copper. Only zinc for infiltration
2. Based on fewer than five data points (i.e., independent monitoring studies)
3. Includes porous pavement, which is not on the list of approved practices.

ND: No Data

Table 12.INF.3. Typical BMP Effluent Concentrations (Source: Winer, 2000)

Practice Group	TSS	TP	TN	Cu[1]	Zn[1]
Infiltration Practices[2]	17	0.05	3.8	4.8	39

1. Units for Zn and Cu are micrograms per liter
2. Data based on fewer than five data points

Limitations

The following general limitations should be recognized when considering installation of infiltration practices:

- ▶ Limited monitoring data are available and field longevity is not well documented.
- ▶ Failure can occur due to improper siting, design, construction and maintenance.
- ▶ Systems are susceptible to clogging by sediment and organic debris
- ▶ There is a risk of ground-water contamination depending on subsurface conditions, land use and aquifer susceptibility.
- ▶ They are not ideal for stormwater runoff from land uses or activities with the potential for high sediment or pollutant loads.
- ▶ They are not recommended for areas with steep slopes.
- ▶ Please not that even though there are potential pollution and physical clogging problems with infiltration, it is one of the most important elements in the stormwater runoff treatment train. fear of the limitations should not prevent well designed systems from being used.

II. Major Design Elements

Physical Feasibility Initial Check

- ▶ **Drainage Area** – It is HIGHLY RECOMMENDED that the following infiltration practices be designed with the indicated maximum drainage areas:
  - Dry well – 1 acre
  - Infiltration Trench – 5 acres
  - Underground Infiltration System – 10 acres
  - Infiltration Basin – between 5 and 50 acres.
- ▶ **Site Topography and Slopes** – Unless slope stability calculations demonstrate otherwise, it is HIGHLY RECOMMENDED that infiltration practices be located a minimum horizontal distance of 200 feet from down-gradient slopes greater than 20%, and that slopes in contributing drainage areas be limited to 15%.
- ▶ **Soils** – It is HIGHLY RECOMMENDED that native soils in proposed infiltration areas have a minimum infiltration rate of 0.2 inches per hour (typically Hydrologic Soil Group A, B and C soils). Initially, soil infiltration rates can be estimated from NRCS soil data, and confirmed with an on-site infiltration evaluation or geotechnical investigation (see Step 6 of the Design Procedures section for investigation procedures). It is HIGHLY RECOMMENDED that native soils have silt/clay contents less than 40% and clay content less than 20%, and that infiltration practices not be situated in fill soils.

Table 12.INF.4 Minimum setback requirements

Setback from	Minimum Distance [feet]
Property Line	10
Building Foundation*	10
Private Well	50
Public Water Supply Well	50
Septic System Tank/Leach Field	35

* Minimum with slopes directed away from the building.

- **Depth to Ground Water Table and Bedrock** – It is REQUIRED that infiltration practices be designed with a minimum vertical distance of 3 feet between the bottom of the infiltration practice and the seasonally high water table or bedrock layer (see also Step 8 under the Design Procedure section). Local authorities may require greater separation depths.

- **Site Location / Minimum Setbacks** – It is HIGHLY RECOMMENDED that infiltration practices not be hydraulically connected to structure foundations or pavement, to avoid seepage and frost heave concerns, respectively. If ground water contamination is a concern, it is RECOMMENDED that ground water mapping be conducted to determine possible connections to adjacent ground water wells. The following (Table 12.INF.4) minimum setbacks are REQUIRED by the Minnesota Department of Health for the design and location of infiltration practices. It will be necessary to consult local ordinances for further guidance on siting infiltration practices.

- **Karst** – It is HIGHLY RECOMMENDED that infiltration practices not be used in active karst formations without adequate geotechnical testing. See also Chapter 13 discussion on Karst features.

Conveyance

It is HIGHLY RECOMMENDED that a flow splitter or diversion structure be provided to divert the Vwq to the infiltration practice and allow larger flows to bypass the practice, unless the infiltration practice is sized to retain Vcp, Vp_{10} or Vp_{100}. Where a flow splitter is not used, it is HIGHLY RECOMMENDED that contributing drainage areas be limited to the appropriate size given the BMP and an overflow be provided within the practice to pass part of the Vwq to a stabilized watercourse or storm drain. It is also HIGHLY RECOMMENDED that overflow associated with the Vp_{10} or Vp_{100} storm (depending on local drainage criteria) be controlled such that velocities are non-erosive at the outlet point (to prevent downstream slope erosion), and that when discharge flows exceed 3 cfs, the designer evaluate the potential for erosion to stabilized areas and infiltration facilities.

Pre-treatment

It is REQUIRED that some form of pre-treatment, such as a plunge pool, sump pit, filter strip, sedimentation basin, grass channel, or a combination of these practices be installed upstream of the infiltration practice. It is HIGHLY RECOMMENDED that the following pre-treatment sizing guidelines be followed:

- Before entering an infiltration practice, stormwater should first enter a pre-treatment practice sized to treat a minimum volume of 25% of the Vwq.

- If the infiltration rate of the native soils exceeds 2 inches per hour a pre-treatment practice capable of treating a minimum volume of 50% of the Vwq should be installed.

- If the infiltration rate of the native soils exceeds 5 inches per hour a pre-treatment practice capable of treating a minimum volume of 100% of the Vwq should be installed.

It is HIGHLY RECOMMENDED that pre-treatment practices be designed such that exit velocities from the pre-treatment systems are non-erosive (less than 3 fps) and flows are evenly distributed across the width of the practice (e.g., by using a level spreader).

It is REQUIRED that some form of pre-treatment, such as a plunge pool, sump pit, filter strip, sedimentation basin, grass channel, or a combination of these practices be installed upstream of the infiltration practice.

Treatment

- **Space Occupied** – Space varies depending on the depth of the practice. Typically, infiltration trenches are three to twelve feet deep with a width less than 25 feet. A dry well is essentially a smaller version of an infiltration trench, consistent with the fact that the drainage area to an infiltration trench is typically five times greater (or larger) than that of a dry well. Underground infiltration systems are larger practices that range in depth from approximately 2 to 12 feet. The surface area of all infiltration practices is a function of MPCA's 48-hour drawdown requirement and the infiltration capacity of the underlying soils.

- **Practice Slope** – It is RECOMMENDED that the bottom of all infiltration practices be flat, in order to enable even distribution and infiltration of stormwater. It is RECOMMENDED that the longitudinal slope range only from the ideal 0% up to 1%, and that lateral slopes be held at 0%.

- **Side Slopes** – It is HIGHLY RECOMMENDED that the maximum side slopes for an infiltration practice be 1:3 (V:H).

- **Depth** – The depth of an infiltration practice is a function of the maximum drawdown time and the design infiltration rate. The REQUIRED drawdown time for infiltration practices is 48 hours or less, and so the depth of the practice should be determined accordingly.

- **Ground-water Protection** – It is REQUIRED that runoff from potential stormwater hotspots (PSHs) not be infiltrated unless adequate pre-treatment has been provided. Infiltration of runoff from confirmed hotspot areas, industrial areas with exposed significant materials, or vehicle fueling and maintenance areas is PROHIBITED.

- **Aesthetics** – Infiltration basins can be effectively integrated into the site planning process, and aesthetically designed as attractive green spaces planted with native vegetation. Infiltration trenches are less conducive to site aesthetics, but the surface of trenches can be designed with turf cover crops if desired.

Landscaping

It is REQUIRED that impervious area construction be completed and pervious areas established with dense and healthy vegetation prior to introduction of stormwater into an infiltration practice.

It is RECOMMENDED that vegetation associated with infiltration practices be established to blend into the surrounding area, that native species be used wherever possible. It is HIGHLY RECOMMENDED that deep rooted plants such as prairie grass be used, because they increase the infiltration capacity of the underlying soils. Dry wells and infiltration trenches can be covered with permeable topsoil and planted with grass to match the surrounding landscape.

Due to soil compaction concerns, it is HIGHLY RECOMMENDED that infiltration areas not be used for recreational purposes unless a soil amendment is used to off-set compaction.

It is HIGHLY RECOMMENDED that vegetation associated with infiltration practices be regularly maintained and bare areas seeded. Mowing

It is REQUIRED that impervious area construction be completed and pervious areas established with dense and healthy vegetation prior to introduction of stormwater into an infiltration practice.

- *Use low-impact earth moving equipment*
- *DO NOT Overexcavate*

practices can be used to maintain native vegetation.

It is RECOMMENDED that soil testing be conducted in infiltration practices, to determine if fertilizer application is warranted. Incorporating mulch or compost into the soil or planting with salt tolerant grasses can counter soil fertility problems caused by high chloride concentrations.

Safety

Dry wells, infiltration trenches and subsurface infiltration systems do not pose any major safety hazards. Infiltration basins should have similar side slope considerations as ponds and wetlands.

If a dry well or infiltration trench is greater than five feet deep, it is REQUIRED that OSHA health and safety guidelines be followed for safe construction practices. Additional information on safety for construction sites is available from OSHA. Use the following link to research safety measures for excavation sites:

http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10930

When riser pipe outlets are used in infiltration basins, it is HIGHLY RECOMMENDED that they be constructed with manholes that either have locks or are sufficiently heavy to prevent easy removal.

Fencing of dry wells and infiltration trenches is neither necessary nor desirable. Infiltration basins may warrant fencing in some situations.

III. Construction Details

CADD based details for pond systems are contained in Appendix D. The following details, with specifications, have been created for infiltration systems:

- Infiltration Basin
- Infiltration Trench
- Subsurface Infiltration System
- Inlet/outlet Structures

IV. Construction Specifications

Given that the construction of infiltration practices incorporates techniques or steps which may be considered non-standard, it is RECOMMENDED that the construction specifications include the following format and information:

I. Temporary Erosion Control

- Installation prior to site disturbance
  - Catch basin/inlet protection
  - Use of BMP as temporary sedimentation basin

II. Excavation, Backfill and Grading

- Timing of grading of infiltration practices (relative to total site development)
- Use of low-impact, earth moving equipment
- Controls to ensure site is not over-excavated
- Restoration in the event of sediment accumulation during construction of practice
- Gravel backfill specifications
- Gravel filter specifications
- Filter fabric specifications
- Observation well specifications

III. Native Plants, Planting and Transplanting (MN Plant List in Appendix E of the Manual)

- Site preparation of planting areas

Table 12.INF.5. Typical Maintenance Problems for Infiltration Trenches and Basins

Problem	Practices Applied To	Comments
Clogging, sediment deposition	Both	Key issue for infiltration practice. Requires vigilant inspection and maintenance.
Surface Vegetation	Both	Often important to maintain vigorous growth at the base of infiltration practices (basins). Important to restrict woody vegetation from the surface of infiltration trenches.
Erosion of contributing land or in channels leading to practice	Both	In these practices, it is important to monitor not only the practice itself, but also upland infiltration to minimize the sediment load.
Damage to filter fabric	Trench	Infrequent but important maintenance concern.
Scouring at Inlet	Both	Similar issues to Ponds. Need to promote non-erosive flows that are evenly distributed
Access Issues	Both	Similar issues to Ponds. Need access for inspection and maintenance.
Concrete Failure	Basins, if they include a riser structure	Similar issues to ponds and wetlands.
Problems with the Embankment	Basins	Similar issues to dry ponds.

- Timing of native seeding and native planting
- Weed control
- Watering of plant material

IV. Construction Sequence Scheduling

- Temporary construction access
- Location of silt fence installation to protect BMPs and downgradient receiving waters
- Removal and storage of excavated material
- Installation of underground utilities
- Rough grading
- Seeding and mulching disturbed areas
- Road construction
- Final grading
- Site stabilization
- Installation of semi-permanent and permanent erosion control measures
- Silt fence removal (often forgotten bu an essential step)

V. Construction Observation

- Adherence to construction documents
- Verification of physical site conditions
- Erosion control measures installed appropriately

It is HIGHLY RECOMMENDED that designs include an observation well consisting of an anchored six-inch diameter perforated PVC pipe fitted with a cap to facilitate periodic inspection and maintenance.

V. Operation and Maintenance

Overview

Effective long-term performance of infiltration practices requires an infiltration management plan (HIGHLY RECOMMENDED), performance monitoring (HIGHLY RECOMMENDED), and a dedicated and routine maintenance schedule with clear guidelines and schedules (REQUIRED).

The infiltration management plan (operation plan) should address the following items: periods of inundation, wet/dry cycling of soils, operating instructions for drawdown valves, gates and removable weirs.

The monitoring plan should address the following items: inspection and efficiency assessment, water quality monitoring, monitoring of ground-water elevations, long-term infiltration capacity and plant tolerances.

Elements to be considered for the development of a maintenance plan are broken into the following categories: Design Phase Maintenance Considerations; Construction Phase Maintenance Considerations; and Post-Construction Maintenance Considerations. In general terms, the most frequently cited maintenance concern for infiltration practices is clogging caused by organic matter and fine silts. Common operational problems include:

- Clogging and sediment deposition
- Erosion of contributing land or in channels leading to the practice
- Maintaining appropriate surface vegetation

Table 12.INF.5 provides a summary of common problems for infiltration trenches and basins.

Design Phase Maintenance Considerations

Implicit in the design guidance in the previous sections is the fact that many design elements for infiltration systems can minimize the maintenance burden and maintain pollutant removal efficiency. Among them are:

- Providing easy access (typically 8 feet wide) to infiltration practices for routine maintenance is REQUIRED. Open lawn areas are RECOMMENDED locations for infiltration practices because of their accessibility.
- It is REQUIRED that a way to visually verify proper system operation be installed with each infiltration practice. It is HIGHLY RECOMMENDED that every dry well, infiltration trench and subsurface infiltration system design include an observation well consisting of an anchored six-inch diameter perforated PVC pipe fitted with a cap to facilitate periodic inspection and maintenance. It is also HIGHLY RECOMMENDED that infiltration basins include a draw down device that can be used for winter diversion and to conduct regular maintenance.
- It is HIGHLY RECOMMENDED that a mechanism such as a multi-stage outlet structure be incorporated into the design of the pre-treatment and infiltration practices to facilitate draining for maintenance purposes.

Construction Phase Maintenance Considerations

Infiltration practices are particularly vulnerable during the construction phase for two reasons. First, if the construction sequence is not followed correctly, construction sediment can clog the practice. In addition, heavy construction can result in compaction of the soil, which can then reduce the soil's infiltration rate. For this reason, a careful construction sequence needs to be followed. Critical construction elements for infiltration practices are as follows:

It is REQUIRED that infiltration systems not be excavated to final grade until the contributing drainage area has been constructed and fully stabilized.

Avoid excessive compaction

- It is REQUIRED that in order to prevent soil compaction, the proposed infiltration area be staked off and marked during construction to prevent heavy equipment and traffic from traveling over it. In addition, it is HIGHLY RECOMMENDED that the side walls of dry wells and infiltration trenches be roughened if they have been smeared by heavy equipment.

Stabilize Vegetation Before and After Construction

- Excessive sediment loadings can occur without the use of proper erosion and sediment control practices during the construction process. It is REQUIRED that upland drainage areas be properly stabilized with a thick layer of vegetation, particularly immediately following construction, to reduce sediment loads. If infiltration practices are in-place during construction activities, it is REQUIRED that sediment and runoff be kept away the infiltration area, such as with diversion berms and soil-stabilizing vegetation around the perimeter of the practice.

Table 12.INF.6 Typical Maintenance Activities for Infiltration Trenches(Source: EPA, 1999)

Activity	Schedule
• Replace pea gravel/topsoil and top surface filter fabric (when clogged).	As needed
• Ensure that contributing area, practice and inlets are clear of debris. • Ensure that the contributing area is stabilized. • Remove sediment and oil/grease from pre-treatment devices, as well as overflow structures. • Mow grass filter strips should be mowed as necessary. Remove grass clippings. • Repair undercut and eroded areas at inflow and outflow structures	Monthly
• Inspect pre-treatment devices and diversion structures for sediment build-up and structural damage. • Remove trees that start to grow in the vicinity of the trench.	Semi-annual Inspection
• Disc or otherwise aerate basin bottom. De-thatch basin bottom.	Annually
• Scrape basin bottom and remove sediment. Restore original cross-section and infiltration rate. Seed or sod to restore ground cover.	Every 5 years
• Perform total rehabilitation of the trench to maintain design storage capacity. • Excavate trench walls to expose clean soil.	Upon Failure

Correctly Install Filter Fabrics

► Large tree roots should be trimmed flush with the sides of dry wells and infiltration trenches to prevent puncturing or tearing of the filter fabric during subsequent installation procedures. When laying out the geotextile, the width should include sufficient material to compensate for perimeter irregularities in the dry well

Table 12.INF.7: Infiltration Practices Cost Components

Implementation Stage	Primary Cost Components	Basic Cost Estimate	Other Considerations
Site Preparation	Tree & plant protection	Protection Cost ($/acre) x Affected Area (acre)	Removal of existing structures, topsoil removal and stockpiling
	Infiltration area protection	Silt fence cost ($/'foot) x Perimeter of infiltration area	
	Clearing & grubbing	Clearing Cost ($/acre) x Affected Area (acre)	
	Topsoil salvage	Salvage Cost ($/acre) x Affected Area	
Site Formation	Excavation / grading	X-ft Depth Excavation Cost ($/acre) x Area (acre)	Soil & rock fill material, tunneling
	Hauling material offsite	Excavation Cost x (% of Material to be hauled away)	
Structural Components	Vault structure (for underground infiltration)	($/structure)	Pipes, catchbasins, manholes, valves, vaults
	Media (for infiltration trenches)	Media cost ($/cubic yard) X filter volume (cubic yard)	
	Geotextile	Geotextile cost ($/cy) x area of trench, including walls	
	inlet structure	($/structure)	
	Overflow structure	($/structure)	
	Observation well	($/structure)	
Site Restoration	Soil preparation	Topsoil or amendment cost ($/acre) x Area (acre)	Tree protection, soil amendments, seed bed preparation, trails
	Seeding	Seeding Cost ($/acre) x Seeded Area (acre)	
	Filter strip	Sod cost ($/square foot) x filter strip area	
	Planting / transplanting	Planting Cost ($/acre) x Planted Area (acre)	
Annual Operation, Maintenance, and Inspection	Sediment removal	Removal Cost ($/acre) x Area (acre) x Frequency (1x / 5yr)	Vegetation maintenance, cleaning of structures
	Debris removal	Removal Cost ($/acre) x Area (acre) x Frequency (2x / 1yr)	
	Inspection	Inspection Cost ($) x Inspection Frequency (6x / 1 yr)	
	Mowing (for some vegetative filters)	Mowing Cost ($) x Mowing Frequency (6x / 1 yr)	

or trench and for a 6-inch minimum top overlap. The filter fabric itself should be tucked under the sand layer on the bottom of the dry well of infiltration trench, and stones or other anchoring objects should be placed on the fabric at the trench sides to keep the excavation open during windy periods. Voids may occur between the fabric and the excavated sides of the practice. Natural soils should be placed in any voids to ensure fabric conformity to the excavation sides.

Carefully Finish Final Grading

- Initial infiltration basin excavation should be carried to within 2 feet of the final elevation of the basin floor. It is REQUIRED that infiltration systems not be excavated to final grade until the contributing drainage area has been constructed and fully stabilized. The final phase excavation should remove all accumulated sediment and be done by light tracked equipment to avoid compaction of the basin floor and provide a well-aerated, highly porous surface texture.

Keep Infiltration Practices "Off-line" until Construction Is Complete

- It is REQUIRED that sediment and runoff be kept completely away from the infiltration area during construction. Thus, infiltration practices should never serve as sediment control devices during site construction. It is HIGHLY RECOMMENDED that construction of infiltration practices be suspended during snowmelt or rainfall, in order to prevent soil smearing, clumping, or compaction.

Establish Permanent Vegetation

- Establishing dense vegetation on the basin side slopes is HIGHLY RECOMMENDED, to reduce erosion and sloughing and provide a natural means of maintaining relatively high infiltration rates. Vegetative cover at inflow points to the basin is also HIGHLY RECOMMENDED to provide erosion protection and reduce sediment accumulation. The use of native grasses is RECOMMENDED for seeding primarily due to their adaptability to local climates and soil conditions.

- Inspections during construction are needed to ensure that the infiltration practice is built in accordance with the approved design and standards and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction to ensure that the contractor's interpretation of the plan is acceptable to the designer. An example construction phase inspection checklist for both infiltration basins and infiltration trenches are provided in Appendix D.

Post-Construction Operation and Maintenance

A maintenance plan clarifying maintenance responsibility is REQUIRED. Effective long-term operation of infiltration practices necessitates a dedicated and routine maintenance schedule with clear guidelines and schedules. Some important post-construction maintenance considerations are provided below. A more detailed checklist of maintenance activities and associated schedules is provided in Appendix D.

- A legally binding and enforceable maintenance agreement should be executed between the practice owner and the local review authority.

- Adequate access must be provided for all infiltration practices for inspection, maintenance, and landscaping upkeep, including appropriate equipment and vehicles.

...it is RECOMMENDED that a minimum of three soil borings or pits be dug (in the same location as the proposed infiltration practice)...

Table 12.INF.8 Summary of Infiltration Practices for Given Drainage Areas.	
Infiltration Practice	**Drainage Area**
Infiltration Basin	5 to 50 acres
Infiltration Trench	less than 5 acres
Dry Wells	less than one acre
Underground Infiltration Systems	less than 10 acres

- ► General infiltration trench maintenance activities and schedule are provided in Table 12.INF.6.

VI. Construction and Maintenance Costs

Chapter 6 outlines a cost estimation method which site planners could use to compare the relative construction and maintenance costs for structural best management practices. These curves are excellent for purposes of comparison; however, it is recommended that construction and maintenance budgets should be based on site specific information. Utilizing Table 12.INF.7 and the cost estimation worksheet in Appendix D, will allow designers to avoid over or under estimation of fixed costs.

Table 12.INF.7 lists the specific site components that are specific to infiltration practices. Not included in this table are those cost items that are common to all construction projects, such as mobilization, traffic control, erosion and sediment control, permitting, etc. A more detailed worksheet, utilizing 2005 construction prices, is contained in Appendix D.

VII. Design Procedure

The following steps outline a recommended design procedure for infiltration practices in compliance with the MPCA Permit for new construction. Design recommendations beyond those specifically required by the permit are also included and marked accordingly.

Design Steps

Step 1. Make a preliminary judgment as to whether site conditions are appropriate for the use of an infiltration practice, and identify the function of the practice in the overall treatment system.

A. Consider basic issues for initial suitability screening, including:

- ► Site drainage area
- ► Site topography and slopes
- ► Soil infiltration capacity
- ► Regional or local depth to ground-water and bedrock
- ► Site location/minimum setbacks
- ► Presence of active Karst

B. Determine how the infiltration practice will fit into the overall stormwater treatment system:

- ► Decide whether the infiltration practice is the only BMP to be employed, or if are there other BMPs addressing some of the treatment requirements.
- ► Decide where on the site the infiltration practice is most likely to be located.

Step 2. Confirm design criteria and applicability.

A. Determine whether the infiltration practice must comply with the MPCA Permit.

B. Check with local officials, watershed organizations, and other agencies to determine if there are any additional restrictions and/or surface water or

Table 12.INF.9 Design Infiltration Rates

Hydrologic Soil Group	Infiltration Rate [inches/hour]	Soil Textures	Corresponding Unified Soil Classification
A	1.6*	Gravel, sandy gravel and silty gravels	**GW** - Well-graded gravels, sandy gravels **GP** – Gap-graded or uniform gravels, sandy gravels **GM** - Silty gravels, silty sandy gravels **SW** - Well-graded, gravelly sands
	0.8	Sand, loamy sand or sandy loam	**SP** - Gap-graded or uniform sands, gravelly sands
B	0.6	Silt loam	**SM** - Silty sands, silty gravelly sands
	0.3	Loam	**MH** – Micaceous silts, diatomaceous silts, volcanic ash
C	0.2	Sandy clay loam	**ML** - Silts, very fine sands, silty or clayey fine sands
D	< 0.2	Clay loam, silty clay loam, sandy clay, silty clay or clay	**GC** – Clayey gravels, clayey sandy gravels **SC** – Clayey sands, clayey gravelly sands **CL** – Low plasticity clays, sandy or silty clays **OL** – Organic silts and clays of low plasticity **CH** – Highly plastic clays and sandy clays **OH** – Organic silts and clays of high plasticity

* This rate is consistent with the infiltration rate provided for the lower end of the Hydrologic Soil Group A soils in the Wisconsin Department of Natural Resources Conservation Practice Standard: Site Evaluation for Stormwater Infiltration.

Source: Thirty guidance manuals and many other stormwater references were reviewed to compile recommended infiltration rates. All of these sources use the following studies as the basis for their recommended infiltration rates: (1) Rawls, Brakensiek and Saxton (1982); (2) Rawls, Gimenez and Grossman (1998); (3) Bouwer and Rice (1984); and (4) Urban Hydrology for Small Watersheds (NRCS). SWWD, 2005, provides field documented data that supports the proposed infiltration rates.

watershed requirements that may apply.

Step 3. Perform field verification of site suitability.

- ► If the initial evaluation indicates that an infiltration practice would be a good BMP for the site, it is RECOMMENDED that a minimum of three **soil borings or pits** be dug (in the same location as the proposed infiltration practice) to verify soil types and infiltration capacity characteristics and to determine the depth to groundwater and bedrock.

- ► It is RECOMMENDED that the minimum depth of the soil borings or pits be five feet below the bottom elevation of the proposed infiltration practice.

- ► It is HIGHLY RECOMMENDED that soil profile descriptions be recorded and include the following information for each soil horizon or layer (Source: Site Evaluation for Stormwater Infiltration, Wisconsin Department of Natural Resources Conservation Practice Standards, 2004):

1. Thickness, in inches or decimal feet
2. Munsell soil color notation
3. Soil mottle or redoximorphic feature color, abundance, size and contrast
4. USDA soil textural class with rock fragment modifiers
5. Soil structure, grade size and shape
6. Soil consistency, root abundance and size
7. Soil boundary
8. Occurrence of saturated soil, impermeable layers/lenses, ground-water, bedrock or disturbed soil

- ► It is HIGHLY RECOMMENDED that the field verification be conducted by a qualified geotechnical professional.

Step 4. Compute runoff control volumes.

Calculate the Water Quality Volume (Vwq), Channel Protection Volume (Vcp), Overbank Flood Protection Volume (Vp_{10}), and the Extreme Flood Volume (Vp_{100}) (see Chapter 10).

If the infiltration practice is being designed to meet the requirements of the MPCA Permit, the REQUIRED treatment volume is the water quality volume of ½ inch of runoff from the new impervious surfaces created from the project (or 1 inch for certain protected waterbodies). If part of the overall Vwq is to be treated by other BMPs, subtract that portion from the Vwq to determine the part of the Vwq to be treated by the infiltration practice.

The design techniques in this section are meant to maximize the volume of stormwater being infiltrated. If the site layout and underlying soil conditions permit, a portion of the Channel Protection Volume (Vcp), Overbank Flood Protection Volume (Vp_{10}), and the Extreme Flood Volume (Vp_{100}) may also be managed in the infiltration practice (see Step 7).

Details on the Unified Stormwater Sizing Criteria are found in Chapter 10.

Step 5. Select design variant based on Physical Suitability Evaluation.

Once the Physical Suitability Evaluation is complete, it is HIGHLY RECOMMENDED that the designer apply the better site design principles in sizing and locating the infiltration practice(s) on the development site. Given the water quality volume and the drainage area, select the appropriate infiltration practice for the first iteration of the design process.

Note: Information collected during the site suitability evaluation (see Steps 1 and 3) should be used to explore the potential for multiple infiltration practices versus relying on a single infiltration facility. The use of smaller infiltration practices dispersed around a development is usually more sustainable than a single regional facility that is more likely to have maintenance and ground-water mounding problems (Source: Site Evaluation for Stormwater Infiltration, Wisconsin Department of Natural Resources Conservation Practice Standards, 2004).

Step 6. Size infiltration practice (Note: Steps 6, 7, 8 and 9 are iterative).

After following the steps outlined above, the designer will presumably know the location of naturally occurring permeable soils, the depth to the water table, bedrock or other impermeable layer, and the contributing drainage area. While the first step in sizing an infiltration practice is selecting the type of infiltration practice for the site, the basic design procedures are very similar.

A. Infiltration Location

Given the steps performed in the Physical Suitability Evaluation, identify the most suitable location for the infiltration practice. Pre-treatment prior to infiltration is REQUIRED to remove total

Table 12.INF.10 Total Correction Factors Divided into Measured Infiltration Rates

Ratio of Design Infiltration Rates[2]	Correction Factor
1	2.5
1.1 to 4.0	3.5
4.1 to 8.0	4.5
8.1 to 16.0	6.5
16.1 or greater	8.5

[1] The method used to evaluate measured infiltration rates was developed by the Wisconsin Department of Natural Resources and is published in *Site Evaluation for Stormwater Infiltration (1002) Wisconsin Department of Natural Resources Conservation Practice Standards 02/04.*

[2] Ratio is determined by dividing the design infiltration rate (Table 12.INF.9) for the textural classification at the bottom of the infiltration device by the design infiltration rate (Table 12.INF.9) for the textural classification of the least permeable soil horizon. The least permeable soil horizon used for the ratio should be within five feet of the bottom of the device or to the depth of the limiting layer.

suspended solids and other pollutants associated with stormwater (see Step 9).

B. Infiltration Rates

If the infiltration rate is not measured, the following table provides infiltration rates for the design of infiltration practices. These infiltration rates represent the long-term infiltration capacity of a practice and are not meant to exhibit the capacity of the soils in the natural state. Select the design infiltration rate from the Table 12.INF.9 based on the least permeable soil horizon within the first five feet below the bottom elevation of the proposed infiltration practice.

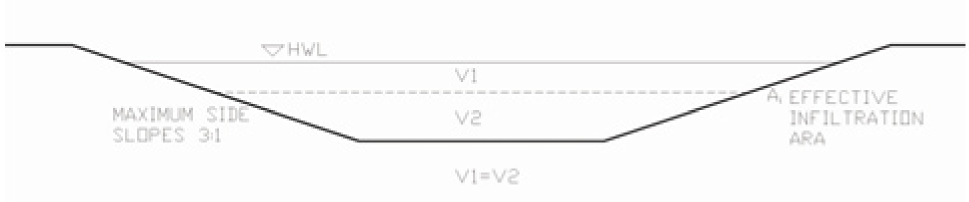
The infiltration capacity and existing hydrologic regime of natural basins are inheritably different than constructed practices and may not meet the General Permit requirements for constructed practices. In the event that a natural depression is being proposed to be used as an infiltration system, the design engineer must demonstrate the following information: infiltration capacity of the system under existing conditions (inches/hour), existing drawdown time for the high water level (HWL) and a natural overflow elevation. The design engineer should also demonstrate that operation of the natural depression under post-development conditions mimics the hydrology of the system under pre-development conditions.

If the infiltration rates are measured the tests shall be conducted at the proposed bottom elevation of the infiltration practice. If the infiltration rate is measured with a double-ring infiltrometer the requirements of ASTM D3385 shall be used for the field test.

The measured infiltration rate shall be divided by a correction factor selected from Table 12.INF.10. The correction factor adjusts the measured infiltration rates for the occurrence of less permeable soil horizons below the surface and the potential variability in the subsurface soil horizons throughout the infiltration site. This correction factor also accounts for the long-term infiltration capacity of the stormwater management facility.

To select the correction factor from Table 12.INF.10, determine the ratio of the design infiltration rates for each location an infiltration measurement was performed. To determine this ratio, the design infiltration rate (Table 12.INF.9) for the surface textural classification is divided by the design infiltration rate for the least permeable soil horizon. For example, a device with a loamy sand (0.8"/hr.) at the surface and least permeable layer of loam (0.3"/hr.) will have a design infiltration rate ratio of about 2.7 and thus a correction factor of 3.5. The depth of the least permeable soil horizon should be within five feet of the proposed bottom

Figure 12.INF.5 Effective Infiltration Areas for Side Slopes Less Than 1V:3H



of the device or to the depth of a limiting layer. In this exercise, if an infiltration rate of 2.5”/hr is measured, the adjustment rate would be 0.71”/hr.

- Depth – The depth of an infiltration practice is a function of the maximum drawdown time and the design infiltration rate. Given the assumed infiltration rate for the practice, determine the maximum depth as follows:

$$D = i \times t$$

Where:

D = maximum depth of practice (inches)

i = infiltration rate (inches/hour)

t = maximum drawdown time (48 hours)

C. Effective Infiltration Area

Given the water quality volume (Vwq) and the maximum depth of the practice (D) calculate the effective infiltration area where the effective infiltration area is defined as the area of the facility that is used to infiltrate runoff and does not include the area used for site access, berms and/or pre-treatment.

For above ground practices that are rectangular in nature (infiltration basins with 1V:3H side slopes or steeper)

$$A_i = V_w/D$$

Where:

A_i = effective infiltration area at the bottom of practice (ft^2)

V_w = design volume (e.g. Vwq) (ft^3)

D = maximum depth of practice (feet) Note: *bottom of the infiltration practice must be at least three feet from the seasonally high ground-water table.*

For above ground practices that have angular sides slopes (infiltration basins with sides slopes shallower that 1V:3H)

$$A_i = V_w/D$$

Where:

A_i = effective infiltration area at half the volume of the practice* (*see figure below)* (ft^2)

V_w = design volume (e.g. Vwq) (ft^3)

D = maximum depth of practice (feet) Note: *bottom of the infiltration practice should be at least three feet from the seasonally high ground-water table.*

* Since there is potentially a significant amount of infiltration that could occur though the sides of the practice, the design engineer should take this surface area into consideration thereby potentially reducing the overall footprint of the stormwater infiltration practice.

For underground practices (e.g. infiltration trenches, dry wells, subsurface infiltration practices):

$$A_i = V_w/nD$$

Where:

A_i = effective infiltration area is the sum of the bottom area and the sides of the practice* (ft^2)

V_w = design volume (e.g. Vwq) (ft^3)

n = porosity of filter media (range of porosity values for sands and gravels: 0.25 to 0.5)

D = maximum depth of practice (feet) Note: *maximum of 12 feet, and separated by at least three feet from seasonally high ground-water table*

* Since underground facilities have potentially more surface area in contact with permeable soils, these practices should take these areas into consideration. Only that portion of the sides that is in contact with naturally permeable material should be used in calculating the effective infiltration area of the practice.

For subsurface infiltration practices, use the procedure described above or technique

recommended by manufacturer and approved by the local or state authority.

D. Volume –

The preliminary volume of the infiltration practice is determined by multiplying the average basin area by the depth of the practice.

The total storage volume for infiltration basins and underground infiltration systems is:

$$V = A \times D$$

Where:

V = Design volume for infiltration basin and underground infiltration system (ft^3)

A = average basin area (square feet)

D = depth of practice (feet)

For those practices that do not involve a media filter (e.g. infiltration basin and underground infiltration systems) this volume represents the total storage volume (design volume) of the practice. For those practices which do involve a media filter (e.g. infiltration trenches and dry wells) this volume represents the void space and the total storage volume will be greater. The following formula can be used to determine the total storage volume (design volume):

The total storage volume for infiltration trenches and dry wells

$$V_T = A \times n \times D_i$$

Where:

V_T = Design volume for infiltration trenches and dry wells (ft^3)

A = average basin area (square feet)

n = porosity of filter media (range of porosity values for sands and gravels: 0.25 to 0.5)

D = depth of practice (feet)

Step 7. Size outlet structure and/or flow diversion structure, if needed (Note: Steps 6, 7, 8 and 9 are iterative).

It is HIGHLY RECOMMENDED that the outlet for the infiltration practice shall safely convey stormwater using all of the following mechanisms (Infiltration Basin, Wisconsin Department of Natural Resources Conservation Practice Standard, 10/04).

- Drawdown valve – Infiltration systems may be designed with a drawdown valve for the removal of standing water for maintenance and winter diversion.
- Emergency spillway – A means to release discharge in excess of the infiltration volume safely into the downstream stormwater conveyance system is REQUIRED.
- Freeboard – It is HIGHLY RECOMMENDED that two feet of freeboard be provided from the 100-year flood elevation of the infiltration practice to the lowest basement floor elevation of residential, commercial, industrial and institutional buildings located adjacent to the BMP, unless local requirements recommend otherwise.
- Drop Structure – Infiltration trenches or subsurface infiltration systems may be designed with a drop structure sized to handle the overflow. This additional volume of stormwater may be directed into the existing stormwater system or it may be diverted to a downstream BMP.

Step 8. Perform ground-water mounding analysis (Note: Steps 6, 7, 8 and 9 are iterative).

Ground water mounding, the process by which a mound of water forms on the water table as a result of recharge at the surface, can be a limiting factor in the design and performance of infiltration practices. A minimum of 3 feet of separation between the bottom of the infiltration practice and **seasonally saturated soils** (or from bedrock) is REQUIRED (5 feet RECOMMENDED) to maintain the hydraulic capacity of the practice and provide adequate water quality treatment. A ground water mounding analysis is RECOMMENDED to verify this separation for infiltration practices.

The most widely known and accepted analytical methods to solve for ground water mounding are based on the work by Hantush (1967) and Glover (1960). The maximum ground water mounding potential should be determined through the use of available analytical and numerical methods. Detailed ground water mounding analysis should be conducted by a trained hydrogeologist or equivalent as part of the site design procedure.

Step 9. Determine pre-treatment volume and design pre-treatment measures (Note: Steps 6, 7, 8 and 9 are iterative).

See the section on pre-treatment earlier in this section for specific pre-treatment design guidance

Step 10. Check volume, peak discharge rates and period of inundation against State, local and watershed organization requirements (Note: Steps 6, 7, 8 and 9 are iterative).

Follow the design procedures identified in the Unified Sizing Criteria (Chapter 10) section of the Manual to determine the volume control and peak discharge requirements for water quality, recharge, channel protection, overbank flood and extreme storm.

Perform hand calculations or model the proposed development scenario using a surface water model appropriate for the hydrologic and hydraulic design considerations specific to the site (see also Chapter 8 and Appendix B of the Manual). This includes defining the parameters of the infiltration practice defined above: elevation and area (defines the storage volume), infiltration rate and method of application (effective infiltration area), and outlet structure and/or flow diversion information. The results of this analysis can be used to determine whether or not the proposed design meets the applicable requirements. If not, the design will have to be re-evaluated (back to Step 5).

The following items are specifically REQUIRED by the MPCA Permit:

- **Volume** – Infiltration or filtration systems shall be sufficient to infiltrate or filter a water quality volume of ½ inch of runoff from the new impervious surfaces created by the project (or 1 inch for certain protected waterbodies). If this criterion is not met, increase the storage volume of the infiltration practice or treat excess water quality volume (Vwq) in an upstream or downstream BMP (see Step 5).

- **Peak Discharge Rates** – Since most infiltration systems are not designed for quantity control they generally do not have peak discharge limits. However outflow

  must be limited such that erosion does not occur down gradient.

- **Period of Inundation** – Infiltration practices shall discharge through the soil or filter media in 48 hours or less. Additional flows that cannot be infiltrated or filtered in 48 hours should be routed to bypass the system through a stabilized discharge point. This criterion was established to provide the following: wet-dry cycling between rainfall events; unsuitable mosquito breeding habitat; suitable habitat for vegetation; aerobic conditions; and storage for back-to-back precipitation events. The period of inundation is defined as the time from the high water level in the practice to 3 to 6 inches above the bottom of the facility. It is assumed that this range is less than 1/5 the bounce in the infiltration practice.

Other design requirements may apply to a particular site. The applicant should confirm local design criteria and applicability (see Step 3).

Step 11. Prepare Vegetation and Landscaping Plan.

A landscaping plan for an infiltration basin or trench should be prepared to indicate how the enhanced swale system will be stabilized and established with vegetation. Landscape design should specify proper grass species and wetland plants based on specific site, soils and hydric conditions present along the channel. Further information on plant selection and use occurs in Appendix E of the manual.

Step 12. Prepare Operation and Maintenance (O&M) Plan.

See Operation and Maintenance section for guidance on preparing an O&M plan.

Step 13. Prepare Cost Estimate.

See Cost Considerations section for guidance on preparing a cost estimate that includes both construction and maintenance costs.

VIII. Links to Other Manuals

Georgia Stormwater Management Manual. 2001. Atlanta Regional Commission. http://www.georgiastormwater.com/

Vermont Stormwater Management Manual. 2002. http://www.vtwaterquality.org/stormwater.htm.

Wisconsin DNR Site Evaluation for Stormwater Infiltration Conservation Practice Standard 1002. 2004. http://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm#Post.

Wisconsin DNR Infiltration Basin Conservation Practice Standard 1003. 2004. http://dnr.wi.gov/org/water/wm/nps/stormwater/techstds.htm#Post.

IX. References

Bouwer, H. and R. C. Rice. 1989. Effect of Water Depth in Ground-water Recharge Basins on Infiltration. Journal of Irrigation and Drainage Engineering, Vol. 115, No. 4, pp. 556-567.

Georgia Stormwater Management Manual. 2001.

Glover, R., 1960. Mathematical Derivations as Pertain to Ground-water Recharge. Report CER60REG70. Agricultural Research Service, USDA, Fort Collins, Colorado. 81 pp.

Hantush, M., 1967. Growth and Decay of Ground-water-Mounds in Response to Uniform Percolation. Water Resources Research, 3(1): 227-234.

Rawls, W., D. Brakensiek, and K. Saxton, 1982. Estimation of Soil Water Properties, Transactions of the American Society of Agricultural Engineers. Vol. 25, No. 5, pp. 1316 – 1320 and 1328.

Rawls, W., D. Giminez, and R. Grossman, 1998. Use of Soil Texture, Bulk Density and Slope of water Retention Curve to Predict Saturated Hydraulic Conductivity, ASAE. Vol. 41(4), pp. 983 – 988.

Metropolitan Council Urban Small Sites Best Management Practice Manual. 2001.

Minnesota Pollution Control Agency Stormwater Best Management Practices Manual. 2000.

Natural Resources Conservation Service, 1986. Urban Hydrology for Small Watersheds, Technical Release 55 (TR-55). ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

South Washington Watershed District (SWWD), 2005. 2004 Infiltration Monitoring Program Final Report. Emmons and Olivier Resources, Inc.

United States Department of Agriculture Natural Resources Conservation Service. TR-55, Urban Hydrology for Small Watersheds. Washington D.C., 1975.

U.S. Environmental Protection Agency, When are Storm Water Discharges Regulated as Class V Wells, June 2003

University of Wisconsin – Extension Wisconsin Storm Water Manual: Technical Design Guidelines for Storm Water Management Practices. 2000.

Winer, R. 2000. National Pollutant Removal Performance Database.

Wisconsin Department of Natural Resources Site Evaluation for Stormwater Infiltration Conservation Practice Standard 1002. 2004.

Wisconsin Department of Natural Resources Infiltration Basin Conservation Practice Standard 1003. 2004.

Wisconsin Department of Natural Resources. Personal conversation with Roger Bannerman. July 2005.

STORMWATER PONDS

Stillwater, MN

Definition:

A constructed basin situated to receive local stormwater runoff and hold designated volumes of runoff for specified periods of time. The objectives are to improve water quality through settling and biological uptake, and prevent downstream channel degradation or flood damage through storage and outflow rate reduction.

KEY CONSIDERATIONS

Design Criteria (for new construction):

- Irregularly shaped with minimum length to width ratio of 1.5:1
- Permanent pool volume of 1800 cubic feet per acre draining to pond.
- Permanent pool depth 3' minimum, 10' maximum at deepest points
- Extended detention (ED) storage sufficient to treat V_{WQ}
- Pre-treatment required (sediment forebay sized at 10% of pond area recommended)
- Stabilized emergency overflow and energy dissipation at all outlets
- Side slopes not to exceed 1V:3H

Benefits:

- Able to effectively reduce many pollutant loads and control runoff flow rates
- Relatively straightforward design procedure
- Potential wildlife habitat and aesthetic or recreational enhancement
- May be used as temporary sedimentation basin during construction

Limitations:

- Relatively large space requirement
- Tends to increase water temperature and may cause downstream thermal impact
- Potential for nuisance insects or odor
- Problematic for areas of low relief, high water table, or near-surface bedrock
- Possible safety concerns

MANAGEMENT SUITABILITY

Med	Water Quality (V_{WQ})
High	Channel Protection (VCP)
High	Overbank Flood Protection (V_{P10})
High	Extreme Flood Protection (V_{P100})
Low	Recharge Volume (VRE)

MECHANISMS

	Infiltration
	Screening/ Filtration
	Temperature Control
X	Settling
X	Evaporation
	Transpiration
	Soil Adsorption (limited)
X	Biological/ Micro. Uptake

POLLUTION REMOVAL

80%	Total Suspended Solids
40%/30%	Nutrients - Total Phosphorus/ Total Nitrogen
60%	Metals - Cadmium, Copper, Lead, and Zinc
70%	Pathogens - Coliform, Streptococci, E. Coli
80%	Toxins - Chloride, Hydrocarbon, Pesticide

SITE FACTORS

25 AC Min*	Drainage Area *10 AC possible if hydrology capable of supporting water levels
25%	Max. Site Slope
0*	Min. Depth to Bedrock *2 ft in PSH areas
0*	Min. Depth to Seasonally High Water Table *pond bottom must be above bedrock
C,D Preferred	NRCS Soil Type *A and B soils require liners
Poor*	Freeze/ Thaw Suitability *unless adapted with additional storage for snowmelt

Description:

Stormwater ponds are constructed basins placed in the landscape to capture stormwater runoff. The pond is graded and outlet structures are designed in such a way that specified volumes of water (part or all of the $\mathbf{V_{WQ}}$, **VCP**, $\mathbf{V_{P10}}$, and $\mathbf{V_{P100}}$) are either held until displaced by future runoff or detained for a specified period of time. While the runoff is being held in the pond, sediment and associated pollutants settle to the bottom. Pollutants can also be removed from the stormwater through microbial, plant and algal biological uptake. Additional stormwater pond storage provided above the $\mathbf{V_{WQ}}$ allocation is used to control flows of particular frequencies at pre-development or other specified levels to prevent downstream channel degradation and flood damage.

Storage in a stormwater pond can be either permanent pool or extended detention storage. As the name implies, water in the permanent pool is meant to remain in the basin, allowing settling and biological uptake to occur between storms and protecting against sediment resuspension. To maintain a permanent pool over a period of time, the pond must be designed with a sufficiently large drainage area. Extended detention storage refers to the volume above the permanent pool which is controlled by an outlet structure, sized so that runoff from larger storms can be captured and released over a period of time, allowing some settling to occur and keeping flow rates in check.

Ponding requirements for new impervious area treatment are mandated in the state Construction General Permit (CGP). It is possible to design a pond with no permanent pool (dry pond, ponded only for a maximum of several days following a storm event), but stormwater ponds used for water quality treatment should be designed with a permanent pool. Dry ponds are highly susceptible to sediment resuspension and generally do not meet water quality performance criteria. However, dry ponds can be employed in some circumstances, such as for supplemental storage when the $\mathbf{V_{WQ}}$ has already been treated with upstream BMPs.

Sediment and pollutant removal in stormwater ponds can be enhanced through the use of multiple cells in succession. In particular, a sediment forebay (pre-treatment basin) sized at 10% of the pond area should be considered upstream of the pond. This allows for settling of heavier materials in a designated area, enhancing the main pond performance and reducing the maintenance burden by concentrating the majority of sediments in one location.

It is also possible to design a pond with no extended detention storage (wet pond), in which the only outlet is the spillway and where 100% of the treated volume is within the permanent pool. When a storm occurs, the treated runoff in the pond is displaced by new (untreated) runoff. Wet ponds are able to fulfill water quality treatment requirements, but do not mitigate the channel degradation or flooding effects of increased flow from larger storms. Also, wet ponds are not generally recommended for cold climates because during frozen conditions, runoff can flow over the ice of the permanent pool, effectively negating the benefits of the intended treatment volume. Generally the most desirable pond configuration for Minnesota is a large enough permanent pool to meet water quality needs, and sufficient extended detention to ensure adequate treatment during frozen conditions.

STORMWATER PONDS

I. Suitability

General

Generally speaking, the term "stormwater pond" may refer to any constructed basin that is built for the purpose of capturing and storing stormwater runoff, either temporarily or for an extended period of time, in order to prevent or mitigate downstream water quantity or quality impacts. Several distinct structure types (wet ponds, dry ponds, etc.) are included in this general category, and they are discussed in more detail below.

Function Within Stormwater Treatment Train

Stormwater ponds are typically installed as an end-of-pipe BMP at the downstream end of the treatment train. Stormwater pond size and outflow regulation requirements can be significantly reduced with the use of additional upstream BMPs. However, due to their size and versatility, stormwater ponds are often the only management practice employed at a site and therefore must be designed to provide adequate water quality and water quantity treatment for all regulated storms.

MPCA Permit Applicability

One of the goals of this manual is to facilitate understanding of and compliance with the MPCA Construction General Permit (CGP), which includes design and performance standards for permanent stormwater management systems. The permit and related documentation can be found online at http://www.pca.state.mn.us/water/stormwater/stormwater-c.html. These standards must be applied in all projects in which at least one acre of new impervious area (or common area of development) is being created, and the permit stipulates certain standards for various categories of stormwater management practices.

For regulatory purposes, stormwater ponds fall under the "Wet Sedimentation Basin" category described in Part III.C.1 of the permit. If used in combination with other practices, credit for combined stormwater treatment can be given as described in Part III.C.4. Due to the statewide prevalence of the MPCA permit, design guidance in this section is presented with the assumption that the permit does apply. Also, although it is expected that in many cases the pond will be used in combination with other practices, standards are described for the case in which it is a stand-alone practice.

The following terms are thus used in the text to distinguish various levels of stormwater pond design guidance:

REQUIRED:	Indicates design standards stipulated by the MPCA Permit (or other consistently applicable regulations).
HIGHLY RECOMMENDED:	Indicates design guidance that is extremely beneficial or necessary for proper functioning of the pond, but not specifically required by the MPCA permit.
RECOMMENDED:	Indicates design guidance that is helpful for pond performance but not critical to the design.

Of course, there are situations, particularly retrofit projects, in which a stormwater pond is constructed without being subject to the conditions of the MPCA permit. While compliance with the permit is not required in these cases, the standards it establishes can provide valuable design guidance to the user. It is also important to note that **additional and potentially more stringent design requirements may apply for a particular pond**, depending on where it is situated both jurisdictionally and within the surrounding landscape.

Design Variants

Several distinct pond design variants (see CADD design in Appendix D)are typically described in current stormwater management literature. While it is possible that any one of these pond types could be beneficially implemented somewhere in Minnesota, both the climatic conditions and the applicable regulations prevalent throughout the state strongly favor the use of one of them in particular, namely the wet extended detention pond. Indeed, **the wet extended detention pond is the only design variant fitting the description of a Wet Sedimentation Basin as described in the MPCA General Stormwater Permit.** For this

...the wet extended detention pond is the only design variant fitting the description of a Wet Sedimentation Basin as described in the MPCA General Stormwater Permit.

reason, much of the discussion in this chapter is focused primarily on wet extended detention ponds; however, all four main design variants are presented here for the sake of completeness.

1. Flow-through pond (no extended detention). Often called a "wet pond" in other literature, a pond that has an essentially unrestricted spillway as its primary outlet, with its crest at the elevation of the permanent pool. Provides water quality treatment by holding a volume of stormwater equal to the permanent pool volume, permitting settling to occur. The water stored in the pond is later displaced by new runoff. Note that "wet sedimentation basin" in the MPCA Permit is not a flow-through pond ("wet pond") but rather a wet extended detention pond. The flow-through pond is generally not a good design option for Minnesota, because the storage volume allocated for treatment is entirely below the permanent pool, making it inaccessible to new runoff during frozen conditions (cold climate considerations are discussed in more detail below and in Chapter 9)

2. Wet extended detention pond. The **Wet Sedimentation Basin** referenced in the MPCA Permit falls under this category. This indicates a combination of permanent pool storage and extended detention storage above the permanent pool to provide additional water quality or rate control.

3. Micropool extended detention pond. This variation of the wet extended detention pond has a markedly smaller permanent pool at the pond outlet to prevent resuspension. Typically, the permanent pool in a micropool extended detention pond will not be large enough to satisfy the requirements of the MPCA Permit.

4. Dry pond. This pond has no permanent pool; it relies only upon extended detention storage for its treatment volume. It is highly susceptible to sediment resuspension and generally only useful for rate control.

Retrofit Suitability

Ponds are widely used for stormwater retrofits, and have two primary applications as a retrofit design. In communities where dry detention ponds were designed for flood control in the past, these facilities can be modified by adding a permanent wet pool for water quality treatment and adapting the outlet structure for channel protection. Alternatively, new ponds can be installed in available open areas as a part of a comprehensive watershed retrofit inventory.

Note that the MPCA Permit permanent pool specifications do not apply to retrofit ponds that serve an existing developed area unless new impervious acreage occurs as part of the retrofit project. Therefore, any of the aforementioned pond variants may be considered, along with other alternative approaches to treatment basin design.

Special Receiving Waters Suitability

Table 12.POND.1 provides guidance regarding the use of stormwater ponds in areas upstream of special receiving waters. This table is an abbreviated version of a larger table in which other BMP groups are similarly evaluated. The corresponding information about other BMPs is presented in the respective sections of this Manual.

Cold Climate Suitability

One of the biggest problems associated with proper pond operation during cold weather is the freezing and clogging of inlet and outlet pipes. To avoid these problems, the CWP (Caraco and Claytor, 1997) made some general design suggestions,

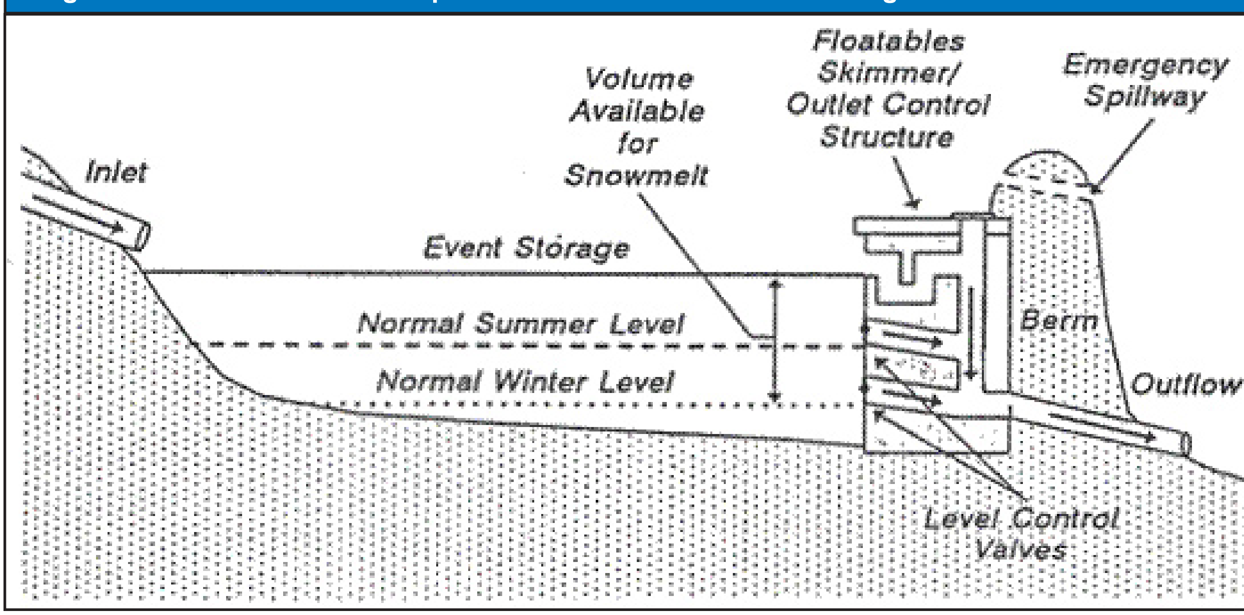
Table 12.POND.1 Special Receiving Waters Suitability for Ponds					
BMP Group	Watershed Management Category				
	A Lakes	B Trout Waters	C Drinking Water [1]	D Wetlands	E Impaired Waters
Wet Extended Detention Pond	PREFERRED	Some variations RESTRICTED due to pool and stream warming concerns	PREFERRED	PREFERRED (alteration of natural wetlands as stormwater wetlands not allowed)	PREFERRED

1. applies to groundwater drinking water source areas only; use the sensitive lakes category to define BMP design restrictions for surface water drinking supplies

which are adapted as follows:

- Inlet pipes should not be submerged, since this can result in freezing and upstream damage or flooding.
- Burying all pipes below the frost line can prevent frost heave and pipe freezing. Wind protection can also be an important consideration for pipes above the frost line. In these cases, designs modifications that have pipes "turn the corner" are helpful.
- Incoporating winter operating levels as part of the design to introduce available storage for melt events (Figure 12.POND.1 and Chapter 9).
- Increase the slope of inlet pipes to a minimum of 1% to prevent standing water in the pipe, reducing the potential for ice formation. This design may be difficult to achieve at sites with flat local slopes.

Figure 12.POND.1. Seasonal Operation for Snowmelt Runoff Management



...dry extended detention ponds are not considered an acceptable option for meeting water quality treatment goals

- If perforated riser pipes are used, the minimum opening diameter should be ½". In addition, the pipe should have a minimum 8" diameter.

- When a standard weir is used, the minimum slot width should be 3", especially when the slot is tall.

- Baffle weirs can prevent ice reformation during the spring melt near the outlet by preventing surface ice from blocking the outlet structure.

- In cold climates, riser hoods should be oversized and reverse slope pipes should draw from at least 6" below the typical ice layer.

- Alternative outlet designs that have been successful include using a pipe encased in a gravel jacket set at the elevation of the aquatic bench as the control for water quality events. This practice both avoids stream warming and serves as a non-freezing outlet.

- Trash racks should be installed at a shallow angle to prevent ice formation.

Water Quantity Treatment

Ponds are one of the best and most cost-effective stormwater treatment practices for providing runoff detention storage for channel protection and overbank flood control. These goals are achieved with the use of extended detention storage, where runoff is stored above the permanent pool and released at a specified rate through a control structure. As discussed in more detail later, wherever an embankment is constructed to store water at a level higher than the surrounding landscape, dam safety regulations must be followed to ensure that downstream property and structures are adequately protected.

Ponds rely on physical, biological, and chemical processes to remove pollutants from incoming

Table 12.POND.2. Reported Percent Removal of Key Pollutants

Practice	TSS [%]	Total Phosphorus [%]	Total Nitrogen [%]	Metals[1] [%]	Bacteria [%]	Hydro-carbons [%]
Wet Extended Detention Pond	80	40	30	60	70	80[2]

Notes:
1. Average of zinc and copper.
2. Based on fewer than five data points (i.e., independent monitoring studies)

Removals represent median values from Winer (2000) and have been rounded.

Table 12.POND.3 Typical BMP Effluent Concentrations

Practice	TSS [mg/l]	TP [mg/l]	TN [mg/l]	Cu [ug/l]	Zn [ug/l]
Wet Extended Detention Pond	10[1]	0.2[1]	1.3[2]	5.0[1]	30[1]

Values from (1) ASCE BMP database and (2) Winer 2000

Stormwater ponds tend to increase water temperature and may cause downstream thermal impacts.

stormwater runoff. The primary treatment mechanism is gravitational settling of particulates and their associated pollutants as stormwater runoff resides in the pond. Another mechanism for the removal of pollutants (particularly nutrients) is uptake by algae and aquatic vegetation. Volatilization and chemical activity can also occur, breaking down and assimilating a number of other stormwater contaminants such as hydrocarbons.

The longer the runoff remains in the pond, the more settling (and associated pollutant removal) and other treatment can occur, and after the particulates reach the bottom of the pond, the permanent pool protects them from resuspension when additional runoff enters the basin. For these reasons, because they lack the crucial permanent pool, **dry extended detention ponds are not considered an acceptable option for meeting water quality treatment goals;** however, they may be appropriate to meet water quantity criteria (Vcp, Vp_{10}, Vp_{100}). It should again be noted that the only type of pond complying with the MPCA Permit is the wet extended detention pond (or wet sedimentation basin) constructed according to the minimum standards outlined in the permit.

The long detention or retention time associated with stormwater ponds can be problematic in coldwater fisheries due to the potential increase in water temperature. In these situations, detention times should be limited to a maximum of 12 hours or other treatment alternatives (e.g., infiltration) should be explored.

Removal efficiencies for key pollutants for wet extended detention ponds are provided in Table 12.POND.2

Typical effluent concentrations for selected water quality parameters are provided in Table 12.POND.3.

Limitations

The following general limitations should be recognized when considering installation of stormwater ponds. Ponds generally:

- Consume a large amount of space
- Tend to increase water temperature and may cause downstream thermal impact
- Have the potential for nuisance insects or odor
- Are problematic for areas of low relief, high water table, or near-surface bedrock
- Pose safety concerns

II. Major Design Elements

Physical Feasibility Initial Check

Before deciding to use a pond for stormwater management, it is helpful to consider several items that bear on the feasibility of using a pond at a given location. The following list of considerations will help in making an initial judgment as to whether or not a pond is the appropriate BMP for the site. Note that none of these guidelines are strictly required by the MPCA Permit, and it may be possible to overcome site deficiencies with additional engineering or the use of other BMPs.

- **Drainage Area** – 25 acres minimum HIGHLY RECOMMENDED, to ensure hydrologic input sufficient to maintain permanent pool; 10 acres (or less) may be acceptable, particularly if the ground water table is intercepted and a water balance indicates that a permanent pool can be sustained.
- **Space Required** – Approximately 1-3% of the tributary drainage area is RECOMMENDED for the pond footprint.
- **Site Topography and Slope** – It is HIGHLY RECOMMENDED that slopes immediately adjacent to ponds be less than 25% but greater than 0.5 – 1% to promote flow towards the pond.

- **Minimum Head** – The elevation difference RECOMMENDED at a site from the inflow to the outflow is 6-10 feet, but lower heads will work at small sites.

- **Minimum Depth to Water Table** – In general, there is no minimum separation distance required with ponds. Intercepting the groundwater table can help sustain a permanent pool. However, some source water protection requirements may dictate a separation distance or an impervious liner if there is a sensitive underlying aquifer and the bottom material of the pond allows for infiltration.

- **Soils** – Underlying soils of hydrologic group "C" or "D" should be adequate to maintain a permanent pool. A liner may be needed for most group "A" soils and some group "B" soils, in order to maintain a permanent pool. A site specific geotechnical investigation should be performed. Also, if earthen embankments are to be constructed, it will be necessary to use suitable soils and to follow guidance in NRCS Pond 378 or other guidelines from the Dam Safety Section of the Minnesota Department of Natural Resources.

- **Wetlands** – It is REQUIRED that stormwater ponds not be located in jurisdictional wetlands.

- **Ground water Protection** – It is HIGHLY RECOMMENDED that ponds treating runoff from Potential Stormwater Hotspots (PSHs) provide excellent pre-treatment capabilities. In some cases (depending on the land use and associated activities), lining the pond may be necessary to protect ground water, particularly when the seasonally high ground water elevation is within three feet of the pond bottom.

- **Karst** – It is RECOMMENDED that ponds not be used in karst areas, due to the long term implication of having deep ponded water. If ponds are used in karst areas, impermeable liners and a minimum 3 foot vertical separation from the barotic rock layer are RECOMMENDED. Geotechnical investigations are necessary in karst areas.

- **Cold Water Fisheries** – Ponds may not be appropriate practices where receiving waters are sensitive cold water fisheries, due to the potential for stream warming from pond outflows. If ponds are used, it is HIGHLY RECOMMENDED that the 1-year, 24-hour storm be detained for no longer than 12 hours. If regulatory provisions allow, a smaller permanent pool with more extended detention storage should be considered.

- **Shallow Soils and Bedrock** – Pond use is limited due to the available depth that may require shallow water depths, affecting the surface area required as well as the aesthetics of the pond. Consider a wetland as an alternative.

Conveyance

Inflow Points

- It is HIGHLY RECOMMENDED that pre-treatment be provided to reduce the future pond maintenance burden. If pre-treatment has not been provided in the contributing watershed, then it is RECOMMENDED that a forebay be provided at each inlet contributing greater than 10% of the total design storm inflow to the pond.

- It is REQUIRED that inlet areas be stabilized to ensure that non-erosive conditions exist during events up to the overbank flood event (i.e., Q_{p10}).

- It is HIGHLY RECOMMENDED that rip-rap or other channel liners be extended below the permanent pool elevation.

- It is HIGHLY RECOMMENDED that inlet pipe inverts be located at the permanent pool elevation. Submerging the inlet pipe can result in freezing and upstream damage.

- It is HIGHLY RECOMMENDED that inlet pipes have a slope of no flatter than 1%, to prevent standing water in the pipe and reduce the potential for ice formation.

- It is HIGHLY RECOMMENDED that pipes be buried below the frost line, to prevent frost heave and pipe freezing.

- It is HIGHLY RECOMMENDED that where open channels are used to convey runoff to the pond, the channels be stabilized to reduce the sediment loads.

Adequate Outfall Protection

Pond outfalls should be designed to not increase erosion or have undue influence on the downstream geomorphology of the stream.

- It is HIGHLY RECOMMENDED that a stilling basin or outlet protection be used to reduce flow velocities from the principal spillway to non-erosive velocities (3.5 to 5.0 fps).

- It is REQUIRED in the CGP that the V_{WQ} is discharged at no more than 5.66 cfs per surface area of land.

- Flared pipe sections that discharge at or near the stream invert or into a step-pool arrangement are RECOMMENDED over headwalls at the spillway outlet.

- It is RECOMMENDED that tree clearing be minimized along the downstream channel and that a forested riparian zone be reestablished in the shortest possible distance. It is also RECOMMENDED that excessive use of riprap be avoided, to minimize stream warming in channels with dry weather flow.

- Local agencies (Watershed Districts, Watershed Management Organizations (WMOs), municipalities, etc.) may have additional outlet control requirements.

Pre-treatment

Construction of pre-treatment measures immediately upstream of the main pond is HIGHLY RECOMMENDED, to reduce the maintenance requirements and increase the longevity of a stormwater treatment pond. A large portion of the overall sediment load (the heavier sediments) can be captured by relatively small (and therefore relatively easy to clean and maintain) BMPs. The larger pond area can thus be devoted to the settling of finer sediments, allowing it to fill more slowly and therefore requiring less frequent maintenance.

It is therefore HIGHLY RECOMMENDED that each pond have a sediment forebay or equivalent upstream pretreatment (non-pond BMPs may serve as pretreatment) at each inflow point that contributes greater than 10% of the inflow volume. A sediment forebay is a small pool, separated from the permanent pool by barriers such as earthen berms, concrete weirs, or gabion baskets, where initial settling of heavier particulates can occur.

- It is REQUIRED that where a forebay is installed, that direct vehicle/equipment access be provided to the forebay for sediment removal and other maintenance activities.

- It is HIGHLY RECOMMENDED that flows from forebays enter the permanent pool area with non-erosive outlet conditions.

- It is RECOMMENDED that the forebay(s) be sized to contain 10% of the water quality volume (Vwq) in a pool that is four to six feet deep. The forebay storage volume counts toward the total permanent pool requirement.

- It is RECOMMENDED that the forebay(s) be designed with a surface area equivalent to 10% of the pond permanent pool surface area or equivalent to 0.1% of the drainage area.

This is an alternative to the preferred active management strategy of drawing down the permanent pool seasonally to provide detention while the permanent pool is frozen.

- It is RECOMMENDED that a fixed vertical sediment depth marker be installed in the forebay to measure sediment deposition over time. The marker should be sturdy and placed deep enough into the bottom of the forebay so that ice movement does not affect its position.

- It is RECOMMENDED that the bottom of the forebay be hardened, using concrete, asphalt, or grouted riprap, to make sediment removal easier.

Treatment

Permanent Pool and Water Quality Volume (Vwq) Sizing for New Impervious Area

- Under the MPCA Permit, it is REQUIRED that stormwater ponds have permanent pool volume (dead storage) equal to at least 1800 cubic feet per acre of drainage to the pond. For example, a 30-acre drainage area requires a permanent pool volume of at least 54,000 cubic feet or 1.24 acre-feet.

- The REQUIRED total storage volume (V_{TS}) equals the sum of the volume in the permanent pool (V_{PP} below the outlet elevation) plus live storage allocation for water quality volume (Vwq). Vwq equals 0.5 or 1.0 inch of runoff per impervious acre, depending on the receiving stream designation – see also Chapter 10 and Appendix F.

- It is REQUIRED that permanent pool depths be a minimum of three feet and maximum of 10 feet at the deepest points. Where phosphorus load reductions are a priority, it is RECOMMENDED that a maximum depth of eight feet be used, to limit the likelihood of stratification and the potential for bottom sediment to release phosphorus.

- If extended detention storage for the Channel Protection Volume (Vcp) is provided, it is RECOMMENDED that the Vwq be computed and routed through the outlet for Vcp. It is REQUIRED that the Vwq be released at a rate not to exceed 5.66 cfs per acre of permanent pool surface area. It is HIGHLY RECOMMENDED that the Vcp be released over a minimum 24 hour period.

- Where phosphorus load reductions are a priority, permanent pool volumes as large as 3600 cubic feet per acre of drainage are RECOMMENDED for enhanced removal.

- To compensate for ice build-up on the permanent pool, it is HIGHLY RECOMMENDED that twelve inches (or a volume equal to the average snow melt) of additional storage be provided. This is an alternative to the preferred active management strategy of drawing down the permanent pool seasonally to provide detention while the permanent pool is frozen.

- Using pumps or bubbling systems can reduce ice build-up and prevent the formation of an anaerobic zone in pond bottoms. Caution must be exercised, however, because of the possibility of thin or no ice cover.

- A water balance is RECOMMENDED to document sufficient inflows to maintain a constant permanent pool during prolonged dry weather conditions. The basic approach to performing a water balance is as follows:

  1. Check maximum drawdown during periods of high evaporation and during an extended period of no appreciable rainfall to ensure that wetland vegetation will survive.

  2. The change in storage within a pond = inflows – outflows.

  3. Potential inflows: runoff, baseflow and rainfall (ground water and surface water).

All pond designs should incorporate an access bench

4. Potential outflows: Infiltration, surface overflow and evapotranspiration.

5. Assume no inflow from baseflow, no outflow losses for infiltration and because only the permanent pool volume is being evaluated, no outflow losses for surface overflows. The validity of these assumptions need to be verified for each design.

Pond Liners

It is HIGHLY RECOMMENDED that pond liners be considered in circumstances where a permanent pool is needed but difficult to maintain due to site conditions, or where seepage from the pond into the groundwater would otherwise occur but must be avoided. This includes:

- Areas with Hydrologic Group A soils, gravel, or fractured bedrock
- Potential Stormwater Hotspots (PSHs)
- Karst terrain

If geotechnical tests confirm the need for a liner, acceptable options include: (a) six to 12 inches of clay soil, including bentonite, (minimum 15% passing the #200 sieve and a maximum permeability of 1 x 10^{-5} cm/sec), (b) a 30 ml poly-liner, or (c) engineering design as approved on a case-by-case basis by MPCA or appropriate review agency.

Grading and Site Layout

The site layout and pond grading affect the pollutant removal capability of the pond as well as the ease of maintenance. Performance is enhanced when multiple treatment pathways are provided by using multiple cells, longer flowpaths, high surface area to volume ratios, complex microtopography, and/or redundant treatment methods (combinations of pool, ED, and marsh). It is RECOMMENDED that a berm or simple weir be used instead of pipes to separate multiple ponds, because of the higher freezing potential of pipes. Specific guidelines are provided below:

- It is HIGHLY RECOMMENDED that pond side slopes within the permanent pool (below the aquatic bench) not exceed 1:2 (V:H).
- It is HIGHLY RECOMMENDED that side slopes to the pond should be 1:3 (V:H) or flatter, and that they terminate on an access bench (see next section).
- It is RECOMMENDED that approximately 15% of the permanent pool surface area be allocated to a shallow (i.e., less than or equal to 18” in depth) zone along the perimeter to promote a shallow marsh littoral zone.
- It is RECOMMENDED that the minimum length to width ratio for ponds be 1.5:1.
- It is RECOMMENDED that the maximum drainage area to surface area ratio be 100:1.
- It is RECOMMENDED that to the greatest extent possible, ponds should be irregularly shaped and long flow paths should be maintained.

Pond Benches

All pond designs should incorporate an access bench (a shallow slope area adjacent to the pond, providing equipment access and preventing people from slipping into the water) and a submerged aquatic bench (a shallow slope area just inside the pond perimeter, facilitating the growth of aquatic plants). This is a HIGHLY RECOMMENDED design practice that may be required by local authorities. Mosquito breeding concerns exist along bench areas. Therefore, it is HIGHLY RECOMMENDED that designers follow recommendations from the Metropolitan Mosquito Control District, contained in Chapter 6.

- **Access Bench:** It is HIGHLY RECOMMENDED that an access bench extending 10 feet outward from the permanent pool edge to the toe of the pond side slope be provided. Narrower benches may be used on sites with extreme site limitations. The maximum cross-slope of the access bench should be 0.06:1 (V:H), or 6%. Access benches are not needed when the pond side slopes are 1:4 (V:H) or flatter.

- **Aquatic Bench:** It is HIGHLY RECOMMENDED that an irregularly configured aquatic bench, extending up to 10 feet inward from the normal shoreline and graded no more than eighteen inches below the permanent pool water surface elevation, be incorporated into the pond.

Maintenance Access

- It is REQUIRED that a maintenance access, with a minimum width of 8', be provided. If feasible, it is RECOMMENDED that the access be 10 feet wide, have a maximum slope of 0.15:1 (V:H) or 15%, and be appropriately stabilized for use by maintenance equipment and vehicles. Steeper grades may be allowable if designed using appropriate materials for the grade.

- It is REQUIRED that the maintenance access extends to the forebay, access bench, riser, and outlet, and allows vehicles to turn around.

Riser in Embankment

- It is REQUIRED that the riser be located so that short-circuiting between inflow points and the riser does not occur.

- It is RECOMMENDED that the riser be located within the embankment for maintenance access, prevention of ice damage, and aesthetics.

Spillway Design

The principle spillway (riser) should be designed for the desired release rates while keeping the future maintenance needs in mind. Lessening the potential for clogging and freezing, creating safe access paths for inspection and maintenance, barring access to children and vandals, and allowing safe draw down of the permanent pool, when necessary, are goals of riser design that consider long-term maintenance needs.

Non-clogging Low Flow Orifice

- It is HIGHLY RECOMMENDED that the low flow orifice be adequately protected from clogging by either an acceptable external trash rack (recommended minimum orifice of 3") or by internal orifice protection that may allow for smaller diameters (recommended minimum orifice of 1"). Appendix D contains design details for both low flow orifice protection options.

- The RECOMMENDED method is a submerged reverse-slope pipe that extends downward from the riser to an inflow point at least one foot below the normal pool elevation (see Appendix D for a typical detail). This should also draw from at least 6" below the typical ice layer. To avoid release of deposited sediment, the pipe should not be installed on the pond floor.

- Alternative methods are to employ a broad crested rectangular, V-notch, or proportional weir, protected by a half-round CMP that extends at least 12 inches below the normal pool. It is HIGHLY RECOMMENDED that the minimum weir slot width be 3", especially when the slot is tall. It is RECOMMENDED that hoods over orifices be oversized to account for ice formation.

Trash Racks

- It is REQUIRED that basin outlets be designed to prevent discharge of floating debris. It is HIGHLY RECOMMENDED that the principal spillway openings be equipped with removable trash racks to prevent clogging by large debris and to restrict access to the interior for safety purposes. US EPA guidance on control of floatables suggests that openings in the range of 1.5 inches are both cost-efficient and effective in removing floatables and large solids.

- It is RECOMMENDED that trash racks be installed at a shallow (~15°) angle to prevent ice formation.

- Baffle weirs (essentially fences in the pond) can prevent ice reformation during the spring melt near the outlet by preventing surface ice from blocking the outlet structure.

Pond Drain

- It is HIGHLY RECOMMENDED that each pond be equipped with a drain that can dewater the pond to the maximum extent possible within 24 hours. The drain pipe should have an elbow or protected intake extending at least 12" above the bottom of the permanent pool to prevent deposited sediment from clogging the pipe or being re-released while the pond is being drained.

Adjustable Gate Valve

- It is RECOMMENDED that the pond drain and possibly the low flow orifice be equipped with an adjustable gate valve (typically a handwheel activated knife gate valve). These valves should be located inside the riser, where they (a) will not normally be inundated and (b) can be operated in a safe manner. To prevent vandalism that alters the pond level, the handwheel should be chained to a ringbolt, manhole step or other fixed object.

- It is RECOMMENDED that both the low flow orifice pipe and the pond drain be sized one pipe size greater than the calculated design diameter and the gate valve be installed and adjusted to an equivalent orifice diameter.

Riser Access

- It is RECOMMENDED that lockable manhole covers and manhole steps within easy reach of valves and other controls be installed, to allow for maintenance access and prevent vandalism.

Emergency Spillway

- It is REQUIRED that an emergency spillway should be provided to pass storms in excess of the pond hydraulic design. It is also REQUIRED that the spillway be stabilized to prevent erosion and designed in accordance with applicable dam safety requirements (NRCS Pond Standard 378 and MnDNR dam safety guidelines). Safety - Dam Safety Program - Division of Waters: Minnesota DNR . The emergency spillway must be located so that downstream structures will not be impacted by spillway discharges. If the spillway crosses the maintenance access, materials meeting the appropriate load requirements must be selected.

Landscaping

Landscaping Plan

- It is HIGHLY RECOMMENDED that a landscaping plan for the stormwater pond and the surrounding area be prepared to indicate how aquatic and terrestrial areas will be stabilized, and established with vegetation (see Appendix E for detailed guidance). Landscaping plans should also include maintenance schedules. It is HIGHLY RECOMMENDED that the plan be prepared by a qualified professional. The following guidance suggests how landscaping can be incorporated into pond design.

- Woody vegetation should not be planted or allowed to grow within 15 feet of the toe of the embankment or 25 feet from the inlet and outlet structures.

- Wherever possible, wetland plants should be encouraged in a pond design, either along the aquatic bench (fringe wetlands), the access bench and side slopes (ED wetlands) or within shallow areas of the pool itself.

- The best elevations for establishing wetland plants, either through transplantation or volunteer colonization, are within six inches (plus or minus) of the normal pool.

- The soils of a pond buffer are often severely compacted during the construction process to ensure stability. The density of these compacted soils can be so great that it effectively prevents root penetration, and therefore, may lead to premature mortality or loss of vigor. Consequently, it is advisable to excavate large and deep holes around the proposed planting sites, and backfill these with uncompacted topsoil or other organic material (see bioretention specifications).

- As a rule of thumb, planting holes should be three times deeper and wider than the diameter of the rootball (of balled and burlap stock), and five times deeper and wider for container grown stock. This practice should enable the stock to develop unconfined root systems.

- Species that require full shade, are susceptible to winterkill, or are prone to wind damage should be avoided. Extra mulching around the base of the tree or shrub is strongly recommended as a means of conserving moisture and suppressing weeds.

Pond Buffers and Setbacks

- It is REQUIRED (Minnesota Department of Health Rule 4725.4350) that a 50’ setback between high water levels of stormwater ponds and public water supply wells be provided.

- It is HIGHLY RECOMMENDED that a pond buffer extending 25 feet outward from the maximum water surface elevation of the pond be provided. Permanent structures (e.g., buildings) should not be constructed within the buffer. This distance may be greater under local regulations.

- The pond buffer should be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers).

- It is HIGHLY RECOMMENDED that existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To help discourage resident geese populations, the buffer can be planted with trees, shrubs and native ground covers.

Safety

- It is REQUIRED that public safety be considered in every aspect of pond design.

- The principal spillway opening should not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard.

- The access and aquatic benches should be landscaped to prevent access to the pond.

- Warning signs prohibiting swimming, skating, and fishing should be posted.

- Pond fencing is generally not encouraged because the fence limits access to emergency personnel. A preferred method is to grade the pond to eliminate steep drop-offs or other safety hazards. Designers should check local requirements since fencing is required by some municipalities.

- Dam safety regulations should be strictly followed with pond design to ensure that downstream property and structures are adequately protected.

III. Construction Details and Specifications

CADD based details for pond systems are contained in Appendix D. The following details, with specifications, have been created for stormwater ponds:

- Stormwater pond plan

- Stormwater pond profile

- Pond inlet

- Riser pipe outlet structure

IV. Operation and Maintenance

Overview

Maintenance is necessary for a stormwater pond to operate as designed on a long-term basis. The pollutant removal, channel protection, and flood control capabilities of ponds will decrease if:

- Permanent pool elevations fluctuate

- Debris blocks the outlet structure

- Pipes or the riser are damaged

- Invasive plants out-compete the wetland plants

- Sediment accumulates in the pond, reducing the storage volume

- Slope stabilizing vegetation is lost

- The structural integrity of the embankment, weir, or riser is compromised.

Pond maintenance activities range in terms of the level of effort and expertise required to perform them. Routine pond and wetland maintenance, such as mowing and removing debris or trash, is needed multiple times each year. Owners may consider an "adopt-a-pond" program in which properly trained citizen volunteers perform basic landscape maintenance activities (the City of Plymouth, for example, has instituted such a program). More significant maintenance such as removing accumulated sediment is needed less frequently, but requires more skilled labor and special equipment. Inspection and repair of critical structural features such as embankments and risers, needs to be performed by a qualified professional (e.g., structural engineer) that has experience in the construction, inspection, and repair of these features.

Design Phase Maintenance Considerations

Implicit in the design guidance in the previous sections, many design elements of pond systems can minimize the maintenance burden and maintain pollutant removal efficiency. Key maintenance considerations are providing access for inspection and maintenance, and designing all outlets and the principal spillway to minimize clogging. Providing easy access (typically 8 feet wide) to all pond components for routine maintenance is REQUIRED.

Stormwater ponds can be designed, constructed and maintained to minimize the likelihood of being desirable habitat for mosquito populations. Designs that incorporate constant inflows and outflows, habitat for natural predators, and constant permanent pool elevations limit the conditions typical of mosquito breeding habitat (see also Chapter 6 discussion on mosquito control).

Construction Phase Maintenance

The construction phase is another critical step where O&M issues can be minimized or avoided.

Table 12.PND.4: Typical Inspection/Maintenance Frequencies for Ponds

Inspection Items	Maintenance Items	Frequency
▪ Ensure that at least 50% of wetland plants survive ▪ Check for invasive wetland plants.	▪ Replant wetland vegetation	One time - After First Year
▪ Check that maintenance access is free and clear. ▪ Inspect low flow orifices, reverse flow pipes, and other pipes for clogging ▪ Check the permanent pool or dry pond area for floating debris, undesirable vegetation. ▪ Investigate the shoreline for erosion ▪ Monitor wetland plant composition and health. ▪ Look for broken signs, locks, and other dangerous items.	▪ Mowing – minimum Spring and Fall ▪ Remove debris ▪ Repair undercut, eroded, and bare soil areas.	Monthly to Quarterly or After Major Storms (>1")
▪ Monitor wetland plant composition and health. ▪ Identify invasive plants ▪ Ensure mechanical components are functional	▪ Trash and debris clean-up day ▪ Remove invasive plants ▪ Harvest wetland plants ▪ Replant wetland vegetation ▪ Repair broken mechanical components if needed	Semi-annual to annual
▪ All routine inspection items above ▪ Inspect riser, barrel, and embankment for damage ▪ Inspect all pipes ▪ Monitor sediment deposition in pond and forebay	▪ Pipe and Riser Repair ▪ Forebay maintenance and sediment removal when needed	Every 1 to 3 years
▪ Monitor sediment deposition in pond and forebay	▪ Forebay maintenance and sediment removal when needed	2-7 years
▪ Remote television inspection of reverse slope pipes, underdrains, and other hard to access piping	▪ Sediment removal from main pond/wetland ▪ Pipe replacement if needed	5-25 years

Inspections during construction are needed to ensure that the practice is built in accordance with the approved design standards and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is acceptable to the professional designer. An example construction phase inspection checklist is provided in Appendix D.

Post-Construction Operation and Maintenance

Operation to Address Frozen Conditions

It is HIGHLY RECOMMENDED that the O&M plan include a provision to lower the level of the permanent pool in the late fall, to provide additional retention storage for snowmelt runoff and ensure that some permanent pool storage is available

Table 12PND.5: Cost Components for Stormwater Ponds			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimate**	**Other Considerations**
Site Preparation	Tree & plant protection	Protection Cost ($/acre) x Affected Area (acre)	Removal of existing structures, topsoil removal and stockpiling
	Topsoil salvage	Salvage cost ($/acre) x Affected Area (acre)	
	Clearing & grubbing	Clearing Cost ($/acre) x Affected Area (acre)	
Site Formation	Excavation / grading	8-ft Depth Excavation Cost ($/acre) x Area (acre)	Soil & rock fill material, tunneling
	Hauling material offsite	Excavation Cost x (% of Material to be hauled away)	
Structural Components	Inlet structure	($/structure)	Pipes, catchbasins, manholes, valves
	Outlet structure	($/structure)	
Site Restoration	Seeding or sodding	Seeding Cost ($/acre) x Seeded Area (acre)	Tree protection, soil amendments, seed bed preparation, trails
	Planting / transplanting	Planting Cost ($/acre) x Planted Area (acre)	
Annual Operation, Maintenance, and Inspection	Debris removal	Removal Cost ($/acre) x Area (acre) x Frequency (2 / 1yr)	Vegetation maintenance, cleaning of structures
	Sediment removal	Removal Cost ($/acre) x Area (acre) x Frequency (1 / 5yr)	
	Gate / valve operation	Operation Cost ($) x Operation Frequency (2 / 1 yr)	
	Inspection	Inspection Cost ($) x Inspection Frequency (2 / 1 yr)	
	Mowing	Mowing Cost ($) x Mowing Frequency (4 / 1 yr)	

above the ice (the permanent pool should not be completely eliminated nor allowed to freeze through completely).

Maintenance

Some important post construction maintenance considerations are provided below. A more detailed checklist of maintenance activities and associated schedules is provided in Appendix D. More detailed maintenance guidance can be found in the Pond and Wetland Maintenance Guidebook (CWP, 2004).

- ► It is REQUIRED that a legally binding and enforceable maintenance agreement be executed between the BMP owner and the local review authority.
- ► Adequate access must be provided for inspection, maintenance, and landscaping upkeep, including appropriate equipment and vehicles. It is RECOMMENDED that a maintenance right of way or easement extend to ponds from a public or private road.
- ► It is HIGHLY RECOMMENDED that ponds be inspected annually during winter freeze periods to look for signs of improper operation.

- It is HIGHLY RECOMMENDED that sediment removal in the forebay occur every 2 to 7 years or after 50% of total forebay capacity has been lost. In areas where road sand is used, an inspection of the forebay and stormwater wetland should be scheduled after the spring melt to determine if clean-out is necessary.

- Sediments excavated from stormwater ponds that do not receive runoff from confirmed hotspots are generally not considered toxic or hazardous material, and can be safely disposed by either land application or land filling. Sediment testing may be necessary prior to sediment disposal when a confirmed hotspot land use is present (see also Chapter 13).

- Periodic mowing of the pond buffer is HIGHLY RECOMMENDED along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year), prairie, or forest.

- Ponds should not be drained during the spring, as temperature stratification and high chloride concentrations at the bottom can occur, which could result in negative downstream effects.

- Care should be exercised while draining the pond to prevent rapid release and minimize the discharge of sediments or anoxic water. The approving jurisdiction should be notified before draining a pond.

- It is REQUIRED that OSHA safety procedures be followed for maintenance activities within enclosed areas, such as outlet structures.

General maintenance activities and schedule are provided in Table 12.PND.4.

V. Cost Considerations

Costs for ponds typically include costs for embankment, riser and spillway structures, outfall protection, vegetative stabilization, excavation, and grading. Additional costs for site preparation can include soil amendments, precision grading, plant materials and creation of occluding layers in coarse-textured soil types if wetlands systems must be created on upland sites due to project constraints. Project costs can be lowered if existing pre-construction site conditions are carefully considered and isolated areas with hydric soils contained within the footprint of the project are utilized as stormwater management facilities.

Additional maintenance costs will be incurred until the establishment of the wetland ecosystem. Invasive plants must be culled and dead plants replaced. The outlet structure may have to be adjusted, based on seasonal observations, to achieve the proper water surface in the pond.

Construction and Maintenance Costs

Chapter 6 outlines a cost estimation method which site planners could use to compare the relative construction and maintenance costs for

If the pond will be used for temporary sediment control during construction, the associated permanent pool volume REQUIRED is either the 2 year, 24 hour storm runoff volume draining to the pond (with minimum 1800 cubic feet for each acre draining to the basin), or in the absence of such a calculation, 3600 cubic feet for each acre draining to the basin. It is also REQUIRED that sediment deposited during construction be removed before normal operation begins (refer to MPCA Permit for additional design requirements).

structural best management practices. These curves are excellent for purposes of comparison; however, it is recommended that construction and maintenance budgets should be based on site specific information. Utilizing Table 12.POND.5 and the cost estimation worksheet in Appendix D, will allow designers to avoid over or under estimation of fixed costs. Table 12.POND.5 lists the specific site components that are specific to stormwater ponds. Not included in this table are those cost items that are common to all construction projects, such as mobilization, traffic control, erosion and sediment control, permitting, etc. A more detailed worksheet, utilizing 2005 construction prices, is contained in Appendix D.

Designers are encouraged to use the cost worksheet included in Appendix D to estimate their BMP construction cost.

VI. Design Procedure

The following steps outline a recommended design procedure for a wet extended detention pond (wet sedimentation basin) in compliance with the MPCA Permit for new construction. Design recommendations beyond those specifically required by the permit are also included and marked accordingly.

Design Steps

Step 1. Make a preliminary judgment as to whether site conditions are appropriate for the use of a stormwater pond, and identify the function of the pond in the overall treatment system.

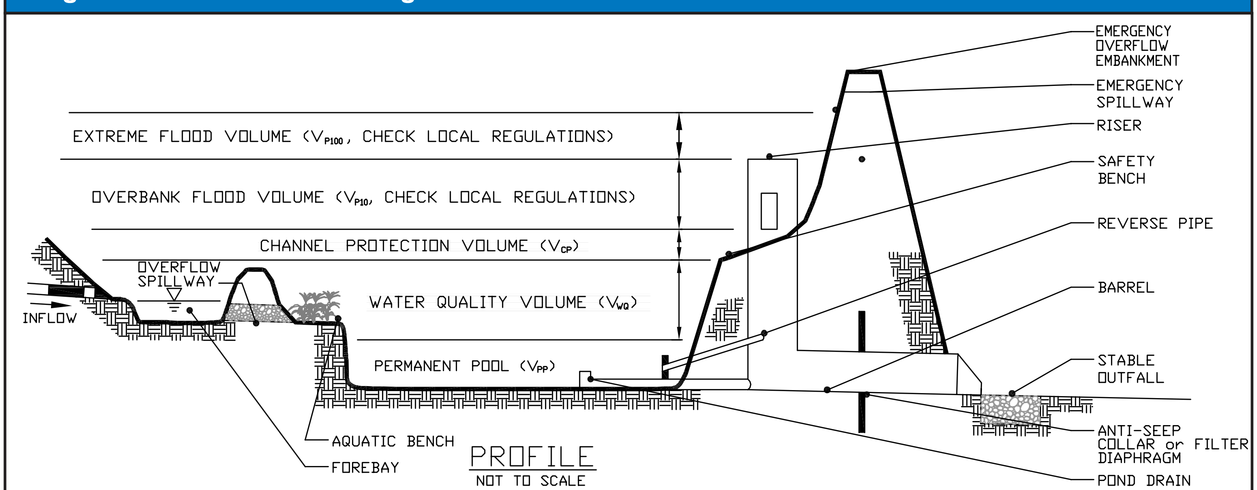
A. Consider basic issues for initial suitability screening, including:

- Site drainage area
- Depth to water table
- Depth to bedrock
- Presence of wetlands
- Soil characteristics
- Receiving water(s)

B. Determine how the pond will fit into the overall stormwater treatment system:

- Decide whether the pond is the only BMP to be employed, or if are there other BMPs (including other ponds) addressing some of the treatment requirements.
- Determine whether the pond needs to treat water quality (Vwq), quantity (Vcp, Qp, Qf), or both.
- Determine whether the pond is being designed as a wet sedimentation basin under the MPCA General Stormwater Permit for Construction Activities.

Figure 12.PND.2 Pond Storage Allocations



- ► Determine whether the pond will be used as a temporary sediment basin during construction.

- ► Decide where on the site the pond is most likely to be located.

Step 2. Confirm design criteria and applicability.

A. Determine whether the pond must comply with the MPCA Permit.

B. Check with local officials, watershed organizations, and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3. Confirm site suitability.

A. Perform field verification of site suitability.

- ► If the initial evaluation indicates that a pond would be a good BMP for the site, it is RECOMMENDED that one boring per acre with a minimum of three soil borings or pits be dug in the same location as the proposed pond to verify soil types and to determine the depth to groundwater and bedrock.

- ► It is RECOMMENDED that the minimum depth of the soil borings or pits be five feet below the bottom elevation of the proposed pond.

- ► It is HIGHLY RECOMMENDED that the field verification be conducted by a qualified geotechnical professional.

B. Perform water balance calculations, if needed.

Step 4. Compute runoff control volumes and permanent pool volume.

Calculate the Permanent Pool Volume (V_{PP}), Water Quality Volume (Vwq), Channel Protection Volume (Vcp), Overbank Flood Protection Volume (Vp_{10}), and the Extreme Flood Volume (Vp_{100}).

$$V_{PP} = 1800 \text{ ft}^3 * A$$

or

$$V_{PP} = 0.5(\text{in}) * A * (1/12)$$

Where:

A = total watershed area in acres draining to pond

If the pond is being designed as a wet detention pond for new construction under the MPCA Permit, then a permanent pool volume equal to 1800 cubic feet for each acre draining to the pond is REQUIRED. This can be calculated as:

In the case where the entire Vwq is to be treated with other BMPs and the pond is being constructed only for rate control, a permanent pool may not be required, although it still may be desirable.

If the pond will be used for temporary sediment control during construction, the associated permanent pool volume REQUIRED is either the 2 year, 24 hour storm runoff volume draining to the

Table 12.PND.6 Example Spreadsheet - Cumulative Volume Above Normal Surface Elevation

Spreadsheet Column Header	Elevation	Area	Average Area	Depth	Volume	Cumulative Volume	Volume Above Permanent Pool
Spreadsheet Column Description	*Elevation of Pond Contour Line*	*Area enclosed by Contour Line*	*Average area of current and previous rows*	*Elevation difference between current and previous rows*	*Volume between current and previous contour*	*Volume between current and lowest contour*	*Volume between current and permanent pool contour*
Example value	900	1000	N/A	N/A	N/A	0	N/A
Example value	902	1200	1100	2	2200	2200	0
Example value	904	1600	1400	2	2800	5000	2800

pond (with minimum 1800 cubic feet for each acre draining to the basin), or in the absence of such a calculation, 3600 cubic feet for each acre draining to the basin. It is also REQUIRED that sediment deposited during construction be removed before normal operation begins (refer to MPCA Permit for additional design requirements).

The water quality volume, V_{WQ}, can be calculated in different ways, depending upon what it discharges to a water:

For normal waters:

V_{WQ} = (0.5 in. * IC) * (1/12)

For "special waters" (see Chapter 10):

V_{WQ} = (1.0 in. * IC) * (1/12)

Where IC = new impervious area (in)

It is RECOMMENDED that the Channel Protection Volume, Vcp, be based on the 1-yr, 24-hr rainfall event, though local ordinances may be more restrictive. It should be noted that the Vcp is inclusive of the Vwq. In other words, the Vwq is contained within the Vcp.

If part of the overall Vwq is to be treated by other BMPs, subtract that portion from the Vwq to determine the part of the Vwq to be treated by the pond. It is assumed that the pond will be the only BMP used for rate control for larger storms. If this is the case, the pond should be designed to treat the entirety of these runoff control volumes. If some portion of these control volumes is treated by other BMPs, it can be subtracted from the overall Vcp, Vp_{10}, and Vp_{100} to determine the volume to be treated by the pond. The configuration of the various storage allocations is shown in the pond profile in Figure 12.POND.2.

Details on the Unified Stormwater Sizing Criteria are found in Chapter 10.

Step 5. Determine location and preliminary geometry.

The preliminary grading plan can be developed with the following procedure:

1. Locate the pond in the lowest elevation area of the site (not in a jurisdictional wetland) and provide space around the pond for maintenance access. Adequate maintenance access of 8' is REQUIRED. 10' minimum width is HIGHLY RECOMMENDED.

2. Establish a primary outlet elevation (normal water level) and/or a pond bottom elevation.

3. Provide storage for the permanent pool below the primary outlet elevation in the main pond area.

4. Include an aquatic bench extending into the permanent pool and a access bench extending out from the permanent pool.

5. Considering the desired pond footprint during the Vwq, Vcp, Vp_{10}, and Vp_{100} design storms, allocate storage volume above the primary outlet elevation for Vwq, Vcp, Vp_{10}, and Vp_{100}, respectively. While developing the grading plan, consider the desired (or required) length to width ratio and side slopes detailed earlier in this section (or in applicable regulations).

6. Once the preliminary grading plan has been developed, determine the associated stage-storage relationship for water surface elevations through the maximum expected levels.

The approximate storage corresponding to a given stage (elevation) can be determined using the average end area method. The area within each of the closed contour lines on the grading plan representing the pond is measured, and the average area of each set of adjacent contours is computed. The approximate volume between the two contours is then calculated as the average area multiplied by the elevation difference.

$$V_{1-2} = \frac{A_1 + A_2}{2} \times (E_2 - E_1)$$

Where:

V_{1-2}= the volume between contour 1 and contour 2,

If the designer chooses to use different structure types, the specific equations used to determine stage-discharge relationships will change, but the general approach will remain the same.

A_1 and A_2 = the areas within closed contours 1 and 2, respectively

E_1 and E_2 = the elevations of contours 1 and 2, respectively.

Cumulative volume above the bottom of the pond, or above the normal water surface elevation, can be calculated by adding subsequent incremental volumes. This is readily accomplished with the use of a spreadsheet prepared as follows in Table 12.POND.6 (the first row of the table below contains the spreadsheet column header, the second row is column description, and the third, fourth, and fifth rows provide an example, with a permanent pool elevation of 902).

The stage-storage relationship will be used to develop a stage-storage-discharge table as outlet structures are designed. This is an iterative process that may include revising the preliminary grading plan and subsequently redetermining the stage-storage relationship (or using an acceptable model to check).

Step 6. Determine pre-treatment (sediment forebay) volume (HIGHLY RECOMMENDED).

In the absence of adequate upstream treatment by other BMPs, it is HIGHLY RECOMMENDED that a sediment forebay or similarly effective pretreatment system be provided at each inlet providing 10% or more of the total design inflow, with a RECOMMENDED volume equal to 10% of the permanent pool volume in a pool 4 to 6 feet deep (at shallower depths, the risk of sediment resuspension in the pretreatment area increases). The forebay storage volume counts toward the total permanent pool requirement. The storage volumes from other BMPs used upstream in the treatment train count toward the water quality volume (V_{WQ}) requirement and thus may be subtracted from it.

Step 7. Consider water quality treatment volume variations for frozen conditions (HIGHLY RECOMMENDED).

When the pond and sediment forebay are frozen, much of the storage is rendered ineffective because stormwater runoff can flow over the ice and bypass the intended treatment. To alleviate this problem, additional extended detention storage (which is available even under frozen conditions) can be designed into the pond by increasing the extended detention storage volume designated for water quality control, or by adding a weir structure to the sediment forebay overflow area (see Figure 12.POND.1).

The average snowmelt volume can be computed from the following equation:

$$\text{Average snowmelt volume (depth/unit area)} = \text{Average snowpack depth at the initiation of the snowmelt period} \times \text{Typical snowpack water at time of melt} - \text{Estimated infiltration volume likely to occur during a 10-day melt period.}$$

A series of maps have been prepared in Chapter 2 (Figures 2.5 - 2.7) that will allow the designer to determine the average depth of snowpack existing at the start of spring snowmelt, the water content of the snowpack during the month of March, and the expected infiltration.

Step 8. Size and design outlet structures.

The following outlet stages should be included in the pond design. It is possible to design one device to meet all stages. Equations included in this step are based on certain assumptions about which types of outlet structures will be used to control

A skimmer or similar device is REQUIRED to prevent the discharge of floating debris.

the various stages. If the designer chooses to use different structure types, the specific equations used to determine stage-discharge relationships will change, but the general approach will remain the same.

- Emergency drain: a drawdown pipe sized to drain the pond within 24 hours to allow access for riser repairs and sediment removal, or to lower the permanent pool in late fall (to provide additional storage during frozen conditions).

- Water quality (low flow) outlet: an outlet (typically an orifice) designed to release Vwq with an average detention time of 12 hours. After designing the orifice, a check should be made to verify that the release rate is no greater than 5.66 cfs/acre of pond surface area. (Calculation steps adapted from Vermont Stormwater Management Manual.)

The average release rate for Vwq is computed as:

$$Q_{WQ\_avg} = \frac{Vwq}{t_{WQ}}$$

Where t_{WQ} = the intended Vwq detention time.

From the stage-storage table, find the elevation associated with Vwq. Calculate the approximate average head on the water quality outlet as:

$$h_{wq\_avg} = \frac{E_{WQ} - E_{PermPool}}{2}$$

Where:

E_{WQ} = the Vwq pool elevation

$E_{PermPool}$ = the elevation of the permanent pool (the invert of the water quality orifice)

The required orifice cross sectional area can then be indirectly computed using the orifice equation:

$$Q_{WQ\_avg} = CA_{WQ}\sqrt{2gh_{wq\_avg}}$$

Where:

C = the orifice coefficient (0.6 is typically used, but may not apply in all cases)

A_{WQ} = the orifice area, and g is gravitational acceleration.

The diameter of the orifice is then d_{wq} = 2(ft)

$$d_{WQ} = 2 \cdot \sqrt{\left(\frac{A_{WQ}}{\pi}\right)}$$

The rate of discharge from the orifice for any head value h_{wq} on the orifice can then be computed as:

$$Q_{WQ} = CA_{WQ}\sqrt{2gh_{wq}}$$

- Channel protection outlet: an outlet designed to release Vcp over a period of 24 hours (minimum Vcp detention time is recommended to be 12 hours). The Vcp pool elevation can be read from the pond stage-storage relationship.

Assuming an orifice is also used to release Vcp, the invert of the Vcp orifice may be placed at the Vwq pool elevation (E_{WQ}).

The average release rate for Vcp is computed as:

$$Q_{CP\_avg} = \frac{Vcp - V_{WQ}}{t_{CP}} - Q_{WQ}$$

Where:

t_{CP} = the intended channel protection volume detention time,

Q_{WQ}= computed (using the above equation for Q_{WQ}), with the head value calculated as follows:

$$h_{wq} = \frac{E_{WQ} + E_{CP}}{2} - E_{PermPool}$$

From the stage-storage table, find the elevation associated with Vcp. The average head on the channel protection outlet can then be calculated as:

$$h_{cp\_avg} = \frac{E_{CP} - E_{WQ}}{2}$$

Again, the required orifice cross sectional area can then be indirectly computed using the orifice equation:

$$Q_{CP\_avg} = CA_{CP}\sqrt{2gh_{cp\_avg}}$$

The diameter of the orifice is then

$$d_{CP} = 2 \cdot \sqrt{\left(\frac{A_{CP}}{\pi}\right)}$$

The rate of discharge from the channel protection orifice for any head value h_{cp} on the channel protection outlet can then be computed as:

$$Q_{CP} = CA_{CP}\sqrt{2gh_{cp}}$$

The combined flow out of the water quality orifice and channel protection orifice at a given water surface elevation can be computed by adding together the discharges from the two structures, for the head values corresponding to the specified water surface elevation.

- Overbank flood control outlet: an outlet (typically a weir) with its invert at the Vcp pool elevation, designed to release Qp_{10} at predevelopment rates (recommended).

- Extreme storm control outlet: an outlet with its invert at or slightly above the Vp_{10} pool elevation, designed to release Qp_{100} at predevelopment rates (recommended), or at minimum to safely pass the Qp_{100} with 1' to 2' of freeboard below the top of the embankment. Check with local officials to determine whether a principal spillway can be used to manage extreme storm flows, or if an emergency spillway (broad-crested weir or earthen embankment, not susceptible to obstruction) is necessary.

Using the determined size information, incorporate the outlet structures into the pond design. Be aware of concerns associated with frozen conditions, particularly the risk of clogging or blockage of outlet structures with ice and the importance of burying pipes below the frost line.

A skimmer or similar device is REQUIRED to prevent the discharge of floating debris.

Step 9. Design spillway and embankments.

The following items are some of the key guidelines to adhere to in the design of spillways and embankments.

- It is REQUIRED that the emergency overflow be stabilized.

- It is REQUIRED that embankments be overfilled by at least 5% to account for settling.

- The REQUIRED minimum embankment width is 6' (wider for embankment height >10' or if maintenance access will be required).

- It is REQUIRED that embankments be adequately stabilized with vegetation or other measures.

- It is HIGHLY RECOMMENDED that side slopes be no steeper than 1:3 (V:H).

Additional design guidance and requirements for spillways and embankments are found in NRCS Pond 378 Conservation Practice Standard for Minnesota, which is available at http://efotg.nrcs.usda.gov/references/public/MN/378mn.pdf.

Step 10. Design inlets.

To prevent freezing and blockage of inflow, it is HIGHLY RECOMMENDED that inlet pipes not be fully submerged and that they be buried below the frost line. Frost and thaw depths for several Minnesota sites are shown at the following website:

http://www.mrr.dot.state.mn.us/research/seasonal_load_limits/thawindex/frost_thaw_graphs.asp.

It is also HIGHLY RECOMMENDED to design the inlet to reduce or prevent scour, by including riprap or flow diffusion devices such as plunge pools or berms.

Step 11. Design sediment forebay

The size of the sediment forebay was determined in Step 6. It is RECOMMENDED that a sediment marker be included in the forebay to indicate the need for sediment removal in the future. A hard bottom surface in the forebay is also RECOMMENDED in order to make sediment removal easier.

As discussed in Step 6, a weir structure added to the forebay will ensure that some pretreatment storage is available, even when the normal forebay is frozen.

Step 12. Design maintenance access and safety features.

- Maintenance access to the pond, forebay, and inlet and outlet structures is REQUIRED. The access routes should be designed with a minimum 10' width and maximum 15% slope.
- Safety features such as obstructive planting that make access difficult, signs warning against fishing and swimming, fencing, and grates over outlet structures should be included as appropriate.
- Aesthetic enhancements such as trails or benches can also be included
- If an outlet structure is greater than five feet deep, it is REQUIRED that OSHA health and safety guidelines be followed for safe construction and access practices. Additional information on safety for construction sites is available from OSHA. Use the following link to research safety measures for excavation sites: http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10930
- OSHA has prepared a flow chart which will help site owners and operators determine if the site safety plan must address confined space procedures: Permit-required Confined Space Decision Flow Chart - 1910.146 App A

Step 13. Check expected pond performance against regulatory requirements.

- Check that Vwq is detained for an average of 12 hours.
- Check that the Vwq release rate does not exceed 5.66 cfs/acre of pond area.
- Determine applicable requirements for Vcp volume and release rate, and verify that the pond performs adequately for the appropriate design event.
- Determine applicable requirements for Qp10 and Qp100 release rates (e.g., predevelopment rates), and check pond release rates (and freeboard) for the appropriate design events.

Step 14. Prepare vegetation and landscaping plan.

A landscaping and planting plan by a qualified professional for the pond and surrounding area should be prepared, utilizing native vegetation wherever possible.

Step 15. Prepare operation and maintenance plan.

Preparation of a plan for operation and maintenance of the pond and associated structures and landscaping is REQUIRED. See the *Operation and Maintenance* section for further details.

Table 12.POND.7 References to Other Manuals	
U.S. Dept of Transportation Federal Highway Administration	http://www.fhwa.dot.gov/environment/ultraurb/3fs4.htm
Georgia Stormwater Management Manual	http://www.georgiastormwater.com/vol2/3-2-1.pdf
Maryland Department of the Environment	http://www.mde.state.md.us/assets/document/chapter3.pdf
Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STRetenExtended.pdf
Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/swm-ch5.pdf
New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/pdf/_SWBMP_9.4%20print.pdf
New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/swmanual/.pdf
Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf
Western Washington	http://www.ecy.wa.gov/pubs/9915.pdf
Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/_bmp47.asp

Step 16. Prepare cost estimate.

Refer to the *Cost Considerations* section for information on preparing a cost estimate for stormwater ponds.Links to Other Manuals

VII. Links to Other Manuals

Table 12.POND.7 contains links contains links to information about wet extended detention ponds contained in other stormwater manuals. Links to information about other types of ponds is not included here, because of their limited applicability in Minnesota.

VIII. References

ASCE/EPA International Stormwater Best Management Practices (BMP) Database. http://www.bmpdatabase.org/.

Center for Watershed Protection (CWP), 2004. Stormwater Pond and Wetland Maintenance Guidebook (draft). Prepared for Tetra Tech, Inc. and USEPA Office of Science and Technology.

Atlanta Regional Commission, 2001. Georgia Stormwater Management Manual.

Metropolitan Council, 2001. *Urban Small Sites Best Management Practice Manual*.

Minnesota Pollution Control Agency, 2000. *Protecting Water Quality in Urban Areas.*

Minnesota Pollution Control Agency. *Permit No. MN R100001: General Permit Authorization to Discharge Stormwater Associated with Construction Activity under the National Pollutant Discharge Elimination System / State Disposal System Permit Program*. August 1, 2003.

Natural Resources Conservation Service. *Conservation Practice Standard – Pond (Code 378)*, February 2005.

Stormwater Manager's Resource Center website, "Construction Standards/Specifications for Ponds." http://www.stormwatercenter.net/, site update 2004.

Toronto and Region Conservation Authority SWAMP Program. *Storm Water Management Facility Sediment Maintenance Guide.* Prepared by Greenland International Consulting Company.

US Environmental Protection Agency (1999). Combined Sewer Overflow Technology Fact Sheet: Floatables Control. United States Environmental Protection Agency, Office of Water, Washington, DC. EPA 832-F99-008.

Vermont Agency of Natural Resources, April, 2002. *The Vermont Stormwater Manual.*

Weiss, P.T., J.S. Gulliver and A.J. Erickson, 2005. *The Cost and Effectiveness of Stormwater Management Practices: Final Report.* University of Minnesota, St. Anthony Falls Hydraulic Laboratory, Minneapolis, Minnesota, 99p.

Winer, R. National Pollutant Removal Performance Database, 2000.

STORMWATER WETLANDS

Stillwater, MN

Definition:

Constructed wetlands systems are used to store and treat runoff by mimicking the function of natural wetlands. However, stormwater wetlands are not natural wetlands and should not be included in natural wetland areas.

KEY CONSIDERATIONS

Design Criteria:

- ► A water budget should be calculated to ensure proper drainage area and to ensure that wetland conditions can be maintained.
- ► A minimum length to width ratio of 2:1 should be maintained during low flow or baseflow conditions.
- ► A minimum of 35% of the total wetland surface area should have a depth of 6 inches or less; 10% to 20% of surface area should be deep pool (1.5 to 6 foot depth).
- ► Constructed wetlands require about 2% to 4% of the area that drains to them.
- ► Thermal effects of discharged waters from stormwater wetlands on receiving bodies of water should be considered.

Benefits:

- ► Good suspended solid and annual nutrient removal
- ► Provides good wildlife habitat and aesthetic value
- ► Low maintenance costs
- ► Provides ground water: surface-water interface

Limitations:

- ► Requires more land than other practices
- ► Requires careful design and planning to ensure wetland hydrology is maintained
- ► Water quality behavior can change seasonally

MANAGEMENT SUITABILITY

High	Water Quality (V_{WQ})
Med.	Channel Protection (V_{CP})
Med.	Overbank Flood Protection (V_{P10})
Med.	Extreme Flood Protection (V_{P100})
Low	Recharge Volume (Re_V)

MECHANISMS

	Infiltration
X	Screening/ Filtration
	Temperature Control
X	Settling
X	Evaporation
X	Transpiration
X	Soil Adsorption
X	Biological/ Micro. Uptake

POLLUTION REMOVAL

75%	Total Suspended Solids
40%	Nutrients - Total Phosphorus/ Total Nitrogen
40%	Metals - Cadmium, Copper, Lead, and Zinc
75%	Pathogens - Bacteria
85%	Toxins - Hydrocarbon

SITE FACTORS

10-25 AC Min	Drainage Area *small applications may require only 5 acres of drainage area
25%	Max. Slope
3' Min*	Min. Depth to Bedrock *if above water supply aquifer or treating hotspots
3' Min*	Min. Depth to Seasonally High Water Table *if above water supply aquifer or treating hotspots
A,B,C,D	NRCS Soil Type
Good	Freeze/ Thaw Suitability
Yes	Potential Hotspot Runoff *requires impermeable liner

Description:

Stormwater wetlands are constructed shallow marsh systems designed to treat stormwater and, to a lesser extent, control runoff volumes in urban environments. Stormwater wetlands are different from natural systems in that they are specifically designed and constructed for the purpose of managing stormwater runoff. Like natural wetlands, stormwater wetlands require adequate hydrologic input to properly function. Water treatment is achieved through settling of particulates in the wetland system and uptake of nutrients and other constituents in the water by vegetation, soil, and biota. Stormwater wetlands can be very effective at removing pollutants and offer additional benefits in terms of aesthetics, ground water interaction, and wildlife and vegetative habitat.

Stormwater wetlands are best suited to removing contaminants other than sediment from flow. If sediment loads are high, pretreatment is required. Pretreatment options include the use of sediment forebays, filter strips, and construction of a pond upstream of the wetland to remove sediment. The choice of a particular pretreatment option depends on site and hydrologic conditions.

Stormwater wetlands are often termed constructed, artificial, manmade, and engineered wetlands.

Design Variations and Schematics:

There are three (3) basic types of stormwater wetlands: 1) shallow wetland, 2) extended detention (ED) shallow wetland, and 3) pond/wetland systems. Each basic design prescribes different amounts of shallow and deep water and amount of dry storage above the wetland. Following is a brief description of the three major types of stormwater wetlands:

- Shallow Wetland – A shallow wetland is designed with different areas of shallow and relatively deeper marsh. The deeper portions of the marsh are located at the sediment forebay at the wetland inlet and the micropool at the wetland's outlet. Shallow wetlands can be designed for smaller drainage areas (5 – 10 acres) though excavation to the water table may be required to sustain wetland hydrology.

- Extended Detention (ED) Shallow Wetland – The ED shallow wetland design incorporates additional water quality treatment detention above the surface of the shallow wetland design. The additional storage area is typically designed to dewater in a period of 24 hours so that vegetation is not damaged. This design requires a smaller project footprint that the shallow wetland system because temporary vertical storage is substituted for shallow marsh storage, though water quality treatment may be reduced as residence time and contact time with vegetation is also likely to diminish.

- Pond/Wetland Systems – This design incorporates a shallow marsh and wet pond to achieve water quality and quantity goals. Stormwater flows into the wet pond first, where sediments and sediment-bound pollutants have the opportunity to settle out and water velocities are reduced before entering the shallow marsh area. Less land is generally required for the pond/wetland system than for either the shallow wetland or ED shallow wetland designs.

STORMWATER WETLANDS

I. Suitability

General

Stormwater wetlands are similar in design to stormwater ponds and mainly differ by their variety of water depths and associated vegetative complex. They require slightly more surface area than stormwater ponds for the same contributing drainage area. Stormwater wetlands are constructed stormwater management practices, not natural wetlands. Like ponds, they can contain a permanent pool and temporary storage for water quality control and runoff quantity control.

Wetlands are widely applicable stormwater treatment practices that provide both water quality treatment and water quantity control. Stormwater wetlands are best suited for drainage areas of at least 10 acres. When designed and maintained properly, stormwater wetlands can be an important aesthetic feature of a site.

Function Within Stormwater Treatment Train

Stormwater wetlands are typically installed at the downstream end of the treatment train (they are considered an end-of-pipe BMP). Stormwater wetland size and outflow regulation requirements can be significantly reduced with the use of additional upstream BMPs. However, when a stormwater wetland is constructed, it is likely to be the only management practice employed at a site, and therefore must be designed to provide adequate water quality and water quantity treatment for all regulated storms.

MPCA Permit Applicability

One of the goals of this Manual is to facilitate understanding of and compliance with the MPCA Construction General Permit (CGP), which includes design and performance standards for permanent stormwater management systems. The permit and related documentation can be found online at http://www.pca.state.mn.us/water/stormwater/stormwater-c.html. These standards must be applied in all projects in which at least one acre of new impervious area is being created, and the permit stipulates certain standards for various categories of stormwater management practices.

For regulatory purposes, stormwater wetlands currently fall under the "Wet Sedimentation Basin" category described in Part III.C.1 of the permit. If used in combination with other practices, credit for combined stormwater treatment can be given as described in Part III.C.4. Due to the statewide prevalence of the MPCA permit, design guidance in this section is presented with the assumption that the permit does apply. Also, although it is expected that in many cases the wetland will be used in combination with other practices, standards are described for the case in which it is a stand-alone practice. Of note, the MPCA will evaluate the need to keep stormwater wetlands under the "wet sedimentation basin" category in future CGP revisions and consider it as a bioretention system instead. Input to MPCA on this would be welcomed.

The following terms are used in the text to distinguish various levels of stormwater wetland design guidance:

REQUIRED:	Indicates design standards stipulated by the MPCA Permit (or other consistently applicable regulations).
HIGHLY RECOMMENDED:	Indicates design guidance that is extremely beneficial or necessary for proper functioning of the wetland, but not specifically required by the MPCA permit.
RECOMMENDED:	Indicates design guidance that is helpful for stormwater wetland performance but not critical to the design.

Of course, there are situations, particularly retrofit projects, in which a stormwater pond is constructed without being subject to the conditions of the MPCA permit. While compliance with the permit is not required in these cases, the standards it establishes can provide valuable design guidance to the user. It is also important to note that **additional and potentially more stringent design requirements may apply for a particular stormwater wetland**, depending on where it is situated both jurisdictionally and within the surrounding landscape.

Design Variants

Stormwater wetlands are constructed with varying amounts of the following three components:

- Shallow marsh area
- Permanent micropool area
- Storage volume above the normal water level

The amount of each of the components named above depends on the desired type of stormwater wetland (e.g., shallow wetland). Figure 12.WETL.1 shows the three major types of stormwater wetlands presented in this Manual.

Stormwater wetland design must be tailored to site characteristics; however, some general RECOMMENDED design criteria for shallow wetland, ED shallow wetland, and pond/wetland design are presented in Table 12.WETL.1.

The proportions of deep water, low marsh, high marsh, and semi-wet marsh are presented above in Table 12.WETL.1 and are defined as:

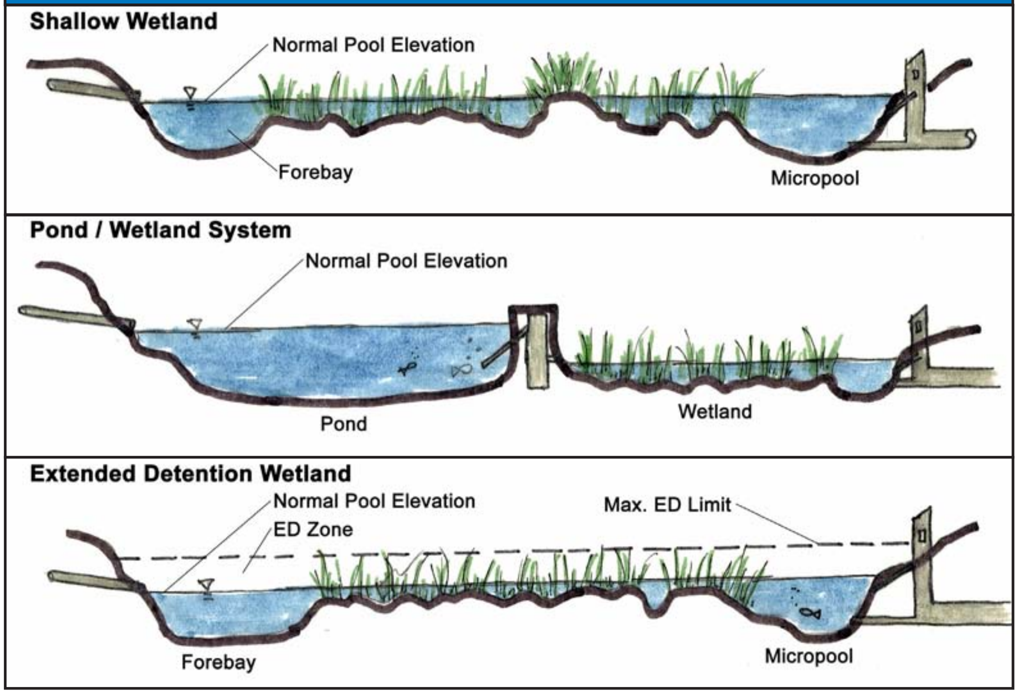
- Deepwater zone – From 1.5 to 6 feet deep. Includes the outlet micropool and the deepwater channels through the wetland facility. This zone supports little emergent wetland vegetation but may support submerged or floating vegetation. It is consistent with the Cowardin Wetland Classification of palustrine aquatic beds.
- Low marsh zone – From 6 to 18 inches below the normal permanent pool or water surface elevation. This zone is suitable for the growing of several emergent wetland plant species.

Table 12.WETL.1. Stormwater Wetland Design Criteria

Design Criteria	Shallow Wetland	Pond/Wetland	ED Shallow Wetland[1]
Wetland/Watershed Ratio (Ac/Ac)	0.2	0.1	0.1
Minimum Drainage Area (Ac)	25	10	25
Length to Width Ratio (minimum) (ft/ft)	2:1	2:1	2:1
Extended Detention (ED)	No	Optional	Yes
Allocation of V_{WQ} (pool/marsh/ED) in %	25/75/0	70/30/0 (includes pond volume)	25/25/50
Allocation of Surface Area (deepwater/low marsh/high marsh/semi-wet) in %	20/35/40/5	45/25/25/5 (includes pond surface area)	10/35/45/10
Forebay	Required	Required	Required
Micropool	Required	Required	Required
Outlet Configuration	Reverse-slope pipe or hooded broad-crested weir	Reverse-slope pipe or hooded broad-crested weir	Reverse-slope pipe or hooded broad-crested weir

1) Note: The ED Shallow Wetland design guidance does not meet the MPCA requirements for permanent volume. The guidance may be applied in a stormwater retrofit situation where area requirements preclude the use of a Shallow Wetland.

Figure 12.WETL.1 Major Stormwater Wetland Types



- High marsh zone – From 6 inches below the pool to the normal pool elevation. This zone will support a greater density and diversity of wetland species than the low marsh zone. The high marsh zone should have a higher surface area to volume ratio than the low marsh zone.
- Semi-wet zone – Those areas above the permanent pool that are inundated during larger storm events. This zone supports a number of species that can survive flooding.

Retrofit Suitability

As a retrofit, stormwater wetlands have the advantage of providing both educational and

Table 12.WETL.2 Design Restrictions for Special Water or Other Sensitive Receiving Watersheds

BMP	Watershed Management Category				
	A Lakes	B Trout Waters	C Drinking Water [a]	D Wetlands	E Impaired Waters
Wetlands	Some variations RESTRICTED due to poor P removal, combined with other treatments.	RESTRICTED except forwooded wetlands	PREFERRED	PREFERRED but no use of natural wetlands	PREFERRED

[a] applies to groundwater drinking water source areas only; use the sensitive lakes category to define BMP Design restrictions for surface water drinking supplies

Table 12.WETL.3 Percent Removal of Key Pollutants						
Practice	TSS [%]	Total Phosphorus [%]	Total Nitrogen [%]	Metals[1] [%]	Bacteria [%]	Hydro-carbons [%]
Stormwater Wetlands	75	40	30	40	80[2]	85[2]

Notes
1. Average of zinc and copper.
2. Based on fewer than five data points (i.e., independent monitoring studies)

Removals represent median values from Winer (2000) and are rounded

habitat value. One disadvantage of wetlands, however, is the difficulty in storing large amounts of runoff without consuming a large amount of land. Therefore, the most common type of wetland retrofit involves the modification of an existing dry or wet pond.

Special Receiving Waters Suitability

The following Table 12.WETL.2 provides guidance regarding the use of wetlands in areas upstream of special receiving waters. This table is an abbreviated version of a larger table in which other BMP groups are similarly evaluated (Chapter 10). The corresponding information about other BMPs is presented in the respective sections of this Manual.

Cold Climate Suitability

Wetland performance can be decreased in spring months when large volumes of runoff occur in a relatively short time carrying the accumulated pollutant load from the winter months. Because stormwater wetlands are relatively shallow, freezing of the shallow pool can occur. Also, freezing of inlet and outlet structures can occur, which will reduce performance of the stormwater wetland. To avoid these problems, the CWP (Caraco and Claytor, 1997) made some general design suggestions, which are adapted as follows:

- Inlet pipes should not be submerged, since this can result in freezing and upstream damage or flooding.
- Burying all pipes below the frost line can prevent frost heave and pipe freezing. Wind protection can also be an important consideration for pipes above the frost line. In these cases, designs modifications that have pipes "turn the corner" are helpful.
- Increase the slope of inlet pipes to a minimum of 1% to prevent standing water in the pipe, reducing the potential for ice formation. This design may be difficult to achieve at sites with flat local slopes.
- If perforated riser pipes are used at the outlet, the minimum opening diameter should be ½". In addition, the pipe should have a minimum 6" diameter.
- When a standard weir is used, the minimum slot width should be 3", especially when the slot is tall.
- Baffle weirs can prevent ice reformation during the spring melt near the outlet by preventing surface ice from blocking the outlet structure.

12.WETL.4 Typical BMP Best Attainable Effluent Concentrations					
Practice	TSS [mg/l]	TP [mg/l]	TN [mg/l]	Cu [ug/l]	Zn [ug/l]
Wetlands	6	0.2	1.7	3.0	50
Values from ASCE bmp database and Winer 2000 (shaded values)					

> ***It is HIGHLY RECOMMENDED that when providing water quantity control in stormwater wetlands, the smallest possible bounce (vertical water level fulctuation) be designed for in order to limit the amount of stress on the vegetation.***

- Alternative outlet designs that have been successful include using a pipe encased in a gravel jacket set at the elevation of the aquatic bench as the control for water quality events. This practice was both avoids stream warming and is also a non-freezing outlet.

- Trash racks should be installed at a shallow angle to prevent ice formation.

Water Quantity Treatment

Stormwater wetlands are well-suited to provide channel protection and overbank flood protection. As in ponds, this is accomplished with live storage (extended detention) above the permanent pool. It is HIGHLY RECOMMENDED that when providing water quantity control in stormwater wetlands, the smallest possible bounce (vertical water level fluctuation) be designed for in order to limit the amount of stress on the vegetation.

Water Quality Treatment

Pollutants are removed from stormwater runoff in a wetland through uptake by wetland vegetation and biota (algae, bacterial), vegetative filtering, soil adsorption, and gravitational settling in the slow moving marsh flow. Volatilization and chemical activity can also occur, breaking down and assimilating a number of other stormwater contaminants such as hydrocarbons.

Pollutant removal efficiencies for selected parameters are provided in Table 12.WETL.3. Optimum effluent concentrations for select parameters are provided in Table 12.WETL.4.

Limitations

The following general limitations should be recognized when considering installation of stormwater wetlands:

- they require more land than other practices;

- they requires careful design and planning to ensure wetland hydrology is maintained; and

- water quality behavior can change seasonally

Major Design Elements

Physical Feasibility Initial Check

Before deciding to construct a wetland for stormwater management, it is helpful to consider several items that bear on the feasibility of using a wetland at a given location. The following list of considerations will help in making an initial judgment as to whether or not a wetland is the appropriate BMP for the site. Note that none of these guidelines are strictly required by the MPCA Permit, and it may be possible to overcome site deficiencies with additional engineering or the use of other BMPs.

- **Drainage Area** – 25 acres minimum HIGHLY RECOMMENDED, ensuring hydrologic input sufficient to maintain permanent pool; 10 acres (or less) may be acceptable, particularly if the ground water table is intercepted and a water balance indicates that a permanent pool can be sustained.

- **Space Required** – Approximately 2-4% of the tributary drainage area is RECOMMENDED for wetland footprint.

- **Minimum Head** – The elevation difference RECOMMENDED at a site from the inflow to the outflow is a minimum of 2 feet. The relatively small head requirement makes stormwater wetlands a feasible practice in areas with shallow soils.

- **Minimum Depth to Water Table** – In general, there is no minimum separation distance required with stormwater wetlands. In fact, intercepting the ground water table is common and helps sustain a permanent pool. However, some source water protection requirements may dictate a separation distance if there is a sensitive underlying aquifer, which means that a liner might be required for portions of the wetland with standing water.

- **Soils** – Underlying soils of hydrologic group "C" or "D" should be adequate to maintain a wetland. Most group "A" soils and some group "B" soils may require a liner. A site specific geotechnical investigation should be performed. Also, if earthen embankments are to be constructed, it will be necessary to use suitable soils.

- **Groundwater Protection** – It is REQUIRED that stormwater wetlands treating runoff from Potential Stormwater Hotspots (PSHs) provide excellent treatment capabilities. In some cases (depending on the land use and associated activities), lining the stormwater wetland may be necessary to protect groundwater, particularly when the seasonally high groundwater elevation is within three feet of the practice bottom.

- **Karst** – Stormwater wetlands are a preferred management technique over stormwater ponds in karst areas, but it is RECOMMENDED that maximum pool depths be 3 to 5 feet. If stormwater wetlands are used in karst areas, impermeable liners may be needed.

- **Cold Water Fisheries** – Stormwater wetlands may not be appropriate practices where receiving waters are sensitive cold water fisheries due to the potential for stream warming from wetland outflows. Suitable vegetative canopy may lessen potential negative effects.

Conveyance

Inflow Points

- It is REQUIRED that inlet areas be stabilized to ensure that non-erosive conditions exist during events up to the overbank flood event (i.e., Q_{p10}).

- It is HIGHLY RECOMMENDED that inlet pipe inverts be located at the permanent pool elevation if the wetland contains a pool. Submerging the inlet pipe is can result in freezing and upstream damage during cold weather.

- It is HIGHLY RECOMMENDED that inlet pipes have a slope of no flatter than 1%, to prevent standing water in the pipe and reduce the potential for ice formation.

- It is HIGHLY RECOMMENDED that pipes be buried below the frost line to prevent frost heave and pipe freezing.

- It is HIGHLY RECOMMENDED that trenches for pipes be over-excavated and backfilled with gravel or sand to prevent frost heave and pipe freezing.

- It is HIGHLY RECOMMENDED that where open channels are used to convey runoff to the wetland, the channels be stabilized to reduce the sediment loads.

Adequate Outfall Protection

Stormwater wetland outfalls should be designed to not increase erosion or have undue influence on the downstream geomorphology of the stream.

- It is HIGHLY RECOMMENDED that a stilling basin or outlet protection be used to reduce flow velocities from the principal spillway to non-erosive velocities (3.5 to 5.0 fps).

- Flared pipe sections that discharge at or near the stream invert or into a step-pool arrangement are RECOMMENDED over headwalls at the spillway outlet.

- It is RECOMMENDED that tree clearing be minimized along the downstream channel and that a forested riparian zone be reestablished in the shortest possible distance. It is also RECOMMENDED that excessive use of riprap be avoided, to minimize stream warming in channels with dry weather flow.

- Local agencies (Watershed Districts, Watershed Management Organizations (WMOs), municipalities, etc.) may have additional outlet control requirements.

Pre-treatment

Sediment forebays are the commonly used pre-treatment method for stormwater wetlands, although other features, such as grassed swales, could be used to remove sediment from runoff before it enters the wetland system. A forebay or equivalent pretreatment should be in place at each inlet to ease the maintenance burden and preserve the longevity of the stormwater wetland. See the section on Stormwater Ponds for design guidance.

Treatment

Permanent Pool (V_{PP}) and Water Quality Volume (V_{WQ}).

Stormwater wetlands follow similar sizing criteria as stormwater ponds. See the Stormwater Ponds section for guidance on sizing the permanent pool volumes, water quality volume, and depth.

A water balance is recommended to ensure sufficient inflows to maintain a constant wetland pool and sustain wetland vegetation during prolonged dry weather conditions. This is of particular importance in stormwater wetlands. The basic approach to performing a water balance is as follows:

1. Check maximum drawdown during periods of high evaporation and during an extended period of no appreciable rainfall to ensure that wetland vegetation will survive.

2. The change in storage within a wetland = inflows – outflows.

3. Potential inflows: runoff, baseflow and rainfall.

4. Potential outflows: Infiltration, surface overflow and evapotranspiration.

5. Assume no inflow from baseflow, no outflow losses for infiltration or for surface overflows. The validity of these assumptions need to be verified for each design.

6. Therefore, change in storage = runoff - evapotranspiration.

If a liner is required for the stormwater wetland, it should be designed following the same guidance as for stormwater ponds.

A water balance is recommended to ensure sufficient inflows to maintain a constant wetland pool and sustain wetland vegetation during prolonged dry weather conditions. This is of particular importance in stormwater wetlands.

A forebay or equivalent pre-treatment should be in place at each inlet to ease the maintenance burden and preserve the longevity of the stormwater wetland. See the section on Storwater Ponds for design guidance.

Grading and Site Layout

Site layout and grading affect the pollutant removal capability of the stormwater wetlands as well as the ease of maintenance. Performance is enhanced when multiple cells, longer flowpaths, high surface area to volume ratios, and complex microtopography are used. Specific design considerations for site layout include:

- It is RECOMMENDED that, to the greatest extent possible, stormwater wetlands be irregularly shaped and long flow paths be maintained.
- Microtopography (small irregular 6 to 24 inch variations in bottom topography) is RECOMMENDED to enhance wetland diversity.
- It is HIGHLY RECOMMENDED that at least 25% of the wetland pool volume of a stormwater wetland be in deepwater zones with a depth greater than four feet.
- It is HIGHLY RECOMMENDED that a minimum of 35% of the total surface area of stormwater wetlands should have a depth of six inches or less, and at least 65% of the total surface area shall be shallower than 18 inches (see mosquito control discussion in Chapter 6).
- It is HIGHLY RECOMMENDED that a micropool be excavated at the wetland outlet to prevent resuspension of sediments.
- It is HIGHLY RECOMMENDED that the extended detention associated with the V_{wq} and V_{cp} not extend more than three feet above the permanent pool at its maximum water surface elevation.
- It is HIGHLY RECOMMENDED that berms be used to separate wetland cells. This reduces the incidence of freezing and requires less maintenance than pipes or concrete weirs.
- Structures such as fascines, coconut rolls, straw bales, or carefully designed stone weirs can be used to create shallow marsh cells in high-energy areas of the stormwater wetland.
- It is HIGHLY RECOMMENDED that the perimeter of all deep pool areas (four feet or greater in depth) be surrounded by an access bench and aquatic bench, as described in the stormwater ponds section. The aquatic benches can be incorporated into the pond microtopography.

Landscaping

Landscaping Plan

It is HIGHLY RECOMMENDED that a qualified landscape professional prepare a Landscaping Plan that includes both plant materials, bedding materials and maintenance schedules. There are many references describing suitable native species of plants for Minnesota. The reader is referred to Appendix E as well as to Shaw and Schmidt, 2003. Plants for Stormwater Design. The following guidelines are RECOMMENDED for landscaping of stormwater wetland facilities.

- A landscaping plan shall be provided that indicates the methods used to establish and maintain wetland coverage. Minimum elements of a plan include: delineation of pondscaping zones, selection of corresponding plant species, planting plan, sequence for preparing wetland bed (including soil amendments, if needed) and sources of plant material.

- Vegetation selection should be based on the anticipated hydrologic function of the stormwater wetland (e.g. water level fluctuation).

- Design should consider control – predation by carp, geese, deer, etc.

- Donor soils for stormwater wetland mulch should not be removed from natural wetlands.

- Wetland soils mixes often contain wetland plant propagules that help to establish the plant community.

- The landscaping plan should provide elements that promote greater wildlife and waterfowl use within the stormwater wetland and buffers.

- The planting schedule should reflect the short growing season. Designers should consider incorporating relatively mature plants, or planting dormant rhizomes during the winter.

- If a minimum coverage of 50% is not achieved in the planted wetland zones after the second growing season, a reinforcement planting is required.

- It is RECOMMENDED that a landscape architect or another landscape professional be consulted in selection of wetland plants.

Constructed Wetlands Buffers and Setbacks

- It is REQUIRED (Minnesota Department of Health Rule 4725.4350) that a 50' setback between high water levels of stormwater ponds and public water supply wells be provided. It is assumed that constructed wetlands fall under the definition of stormwater ponds in Rule 4725.4350.

- It is HIGHLY RECOMMENDED that a buffer extending 25 feet outward from the maximum water surface elevation be provided. Permanent structures (e.g., buildings) should not be constructed within the buffer. This distance may be greater under local regulations.

- The buffer should be contiguous with other buffer areas that are required by existing regulations (e.g., stream buffers).

- It is HIGHLY RECOMMENDED that existing trees should be preserved in the buffer area during construction. It is desirable to locate forest conservation areas adjacent to ponds. To help discourage resident geese populations, the buffer can be planted with trees, shrubs and native ground covers.

Safety

- It is REQUIRED that public safety be considered in every aspect of stormwater wetland design.

- The principal spillway opening should not permit access by small children, and endwalls above pipe outfalls greater than 48 inches in diameter should be fenced to prevent a hazard.

- The access and aquatic benches should be landscaped to prevent access to the wetland.

- Warning signs prohibiting swimming, skating, and fishing should be posted.

- Wetland fencing is generally not encouraged, but may be required by some municipalities. A preferred method is to grade to eliminate steep drop-offs or other safety hazards.

- Dam safety regulations should be strictly followed with stormwater wetland design to ensure that downstream property and structures are adequately protected.

III. Construction Details and Specifications

CADD-based details for pond and wetland systems are contained in Appendix D. The following details, with specifications, have been created for stormwater ponds/wetlands:

- TYPICAL POND PLAN AND PROFILE

- ▶ SHALLOW WETLAND PLAN AND PROFILE
- ▶ EXTENDED DETENTION SHALLOW WETLAND PLAN AND PROFILE
- ▶ OUTLET STRUCTURE DETAILS

IV. *Operation and Maintenance*

Overview

Maintenance is necessary for a stormwater wetland to operate as designed on a long-term basis. The pollutant removal, channel protection, and flood control capabilities of stormwater wetlands will decrease if:

- ▶ Wetland pool elevations fluctuate dramatically
- ▶ Debris blocks the outlet structure
- ▶ Pipes or the riser are damaged
- ▶ Invasive plants out-compete the wetland plants
- ▶ Sediment accumulates in the stormwater wetland, reducing the storage volume
- ▶ Slope stabilizing and desirable wetland vegetation is lost
- ▶ The structural integrity of the embankment, weir, or riser is compromised.

Stormwater wetland maintenance activities range in terms of the level of effort and expertise required to perform them. Routine stormwater wetland maintenance, such as mowing and removing debris or trash, is needed multiple times each year, but can be performed by citizen volunteers. More significant maintenance, such as removing accumulated sediment, is needed less frequently but requires more skilled labor and special equipment. Inspection and repair of critical structural features such as embankments and risers, needs to be performed by a qualified professional (e.g., structural engineer) that has experience in the construction, inspection, and repair of these features.

Design Phase Maintenance Considerations

The following references may be consulted for more information on stormwater wetland maintenance:

- ▶ City of Plymouth, MN, Pond Maintenance Policy. 2005.
- ▶ Center for Watershed Protection, 2004. *Stormwater Pond and Wetland Maintenance Guidebook*.
- ▶ GIC, 1999. “Storm Water Management Facility Sediment Maintenance Guide”. TheToronto and Region Conservation Authority, Ontario Ministry of the Environment SWAMP Program. By: Greenland International Consulting Inc. August 1999.

Implicit in the design guidance in the previous sections, many design elements of stormwater wetland systems can minimize the maintenance burden and maintain pollutant removal efficiency. Primarily, providing easy access (typically 8 feet wide) to stormwater wetlands for routine maintenance is REQUIRED.

Mosquito control is of particular concern in the case of stormwater wetlands. They can be designed, constructed and maintained to minimize the likelihood of being desirable habitat for mosquito populations, but no design will eliminate tem completely. Designs that incorporate constant inflows and outflows, habitat for natural predators, and constant permanent pool elevations limit the conditions typical of mosquito breeding habitat. See Chapter 6 for an in-depth discussion of mosquito concerns in stormwater management.

Construction Phase Maintenance

The construction phase is another critical step where O&M issues can be minimized or avoided.

Inspections during construction are needed to ensure that the stormwater wetland is built in accordance with the approved design and standards and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction, to ensure that the contractor's interpretation of the plan is acceptable to the professional designer. An example construction phase inspection checklist is provided in Appendix D.

Post Construction Operation and Maintenance

Proper post-construction maintenance is important to the long-term performance of a stormwater wetland. Potential problems due to lack of maintenance include:

- A clogged outlet structure can increase water levels, killing vegetation and reducing the wetland's ability to attenuate and store floods. Water quality can be compromised by not providing adequate storage time.

- Excess sediment can reduce storage volumes leading to many of the problems outlined above.

- Nuisance issues such as beaver and muskrat burrows/dens can threaten the integrity of embankments.

Some important post construction maintenance considerations are provided below. A more detailed checklist of maintenance activities and associated schedules is provided in Appendix D. More detailed maintenance guidance can be found in the Pond and Wetland Maintenance Guidebook (CWP, 2004).

- It is REQUIRED that a legally binding and enforceable maintenance agreement be executed between the practice owner and the local review authority.

- Adequate access must be provided for inspection, maintenance, and landscaping upkeep, including appropriate equipment and vehicles. It is RECOMMENDED that a maintenance right of way or easement extend to ponds from a public or private road.

- It is HIGHLY RECOMMENDED that stormwater wetlands be inspected annually during winter freeze periods to look for signs of improper operation.

- It is HIGHLY RECOMMENDED that sediment removal in the forebay occur every 2 to 7 years or after 50% of total forebay capacity has been lost. In areas where road sand is used, an inspection of the forebay and stormwater wetland should be scheduled after the spring melt to determine if clean-out is necessary.

- Sediments excavated from stormwater wetlands that do not receive runoff from confirmed hotspots are generally not considered toxic or hazardous material, and can be safely disposed by either land application or land filling. Sediment testing may be necessary prior to sediment disposal when a confirmed hotspot land use is present (see also Chapter 13).

- Periodic mowing of the stormwater wetland buffer is HIGHLY RECOMMENDED along maintenance rights-of-way and the embankment. The remaining buffer can be managed as a meadow (mowing every other year), prairie, or forest.

- General maintenance activities and schedule are provided in Table 12.WETL.5.

V. *Cost Considerations*

Cost factors for stormwater management ponds are extremely sensitive to site conditions. Availability of materials for embankment construction, outlet protection, cost of excavation, liner materials, and land costs are significant factors. Maintenance and inspection costs for mowing and periodic dredging are post-development factors. Other technologies such as infiltration trenches may be more cost-effective in smaller drainage areas due to construction and long-term maintenance costs (Young *et al.*, 1996). Costs for ponds typically include costs for embankment, riser and spillway structures, outfall protection, vegetative stabilization, excavation, and grading. Additional costs for site preparation can include soil amendments, precision grading, plant materials

Table 12.WETL.5: Typical Inspection/Maintenance Frequencies for Stormwater Wetlands		
Inspection Items	**Maintenance Items**	**Frequency**
▪ Ensure that at least 50% of wetland plants survive ▪ Check for invasive wetland plants.	▪ Replant wetland vegetation	One time - After First Year
▪ Inspect low flow orifices and other pipes for clogging ▪ Check the permanent pool or dry pond area for floating debris, undesirable vegetation. ▪ Investigate the shoreline for erosion ▪ Monitor wetland plant composition and health. ▪ Look for broken signs, locks, and other dangerous items.	▪ Mowing – minimum Spring and Fall ▪ Remove debris ▪ Repair undercut, eroded, and bare soil areas.	Monthly to Quarterly or After Major Storms (>1")
▪ Monitor wetland plant composition and health. ▪ Identify invasive plants ▪ Assure mechanical components are functional	▪ Trash and debris clean-up day ▪ Remove invasive plants ▪ Harvest wetland plants ▪ Replant wetland vegetation ▪ Repair broken mechanical components if needed	Semi-annual to annual
▪ All routine inspection items above ▪ Inspect riser, barrel, and embankment for damage ▪ Inspect all pipes ▪ Monitor sediment deposition in facility and forebay	▪ Pipe and Riser Repair ▪ Forebay maintenance and sediment removal when needed	Every 1 to 3 years
▪ Monitor sediment deposition in facility and forebay	▪ Forebay maintenance and sediment removal when needed	2-7 years or 50% loss of sediment forebay storage
▪ Remote television inspection of reverse slope pipes, underdrains, and other hard to access piping	▪ Sediment removal from main pond/wetland ▪ Pipe replacement if needed	5-25 years

and creation of occluding layers in coarse-textured soil types if wetlands systems must be created on upland sites due to project constraints. Project costs can be lowered if existing pre-construction site conditions are carefully considered and isolated areas with hydric soils contained within the footprint of the project are utilized as stormwater management facilities.

Additional maintenance costs may be incurred until the establishment of the wetland ecosystem. Invasive plants must be culled and dead plants replaced. The outlet structure may have to be adjusted, based on seasonal observations, to

Table 12.WETL.6. Primary cost components for stormwater wetlands			
Implementation Stage	**Primary Cost Components**	**Basic Cost Estimate**	**Other Considerations**
Site Preparation	Tree & plant protection	Protection Cost ($/acre) x Affected Area (acre)	Removal of existing structures, topsoil removal and stockpiling
	Topsoil salvage	Salvage Cost ($/acre) x Affected Area (acre)	
	Clearing & grubbing	Clearing Cost ($/acre) x Affected Area (acre)	
Site Formation	Excavation / grading	4-ft Depth Excavation Cost ($/acre) x Area (acre)	Soil & rock fill material, tunneling
	Hauling material offsite	Excavation Cost x (% of Material to be hauled away)	
Structural Components	Inlet structure	($/structure)	Pipes, catchbasins, manholes, valves
	Outlet structure	($/structure)	
Site Restoration	Soil Preparation	Soil cost ($/acre) x Seeding/planting area (1 ft average depth per acre)	Tree protection, soil amendments, seed bed preparation, trails
	Seeding (or sodding)	Seeding Cost ($/acre) x Seeded Area (acre)	
	Planting / transplanting	Planting Cost ($/acre) x Planted Area (acre)	
Annual Operation, Maintenance, and Inspection	Debris removal	Removal Cost ($/acre) x Area (acre) x Frequency (2 / 1yr)	Vegetation maintenance, cleaning of structures
	Invasive plant removal	Labor Cost ($/hr) X Time X Frequency	
	Sediment removal	Removal Cost ($/acre) x Area (acre) x Frequency (1 / 5yr)	
	Erosion Repair	Repair cost ($/area) x Area Affected	
	Gate / valve operation	Operation Cost ($) x Operation Frequency (2 / 1 yr)	
	Inspection	Inspection Cost ($) x Inspection Frequency (2 / 1 yr)	
	Mowing	Mowing Cost ($) x Mowing Frequency (4 / 1 yr)	

achieve the proper water surface in the pond. (FHWA, 1997).

Detailed Cost Estimate

The most appropriate technique for determining the cost to construct and maintain a specific BMP will be to apply unit costs to each component of construction, operation and/or maintenance. Table 12.WETL.6 represents the typical components for stormwater wetlands. This table presents those components of a construction project that are unique to this best management practice. Costs that would be associated with all aspects of a construction site, such as erosion and sediment control, mobilization, or traffic control, are not presented as unique costs.

Designers are encouraged to use the cost worksheet included in Appendix D to estimate their BMP construction cost.

VI. *Design Procedure*

As previously indicated, if the stormwater wetland is being designed to meet requirements for permanent storm water management in the MPCA CGP, the design criteria of the permit for Wet Sedimentation Basins apply. The following procedure is based on those criteria. If the stormwater wetland is being designed as a retrofit or is not subject to the criteria listed in the MPCA permit, then the criteria listed in the permit are not required to be followed but may be used for general guidance.

Step by Step Design Procedure:

Step 1. Make a preliminary judgment as to whether site conditions are appropriate for the use of a stormwater wetland, and identify the function of the wetland in the overall treatment system.

A. Consider basic issues for initial suitability screening, including:

- Site drainage area
- Soils
- Slopes
- Space required for wetland
- Depth to water table
- Minimum head
- Receiving waters

B. Determine how the wetland will fit into the overall stormwater treatment system

- Are other BMPs to be used in concert with the constructed wetland?
- Will a pond be part of the wetland design and if so, where?

Step 2. Confirm local design criteria and applicability.

A. Determine whether the wetland must comply with the MPCA Permit.

B. Check with local officials and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3. Confirm site suitability

A. Perform field verification of site suitability.

- If the initial evaluation indicates that a wetland would be a good BMP for the site, it is RECOMMENDED that a sufficient number of soil borings be taken to ensure wetland that conditions (hydrologic and vegetative) can be maintained after construction. The number of borings will vary depending on size of the site, parent material and design complexity. For example, a design that requires compacted earth material to form a dike will likely require more borings than one without this feature.
- It is RECOMMENDED that the soil borings or pits be five feet below the bottom elevation of the proposed stormwater wetland.
- It is HIGHLY RECOMMENDED that the field verification be conducted by a qualified geotechnical professional.

B. Perform water balance calculations if needed.

Step 4. Compute runoff control volumes and permanent pool volume.

Calculate the Permanent Wetland Pool Volume (V_{PP}), if needed, Water Quality Volume (Vwq), Channel Protection Volume (Vcp), Overbank Flood Protection Volume (Vp_{10}), and the Extreme Flood Volume (Vp_{100}).

If the wetland is being designed as a wet detention pond under the MPCA permit, then a Permanent Wetland Pool Volume, V_{PP}, of 1800 cubic feet of storage below the outlet pipe for each acre that drains to the wetland is REQUIRED. This can be calculated as:

Figure 12.WETL.4 Shallow Wetland Profile

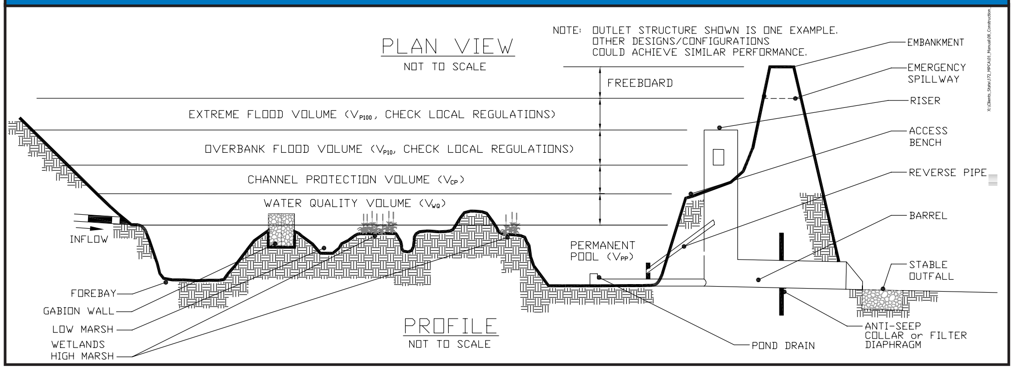
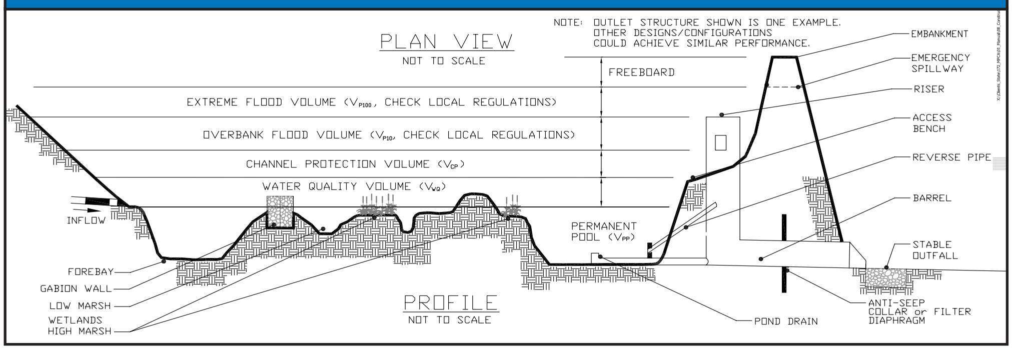


Figure 12.WETL.5 Extended Detention Shallow Wetland Profile



V_{PP} = 1800ft^3 * A

or

V_{PP} = (0.5 inches * IC) * (1/12)

Where:
A = total watershed area in acres draining to the pool

In the case where the entire Vwq is to be treated with other BMPs and the wetland is being constructed only for rate control, a permanent pool may not be required, although it still may be desirable.

The water quality volume, Vwq, can be calculated as:

For normal waters:

V_{WQ} = (0.5 inches * IC) * (1/12)

For special waters (see Chapter 10):

V_{WQ} = (1.0 inches * IC) * (1/12)

Where:
A_i = the new impervious area in acres.

It is recommended that the Channel Protection Volume, Vcp, be based on the 1-yr, 24-hr rainfall event, though local ordinances may be more restrictive. It should be noted that the Vcp is inclusive of the Vwq. In other words, the Vwq is contained within the Vcp.

If part of the overall Vwq is to be treated by other BMPs, subtract that portion from the Vwq to determine the part of the Vwq to be treated by the stormwater wetland. If some portion of the other control volumes is treated by other BMPs, it can be subtracted from the overall Vcp, Vp_{10}, and Vp_{100} to determine the volume to be treated by the wetland. The configuration of the various storage allocations is shown in the stormwater wetland profile in Figures 12.WETL.4 and 12.WETL.5.

Additional details on the Unified Stormwater Sizing Criteria are found in Chapter 10.

Step 5. Determine pre-treatment (sediment forebay) volume (HIGHLY RECOMMENDED).

In the absence of adequate upstream treatment by other BMPs, it is HIGHLY RECOMMENDED that a sediment forebay or similarly effective pretreatment system be provided at each inlet providing 10% or more of the total design inflow, with a RECOMMENDED volume equal to 10% of the computed wetland permanent pool volume (V_{PP}) in a pool 4 to 6 feet deep. The forebay storage volume counts toward the total V_{PP} requirement and may be subtracted from the V_{PP} for subsequent calculations. Similarly, the storage volume from other BMPs used upstream of the constructed wetland in the treatment train counts toward the total V_{wq} requirement and may be subtracted from it.

Step 6. Allocate the remaining V_{PP} and V_{WQ} volumes among marsh, micropool, and ED volumes.

Taking into consideration that 10% of the required permanent pool volume has already been allocated to the pre-treatment forebay, the remaining required volume may be allocated between marsh, micropool, and ED volumes using the recommendations presented in Table 12.WETL.1 to meet the CGP or local requirements.

Step 7. Determine wetland location and preliminary geometry, including distribution of wetland depth zones.

This step involves initially laying out the wetland design and determining the distribution of wetland surface area among the various depth zones (high marsh, low marsh, and deep water). A stage-storage relationship should be developed to describe the storage requirements and to set the elevation of the wetland pool elevation, the water quality volume, the extended detention volume (if applicable), the channel protection volume, etc.

The proportion of surface area recommended to place in the various depth zones for each type of constructed wetland is shown in Table 12.WETL.1. Other guidelines for constructed wetland layout are:

- Provide maintenance access (10' width for trucks/machinery)
- Length to width ratios as presented in Table 12.WETL.1.

Step 8. Consider water quality treatment volume variations for frozen conditions (HIGHLY RECOMMENDED).

When the pond and sediment forebay are frozen, much of the storage is rendered ineffective because stormwater runoff can flow over the ice and bypass the intended treatment. To alleviate this problem, additional extended detention storage (which is available even under frozen conditions) can be designed into the pond by increasing the extended detention storage volume designated for water quality control, or by adding a weir structure to the sediment forebay overflow area (see discussion in Chapter 9).

The average snowmelt volume can be computed from the following equation:

Average snowmelt volume (depth/ unit area)	=	Average snowpack depth at the initiation of the snowmelt period	x	Typical snowpack water at time of melt	–	Estimated infiltration volume likely to occur during a 10-day melt period.

A series of maps have been prepared in Chapter 2 (Figures 2.5-2.7) that will allow the designer to determine the average depth of snowpack existing at the start of spring snowmelt, the water content of the snowpack during the month of March and the expected infiltration.

Step 9. Compute extended detention outlet release rate(s), and establish Vcp elevation.

Shallow Wetland: The Vcp elevation is determined from the stage-storage relationships and the outlet is then sized to release the channel protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams). The channel protection outlet should have a minimum diameter of 3 inches and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged 12 to 18 inches below the elevation of the wetland pool, or 6 inches below the normal ice depth, where outlet depths permit, is recommended. Adjustable gate valves can also be used to achieve these equivalent diameters.

1. The desired release rate may then be calculated by:

$$Q_{CP} = \frac{Vcp\left[ft^3\right]}{t\left[s\right]}$$

Where:
t = the detention time in seconds determined above

Check to determine if Q_{CP} is less than or equal to 5.66 cfs per acre of surface area of the wetland. If Q_{CP} meets the criterion, proceed to the next step in the process. If Q_{CP} is greater than 5.66 cfs, the release time should be increased or a two-stage outlet should be used whereby the first outlet is able to discharge V_{WQ} to meet the permit requirements. A two-stage outlet procedure is presented for the ED Shallow Wetland.

2. The average head is calculated as:

$$h_{avg} = \frac{\left(EL_{CP}\left[ft\right] - EL_{WP}\left[ft\right]\right)}{2}$$

Where:
EL_{CP} = the elevation of the channel protection volume and EL_{WP} is the wetland pool elevation.

3. Given the design release rate, estimated in #1 above, an outlet may be sized using either the weir or orifice equations.

4. The discharge from the wetland can then be computed for any elevation between EL_{CP} and the wetland pool elevation.

ED Shallow Wetland: Based on the elevations established in Step 6 for the extended detention portion of the water quality volume, the water quality outlet is sized to release this extended detention volume in 24 hours. If a water quality orifice is used, it should have a minimum diameter of 3 inches, and should be adequately protected from clogging by an acceptable external trash rack. A reverse slope pipe attached to the riser, with its inlet submerged one foot below the elevation of the permanent pool, is a recommended design. Adjustable gate valves can also be used to achieve this equivalent diameter. The V_{CP} elevation is then determined from the stage-storage relationship. The invert of the channel protection outlet is located at the water quality extended detention elevation, and the structure outlet is sized to release the channel protection storage volume over a 24-hour period (12-hour extended detention may be warranted in some cold water streams).

Steps to compute the ED outlet are similar to those presented above for the Shallow Wetland. In this procedure V_{WQ} is equal to the extended detention volume.

1. The time period over which to release the V_{WQ} volume is typically 24 hours, though this time may be reduced to 12 hours depending on thermal concerns of receiving bodies of water.

2. The release rate may then be calculated by:

$$Q_{WQ} = \frac{V_{WQ}\left[ft^3\right]}{t\left[s\right]}$$

where:
t = the detention time in seconds determined above

Check to determine if Q_{wq} is less than or equal to 5.66 cfs per acre of surface area of the wetland. If Q_{wq} meets the criterion, proceed to the next step in the process. If Q_{wq} is greater than 5.66 cfs, the release time should be increased.

3. The average head is calculated as:

$$h_{avg} = \frac{\left(EL_{WQ}\left[ft\right] - EL_{WP}\left[ft\right]\right)}{2}$$

where EL_{WQ} is the elevation of the water quality volume elevation and EL_{WP} is the wetland pool elevation.

4. Depending upon the outlet configuration, use the weir or orifice equation to calculate the outlet size.

5. The discharge from the wetland through the primary outlet device can then be computed for any elevation between EL_{WQ} and the wetland pool elevation. The next step is to calculate the secondary outlet size to drain the channel protection volume.

6. The release rate may then be calculated by:

$$Q_{CP} = \frac{V_{CP}\,[ft^3] - V_{WQ}\,[ft^3]}{t\,[s]} - Q_{WQ}(@EL_{CP})$$

where t is the time in seconds determined above in 2. Check to determine if Q_{cp} meets all design requirements.

7. The average head is calculated as:

$$h_{avg} = \frac{(EL_{CP}\,[ft] - EL_{WQ}\,[ft])}{2}$$

where EL_{CP} is the elevation of the channel protection volume and EL_{WQ} is the water quality elevation.

8. The appropriate outlet equation can then be used to calculate the outlet's opening size based on the Qcp computed above. For example, if an orifice is used for an outlet, its opening size, A_{CP}, can be computed as:

$$A_{CP} = \frac{Q_{CP}\,[cfs]}{C(2g[ft/s^2]h_{avg}[ft])^{0.5}}$$

where g [ft/s/s] is the gravitational constant equal to 32.2 ft/s²,

The discharge coefficient, C, can be conservatively estimated to be 0.6.

The diameter of the opening can then be solved for:

$$d_{CP} = 2\left(\frac{A_{CP}\,[ft^2]}{\pi}\right)^{0.5}$$

9. The discharge from the wetland can then be computed for any elevation above the water quality elevation as:

$Q_{CP} = Kh^{0.5}$

where $K = CA_{CP}\,[ft]\,(2g\,[\frac{ft}{s^2}])^{0.5}$ and

$$h = EL_{WS}\,[ft] - EL_{WP}\,[ft] - d_{CP}/2\,[ft]$$

Step 9. Calculate Q_{p10} (10-year storm) release rate and water surface elevation.

Set up a stage-storage-discharge relationship for the control structure for the desired number of outlets and the 10-year storm. The procedure will be similar to that outlined above for the Shallow ED wetland.

Step 10. Design embankment(s) and spillway(s).

Size emergency spillway, calculate 100-year water surface elevation, set top of embankment elevation, and analyze safe passage of the Extreme Flood Volume (Vp_{100}).

At final design, provide safe passage for the 100-year event. Attenuation may not be required.

The following guidelines should also be followed (see NRCS Practice Standard 378 for further guidance):

- Embankments should be stabilized with vegetation (no trees) or riprap.
- Embankments may require a core-trench if geotechnical considerations warrant.

- Embankment side slopes should not be steeper than 3H:1V on the front, 2H:1V on the back (impounded side).
- Minimum embankment top width is 6' (8' if equipment access is necessary).
- Material consolidation and shrinkage needs to be factored into embankment design.
- Emergency overflows must be stabilized

Step 11. Design Inlets

To prevent freezing and associated blockage of the inflow, inlet pipes should not be completely submerged, and to the extent possible they should be buried below the frost line. It is also important to design the inlet to reduce or prevent scour, by including riprap or flow diffusion devices such as plunge pools or berms. To prevent standing water in the pipe, which reduces the potential for ice formation in the pipe, increase the slope to 1% if conditions permit.

Step 12. Design sediment forebay

It is recommended that a sediment marker be included in the forebay to indicate the need for sediment removal in the future. Also, a hard bottom surface in the forebay will make sediment removal easier, but note that a hard bottom surface will likely result in reduced vegetative and biotic processes that remove pollutants.

Step 13. Design outlet structures,

Be aware of concerns associated with frozen conditions, particularly the risk of clogging or blockage of outlet structures with ice.

- For weir structures, the minimum slot width should be 3".
- The minimum outlet pipe diameter should be 18", with a minimum slope of 1%.
- Outlet pipes should be buried below the frost line to the extent possible. Information on frost depths can be found from the Minnesota Department of Transportation at : http://www.mrr.dot.state.mn.us/research/seasonal_load_limits/thawindex/frost_thaw_graphs.asp
- If a riser pipe with an orifice outlet is used, the orifice should be protected by a hood that draws water from 12 to 18 inches below the normal wetland pool elevation, or 6" below the normal ice layer if known, if outlet site conditions permit.
- Trash racks should be installed at a shallow angle in order to discourage ice formation.
- A baffle weir or skimmer can be used to keep organic floatables in the wetland and prevent ice or debris from blocking the outlet.

Also, outlet pipes through the embankment should be equipped with an anti-seepage collar to prevent failure.

Step 14. Design maintenance access and safety features.

- Maintenance access to the pond, forebay, and inlet and outlet structures is REQUIRED. The access routes should be designed with a minimum 10' width and maximum 15% slope.
- Safety features such as obstructive planting that make access difficult, signs warning against fishing and swimming, fencing, and grates over outlet structures should be included as appropriate.
- Aesthetic enhancements such as trails or benches can also be included

- If an outlet structure is greater than five feet deep, it is REQUIRED that OSHA health and safety guidelines be followed for safe construction and access practices. Additional information on safety for construction sites is available from OSHA. Use the following link to research safety measures for excavation sites:

http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10930

- OSHA has prepared a flow chart which will help site owners and operators determine if the site safety plan must address confined space procedures:

Permit-required Confined Space Decision Flow Chart - 1910.146 App A

Step 15. Check expected pond performance against regulatory requirements.

- Check that Vwq is detained for an average of 12 hours.
- Check that the Vwq release rate does not exceed 5.66 cfs/acre of pond area.
- Determine applicable requirements for Vcp volume and release rate, and verify that the constructed wetland performs adequately for the appropriate design event.
- Determine applicable requirements for Qp10 and Qp100 release rates (e.g., predevelopment rates), and check release rates (and freeboard) for the appropriate design events.

Step 16. Prepare Vegetation and Landscaping Plan.

A landscaping and planting plan by a qualified professional for the pond and surrounding area should be prepared, utilizing native vegetation wherever possible. See Major Design Elements section for guidance on preparing vegetation and landscaping management plan.

Step 17. Prepare Operation and Maintenance (O&M) Plan.

Preparation of a plan for operation and maintenance of the pond and associated structures and landscaping is REQUIRED. See the *Operation and Maintenance* section for further details.

Step 18. Prepare cost estimate.

Refer to the *Cost Considerations* section and Appendix D for guidance on preparing a cost estimate for constructed wetlands.

VII. References

ASCE/EPA International Stormwater Best Management Practices (BMP) Database. http://www.bmpdatabase.org/.

Center for Watershed Protection, 2004. *Stormwater Pond and Wetland Maintenance Guidebook*.

(FHWA Ultra Urban BMP Manual) "Ultra-Urban Best Management Practices." Federal Highway Administration, Washington, D.C., 1997 http://www.fhwa.dot.gov/environment/ultraurb/index.htm

MPCA, 2000. *Protecting Water Quality in Urban Areas*.

Natural Resources Conservation Service. Conservation Practice Standard 378, Pond.

Caraco, D. and R. Claytor. 1997. *Stormwater BMP Design Supplement for Cold Climates*. Center for Watershed Protection. Ellicott City, MD.

Shaw, D. and R. Schmidt. 2003. Plants for Stormwater Design. Minnesota Pollution Control Agency, St. Paul, MN.

Winer, R. 2000. *National Pollutant Removal Performance Database*. Center for Watershed Protection, Ellicott City, MD.

Young, G Kenneth, Stuart Stein, Pamela Cole, Traci Kammer, Frank Graziano, Fred Bank. 1996. Evaluation and Management of Highway Runoff Water Quality. Office of Environment and Planning, Federal Highway Administration, Washington, D.C.

Chapter 13

Additional Guidance for Karst, Shallow Bedrock, Ground Water, Soils with Low Infiltration Capacity, Potential Stormwater Hotspots (PSHs) and Sediment Disposal Areas

VOLUME 2 - TECHNICAL AND ENGINEERING GUIDANCE

Chapter 13

Additional Guidance for Karst, Shallow Bedrock, Ground Water, Soils with Low Infiltration Capacity, Potential Stormwater Hotspots (PSHs) and Sediment Disposal Areas

Contents

I. Introduction

Issue Paper H in Appendix J (Potential Stormwater Hotspots, Pollution Prevention, Ground Water Concerns and Related Issues) addressed a series of issues that are important for proper stormwater management in Minnesota. Many of these issues are scattered about the Manual, but it was deemed important to summarize these issues in a single location within this chapter. Readers interested in more detail than is concerned in this summary should refer to Issue Paper H text (Appendix J).

To a large extent each topic area stands on its own. However, if there is a common thread across the areas it relates to protecting ground water and designing sites and stormwater practices as a function of ground water-related constraints. It is important to note that these topics involve several challenging stormwater management issues that do not always have clear or universal answers and which do not always lend themselves to a strict regulatory approach. Rather, many of these topics require thoughtful consideration by designers and plan reviewers to ensure that the most appropriate structural and nonstructural measures are implemented at a site. Finding the best solutions for these unique site constraints often requires a collaborative approach between designer and regulator. With that in mind, much of the content presented here and elsewhere in the Manual can be used as technical assistance material.

II. BMP Constraints and Design Criteria for Special Soil/Geologic Conditions

Background

Certain regions of Minnesota contain challenging physiographic features that require thoughtful stormwater design. Specifically, the following three conditions merit special attention:

- Karst
- Bedrock and shallow soils
- Soil with low infiltration capacity

Karst

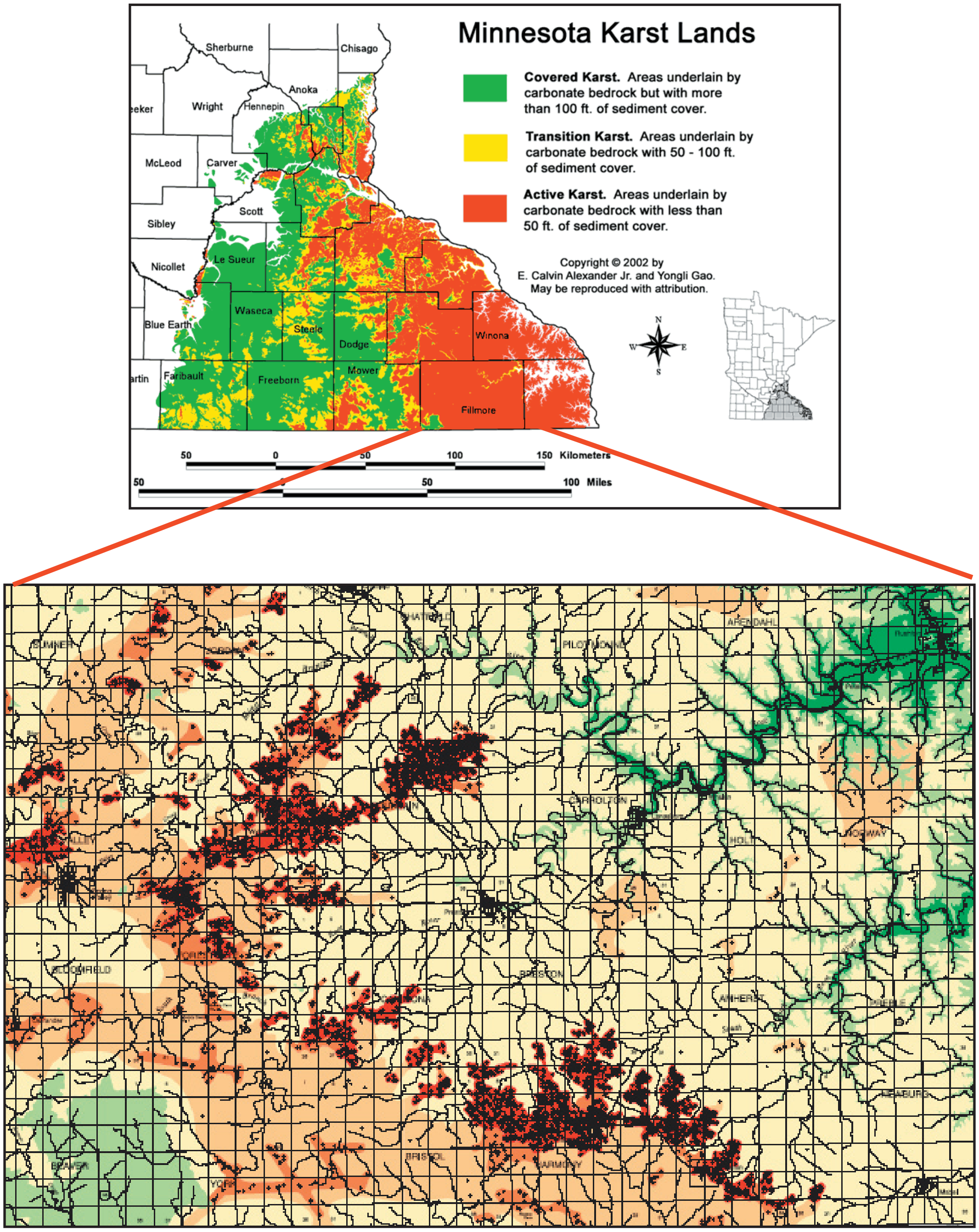
Karst regions are predominantly found in the southeastern portion of the state (Figures 13.1a and A.14) and have important implications with respect to geotechnical testing, infiltration, pre-treatment and ponding of runoff. Figure 13.1b shows that caution must be used in interpreting the geographic depiction of karst lands. The figure shows the difference in a generalized map (13.1a) of active karst versus a county-scale map (13.1b) of actual karstic features.

In karst settings where karstic conditions are known to exist, additional constraints and considerations need to be evaluated prior to implementing most structural BMPs. Of particular concern in karst settings is the formation of sinkholes as a result of hydraulic head build up and/or dissolution of carbonate rock (e.g., limestone) or erosion of bedrock (see sidebar) present underneath or adjacent to BMPs. Where karst conditions exist, there are no prescriptive rules of thumb or universally accepted management approaches because of the variability intrinsic to karst terrain. An adaptation of a familiar old saying is very appropriate: the only thing predictable about the behavior of water in a karst system is its unpredictability.

In general when underlying karst is known or even suspected to be present at the site, stormwater runoff should not be concentrated and discharged into known sinkholes, but should rather be dispersed, or soaked into the ground after adequate pre-cleaning, or conveyed to a collection and transmission system away from the area via vegetated drainageways. In other cases, it may be impossible to remove water from an area with sinkholes or away from karst geology, so common sense clean-up of the water and discharge into the karstic area is a reasonable management approach, especially if some filtering soil is available between the land surface and the karst formation.

Some communities around the country have developed karst area design specifications and soil investigation procedures for siting and designing stormwater BMPs. The following sections represent adaptations from a handful of these communities (e.g., Carroll County, MD [1996a and b]; St. Johns River Water Management District, FL [2001]; and Jefferson County, WV [Laughland

Figure 13.1a Minnesota Karst Lands (Source: Alexander and Gao, 2002) and 13.1b Fillmore County Geologic Atlas (Source: Minnesota Geological Survey)



2003]) and should be viewed only as a potential starting point. That is, the complete Minnesota experience is not represented by these resources, but they do represent products that have been put together to assist local stormwater managers deal with karst problems. Additional input was obtained from Professor Calvin Alexander (University of Minnesota) and Jeff Green (Minnesota DNR).

General Stormwater Management Guidelines for Karst Areas

The following general guidelines are based on advice offered by many different sources. Again, the uncertainty characteristic of karst terrain and water movement should be the primary dictate when considering how much additional information to collect in these areas before proceeding with BMP installation. The following guidelines do not contain substantial prescriptive information because of the variability inherent to karst geology in Minnesota.

- Developers, communities, public works agents and others managing stormwater should conduct thorough geotechnical investigations prior to proceeding with projects or building in active karst areas. The level of geotechnical investigation will depend on the likelihood of active karst being present and the regulatory requirements within the area. They should identify the karst features encountered and report to the appropriate state agency, such as the Department of Natural Resources (DNR) and Minnesota Geological Survey (MGS), and local agencies (such as the city, township or county) any existing sinkholes on a piece of land intended for development. These known occurrences should be surveyed for specific location and permanently recorded on the property deed. For transition karst areas, local discretion and the likelihood of karstic features should be used to determine the amount of geotechnical investigation.
- Knowledge of the presence of sinkholes is an absolute indication of active karst. In these cases, an easement or reserve area should be identified on the development plats for the project so that all future landowners know of the presence of active karst on their property.

Pond Water Disappears in Karst Collapse

On the evening of October 4, 2005 a six-inch storm hit the eastern metro area. Sometime during that storm, a very large stormwater pond in Woodbury drained fully through a collapsed karst feature in the lower part of the St. Peter sandstone, probably into void space dissolved in the underlying Prairie du Chien group (Calvin Alexander, personal communication, October 2005). Figure 13.2 sets the scale of the collapse measured by Alexander at about 100 feet long by 60 feet wide by 20 feet deep. Figure 13.3 is of Alexander standing in the hole. The lesson is that not all karst features are in carbonate rocks in souteast Minnesota.

Figure 13.2 Collapsed Karst Feature

Figure 13.3 Calvin Alexander in Collapsed Karst Hole (Source: Kristin Daniels, 2005)

- In many cases, identified sinkholes can and should be remediated and stormwater directed away. In other cases, remediation is not possible and the normal regional hydrologic patterns must be maintained. In this case, however, precautions should be taken to pre-treat any water that drains into a known sinkhole area. If at all possible, runoff should be routed away from active karst features because of the possibility of subsurface flow into the karst formation.
- BMPs should be designed off-line to better manage volumes and flow rates from individual facilities.
- Discharges from stormwater management facilities or directly from impervious surfaces should not be routed directly to the nearest sinkhole. Because active karst areas can be quite large in Minnesota, discharges may be routed to a baseflow stream via a pipe or lined ditch or channel to remove flow from the area, provided the stream does not disappear into an active karst feature.
- Sinkholes developing within stormwater management facilities should be reported as soon as possible after the first observation of occurrence. They should then be repaired, abandoned, adapted, managed and/or observed for future changes, whichever of these are appropriate for proper management.
- Sinkhole formation is less likely when water is allowed to soak diffusely into the soil and when stormwater is managed for smaller, more diffuse quantities that limit the volume and rates of flow handled by each BMP. Practices such as swales, bioretention, and vegetated filters should be considered first at a site. However, not all sites lend themselves to this type of management approach and could require use of the active karst region for proper management. Under these conditions, adequate precautions should be taken to assure that all potential contaminants are removed from the infiltrating stormwater.
- Where ponds and wetlands are deemed necessary, they should be designed and constructed with a properly engineered synthetic liner. A *minimum* of three feet (ten feet is preferred) of unconsolidated soil material should exist between the bottom of the pond or wetland and the surface of the bedrock layer. Pond and wetland depths should be fairly uniform and limited to no more than ten feet in depth.

Table 13.1 provides an overview of karst related design considerations for the five structural practice groups identified in Chapter 12.

Investigation for Karst Areas

Karst investigations are recommended for all stormwater facilities that are located in an active karst area with known karstic features (sinkholes, solution cavities, direct hydraulic connection between surface water and ground water). The purpose of a karst investigation is to identify subsurface voids, cavities, fractures, or other discontinuities which could pose an environmental concern or a construction hazard to an existing or proposed stormwater management facility. Of special concern is preventing the possibility that an unimpeded route will be provided to move polluted runoff into the regional ground water system. The guidelines outlined below should not be interpreted as all-inclusive. The design of any geotechnical investigation should reflect the size and complexity of the proposed project, as well as local knowledge of the threat posed by the karstic geology.

Because of the complexity inherent to active karst areas, there is no single set of investigatory guidelines that works for every location. Typically, however, the sequence involves some visual observation for the presence of sinkhole features (the single easiest evidence that active karst is present), followed by an assessment of the subsurface heterogeneity (variability) of the site through geophysical investigation and/or excavation. With this information in-hand, borings or observation wells can then be accurately installed to obtain vertical data surrounding or within a karst feature. The following sections describe general guidance that may or may not be used depending upon the local situation and information deemed as needed.

Table 13.1 Structural BMP Use in Karst Settings		
BMP		**Karst Considerations***
Bioretention		If contaminant levels remain high after treatment or if water inflow presents a threat, an under-drain and/or use of a synthetic or other impermeable membrane liner should be considered to seal the bottom of the system
Filtration	Media	See the note above
	Vegetative	▶ Avoid water ponding ▶ Should be engineered to avoid channel erosion and optimize pollutant removal
Infiltration	Infiltration Trench Infiltration Basin	▶ Not typically recommended in active karst areas due to sinkhole formation and inadequate treatment by a scarcity of underlying soils ▶ If used, should have supporting geotechnical investigations and calculations ▶ Pre-treatment should be extensive to limit risk of ground water contamination ▶ Local review authority should be consulted for approval
Stormwater Ponds		▶ Should be constructed with a synthetic or clay liner in active karst areas ▶ Should have supporting geotechnical investigations and calculations ▶ Should be limited to a maximum ponding depth (e.g., < 10 feet)
Constructed Wetlands		▶ Should be constructed with a synthetic or clay liner in active karst areas ▶ Should have supporting geotechnical investigations and calculations ▶ Should be limited to a maximum ponding depth (e.g., < 10 feet)

* Many of these recommendations will be dictated by the findings of the geotechnical study done at the site by qualified and experienced personnel, and will be a reflection of the type of karst exposure likely.

Subsurface Material

The investigation should determine the nature and thickness of subsurface materials, including depth to bedrock and the water table. Subsurface data may be acquired by backhoe excavation and/or soil boring. These field data should be supplemented by geophysical investigation techniques deemed appropriate by a qualified professional, which will show the location of karst formations under the surface. This is an iterative process that might need to be repeated until the desired detailed knowledge of the site is obtained and fully understood. The data listed below should be acquired under the direct supervision of a qualified and experienced karst scientist. Pertinent site information to collect includes the following:

- ▶ Bedrock characteristics (ex. type, geologic contacts, faults, geologic structure, rock surface configuration)
- ▶ Soil characteristics (ex. type, thickness, mapped unit, geologic source/history)
- ▶ Photo-geologic fracture trace map
- ▶ Bedrock outcrop areas
- ▶ Sinkholes and/or other closed depressions

- Perennial and/or intermittent streams, and their flow behavior (ex. a stream in a karst area that loses volume could be a good indication of sinkhole infiltration)

Geophysical and Dye Techniques

There are many different techniques available to view the nature of the subsurface in karst areas. These techniques can be used to detect the presence of karst features or to collect additional data on the character of a known feature. Stormwater managers in need of subsurface geophysical surveys are encouraged to obtain the services of a qualified geophysicist experienced in karst geology. Some of the geophysical techniques available for use in karst terrain include: seismic refraction, ground-penetrating radar, and electric resistivity.

The surest way to determine the flow path of water in karst geology is to inject dye into the karst feature (sinkhole or fracture) and watch to see where it emerges, usually from a spring. The emergence of a known dye from a spring grants certainty to a suspicion that ground water moves in a particular pattern. Dye tracing can vary substantially in cost depending upon the local karst complexity, but it can be a reasonably priced alternative, especially when the certainty is needed.

Location of Borings

Once the character of the cover material is known and understood, borings can be used to obtain the details of the subsurface karst features at specific locations. It must be noted, however, that the local variability typical of karst areas could mean that a very different subsurface could exist a very small distance away, perhaps as little as six-inches. To accommodate this variability, the number and type of borings must be carefully assessed. If the goal is to locate a boring down the center of a sinkhole, the previous geophysical tests or excavation results can show the likely single location to achieve that goal. If the goal is to "characterize" the entire site, then an evaluation needs to occur to determine the number and depth needed to adequately represent the site. Again, the analyst must acknowledge the extreme variability and recognize that details can easily be missed. Some general guidance for locating borings include:

- Getting at least one boring in each geologic unit present, as mapped by the Minnesota (MGS) and U.S. Geological Surveys (USGS) and local county records
- Placing an adequate number as determined by a site investigation near on-site geologic or geomorphic indications of the presence of sinkholes or related karst features
- Locating along photo-geologic fracture traces
- Locating adjacent to bedrock outcrop areas
- Locating a sufficient number to adequately represent the area under any proposed stormwater facility
- Documenting any areas identified as anomalies from any existing geophysical or other subsurface studies

Number and Depth of Borings

The number and depth of borings will depend entirely upon the results of the subsurface evaluation obtained from the observational, geophysical, and excavation studies, and other borings. There are no prescriptive guidelines to determine the number and depth of borings. These will have to be determined by the qualified staff conducting the BMP management evaluation based upon the data needs of the installation. The borings must extend well below the bottom elevation of the designed BMP, however, to make sure that there are no karst features that will be encountered or impacted as a result of the installation.

Identification of Material

All material identified by the excavation and geophysical studies and penetrated by the boring should be identified, as follows:

- Description, logging, and sampling for the entire depth of the boring.
- Any stains, odors, or other indications of environmental degradation.
- A minimum laboratory analysis of two soil samples, representative of the material penetrated including potential limiting

horizons, with the results compared to the field descriptions.

- Identified characteristics should include, as a minimum: color; mineral composition; grain size, shape, sorting and degree of saturation.
- Any indications of water saturation should be carefully logged, to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed should be provided. Be aware that ground water levels in karst can change dramatically in short periods of time and will not necessarily leave mottled or gleyed evidence.
- Water levels in all borings should be recorded over a time-period reflective of anticipated water level fluctuation. That is, water levels in karst geology can vary dramatically and rapidly. The boring should remain fully open to a total depth reflective of these variations and over a time that will accurately show the variation. Be advised that to get a complete picture, this could be a long-term period. Measurements could of course be collected during a period of operation of a BMP, which could be adjusted based on the findings of the data collection.
- When conducting a standard penetration test (SPT), estimation of soil engineering characteristics, including "N" or estimated unconfined compressive strength, should be reported.

Evaluation

At least one subsurface cross section should be provided for the BMP installation, showing confining layers, depth to bedrock, and water table (if encountered). It should extend through a central portion of the proposed installation, using the actual geophysical and boring data. A sketch map or formal construction plan indicating the location and dimension of the proposed practice and line of cross section should be included for reference, or as a base map for presentation of subsurface data.

Sinkhole Remediation

There are several approaches to sinkhole remediation if it is found that such an approach is desirable. Sinkhole sealing involves investigation, stabilization, filling and final grading. In the investigation phase, the areal extent and depth of the sinkhole(s) should be determined. The investigation may consist of excavation to bedrock, soil borings, and/or geophysical studies. Sealing small-sized sinkholes is normally achieved by digging out the sinkhole to bedrock, plugging the hole with concrete, installing several impermeable soil layers interspersed with plastic or geotextile, and crowning with an impermeable layer and topsoil. For moderate sinkholes, an engineered subsurface structure is usually required.

It is often not feasible to seal large sinkholes so other remediation options must be pursued. These could include construction of a low-head berm around the sinkhole, clean-out of the sinkhole to make sure all potentially contaminating materials are removed, landscaping and conversion of land use in the sinkhole to open space or recreation, provided it can be done in a manner that provides adequate safety. In any of these cases, pre-treatment of any stormwater entering the sinkhole is imperative. Final grading of sinkholes in open space settings should include the placement of low permeability topsoil or clay and a vegetative cover, with a positive grade maintained away from the sinkhole location to avoid ponding or infiltration, if feasible.

Monitoring of BMPs in Karst Regions

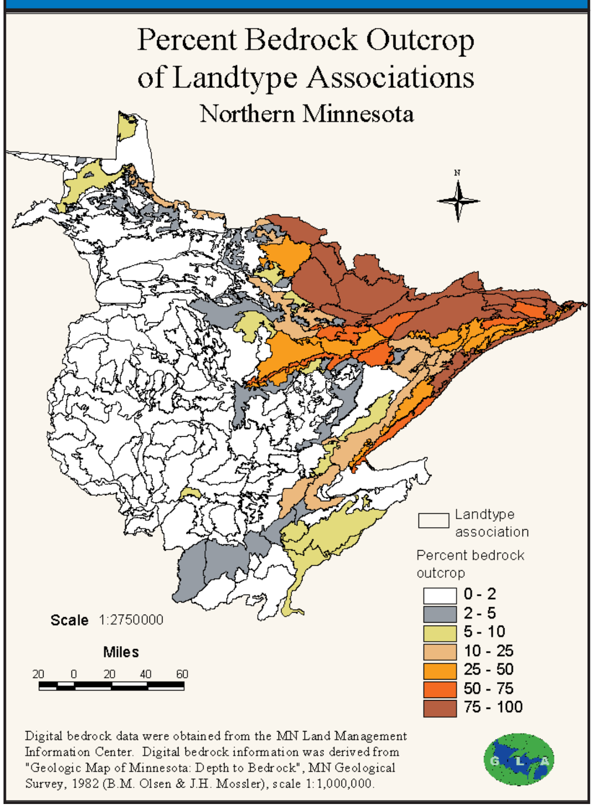
A water quality monitoring system installed, operated and maintained by the owner/operator may be desirable or even required under some circumstances, particularly where drinking water supplies are derived from ground water or in association with known sources of contamination. The location of monitoring wells or BMP performance monitoring will again depend upon the nature of the BMP and surrounding karst characteristics. As with all nonpoint source related monitoring, the capture of runoff events is the key goal. In karst areas, this could mean the installation of a monitoring system designed to reflect variable water behavior typical of karst water flow. Attempting to monitor this behavior without a thorough understanding of the local geology will be difficult and could lead to a wasted effort.

Shallow Bedrock and Ground Water

Bedrock and shallow soils are found in many portions of the state, but are a particular problem in the northeastern region of the state (Figures 13.4 and A.12). The stormwater management implications of shallow bedrock affect infiltration, ponding depths, and the use of underground practices.

Sites with shallow bedrock or ground water (defined for the purpose of this paper as bedrock within six feet or less of ground surface and ground water less than three feet below the ground surface) present a host of challenges to the design engineer. However, these challenges can be managed and designed. Similar to karst, there are general guidelines to consider when designing stormwater management practices in these areas, as presented below. Special caution for steep slopes and hidden bedrock fractures is urged.

Figure 13.4 Bedrock Outcroppings Areas in Northern Minnesota (Source: Great Lakes Association)



General Stormwater Management Guidelines for Areas with Shallow Bedrock and Soils

- Developers should conduct thorough geotechnical investigations in areas with defined shallow bedrock and soils when contact with the bedrock or lack of adequate soil depth could cause a stormwater-related problem.
- A site geotechnical analysis similar to karst is recommended.
- Where infiltration is used, BMP depths will be limited. In fact, infiltration may be altogether infeasible at the site if a minimum three foot separation between the bottom of the practice and bedrock cannot be achieved.
- Design specifications for allowable ponding depths (e.g., live storage) in filters, swales, and bioretention should be considered to up to 12 inches (typical allowable depths range from six to nine inches). This will help reduce the required surface area of these facilities.
- Underground practices such as filters will be possible but very expensive if blasting required.
- Potential Stormwater Hotspot (PSH) infiltration may not be desirable due to potential for connections with bedrock fracture zones (see later section for a detailed discussion of PSHs).
- Stormwater wetlands will have greater potential than ponds for larger storage facilities due to limitation on ponding depths. However, this means larger surface area to drainage area ratios will be required.
- Engineered soil compost amendments may be required where soils are less than three feet deep to be eligible for certain stormwater credits (see Chapter 11 for credits discussion, specifically Impervious Cover Disconnection and Rooftop Disconnection).

<table>
<tr><th colspan="3">Table 13.2 Structural BMP Use in Shallow Bedrock and Soil Settings</th></tr>
<tr><th colspan="2">BMP</th><th>Shallow Bedrock and Soil Considerations</th></tr>
<tr><td colspan="2">Bioretention</td><td>Should be constructed with an under-drain if minimum separation distance of three feet is not present between practice bottom and bedrock</td></tr>
<tr><td rowspan="2">Filtration</td><td>Media</td><td>▶ Recommended practice in areas of shallow bedrock and soil
▶ Can be located in bedrock, but will be expensive due to blasting</td></tr>
<tr><td>Vegetative</td><td>▶ Recommended practice in areas of shallow bedrock and soil
▶ Dry swales with engineered soil media will need an under-drain if minimum separation distance of three feet is not present between practice bottom and bedrock</td></tr>
<tr><td rowspan="2">Infiltration</td><td>Infiltration Trench</td><td rowspan="2">▶ Will be limited due to minimum separation requirement. Surface area to depth ratios of practices may need to be larger. Arch pipe and other perforated storage “vault” practices can help increase treatment volumes within limited spaces.
▶ If used, should have supporting geotechnical investigations and calculations
▶ Use with PSHs should be carefully considered. Pre-treatment should be extensive to limit risk of ground water contamination
▶ Local review authority should be consulted for approval</td></tr>
<tr><td>Infiltration Basin</td></tr>
<tr><td colspan="2">Stormwater Ponds</td><td>▶ Will have depth limitation to consider, making surface areas larger for a given storage volume
▶ Shallower depths may be undesirable from an aesthetic standpoint, particularly if wide fluctuations in water level are expected
▶ Bedrock should act like a liner and help to maintain a permanent pool, unless fracture zone is present</td></tr>
<tr><td colspan="2">Constructed Wetlands</td><td>▶ Applied more easily than ponds, but will also require larger surface area to drainage area ratios.
▶ Bedrock should act like a liner and help to maintain a permanent pool, unless fracture zone is present</td></tr>
</table>

Table 13.2 provides an overview of shallow bedrock and soil related design considerations for the five structural practice groups identified in Chapter 12.

Investigation for Shallow Bedrock Areas

Geotechnical investigations are recommended for all proposed stormwater facilities located in regions with shallow bedrock and soils. The recommended approach is similar to those for karst areas. The purpose of the investigation is to identify subsurface conditions which could pose an environmental concern or a construction hazard to a proposed stormwater management practice. The guidelines outlined below should not be interpreted as all-inclusive. The design of any subsurface investigation should reflect the size and complexity of the proposed project.

Subsurface Material

The investigation should determine the nature and thickness of subsurface materials, including depth to bedrock and to the water table. Subsurface data may be acquired by backhoe excavation and/or soil boring. These field data should be supplemented by geophysical investigation techniques deemed appropriate by a qualified professional, which will show the location of bedrock formations under the surface. The data listed below should be acquired under the direct supervision of a qualified geologist, geotechnical engineer, or soil scientist who is experienced in conducting such studies. Pertinent site information shall be collected which should include the following:

- Bedrock characteristics (type, geologic contacts, faults, geologic structure, rock surface configuration).
- Soil characteristics (type, thickness, mapped unit).
- Bedrock outcrop areas.

Location of Borings

Borings should be located in order to provide representative area coverage of the of the proposed BMP facilities. The location of borings should be:

- In each geologic unit present, as mapped by the Minnesota (MGS) and U.S. Geological Surveys (USGS) and local county records;
- Next to bedrock outcrop areas (e.g., within ten feet);
- Near the edges and center of the proposed practice and spaced at equal distances from one another; and
- Near any areas identified as anomalies from any existing geophysical studies.

Number of Borings

The number of recommended borings are:

- Infiltration trenches, bioretention, and filters - a minimum of two per practice.
- Ponds/wetlands - a minimum of three per practice, or three per acre, whichever is greater.
- Additional borings - to define lateral extent of limiting horizons, or site specific conditions, where applicable.

Depth of Borings

Borings should be extended to a minimum depth of five feet below the lowest proposed grade within the practice unless auger/backhoe refusal is encountered.

Identification of Material

All material penetrated by the boring should be identified, as follows:

- Description, logging, and sampling for the entire depth of the boring.
- Any stains, odors, or other indications of environmental degradation.
- A minimum laboratory analysis of two soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to the field descriptions.
- Identified characteristics should include, as a minimum: color; mineral composition; grain size, shape, and sorting; and saturation.
- Any indications of water saturation should be carefully logged, to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed should be provided.
- Water levels in all borings should be taken at the time of completion and again 24 hours after completion. The boring should remain fully open to total depth of these measurements.
- When conducting a standard penetration test (SPT), estimation of soil engineering characteristics, including "N" or estimated unconfined compressive strength.

Evaluation

At least one subsurface cross section through the proposed practice should be provided, showing confining layers, depth to bedrock, and water table (if encountered). It should extend through a central portion of the proposed practice, using the actual or projected boring data. A sketch map or formal construction plan indicating the location and dimension of the proposed practice and line of cross section should be included for reference, or as a base map for presentation of subsurface data.

Shallow Depth to Ground Water

There is a large portion of the state (more than 50%) where the ground water is located less than three feet from the surface. In these areas it may be impossible to get the three feet of separation from the bottom of an infiltration practice and the seasonally saturated ground water table required under the NPDES Construction General Permit. Other treatment methods need to be considered in these areas.

When constructing a pond that will likely intercept the ground water table, a close examination of the land uses that will contribute runoff to the pond should be the first step in the design process. If a potential stormwater hotspot is identified as a contributor then it is the recommendation of the MPCA that the pond include a liner to protect against ground water contamination.

MPCA is often asked why it would allow a sedimentation pond (no liner) to be constructed that may intercept the water table, but require a minimum of three feet of separation from the bottom of any constructed infiltration practice and the water table. The treatment processes for these two practices are very different and may help to explain the requirements. A sedimentation pond achieves treatment of stormwater runoff through the act of settling out suspended solids before the discharge point. If the basin is large enough and has a long detention time, additional treatment through biological uptake and microbial action can also occur. An infiltration practice removes pollutants through filtering that occurs in the three foot soil layer beneath the practice along with the biologic and microbial activity that takes place in the layer under aerobic conditions. The soils under the practice need time between events to aerate so they function hydraulically as well as provide aerobic treatment.

Soil with Low Infiltration Capacity

Soils with low infiltration capacity are found throughout the state. Details of where to find soils that can and cannot be used for infiltration systems should begin with available county soil surveys, most of which are available digitally (Figure 13.5). However, these surveys are not accurate enough to determine site specific characteristics suitable for infiltration systems, so a detailed site analysis is recommended. Stormwater management limitations in areas with tight soils generally preclude large-scale infiltration and ground water recharge (infiltration that passes into the ground water system). These soils will typically be categorized under Hydrologic Soil Group (HSG) D and have other characteristics as shown in Table 13.3. The infiltration rates noted in Table 13.3 are conservative estimates of long-term, sustainable infiltration rates that have been documented in Minnesota. They are based on in-situ measurement within existing infiltration practices in Minnesota, rather than national numbers or rates based on laboratory columns.

Sites with poorly infiltrating soils (defined as soils with infiltration rates less than 0.2 inches per

Figure 13.5 Availability of Digital Soil Surveys in Minnesota (Source: NRCS)

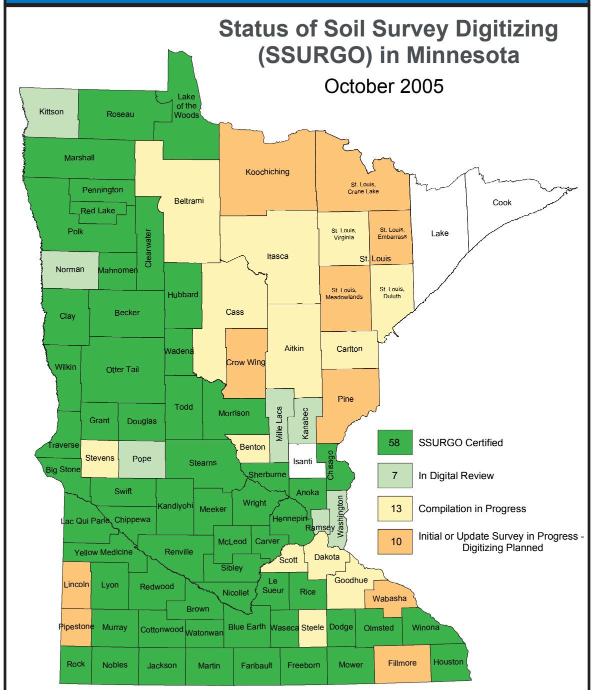


Table 13.3 Infiltration Rates of Hydrologic Soil Group Classifications (Browns Creek Watershed District)

Hydrologic Soil Group	**Infiltration Rate** [inches/hour]	Soil Textures	Corresponding Unified Soil Classification
A	1.63 – 0.8	Sand, loamy sand or sandy loam	**GW** - Well-graded gravels, sandy gravels **GP** - Gap-graded or uniform gravels, sandy gravels **GM** - Silty gravels, silty sandy gravels **SW** - Well-graded, gravelly sands **SP** - Gap-graded or uniform sands, gravelly sands
B	0.6 – 0.3	Silt loam or loam	**SM** - Silty sands, silty gravelly sands **MH** - Micaceous silts, diatomaceous silts, volcanic ash
C	0.2	Sandy clay loam	**ML** - Silts, very fine sands, silty or clayey fine sands
D	< 0.2	Clay loam, silty clay loam, sandy clay, silty clay or clay	**GC** - Clayey gravels, clayey sandy gravels **SC** - Clayey sands, clayey gravelly sands **CL** - Low plasticity clays, sandy or silty clays **OL** - Organic silts and clays of low plasticity **CH** - Highly plastic clays and sandy clays **OH** - Organic silts and clays of high plasticity

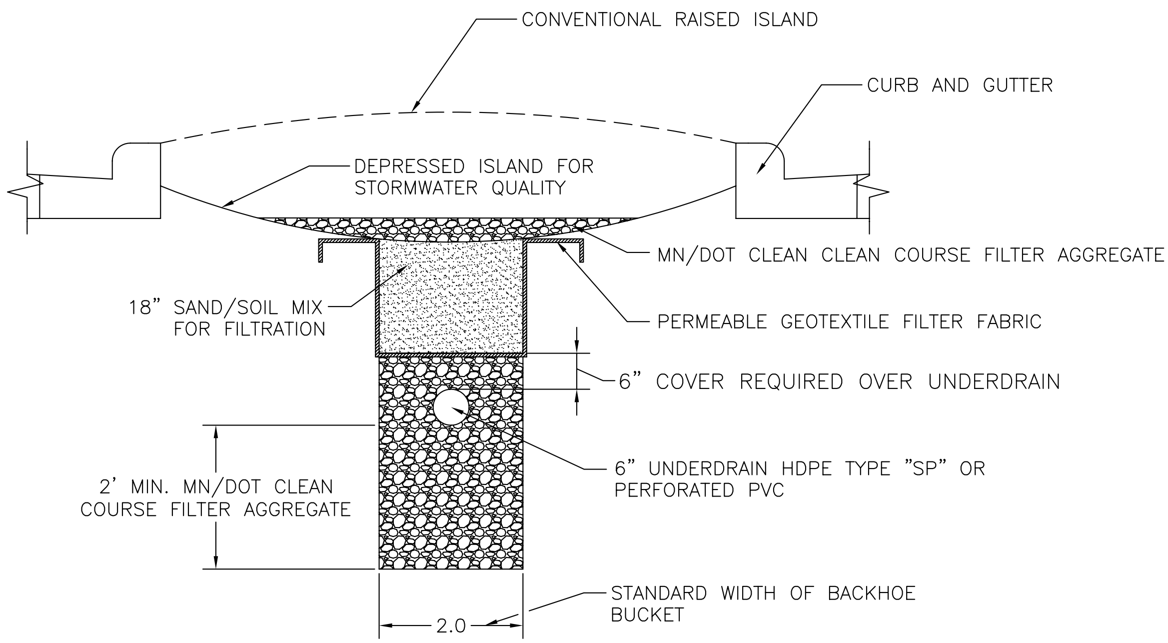
hour) limit the number of practices that can used for stormwater management on a site or specific area of a site. Certain watershed organizations in Minnesota do not allow the use (or strongly discourage the use) of infiltration practices where soil infiltration capacity is low. This does not mean, however, that these tight soils don't have any infiltration and recharge capabilities. So it may be possible for sites to meet recharge objectives as long as appropriate design modifications have been incorporated.

General guidelines to consider when designing stormwater management practices in areas with poor infiltration capacity are presented below.

General Stormwater Management Guidelines for Sites with Low Infiltration Capacity Soils

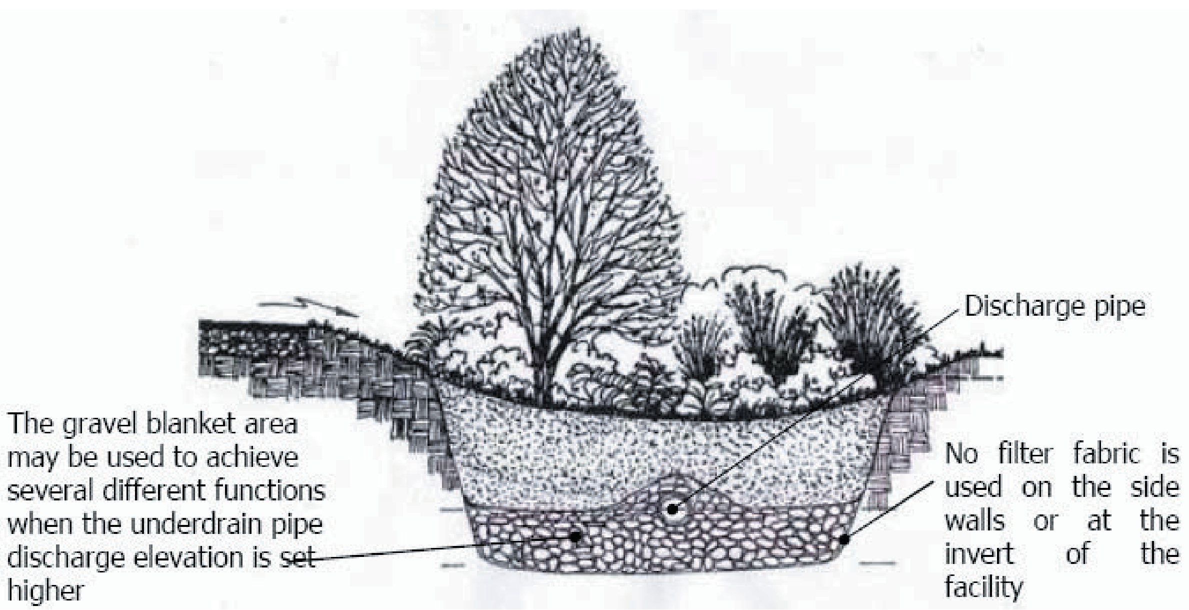
- Local soil surveys should be used for preliminary determination of infiltration capacity of site soils; however, on-site soil testing is recommended to accurately characterize site soils if local surveys characterize site soils as either HSG C or D.
- Recharge criteria, if applicable, can still be met using infiltration practices or modified filter designs (Figures 13.6 and 13.7), as long as they are appropriately designed.
- Soil compost amendments may be required to increase pervious area storage and filtration rates for sites with HSG C and D soils that are expected to receive either rooftop or surface IC disconnection in accordance with certain stormwater credits (see Chapter 11 for credits discussion, specifically Impervious Cover Disconnection and Rooftop Disconnection).
- Where volume reduction is a primary objective for a site (e.g., potentially a receiving water-based goal due to channel erosion, nuisance flooding, or inadequate infrastructure capacity), emphasis should be placed on practices that promote runoff reuse and evapotranspiration such

Figure 13.6 Modified Sand Filter Design (Source: Covington, 2002)



NOTE: SAND MUST CONFORM TO MN/DOT 3126 SPECIFICATIONS AND SOIL MUST BE ENGINEER APPROVED LOAM. THIS MUST BE CERTIFIED AS PART OF THE AS-BUILT.

Figure 13.7 Bioretention with Infiltration Gallery (Source: Prince George's County, 2002)



as cisterns, rain barrels, greenroofs, rain gardens, evaporative systems, and bioretention.

Table 13.4 provides an overview of low infiltration capacity soil related design considerations for the five structural practice groups identified in Chapter 12.

Investigation for Low Infiltration Capacity Soils

Soil testing is recommended for all proposed stormwater facilities that plan to have a recharge or infiltration component to their design. Testing can be less rigorous than that for karst areas or sites with shallow bedrock and soils. The purpose of the testing is to identify and confirm the soil characteristics and determine their suitability, if any, for infiltration practices. The guidelines outlined below should not be interpreted as all-inclusive. The design of any subsurface investigation should reflect the size and complexity of the proposed project.

Location of Borings

Borings should be located in order to provide representative area coverage of the of the proposed BMP facilities. The location of borings should be:

- In each geologic unit present, as mapped by the Minnesota (MGS) and U.S. Geological Surveys (USGS) and local county records;
- Near the edges and center of the proposed practice and spaced at equal distances from one another; and
- Near any areas identified as anomalies from any existing geophysical studies.

Number of Borings

The number of recommended borings are:

- Infiltration trenches, bioretention, and filters - a minimum of two per practice.

Table 13.4 Structural BMP Use in Soils with Low Infiltration Capacity

BMP		Low Infiltration Capacity Soil Considerations
Bioretention		Should be constructed with an under-drain. Recharge criteria, if applicable, can be met by modifying the design to include an infiltration gallery below the under-drain, so long as it is appropriately sized (Figure 13.7).
Filters	Media	► Recommended practice in "tight" soils. Some design variants can be modified to incorporate an infiltration gallery that can help meet recharge criteria, if properly sized (Figure 4).
	Vegetative	► Recommended practice in areas of shallow bedrock and soil ► Dry swales with engineered soil media will need an under-drain if minimum separation distance of three feet is not present between practice bottom and bedrock
Infiltration	Infiltration Trench Infiltration Basin	► Not recommended as a practice ► Soils analysis should be conducted to confirm limiting aspects of soil profile.
Stormwater Wetlands		► Acceptable practice with "tight" soils. Soils should help maintain permanent pool.
Constructed Wetlands		► Acceptable practice with "tight" soils. Soils should help maintain permanent pool if practice is not tied into ground water table. ► Compost amendments may be necessary to establish suitable planting beds.

- Ponds/wetlands - a minimum of three per practice, or three per acre, whichever is greater.
- Additional borings - to define lateral extent of limiting horizons, or site specific conditions, where applicable.

Depth of Borings

Borings should be extended to a minimum depth of five feet below the lowest proposed grade within the practice unless auger/backhoe refusal is encountered.

Identification of Material

All material penetrated by the boring should be identified, as follows:

- Description, logging, and sampling for the entire depth of the boring.
- Any stains, odors, or other indications of environmental degradation.
- A minimum laboratory analysis of two soil samples, representative of the material penetrated including potential limiting horizons, with the results compared to the field descriptions.
- Identified characteristics should include, as a minimum: color; mineral composition; grain size, shape, and sorting; and saturation.
- Any indications of water saturation should be carefully logged, to include both perched and ground water table levels, and descriptions of soils that are mottled or gleyed should be provided.
- Water levels in all borings should be taken at the time of completion and again 24 hours after completion. The boring should remain fully open to total depth of these measurements.

Infiltration Rate Testing

Soil permeabilities should be determined in the field using the following procedure (MDE, 2000), or an accepted alternative method.

- Install casing (solid 6-inch diameter) to 36" below proposed practice bottom.
- Remove any smeared soiled surfaces and provide a natural soil interface into which water may percolate. Remove all loose material from the casing. Upon the tester's discretion, a two-inch layer of coarse sand or fine gravel may be placed to protect the bottom from scouring. Fill casing with clean water to a depth of 36" and allow to pre-soak for up to twenty-four hours.
- Refill casing with another 36" of clean water and monitor water level (measured drop from the top of the casing) for one hour. Repeat this procedure (filling the casing each time) three additional times, for a total of four observations. Upon the tester's discretion, the final field rate may either be the average of the four observations, or the value of the last observation. The final rate should be reported in inches per hour.
- May be done through a boring or open excavation.
- The location of the test should correspond to the practice location.
- Upon completion of the testing, the casings should be immediately pulled, and the test pit should be back-filled.

III. Runoff Source Constraints

This section describes problems associated with potentially poor quality water flowing into a BMP or sediment accumulating in a BMP.

Potential Stormwater Hotspots (PSHs)

Background

This section reviews several land uses and associated pollutant generating activities by looking in more depth at the broader considerations of stormwater management and source control at these sites.

It is important to note that designation as a PSH does *not* imply that a site is a hotspot, but rather that the land use and associated on-site activities have

Figure 13.8 Five Types of Potential Stormwater Hotspots (Source Transport-Related Photo: University of Minnesota Design Center)

Commercial

Industrial

Institutional

Municipal

Transport-Related

the potential to generate higher pollutant runoff loads compared to other land uses. Designation as a PSH serves as a useful reminder to designers and reviewers that more careful consideration of the site is warranted. Ultimately, a PSH site designation may dictate that certain practices and/or design criteria are promoted or discouraged.

Designation of PSHs

PSHs are defined as commercial, industrial, institutional, municipal, or transportation-related operations (Figure 13.8) that produce higher levels of stormwater pollutants, and/or present a higher potential risk for spills, leaks or illicit discharges (Schueler *et al*., 2004). Table 13.5 provides a listing of potential PSHs associated by major land use category. A description of the major land use category is provided below. Note that some of these land uses fall under the requirements for Phase II NPDES industrial stormwater permits.

Commercial PSHs

Commercial PSHs consist of a small group of businesses associated with a specific activity or operation that generates higher pollutant loads in a subwatershed. Each kind of commercial hotspot generates its own blend of stormwater pollutants, which can include nutrients, hydrocarbons, metals, trash and pesticides. Commercial PSHs typically have a great deal of vehicle traffic, generate waste or wash water, handle fuel or repair vehicles, or store products outside. While commercial PSHs are quite diverse, they are often clustered together. Most commercial PSHs are unregulated, although a few are regulated under the NPDES industrial stormwater permit program (see later section), by local ordinance or by federal/state law if they handle even small quantities of hazardous material.

Industrial PSHs

Industrial PSHs are a major focus for pollution prevention if they use, generate, handle or store pollutants that can potentially be washed away in stormwater runoff, spilled, or inadvertently discharged to the storm drain system. Each type of industrial PSH generates its own blend of stormwater pollutants, but as a group, they generally produce higher levels of metals, hydrocarbons and sediment.

Many industrial operations are regulated under the NPDES industrial stormwater permit program,

Table 13.5 Examples of Potential Pollutant Generating Land Uses*		
Land Use Category	**Land Use**	
Commercial	▶ Animal care services ▶ Building material ▶ Commercial car washes ▶ Convenience stores ▶ Laundries and dry cleaners ▶ Lawn care companies ▶ Gas stations	▶ Nurseries and garden centers ▶ Petroleum wholesalers ▶ Fast food restaurants ▶ Shopping centers ▶ Vehicle maintenance and repair ▶ Wholesale food and beverage
Industrial	▶ Auto recyclers ▶ Boat building and repair facilities	▶ Recycling centers and scrap yards ▶ Warehouses
Institutional	▶ Cemeteries ▶ Churches ▶ Colleges ▶ Corporate office parks	▶ Hospitals ▶ Private schools ▶ Private golf courses
Municipal	▶ Composting facilities ▶ Fleet storage and school bus depots ▶ Landfills/solid waste facilities ▶ Local streets and storm drains ▶ Pesticide use in rights-of-way ▶ Public golf courses	▶ Public schools ▶ Public works yards ▶ Maintenance depots ▶ Solid waste facilities ▶ Wastewater treatment plants
Transport Related	▶ Airports ▶ Bus depots ▶ Rental car lots ▶ Railroad stations and associated maintenance facilities	▶ Ports ▶ Highway maintenance facilities ▶ Trucking companies and distribution centers
*This list is not all-inclusive, nor does mention here indicate that all such occurrences will be PSHs; rather, these are examples of typical land uses that could be PSHs		

although individual owners or operators may be unaware of their permit status.

Institutional PSHs

Institutional PSHs include larger, privately-owned facilities that have extensive parking, landscaping, or turf cover. In addition, institutions may contain fleet vehicles and large maintenance operations. By and large, institutional PSHs are not regulated. The most common pollutants generated by institutional PSHs are nutrients and pesticides applied to maintain grounds and landscaping. In addition, large parking lots can produce stormwater runoff and associated pollutants, and are natural targets for stormwater retrofitting. Institutional landowners can be important partners in subwatershed restoration, given the importance of their stewardship practices on the open lands they maintain.

Municipal PSHs

Municipal PSHs include many local government operations that handle solid waste, wastewater, road and vehicle maintenance, bulk storage areas for road salt and sand, and yard waste. Many of these municipal operations are regulated PSHs in MS4 communities. Municipal PSHs must prepare the same pollution prevention plans and implement source control practices as any other regulated PSHs. Municipal PSHs can generate the full range of stormwater pollutants, including nutrients, hydrocarbons, metals, chloride, pesticides, bacteria, and trash. It is common in Minnesota for each municipality and many commercial centers to store a stockpile of road salt. Although these piles

Figure 13.9 Six Common Operations to Assess at PSHs

are generally not subject to regulation unless they cause a documented water quality problem, MS4 municipal programs should take responsibility for managing these piles in a pollution free manner. Further discussion of salt pile management occurred in Chapter 9, the snow management section of the Manual.

Transport-Related PSHs

Transportation-related uses are the last category of PSHs to consider. Many, but not all, transportation-related uses are regulated PSHs. They tend to generate higher loads of hydrocarbons, metals, and sediment in stormwater runoff, can be associated with large areas of impervious cover, and have extensive private storm drain systems. Fluid leakage from these sites can be a major source of contamination, as can the addition of sand and salt during the cold weather season. Road surfaces are not automatically considered as PSHs unless they have been shown locally to be such sources.

Pollutant Generating Operations/ Activities

Perhaps of more significant consideration, is an understanding of the types of pollutant generating activities that commonly occur in association with various PSH operations (Figure 13.9). Table 13.6 provides a summary of six common operations and a subset of related activities that can contribute to stormwater quality problems at a site. A more detailed description of each operation is provided below.

Vehicle Operations

Nearly all PSHs devote some portion of the site to vehicle operations such as maintenance, repair, recycling, fueling, washing or long-term parking. Vehicle operations can be a significant source of trace metals, oil, grease, and hydrocarbons, and are the first operations inspected during a hotspot source investigation. Vehicle maintenance and repair operations often produce waste oil, fluids and other hazardous products, particularly if work areas are connected to the storm drain system. Routing protective rooftop runoff through a fueling area has become a common practice in Minnesota; simple re-routing of runoff away from a potential fuel wash-off location could eliminate this from the hotspot list.

Outdoor Materials

Most PSH sites handle some kind of material that can create stormwater problems if not properly handled or stored. The first step is to inventory the type and hazard level of materials at the site. Next, it is important to examine loading and unloading areas to see if materials are exposed to rainfall and/or are connected to the storm drain system. Third, any materials stored outdoors that could potentially be exposed to rainfall or runoff should be investigated. Public and private road salt and

Table 13.6 Polluting Activities Associated With Common PSH Operations	
PSH Operation	**Polluting Activity**
Vehicle Operations	► Improper disposal of fluids down shop and storm drains ► Spilled fuel, leaks and drips from wrecked vehicles ► Hosing of outdoor work areas ► Wash water from cleaning ► Uncovered outdoor storage of liquids/oils/batteries spills ► Pollutant wash-off from parking lot
Outdoor Materials	► Spills at loading areas ► Hosing/washing of loading areas into shop or storm drains ► Wash-off of uncovered bulk materials and liquids stored outside, of particular concern in MN are road salt storage areas ► Leaks and spills
Waste Management	► Spills and leaks of liquids ► Dumping into storm drains ► Leaking dumpsters (Dumpster juice) ► Wash-off of dumpster spillage ► Accumulation of particulate deposits
Physical Plant Maintenance	► Discharges from power washing and steam cleaning ► Wash-off of fine particles from painting/ sandblasting operations ► Rinse water and wash water discharges during cleanup ► Temporary outdoor storage ► Runoff from degreasing and re-surfacing
Turf and Landscaping	► Non-target irrigation ► Runoff of nutrients and pesticides ► Deposition and subsequent washoff of soil and organic matter on impervious surfaces ► Improper rinsing of fertilizer/pesticide applicators
Unique PSH Operations (Pools, Golf Courses, Marinas, Construction, Restaurants, Hobby Farms)	Varies but includes: ► Discharge of chlorinated water from pools ► Improper disposal of sewage and grease ► Wash off of livestock manure ► Soil erosion ► Runoff of pesticides ► Salt storage

sand storage areas are of particular concern for this category.

Waste Management

Every business generates waste as part of its daily operations, most of which is temporarily stored at the site pending disposal. The third common hotspot operation involves the way waste products are stored and disposed of at the site in relation to the storm drain system. In some sites, simple practices such as dumpster management (problem exemplified in Figure 13.10) can reduce pollutants, whereas other sites may require more sophisticated spill prevention and response plans.

Physical Plant Practices

The fourth hotspot operation relates to practices used to clean, maintain or repair the physical plant, which includes the building, outdoor work areas and parking lots. Routine cleaning and maintenance practices can cause runoff of sediment, nutrients, paints, and solvents from the site. Sanding, painting, power-washing, resealing or resurfacing roofs or parking lots always deserves particular

Figure 13.10 Leakage from a Compacter/Dumpster Directly into a Storm Sewer

scrutiny, especially when performed near storm drains.

Turf and Landscaping

The fifth common hotspot operation involves practices used to maintain turf or landscaping at the site. Many commercial, institutional and municipal sites hire contractors to maintain turf and landscaping, apply fertilizers or pesticides, and provide irrigation. Current landscaping practices should be thoroughly evaluated at each site to determine whether they are generating runoff of nutrients, pesticides, organic carbon, or are producing non-target irrigation flows.

Unique Hotspot Operations

Some operations simply resist neat classification, and this last category includes unique sites known to generate specific pollutants. Examples include swimming pools, construction operations, golf courses, fairgrounds/racetracks, marinas, hobby farms, and restaurants.

Chapter 9 discussed the common PSH of salt storage and the environmental threats that result from our need as a state for safe winter roads. Water quality problems from very soluble Na, Cl and cyanide have been documented as resulting from stored salt piles. MPCA does not regulate the storage of salt unless the storage becomes a documented contamination problem. Instead, the state encourages all public and private entities storing salt to follow the Salt Institute's (http://www.saltinstitute.org/) recommended BMPs, which include such things as covering, impervious pads and drainage routing. MS4 communities are asked by MPCA to include a salt management component in their municipal pollution prevention programs.

The potential for each hotspot operation to generate nutrients, metals, hydrocarbons, toxins and other pollutants is represented in Table 13.7.

Stormwater Management Design at PSHs

Understanding the types of future operations expected to occur on a site helps designers develop a more thoughtful stormwater management and pollution prevention plan for a given site. This approach provides more flexibility in terms of what stormwater treatment approaches are appropriate for different portions of a site. Runoff management at PSHs should also be linked to the pollutant(s) of greatest concern in the subwatershed. Similarly, understanding the pollutants potentially generated by a site operation provides designers with

Table 13.7 Stormwater Pollutants Associated With Common Operations at Potential Stormwater Hotspots (Source: Schueler *et al.*, 2004)

Operation or Activity	Nutrients	Metals	Oil / Hydrocarbons	Toxics	Others
Vehicle Repair	◔	●	●	●	
Vehicle Fueling	◔	●	●	●	(MTBE not used in MN)
Vehicle Washing	●	◐	◐	●	Water Volume
Vehicle Storage	○	◐	●	◔	Trash
Outdoor Loading	◐	◐	◔	◔	Organic Matter
Outdoor Storage	◐	◐	◐	◐	
Liquid Spills	◐	◐	●	●	
Dumpsters	◐	◐	◐	●	Trash
Building Repair	◔	◐	◐	◐	Trash
Building Maintenance	○	●	◔	◐	
Parking Lot Maintenance	◔	◐	●	◐	Chloride
Turf Management	●	○	○	●	Pesticides
Landscaping	●	○	○	●	Pesticides
Pool Discharges	○	○	○	○	Chlorine
Golf Courses	●	◔	○	●	Pesticides
Hobby Farms/Race Tracks	◐	○	○	○	Bacteria
Construction	◐	◔	◔	◐	Trash, Sanitary Waste, Sediment
Marinas	◐	◐	◐	●	Bacteria
Restaurants	◐	○	●	○	Grease

Key:
- ● major contributor
- ◐ moderate contributor
- ◔ minor contributor
- ○ not a pollutant source

important information on proper selection, siting, design, and maintenance of the nonstructural (e.g., source control or pollution prevention) and structural practices that will be most effective at the PSH site.

The most cost effective approach to managing stormwater at potential hotspot sites is to employ a variety of non-structural pollution prevention, and source control measures. To do this effectively, it is necessary to have a thorough understanding of a site and the respective areas of the site where specific operations will occur. Hogland, *et al.* (2003) suggest most of the following principles for design:

- Develop detailed mapping of the different areas of the site along with associated planned activities and the preliminary drainage design.
- Separate hotspot activity areas from non-hotspot activity areas, if possible.
- Prevent or confine drips and spills.
- Enclose or cover pollutant generating activity areas and regularly provide cleanup of these areas.
- Provide spill prevention and clean-up equipment at strategic locations on site.

Figure 13.11 Examples of Common Pollution Prevention Practices at PSHs

Wash Water Containment

Secondary Containment of Outdoor Storage

Covered Loading Area

- ► Provide pre-treatment and spill containment measures such as catch basins and inserts, oil-water separators, etc.
- ► Strategically locate slopes and separation berms to prevent co-mingling of dirty and clean runoff.
- ► Retain and reuse stormwater for irrigation, wash down water, or other onsite uses.
- ► Maintain equipment to minimize leaks.
- ► Train and educate employees, management and customers.

Meeting the design intent of the non-structural practices above typically involves simple and low-cost measures to address routine operations at a site. For example, the non-structural design components for a vehicle maintenance operation might involve the use of drip pans under vehicles, tarps covering disabled vehicles, dry cleanup methods for spills, proper disposal of used fluids, and covering and secondary containment for any outdoor storage areas. Each of these practices also requires employee training and strong management commitment. In most cases, these practices save time and money, reduce liability and do not greatly interfere with normal operations. Examples of common pollution prevention practices are illustrated in Figure 13.11.

A more complete summary of 15 basic pollution prevention practices applied at PSH operations is provided in Table 13.8 (Schueler *et al*., 2004).

After considering the non-structural elements to incorporate into a site based on its layout and proposed operations, designers need to assess what structural practices will be most appropriate given site constraints while providing the greatest pollutant loading reductions for targeted pollutants. Table 13.9 presents representative pollutant removal data for common PSH pollutants of concern as a function of practice group. Details on BMP design and performance occur in design and fact sheets in Chapter 12.

It is often receiving water designation or watershed classification that will drive the criteria and associated practices that are acceptable for use. However, by virtue of being a PSH there are a set of general guidelines to always consider when designing structural stormwater management systems. The following should be carefully considered by designers when specifying and siting practices at PSHs.

- ► Convey and treat the mostly clean runoff separately from the dirty runoff.
- ► Infiltrate only the mostly clean water.
- ► Pre-treatment, pre-treatment, pre-treatment. This includes oversizing sediment trapping features such as forebays and sedimentation chambers; incorporating appropriate proprietary and nonproprietary practices for spill control purposes and treatment redundancy; oversizing pre-treatment features for infiltration facilities such as swales, filter strips, and level spreaders; and ensuring full site stabilization before bringing practices online.
- ► Consider closed systems with liners, under-drains, or comparable safeguards against infiltration for practices that manage dirty waters.
- ► Locate practices offline and minimize offsite run-on with appropriate diversions.

Table 13.8 Pollution Prevention Practices for PSH Operations (Source: Schueler *et al.* 2004)		
PSH Operation	**Profile Sheet***	**Pollution Prevention Practices**
Vehicle Maintenance and Repair	H-1	Drip pans, tarps, dry clean-up methods for spills, cover outdoor storage areas, secondary containment, discharge washwater to sanitary system, proper disposal of used fluids, disconnect storm drains, automatic shutoff nozzles, signs, employee training, spill response plans
Vehicle Fueling	H-2	
Vehicle Washing	H-3	
Vehicle Storage	H-4	
Loading and Unloading	H-5	Cover loading areas, secondary containment, storm drain disconnection or treatment, inventory control, dry cleaning methods, employee training
Outdoor Storage	H-6	
Spill Prevention and Response	H-7	Inventory materials, employee training, spill planning, spill clean up materials, dumpster management, disconnect from storm drain or treat. Liquid separation/ containment
Dumpster Management	H-8	
Building Repair and Remodeling	H-9	Temporary covers/tarps, contractor training, proper cleanup and disposal procedures, keep wash and rinse-water from storm drain, dry cleaning methods
Building Maintenance	H-10	
Parking Lot Maintenance	H-11	
Turf Management	H-12	Integrated pest management, reduce non-target irrigation, careful applications, proper disposal of landscaping waste, avoid leaf blowing and hosing to storm drain
Landscaping/Grounds Care	H-13	
Swimming Pool Discharges	H-14	Varies, depending on the unique hotspot operation
Other Unique Hotspots	H-15	

*Due to the volume of material, the reader is referred to Schueler *et al*. (2004) to see the profile sheets. Each profile sheet explains how the practice influences water quality, and lists the type of PSH operation where it is normally applied. The sheets also identify the primary people at the hotspot operation that need to be trained in pollution prevention. Next, each sheet reviews important feasibility and implementation considerations, and summarizes available cost data. Each profile sheet concludes with a directory of the best available internet resources and training materials for the pollution prevention practice.

It should also be noted that the profile sheets developed by Schueler *et al*. (2004) are written primarily from the perspective that the site(s) in question is an existing site and pollution prevention measures are recommended as a retrofit approach. Designers of new sites, however, can still use the guidance effectively.

Wright *et al*. (2004) provide a detailed description of a rapid field assessment protocol for identifying PSHs and the appropriate pollution prevention practices for the activities causing pollution. The protocol is known as the Unified Subwatershed and Site Reconnaissance (USSR) and the PSH assessment is called a Hotspot Site Investigation. These methods are not directly applicable to greenfield development or redevelopment situations; however, they have significant application for NPDES Phase II MS4 communities that are working towards compliance with minimum measure numbers 1, 2, 3, and 6 (public education and outreach, public participation/involvement, illicit discharge detection and elimination, and pollution prevention/good housekeeping, respectively).

- ► Establish rigorous maintenance and inspection schedules for practices receiving the dirty waters.
- ► For ponds and wetlands, over-design by between 10-25% the allowable storage volume for sediment accumulation over time if sediment is a problem.

Infiltration practices are the practice group that requires the most scrutiny prior to implementation at a PSH. A conservative approach would avoid the use of infiltration practices at a PSH; however, with appropriate site and conveyance design it is possible for the designer to incorporate infiltration into many sites to treat areas sufficiently separated

Table 13.9 Percent Removal of Key Pollutants by Practice Group				
Practice	Total Nitrogen [%]	Metals[1] [%]	Bacteria [%]	Hydrocarbons [%]
Detention Ponds	25	60	70[2]	80[2]
Wet Ponds	30	60	70	80[2]
Stormwater Wetlands	30	40	75[2]	85[2]
Filtering Practices and Bioretention	35	65	45[2]	80[2]
Infiltration Practices[3]	50	80[2]	N/A	N/A
Vegetated Swales and Grass Channels[4]	80[2]	60	N/A	60[2]

[1] Average of zinc and copper. Only zinc for infiltration
[2] Based on fewer than five data points (e.g., independent monitoring studies)
[3] Includes porous pavement as primarily a volume reduction BMP – MPCA does not consider porous pavement alone as a treatment practice.
[4] Higher removal rates for dry swales.
N/A: Data not available
Removals represent median values from Winer (2000)

from pollutant generating activities. Most other practice groups should be acceptable for use in treating PSH runoff, so long as appropriate design modifications are incorporated. Most design modifications are simple and in the form of enhanced pre-treatment, over-design, or design redundancies. Others are added features that limit the likelihood of ground water recharge. For example, practice groups such as bioretention, ponds and wetlands that receive runoff from pollutant generating activities should be designed with the necessary features to minimize the chance of ground water contamination. This includes using impermeable liners. The use of ponds and wetlands without liners should also be avoided where water tables are shallow and the practice would likely intercept the water table.

Importance of Plan Review at Proposed PSHs

Ultimately, the level of safeguards that are in place when providing stormwater management at PSHs should be related to the expected review process. Communities that can allocate adequate and qualified staff to effectively review all stormwater management plans for proposed PSHs can arguably provide designers with great flexibility as to how to meet the management criteria required at a site. In these cases, designers should have most of the accepted stormwater treatment practices at their disposal for implementation. However, for communities that don't have the resources to provide the necessary level of site and stormwater management plan review, a more conservative approach to allowable treatment practices should be taken.

In many cases, industrial PSHs will be covered by the NPDES industrial stormwater permit or by some other federal/state permitting program related to the materials they store or handle on site. Communities are encouraged to focus their attention on the unregulated PSH sites.

NPDES Industrial Stormwater Requirements

Background

An analysis of the state industrial stormwater permitting program exists in Issue Paper H (Appendix J) and will not be repeated here. Suffice it to say that the program is very short on resources and has received little implementation direction from EPA, leaving regulated parties often wondering about their permit status and program sufficiency.

Permit Requirements

Industrial PSHs that are regulated under NPDES stormwater permits must prepare stormwater pollution prevention plans or SWPPPs, and implement source control practices at the facility. These plans must include spill response and prevention, employee training, and implementation of pollution prevention practices to reduce exposure of products to rainfall or runoff. In some cases, stormwater treatment practices may need to be installed at the site to remove pollutants from runoff. Permitted industrial PSHs should be regularly inspected to determine if they are complying with the SWPPP, or even possess a permit. However, the MPCA does not inspect any facilities because of the staffing cut-backs it has experienced. In lieu of this, communities could conduct their own site visits as part of its local stormwater program. The storm drain system should also be investigated to determine if an industrial PSH is generating illicit discharges of sewage or other pollutants. Methods to detect and correct illicit discharges are described in Brown *et al*. (2004).

Industrial NPDES stormwater permits are an important regulatory tool at many PSH operations. Significant penalties can be imposed for non-compliance. State and federal regulators are still grappling with the administration of industrial stormwater permits, and they remain an imperfect tool for several reasons. First, the permit system allows potential hotspot operators to prepare and implement their own pollution prevention plans and to keep them on site rather than sending them to MPCA. If a particular plan is weak or is only a paper exercise, the Agency might never know until it is too late. Second, very few trained state or federal-level inspectors are available to inspect and enforce the thousands of industrial sites covered by the permit program. Third, although communities usually have the best understanding of how the local stormwater network works, they lack direct authority to inspect or enforce regulated PSHs, although they can refer them to state agencies for enforcement. Communities can also address these sites through other programs, such as zoning, stormwater utility or conditional use permits, and can address potential problems whenever new construction at the facility occurs. All three problems can be overcome if the locality works with industry and state regulatory agencies to share hotspot inspection and enforcement responsibilities as part of industrial permitting or MS4 programs. Portland (OR) recently negotiated such an agreement to expand the reach of its hotspot inspection program (Pronold, 2000).

From the regulated community standpoint, the lack of a viable, well funded state industrial stormwater permit program has resulted in uncertainty over regulatory status and frustration over paying an annual fee with no return. An industrial stormwater permit holder could conceivably have several different programs that address stormwater management, including local MS4 authority with its set of stormwater controls. Also, most industry handling polluting materials likely comes under the authority of a related regulations, such as hazardous waste spill prevention or chemical storage laws, each of which could have a stormwater component.

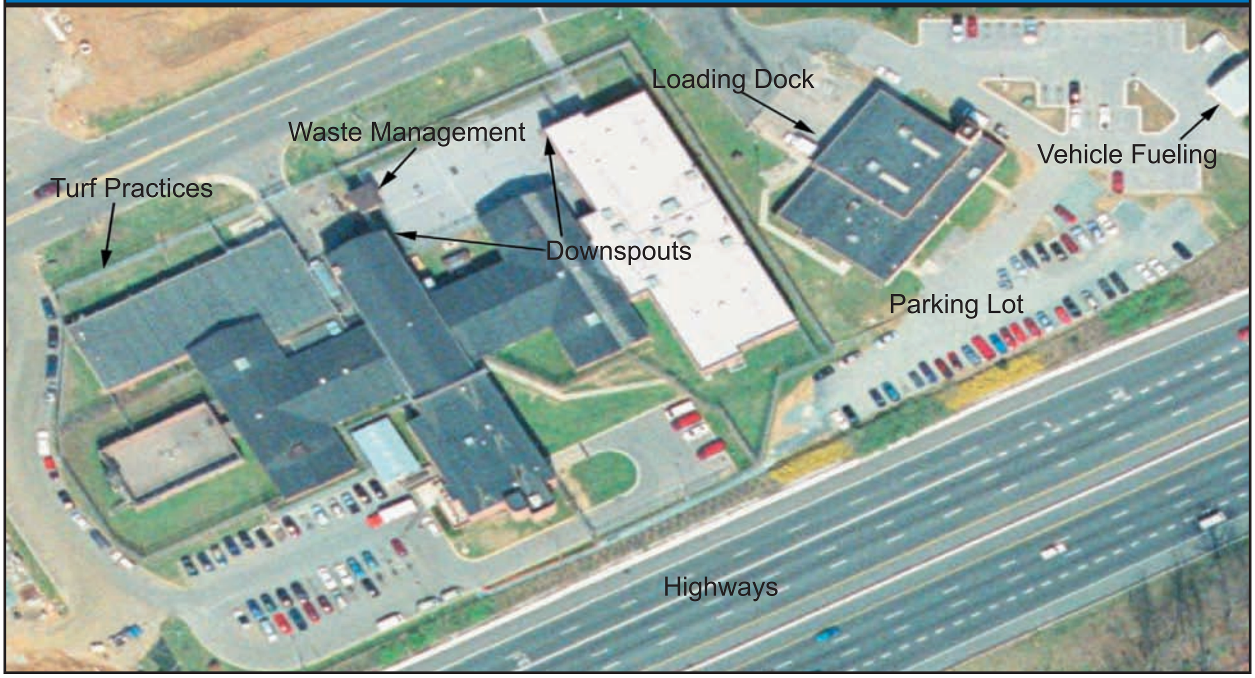
Most industrial stormwater permit issues will not be solved until a viable state and federal regulatory program exists. Until this happens, communities and industrial permit holders are urged to work together to define problems and solutions within the SWPPP framework.

Guidance on Infiltration of Runoff from PSHs

Background

Preventing or minimizing the likelihood of contaminated runoff from leaving a PSH site is the core objective of stormwater management at these sites. Introduction of contaminated runoff to the ground water is probably the greatest concern in developing effective stormwater management plans at PSHs. This is for three primary reasons: 1) ground water contamination is hard to detect immediately and therefore can persist over long periods of time prior to any mitigation; 2) there is an immediate public health threat associated with ground water contamination in areas where ground water is the primary drinking water source, which is most of Minnesota; and 3) mitigation, when needed, is often difficult and is usually very expensive. This Section focuses on these issues and presents a potential approach for establishing design guidelines for infiltration based on the six common operational areas presented in Table 13.6 plus a seventh area that addresses major transportation routes (e.g., highways). Figure

Figure 13.12 Operational Areas Subject to Infiltration Guidelines



13.12 serves as a frame of reference for revisiting these areas.

Potential for PSH Impact on Ground Water

Several areas of the Manual have addressed the need for extreme caution when dealing with the introduction of stormwater runoff into the ground via infiltration systems or even low impact development-type techniques that encourage infiltration naturally. The information presented in this chapter again illustrates the potential for ground water contamination from sites with high levels of contaminating material wash-off.

This issue gets particularly important when the infiltration occurs within a defined drinking water source area. Figure 13.13 shows the locations of MDH source water protection areas (http://www.health.state.mn.us/divs/eh/water/swp/index.htm) in a graphic from January 2004. Please be aware that these coverages are subject to change and that new coverages are being added to these. For details on exact locations, please contact MDH.

It is also important to note that Figure 13.13 shows only the public systems covered under the MDH program. There are thousands of additional private and domestic wells that could be impacted by PSHs and not subject to any special protections against stormwater runoff.

Infiltration Guidance at PSHs

Table 13.12 provides potential infiltration guidelines associated with each of the seven operational areas. Infiltration at PSHs relies on overall site design and facility operations management. Good design and committed, well-trained facility staff should make infiltration possible for certain areas of the site. Where uncertainty is present, designers should avoid infiltration practices. The Minnesota Department of Health recommends that infiltration should not be used within the one-year wellhead protection area and limited in vulnerable wells for the 10-year wellhead protection area.

BMP Sediment Quality, Testing and Disposal Guidelines

Background

Sedimentation is a primary removal process of most stormwater treatment practices. When practices are performing as intended, sediment

Figure 13.13 January 2004 location of Source Water Protection Areas (Source: MDH)

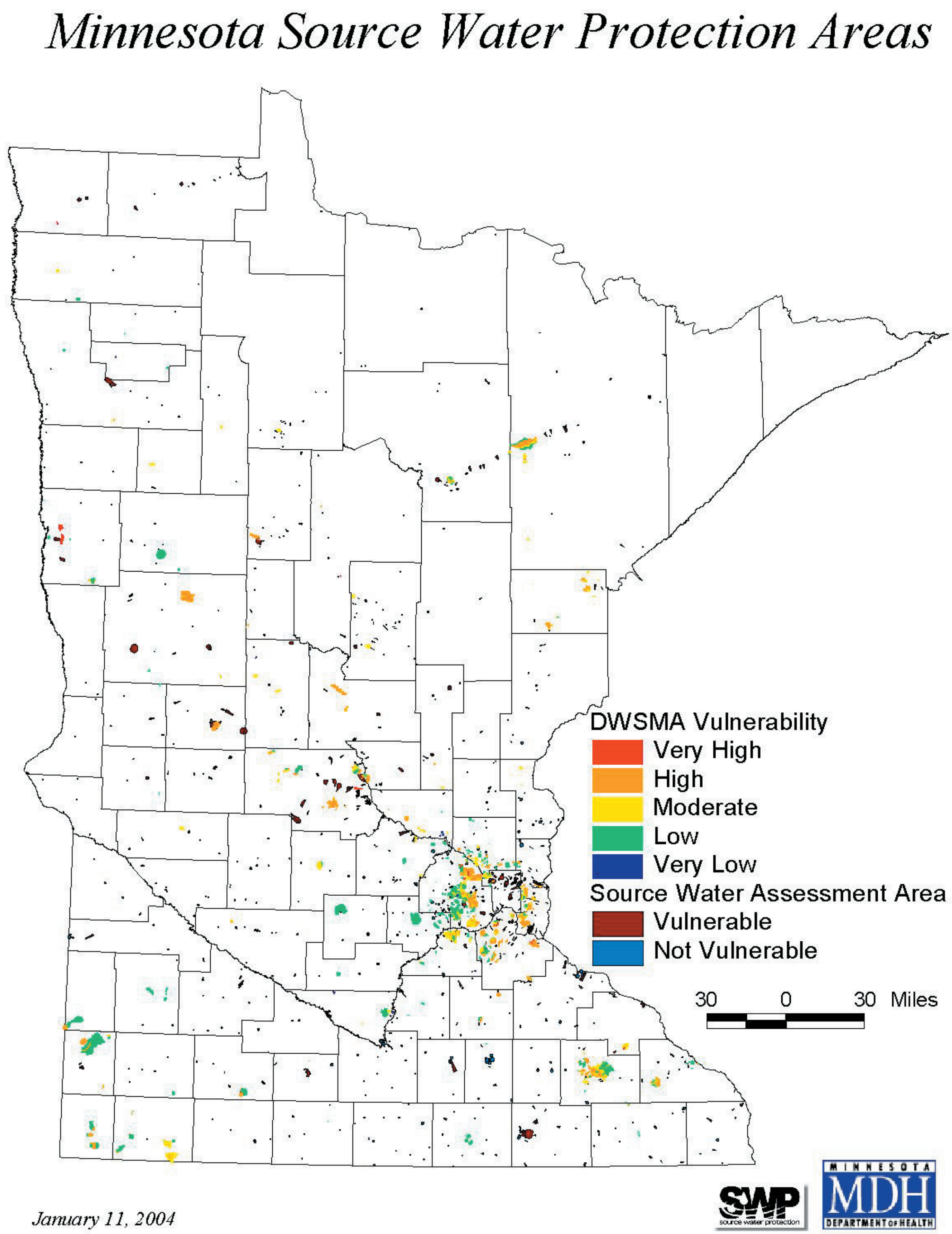


Table 13.12 Infiltration Guidelines for Potential Stormwater Hotspots

Operational Area	Potential Infiltration Guidelines
Turf Practices	Infiltration okay so long as no run-on or co-mingling from higher pollutant loading areas and appropriate pre-treatment provided for specified practice. Chemical management needed to limit the amount of fertilizer and pesticides added to the turf.
Downspouts	Infiltration okay so long as no run-on or co-mingling from higher pollutant loading areas, no polluting exhaust from a vent or stack deposits on the rooftop, and appropriate pre-treatment provided for specified practice
Parking Lots	Infiltration okay with following provisions: ► No run-on from higher pollutant loading areas. ► Limited salt application or use of alternative deicers ► Enhanced pre-treatment requirements such as (suggested unless better local information available) minimum vegetative filter length of 20 feet, maximum velocity in conveyance channels to infiltration practice of one foot per second, plunge pools and sediment basins/chambers with volumes of at least 25% of the water quality volume. ► Only daily "commuter" parking areas and no long-term car/truck storage sites
Waste and Material Storage*	Infiltration not typically recommended but possible where spill prevention and containment measures are in place such as catch basin inserts and oil and grit separators. Also possible if redundant treatment is provided such as filtering prior to infiltration. Infiltration should be prohibited in areas of exposed salt and mixed sand/salt storage and processing.
Loading Docks*	Infiltration not typically recommended but possible where spill prevention and containment measures are in place such as catch basin inserts and oil and grit separators. Also possible if redundant treatment is provided such as filtering prior to infiltration.
Vehicle Fueling*	Infiltration not allowed by MPCA for new construction under the CGP.
Highways*	Infiltration possible where enhanced pre-treatment is provided as described under parking lots. Where highways are within source water protection areas and other sensitive watersheds additional measures should be in place such as spill prevention and containment measures (e.g., non-clogging catch basin inserts and oil and grit separators).

* indicates operational area with likelihood of having higher pollutant loadings

is trapped and accumulates over time. Routine maintenance procedures are necessary and should be planned to evacuate and dispose of the accumulated sediment. The frequency of this action will be a function of the practice type, the land use draining to the practice, and design features that account for sediment accumulation over time.

There are several BMPs besides ponds that are intended to capture sediment or particulate material. For example, pre-treatment supplements such as forebays and proprietary chambers, non-clogging catch-basin inserts, filters, and bioretention all function well to remove particulate material from runoff. Each of these systems will need to have a maintenance program that removes and disposes of material.

Existing research on stormwater treatment practices has primarily focused on the movement of pollutants into and out of the practice as a measure of pollutant removal performance. Most of the monitoring studies have shown that the practice groups identified in Chapter 12 are quite effective in trapping sediment and associated pollutants carried in urban stormwater. Much less is known, however, about the fate and makeup of stormwater sediment and associated pollutants once they are trapped in a practice.

Of all the practice groups, most is known about ponds and wetlands with respect to the nature and characterization of trapped sediment and its buildup. Due to the lack of data for other practice groups, it is necessary to extrapolate findings and knowledge from ponds and wetlands in combination with best professional judgment when considering design and maintenance implications for sediment removal.

The sediment layer in stormwater treatment practices builds up over time and pollutants can remain trapped within this layer until it is excavated during a maintenance clean-out. In most cases the sediment is eventually excavated, dewatered, and applied back to a land surface or disposed of in a conventional landfill. In very limited situations, depending upon the source of the contamination, sediment that builds up in stormwater quality treatment practices may be classified as hazardous waste under the Resource Conservation and Recovery Act (RCRA) of 1976 (Jones *et al*., 1996). Understanding the potential for hazardous sediment and implementing appropriate controls and practices to minimize the risk of this characterization are important considerations for design engineers and property owners to be aware of. This section identifies those key considerations and associated design features to manage accumulated sediment in stormwater treatment practices.

Schueler (2000) provides a good summary on the pollutant dynamics of pond muck in Issue Paper H (Appendix J). The paper reviews research conducted on bottom sediment chemistry for 50 stormwater ponds and wetlands. Some key findings are:

- Annual deposition rates of sediment range from 0.1 to 1.0 inches per year. The greatest rates tend to be observed near the inlets. Deposition rates are greater for ponds that are small in relation to the contributing drainage area and for facilities that are on-line (e.g., located directly on streams). A similar study in Minnesota (Polta, 2004), although with a mass rather than depth focus, found that an 80% effective stormwater pond in an urban area can retain from 350 - 2500 pounds of solids per acre of drainage area every year.
- Phosphorus levels in pond sediment are 2.5 to 10 times higher than parent soils. Trace metals concentrations are 5 to 30 times higher in the sediment compared to the parent soils and are directly related to the land use of the drainage area (enrichment increases from residential to commercial to highways).
- None of over 400 sediment samples from the 50 pond sites exceeded EPA's land application criteria for metals and usually less than 5% of the bulk metal concentration was susceptible to leaching.
- Macroinvertebrate communities found in pond sediment had poor diversity and characteristics of high pollution stress.
- Metal concentrations in pond sediment were similar to those found in dry pond soils, grassed swale soils, and sand filter sedimentation chambers and filter beds, although based on limited data.

When is Sediment Considered to be Hazardous?

MPCA does not have sediment quality standards with which to define levels of contamination. There are, however, two other ways in which MPCA defines "contamination". First, MPCA defines sediment quality targets (SQTs) that were adopted for use in the St. Louis River Area of Concern as the state benchmark values for making comparisons to surficial sediment chemistry measurements (see MPCA Web page at http://www.pca.state.mn.us/water/sediments/index.html). Secondly, several RCRA (federal Resource Conservation and Recovery Act) designated hazardous waste compounds have been detected in urban stormwater runoff. Examples include: solvents, degreasers, pesticides, herbicides, fungicides, and hydraulic fluids. Sampling of sediment and analysis for groups of potentially toxic chemicals (ex., metals, solvent, oil/hydrocarbons) will indicate the level of contamination in the material.

The presence of a RCRA designated compound in sediment trapped by a stormwater treatment practice does not necessarily mean the sediment is considered hazardous, unless a defined level of the contaminant is exceeded through a sediment chemical extraction test called the TCLP (Toxicity Characteristic Leaching Procedure). If "hazardous" levels are exceeded (unlikely for urban BMPs), the waste must be disposed of in an authorized hazardous waste facility out of state because Minnesota does not have its own. If the waste is less than hazardous, but still showing signs of contamination, it can be disposed of in an industrial landfill, a municipal landfill or land applied (requiring an MPCA permit) depending upon the level and nature of the contaminant(s). If there are low levels of contamination or none is detected, BMP solids can be used (with caution!) as local fill. Deposition near children's play areas should always be avoided.

MPCA urges anyone interested in removing material from a BMP and not knowledgeable about the character of the material being removed to contact MPCA via its sediment web page noted above. The BMP manager is ultimately responsible for any pollution caused by the improper disposal of these wastes.

Design engineers and facility managers at PSHs should be familiar with RCRA-listed pollutants and the likelihood of these compounds being present on site. Similarly, these individuals and runoff control managers (ex. MS4 communities, watershed organizations, Mn/DOT) should be aware of the fact that many pollutants regulated by RCRA adsorb onto sediments and that most stormwater facilities require sediment removal as a component of their long-term maintenance regimen (Jones *et al*., 1996).

Reducing the Risk

Several prudent measures should be taken to reduce the risk that sediments in stormwater treatment practices will be classified as hazardous. The following guidelines (adapted from Schueler, 2000 and Jones *et al*., 1996) should be assessed as stormwater management plans are developed for individual sites.

- ► Prevent or reduce to the maximum extent practicable contact between RCRA-listed pollutants and precipitation or stormwater runoff. This can be accomplished by educating facility staff; maintaining detailed and accurate inventory of materials; providing covered and contained storage areas; using acceptable sanitary sewer connections with appropriate pre-treatment procedures (see EPA's pre-treatment program guidelines for more information at http://cfpub.epa.gov/npdes/home.cfm?program_id=3) for proper disposal of certain non-stormwater waste streams, and developing effective pollution prevention and spill containment practices and procedures.
- ► Consider site drainage carefully with an eye towards separating cleaner runoff from dirty runoff. Treat areas such as rooftops (not near hazardous material releases), walkways, and some parking areas with separate water quality practices where there is a low risk of hazardous pollutant loads. Practices such as bioretention, infiltration trenches, and swales can be effectively used to treat these areas. Isolate and minimize potential problem areas, and provide enhanced pre-treatment for these locations using sedimentation basins or traps and appropriate proprietary practices.
- ► Minimize the quantity of sediment that enters facilities over time by ensuring good erosion and sediment control practices are in place during and after construction. Post-construction considerations include maintaining complete vegetative cover in pervious areas and limiting use of sand during winter periods. Much of the post-construction sediment is knocked off of vehicular carriers (tires, mud-flaps and under-carriage) during loading and unloading at a facility.
- ► Employ techniques such as aerators or fountains in ponds to promote pollutant removal of certain organic compounds through volatilization. If there are hazardous levels of any of these chemicals, MPCA needs to be contacted to develop a mitigation program that might not allow the volatilization system.
- ► Oversize sediment storage volumes in stormwater treatment practices to

reduce the frequency of needed sediment removal.

- ► Where ponds are used, design forebays to provide optimized pre-treatment by sizing for at least 10% of the water quality volume, providing adequate depth, and designing for exit velocities no greater than one foot per second at the maximum design inflow to reduce likelihood of scouring and resuspension.
- ► PSHs should design practices and adjacent areas with sufficient space to accommodate dewatering of sediments once evacuated from a practice. Even when sediment is not considered to be hazardous, they will not typically be accepted at conventional solid waste landfills unless sufficiently dewatered.
- ► Construct facilities off-line to avoid consequences associated with impacting "waters of the state."
- ► Institute strict and regular housekeeping and source control measures.

Sampling and Disposal of Sediment

Operators and owners of PSH sites with a high likelihood of having trapped stormwater sediments being classified as hazardous should be aware of the requirements associated with sampling and characterizing the sediments. Operators and owners should communicate with regulators in advance of plans to evacuate and dispose of sediment from stormwater treatment practices in these situations. EPA sampling guidelines exist to aid in the determination of the appropriate number of samples to collect, selecting the appropriate analytical techniques, ensuring proper QA/QC, and identifying qualified labs to conduct the analyses. Potential hazardous pollutants should be identified in advance to streamline this process. The MPCA Web site for guidance on sampling of suspected contaminated sediment is http://www.pca.state.mn.us/water/sediments/. EPA guidance on sediment sampling is tied to specific programs available at http://www.epa.gov/waterscience/cs/.

As previously stated, available data indicates that most accumulated sediment in stormwater treatment practices does not constitute a hazardous or toxic waste. Therefore, it can be safely disposed of using conventional techniques such as for fill, land application, or landfill material, according to MPCA rules and guidance. Sites and associated stormwater facilities where the risk of hazardous waste characterization is deemed to be high should sample sediment prior to evacuation to determine whether it is hazardous or not. If the sediment is not hazardous, then disposal as described above is acceptable. If a hazardous characterization is made, then sediment must be disposed of at facilities authorized and certified to receive the waste so that it can be properly handled and disposed of. Because there are no hazardous waste landfills in Minnesota, this necessitates exporting it out of state.

IV. References

Alexander, E.C. and Y. Gao, 2002. Copyrighted graphic of Minnesota Karst Lands.

Brown, E., D. Caraco and R. Pitt, 2004. Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessment. Center for Watershed Protection, Ellicott City, MD.

Carroll County, MD. 1996a. Draft Water Resource Management Manual.

Carroll County, MD. 1996b. Draft Water Resource Management Ordinance.

Covington, M. 2002. Modified Sand Filter Design (The Herring/Frock Method). Presented at Delaware Sediment and Stormwater 2002 Conference – The Race for Clean Water. Dover, DE.

Duke, D., K. Patel, and B. Masek. 1999. "Widespread Failure to Comply with U.S. Stormwater Regulations for Industry-Part I: Publicly Available Data to Estimate Number of Potentially Regulated Facilities." Environmental Engineering Science. Vol. 16(4).

Duke, D. and K. Shaver. 1999. "Widespread Failure to Comply with U.S. Stormwater Regulations for Industry-Part II: Facility-Level Evaluations to Estimate Number of Regulated Facilities." Environmental Engineering Science. Vol. 16(4).

Hogland, W., M. Marques, and V. Karlaviciene. 2003. Stormwater Runoff From Industrial Areas and Pollution Transport. Proceedings from 1st International Conference on Urban Drainage and

Highway Runoff in Cold Climate. Riksgränsen, Sweden.

Jones, J., S. Anderson, J. Fognani, F. R. MacGregor, and T. Axley. 1996. "Stormwater Best Management Practices: When is Sediment Considered Hazardous?" Water Environment & Technology.

Laughland, J. C. Stormwater Management Design in Karst Terrain: Adjusting Hydrology Models and Using Karstic Features.http://www.planetrussell.net/fdg/fdg_demo_green.html. Accessed October, 2003.

Maryland Department of the Environment (MDE), 2000. 2000 Maryland Stormwater Design Manual, Volumes I and II. Prepared by the Center for Watershed Protection and MDE.

Pitt, R. 2001. Methods for Detection of Inappropriate Discharges to Storm Drainage Systems: Background Literature and Summary of Findings. Tuscaloosa, AL.

Polta, R., 2004. A Survey of Regulations Used to Control the Use and Disposal of Stormwater Pond Sediments in the United States and Canada. EQA Report 04-542, Metropolitan Council Environmental Services, St. Paul, MN.

Prince George's County Maryland. 2002. Prince George's County Bioretention Manual. Department of Environmental Resources.

Pronold, M., 2000. Administering the NPDES Industrial Stormwater Program in Proceedings: National Conference on Tools for Urban Water Resource Management and Protection. U.S. EPA, Office of Research and Development, EPA/625-R-00-001.

Schueler, T., 2000. Pollutant Dynamics of Pond Muck. Watershed Protection Techniques, 1(2): 39-46. Center for Watershed Protection, Ellicott City, MD.

Schueler, T., C. Swann, T. Wright, and S. Sprinkle. 2004. Urban Subwatershed Restoration Manual No. 8: Pollution Source Control Practices, Version 1.0. Center for Watershed Protection. Ellicott City, MD.

St. Johns River Management District (SJRMD). 2001. Applicant's Handbook: Regulation of Stormwater Management Systems. Palatka, FL.

Winer, R. 2000. National Pollutant Removal Performance Database for Stormwater Treatment Practices. 2nd Edition. Center for Watershed Protection. Ellicott City, MD.

Wright, T., C. Swann, K. Cappiella, and T. Schueler. 2004. Urban Subwatershed Restoration Manual No. 11: Unified Subwatershed and Site Reconnaissance: A User's Manual, Version 1.0. Center for Watershed Protection. Ellicott City, MD.

Chapter 14

Minnesota Case Study Examples of BMP Design

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VOLUME 2 - TECHNICAL AND ENGINEERING GUIDANCE

Chapter 14

Minnesota Case Study Examples of BMP Design

This chapter provides case studies of stormwater management activities and BMP implementation at project sites around the state.

Contents

I. Burnsville Rain Gardens Case Study: Retrofitting for Water Quality

Location: Burnsville
Landscape Setting: Suburban residential
Drainage area: 5.3 acres, 25 houses (17 with rain gardens)
Project timeline: 2001 – 2006
Project cost: $147,000
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Issue

Over the past decades, Burnsville's Crystal Lake had seen a marked decrease in water clarity, due in part to algae bloom resulting from increased phosphorus entering the lake. Water quality typically decreased from spring to late summer, which impacted recreational use of the lake.

Background

Recognizing that incoming stormwater from surrounding residential neighborhoods was an important factor in lake health, the City of Burnsville sought an alternative treatment method to reduce that runoff. However, curb and gutter was already in place in the 20-year-old neighborhoods near the lake, and there was insufficient room for traditional stormwater ponds.

Rain gardens—shallow, vegetated depressions that capture runoff and allow it to soak into the ground—emerged as the best solution. In addition to suiting the space and budget constraints in this fully built residential area, rain gardens offer visual amenity that tend to increase residents' commitment to help implement and maintain them.

With the help of two grants—$30,000 from the city and $117,000 from the Metropolitan Council—Burnsville was not only able to design and build the gardens, but to implement a study to gauge their effectiveness. A paired watershed study—monitoring one 5.3 acre neighborhood

Figure 14.1 Burnsville Rain Garden

Figure 14.2 Control and Treatment Watersheds

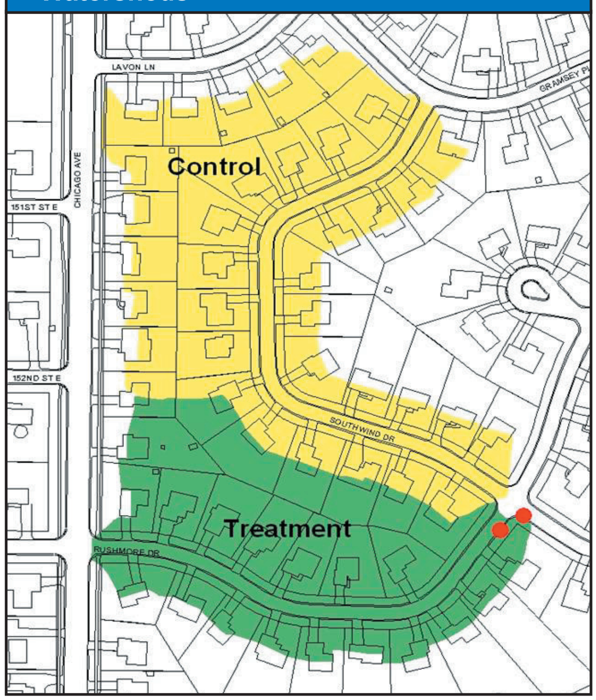
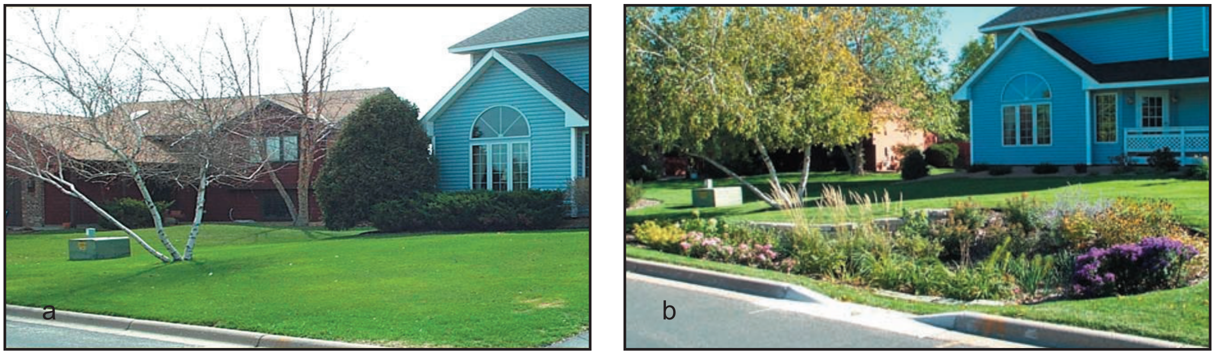


Figure 14.3 (a) Home Before Installation of Rain Garden and (b) Home After Installation of Rain Garden



with 17 rain gardens and a similar, no-rain-garden neighborhood nearby—allowed the city and its partners to see how the BMPs performed during actual storm events.

Implementation

To get baseline data, gauges were installed in each neighborhood to measure runoff for two summers prior to rain garden installation.

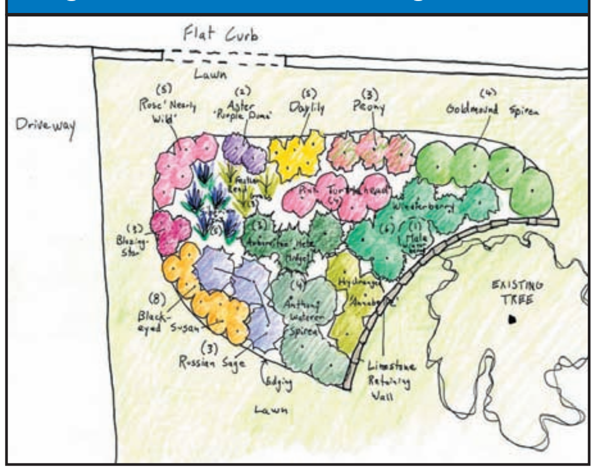
Since the greatest concentration of pollutants is washed off impervious surfaces during the first inch of precipitation, rain gardens are designed to accommodate that “first flush” from a given watershed. The Burnsville gardens were designed to accommodate 0.9” and drain rapidly, within 24 to 48 hours. Rain gardens can be planted with many types of vegetation, including native perennials and shrubs or cultivated varieties. The Burnsville participants were given the choice of three basic garden styles: native wildflower, cultivated perennials and/or shrubs.

Following evaluations of soil and topography, city staff and consultants sought to educate area residents about efforts to improve Crystal Lake water clarity and how rain gardens fit into the picture. The Rushmore Drive neighborhood, characterized by gentle topography and sandy soils, was selected, with hopes of getting at least 30 percent of the 25 residents to participate. As it happened, 85 percent of households signed on, resulting in 17 gardens—13 in front yards, 4 in back. All but one selected a scheme using low-maintenance cultivated perennials and shrubs, which tend to look neater than an all-native garden.

Grading plans, created by engineer Kurt Leuthold, in consultation with landscape architect Fred Rozumalski, incorporated stone retaining walls and gradual slopes from street to basin. During the design phase, Gopher One marked underground utilities so they could be accurately surveyed. The project engineer stresses the importance of this step to help minimize pre-construction surprises and changes.

The landscape architect met with homeowners and drew up planting plans that considered individual resident preferences. Each garden is separated from the street and curb cut by a mow strip, which serves two purposes: to lend a neat, intentional edge to the garden and to trap sediment traveling with the rainwater. The planting designs emphasize showy groupings of tidy-looking plants, which enhance the appearance of the front yards. Construction began in fall 2003. In order to avoid hitting utilities and to ensure proper flow, precise

Figure 14.4 Rain Garden Design



grading of the gardens was critical, as was close adherence to soil specifications and avoiding compaction. Native sandy topsoil was stockpiled and mixed with compost, then installed at a depth of 12 inches following grading. To ensure quality, the city relied on the engineering consultant to do extensive construction observation, and Gopher One marked utilities two additional times—before sod stripping and soil removal and also prior to grading.

Small construction companies were more responsive to the request for bids on this relatively small project (the grading budget was $50,000); city staff indicated that in the future they would not solicit bids from large companies for a project of this scale.

Instead of having planting completed by the contractor, the Burnsville project utilized resident-volunteers to plant their own gardens, with the help of the landscape architect and city staff. This not only helped keep the budget down, but gave homeowners a hands-on investment in their gardens, and familiarized them with the plants.

In order to let plants become established before being inundated, curb cuts were not made until spring 2004. It is important to design curb cuts sufficiently wide so stormwater actually reaches the gardens; a too-narrow cut can allow water to wash on by. At Burnsville, the typical curb opening was 6 feet, with 2 feet tapering sections on each side.

Costs

Cost per garden was approximately $7500, with about $500 of this going toward plants.

Results

Resident reviews have been favorable (an important factor in ongoing success of the gardens), and the monitoring data indicates excellent results.

2004 monitoring data showed that the rain gardens achieved an 80 percent reduction in runoff volume in 49 rain events. Most basins drained dry within 3 to 4 hours. During winter, some ice build-up was evident, but as the melt infiltrated, ice collapsed and disappeared with no adverse effects.

Future Actions

The Dakota County Soil and Water Conservation District conducted runoff audits on each lot in the study neighborhood to provide homeowners with additional suggestions on reducing runoff from their properties, such as redirecting downspouts, installing rain barrels to capture roof runoff and aerating lawns to enhance infiltration.

Another effort to benefit Crystal Lake, a single infiltration basin in West Buck Hill Park, was installed in fall 2004. It accepts runoff from a 25-acre subwatershed.

The Burnsville rain garden project area and control neighborhood are being monitored through 2005. While the success of the project recommends installing more rain gardens elsewhere in the city, the project coordinator has departed, so it is unclear whether additional gardens will be built in the near future.

Figure 14.5 Street Scene

II. Heritage Park Case Study: An Urban Retrofit

Location: Minneapolis
Landscape Setting: Urban
Drainage Area: ~400 acres
Project Area: 145 acres
Project Timeline: 2001 - 2007
Project Cost: $225 million
($75 million infrastructure, $150 million housing)
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Issue

In the ultra-urban setting of Minneapolis, space for stormwater infrastructure is at a premium in urban retrofit projects such as Heritage Park due to demand for affordable housing intensity and physical constraints. Stormwater from the site before redevelopment was collected through a large underground tunnel system and discharged without pre-treatment directly to the Mississippi River. The challenge at this 145-acre redevelopment site was to incorporate stormwater amenities into the overall site design and best utilize the limited space available.

Background

The Near Northside neighborhood of Minneapolis was originally developed in the late 19th century on land characterized by low-lying swamps, tributary springs, upland seepage and surface runoff areas associated with Bassett Creek. As part of several generations of attempts to build sound low-income housing, the wetland and floodplain areas were filled and drained in the early 20th century. The early single-family structures built here failed, due to these unstable conditions and were replaced by higher-density rowhouses in public housing projects. These also experienced differential settling of structures, utilities, streets and sidewalks over time due to the poor soil conditions.

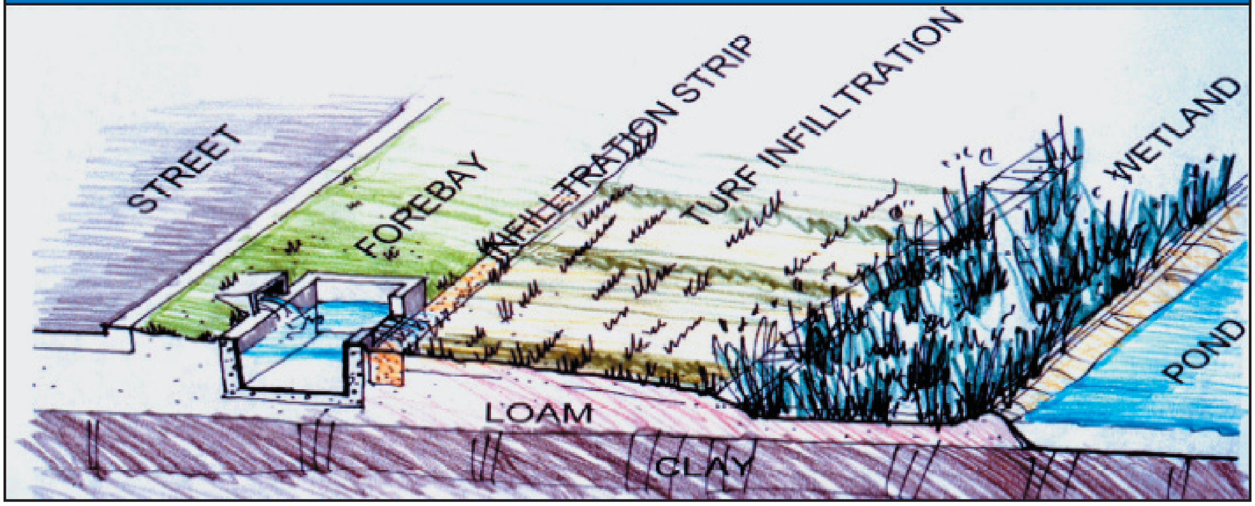
Stormwater management at the time consisted of directing surface water runoff (including Bassett Creek) through a large underground tunnel system to reduce flooding problems in the area. This tunnel system discharged directly to the Mississippi River. The originally constructed tunnel was replaced in 1992 in a new alignment several blocks to the south to handle the considerably higher runoff volume resulting from suburban and freeway development, leaving the old tunnel in place for local conveyance.

In 1992, the public housing developments occupying the site were the target of a lawsuit charging segregation and isolation of public housing residents. The lawsuit was settled in 1995 through a Decree to determine a re-use plan for the site through a community-based focus group process. The Action Plan developed from these recommendations called for reconnecting the site to surrounding neighborhoods and amenities, demolishing the public housing units, and replacing them with mixed-income housing (25% public housing), and a system of parks and open space. The Action Plan was approved in federal court in 1997 and was followed by a Master Plan approved in 2000. The Master Plan called for 900 new mixed-income homes, a combination of rental and for-sale, affordable to families at all income levels. The first units were occupied in November, 2000 and construction is still under way on the remainder.

Implementation

Stormwater infrastructure for Heritage Park was based on a design that includes a combination of engineered and natural systems set within the

Figure 14.6 Heritage Park Treatment Train



development's park and open space amenities. These serve not only as an effective stormwater treatment system but also restore a sense of place to the traditionally low-income, amenity-poor neighborhood. The stormwater infrastructure for the site treats runoff and non-point source pollution from the 143-acre redevelopment area as well as neighboring residential, commercial, and industrial areas for a total treatment area of roughly 400 acres.

The general stormwater "treatment train" design used for the Heritage Park project area; each step of the process incrementally cleanses the water further. Rainwater running off the streets and park areas carries sediments and pollutants. The Heritage Park system routes the stormwater runoff through grit chambers or forebays to remove sediments, then filters the runoff through plantings and the soil profile before flowing into the open water amenities.

The stormwater treatment system is the core of the park and open space component of the project, merging upland and wetland native plant communities with filtration-based processes to remove pollutants. Larger pond systems anchor the park areas while smaller ponds, wetlands and filtration systems are blended into the transportation corridors and edges of the large park areas.

Stormwater generally enters the system through typical urban catch basins and storm sewers and passes through either grit chambers or into trench forebays for initial removal of large particles. Water is then routed to filtration galleries, which consist of wet meadow or wet prairie plant communities. These galleries promote infiltration, using the cleansing ability of natural vegetation and soil filtration and reducing the velocity and quantity of stormwater. Water then moves directly to ponds or wetlands for further treatment and is then conveyed downstream to the Mississippi River. All surface conveyances are vegetated with native plant communities.

Pre-Treatment Systems

Grit Chambers: Grit chambers are designed to remove large particles and debris from stormwater. Eleven Continuous Deflective Separation® (CDS) units were installed at Heritage Park (see Chapter 12 for more on hydrodynamic devices). Stormwater is diverted from the conveyance system by a weir and flows through an inlet and across a stainless steel screen whose size was based on site-specific performance standards. The unit has a system bypass that allows excessive stormwater flows to continue downstream via the storm sewer system.

Trench Forebays: Trench forebays are located upslope from filtration basins and are engineered pre-treatment systems that act both as flow spreaders, which reduce the velocity of water before it enters the filtration basin, and sediment collectors. The trench forebays will be planted with wetland plants and have a buffer of short grass prairie plantings.

Figure 14.7 Installation of Trench Forebay

Level Spreaders: Level spreaders are located upslope from filtration basins at the transition point between short grass prairie and wetland community to promote even, low-velocity sheet flow into the filtration basins, preventing erosion and enhancing filtration.

Final Treatment Systems

Filtration Basins: Filtration basins treat stormwater through vegetative and soil filtration. As water moves through the soil profile, the pollutants are retained and the cleansed water moves either laterally through drain tiles or vertically to clay soils and then on to open water features. Vegetation is a key aspect of filtration systems. Above ground biomass slows the lateral movements of water and prevents soil erosion and root system increases also increase filtration rates. The filtration system outflows to conveyance channels or downstream ponds. Filtration systems are effective at removing phosphorus, suspended solids, and pollutants that adsorb to particles, such as heavy metals, but require pre-treatment to prevent clogging.

Stormwater Detention Ponds: Pond systems are effective at attenuating flows and removing suspended solids, floatables, fecal coliform bacteria, and particulate bound pollutants. Small ponds located in the boulevard system collect runoff and provide pre-treatment, retaining pollutants in the permanent water pool before passing water downstream to filtration basins or channels.

Results

The project is currently working to develop monitoring programs and solicit community partners. Vegetation-based treatment systems need two or three years to become fully established and reach peak efficiency. Options being considered are the City of Minneapolis NPDES stormwater monitoring program, or enlisting the aid of the Mississippi River Watershed Management Organization for monitoring stormwater quality at the downstream end of the Heritage Park system, which would be the end of the treatment train and would provide data on runoff quality entering the Mississippi River. The project will serve as a model for urban areas for how to integrate stormwater management into the urban fabric and harvest it to create high quality neighborhood amenities.

Costs

Total costs for the planning and installation of stormwater infrastructure and wetlands portion of the project is estimated at approximately $7.8 million over a five-year period. The Mississippi Watershed Management Organization was a major contributor for this portion of the project along with additional funding from the McKnight Foundation, Metropolitan Council, Hennepin County, U.S. Housing and Urban Development (HUD), and the City of Minneapolis.

Future Actions

This is an on-going project. Since the stormwater treatment system is tied closely to other infrastructure components of the project, the phasing of housing construction dictates treatment system implementation. The stormwater treatment system in Heritage Park is the spine of the new development. Larger pond systems anchor the park areas, while smaller ponds, wetlands and filtration systems are blended into the transportation corridors and the edges of the large park areas. Harvesting stormwater from the impervious surfaces allows the normally disruptive urban hydrologic pattern to be managed so that large expanses of wet prairie, wet meadow, and wetlands are created.

Regular maintenance activities are necessary for the system to function as intended. These activities include the clean-out of settleable solids, floatables, trash, and debris from sump structures in the grit chambers by a vacuum truck. The trench forebays also accumulate sediment, which will be periodically removed by bobcats or loaders. The trench forebays will need to be replanted after this maintenance.

III. University of Minnesota Landscape Arboretum Case Study: Runoff Model and Rain Gardens

Location: Chanhassen
Landscape Setting: Suburban
Drainage area: Runoff Model = 25,000 sf, Rain Gardens = 18,000 sf
Project timeline: Runoff Model 2002, Rain Gardens 2003
Project cost: Runoff Model $550,000
Rain Gardens $200,000
More information:

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Richard@arboretum.umn.edu

or

Minnesota Landscape Arboretum
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Peter@arboretum.umn.edu

Issue

There are few, if any, public models demonstrating water runoff absorption solutions. The runoff model parking lot and the rain gardens attempt to demonstrate several actions that can increase absorption and thereby decrease runoff from hard surfaces and also demonstrate the relative difference it makes. These particular sites, similar to sites throughout the Twin Cities Metropolitan area, have heavy clay/silt soils.

Background

As the urban landscape has become more highly developed, polluted storm runoff has emerged as a major problem. When pavement, rooftops, and other hard surfaces replace grass, trees, and native plants, then rain and melting snow can no longer seep slowly into the earth. Instead, stormwater flows over these hard surfaces, picking up pollutants such as oil, fertilizers, and pesticides and depositing them in storm sewers that eventually lead into natural water bodies such as local lakes and streams. Serious water quality problems are the result of this phenomenon.

Rain gardens and absorption devices represent alternative stormwater management practices, using vegetation and innovative design features to improve water infiltration and maximize pollutant removal. An accessible runoff model and rain gardens at the Minnesota Landscape Arboretum demonstrates for urban planners, landscape designers, city officials, and the general public the potential positive impact of these important and replicable tools for stormwater runoff management.

Rain gardens and absorptive surfaces may be suitable for any land use situation, including industrial, commercial, and residential. Therefore, target audiences for these demonstration projects include architects, engineers, city planners, other public officials, watershed managers, hydrologists, legislators, and homeowners.

Commercial developers and public officials face increasing regulations related to stormwater management and wetland mitigation. The runoff model demonstration project and the rain gardens offers alternative strategies to consider that enhance the appearance of parking lots and other projects, at the same time lessening potential detrimental impact on water quality.

Figure 14.8 Parking Lot Rain Garden

Homeowners are interested in learning about rain gardens, incorporating plantings to attract birds and butterflies and about reducing pollutants reaching natural community water bodies. In addition, homeowners who seek permits for additions to their home structures benefit from ideas such as converting driveway "hard structure" into a "non-hard cover" such as grass-crete or permeable paving units.

In 2001 the Arboretum decided to add to its display of runoff water disposal/purification alternatives by creating a runoff water disposal model in a new parking lot. It would demonstrate the difference between nearly 100% runoff to nearly 0% runoff.

These parking lots are used by visitors and staff at the Marion Andrus Children's Learning Center at the Arboretum. They are set within the Arboretum boundaries and are surrounded by maple-basswood-oak forest and wetlands (mostly deteriorated).

Project objectives included the following:

- Demonstrate new design paradigms for parking lots and other "hard surface" developments, including curbless paving and a variety of bioretention techniques related to reducing stormwater runoff and sediment.
- Demonstrate a variety of applicable materials for paving, planting and filtering.
- Demonstrate remedial techniques for use with existing pavements, including infiltration strips and crosswalk edges.

Figure 14.9 Overview of Runoff Model

- Demonstrate attendant techniques for treating stormwater quality, such as planted filter swales and sedimentation basins.
- Record, compare, and disseminate longitudinal observations about costs and effectiveness of each of the five rain garden segments.
- Educate visitors about the importance of effective stormwater runoff management in assuring urban ecological well being.

Implementation

The runoff model consists of five clearly defined areas of equal size, each with a different level of runoff infiltration and each draining to its own ponding area or sump where the quantity of runoff can be observed and compared, one area to another.

The five distinct areas are separated by concrete access/watershed dividers and consist of the following:

A. Bituminous parking area with adjacent paved slope and paved filter area, a worst case scenario included for comparison purposes.

B. Bituminous parking area with adjacent lawn slope and lawn filter area.

C. Bituminous parking area with a vegetated island, and adjacent vegetated slope and lawn filter area.

D. Bituminous parking area with rock filled trench drains, adjacent vegetated slope and vegetated filter area.

E. Permeable pavement or "grass-crete" parking area with rock filled trench drains, adjacent vegetated slope and vegetated filter area.

A photographic record of the installation process has been maintained. Each overflow pool or catchment area is designed so that accurate measurements can be taken. The time to construct this as a model would not reflect the costs of installing any one of the five model watersheds. Obviously installment of a porous paver surface is more time consuming but hugely more effective in absorbing water.

Figure 14.10 Curb Cut for Rain Garden

Adjacent to the runoff model is a parking lot with swaled rain gardens. The swales have 2 feet of sand topped with 6 inches of sandy top soil and planted with drought resistant (mostly native) plants. A subsurface drain below the sand and overflow yard-drains help manage excessive rain events. The overflow and subsurface drains go directly to a NURP pond.

Costs

Runoff Model:
5 constructed drainage areas @ 4770 sq. ft. each
Project total cost: $550,000

Rain Gardens:
18,000 sq. ft.total runoff area
Project total cost: $200,000

Results

These models have been quite successful, as they have worked very well. 100% runoff is achieved on the totally paved surface, nearly 100% absorption on the paver surface and more or less absorption on the amount of planting and the rock filled trenches. The rain gardens work very effectively. The only problem with these models is attracting to the site those people who could most benefit from the knowledge learned.

Future Actions

The intent is to develop a take home brochure describing the benefits of using absorption surfaces and the costs involved. It is hoped this will be available by early 2006. Interpretive signage will be installed at the rain gardens by late summer 2005. Perhaps a brochure on these gardens will follow.

Maintenance of the rain gardens is within normal garden weeding and watering but has been lessened by the use of coco-matting over the soil before planting occurred. The runoff model, of course, requires more maintenance because of the collection pools.

The runoff model has been maintained and some rain events recorded, but good data is still lacking and this effort is continuing to be pursued.

Figure 14.11 Runoff Model Collection Pools

IV. Silver Creek Cliff Trail Case Study: Meeting Stormwater Discharge Requirements Using Compost

Location: Trunk Highway 61, North Shore
Landscape Setting: Roadway in Historic Viewshed of Lake Superior
Drainage Area: 16 acres
Project Area: 2 acres
Project Timeline: 2004
Project Cost: Available Upon Request
More Information: Dwayne Stenlund
Mn/DOT
(651) 284-3787
dwayne.stenlund@dot.state.mn.us

Issue

Mn/DOT wanted to construct a project to add a bituminous bike trail and parking area within the old right-of-way of historic Trunk Highway 61 near the Silver Creek Cliff Tunnel on the North Shore of Lake Superior. The project area had a number of significant constraints for implementing traditional construction Best Management Practices (BMPs). These constraints included: its location in a historic viewshed; the presence of rare, threatened, and endangered plants and animals at the site; direct stormwater drainage to Lake Superior (a special water of the state); and poor soils with close proximity to bedrock. These all combined to make design and implementation of temporary and permanent stormwater management for this project a unique challenge.

Background

The old roadbed of Trunk Highway 61 is located on the outside of the Silver Creek Cliff Tunnel and is considered to be a historic roadway. As such, a project to preserve the area and provide safe public access to it was proposed through construction of a pedestrian trail and parking area.

Site constraints in the project area made implementation of traditional stormwater management techniques impractical and unfeasible for the site. All stormwater from the project drains through multiple exit points to Lake Superior, which has prohibited and restricted discharge areas and a special water of the state. Peregrine falcons have established nesting areas in the rock face above the trail site, so the project had to avoid disturbing the birds during their critical nesting season. Rare plant species were identified at the toe of the slope requiring a design configuration of the project to avoid impacting them. The design also had to complement the historic nature of the site itself and not obstruct or adversely alter the historic viewshed of the lake. Stormwater management was further complicated by underlying soil materials, since this area is dominated by exposed rock and thin soils.

Implementation

An important step early in the project planning process was the development of a detailed Stormwater Pollution Prevention Plan (SWPPP). Since site constraints did not allow for implementation of traditional stormwater

Figure 14.12 Perimeter Control Using Compost Filter Logs

Figure 14.13 Some Site Constraints for the Project

management techniques, an Alternative Treatment proposal for permanent stormwater management was developed for the area. The Alternative Treatment proposal was included in a hybrid SWPPP that also addressed temporary erosion and sediment control techniques to be implemented during construction. This hybrid SWPPP utilized the feasible and appropriate portions of the normal SWPPP, but added an operational component to the SWPPP with special provisions for time of year, water quality treatment and rapid stabilization.

Stabilization was required within 3 days in areas with 1:3 or steeper slopes and within 7 days in areas flatter than this. The rapid stabilization plan utilized compost filter logs for perimeter control, ditch checks, and field inlet protection, and bioretention swales designed to meet the requirements. Temporary erosion control practices included in the hybrid SWPPP described rapid stabilization procedures for ditches, inlets, outlets, and ditch checks within 1 day and plans included detailed descriptions of where each stabilization standard applied on the site. Since a typical living swale could not be designed to meet stormwater treatment requirements with the soil features at the site, a compost bioswale system was designed for water retention, filtration and nutrient capture. This bioswale was developed for water quality treatment using known parameters of leaf and grass clipping feedstock compost.

The SWPPP included operational provisions for contractors and subcontractors and outlined a system of random site visits by the design team as a quality control measure to ensure implementation of these provisions. It also designated an Erosion Control supervisor, who had responsibility for implementation of the SWPPP including oversight during project construction, implementation of training for contractors and subcontractors, inspection and monitoring, and identification and correction of any deficiencies as the project progressed.

Construction timing was planned to be outside of the peregrine falcon nesting season (after July 15th, 2004) and DNR personnel checked

Figure 14.14 Compost Soil Amendment for Rapid Vegetation and Stabilization

the nesting sites to ensure that the birds had vacated them before construction was allowed to begin. Rare plant impacts were avoided by design alterations for construction of a bridge in the area rather than the more common practice of blasting the rock and adding slope fill for the trail. Impervious surface reduction and increases in vegetation were enhanced by compost additions to thin topsoils.

Permanent erosion control practices included a 2" thick compost blanket, slow release fertilizer and a system of vegetated swales and drainage filters for the parking lot inlet. Compost filter logs were also used as post-construction stormwater controls as the filter logs vegetated over time, and a special seed mix was developed for the project.

Results

The project resulted in an overall reduction of impervious surface area and an increase of vegetation along the trail.

Costs

Available by request from contact listed above.

Future Actions

The techniques used for this project were very successful at addressing both temporary and permanent stormwater management and erosion and sediment control in shallow soils and bedrock areas with unique constraints. This project will be used as a model for future projects in areas with similar conditions.

(a) (b)

Figure 14.15 Rapid Stabilization and Revegetation Using Compost and Vegetative Mat (a) Installation and (b) After Stabilization (Note that areas utilizing compost vegetated more quickly and completely than areas using the vegetative mat.)

V. Minneapolis Chain of Lakes Case Study: A Stormwater Management Treatment Train Approach to Improving Lake Water Quality

Location: Minneapolis
Landscape Setting: Urban
Drainage area: 7,000 acres
Project timeline: 1990 - 2001
Project cost: $12.4 million
More information: Bruce Wilson
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Issue

The Minneapolis Chain of Lakes consists of (from the top of the watershed downstream) Twin Lakes, Brownie Lake, Cedar Lake, Lake of the Isles, Lake Calhoun and Lake Harriet). It is located 2.5 miles southwest of downtown Minneapolis. Decades of intense recreational use, urban development, and stormwater inputs had slowly degraded the lakes' water quality.

Background

In 1990, the Minneapolis Chain of Lakes Clean Water Partnership (CWP) was formed to address the water quality problems the Chain of Lakes were facing. From the beginning, citizen participation has been at the core of the CWP management process and was vital to the overall success of the project. The Chain of Lakes Water Quality Management Citizens Advisory Committee (CAC) was formed and used a consensus-based process to develop a management plan that included water quality goals and recommendations that were submitted to the Minneapolis Park and Recreation Board.

The primary focus for long-term management was to reduce the amounts of total phosphorus and sediments reaching the lakes from watershed sources. Targeted reduction amounts were defined by the CAC and set to achieve specific recreation-based water quality goals (water clarity, fisheries, avoidance of algal blooms, etc.)

As a first step, state-of-the-art continuous computerized monitoring of the largest stormsewer inlets and outlets was performed. These were reduced into pollutant loads using FLUX and BATHTUB models to simulate lake water quality.

In order to achieve the desired lake goals, a series of strategies were developed for a multi-pronged campaign including:

- Increasing public awareness
- Managing goose and carp populations
- Phased large-scale projects for stormwater runoff treatment
- Rehabilitation of shorelines
- Improved housekeeping through better street sweeping practices

Figure 14.16 Boat Traffic on Lake Calhoun with Downtown Minneapolis in the Background

- Alum treatments to reduce phosphorus generated by lake sediments
- Increased enforcement and regulatory efforts

Citizen feedback was essential during the design and implementation phase to tailor design to local aesthetic preferences and increase local acceptance.

Implementation

Long-term public education efforts began in 1993 and continue to the present. Through the use of survey and education efforts, the CWP determined that the most successful means of education local residents was through the local neighborhood newspapers. Education efforts targeted homeowner fertilizer and pesticide use.

Physical rehabilitation efforts began in 1995 in the upper watershed reaches of the system and progressed downstream through the chain of lakes to lower areas of the watershed. Three water quality measures were followed: lake transparency, total phosphorus, and concentrations of chlorophyll *a*.

In 1996, Twin Lakes was dredged. Three wet sediment basins and a new wetland treatment for water quality polishing were constructed near Cedar Lake. Significant sediment and nutrient loads were being transported through Twin Lakes and into Cedar Lake. In a small park upstream of Twin Lakes, a 5,808 cubic yard wet volume pond was constructed.

The Cedar Meadows pond, a two-celled wet pond with a total wet volume of 18,069 cubic yards, was constructed across from Cedar Lake. An earthen berm divides the sedimentation cell from a created wetland cell, but problems were encountered with the carp population migrating into the wetland so additional fish screen barrier was put into place.

In 1998, construction of the three-celled Southwest Calhoun ponds (26,781 cubic yards) commenced adjacent to Lake Calhoun. The first cell was a sedimentation pond while cells 2 and 3 were designed to look like wetlands. Significant landscaping including a walkway and observation area and riparian buffer were added to this high-traffic site to make it a park amenity.

Moving downstream, erosion prevention and mitigation measures were implemented on areas of eroded shores in Cedar Lake, Lake of the Isles, Lake Calhoun, and Lake Harriet. Alum treatments were conducted in these same for lakes at different times during the period of 1996-2001. This treatment was followed by the installation of numerous grit chambers, pocket wetlands, and housekeeping changes.

Costs

Funding for the CWP initiatives has come mainly from local partner sources as outlined in Figure 14.17 below.

Results

Over the past 15 years, the CWP initiatives have accomplished approximately $12.4 million in rehabilitation actions. This is believed to be one of the largest urban lake restoration projects in the nation. These efforts have been rewarded by a statistical improvement of the water quality in Lakes Cedar, Harriet, and Calhoun.

Public education campaigns have seen an over 50% reduction in pesticides in stormwater runoff from the contributing watershed. Alum treatments

Figure 14.17 Breakdown of Funding Sources for CWP Initiatives

Partner	Total Cost
Minneapolis Park and Recreation Board	$1,506
City of Minneapolis	$2,638,401
Minnehaha Creek Watershed District	$6,086,497
City of St. Louis Park	$662,730
MPCA Clean Water Partnership Grants (state)	$1,243,980
USEPA Section 319 Grants	$255,000

have locked up the accumulated historical phosphorus in lake sediments and treatment ponds have resulted in the reduction of new phosphorus loading into the system. Stormwater treatment ponds range from a 25% removal rate to a 66% removal rate and measurable changes have been seen in a relatively short period of time.

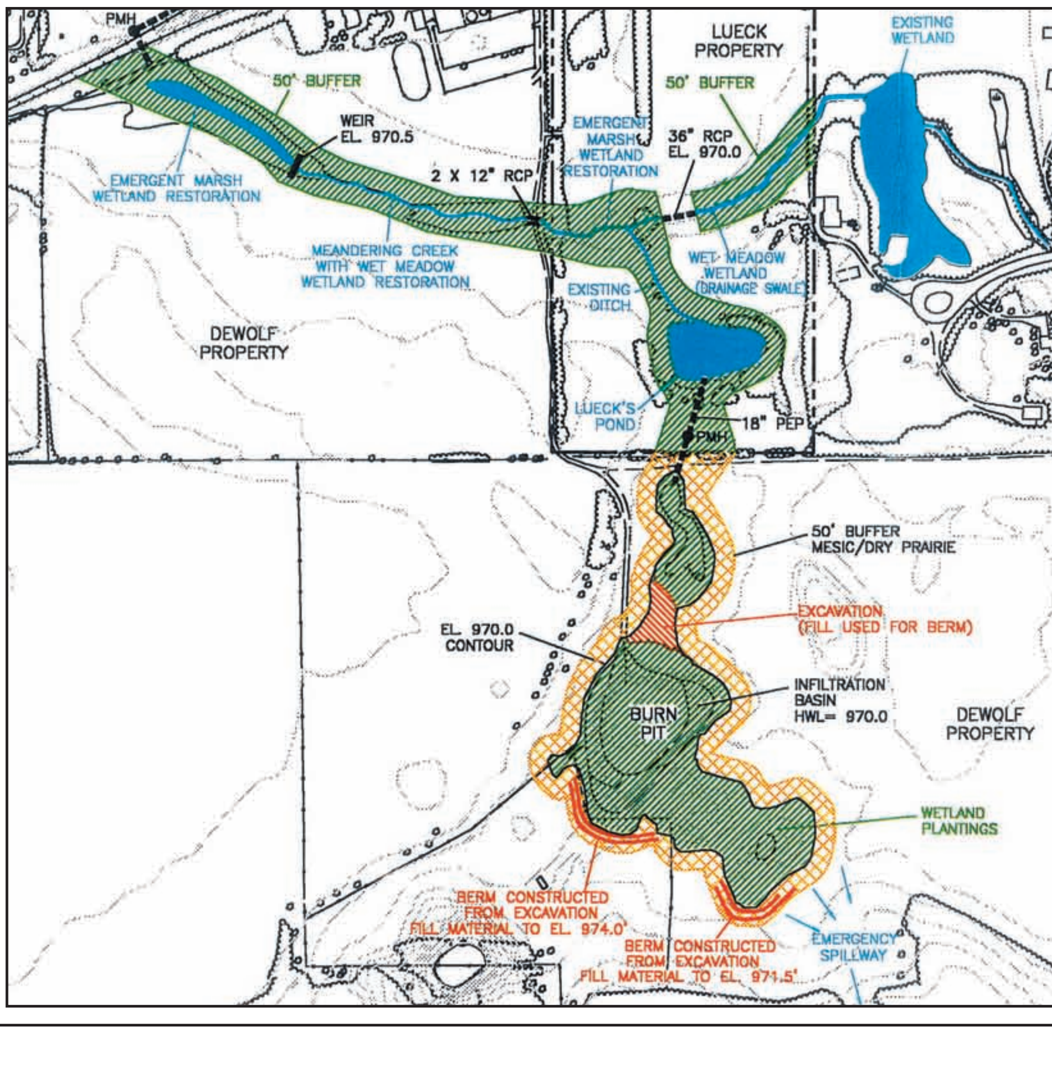
Future Actions

Intensively used resources need substantial resources dedicated to maintaining them each year. They also need to be intensively managed. Continued monitoring, operations, and maintenance to the popular Chain of Lakes will continue well into the future.

VI. Brown's Creek Trout Habitat Preservation Project Case Study: Thermal Protection of a Trout Stream Resource and Infiltration Within Land-Locked Basins

Location: Washington County
Landscape Setting: Rural/Suburban
Drainage area: 2,400 acres
Lake area: 92 acres
Project timeline: 2000-2001
Project cost: $613,230
More information: Cecilio Olivier
Emmons and Olivier Resources, Inc.
(651)770-8448
colivier@eorinc.com

Figure 14.18 Site Overview Map



Issue

Much of the headwater portion of the Brown's Creek Watershed contains land-locked lakes and wetlands. Many of these basins have no direct connection to Brown's Creek. Since the late 1980's the Goggins Lake-School Section Lake basin and several associated wetland basins have experienced high water conditions and had effectively merged to become a single basin. Since 1995, high water conditions have prevailed and flooded several homes, inundated roadways, flooded septic systems and wells in the City of Hugo. Because Goggins Lake had no outlet, lake elevations continued to rise and damage additional property. Providing an outlet to the system had the potential to adversely affect Brown's Creek, a designated trout stream, and its associated headwaters wetlands through thermal impacts, increased erosion and sedimentation.

Background

The goal of the Trout Habitat Preservation Project was to restore a controlled overflow to control lake elevations, while reducing the impact to Brown's Creek, a naturally producing trout stream, and other significant natural resources of the watershed. The Brown's Creek Watershed Management Organization (now the Brown's Creek Watershed District) evaluated the feasibility of installing an outlet control structure on Goggins Lake that would drain, via open ditches, to the headwaters of Brown's Creek.

Standard engineering approaches (e.g., placement of an outlet pipe) did not prove to be suitable as a stand-alone solution to provide outlet control because of potential thermal and water quality/quantity impacts to the Brown's Creek trout fishery. An alternative design approach was necessary to address the trout stream impacts. Since thermal impacts to the trout fisheries of Brown's Creek was one of the primary concerns, the solution emphasized infiltration management to recharge ground water and reduce surface water runoff, while reducing the flooding problems on Goggins Lake.

Implementation

The Trout Habitat Preservation Project included an analysis of historic natural overland drainage routes and the design/implementation of a combined wetland creation-infiltration ground water recharge system. Normal overflow for the lake was determined to be approximately 970.5 feet. Modeling indicated that the 100-year event could bring lake levels up to 971.65 feet and lake levels could rise to 974 feet under extreme high water conditions. An infiltration analysis was completed based on considerable testing of surficial features and included the installation of monitoring wells and soil borings.

To provide an outlet to Goggins Lake, an existing manhole structure was modified at County Road 7. A time and temperature-dependent valve was installed allowing the District an extra level of control when fluctuations in water temperature and rainfall amount could lead to negative impacts to either upstream residents or downstream Brown's Creek. This allows the lake to drain to an elevation of 970.5 feet with a potential low flow discharge to an elevation of 968.7 feet.

The trout fisheries of Brown's Creek were protected and enhanced by minimizing thermal impacts and promoting ground water recharge. This was accomplished through infiltrating and storing stormwater in a series of 3 created wetlands and 3 infiltration basins rather than discharging directly to Brown's Creek. Water from the lake discharges to a constructed wetland south of the lake, which is controlled by an overflow weir at an elevation of 970.5 feet. The wetland encompasses 2 acres and is surrounded by a 25-foot buffer. Outflow from the wetland flows through a second 2-acre constructed wetland drainageway and into a third constructed wetland that will be excavated

Figure 14.19 Outlet from Pond 2

Figure 14.20 Reinforced Vegetated Conveyance

to an elevation of 968.0 feet. When the water surface elevation is less than 970 feet within the third wetland, lake discharge will flow to a small infiltration basin with highly permeable soils (infiltration rate of 1-3 cubic feet per second) located on private property to the south that used to function as a tree burning and disposal area. When the elevation is higher, water will overflow via the weir into a reach of meandering channel, proceed downstream in existing drainageways through a residential development, and outlet into a headwaters wetland of Brown's Creek.

Soft engineering that mimics the natural hydrology of the area was incorporated into the design. Placement of features was done to protect other natural resources of the Brown's Creek Watershed that could be negatively impacted by standard stormwater management practices. Taken as a whole, this provided for an efficient, non-intrusive system that can perform with very little maintenance needed.

Results

Goggins Lake now provides the outlet for the entire Plaisted/Goggins/School Section Lake hydraulic system, a drainage area of about 2,400 acres. Nine acres of wetland were created. The project (and follow up buy-out of one residence) achieved 100% of the goal to eliminate flooding of homes and properties and has addressed 100% of the goal to protect Brown's Creek from fluctuations in the inflow hydrograph and poor water quality (both pollutant concentration and thermal) coming off of the watershed to this lake system.

Costs

Project: $613,230

Ongoing monitoring: $38,775

Future Actions

The Brown's Creek Watershed District has an ongoing monitoring program to ensure that the installed system continues to fulfill the objective of flood relief and natural resource protection. The annual District budget includes moneys for the continuous monitoring of water temperature and elevation at the outlet of Goggins Lake and throughout the system.

Maintaining a healthy stream currently provides an educational tool for the local high school as well. Stillwater High School has partnered with the Washington Conservation District to monitor and study macroinvertebrate populations within Brown's Creek.

The results of this project provides design standards and protocols to outlet stormwater from other land-locked basins in the Brown's Creek Watershed. The results may also be transferable to other similar (same geologic landform) land-locked basins within Washington County and sets the stage for environmentally sound stormwater management in other trout stream watersheds in Minnesota.

Figure 14.21 Infiltration Area

VII. Stormwater Management in Bemidji Case Study: Retrofitting Leads to Proactive Planning

Location: Bemidji
Landscape Setting: Urban
Drainage area: 400,000 acres
Lake area: 6,500 acres
Project timeline: 1989 - present
Project cost: Available Upon Request
More information: Jeff Hrubes
Minnesota Pollution Control Agency
(218) 828-2227
jeff.hrubes@state.mn.us

Issue

Lake Bemidji is a large recreational lake and popular tourist destination for visitors statewide. As such, maintaining the water quality in the lake has important economic ramifications for the region. Outdated stormwater treatment facilities routed stormwater from the City of Bemidji and surrounding areas directly into the lake without treatment, increasing nutrient and sediment levels and threatening water quality. Increasing population and development in the lake's watershed have added other pressures to the lake ecosystem.

Background

Lake Bemidji is a large 6,500-acre mesotrophic lake (a "sensitive lake" under the Chapter 10 definition) located in the Northern Lakes and Forests Ecoregion. The Mississippi River enters Lake Bemidji along the southern shore after flowing through Lake Irving, a shallow 620-acre, eutrophic lake just upstream. Land use within the 400,000-acre watershed is quite diverse with 65% forested, 13 % open water and wetland, 18% pasture and cultivated land and 2% urban residential. Population within the Bemidji city limits has remained relatively steady over the last few years, but there has been substantial population growth in the townships surrounding Bemidji, a trend that is expected to continue.

The Phase I Lake Bemidji Watershed Study was conducted from 1989-1990 and as a result the Lake Bemidji Watershed Management Project (LBWMP) was initiated. The LBWMP is a Clean Water Partnership project with the Minnesota Pollution Control Agency and over 20 other cooperating agencies and groups. The conclusions of the year-long study indicated that water quality in Lake Bemidji was good but nutrient levels, particularly phosphorus, were just below the level where nuisance algae blooms would begin to occur. The Steering Committee for the LBWMP identified seven areas of primary concern within the watershed including urban runoff. Using grant dollars and local contributions, the City looked at retrofitting existing stormwatersheds to provide some level of treatment for phosphorus and sediment and also began adopting stormwater management strategies that were more appropriate for growing areas of the city.

Implementation

Cameron Park Project

One of the centerpieces of the LBWMP was the construction of the Cameron Park Stormwater Control Project. Sediments had formed a delta, which extended nearly 100 feet into the lake, extending from the stormwater outfall located near the popular park. The Park Commission as well as the city council carefully weighed the potential uses of the area proposed for the facility. Recreational open space and public facilities along the shore of Lake Bemidji are at a premium but the decision was ultimately made that long-term protection of the lake required using some of this land for stormwater management. Construction began in August of 1993.

The stormwater control complex consists of a two-chamber wet detention pond system with an energy dissipater at the inlet to the first basin. Stormwater flows through the first basin where larger sand particles settle out. It then flows over an earthen berm spillway into the second basin of the system and through an outlet structure leading to Lake Bemidji. The basins were sized to treat the "first flush", which contains the highest concentration of pollutants and sediments, and fully contain a 24-hour rainstorm of approximately 1.9 inches from the 140-acre subwatershed of Bemidji. Also installed in 1993 was an in-line sediment trap placed on a storm sewer, which drains approximately 40 acres of the downtown Bemidji area.

As mitigation for wetland impacts associated with this project, a restoration/enhancement of a wetland area on the campus of the Bemidji Middle School also had ancillary stormwater benefits. This area treats runoff from the Middle School campus and other upstream areas including an area of commercial development which includes a large retail operation along Paul Bunyan Drive. This project restored wetland functions through installation of water control structure in a ditch draining the wetland and provided a more diverse wetland environment for students.

Tourist Information Center

In 1995, the city of Bemidji installed a stormwater treatment system as an integral part of a reconstruction project at the new Tourist Information Center. This project collects and treats stormwater from 2 subwatersheds, totaling approximately 16 acres of major transportation and commercial land uses that had discharged directly into Lake Bemidji. A combination of techniques was used in the system, which incorporates wet ponding, an aeration fountain which also acts as a visual amenity to the site, and plantings with native vegetation tolerant to stormwater fluctuations.

Comprehensive Planning

In 1996, the City completed an updated comprehensive plan that included stormwater management strategies. These included adopting a policy that required newly developing areas to retain 75% of the runoff from a 10-year storm event on site before any discharge is allowed into the municipal stormwater system. This policy was first implemented when an 80-acre area of retail and commercial development began construction on the west side of the city. In this area, on-site stormwater detention discharge through a conveyance system that runs through a series of three wetland treatment basins constructed on city-owned property before discharging through the Middle School wetland complex and ultimately to Lake Irving.

In 1997 the City of Bemidji installed a set of treatment basins in Diamond Point Park. These basins treat stormwater from 2 subwatersheds of approximately 30 acres and 110 acres respectively. The area available was limited by several factors including the lake, street and surrounding park trees. There was a strong sense that the basins had to be integrated into the park landscape. A large (~1.5 acre) parking lot had its runoff redirected from the stormsewer system to discharge along the edge of the athletic fields.

Stormwater treatment has been integrated into other highway and residential street reconstruction projects around Bemidji, this includes implementation of a stormwater utility for the City. Two transportation projects that were begun in 2000 and 2001 also integrated stormwater management. Runoff from the major transportation corridor along the south shore will direct small event and the first flush of stormwater to a treatment basin constructed along the shore of Lake Irving. A residential street construction project along Lake Bemidji incorporated a proprietary stormwater treatment product into the project.

Public Education

A public education campaign has been an integral part in the City's stormwater management efforts. Information and education about urban runoff has centered around the construction of stormwater facilities by the City. News articles, newsletters and public service announcements have been used to provide a general background to citizens about urban runoff. Presentations have been given to a wide variety of audiences ranging from school children to Bemidji State University students to service clubs and citizen's groups around Bemidji using a tabletop stormwater model. In addition to the general information provided, the LBWMP participated in a project with the Minnesota Extension Service, Minnesota Board of Water and Soil Resources, the City of Bemidji and several Girl Scout troops in the area. In this project, the

Girl Scouts stenciled stormwater inlets to remind citizens that the storm drains led directly to Lakes Irving and Bemidji and talked with homeowners about the effects of urban runoff.

In Cameron Park, in order to utilize the high visibility of the site for educational purposes, signs were installed explaining some of the sources of urban runoff pollution and how this stormwater treatment system is protecting Lake Bemidji. Approximately 30,000 visitors stop in annually at the Tourist Information Center, many of them stroll around the basin that has been planted with native vegetation and landscaped to enhance appearance and attract visitor attention. A series of signs informs visitors to the area about stormwater pollution and the treatment taking place in this basin. Continuing studies and monitoring of the systems are made possible through cooperation with Bemidji State University researchers, local schools and community groups such as 4-H.

Results

Cameron Park Project

Preliminary data indicated that approximately 80-100 cubic yards of material (sediment and other debris) were trapped in the initial basin during the first 2 years of operation. Approximately 3 inches of material were deposited over the bottom of the forebay basin during the first year of operation. This fits well with the initial estimates of sediment clean-out in the forebay at approximately 5-10 year intervals depending on deposition rates. The in-line sediment trap also trapped over 70 cubic yards of sediment within the first 2 years of operation.

Further monitoring of this system took place in 1998 and 1999. Effectiveness was measured in two different ways. In one study, flow volumes into and out of the basin were measured and water quality samples were taken. Total phosphorus and sediment loading rates were calculated from this information. During the monitoring period, there were only three storm events that were large enough to discharge to Lake Bemidji.

Because of the minimal discharge to the lake, the basin retained almost 90% of the phosphorus and over 95% of the sediment load contained in the stormwater. The second monitoring effort looked specifically at phosphorus concentrations during flow-through events, that is, storms large enough to discharge to the lake. Three flow-through events were monitored for total phosphorus concentration during this study. Phosphorus concentrations of the outflow averaged 55% lower than those of the incoming stormwater for these events.

Visitor's Center

Research conducted as a master's thesis by a Bemidji State University student indicated that this basin removes approximately 66% of the total phosphorus contained in the stormwater.

Cost

Available upon request for specific projects.

Future Actions

The city has had very good success in combining its retrofit projects within a larger framework of stormwater management which includes planning and public outreach and education. The city will continue to follow this successful model for future projects.

VIII. State Highway 23 Through Spicer Case Study: Stormwater Management for Linear Projects

Location: Highway 23 through Spicer
Landscape Setting: Highway Right-of-Way
Project Area: 11.5 miles of Highway 23 from north of Willmar to north of New London
Project Timeline: 1995-2005
Project Cost: $37.9 million
More Information: Jim Christensen
Mn/DOT Project Manager
(320) 214-3719
jim.christensen@dot.state.mn.us

Issue:

Green Lake and Nest Lake are economically important recreation areas near the City of Spicer. The expansion of State Highway 23 to a four-lane facility will go through the city of Spicer and the environmentally sensitive Green Lake/ Nest Lake recreational area. Due to economic importance, the highway's proximity to the lakes, the abundance of wetlands in the area, and limited space for stormwater treatment in the highway right-of-way, stormwater management and water quality issues were controversial.

Background:

The City of Spicer lies in an area rich in aquatic resources including many lakes, streams, and wetlands. Tourism based on the natural environment is an important component of the economy of the area. Maintenance or improvement of the water quality to support activities such as

Figure 14.22 Highway 23 Through Spicer

Figure 14.23 Temporary Sedimentation Basin

fishing, swimming, and boating is a high priority. Stormwater runoff and nutrient loading into Green Lake especially was a major issue for this recreationally important feature.

The entire area is experiencing rapid growth. Highway 23, which runs through the city is seeing increased congestion and traffic accidents especially during peak travel weekends and holidays in the summer. In late 1995, the Highway 23 Task Force was formed to promote improvements to the highway corridor. Members felt that a four-lane connection from Willmar to I-94 would improve the capacity and safety of the roadway and foster economic development opportunities in Willmar and the adjacent areas of New London and Spicer. The Minnesota Department of Transportation (Mn/DOT) completed a corridor study in 1997, which identified a need for this four-lane connection from Willmar to New London.

In 1998, a natural resource assessment process began. The location, quality and priority of all wetlands, lakes, and prairie remnants were inventoried and identified which helped to guide the placement of the roadway alignment. Mitigation opportunities were developed by an interagency team including specialists from Mn/DOT, the Department of Natural Resources (DNR), Kandiyohi County, U.S. Fish and Wildlife, and private consultants. Their recommendations focused on opportunities that would enhance the natural resources within the Green Lake drainage area.

The results of a 1998 Scoping Study revealed that the best option would be to expand the roadway on the existing alignment. The Environmental Assessment process was completed in 2000 and detail design and right-of-way acquisition occurred in 2001-2002. Construction on the project began in 2003.

Implementation:

In 2001, a Water Quality Advisory Committee (WQAC) was formed through a joint agreement with Mn/DOT, DNR and the Minnesota Pollution Control Agency (MPCA). Seventeen members representing stakeholders from a variety of agencies, municipalities, and community organizations met 25 times in 2001-2002 to discuss water quality and stormwater management issues. The function of the group was to review Mn/DOTs stormwater management strategy and to reach consensus on how to address water quality and water quantity impacts related to the reconstruction of Trunk Highway 23 through Spicer. Significant water quality impairments existed in the urbanized areas due to stormwater runoff from pollutant discharges into lakes, wetlands and other resource concerns.

The focus of the WQAC was to develop a water quality plan the met the goals of no net increase of nutrients flowing into area lakes and if possible to decrease these nutrient flows. Green Lake, adjacent to the project was widely recognized for its water quality, sport fishery, and recreational importance and was a focus for protection. The activities of the WQAC functioned to assist and advise Mn/DOT's Detail Design Team as they prepared detailed water quality and maintenance plans which would sustain the area's water resources through nutrient and stormwater

Figure 14.24 Filtration System Installation

Figure 14.25 Installation of Grit Chamber

management and also to evaluate options and develop recommendations to be incorporated into the design.

A variety of site-specific strategies for the corridor including settling and retention ponds, vegetated drainage swales, filtration and infiltration systems and sediment traps were ultimately agreed upon. A water quality mitigation plan was developed and finalized in 2002 that treats all stormwater runoff from the highway corridor prior to discharging to receiving water bodies. Mn/DOT District 8 has been pursuing potential wetland restoration opportunities so that the outcome is a high priority and targeted location, not just the closest land available. This strategy worked well to alleviate some of the constraints of identifying suitable mitigation areas within the narrow project right-of way.

The plan provides treatment for all runoff from Highway 23 as well as incorporating several large areas of downtown Spicer that were not previously receiving treatment. It was estimated through water quality modeling that approximately 26 pounds of phosphorus per year was contributed by Highway 23 into Green Lake pre-construction.

Results

Project construction is projected to be completed by the end of 2005. After completion, it will undergo post- construction stabilization and monitoring. With the reconstruction of the highway and redirection of runoff to treatment methods, an anticipated 23% decrease in phosphorus loading into Green Lake (down to 20 pounds per year) is anticipated. The project has met its goal of no net increase and is expected to result in a decrease in nutrient loading due to the treatment provided in previously untreated areas of Spicer.

The formation of a committee of this magnitude was unusual for transportation projects in Minnesota. The structure of the WQAC allowed for technical investigations of issues as they developed, a holistic approach to stormwater management and local stakeholder involvement. The resulting water resources plan was one of the most innovative and encompassing plan packages produced by Mn/DOT and can be used as a model for future local and statewide roadway projects.

Costs

$37.9 million

Future Actions

Post construction monitoring will be conducted in one location within the city of Spicer by Mn/DOT and in two other locations within the city of Spicer by a private consultant through October 2006. These locations were monitored for one year before the project commenced and during project construction.

A minimum of yearly inspections to all components of the stormwater management system will be conducted. Grit chambers will be cleaned out as necessary but at a minimum of twice yearly. Periodic maintenance will be performed on the settling basins and ponding areas to ensure continued proper functioning.

IX. City of Wykoff Case Study: Stormwater Remediation in a Karst Area

Location: Wykoff
Landscape Setting: Rural
Drainage area: Varies
Project timeline: 1998-1999
Project cost: $47,700
More information: **Donna Rasmussen**
Fillmore Soil & Water Conservation District
(507) 765-3878
donna.rasmussen@mn.nacdnet.net

Issue

The City of Wykoff is located in a karst area (underlain with limestone with < 50 feet of unconsolidated material over it). There are a large number of sinkholes in the area. Historically the city used sinkholes as its stormwater receptors, with storm sewers outletting directly into four sinkholes in the center, to the east and to the west of town. The sinkholes directly accessed the ground water in the area and potential for contamination of surface and ground water resources was very high.

Background

The City of Wykoff is located in western Fillmore County. From 1992-1994, the County Geologic Atlas was created by the Minnesota Department of Natural Resources (DNR) and the Minnesota Geological Survey (MGS). This project included several dye tracing studies in the Wykoff area. Studies indicated that dye traveled rapidly through the karst features and emerged through springs which fed the nearby trout streams of Mahoods Creek, Watson Creek and Spring Valley Creek. DNR Waters and U of M Geology Dept. staff did two additional dye traces from stormwater receptor sinkholes to demonstrate the connection between them and the springs on Mahood's Creek and allow for future monitoring.

Implementation

In the late 1990's the city began to move forward with the idea of upgrading their water, sewer, and stormwater systems. The city applied for but did not receive grant funding for a total upgrade of all street and storm sewer systems. A variety of options were considered for addressing stormwater discharge into the sinkholes. Several state and local agencies including the Fillmore SWCD, the City of Wykoff, the Natural Resource Conservation Service (NRCS), the DNR, the Minnesota Pollution Control Agency (MPCA), the Board of Water and Soil Resources (BWSR) and the University of Minnesota all cooperated on

Figure 14.26 Inventoried Sinkholes in the Wykoff Area

various phases of this project, which resulted in four sinkholes being modified.

City funds were available to reconstruct stormsewer and upgrade streets in the western part of town that discharged into a buried sinkhole to the south of town. As part of this reconstruction and upgrade, the system was engineered so that only local surface flow was routed to this sinkhole. Gutter and stormsewer flow were diverted away from this sinkhole and treatment provided elsewhere.

In the east part of town, the Fillmore SWCD received BWSR funding to address the issues in this sinkhole which received approximately 1/3 of the city's stormwater. It was in an area that was frequently used as an illegal dump site for demolition material and other refuse and also received direct runoff from a nearby trucking company, so there was a high possibility for contamination.

First, the dumped material was removed from the site and disposed of properly at a landfill. The sinkhole was then excavated down to the bedrock opening. The sinkhole was sealed by placing layers of progressively smaller rock and filter cloth over the swallow hole. The area was then backfilled and graded allowing for installation of a grassed waterway. Stormwater was redirected across the sinkhole to this grassed waterway and conveyed away from the city. Discharge flow is filtered through the vegetation and dispersed over the area to allow for infiltration. A second sinkhole is located ½ mile away from the sealed sinkhole and may receive some of this redirected water. However, the filtering treatment that the water will receive from overland flow through vegetation will greatly reduce or eliminate pollutant levels entering this second sinkhole. Best Management Practices were applied in the watershed to reduce stormwater runoff contamination before it reached the discharge point. These BMPs included an educational campaign and involvement of civic groups like the local 4-H which did storm drain stenciling.

In the far west part of town, the situation was more complicated and a variety of options were explored. The City received a grant from the DNR to partially cover the design and implementation of the remedial measures. The engineering firm WHKS designed a system to re-route stormwater away from the sinkhole into a swale that flows out of town. However, the sinkhole still received overland flow so some treatment was still necessary.

Figure 14.27 Ground water Flow Patterns in Wykoff Area as Determined by Dye Tracer Studies

To treat this overland flow, the sinkhole was excavated down to the opening in the bedrock. A perforated inlet pipe wrapped with filter cloth was positioned over the bedrock opening with large diameter rock placed around it. The excavation was then backfilled with smaller diameter rock and pea gravel. The pipe was in place to allow water that flowed into the sinkhole to be routed into the bedrock opening after it passed through the rock and filter cloth.

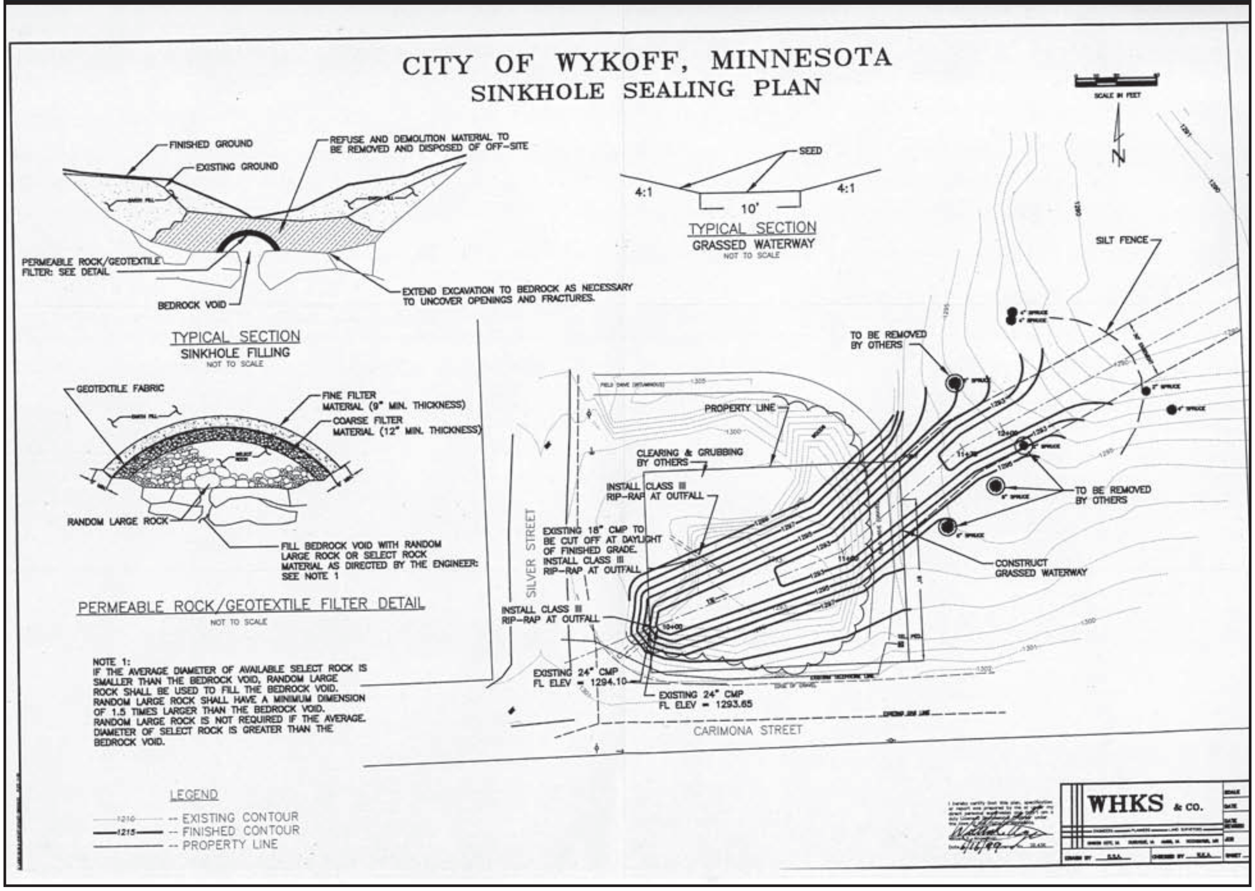
Costs

Total cost for all aspects of the project was approximately $47,700, half of which was born by the city and the other half paid for by a Department of Natural Resources Conservation Partners Grant and a Board of Water Resources grant.

Results

City stormwater discharge was successfully diverted away from the sinkholes or pre-treated before entering the sinkholes. This resulted in a decreased contamination potential to local

Figure 14.28 Sinkhole Sealing Plan



aquifers, private water wells, and surface water bodies fed by ground water springs. The project increased awareness of ground water issues and contamination potential in the city.

Future Work

Water quality monitoring will continue. Trends in water quality will be evaluated and are expected to show signs of improvement. Waterways and sinkhole areas are being monitored to ensure proper maintenance of the waterway and avoid redevelopment of the sinkhole due to ponded water or erosion.

X. Lake Phalen Shoreland Restoration Case Study: Shore Restoration of a High-Use Urban Lake

Location: St. Paul
Landscape Setting: Urban-residential
Drainage area: 23 sq. mi.
Lake area: 200 acres
Project timeline: 2001 - present
Project cost: $350,000
More information: Bill Bartodziej
Ramsey-Washington Metro Watershed District
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Issue

In 2000, 80% of the Phalen lakeshore was in a highly degraded state. Shoreline areas were composed of various blends of rip-rap, invasive weed species, turf grass, and bank slumping that was dangerous in areas and aesthetically unappealing to view. In 2001, the Ramsey-Washington Metro Watershed District, City of St. Paul, Minnesota Department of Natural Resources and other partners began a five-year lake shoreland ecological restoration project. The overall goal was to reintroduce diverse Minnesota native plant shoreland communities in areas that were experiencing moderate to severe erosion due to human disturbance and stormwater inflows into the lake.

Stormwater and Shorelines

Influxes of stormwater into a lake system can cause changes in hydrology and increases in nutrient concentrations that have the ability to increase shoreland erosion, reduce native plant diversity, and favor weedy invasive plants (e.g., reed-canary grass, purple loosestrife, and hybrid cattail) along the shore. To combat erosion, especially in developed watersheds, the standard shore management tool has been the addition of rock – a hard armoring technique. Although this approach is often effective at reducing erosion and slowing soil loss, the downside is that the quality of shore habitats critical for fish and wildlife usually decreases. Numerous government agencies and individual shoreland owners are opting to use native plant communities to stabilize shores instead of the more traditional approaches like rock rip rap and sea walls. The main selling points of ecological restoration are that shoreland habitats and aesthetics are enhanced, natural vegetated buffers have the ability to improve water quality, and in most instances plants are cheaper than rock.

Background

Lake Phalen is a 200-acre urban-residential lake located in a St. Paul city park. It is one of the most popular parks in the Twin Cities metropolitan area, receiving approximately one-half million visits each year. Bike and walking trails encircle the entire lake, fishing is popular from shore and by boat, and it is the only public swimming beach in St. Paul.

Immediately after park acquisition in 1899, wetlands along the shore were filled to create open turf spaces to the water's edge, and a base for roads and pathways. Historical city documents report that "dredge material is used for filling low, marshy land adjacent to the lakeshore, and these now unsightly places are being converted to lawn spaces." These disturbances spurred shore erosion and beginning in 1910, rock rip rap was used as a fix.

In the 1940s, the Phalen watershed began its conversion from agricultural to residential land use. By the late 1990s, over 95% of the watershed was developed. With the change in land use, the frequency and magnitude of flood events have increased on Phalen. In certain drainage areas within the watershed, stormwater is routed directly into the lake. Shorelines are more susceptible during high water events to erosion from wave action. By 2000, this type of erosion was common along numerous shore areas. Bank slumping accelerated by high water periods caused steep drops that created serious hazards to park patrons. Certain pathway segments were also in danger of collapse.

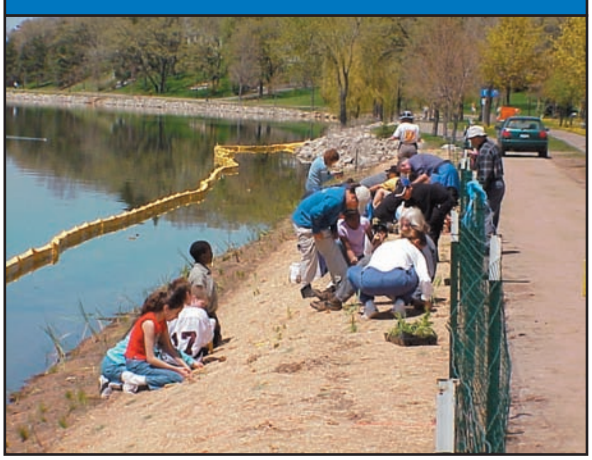
A restoration plan was developed that called for over 1.2 miles of degraded shore to be restored using various methods that rely on native vegetation for shore stabilization. For each shore restoration segment, upland, wetland transitional, and emergent zones were designed.

Implementation

At the start of the project, Watershed District staff approached local schools and described the project as a unique opportunity to teach about water management and ecological restoration in an urban setting. Students learned about lake ecology, shore restoration, and watershed concepts, then had a chance to dig in the dirt and install native plants. Since 2002, civic and school groups have donated approximately 75% of the labor used in this ecological restoration. 1,500 local school students from thirteen schools clocked close to 3,000 volunteer hours, and over 70 adults contributed greater than 500 hours assisting with education efforts and field exercises.

Site factors (e.g., hydrology, wave action, sediment type, slope, human disturbance) influenced the restoration approach and the target plant community types. Also, aesthetics, lake views and access shaped the plant lists. Heavy machinery was used to remove old rip-rap and to recontour the shore slopes in preparation of the plantings.

Figure 14.29 Volunteer Planting on Southeast Shore



A variety of revegetation approaches were tried in the transitional and emergent zones. Along the shore, rock berms and coconut rolls (i.e., biologs) were installed to protect young plantings from wave action. Synthetic and biodegradable erosion control blankets were used along the toe of the slope. A variety of custom grown plant material was used, including prevegetated erosion control blankets (2m x 3.5m), smaller prevegetated blanket mats -- 0.3m x 0.5m (pv-mats), 1-gallon containers, and 4" pots. Time of planting was varied and survival rates monitored. Of the three main community types included in the natural buffers, the emergent zone has presented the most challenge in Lake Phalen. This is due to water level fluctuation from stormwater inputs, wave action, human disturbance, and muskrat. In the transitional and emergent zones, 1-gallon containers and pv-mats had the highest rates of survival. Bulrush (*Scirpus sp.*) had good establishment and expansion via rhizomes when pv-mats were used. In some areas supplemental planting was necessary when a particular planting method showed marginal results. Lake access points – limestone steps down to the water - were incorporated into most restoration segments. This increased safety and also reduced the amount of foot traffic in the natural buffer areas.

Site maintenance along the shore mainly focused on controlling the invasive reed-canary grass (*Phalaris arundinacea*). Young infestations of yellow and white sweet clover (*Melilotus officinalis and Melilotus alba*), bird's foot trefoil (*Lotus corniculatus*), and spotted knapweed (*Centaurea maculosa*) were diligently treated in the upland prairie areas. Prescribed burns were conducted with Watershed District and the City of St. Paul staff in spring 2005. As the shoreland restoration sites matured, maintenance activities substantially dropped.

Results

Five years of activities has resulted in reaching the project goal of restoration of 1.2 miles of shoreland and improvements to riparian habitat and aesthetics. The community has accepted and been very involved in the project. Over eighty

Figure 14.30 South Shore (a) Before Restoration and (b) After Restoration

(a) (b)

native plant species have become established across all three of the planting zones and erosion has been reduced to normal levels. Casual observation has suggested that certain fish and wildlife species are using the restoration areas. For instance, bluegill (*Lepomis macrochirus*) have constructed numerous spawning beds amongst 2-yr old hard-stem bulrush. Leopard frogs (*Rana pipiens*) have colonized a 3-yr old wet meadow transitional zone and are often detected swimming along the water's edge. Surveys prior to the shore restoration project indicated that frogs were extremely rare along the shore. Great blue heron (*Ardea herodias*) and other wading bird species are commonly seen feeding on small fish associated with newly established sedges and bulrushes. Butterflies and bees are now a common sight in the transitional and upland plant communities.

The limestone access areas have become popular stopping points for walkers, fisherman, and for kids that just want to play in the water. Citizens from neighborhoods around the lake are in touch with this exceptional resource by learning about the ecosystem and the restoration project in the classroom, and by assisting with a variety of field exercises. Local newspapers and television news programs have featured this project, highlighting ecological lakeshore restoration as a new approach to combating the longstanding problem of erosion, in part, due to watershed characteristics and stormwater inputs.

Costs

The total cash outlay for the 5-year restoration was close to $350,000, or approximately $50 per linear foot of shoreline. Costs were kept low with generous in-kind contributions from project partners and a substantial input of student volunteer hours. Without these in-kind contributions, it is likely that this restoration would run closer to $100 per linear foot. The traditional approach using rock rip rap to reduce erosion, would cost approximately $150 per linear foot and not address habitat and aesthetic issues.

Future Actions

Long-term monitoring is planned to evaluate the various shoreland restoration techniques used, and to determine maintenance needs. A study to assess vegetation communities of restored shoreland areas is currently being conducted by a University of Minnesota graduate student. Five shoreland segments on Lake Phalen will be quantitatively sampled in the summer of 2005. Results will be compared with other shore restoration sites being evaluated in the Twin Cities metro area. The study will help determine the success of restoration methods, identify maintenance requirements for a variety of shoreland habitats, and determine which suites of native plant species establish well in lake systems with developed watersheds. Watershed District and the City of St. Paul staff and volunteers are committed to maintaining the restored shore segments in order to ensure that

Figure 14.31 West Shore Before Restoration

Figure 14.32 West Shore Excavation

Figure 14.33 West Shore After Restoration

the natural buffers properly establish and remain high quality over time. A certain level of continued maintenance and monitoring are necessary in ecological restorations residing in urban-residential watersheds.

XI. Tanners Lake Case Study: Alum Injection for Phosphorus Removal

Location: Maplewood
Landscape Setting: Suburban
Drainage area: 1,954 acres
Treatment area: 1 acre
Project implementation: 1997
Project cost: $663,000
More information: Cliff Aichinger
Ramsey-Washington Metro Watershed District
(651) 704-2089
cliff@rwmwd.org

Issue

Tanners Lake is located approximately 5 miles east of downtown St. Paul and suffers from common problems associated with urbanization of a lake's watershed: snowmelt and stormwater runoff quantities to the lake have increased; water entering the lake carries nutrients and debris from storm sewers, highways, and parking lots from the surrounding watershed; and algal blooms and the abundance of aquatic vegetation have increased.

Background

Ramsey-Washington Metro Watershed District (RWMWD) has attempted to address the water quality problems of Tanners Lake through District programs and enforcement of policies. In 1987 the District completed a wetland enhancement project immediately upstream from Tanners Lake to treat runoff waters from a large northern subwatershed (G3). However, water quality problems persisted in Tanners Lake despite these efforts. In 1988 the District received a Clean Lakes Program Phase I Diagnostic Study grant to evaluate the lake's problems and determine feasible lake improvement measures. In 1989, a year-long water quality monitoring program of the lake and its inflows and outflows characterized the current lake water quality. Summer water quality parameters including total phosphorus and chlorophyll concentrations and Secchi transparencies indicated that the lake was eutrophic. Mesotrophic status is considered a feasible goal, so it was clear that efforts to improve the lake water quality must focus on reducing the phosphorus load to the lake. Analyses of the lake's inflows and outflows showed that the greatest source of phosphorus for Tanners Lake subwatershed G3, which enters the lake via a small stream on the north end.

Water quality goals for Tanners Lake were established to meet the local desire for water quality improvement and to underscore the local desire for water quality management to improve the water quality of Tanners Lake so that it is consistently suitable for all types of uses. Swimming was the most sensitive recreational use of the lake and complaints of lake users centered on the problem of algal proliferation. Therefore, a reduction of the algal population in the lake was considered a primary goal.

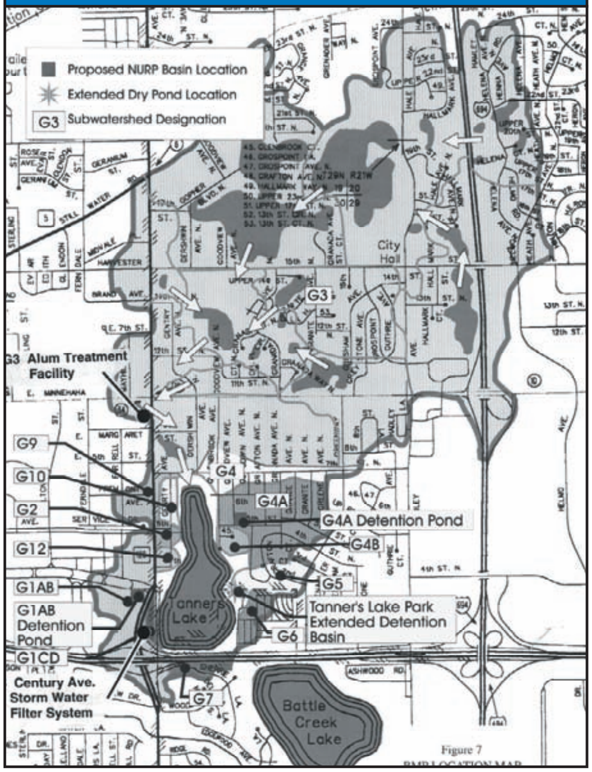
Implementation

The District examined assumptions, effectiveness and costs of various options available to reach the established water quality goals. A variety of best management practices were identified to help achieve or exceed these goals:

- Public Education
- Street Sweeping
- Wet Detention Ponds
- Extended Dry Ponds
- Enhancement of Existing Wetlands
- Chemical Treatment of Stormwater
- Metalimnetic Aeration

Fifteen separate options were identified and evaluated to estimate the range of costs for each option, estimate the removal of nutrients and other pollutants from stormwater, and estimate

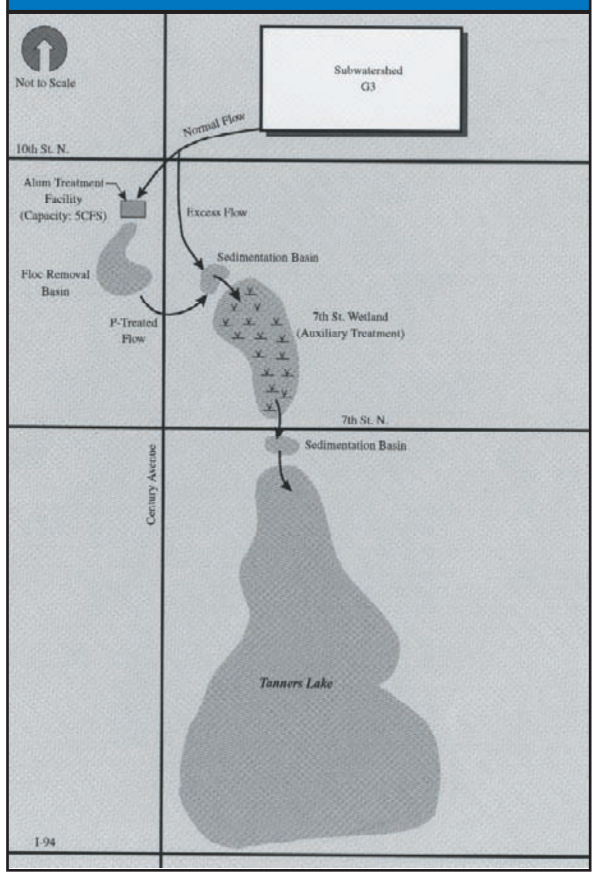
Figure 14.34 Tanners Lake Watershed and Subwatershed Areas



the resulting Secchi disc transparency achieved by implementing each option. Based upon the cost effectiveness analysis, the RWMWD Board of Managers selected an option that included the construction of two detention ponds in subwatersheds G1-AB and G4-A, an extended dry pond in subwatershed G5, and an alum treatment facility, in addition to an education and monitoring campaign.

Although use of alum treatment for water treatment and purification is not a new technology, its application to stormwater management is still a developing technology. The RWMWD application has several unique features: its design to address treatment of base stream flows, storm event flows, and seasonal changes in stormwater temperature and pH; its off-line system design; its thorough bench testing to address dosing for optimal phosphorus removal under various conditions; and, its design to comply with specific dissolved and total aluminum discharge standards. The alum treatment facility was installed to treat inflow from Subwatershed G3 at a location is immediately upstream from the wetland treatment facility. The facility injects the phosphorus-binding chemical, alum, in flow proportional quantities to strip the lake inflow of approximately 90 percent of its phosphorus load. The analysis of storm flow rates during the 1989 diagnostic study indicated that 85% of all the stream flows from subwatershed G3 were less than 5 cfs. All flows less than or equal to 5 cfs are diverted to the alum treatment system, and any flows greater than 5 cfs by-pass the diversion structure and flow directly to the wetland treatment system. A settling basin below the injection point was constructed to provide additional removal of the alum floc generated by the treatment process. The treatment facility design (i.e., off-line and treating only flows less than or equal to 5 cfs) will ensure that treated water has adequate settling time to remove all the alum floc before leaving the basin. The design also prevents basin scouring, which could dislodge settled alum floc. Thus, none of the alum floc will be allowed to enter the lake.

Figure 14.35 Alum Treatment Off-line System Schematic



Costs

The facility is managed by District staff. Operations costs include staff time, alum supplies, routine equipment maintenance, utility charges (phone, electric water), permitting costs, and monitoring. Pond maintenance will also be annualized when a routine management plan is developed. Current annual operation costs are estimated at $30,000 (not including pond maintenance).

Results

The Alum Treatment Facility has been extremely effective at reducing phosphorus loading to Tanners Lake. Figures below show the reductions achieved in past years.

These reductions fluctuate annually depending on climatic conditions (primarily flow rainfall volumes and intensities). Fluctuations have also resulted from changes in dosing rates and operational changes to the plant to improve efficiency and flock formation. Due to the treatment of this large northern subwatershed by the alum facility, the lake has achieved and exceeded our goals for phosphorus and secchi disc readings:

- The operation of the Treatment Facility has led to a 47% Total Phosphorus load reduction to Tanners Lake, in an average year.
- Tanners Lake phosphorus: average summer phosphorus has declined from 0.055 mg/L in 1997 to 0.025 mg/L in 2002
- Tanners Lake response: trend of increased clarity and reduced algal growth since 2000.

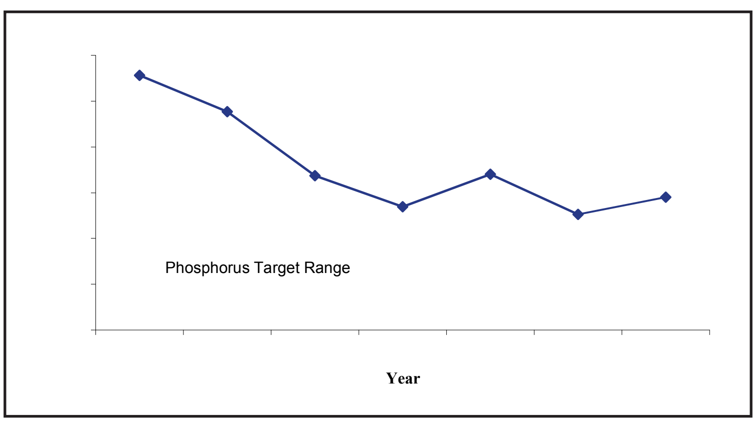
Future Actions

The RWMWD has been continuously monitoring the facility since its completion in 1997. Under the permit issued by the MPCA and the Minnesota DNR, the facility is monitored for inflow volume, inflow and outflow phosphorus and aluminum, and injected alum volumes. This data had been studied and used to improve treatment methods, alum dosage, and plant operations.

The RWMWD has made application and expects to receive its second five-year operations permit from the MPCA in 2005. This permit is expected to require continued monitoring of flows, alum injection volumes, pH levels, inflow and outflow dissolved and total aluminum levels, and inflow and outflow phosphorus. Annual reports will be provided to the MPCA.

An ongoing maintenance issue is the accumulation of alum flock in the facility settling pond. Accumulated flock was removed in the winter of 2003-2004. At that time the suspended flock had filled more than half of the pond volume and was impacting treatment effectiveness and increasing outflow aluminum levels. A flock management plan is being developed to annually remove accumulated flock from the pond bottom.

Figure 14.36 Phosphorus Level Reductions in Tanner's Lake



XII. References

Aplikowski, S., J. Hafner, and B. Wilson. 2005. Minneapolis Chain of Lakes: A decade of Watershed Rehabilitation. Lakeline. Spring 2005.

Barodziej, W. and S. Blood. 2004. Shore Restoration of a High-use Urban Lake.

Busacker, G. 2004. Protecting Water Resources Based on a Collaborative Community Effort. AASHTO National Environmental Stewardship Competition Application.

City of Minneapolis. 2004. City of Minneapolis Heritage Park: Near North Wetlands and Stormwater Management 2005 CIP Budget Documentation (and associated educational flyers).

Emmons and Olivier Resources, Inc. 2004. Trout Habitat Preservation Project (THPP) 2004 MAWD Project and Program of the Year Nomination Form.

Fillmore Soil and Water Conservation District. 1998. City of Wykoff Sinkhole/Stormw Water Discharge Project. MN BWSR FY 99 State Cost Share Special Project Application.

Minnesota Department of Transportation. 2005. Highway 23 Reconstrustion Website. http://www.dot.state.mn.us/d8/projects/23/

Ramsey-Washington Metro Watershed District. 2001. Tanners Lake Water Quality Improvement Project. Project Report.

Stenlund, D. 2005. Meeting Stormwater Discharge Requirements Using Compost Along Silver Cliff Creek Trail, SWPPP Development and Implementation with Compost as a Primary Best Management Practice. Powerpoint Presentation Presented at the 2005 Minnesota Air, Water, and Waste Conference, February 12, 2005.

and Co. 1999. City of Wykoff, Minnesota Sinkhole Sealing Plan.

XIII. Submittals

Thanks to the following for submittals of narrative, images, and conducting reviews of the case studies:

- Burnsville Rain Gardens: Leslie Yetka (City of Burnsville), Kurt Leuthold, Fred Rozumalski, and Diane Hellekson (Barr Engineering)
- Heritage Park: Lois Eberhart (City of Minneapolis)
- University of Minnesota Landscape Arboretum: Peter Olin and Bonnie Ronning (Landscape Arboretum)
- Silver Cilff Creek Trail: Dwayne Stenlund (Mn/DOT)
- Minneapolis Chain of Lakes: Bruce Wilson and Mary Osborne (MPCA)
- Brown's Creek Trout Habitat Preservation Project: Cecilio Olivier, Ryan Flemming, and Kristen Larson (Emmons and Olivier Resources, Inc.)
- Bemidji Stormwater Management: Jeff Hrubes (MPCA) and Chris Parthun (Beltrami SWCD)
- Highway 23 Through Spicer: Paul Rasmussen (Mn/DOT)
- City of Wykoff: Jeff Green (DNR), Donna Rasmussen (Fillmore County SWCD)
- Lake Phalen Restoration: Bill Bartodzieg (Ramsey-Washington Metro Watershed District)
- Tanners Lake Alum Treatment: Cliff Aichinger (Ramsey-Washington Metro Watershed District)

Appendix A

Minnesota Factors

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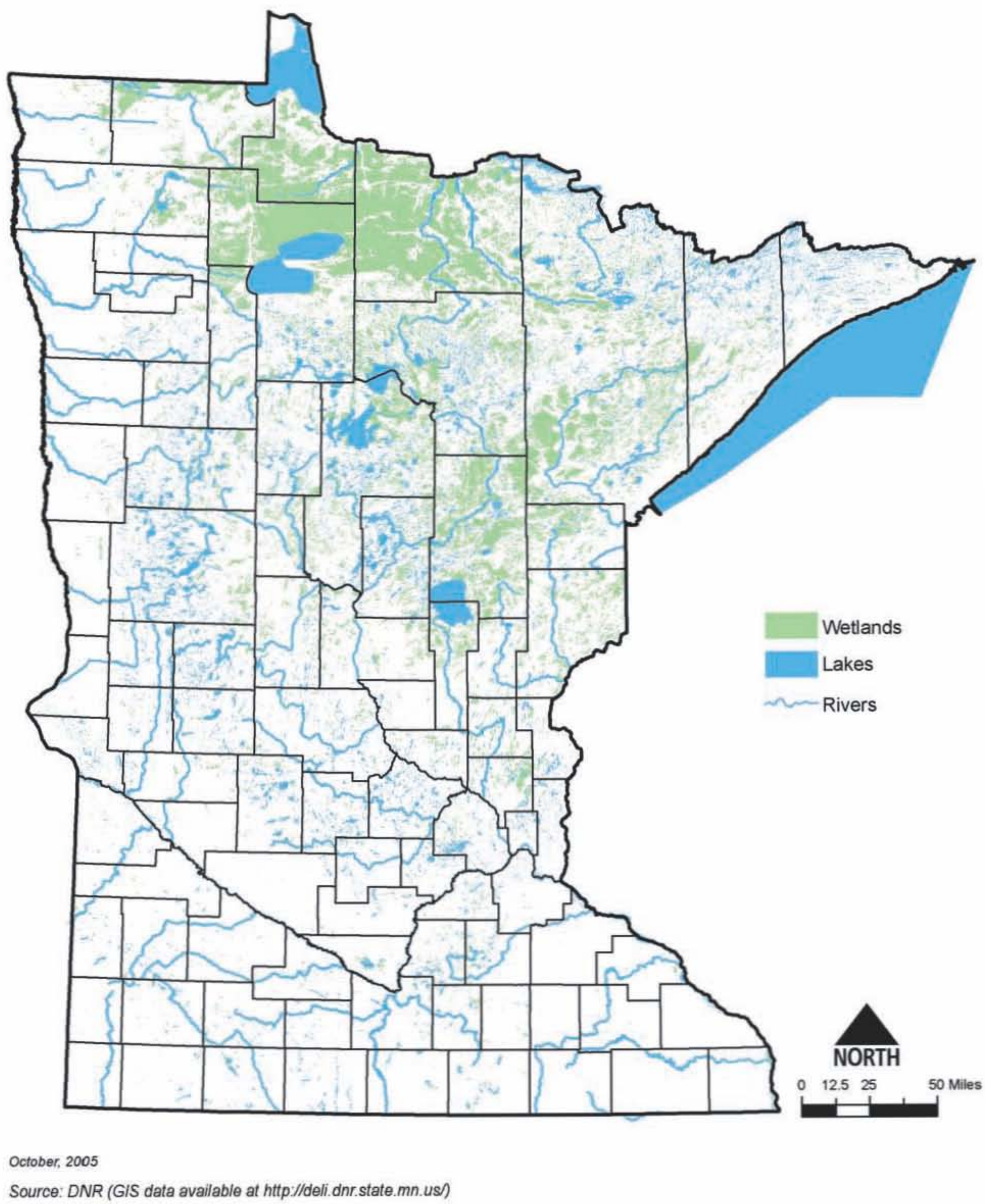
APPENDICES

Appendix A

Minnesota Factors

Contents

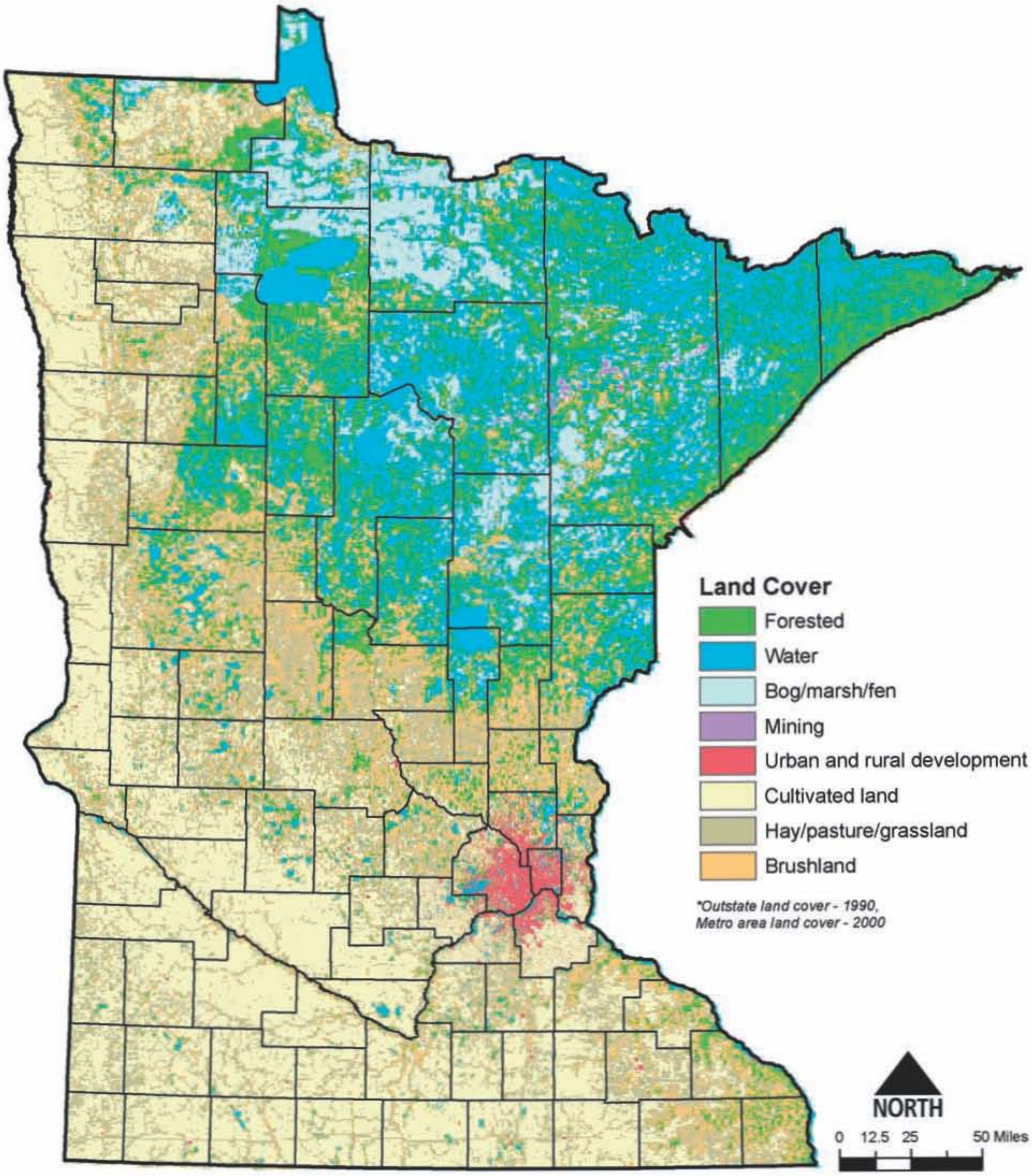
Figure A.1 Water and Wetlands



October, 2005

Source: DNR (GIS data available at http://deli.dnr.state.mn.us/)

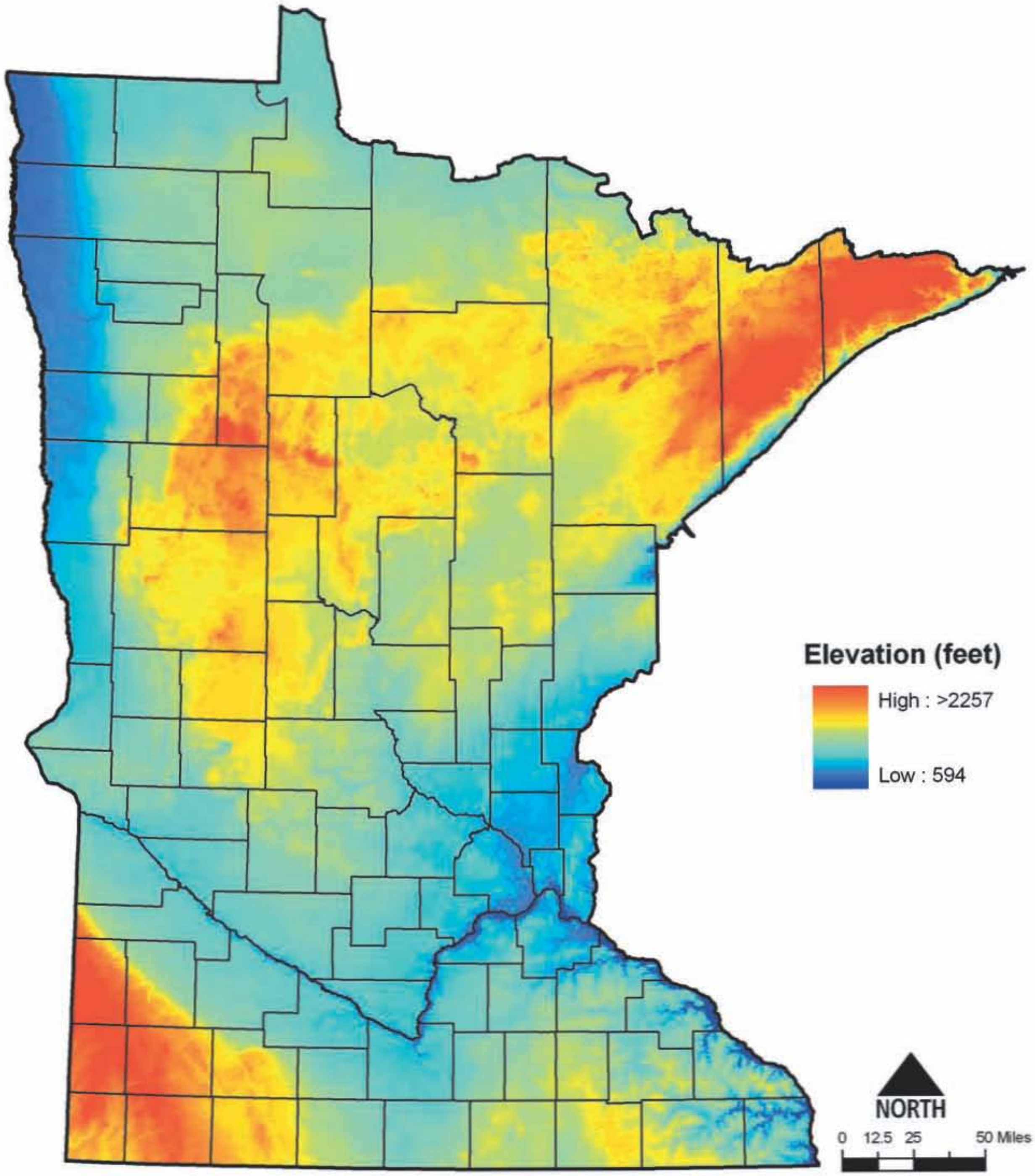
Figure A.2 Existing Land Cover*



October, 2005

Sources: DNR (GIS data available at http://deli.dnr.state.mn.us/), Metropolitan Council (GIS data available at http://www.datafinder.org/)

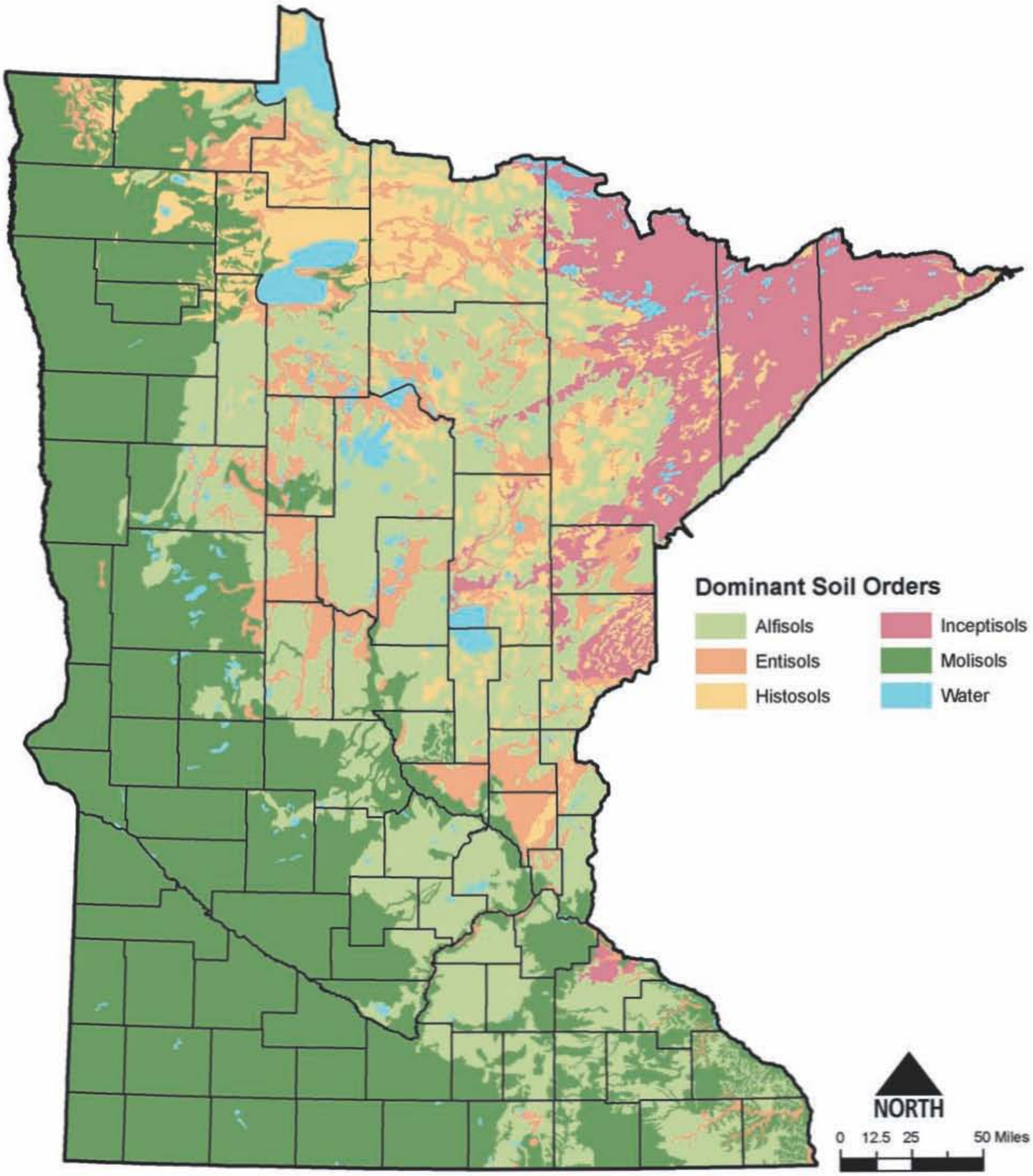
Figure A.3 Elevation



October, 2005

Sources: ESRI (digital elevation model) DNR (GIS data available at http://deli.dnr.state.mn.us)

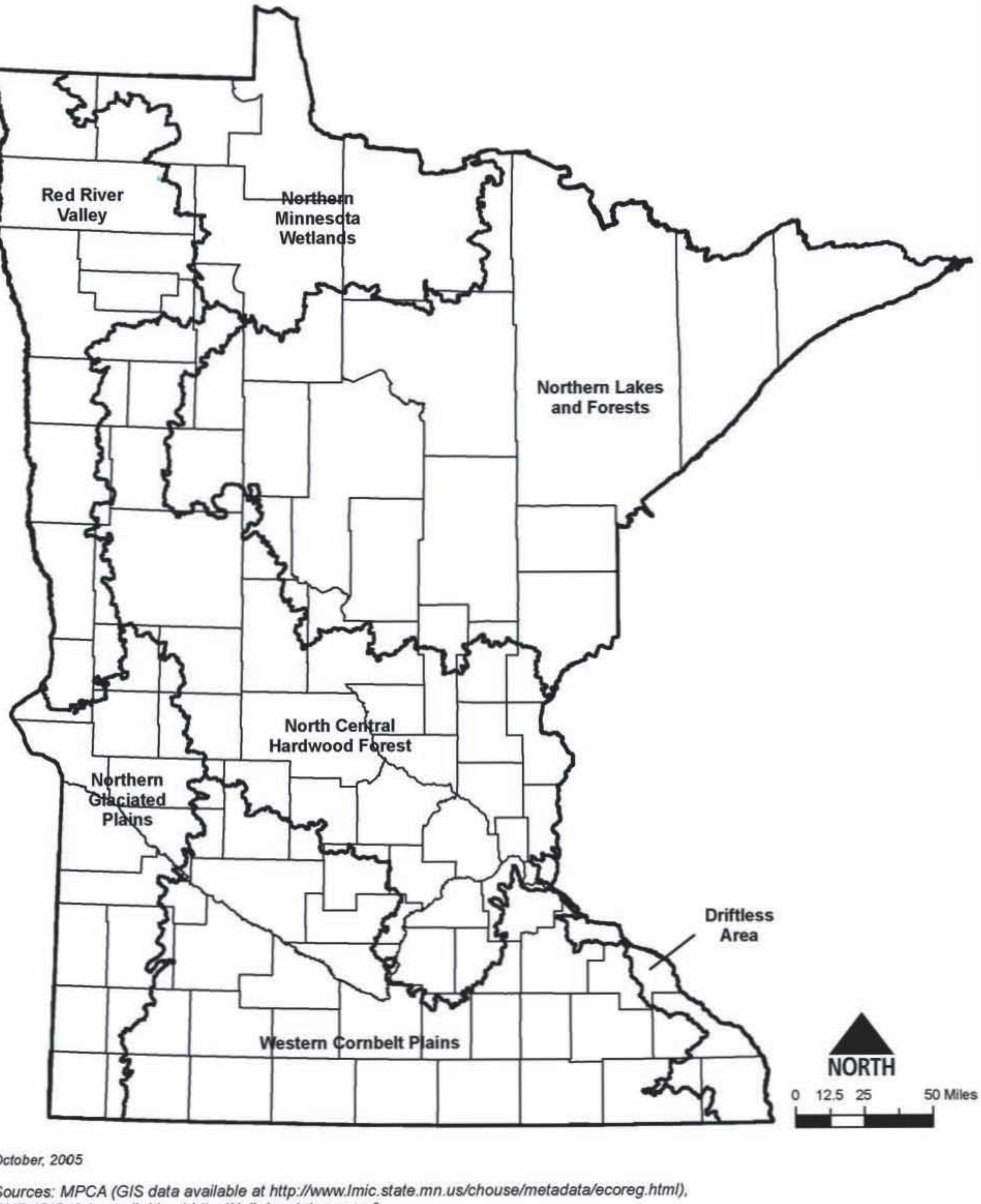
Figure A.4 Soils



October, 2005

Sources: NRCS (GIS data available at http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/data/mn.html), DNR (GIS data available at http://deli.dnr.state.mn.us/)

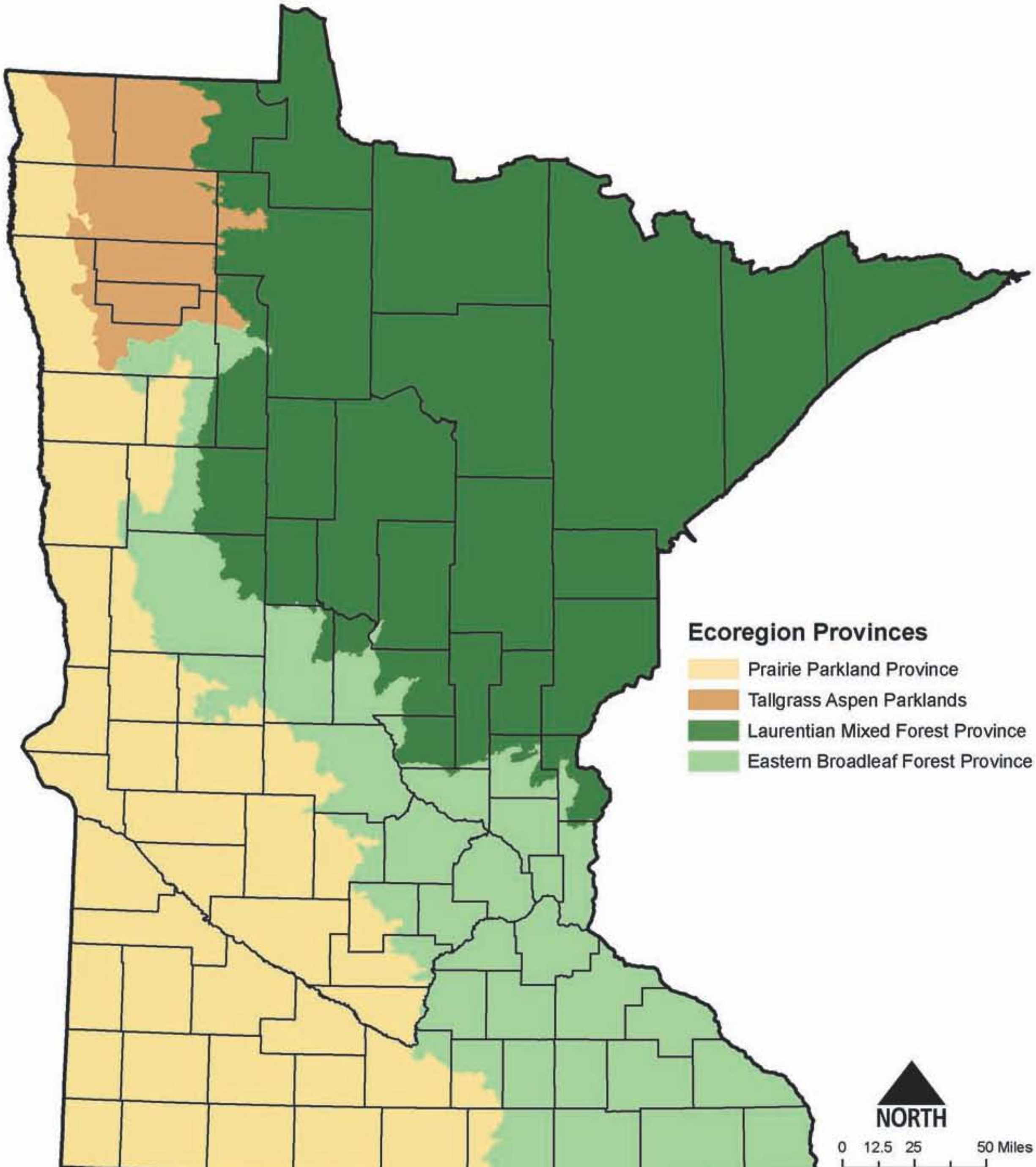
Figure A.5 MPCA Ecoregions



October, 2005

Sources: MPCA (GIS data available at http://www.lmic.state.mn.us/chouse/metadata/ecoreg.html), DNR (GIS data available at http://deli.dnr.state.mn.us/)

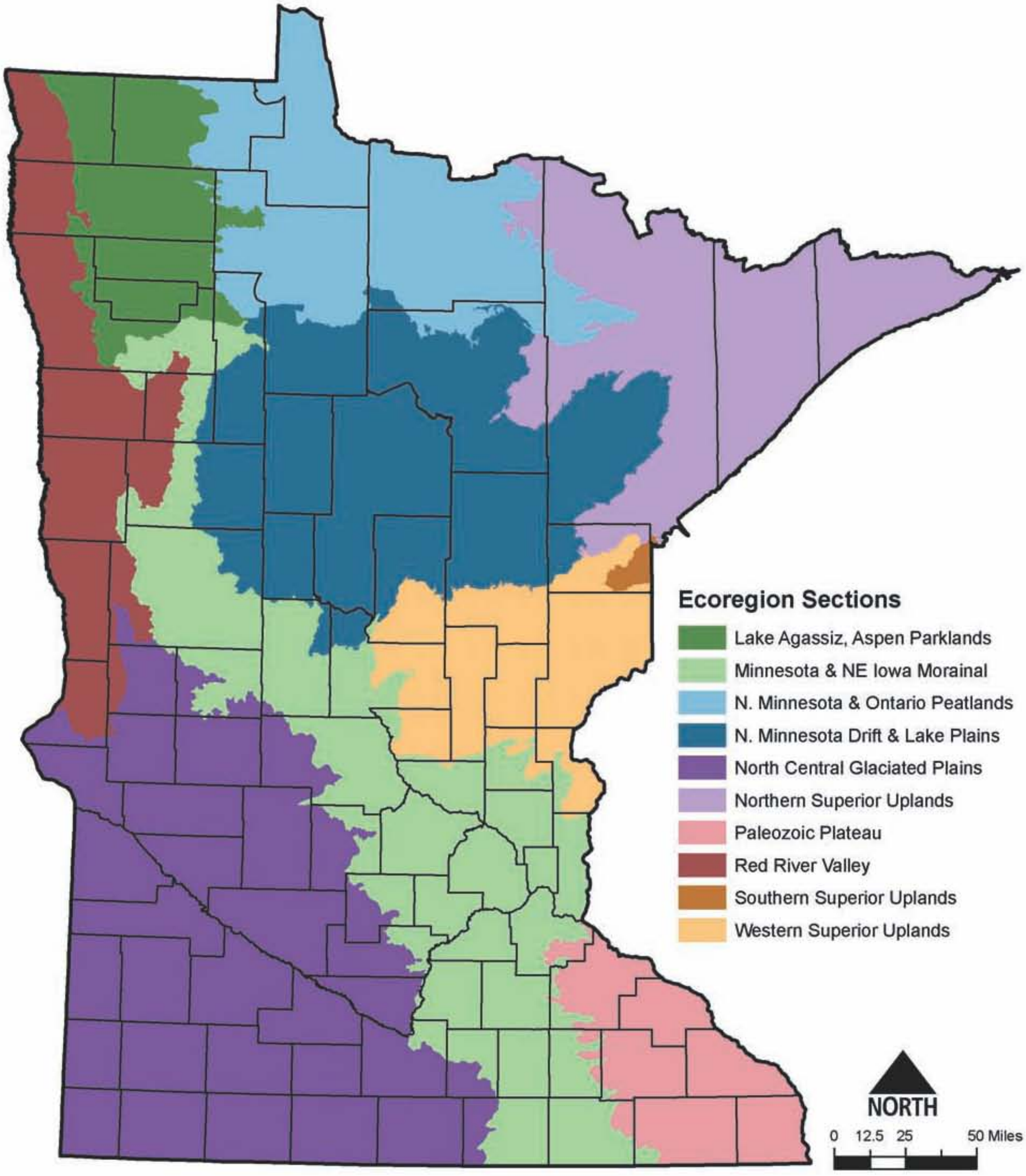
Figure A.6 Ecoregion Provinces (Department of Natural Resources)



October, 2005

Sources: DNR (GIS data available at http://deli.dnr.state.mn.us/)

Figure A.7 Ecoregion Sections (Department of Natural Resources)



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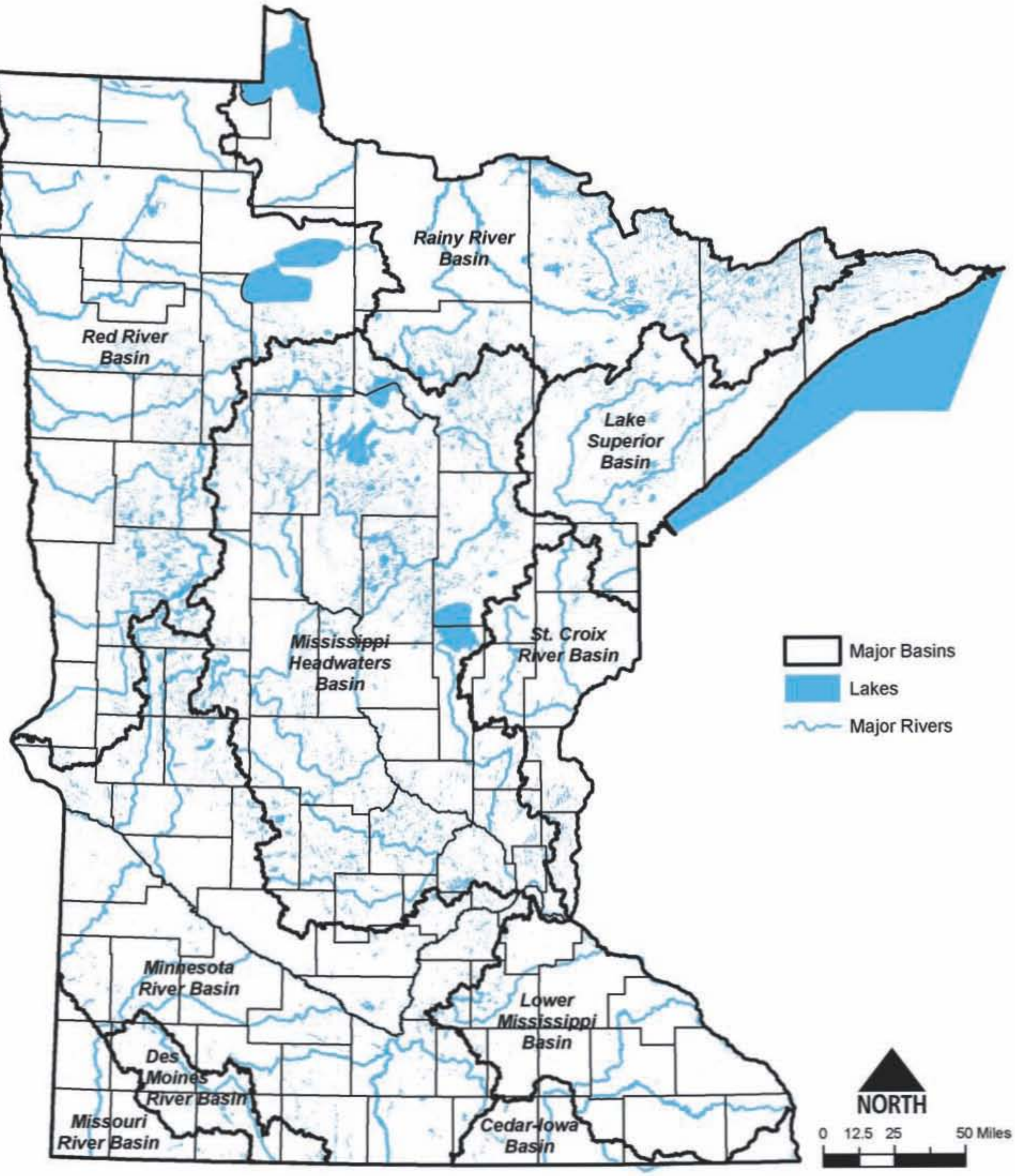
Sources: DNR (GIS data available at http://deli.dnr.state.mn.us/)

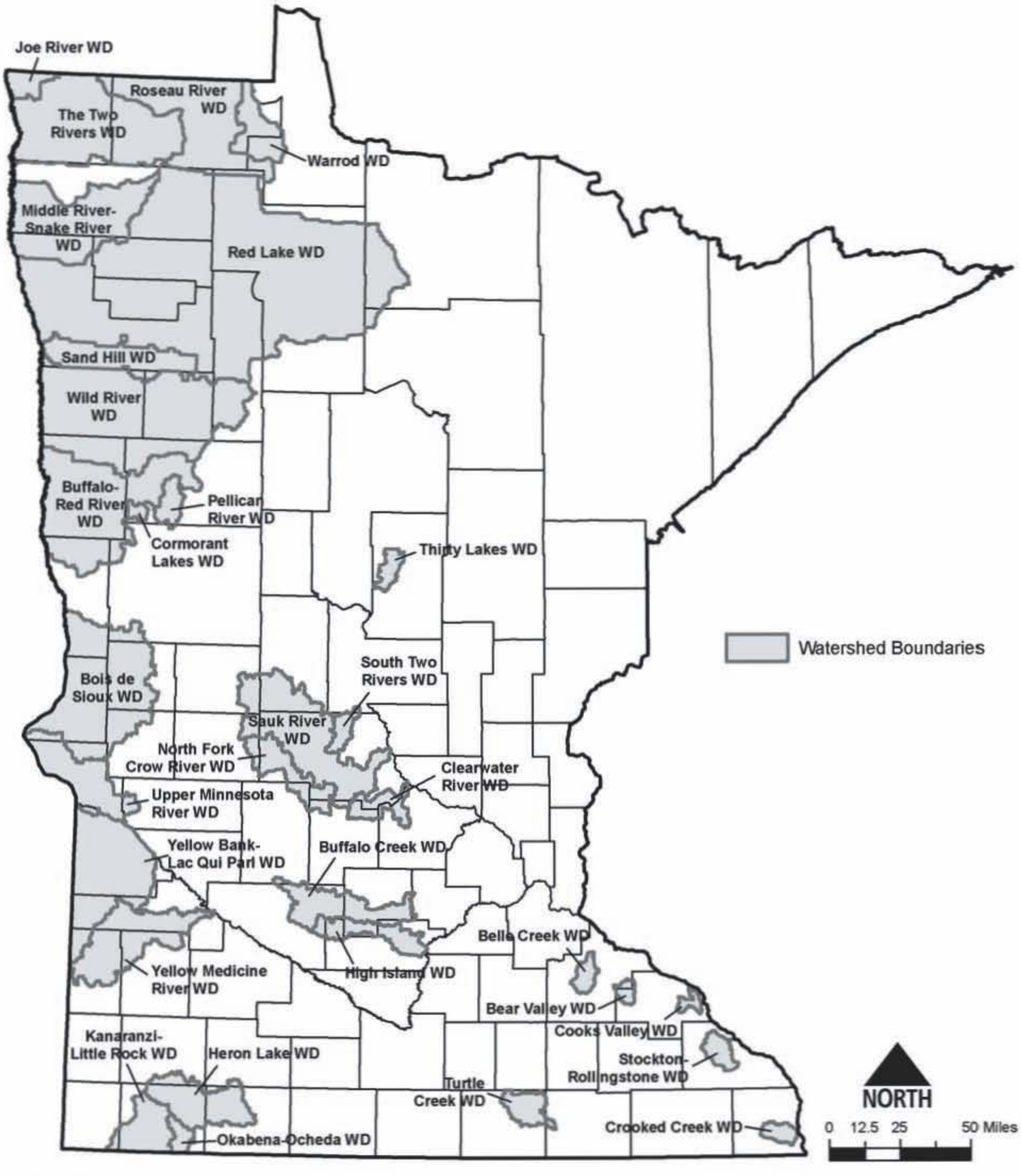
Figure A.8 Major Basins



October, 2005

Sources: DNR (GIS data available at http://deli.dnr.state.mn.us/)

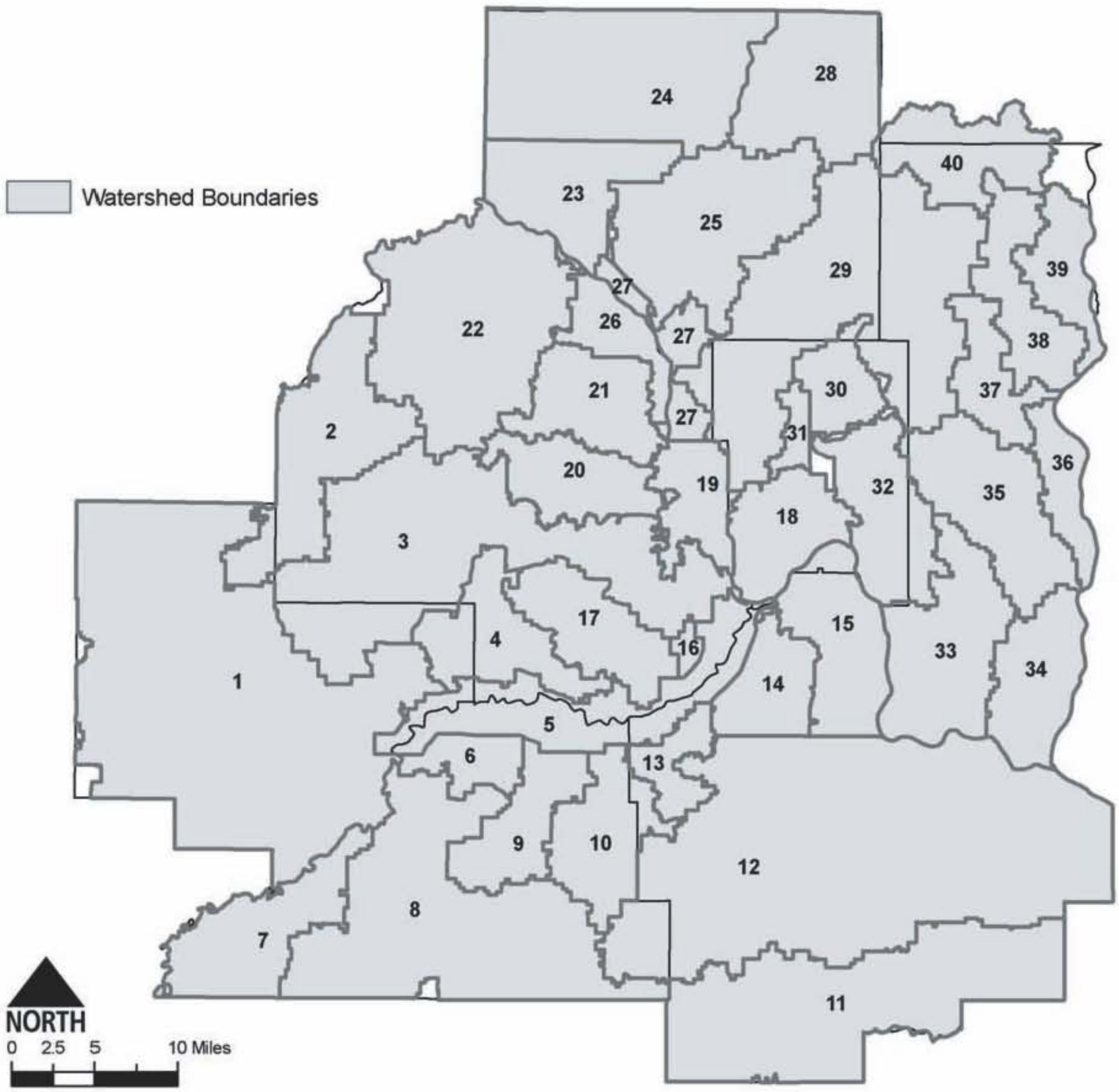
Figure A.9a Watershed Districts (Out-state)



October, 2005

Sources: BWSR, MN DNR (GIS data available at http://deli.dnr.state.mn.us/)
More information on Watershed Districts and Watershed Management Organiations is available at http://www.mnwatershed.org/

Figure A.9b Watershed Districts and Watershed Management Organizations (7 County Metro Area)

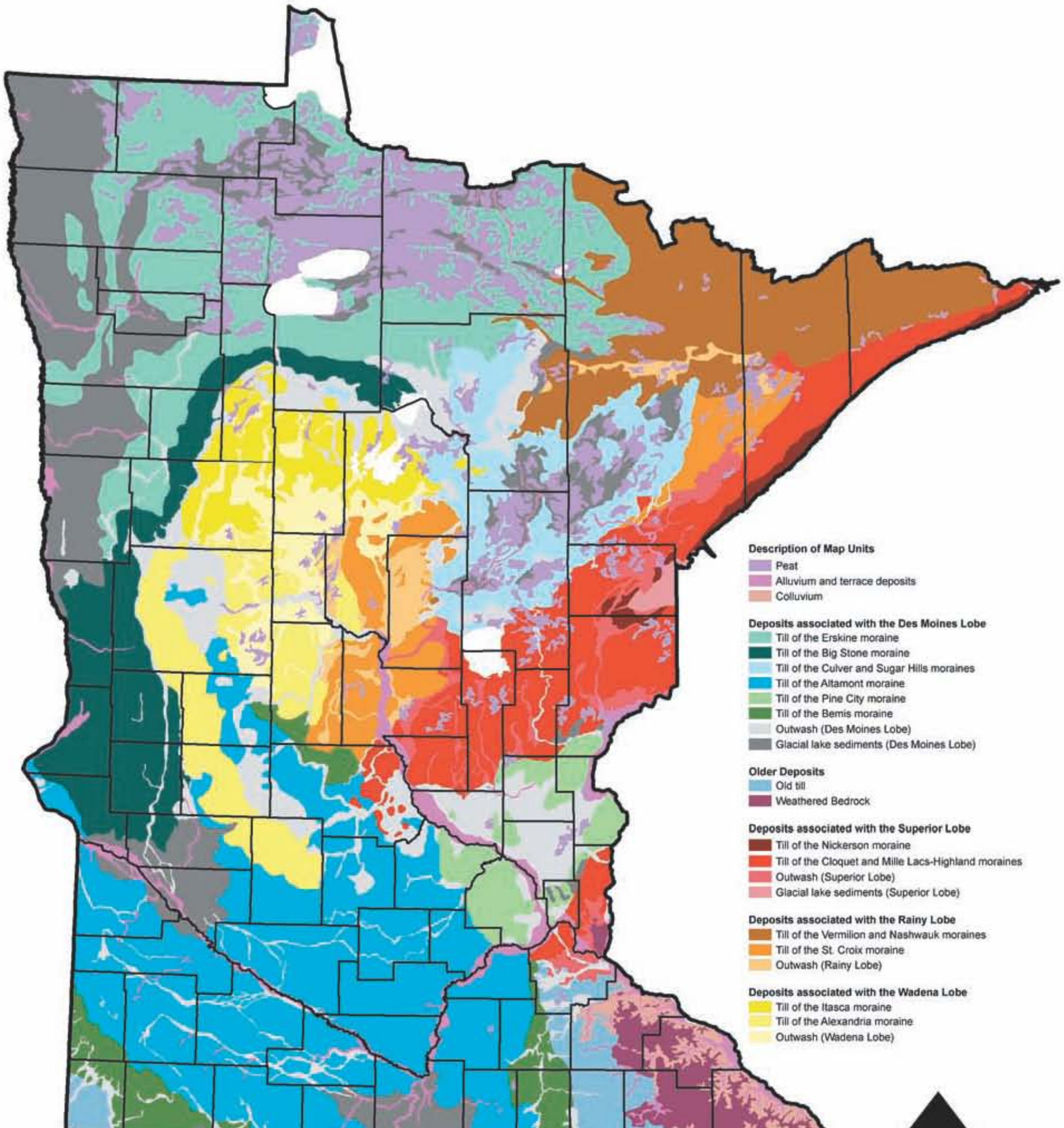


1 = Carver County Watershed Authority
2 = Pioneer-Sarah Creek
3 = Minnehaha Creek WD
4 = Riley-Purgatory-Bluff Creek WD
5 = Lower Minnesota River WD
6 = Shakopee Basin (Scott County)
7 = Southwest (Scott County)
8 = Sand Creek (Scott County)
9 = Prior Lake-Spring Lake WD
10 = Credit River (Scott County)
11 = North Cannon River WMO
12 = Vermillion River (Dakota County)
13 = Black Dog Lake WMO
14 = Gun club Lake WMO
15 = Lower Mississippi River WMO
16 = Richfield-Bloomington WMO
17 = Nine Mile Creek WD
18 = Capitol Region WD
19 = Mississippi River WMO
20 = Bassett Creek WMO
21 = Shingle Creek WMO
22 = Elm Creek WMO
23 = Lower Rum River WMO
24 = Upper Rum River WMO
25 = Coon Creek WD
26 = West Mississippi River WMO
27 = Six Cities WMO
28 = Sunrise River WMO
29 = Rice Creek WD
30 = Vadnais Lake Area WMO
31 = Grass Lake WMO
32 = Ramsey-Washington-Metro WD
33 = South Washington WD
34 = Lower St. Croix WMO
35 = Valley Branch WD
36 = Middle St. Croix WMO
37 = Browns Creek WMO
38 = Carnelian Marine WD
39 = Marine on St. Croix WMO
40 = Forest Lake-Comfort Lake WD

October, 2005

Sources: BWSR, DNR (lakes, major rivers, state outline, county boundaries; GIS data available at http://deli.dnr.state.mn.us/)
More information on Watershed Districts and Watershed Management Organiations is available at http://www.mnwatershed.org/

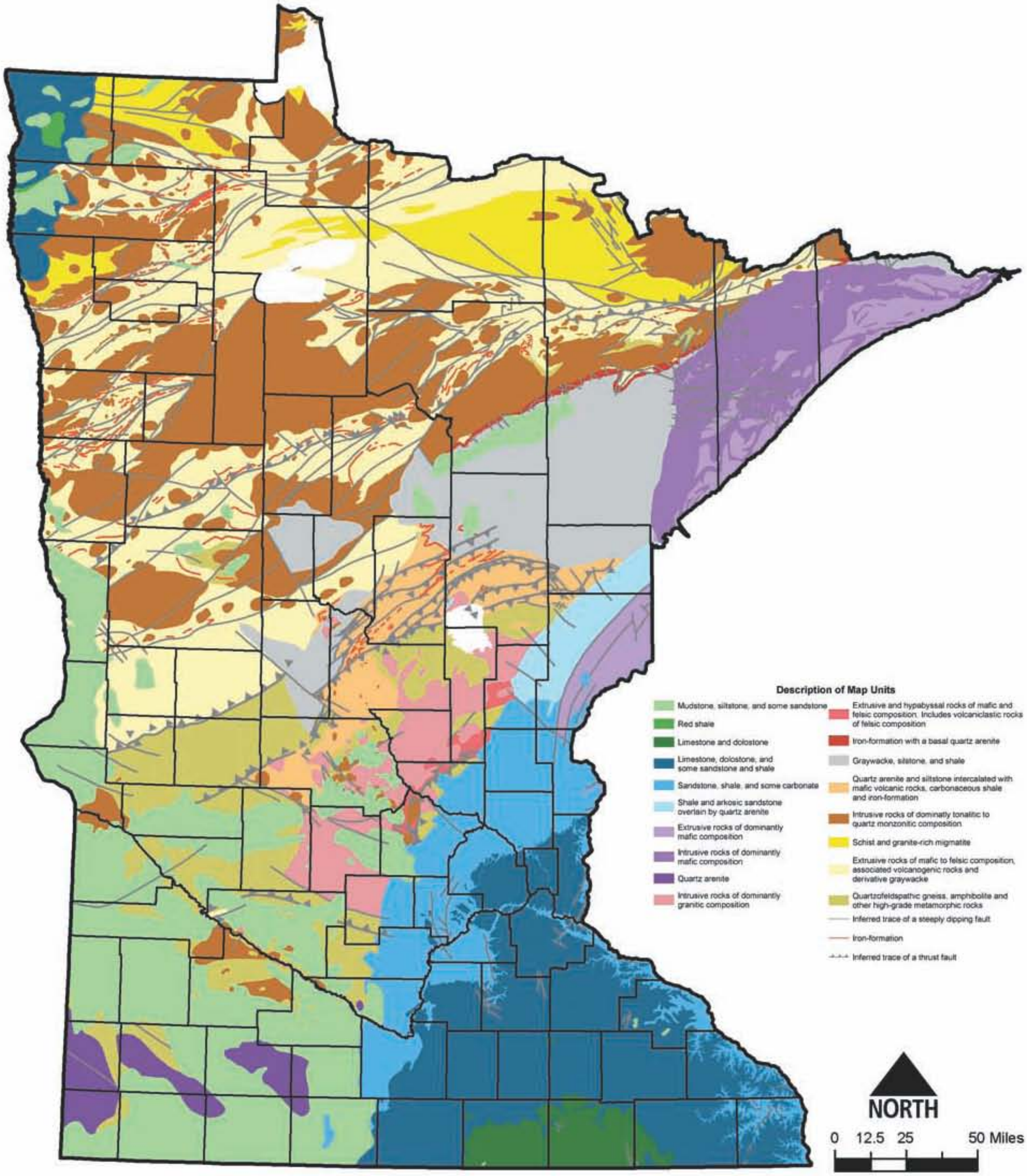
Figure A.10 Surficial Geology



October, 2005

Sources: MGS (Surficial Geology. This map is modified from Hobbs, H.C., and Goebel, J.E., 1982, Geologic map of Minnesota, Quaternary geology. Compilation by B.A. Lusardisurficial geology; GIS data available at http://www.geo.umn.edu/mgs/currentpubs.htm#anonftp), DNR (GIS data available at http://deli.dnr.state.mn.us/)

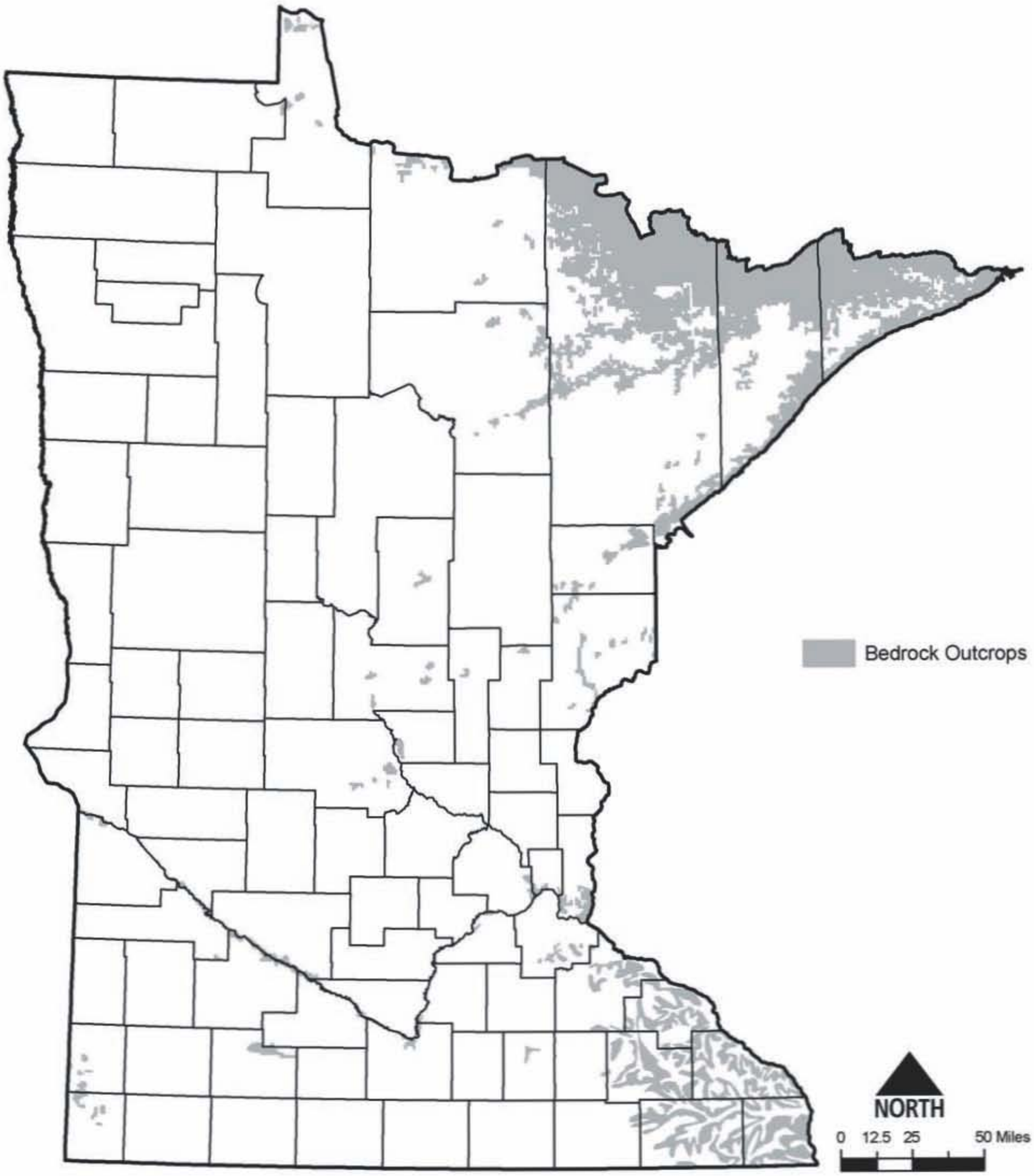
Figure A.11 Bedrock Geology



October, 2005

Sources: MGS (bedrock geology modified from G.B. Morey and Joyce Meints, 2000, compilation by R.G. Tipping and B.A. Lusardi; GIS data available at http://www.geo.umn.edu/mgs/currentpubs.htm#anonftp), DNR (GIS data available at http://deli.dnr.state.mn.us/)

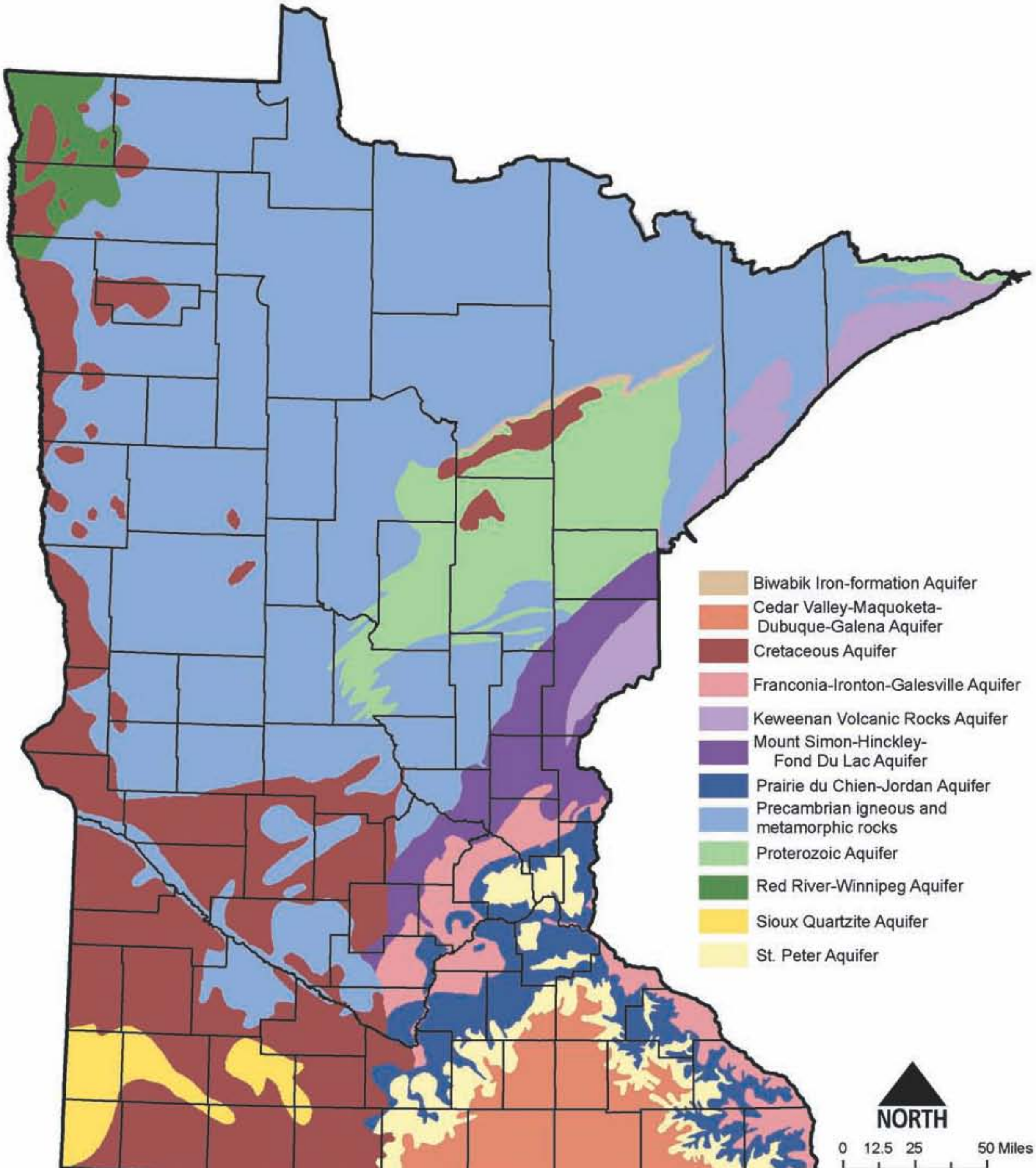
Figure A.12 Bedrock Outcrops



October, 2005

Sources: MGS (GIS data available at http://www.geo.umn.edu/mgs/currentpubs.htm#anonftp), DNR (GIS data available at http://deli.dnr.state.mn.us/)

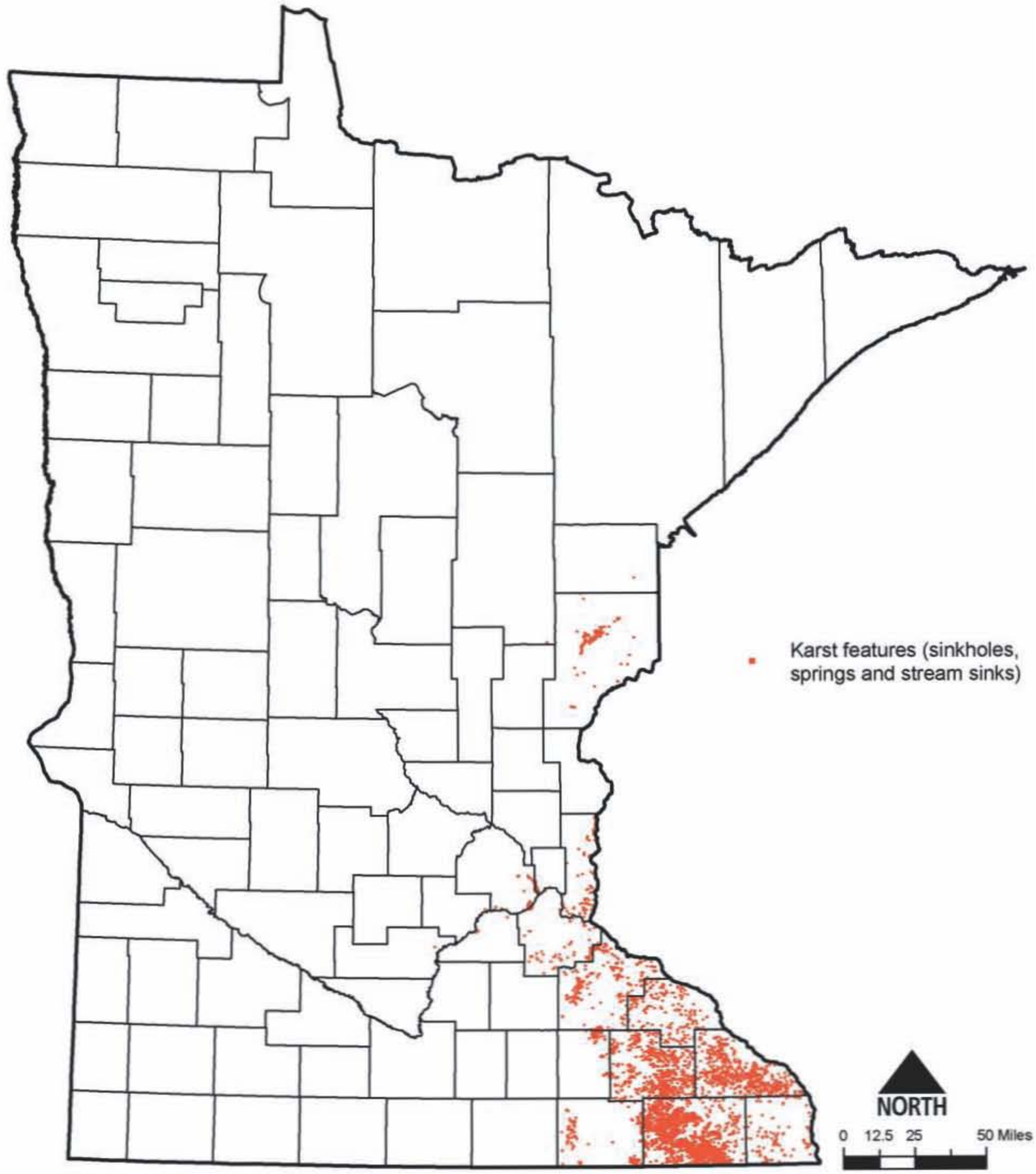
Figure A.13 Major Aquifers



October, 2005

Sources: MGS (major aquifers from Minnesota's Bedrock Hydrogeology by Roman Kanivetsky, 1979; GIS data available at http://www.lmic.state.mn.us/chouse/metadata/hydqgeo.html), DNR (GIS data available at http://deli.dnr.state.mn.us/)

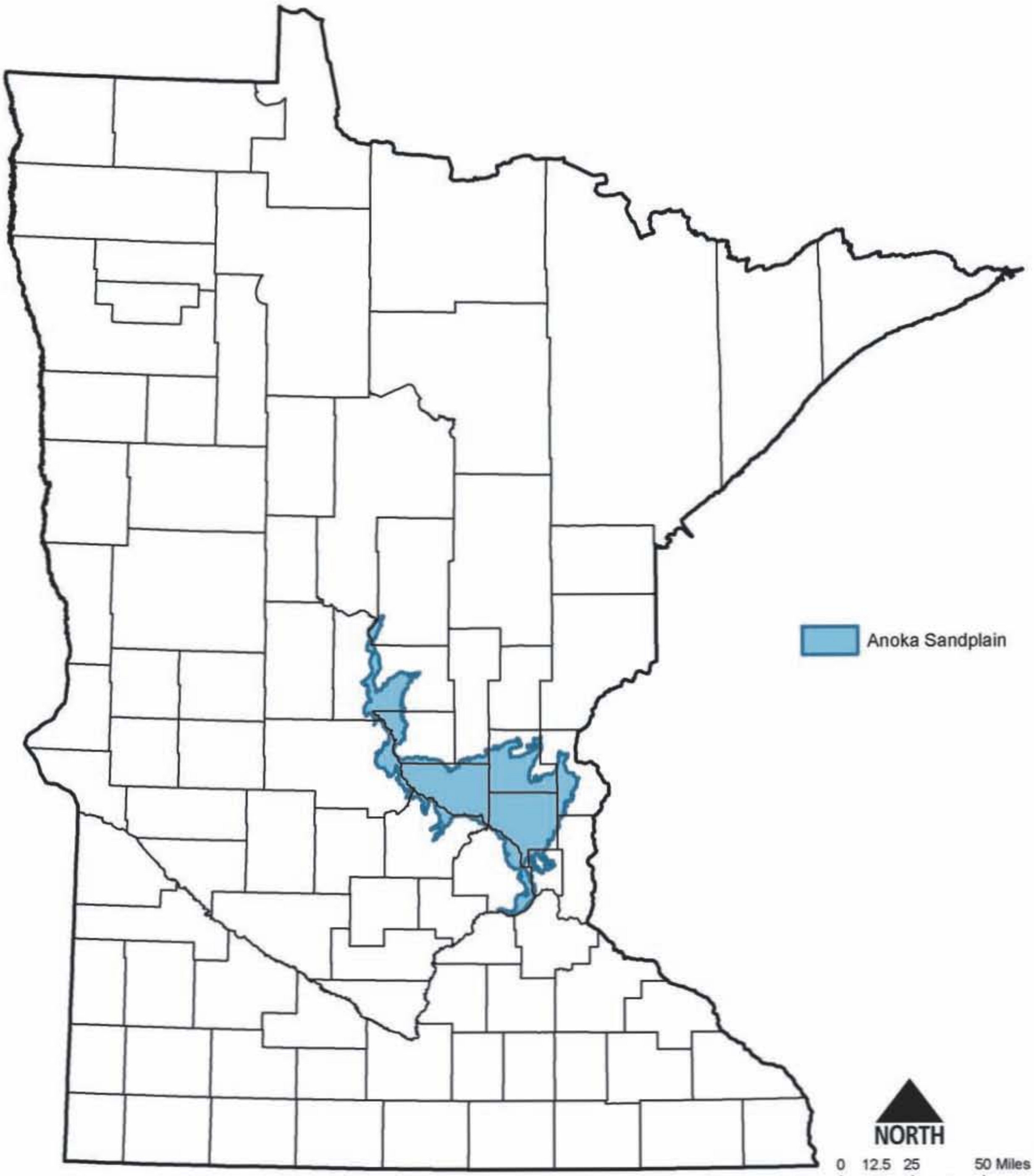
Figure A.14 Known Karst Features



October, 2005

Sources: MGS (GIS data available at http://www.geo.umn.edu/mgs/currentpubs.htm#anonftp), DNR (GIS data available at http://deli.dnr.state.mn.us/)

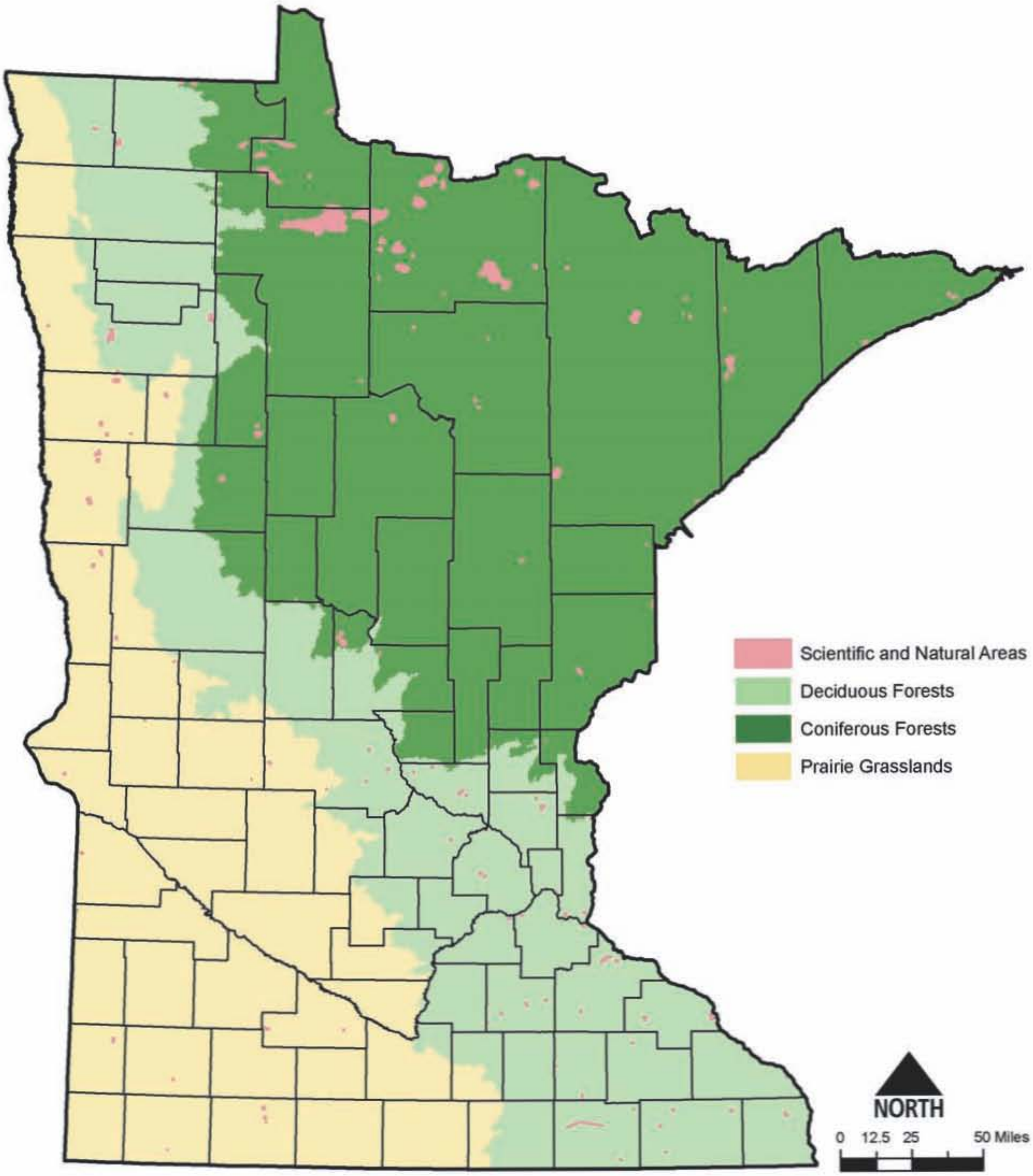
Figure A.15 Anoka Sandplain



October, 2005

Sources: DNR (GIS data available at http://deli.dnr.state.mn.us/)

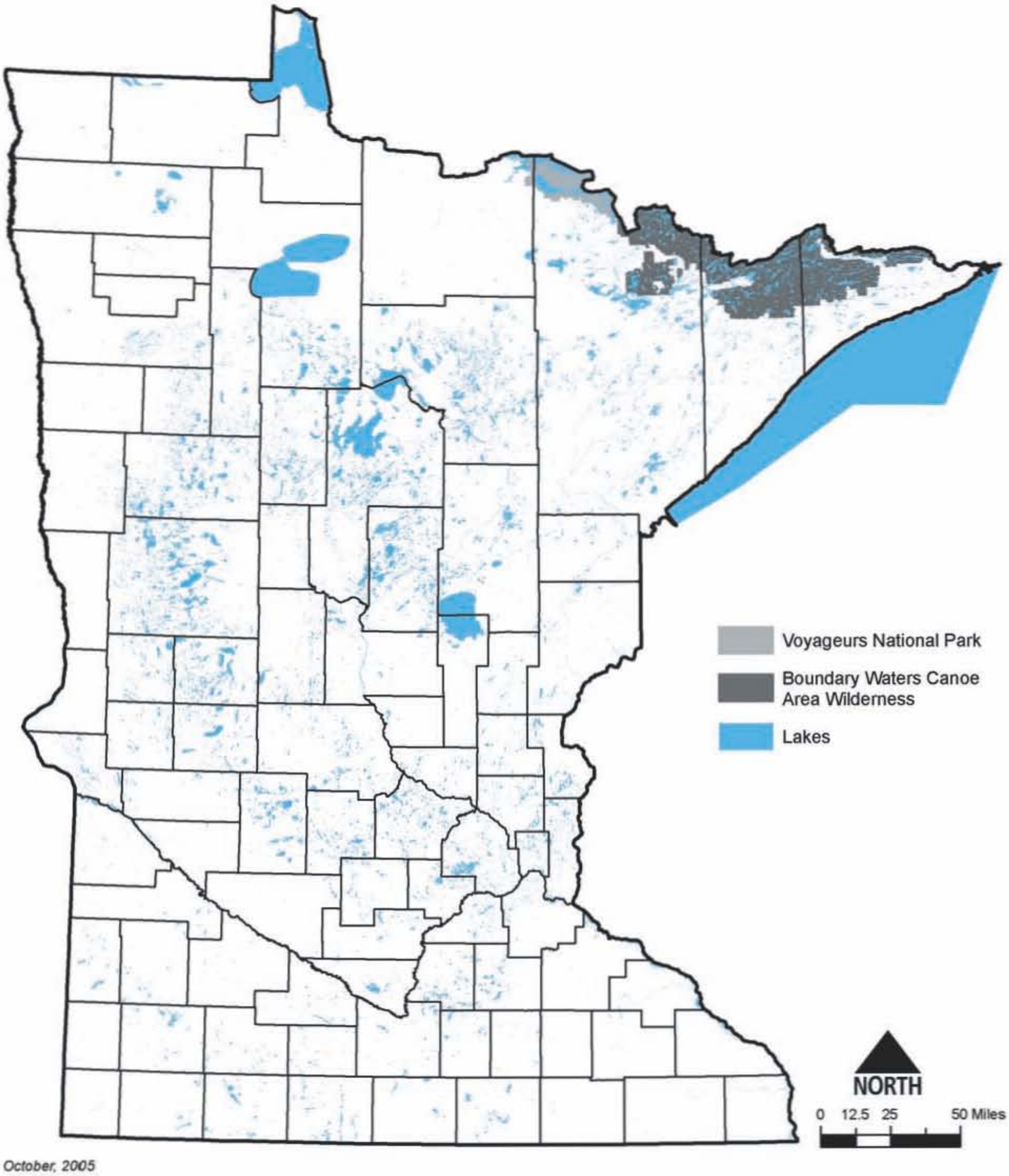
Figure A.16 Scientific and Natural Areas



October, 2005

Sources: DNR (GIS data available at http://deli.dnr.state.mn.us/)
More information on Scientific and Natural Areas is available at http://www.dnr.state.mn.us/snas/index.html

Figure A17. National Parks and Wilderness Areas



October, 2005

Sources: DNR (GIS data available at http://deli.dnr.state.mn.us/)
More information on Voyageurs National Park is available at http://www.nps.gov/voya/
More information on the BWCAW is available at http://www.bwcaw.org/

Appendix B

Selection of Appropriate Computer Models

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APPENDICES

Appendix B

Selection of Appropriate Computer Models

Contents

I. Hydrologic Models

Rational Method

The rational method is a simple calculation of peak flow based on drainage area, rainfall intensity, and a non-dimensional runoff coefficient. The peak flow is calculated as the rainfall intensity in inches per hour multiplied by the runoff coefficient and the drainage area in acres. The peak flow, *Q*, is calculated in cfs as $Q = CiA$ where *C* is the runoff coefficient, *i* is the rainfall intensity, and *A* is the drainage area. The conversion factor of 1.008 is necessary to convert acre-inches per hour to cfs, but this is typically not used. This method is best used only for simple approximations of peak flow from small watersheds.

HEC-1

HEC-1 is a rainfall-runoff model developed by the U.S. Army Corps of Engineers. HEC-1 is a single storm event, lumped parameter model that includes several options for modeling rainfall, losses, unit hydrographs, and stream routing. The model is designed to simulate the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components. Each component models an aspect of the precipitation-runoff process within a portion of the basin. A component may represent a surface runoff entity, a stream channel, or a reservoir. Representation of a component requires a set of parameters which specify the particular characteristics of the component and mathematical relations which describe the physical processes. The result of the modeling process is the computation of stream flow hydrographs at the desired locations in the river basin. The upgraded version of this model is HEC-HMS.

The HEC-1 program is available to the public and can be downloaded from the U.S. Army Corps of Engineers Web site at: http://www.hec.usace.army.mil/software/legacysoftware/hec1/hec1-download.htm.

HEC-HMS

HEC-HMS is a rainfall-runoff model developed by the U.S. Army Corps of Engineers to compute runoff hydrographs for a network of watersheds. The model evaluates infiltration losses, transforms precipitation into runoff hydrographs, and routes hydrographs through open channel routing. A variety of calculation methods can be selected including SCS curve number or Green and Ampt infiltration, Clark, Snyder or SCS unit hydrograph methods, and Muskingum, Puls, or lag routing methods. Precipitation inputs can be evaluated using a number of historical or synthetic methods and one evapotranspiration method.

The HEC-HMS program is available to the public and can be downloaded from the U.S. Army Corps of Engineers Web site at: http://www.hec.usace.army.mil/software/hec-hms/hechms-download.html

TR-20

Technical Release No. 20 (TR-20): Computer Program for Project Formulation Hydrology was developed by the hydrology branch of the U.S.D.A. Soil Conservation Service in 1964. TR-20 is a single-event rainfall-runoff model that is typically used with a design storm for rainfall input. There is no provision for recovery of initial abstraction or infiltration during periods of no rainfall within an event. The program computes runoff hydrographs, routes flows through channel reaches and reservoirs, and combines hydrographs at confluences of the watershed stream system. Runoff hydrographs are computed using the SCS runoff equation and the SCS dimensionless unit hydrograph. A rainfall-runoff analysis can be performed on as many as 200 subwatersheds or reaches and 99 structures in any one continuous run. TR-20 does not provide for losses of runoff in the transmission of the flood hydrograph due to seepage or other causes of flood water loss.

TR-20 is currently being re-written by the Natural Resources Conservation Service (NRCS). The revised program, Win TR-20, will have a windows-base input editor. A Beta Test version is available on the NRCS Web site: http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr20.html

Win TR-55

Technical Release 55 (TR-55): Urban Hydrology for Small Watersheds was developed by the U.S.D.A. Soil Conservation Service, now the Natural

Resources Conservation Service (NRCS), in 1975 as a simplified procedure to calculate storm runoff volume, peak rate of discharge, hydrographs and storage volumes. In 1998, Technical Release 55 and the computer software were revised to what is now called WinTR-55. The changes in this revised version of TR-55 include: upgraded source code to Visual Basic, changed philosophy of data input, development of a Windows interface and output post-processor, enhanced hydrograph-generation capability of the software and flood routing hydrographs through stream reaches and reservoirs.

WinTR-55 is a single-event rainfall-runoff small watershed hydrologic model. The model is an input/output interface which runs WinTR-20 in the background to generate, route and add hydrographs. The WinTR-55 generates hydrographs from both urban and agricultural areas at selected points along the stream system. Hydrographs are routed downstream through channels and/or reservoirs. Multiple sub-areas can be modeled within the watershed. A rainfall-runoff analysis can be performed on up to ten sub-areas and up to ten reaches. The total drainage area modeled can not exceed 25 square miles.

WinTR-55 is available on the NRCS Web site: http://www.wcc.nrcs.usda.gov/hydro/hydro-tools-models-wintr55.html

II. Hydraulic Models

HEC-RAS

HEC-RAS is a river hydraulics model developed by the U.S. Army Corps of Engineers to compute one-dimensional water surface profiles for steady or unsteady flow. Computation of steady flow water surface profiles is intended for flood plain studies and floodway encroachment evaluations. HEC-RAS uses the solution of the one-dimensional energy equation with energy losses evaluated for friction and contraction and expansion losses in order to compute water surface profiles. In areas with rapidly varied water surface profiles, HEC-RAS uses the solution of the momentum equation. Unsteady flow simulation can evaluate subcritical flow regimes as well as mixed flow regimes including supercritical, hydraulic jumps, and draw downs. Sediment transport calculation capability will be added in future versions of the model.

The HEC-RAS program is available to the public and can be downloaded from the U.S. Army Corps of Engineers Web site at: http://www.hec.usace.army.mil/software/hec-ras/hecras-download.html

HEC-2

HEC-2 is a rainfall-runoff model developed by the U.S. Army Corps of Engineers to compute steady-state water surface elevation profiles in natural and constructed channels. HEC-2 uses the standard step method for water surface profile calculations assuming that flow is one-dimensional, gradually varied steady flow. Subcritical and supercritical flow profiles may be evaluated. The water surface profile through structures such as bridges, culverts, weirs and other types of structures can be computed. The upgraded version of this model is HEC-RAS.

The HEC-2 program is available to the public and can be downloaded from the U.S. Army Corps of Engineers Web site at: http://www.hec.usace.army.mil/software/legacysoftware/hec1/hec1-download.htm.

WSPRO

WSPRO is a model for water surface profile computations developed by the U.S. Geological Survey. The model evaluates one-dimensional water surface profiles for systems with gradually-varied, steady flow. The open channel calculations are conducted using backwater techniques and energy balancing methods. Single opening bridges use the orifice flow equation and flow through culverts is computed using a regression equation at the inlet and an energy balance at the outlet.

The WSPRO program is available to the public and can be downloaded from the U.S. Geological Survey Web site at: http://water.usgs.gov/software/wspro.html

CULVERTMASTER

CulvertMaster is a hydraulic analysis program for culvert design. The model uses the U.S. Federal Highway Administration Hydraulic Design of Highway Culverts methodology to provide estimates for headwater elevation, hydraulic grade lines, discharge, and culvert sizing. Rainfall and watershed analysis using the SCS Method or Rational Method can be incorporated if the peak flow rate is not known.

CulvertMaster is a proprietary model that can be obtained from Haestad Methods, Bentley Systems, Inc. http://www.haestad.com/software/culvertmaster/

FLOWMASTER

FlowMaster is a hydraulic analysis program used for the design and analysis of open channels, pressure pipes, inlets, gutters, weirs, and orifices. Mannings, Hasen-Williams, Kutter, Darcy-Weisbach, or Colebrook-White equations are used in the calculations.

FlowMaster is a proprietary model that can be obtained from Haestad Methods, Bentley Systems, Inc.http://www.haestad.com/software/flowmaster/

III. Combined Hydraulic and Hydrologic Models

HydroCAD

HydroCAD is a computer aided design program for modeling the hydrology and hydraulics of stormwater runoff. Runoff hydrographs are computed using the SCS runoff equation and the SCS dimensionless unit hydrograph. For the hydrologic computations, there is no provision for recovery of initial abstraction or infiltration during periods of no rainfall within an event. The program computes runoff hydrographs, routes flows through channel reaches and reservoirs, and combines hydrographs at confluences of the watershed stream system. HydroCAD has the ability to simulate backwater conditions by allowing the user to define the backwater elevation prior to simulating a rainfall event.

HydroCAD is a proprietary model and can be obtained from HydroCAD Software Solutions LLC. http://www.hydrocad.net/

PondPack

PondPack is a program for modeling and design of the hydrology and hydraulics of stormwater runoff and pond networks. Rainfall analyses can be conducted using a number of synthetic or historic storm events using methods such as SCS rainfall distributions, intensity-duration-frequency curves, or recorded rainfall data. Infiltration and runoff can be computed using the SCS curve number method or the Green and Ampt or Horton infiltration methods. Hydrographs are computed using the SCS Method or the Rational Method. Channel routing is conducted using the Muskingun, translation, or Modified Puls methods. Outlet calculations can be performed for outlets such as weirs, culverts, orifices, and risers. The program can assist in the determination of pond sizes.

PondPack is a proprietary model that can be obtained from Haestad Methods, Bentley Systems, Inc. http://www.haestad.com/software/pondpack/default.asp

SWMM-Based Programs

The Storm Water Management Model (SWMM) was originally developed for the Environmental Protection Agency (EPA) in 1971 by Metcalf and Eddy, Inc., Water Resources Engineers, Inc. and the University of Florida. SWMM is a dynamic rainfall-runoff and water quality simulation model, primarily but not exclusively for urban areas, for single-event or long-term (continuous) simulation.

The Storm Water Management Model (SWMM) is a comprehensive computer model for analysis of quantity and quality problems associated with urban runoff. Both single-event and continuous simulation can be performed on catchments having storm sewers, or combined sewers and natural drainage, for prediction of flows, stages and pollutant concentrations. Extran Block solves complete dynamic flow routing equations (St. Venant equations) for accurate simulation of backwater, looped connections, surcharging, and pressure flow. A modeler can simulate all aspects of the urban hydrologic and quality cycles, including rainfall, snow melt, surface and subsurface runoff, flow routing through drainage network, storage and treatment. Statistical analyses can be performed on long-term precipitation data and on output from continuous simulation. SWMM can be used for planning and design. Planning mode is used for an overall assessment of urban runoff problem or proposed abatement options.

The SWMM program is available to the public and can be downloaded from the U.S. Environmental Protection Agency's website at: http://www.epa.gov/ceampubl/swater/swmm/index.htm

The proprietary shells, XP-SWMM and PC-SWMM, provide the basic computations of EPA-SWMM with a graphic user interface, additional tools, and some additional computational capabilities. XP-SWMM is available on the XP Software company Web site: http://www.xpsoftware.com/products/xpswmm.htm. PC-SWMM is available on the Computational Hydraulics International Web site: http://www.computationalhydraulics.com/Software/PCSWMM/

IV. Water Quality Models

SLAMM

The Source Loading and Management Model is a water quality model developed by John Voorhees and Robert Pitt for evaluation of nonpoint pollution in urban areas. The model is based on field observations of infiltration practices, wet detention ponds, porous pavement, street sweeping and other source area and outfall control practices. The focus of the model is on small storm hydrology and particulate washoff.

Local data files for input into SLAMM may be obtained from the U.S. Geological Survey at their Web site:

http://wi.water.usgs.gov/slamm/. The SLAMM model may be obtained from PV & Associates at their Web site: http://www.winslamm.com/

P8

P8, Program for Predicting Polluting Particle Passage through Pits, Puddles & Ponds, is a physically-based model developed by William Walker to predict the generation and transport of stormwater runoff pollutants in urban watersheds. The model simulates runoff and pollutant transport for a maximum of 24 watersheds, 24 stormwater best management practices (BMPs), 5 particle size classes, and 10 water quality components. The model simulates pollutant transport and removal in a variety of BMPs including swales, buffer strips, detention ponds (dry, wet and extended), flow splitters, and infiltration basins (offline and online). Model simulations are driven by a continuous hourly rainfall time series. P8 has been designed to require a minimum of site-specific data, which are expressed in terminology familiar to most engineers and planners. An extensive user interface providing interactive operation, spreadsheet-like menus, help screens and high resolution graphics facilitate model use.

A copy of P8 may be obtained (free of charge) from William W. Walker at the following Web site: http://wwwalker.net/.

BASINS

The Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) model is a multipurpose environmental analysis system developed by the U.S. Environmental Protection Agency's (EPA's) Office of Water. The model was originally introduced in 1996 and has had subsequent releases in 1998 and 2001. BASINS allows for the assessment of large amounts of point and non-point source data in a format that is easy to use and understand. BASINS incorporates a number of model interfaces that it uses to assess water quality at selected stream sites or throughout the watershed. These model interfaces include:

- QUAL2E: A water quality and eutrophication model
- WinHSPF: A watershed scale model for estimating in-stream concentrations resulting from loadings from point and non-point sources
- SWAT: A physical based, watershed scale model that was developed to predict the impacts of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land uses and management conditions over long periods of time.
- PLOAD: A pollutant loading model.

BASINS may be obtained on the following EPA Web site: http://www.epa.gove/waterscience/basins/. The EPA's Office of Science and Technology provides technical support to users of the BASINS system. This technical support can be obtained at the following Web site: http://www.epa.gov/ost/basins.

PONDNET

The PONDNET model (Walker, 1987) is an empirical model developed to evaluate flow and phosphorous routing in Pond Networks. The following input parameters are defined by the user in evaluating the water quality performance of a pond: watershed area (acres), runoff coefficient, pond surface area (acres), pond mean depth (feet), period length (years), period precipitation (inches) and phosphorous concentrations (ppb). The spreadsheet is designed so that the phosphorous removal of multiple ponds in series can be evaluated.

A copy of PONDNET may be requested from William W. Walker at the following Web site: http://wwwalker.net/.

WiLMS

The Wisconsin Lake Modeling Suite (WiLMS) is a screening level land use management/lake water quality evaluation tool developed by the Wisconsin Department of Natural Resources. It is a spreadsheet of thirteen lake model equations used to predict the total phosphorus (TP) concentration in a lake. TP loads can be entered either as point sources or by entering export coefficients for land uses.

WiLMS can be downloaded for free at the following Wisconsin DNR Web site: http://www.dnr.state.wi.us/org/water/fhp/lakes/laketool.htm

Bathtub

Bathtub is an empirical model of reservoir eutrophication developed by the U.S. Army Corps of Engineers. Single basins can be modeled, in addition to a network of basins that interact with one another. The model uses steady-state water and nutrient balance calculations in a spatially segmented hydraulic network, which accounts for advective and diffusive transport and nutrient sedimentation.

Bathtub can be download for free at the following U.S. Army Corps of Engineers website: http://el.erdc.usace.army.mil/products.cfm?Topic=model&Type=watqual

WASP

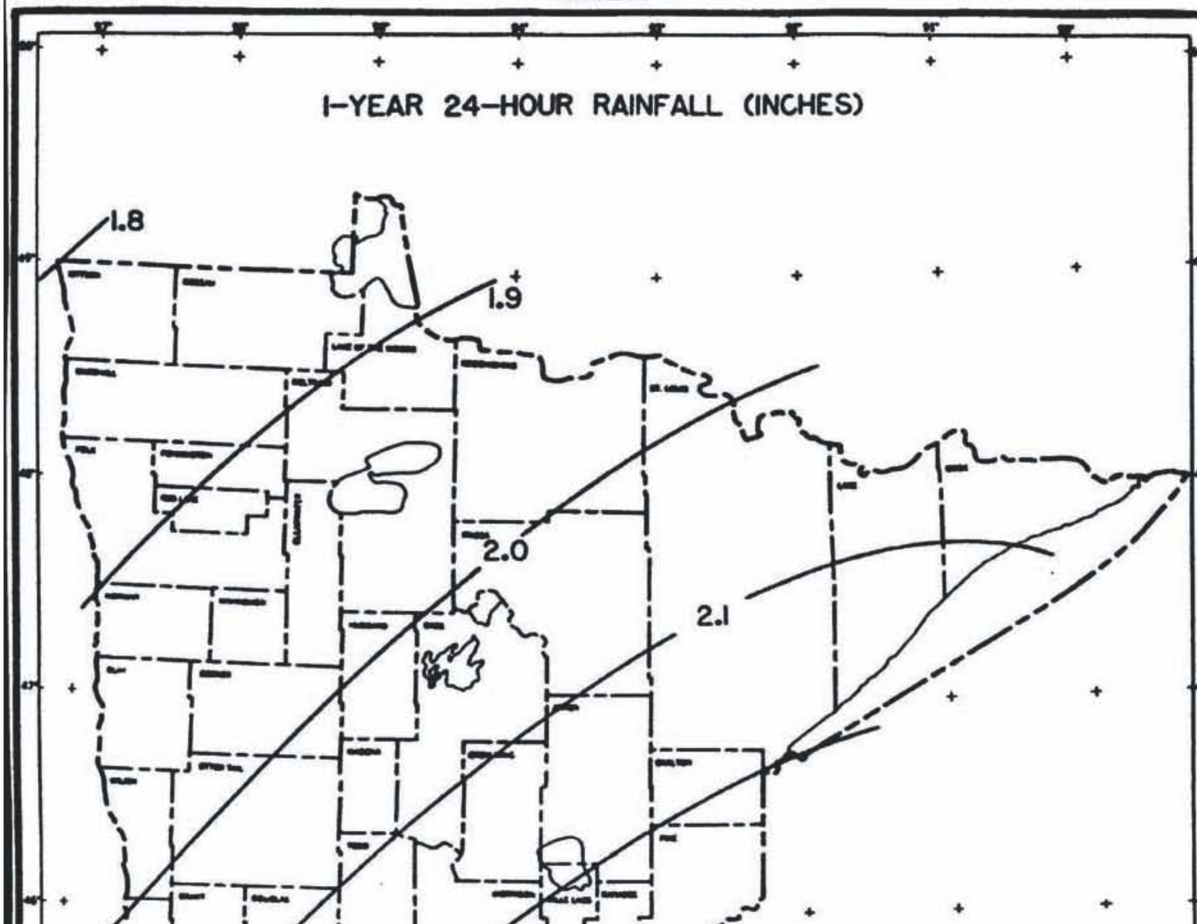
WASP, Water Quality Analysis Simulation Program, is a model developed by the U.S. EPA to evaluate the fate and transport of contaminants in surface waters such as lakes and ponds. The model evaluates advection, dispersion, mass loading, and boundary exchange in one, two, or three dimensions. A variety of pollutants can be modeled with this program including nutrients, dissolved oxygen, BOD, algae, organic chemicals, metals, pathogens, and temperature.

The WASP program can be downloaded from the U.S. EPA Web site: http://www.epa.gov/athens/wwqtsc/html/wasp.html

SWMM-Based Programs

SWMM is a hydraulic and hydrologic modeling system that also has a water quality component. Please see the full description above for more details on the model.

V. Supplemental Graphics: TP-40 and Precipitation Frequency Graphs



1-YEAR 24-HOUR RAINFALL (INCHES)
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
SOURCE: USWB TP 40

FIGURE 1-2

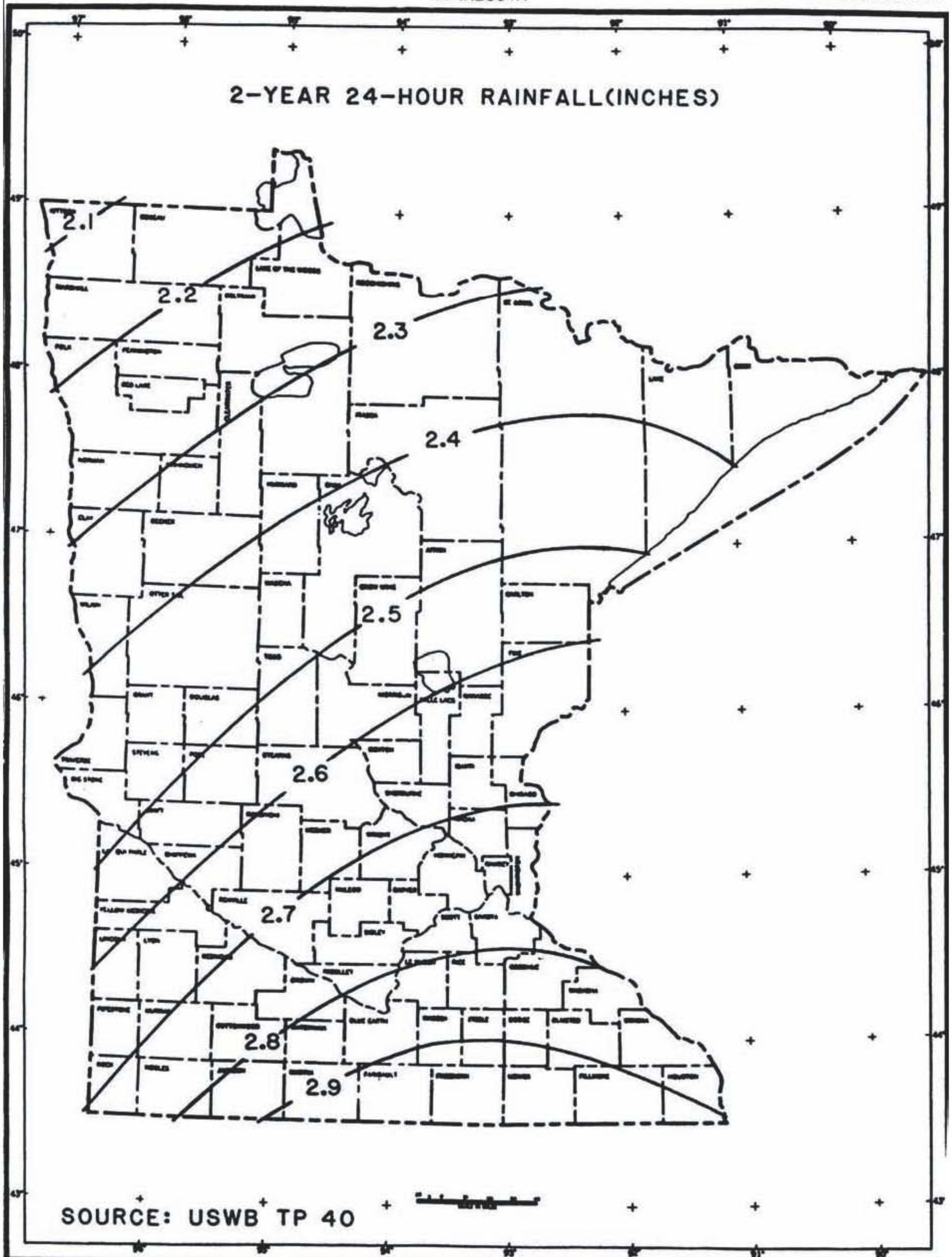

2-YEAR 24-HOUR RAINFALL(INCHES)
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
SOURCE: USWB TP 40

FIGURE 1-3

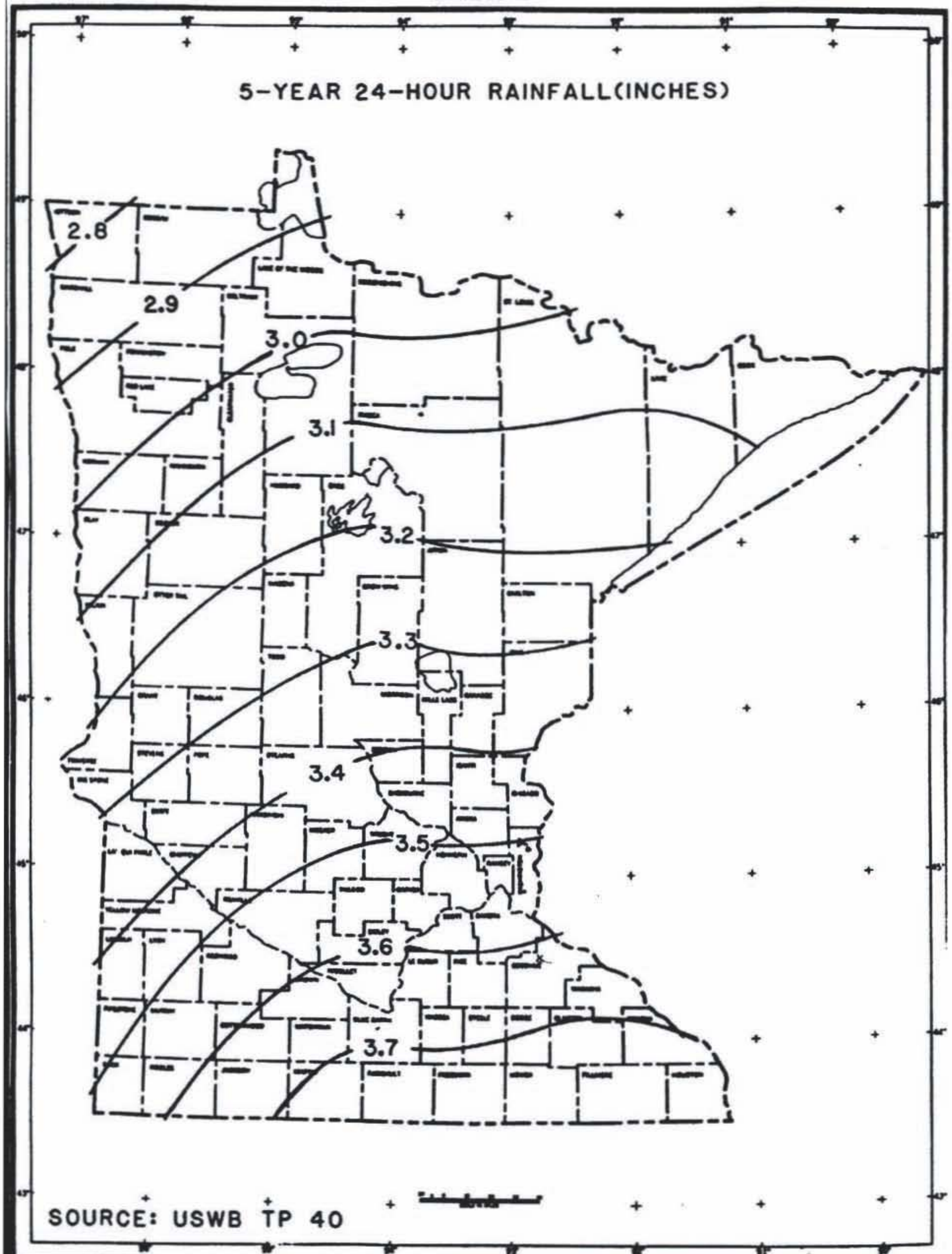

5-YEAR 24-HOUR RAINFALL(INCHES)
2.8
2.9
3.0
3.1
3.2
3.3
3.4
3.5
3.6
3.7
SOURCE: USWB TP 40

FIGURE I-4

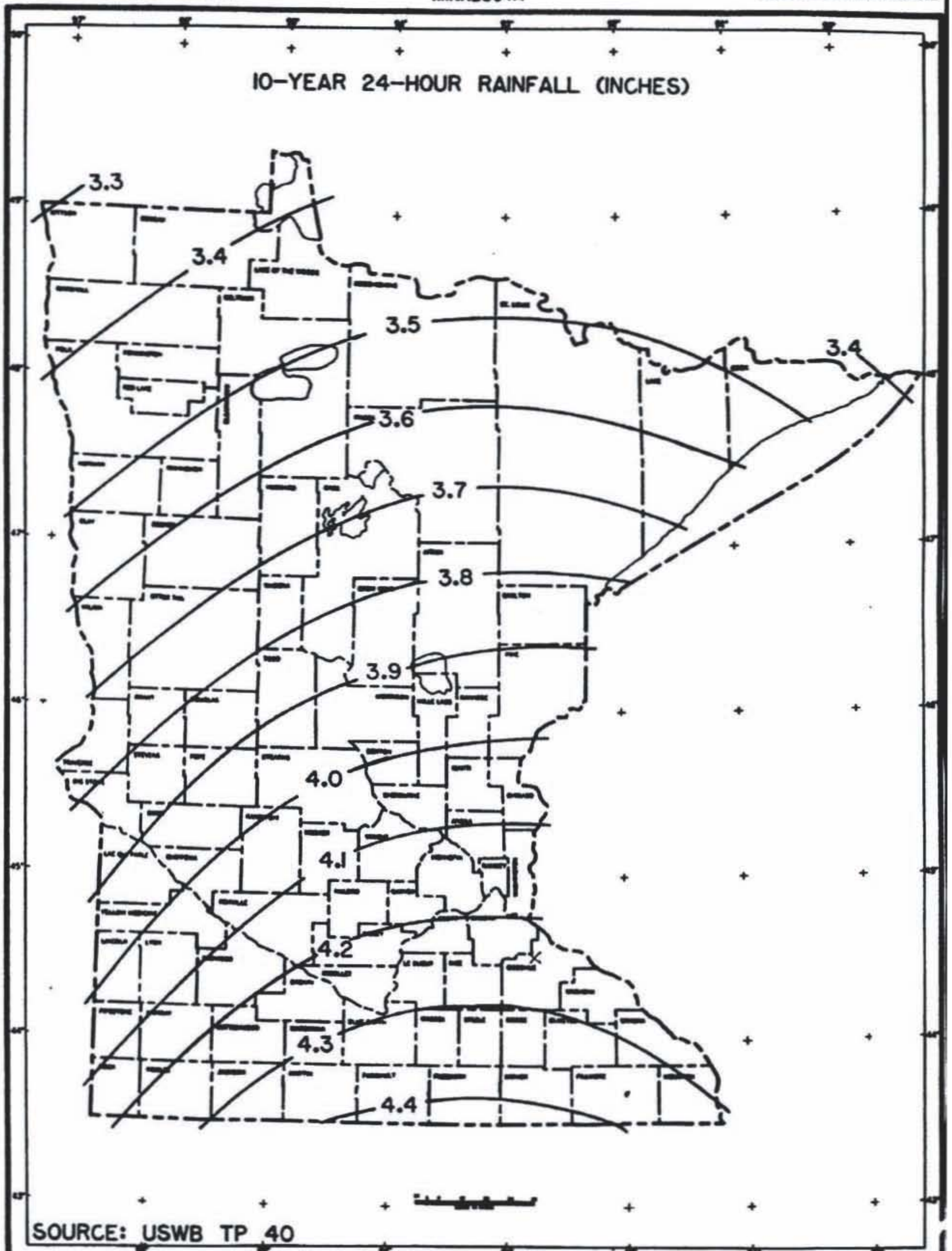

10-YEAR 24-HOUR RAINFALL (INCHES)
3.3
3.4
3.5
3.4
3.6
3.7
3.8
3.9
4.0
4.1
4.2
4.3
4.4
SOURCE: USWB TP 40

FIGURE I-5

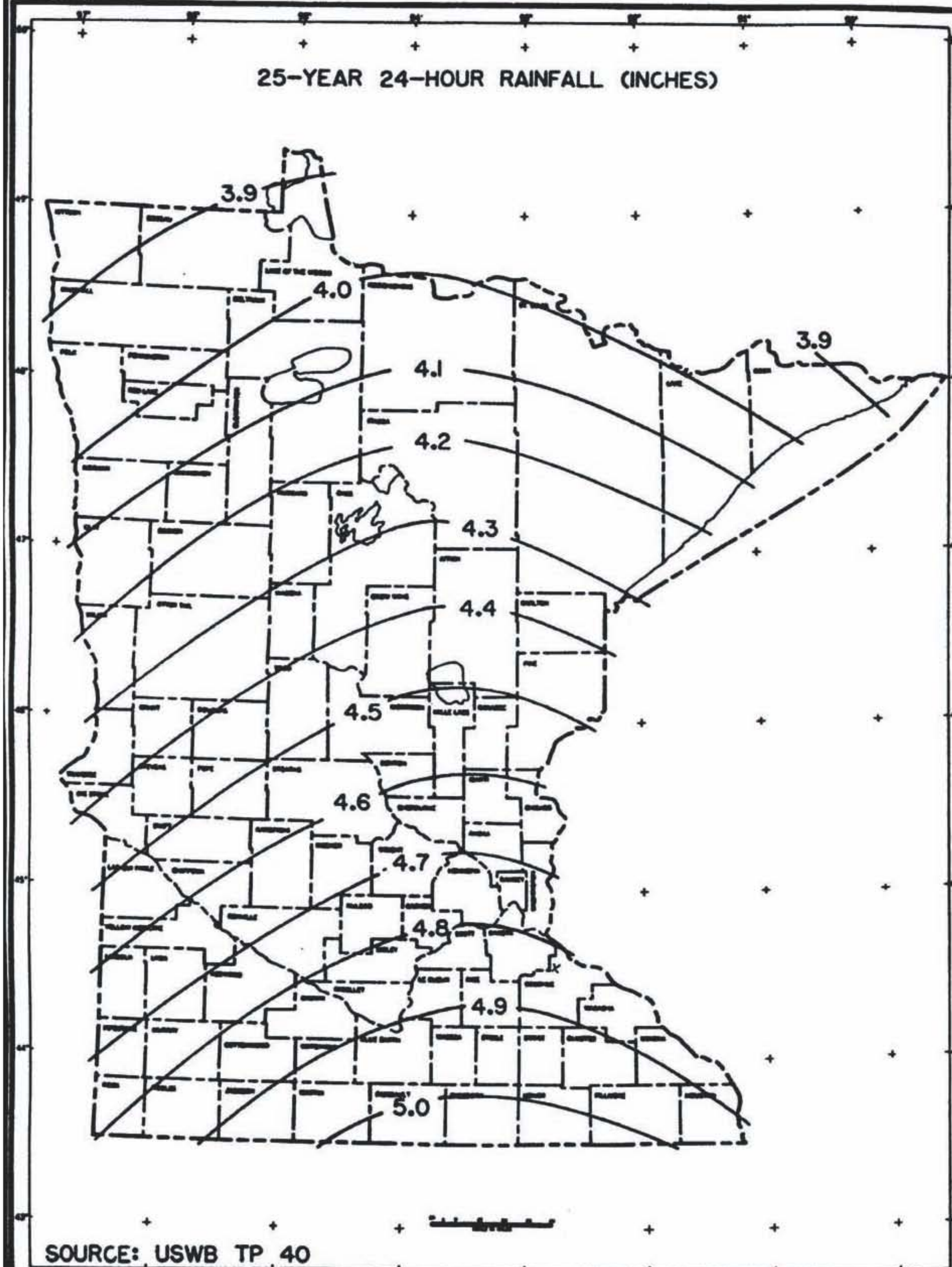

25-YEAR 24-HOUR RAINFALL (INCHES)
3.9
4.0
3.9
4.1
4.2
4.3
4.4
4.5
4.6
4.7
4.8
4.9
5.0
SOURCE: USWB TP 40

FIGURE 1-6

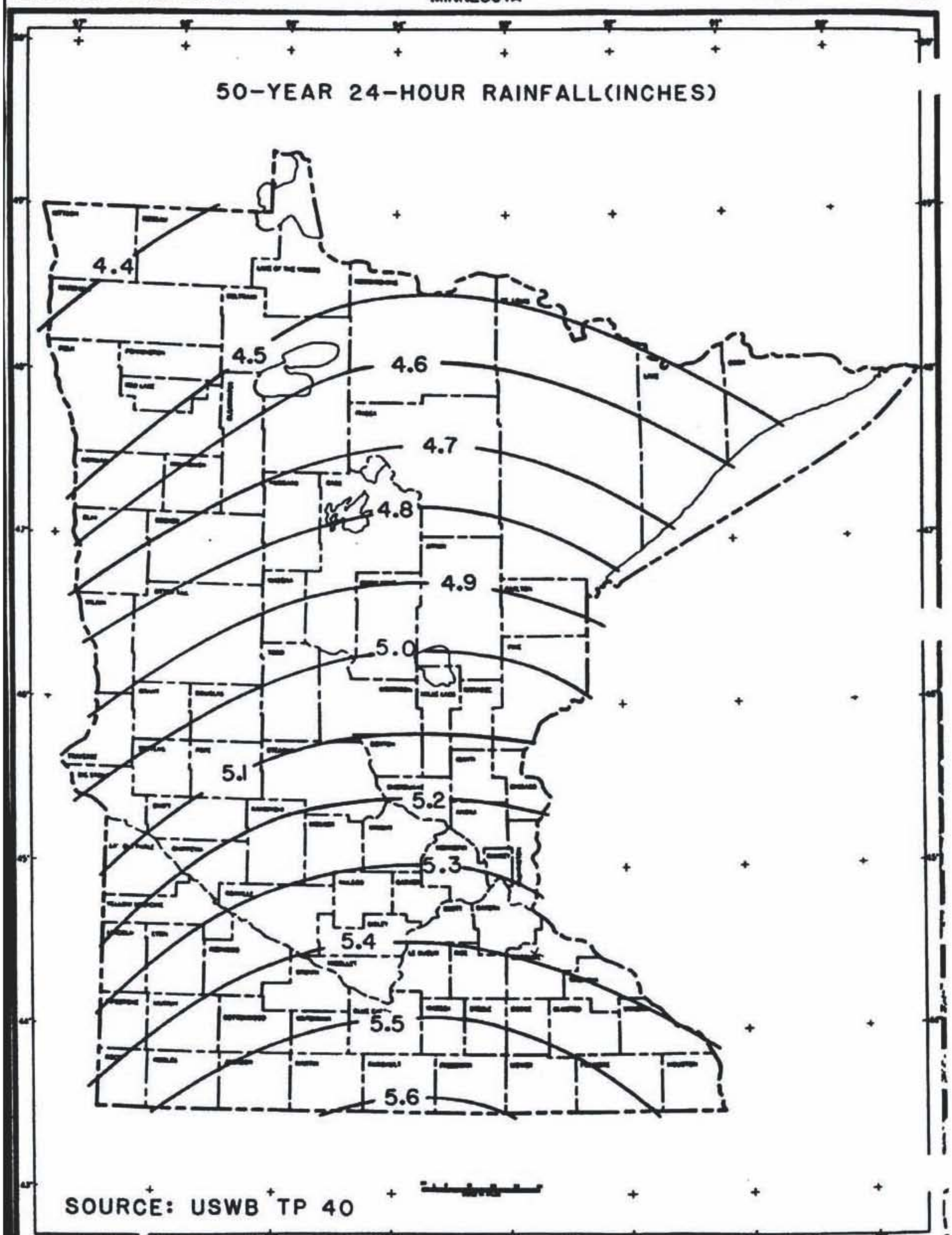

50-YEAR 24-HOUR RAINFALL (INCHES)
4.4
4.5
4.6
4.7
4.8
4.9
5.0
5.1
5.2
5.3
5.4
5.5
5.6
SOURCE: USWB TP 40

FIGURE 1-7

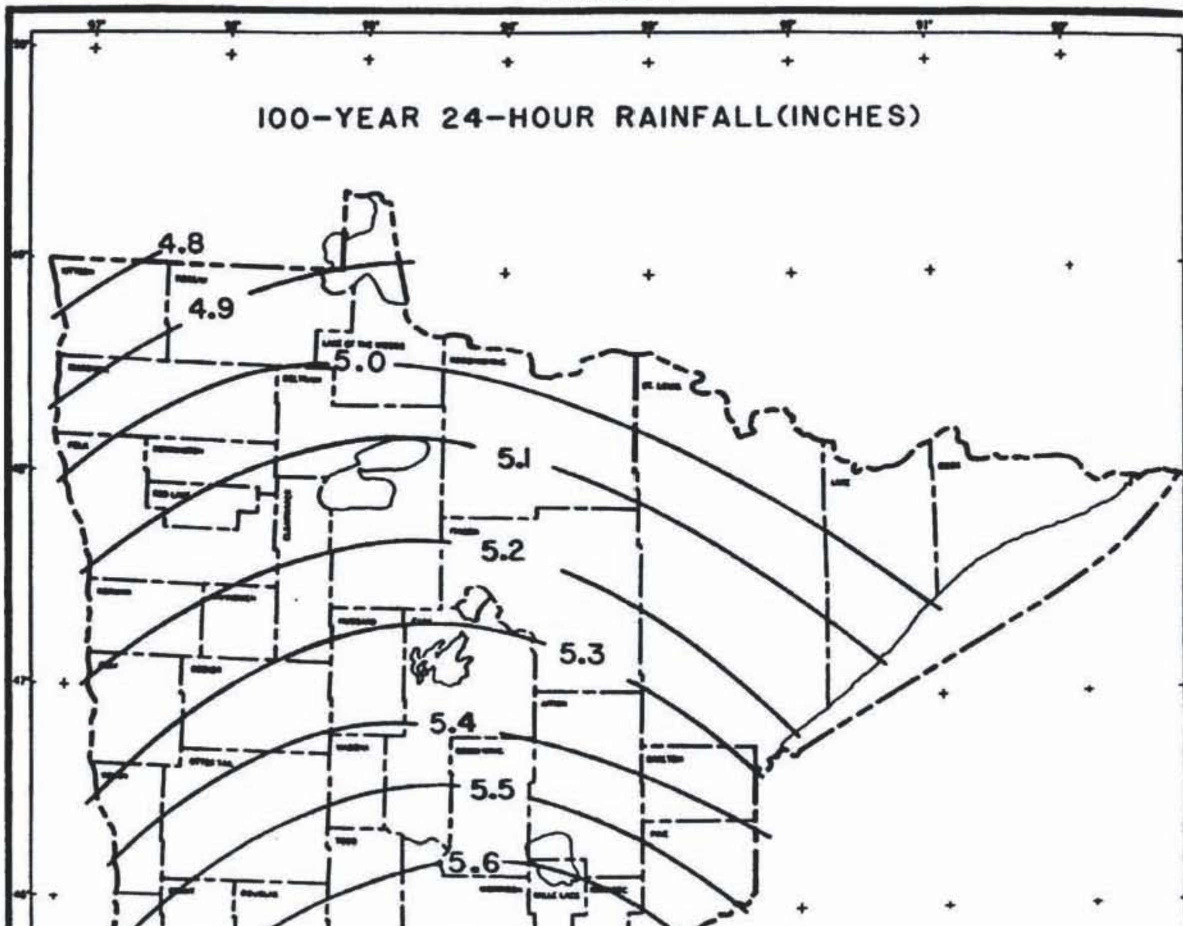
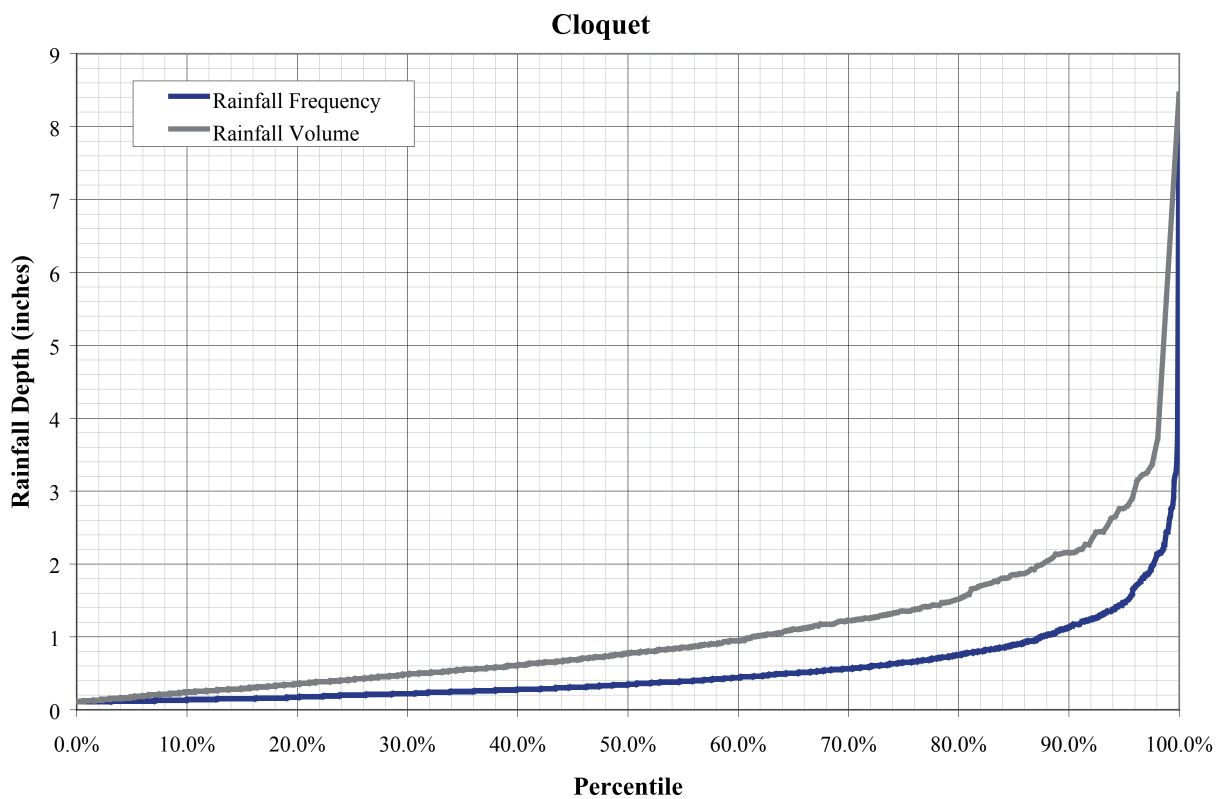
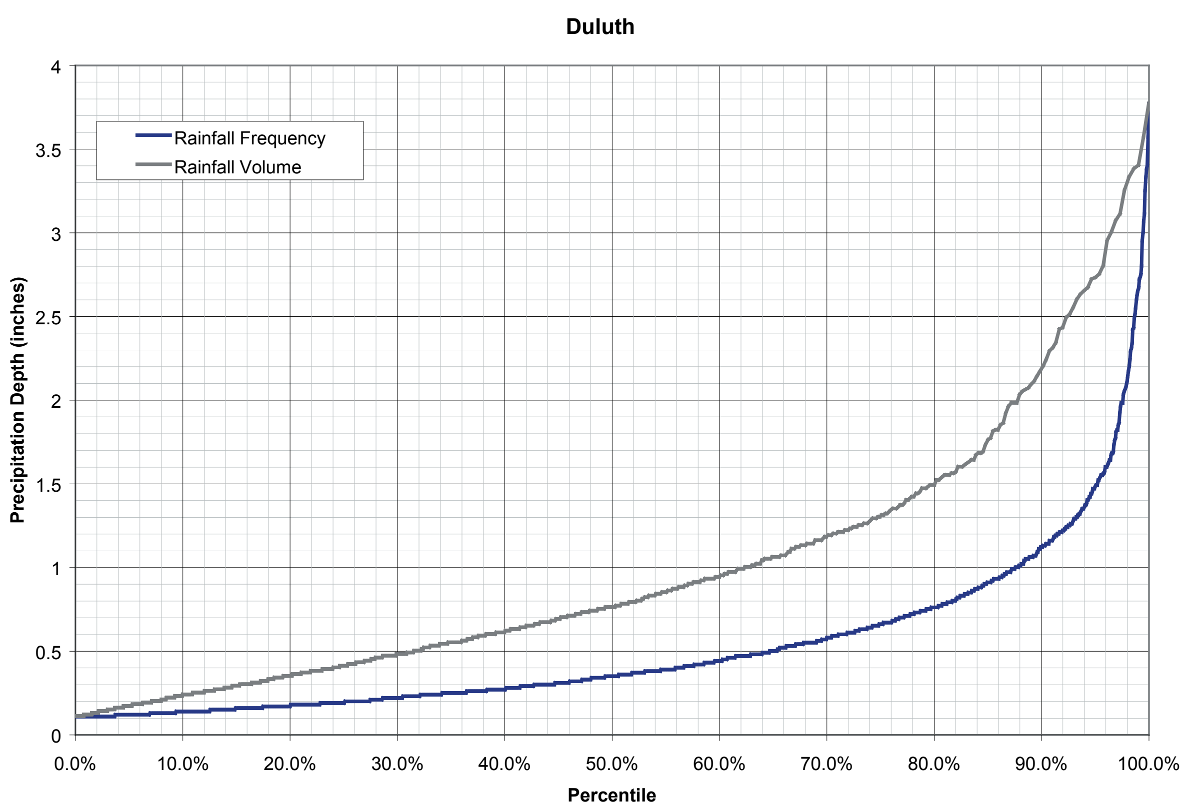
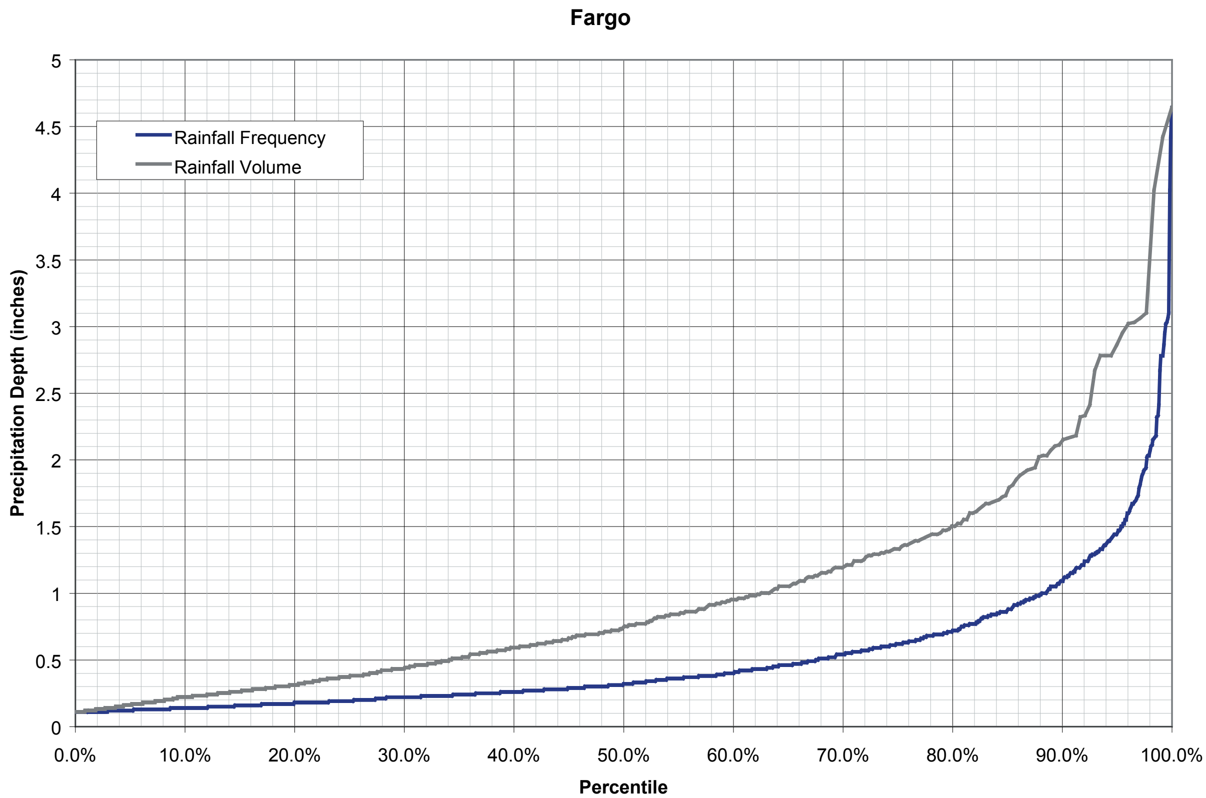
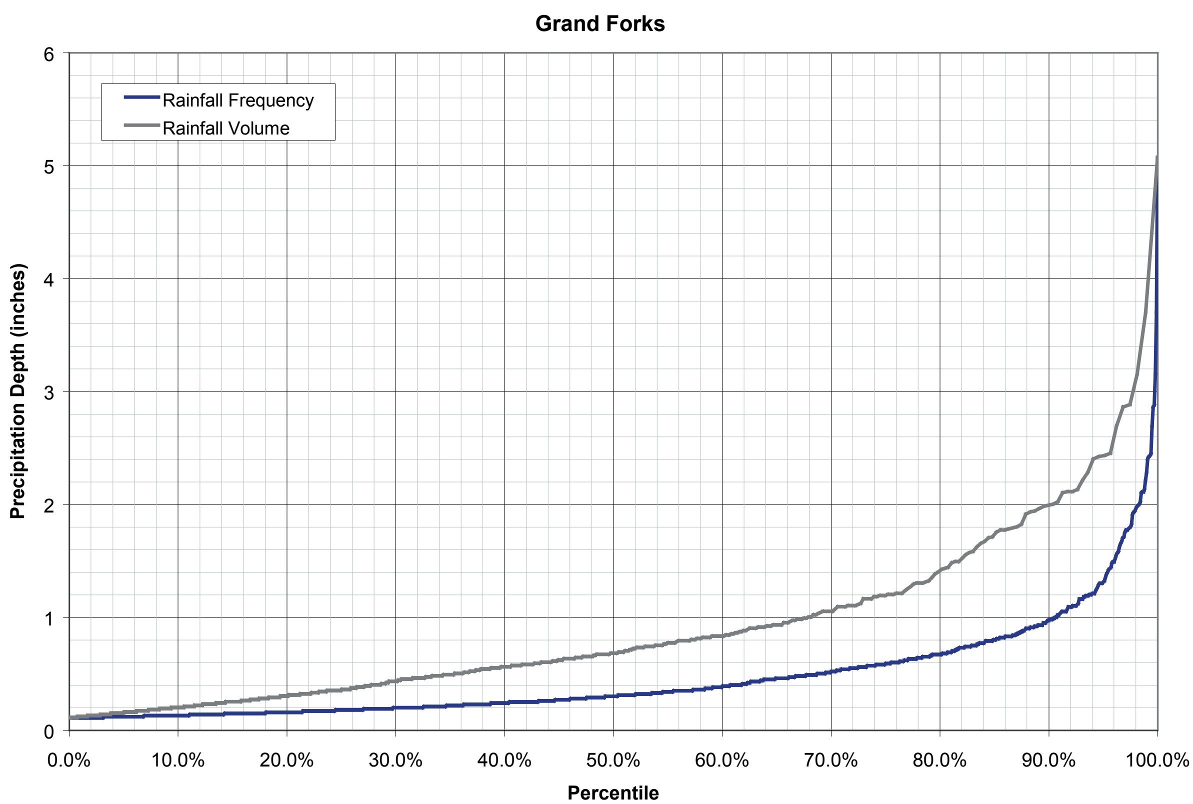

100-YEAR 24-HOUR RAINFALL(INCHES)
4.8
4.9
5.0
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
6.0
6.1
6.2
SOURCE: USWB TP 40

FIGURE 1-8

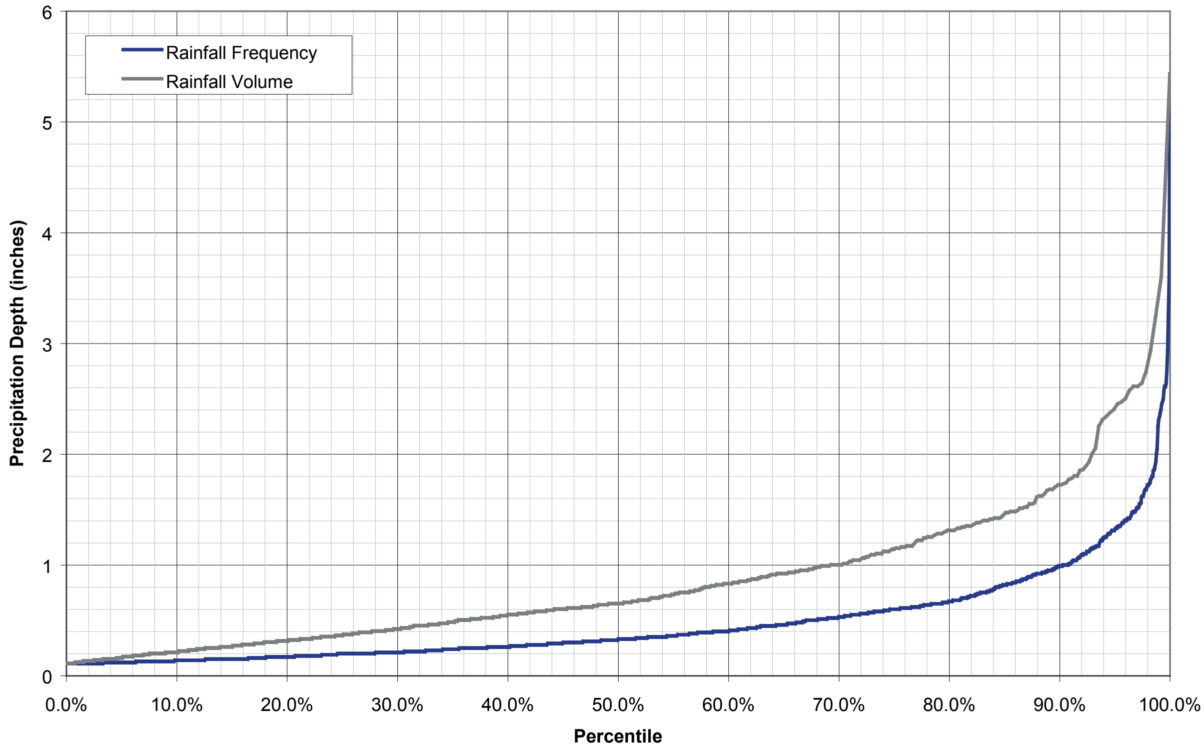

Cloquet
Rainfall Frequency
Rainfall Volume
Rainfall Depth (inches)
Percentile
0
1
2
3
4
5
6
7
8
9
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%


Duluth
Rainfall Frequency
Rainfall Volume
Precipitation Depth (inches)
Percentile
0
0.5
1
1.5
2
2.5
3
3.5
4
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%

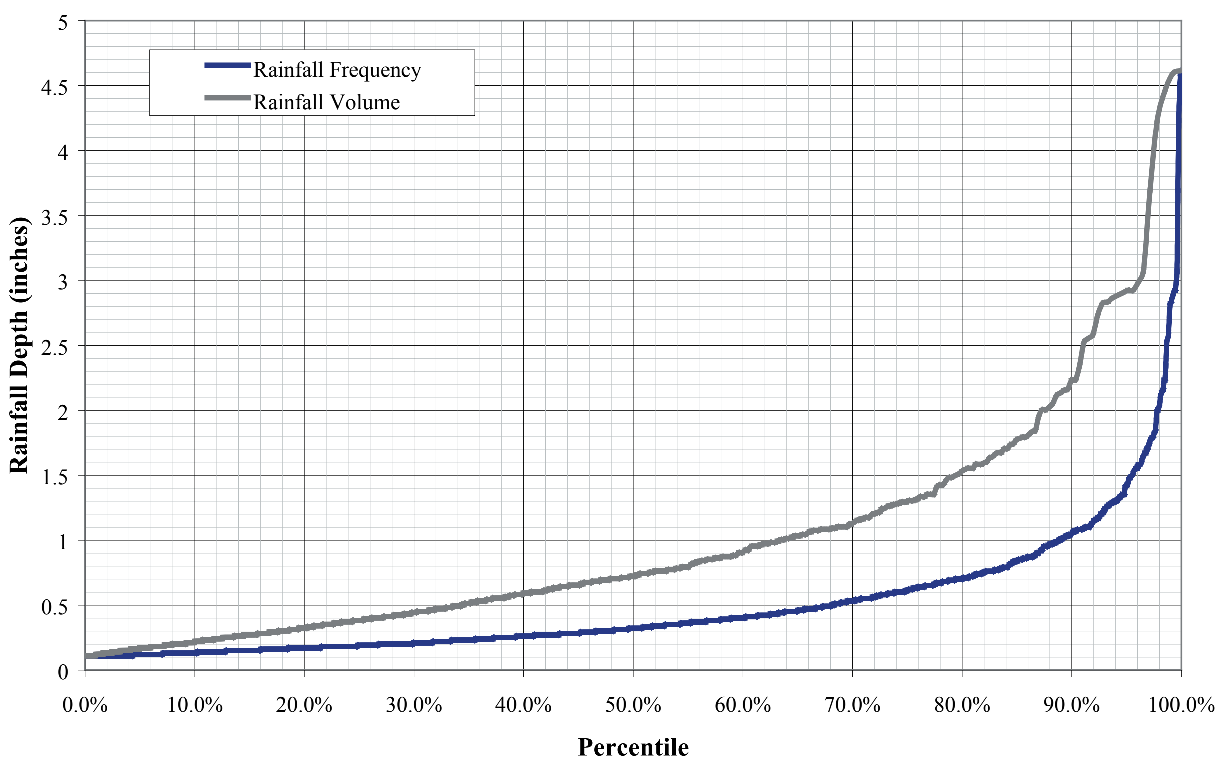

Fargo
Rainfall Frequency
Rainfall Volume
Precipitation Depth (inches)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%
Percentile

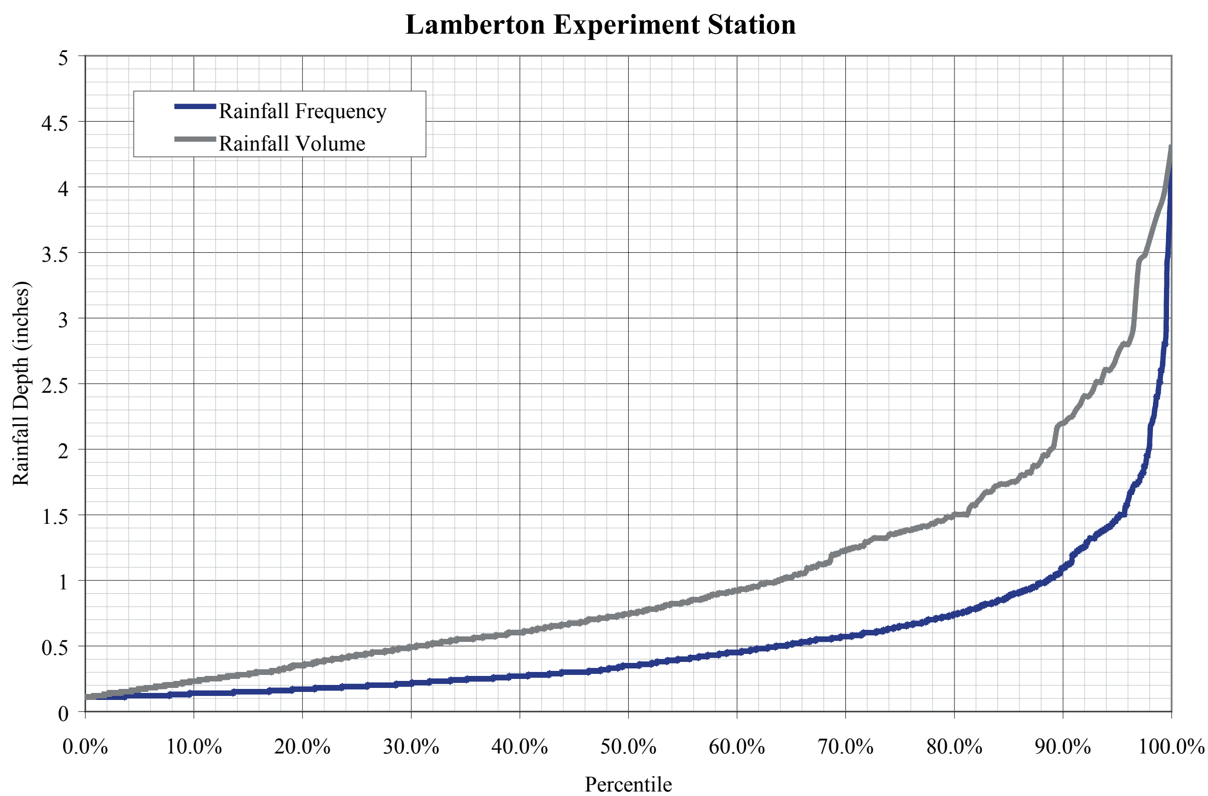

Grand Forks
Rainfall Frequency
Rainfall Volume
Precipitation Depth (inches)
6
5
4
3
2
1
0
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%
Percentile

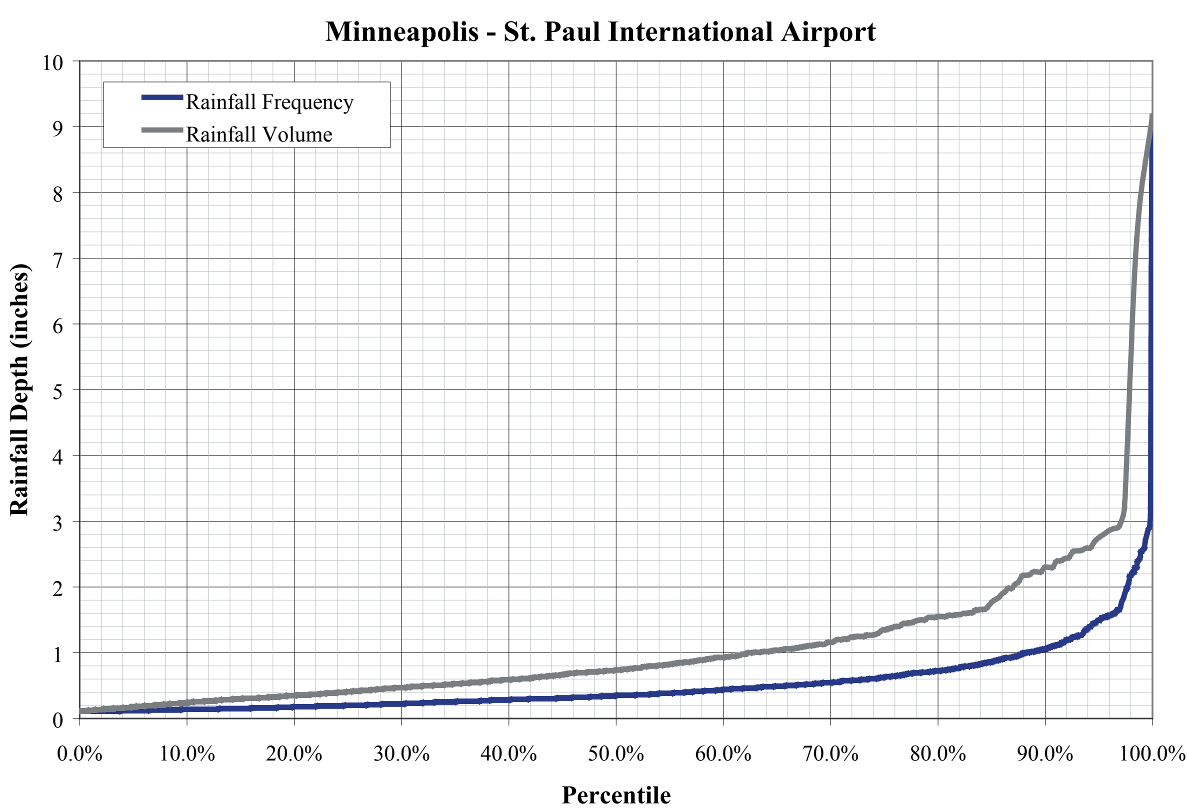
Grand Marais

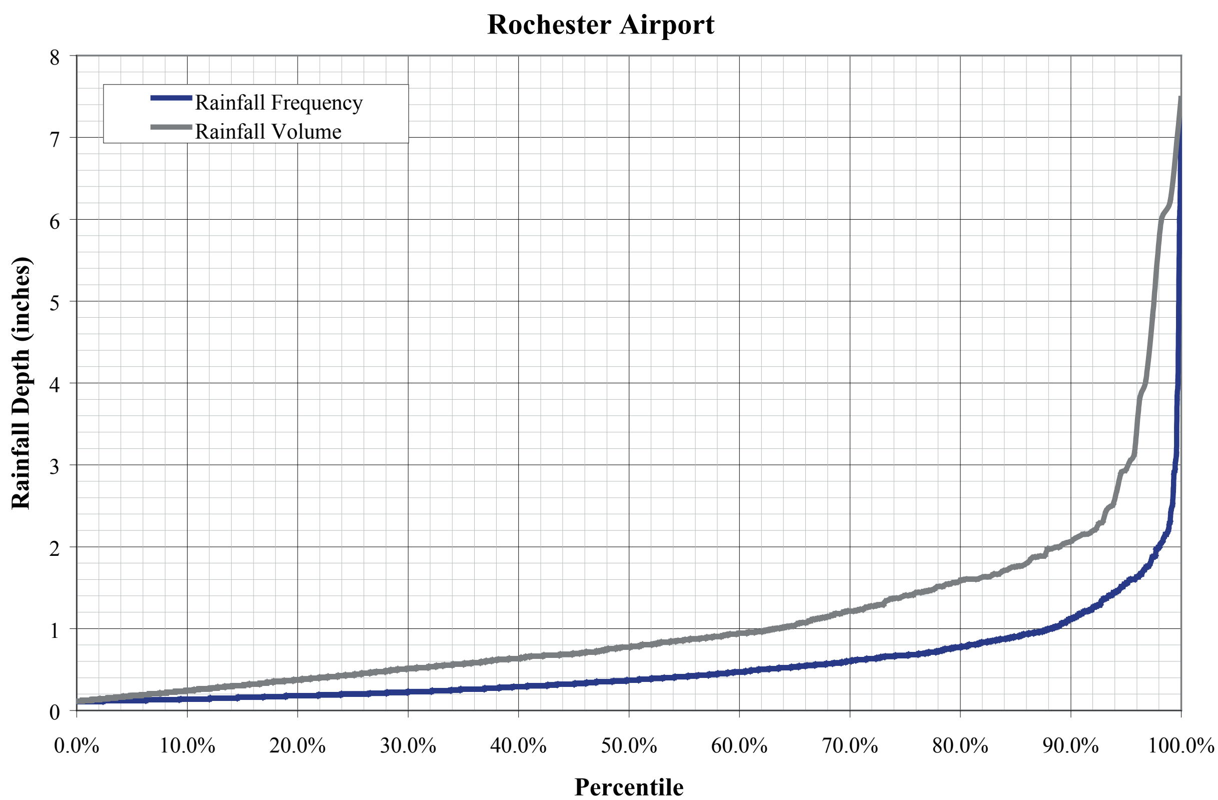


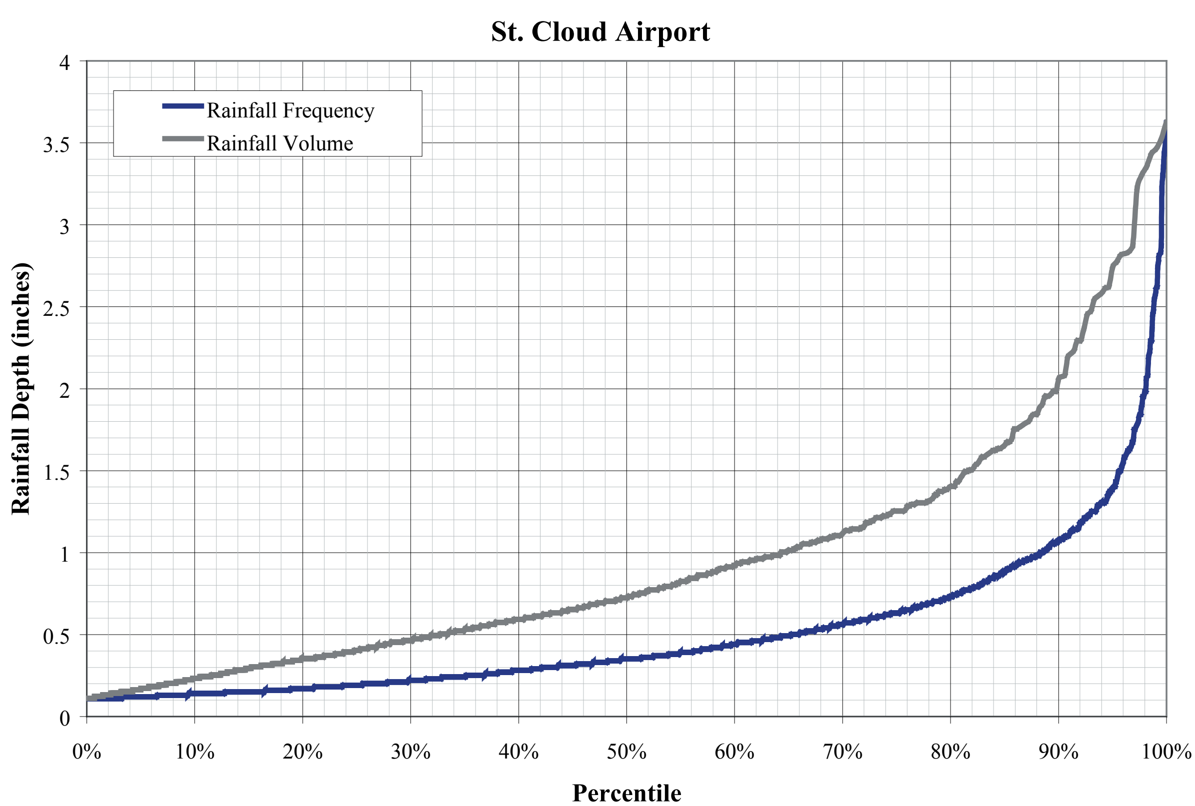
Itasca

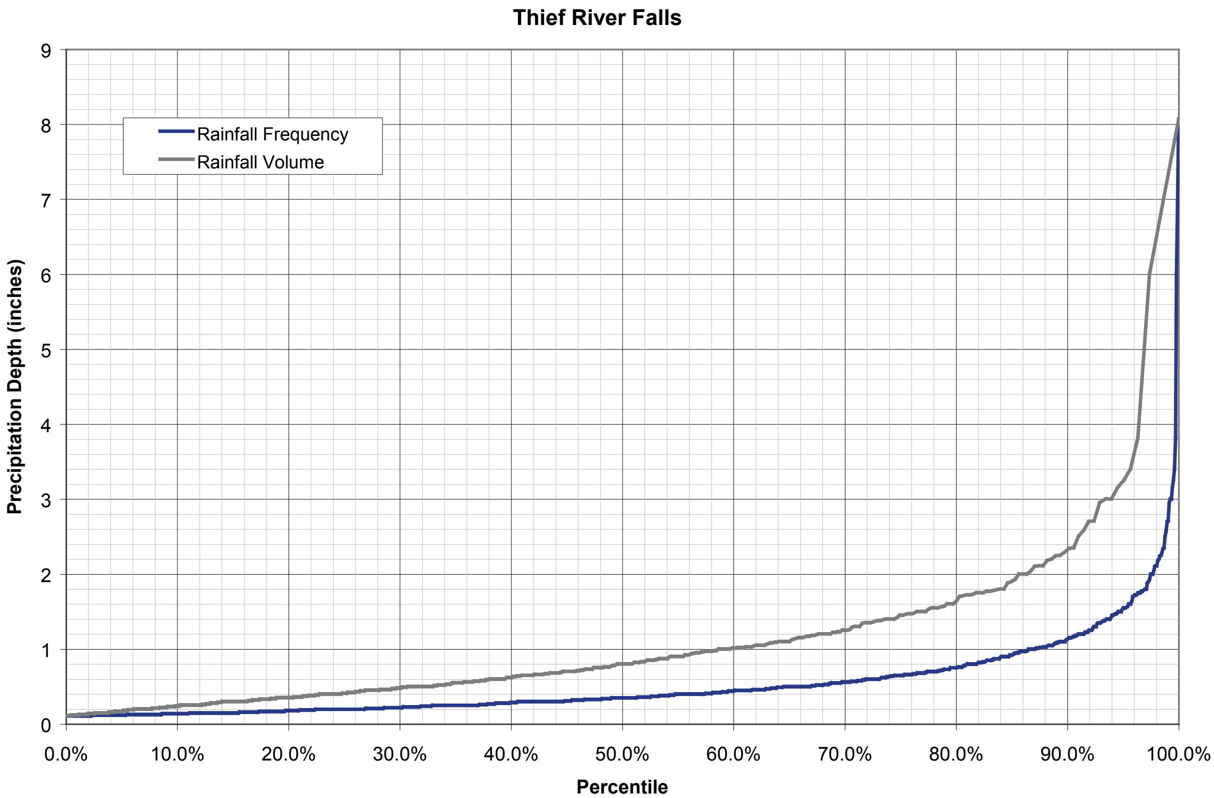



Lamberton Experiment Station
Rainfall Frequency
Rainfall Volume
Rainfall Depth (inches)
Percentile
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%


Minneapolis - St. Paul International Airport
Rainfall Frequency
Rainfall Volume
Rainfall Depth (inches)
Percentile
0
1
2
3
4
5
6
7
8
9
10
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%


Rochester Airport
Rainfall Frequency
Rainfall Volume
Rainfall Depth (inches)
Percentile
0
1
2
3
4
5
6
7
8
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%


St. Cloud Airport
Rainfall Frequency
Rainfall Volume
Rainfall Depth (inches)
Percentile
0
0.5
1
1.5
2
2.5
3
3.5
4
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%


Thief River Falls
Rainfall Frequency
Rainfall Volume
Precipitation Depth (inches)
Percentile
0
1
2
3
4
5
6
7
8
9
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
70.0%
80.0%
90.0%
100.0%

Appendix C

Links to Other Resources and Manuals

Appendix C

Links to Other Resources and Manuals

Contents

Table C.1 Links to Other Manuals

Locale	Manual	Source	Web site
British Columbia	Stormwater Planning: A Guidebook for British Columbia	Government of British Columbia	http://wlapwww.gov.bc.ca/epd/epdpa/mpp/stormwater/stormwater.html
California	Stormwater Best Management Handbooks	California Stormwater Quality Association	http://www.cabmphandbooks.com/
Cold Climates	Stormwater Practices for Cold Climates	Center for Watershed Protection	http://www.stormwatercenter.net/Cold%20Climates/cold-climates.htm
Colorado	Erosion Control and Stormwater Quality Guide	Colorado Department of Transportation	http://www.dot.state.co.us/Environmental/envWaterQual/docs/swqGuide.pdf
Connecticut	2004 Connecticut Stormwater Manual	Connecticut Department of Environmental Protection	http://dep.state.ct.us/wtr/stormwater/strmwtrman.htm#download
Delaware	Conservation Design for Stormwater Management Guidance Manual (order form)	Delaware Sediment and Stormwater Program	http://www.dnrec.state.de.us/DNREC2000/Divisions/Soil/Stormwater/Apps/DesignManualRequest.htm
Georgia	Georgia Stormwater Management Manual	Atlanta Regional Commission	http://www.georgiastormwater.com/
Great Lakes	Catching the Rain: A Great Lakes Resource Guide for Natural Stormwater Management	American Rivers	http://www.americanrivers.org/newreportonstormwatermanagement.html
Idaho	Catalog of Stormwater BMPs for Idaho Cities and Counties	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/permits_forms/permitting/catalog_bmps.cfm
Illinois	Illinois Urban Manual	NRCS	http://www.il.nrcs.usda.gov/technical/engineer/urban/contents.html
Maryland	Low Impact Development Hydrologic Analysis	Prince George's County, Maryland	http://www.lowimpactdevelopment.org/ftp/LID_Hydrology_National_Manual.pdf
Maryland	Maryland Chesapeake and Atlantic Coastal Bays Critical Area 10% Rule Guidance Manual	Center for Watershed Protection	http://www.dnr.state.md.us/criticalarea/10percent_rule_manual/manual.pdf
Maryland	Maryland Stormwater Design Manual Volumes I and II	Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp

Table C.1 Links to Other Manuals

Locale	Manual	Source	Web site
Michigan	Guidebook of Best Management Practices for Michigan Watersheds	Michigan Department of Environmental Quality	http://www.deq.state.mi.us/documents/deq-swq-nps-WholeGuidebook.pdf
Minnesota	Alternative Stormwater Best Management Practices Guidebook	Valley Branch Watershed District	http://www.vbwd.org/vbmanual/VBmanual.pdf
Minnesota	Erosion Control Handbook for Local Roads	Center for Transportation Studies	http://www.mnltap.umn.edu/pdf/erosioncontrolhandbook.pdf
Minnesota	Protecting Water Quality in Urban Areas: Best Management Practices for Dealing with Storm Water Runoff from Urban, Suburban, and Developing Areas of Minnesota	Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html
Minnesota	Shoreland Best Management Practices	University of Minnesota Extension Services	http://www.extension.umn.edu/distribution/naturalresources/DD6946.html
Minnesota	Urban Small Sites Best Management Practice Manual	Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm
Nationwide	National Engineering Handbooks	NRCS	http://www.info.usda.gov/CED/Search.cfm?STRING=NEH&XAUD=24#National%20Engine
Nationwide	Planning and Design Manual for the Control of Erosion, Sediment, and Stormwater	U.S. Department of Agriculture	http://www.abe.msstate.edu/Tools/csd/p-dm/
Nationwide	Protecting Natural Wetlands: A Guide to Stormwater Best Management Practices	U.S. Environmental Protection Agency	http://www.epa.gov/owow/wetlands/pdf/protecti.pdf
Nationwide	Site Planning for Urban Stream Protection	Center for Watershed Protection	http://www.cwp.org/SPSP/TOC.htm
Nationwide	Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring	U.S. Federal Highway Administration	http://www.fhwa.dot.gov/environment/ultraurb/index.htm
New Jersey	New Jersey Stormwater Best Management Practices Manual	New Jersey Department of Environmental Protection	http://www.nj.gov/dep/watershedmgt/bmpmanualfeb2004.htm

Table C.1 Links to Other Manuals

Locale	Manual	Source	Web site
New York	New York State Stormwater Management Design Manual	New York State Department of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/index.html
North Carolina	Stormwater Best Management Practices	North Carolina Department of Environment and Natural Resources	http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm
Oregon	Portland's Stormwater Management Manual	Portland Bureau of Environmental Services	http://www.portlandonline.com/bes/index.cfm?c=35117
Pennsylvania	Draft Stormwater Best Management Practices Manual	Pennsylvania Department of Environmental Protection	http://www.dep.state.pa.us/dep/subject/advcoun/Stormwater/stormwatercomm.htm
Vermont	Vermont Stormwater Management Manual	Vermont Agency of Natural Resources	http://www.vtwaterquality.org/stormwater/docs/sw_manual-vol1.pdf
Vermont	Vermont Stormwater Resources	Vermont Water Quality Division	http://www.vtwaterquality.org/cfm/ref/Ref_Stormwater.cfm
Virginia	Virginia Stormwater Management Handbook	Department of Conservation and Recreation	http://www.dcr.state.va.us/sw/stormwat.htm#pubs
Washington	Highway Runoff Manual	Washington State Department of Transportation	http://www.wsdot.wa.gov/fasc/EngineeringPublications/Manuals/HighwayRunoff2004.pdf
Washington	King County, Washington Surface Design Manual	King County Department of Natural Resources	http://dnr.metrokc.gov/wlr/dss/manual.htm
Washington	Stormwater Management Manual for Western Washington	Washington State Department of Ecology Water Quality Program	http://www.ecy.wa.gov/programs/wq/stormwater/Manual%20PDFs/searchable_file.pdf
Wisconsin	Dane County Erosion Control and Stormwater Management Manual	Dane County, Wisconsin	http://www.co.dane.wi.us/commissions/lakes/pdf/stormwater/ecsm_manual.pdf

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Bioretention	Raingardens	City of Eugene, Oregon	http://www.ci.eugene.or.us/pw/storm/bmp/	http://www.ci.eugene.or.us/pw/storm/bmp/Chap4pt5.pdf	
		Dane County, Wisconsin	http://www.co.dane.wi.us/commissions/lakes/stormwatermanual.shtml	http://www.co.dane.wi.us/commissions/lakes/pdf/stormwater/ecsm_manual.pdf	128
		Dane County, Wisconsin	http://www.co.dane.wi.us/commissions/lakes/raingarden.shtml		
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STInfilOnLot.pdf	9
		Marcy-Holmes Neighborhood Association	http://www.marcy-holmes.org/projects/rainwater/index.html	http://www.marcy-holmes.org/projects/rainwater/3.html	
		University of Wisconsin Extension	http://clean-water.uwex.edu/pubs/raingarden/	http://clean-water.uwex.edu/pubs/raingarden/rgmanual.pdf	
		Dave Stack, MN	http://www.mninter.net/~stack/	http://www.mninter.net/~stack/rain/index.htm	
		City of Maplewood, MN		http://www.ci.maplewood.mn.us/index.asp?Type=B_BASIC&SEC={F2C03470-D6B5-4572-98F0-F79819643C2A}	
	Depressed Parking Lot Islands	Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_RPPImpParking.pdf	
	Bioretention	Dane County, Wisconsin	http://www.co.dane.wi.us	http://www.co.dane.wi.us/commissions/lakes/pdf/stormwater/ecsm_manual.pdf	
		U.S. Dept of Transportation Federal Highway Administration	http://www.fhwa.dot.gov/environment/ultraurb/	http://www.fhwa.dot.gov/environment/ultraurb/3fs3.htm	

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Bioretention	Bioretention	U.S. Enviromental Protection Agency	http://www.epa.gov/owm/mtb/mtbfact.htm	http://www.epa.gov/owm/mtb/biortn.pdf	
		Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	33-43
		California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/TC-32.pdf	
		Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-2-3.pdf	
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.state.nj.us/dep/watershedmgt/DOCS/BMP_DOCS/bmpfeb2004pdfs/feb2004chap9_1.pdf	
		North Carolina Division of Water Quality	http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm#StormwaterManuals	http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/BMP_Manual.PDF	29-64
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	44-59
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	65-75

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Bioretention	Bioretention	Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-11.pdf	
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Filtering%20Practice/Bioretention.htm	
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp44.asp	
	Biofiltration Swale	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp38.asp	
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	199-226
Infiltration	Infiltration Trenches	City of Eugene, Oregon	http://www.ci.eugene.or.us/pw/storm/bmp/	http://www.ci.eugene.or.us/pw/storm/bmp/Chap4pt2.pdf	
		California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/TC-10.pdf	
		California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/SD-11.pdf	
		Dane County, Wisconsin		http://www.co.dane.wi.us/commissions/lakes/pdf/stormwater/ecsm_manual.pdf	96

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Infiltration	Infiltration Trenches	U.S. Dept of Transportation Federal Highway Administration	http://www.fhwa.dot.gov/environment/ultraurb/	http://www.fhwa.dot.gov/environment/ultraurb/3fs1.htm	
		Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-2-5.pdf	
		NRCS Illinois Urban Manual	http://www.il.nrcs.usda.gov/technical/engineer/urban/standards/urstnd_alpha.html	http://www.il.nrcs.usda.gov/technical/engineer/urban/standards/urbst847.html	
		U.S. Enviromental Protection Agency	http://www.epa.gov/owm/mtb/mtbfact.htm	http://www.epa.gov/owm/mtb/infltrenc.pdf	
		Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	27-32
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STInfilTrenches.pdf	
		Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch4.pdf	117-12
		North Carolina Division of Water Quality	http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm#StormwaterManuals	http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/BMP_Manual.PDF	81-84
		Northern Virginia Regional Commission	http://www.novaregion.org/environmental.htm	http://www.novaregion.org/pdf/NVBMP-Handbook.pdf	77-96

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Infiltration	Infiltration Trenches	New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	31-43
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	57-64
		Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-10.pdf	
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	166-171
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Infiltration%20Practice/Infiltration%20Trench.htm	
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp43.asp	
	Infiltration Basins	City of Eugene, Oregon	http://www.ci.eugene.or.us/pw/storm/bmp/	http://www.ci.eugene.or.us/pw/storm/bmp/Chap4pt2.pdf	
		California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/TC-11.pdf	
		U.S. Dept of Transportation Federal Highway Administration	http://www.fhwa.dot.gov/environment/ultraurb/	http://www.fhwa.dot.gov/environment/ultraurb/3fs2.htm	

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Infiltration	Infiltration Basins	Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	27-32
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm/CH3_STInfilBasins.pdf	
		Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch4.pdf	112-116
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.state.nj.us/dep/watershedmgt/DOCS/BMP_DOCS/bmpfeb2004pdfs/feb2004chap9_5.pdf	
		North Carolina Division of Water Quality	http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm#StormwaterManuals	http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/BMP_Manual.PDF	81-84
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	31-43
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	57-64
		Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-10.pdf	
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	164-165

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Infiltration	Infiltration Basin	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Infiltration%20Practice/Infiltration%20Basin.htm	
	Bioinfiltration Swale	Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	172-173
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp38b.asp	
Open Channel	Wet Swale	U.S. Dept of Transportation Federal Highway Administration	http://www.fhwa.dot.gov/environment/ultraurb/	http://www.fhwa.dot.gov/environment/ultraurb/3fs10.htm	
		Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-2-6.pdf	
		City of Eugene, Oregon	http://www.ci.eugene.or.us/pw/storm/bmp/	http://www.ci.eugene.or.us/pw/storm/bmp/Chap4pt4.pdf	
Open Channel	Wet Swale	Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	44-48
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STConstWLWetSwale.pdf	
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	59-65

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Open Channel	Wet Swale	Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	75-81
	Dry Swale	U.S. Dept of Transportation Federal Highway Administration	http://www.fhwa.dot.gov/environment/ultraurb/	http://www.fhwa.dot.gov/environment/ultraurb/3fs10.htm	
		Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-2-6.pdf	
		Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	44-48
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STDetDrySwale.pdf	
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	59-65
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	75-81
Filtration	Surface Sand Filter	Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	33-43
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.9.pdf	

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Filtration	Surface Sand Filter	New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	44-59
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	65-75
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Filtering%20Practice/Sand%20and%20Organic%20Filter%20Strip.htm	
	Underground Sand Filter	Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	33-43
		Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch4.pdf	121-124
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.9.pdf	
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	44-59
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	65-75

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Filtration	Underground Sand Filter	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Filtering%20Practice/Sand%20and%20Organic%20Filter%20Strip.htm	
	Perimeter Sand Filter	Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	33-43
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.9.pdf	
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	44-59
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	65-75
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Filtering%20Practice/Sand%20and%20Organic%20Filter%20Strip.htm	
	Organic Filter	Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	33-43
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	44-59

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Filtration	Organic Filter	Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	65-75
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Filtering%20Practice/Sand%20and%20Organic%20Filter%20Strip.htm	
	Pocket Sand Filter	Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	33-43
	Vegetated Filters (Strips and Buffers)	City of Eugene, Oregon	http://www.ci.eugene.or.us/pw/storm/bmp/	http://www.ci.eugene.or.us/pw/storm/bmp/Chap4pt4.pdf	
		Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch4.pdf	101-105
		North Carolina Division of Water Quality	http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm#StormwaterManuals	http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/BMP_Manual.PDF	76-79
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	81-87
		City of Eugene, Oregon	http://www.ci.eugene.or.us/pw/storm/bmp/	http://www.ci.eugene.or.us/pw/storm/bmp/Chap4pt4.pdf	
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.state.nj.us/dep/watershedmgt/DOCS/BMP_DOCS/bmpfeb2004pdfs/feb2004chap9_10.pdf	
		Northern Virginia Regional Commission	http://www.novaregion.org/environmental.htm	http://www.novaregion.org/pdf/NVBMP-Handbook.pdf	141-144

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Filtration	Vegetated Filters (Strips and Buffers)	Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-14.pdf	
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Filtering%20Practice/Grassed%20Filter%20Strip.htm	
		NRCS Illinois Urban Manual	http://www.il.nrcs.usda.gov/technical/engineer/urban/standards/urstnd_alpha.html	http://www.il.nrcs.usda.gov/technical/engineer/urban/standards/urbst835.html	
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp39.asp	
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp26.asp	
	Sand Filters	North Carolina Division of Water Quality	http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm#StormwaterManuals	http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/BMP_Manual.PDF	23-25
		Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-12.pdf	
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	174-198
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp40.asp	

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Filtration	Compost Stormwater Filter	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp41.asp	
Wetlands	Shallow Marsh/Wetland	U.S. Dept of Transportation Federal Highway Administration	http://www.fhwa.dot.gov/environment/ultraurb/	http://www.fhwa.dot.gov/environment/ultraurb/3fs5.htm	
		Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch5.pdf	48-51
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.2%20print.pdf	
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	22-30
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	48-57
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Wetland/Wetland.htm	
	Biodetention Basin	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp49.asp	
	Marsh Vegetation	Northern Virginia Regional Commission	http://www.novaregion.org/environmental.htm	http://www.novaregion.org/pdf/NVBMP-Handbook.pdf	144-148

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Wetlands	Extended Detention (Shallow) Wetland	City of Eugene, Oregon	http://www.ci.eugene.or.us/pw/storm/bmp/	http://www.ci.eugene.or.us/pw/storm/bmp/Chap4pt3.pdf	
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.2%20print.pdf	
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	22-30
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	48-57
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Wetland/Wetland.htm	
	Gravel Wetland	Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	48-57
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Wetland/Wetland.htm	
	Pond/Wetland System	New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.2%20print.pdf	

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Wetlands	Pond/Wetland System	New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	22-30
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	48-57
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Wetland/Wetland.htm	
	Stormwater/ Constructed Treatment Wetland	City of Eugene, Oregon	http://www.ci.eugene.or.us/pw/storm/bmp/	http://www.ci.eugene.or.us/pw/storm/bmp/Chap4pt3.pdf	
		City of Portland Environmental Services	http://www.cleanrivers-pdx.org/tech_resources/2002_swmm.htm	http://www.cleanrivers-pdx.org/tech_resources/smm/2002 Stormwater Manual/Adobe Acrobat 2/G) Chapter3- Alternative Methods.pdf	29-31
		Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-09.pdf	
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	250-257
	Pocket Wetland	New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	22-30
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Wetland/Wetland.htm	

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Ponds	Wet Pond/ Retention Basin	City of Eugene, Oregon	http://www.ci.eugene.or.us/pw/storm/bmp/	http://www.ci.eugene.or.us/pw/storm/bmp/Chap4pt3.pdf	
		California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/TC-2 .pdf	
		Dane County, Wisconsin	http://www.co.dane.wi.us/commissions/lakes/stormwatermanual.shtml	http://www.co.dane.wi.us/commissions/lakes/pdf/stormwater/ecsm_manual.pdf	62
		Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-2-1.pdf	
		U.S. Enviromental Protection Agency	http://www.epa.gov/owm/mtb/mtbfact.htm	http://www.epa.gov/owm/mtb/wetdtnpn.pdf	
		Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	4-17
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STRetenWetPond.pdf	
		Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch5.pdf	45-47
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.state.nj.us/dep/watershedmgt/DOCS/BMP_DOCS/bmpfeb2004pdfs/feb2004chap9_11.pdf	
		North Carolina Division of Water Quality	http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm#StormwaterManuals	http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/BMP_Manual.PDF	2-10

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Ponds	Wet Pond/ Retention Basin	Northern Virginia Regional Commission	http://www.novaregion.org/environmental.htm	http://www.novaregion.org/pdf/NVBMP-Handbook.pdf	68-74
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	3-21
		City of Portland Environmental Services	http://www.cleanrivers-pdx.org/tech_resources/2002_swmm.htm	http://www.cleanrivers-pdx.org/tech_resources/smm/2002 Stormwater Manual/Adobe Acrobat 2/G) Chapter3- Alternative Methods.pdf	14-28
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	33-47
		Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-06.pdf	
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	226-242
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Pond/Wet%20Pond.htm	
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp45.asp	
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp46.asp	

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Ponds	Wet Extended Detention Pond	U.S. Dept of Transportation Federal Highway Administration	http://www.fhwa.dot.gov/environment/ultraurb/	http://www.fhwa.dot.gov/environment/ultraurb/3fs4.htm	
		Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-2-1.pdf	
		Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	4-17
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STRetenExtended.pdf	
		Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch5.pdf	
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.4%20print.pdf	
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	3-21
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	33-47
		City of Portland Environmental Services	http://www.cleanrivers-pdx.org/tech_resources/2002_swmm.htm	http://www.cleanrivers-pdx.org/tech_resources/smm/2002 Stormwater Manual/Adobe Acrobat 2/G) Chapter3- Alternative Methods.pdf	14-28
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	258-264

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Ponds	Dry Extended Detention Basin	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp47.asp	
		California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/TC-22.pdf	
		Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-4-1.pdf	
		North Carolina Division of Water Quality	http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm#StormwaterManuals	http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/BMP_Manual.PDF	71-74
		Northern Virginia Regional Commission	http://www.novaregion.org/environmental.htm	http://www.novaregion.org/pdf/NVBMP-Handbook.pdf	61-67
		Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-07.pdf	
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://64.233.161.104/search?q=cache:q6MYeLNbHioJ:www.stormwatercenter.net/Assorted%2520Fact%2520Sheets/Tool6_Stormwater_Practices/Pond/Dry%2520ED%2520Pond.htm+Stormwater+management+Fact+Sheet:+Dry+Extended&hl=en&lr=&strip=0	
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp48.asp	

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Ponds	Micropool Extended Detention Pond	Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-2-1.pdf	
		Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	4-17
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	3-21
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	33-47
	Multiple Pond System	Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	4-17
		Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch5.pdf	38-39
		New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	3-21
	Multiple Pond System	Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	33-47
	Pocket Pond	Maryland Department of the Environment	http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/stormwater_design/index.asp	http://www.mde.state.md.us/assets/document/chapter3.pdf	4-17

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Ponds	Pocket Pond	New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	3-21
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	33-47
Miscellaneous	Dry Ponds/ Modified Dry Ponds	Dane County, Wisconsin	http://www.co.dane.wi.us/commissions/lakes/stormwatermanual.shtml	http://www.co.dane.wi.us/commissions/lakes/pdf/stormwater/ecsm_manual.pdf	58
		Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-4-1.pdf	
		Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch5.pdf	52-53
		City of Portland Environmental Services	http://www.cleanrivers-pdx.org/tech_resources/2002_swmm.htm	http://www.cleanrivers-pdx.org/tech_resources/smm/2002 Stormwater Manual/Adobe Acrobat 2/G) Chapter3- Alternative Methods.pdf	14-28
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	81-87
	Oil/Grit Separators/ Water Quality Inlets	Northern Virginia Regional Commission	http://www.novaregion.org/environmental.htm	http://www.novaregion.org/pdf/NVBMP-Handbook.pdf	117-120
		City of Portland Environmental Services	http://www.cleanrivers-pdx.org/tech_resources/2002_swmm.htm	http://www.cleanrivers-pdx.org/tech_resources/smm/2002 Stormwater Manual/Adobe Acrobat 2/G) Chapter3- Alternative Methods.pdf	40-43
	Oil/Grit Separators/ Water Quality inlets	Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	81-87

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Miscellaneous	Oil/Grit Separators/ Water Quality Inlets	Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	265-275
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp52.asp	
	Manufactured Treatment Devices	New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.6.pdf	
		City of Portland Environmental Services	http://www.cleanrivers-pdx.org/tech_resources/2002_swmm.htm	http://www.cleanrivers-pdx.org/tech_resources/smm/2002 Stormwater Manual/Adobe Acrobat 2/G) Chapter3- Alternative Methods.pdf	39
		Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-15.pdf	
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	284-287
	Catch Basin Inserts	Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	282-283
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp42.asp	
	Underground Storage	Northern Virginia Regional Commission	http://www.novaregion.org/environmental.htm	http://www.novaregion.org/pdf/NVBMP-Handbook.pdf	120-130
		City of Portland Environmental Services	http://www.cleanrivers-pdx.org/tech_resources/2002_swmm.htm	http://www.cleanrivers-pdx.org/tech_resources/smm/2002 Stormwater Manual/Adobe Acrobat 2/G) Chapter3- Alternative Methods.pdf	32-37
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	81-87

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Miscellaneous	Media Filters	Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	279-281
	Amended Sand Filters	Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	282
	Wetvaults	Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	243-250
	Hydrodynamic/ Swirl Concentrator Devices	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp51.asp	
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	81-87
	Vegetated Swales/ Grassed Channels	California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/TC-3 .pdf	
		Dane County, Wisconsin	http://www.co.dane.wi.us/commissions/lakes/stormwatermanual.shtml	http://www.co.dane.wi.us/commissions/lakes/pdf/stormwater/ecsm_manual.pdf	92
		Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-3-2.pdf	
		NRCS Illinois Urban Manual	http://www.il.nrcs.usda.gov/technical/engineer/urban/standards/urstnd_alpha.html	http://www.il.nrcs.usda.gov/technical/engineer/urban/standards/urbst840.html	
		U.S. Enviromental Protection Agency	http://www.epa.gov/owm/mtb/mtbfact.htm	http://www.epa.gov/owm/mtb/vegswale.pdf	
		Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch4.pdf	106-111

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Miscellaneous	Vegetated Swales/ Grassed Channels	North Carolina Division of Water Quality	http://h2o.enr.state.nc.us/su/Manuals_Factsheets.htm#StormwaterManuals	http://h2o.enr.state.nc.us/su/PDF_Files/SW_Documents/BMP_Manual.PDF	66-69
		Northern Virginia Regional Commission	http://www.novaregion.org/environmental.htm	http://www.novaregion.org/pdf/NVBMP-Handbook.pdf	136-140
		City of Portland Environmental Services	http://www.cleanrivers-pdx.org/tech_resources/2002_swmm.htm	http://www.cleanrivers-pdx.org/tech_resources/smm/2002 Stormwater Manual/Adobe Acrobat 2/G) Chapter3- Alternative Methods.pdf	8-13
		Vermont Water Quality Division	http://www.anr.state.vt.us/dec/waterq/cfm/ref/Ref_Stormwater.cfm	http://www.anr.state.vt.us/dec/waterq/stormwater/docs/sw_manual-vol1.pdf	75-81
		Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-13.pdf	
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/Open%20Channel%20Practice/Grassed%20Channel.htm	
		Spokane County	http://www.spokanecounty.org/utilities/stormwtr/	http://www.spokanecounty.org/utilities/stormwtr/swale.asp	
	Dry Wells/ Soakaway Pits/Roof Downspout System	California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/SD-11.pdf	
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STInfilOnLot.pdf	4
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.njstormwater.org/tier_A/pdf/NJ_SWBMP_9.3%20print.pdf	

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Miscellaneous	Dry Wells/ Soakaway Pits Downspout System	New York State Dept. of Environmental Conservation	http://www.dec.state.ny.us/website/dow/toolbox/swmanual/#Downloads	http://www.dec.state.ny.us/website/dow/swmanual/chapter6.pdf	31-43
		Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-10.pdf	
	Online Storage	Minnesota Pollution Control Agency	http://www.pca.state.mn.us/water/pubs/sw-bmpmanual.html	http://www.pca.state.mn.us/water/pubs/swm-ch5.pdf	36
	Green Roofs	City of Eugene, Oregon	http://www.ci.eugene.or.us/pw/storm/bmp/	http://www.ci.eugene.or.us/pw/storm/bmp/Chap2pt2.pdf	
		Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/residential.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/green-rooftops.htm	
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm/CH3_RPPImpGreenRoof.pdf	
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	112-113
		Marcy-Holmes Neighborhood Association	http://www.marcy-holmes.org/projects/rainwater/index.html	http://www.marcy-holmes.org/projects/rainwater/6.html	
		Green Roofs for Healthy Cities		http://peck.ca/grhcc/	
		Northwest EcoBuilding Guild		http://www.ecobuilding.org/proj/ecoroof/index.html	

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Miscellaneous	Porous Pavement	California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/SD-20.pdf	
		Dane County, Wisconsin	http://www.co.dane.wi.us/commissions/lakes/stormwatermanual.shtml	http://www.co.dane.wi.us/commissions/lakes/pdf/stormwater/ecsm_manual.pdf	122
		U.S. Dept. of Transportation Federal Highway Administration	http://www.fhwa.dot.gov/environment/ultraurb/	http://www.fhwa.dot.gov/environment/ultraurb/3fs15.htm	
		Georgia Stormwater Management Manual	http://www.georgiastormwater.com	http://www.georgiastormwater.com/vol2/3-3-7.pdf	
		NRCS Illinois Urban Manual	http://www.il.nrcs.usda.gov/technical/engineer/urban/standards/urstnd_alpha.html	http://www.il.nrcs.usda.gov/technical/engineer/urban/standards/urbst890.html	
		U.S. Enviromental Protection Agency	http://www.epa.gov/owm/mtb/mtbfact.htm	http://www.epa.gov/owm/mtb/porouspa.pdf	
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm/CH3_RPPImpTurfPaver.pdf	
		New Jersey Department of Environmental Protection	http://www.njstormwater.org/tier_A/bmp_manual.htm	http://www.state.nj.us/dep/watershedmgt/DOCS/BMP_DOCS/bmpfeb2004pdfs/feb2004chap9_7.pdf	
		Northern Virginia Regional Commission	http://www.novaregion.org/environmental.htm	http://www.novaregion.org/pdf/NVBMP-Handbook.pdf	110-116

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Miscellaneious	Porous Pavement	Virginia Soil & Water Conservation	http://www.dcr.state.va.us/sw/stormwat.htm	http://www.dcr.virginia.gov/sw/docs/swm/Chapter_3-10.pdf	
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	126-143
		Marcy-Holmes Neighborhood Association	http://www.marcy-holmes.org/projects/rainwater/index.html	http://www.marcy-holmes.org/projects/rainwater/5.html	
	Animal Waste Collection/ Control	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/residential.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/AnimalWasteCollection.htm	
	Car Washing	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/residential.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/CarWashing.htm	
		Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp09.asp	
	Landscaping and Lawn Care	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/residential.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/LandscapingandLawnCare.htm	
	Pest Control	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/residential.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/PestControl.htm	

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Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Miscellaneous	Automobile Maintenance	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/residential.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/AutomobileMaintenance.htm	
	Septic System Control	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/residential.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/SepticSystemControls.htm	
	Rain Barrels/ Cisterns	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/residential.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/rain_barrels.htm	
	Rain Barrels/ Cisterns	California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/SD-11.pdf	
		Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STInfilOnLot.pdf	8
		Clean Air Gardening	http://www.cleanairgardening.com/	http://www.cleanairgardening.com/rainbarrels.html	
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	114-115
		Marcy-Holmes Neighborhood Association	http://www.marcy-holmes.org/projects/rainwater/index.html	http://www.marcy-holmes.org/projects/rainwater/4.html	
	Reduced Lot Grading (Slopes)	Metropolitan Council	http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm	http://www.metrocouncil.org/environment/Watershed/BMP/CH3_STInfilOnLot.pdf	3

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Miscellaneous	Retention & Irrigation Systems	California Stormwater Quality Association	http://www.cabmphandbooks.com/Development.asp	http://www.cabmphandbooks.com/Documents/Development/TC-12.pdf	
	Septic System Control	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/municipal.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/SepticSystemControls.htm	
	Bridge and Roadway Maintenance	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/municipal.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/BridgeandRoadwayMaintenance.htm	
	Illegal Dumping Controls	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/municipal.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/IllegalDumpingControl.htm	
	Cover for Materials and Equipment	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp07.asp	
	Spill Prevention and Control	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp08.asp	
	Waste Management	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp10.asp	

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Miscellaneous	Catchbasins	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/municipal.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/CatchBasins.htm	
	Parking Lot and Street Cleaning	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool8-Stewardship/municipal.htm	http://www.stormwatercenter.net/Pollution_Prevention_Factsheets/ParkingLotandStreetCleaning.htm	
		Northern Virginia Regional Commission	http://www.novaregion.org/environmental.htm	http://www.novaregion.org/pdf/NVBMP-Handbook.pdf	131-135
		Western Washington	http://www.ecy.wa.gov/biblio/9915.html	http://www.ecy.wa.gov/pubs/9915.pdf	288
	Open Space Design	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/SiteDesign_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/open_space.htm	
	Narrower Residential Streets	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/SiteDesign_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/narrow_streets.htm	
	Green Parking	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/SiteDesign_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/GreenParking.htm	

Table C.2 Best Management Practices

Category	BMP	Information Source	Host Web site	Direct Website/PDF	Page #
Miscellaneous	Alternative Turnarounds	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/SiteDesign_mainpage.htm	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool4_Site_Design/AlternativeTurnarounds.htm	
	Stormwater Practices for Cold Climates	Stormwater Manager's Resource Center	http://www.stormwatercenter.net/Assorted%20Fact%20Sheets/Tool6_Stormwater_Practices/StormwaterPractices_mainpage.htm	http://www.stormwatercenter.net/Cold%20Climates/cold-climates.htm	
	Dust Control	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp06.asp	
	Level Spreader	Idaho Department of Environmental Quality	http://www.deq.state.id.us/water/stormwater_catalog/chapter1_3.asp	http://www.deq.state.id.us/water/stormwater_catalog/doc_bmp53.asp	
	Low Impact Development	Low Impact Development Center		http://www.lowimpactdevelopment.org/	
		U.S. Enviromental Protection Agency		http://www.epa.gov/owow/nps/lid/	

Appendix D

Construction Support

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Appendix D

Construction Support

Contents

BIORETENTION - Construction Inspection Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	
Inspector:	

Construction Sequence	Satisfactory / Unsatisfactory	Comments
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
Soil tested for permeability		
Project benchmark near site		
Facility location staked out		
Temporary erosion and sediment protection properly installed		
2. Excavation		
Lateral slopes completely level		
Soils not compacted during excavation		
Longitudinal slopes within design range		
Stockpile location not adjacent to excavation area and stabilized with vegetation and/or silt fence		
3. Structural Components		
Stone diaphragm installed per plans		
Outlets installed pre plans		
Underdrain installed to grade		
Pretreatment devices installed per plans		
Soil bed composition and texture conforms to specifications		
4. Vegetation		
Complies with planting specs		
Bioretention Construction Inspection Checklist		

Construction Sequence	Satisfactory / Unsatisfactory	Comments
Topsoil complies with specs in composition and placement		
Soil properly stabilized for permanent erosion control		
5. Final Inspection		
Dimensions per plans		
Pretreatment operational		
Inlet/outlet operational		
Soil/ filter bed permeability verified		
Effective stand of vegetation stabilized		
Construction generated sediments removed		
Contributing watershed stabilized before flow is diverted to the practice		

Comments:

Actions to be taken:

Bioretention Construction Inspection Checklist

Media Filter System - Construction Inspection Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	
Inspector:	

Construction Sequence	Satisfactory / Unsatisfactory	Comments
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
Soil tested for permeability		
Project benchmark near site		
Facility location staked out		
Temporary erosion and sediment protection properly installed		
2. Excavation		
Side slopes stable		
Foundation cleared of debris		
Excavation does not compact subsoil, if infiltration component of design		
Stockpile location not adjacent to excavation area and stabilized with vegetation and/ or silt fence		
3. Structural Components		
Materials per specifications		
Forms adequately sized		
Concrete meets standards		
Prefabricated joints sealed		
Under-drains (size, materials) per specifications		
4. Vegetation		
Contributing area stabilized with vegetation and/ or erosion blankets		
Media Filter Systems Construction Inspection Checklist		

Construction Sequence	Satisfactory / Unsatisfactory	Comments
Filter material per specification		
Under-drains installed to grade		
Flow diversion structure insalled per plans		
Pre-treatment devices installed per plans		
Level overflow weirs, multiple orifices, distribution slots		
5. Final Inspection		
Dimensions per plans		
Surface completely level		
Pre-treatment device operational		
Structural components operational		
Inlet/ outlet operational		
Contributing watershed stabilized before flow is diverted to the practice		

Comments:

Actions to be taken:

Media Filter Systems Construction Inspection Checklist

Vegetative Filter System - Construction Inspection Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	
Inspector:	

Construction Sequence	Satisfactory / Unsatisfactory	Comments
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Facility area cleared		
Project benchmark near site		
Facility location staked out		
Temporary erosion and sediment protection properly installed		
2. Excavation		
Size and location per plans		
Side slopes stable		
Soil permeability verified		
Groundwater / bedrock verified		
Lateral slopes completely level		
Longitudinal slopes within design range		
Subsoils not compacted during excavation		
Stockpile location not adjacent to excavation area and stabilized with vegetation and/ or silt fence		
3. Check Dams		
Dimensions per plans		
Spacing and grade installed per plans		
Materials per specifications		
4. Structural Components		
Filter material per specification		
Vegetative Filter Construction Inspection Checklist		

Construction Sequence	Satisfactory / Unsatisfactory	Comments
Under-drains installed to grade		
Under-drain installed per plans		
Inlet installed per plans		
Pre-treatment devices installed per plans		
5. Vegetation		
Dimensions per plans		
Check dams operational		
Inlet / outlet operational		
Effective stand of vegetation and stabilization		
Contributing watershed stabilized before flow is routed to the facility		
Comments:		
Actions to be taken:		

Vegetative Filter Construction Inspection Checklist

Infiltration Trench - Construction Inspection Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	
Inspector:	

Construction Sequence	Satisfactory / Unsatisfactory	Comments
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Soil permeability verified		
Groundwater / bedrock verified		
Project benchmark established		
Facility location staked out		
Temporary erosion and sediment control established		
2. Excavation		
Size and location per plans		
Side slopes stable		
Depth adjusted to soil layer with specified soil type and permeability		
Sub-soil not adjacent to excavation area and stabilized with vegetation and/ or silt fence		
Stockpile location not adjacent to excavation area and stabilized with vegetation and/ or silt fence		
3. Filter Fabric Placement		
Fabric per specifications		
Placed per plan location		
4. Aggregate Material		
Size as specified		
Clean / washed material		
Infiltration Trench Construction Inspection Checklist		

Construction Sequence	Satisfactory / Unsatisfactory	Comments
Placed properly		
5. Observation Well		
Pipe size per plans		
Under-drain installed per plans		
Inlet installed per plans		
Pre-treatment devices installed per plans		
6. Vegetation		
Complies with planting specifications		
Topsoil complies with composition and placement in specifications		
Permanent erosion control measures in place		
7. Final Inspection		
Dimensions per plans		
Check dams operational		
Inlet / outlet operational		
Effective stand of vegetation and stabilization		
Contributing watershed stabilized before flow is routed to the facility		

Comments:

Actions to be taken:

Infiltration Trench Construction Inspection Checklist

Infiltration Basin - Construction Inspection Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	
Inspector:	

Construction Sequence	Satisfactory / Unsatisfactory	Comments
1. Pre-Construction		
Pre-construction meeting		
Runoff diverted		
Soil permeability verified		
Groundwater / bedrock verified		
Project benchmark established		
Facility location staked out		
Temporary erosion and sediment control established		
2. Excavation		
Size and location per plans		
Side slopes stable		
Depth adjusted to soil layer with specified soil type and permeability		
Sub-soil not adjacent to excavation area and stabilized with vegetation and/ or silt fence		
Stockpile location not adjacent to excavation area and stabilized with vegetation and/ or silt fence		
3. Embankment		
Anti-seep collar or filter diaphragm per plans		
Fill material per specifications		
4. Final Excavation		
Drainage area stabilized		
Sediment removed from facility		
Infiltration Basin Construction Inspection Checklist		

Construction Sequence	Satisfactory / Unsatisfactory	Comments
Basin floor tilled		
Facility stabilized		
Removable cap / footplate per plans		
Initial depth = ________ feet		
5. Final Inspection		
Pre-treatment facility operational		
Contributing watershed stabilized prior to flow diversion		
Inlet and outlet operational		

Comments:

Actions to be taken:

Infiltration Basin Construction Inspection Checklist

Stormwater Pond/ Wetland - Construction Inspection Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	
Inspector:	

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
1. Pre-Construction/Materials and Equipment		
Pre-construction meeting		
Pipe and appurtenances on-site prior to construction and dimensions checked		
1. Material (including protective coating, if specified)		
2. Diameter		
3. Dimensions of metal riser or pre-cast concrete outlet structure		
4. Required dimensions between water control structures (orifices, weirs, etc.) are in accordance with approved plans		
5. Barrel stub for prefabricated pipe structures at proper angle for design barrel slope		
6. Number and dimensions of prefabricated anti-seep collars		
7. Watertight connectors and gaskets		
8. Outlet drain valve		
Project benchmark near pond site		
Facility location staked out		
Equipment for temporary de-watering		
Temporary erosion and sediment control in place		
2. Subgrade Preparation		
Area beneath embankment stripped of all vegetation, topsoil, and organic matter		
3. Pipe Installation		
Method of installation detailed on plans		
A. Bed preparation		
Installation trench excavated with specified side slopes		
Stormwater Pond/ Wetland Construction Inspeciton Checklist		

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
Stable, uniform, dry subgrade of relatively impervious material (If subgrade is wet, contractor shall have defined steps before proceeding with installation)		
Invert at proper elevation and grade		
B. Pipe placement		
Metal / plastic pipe		
1. Watertight connectors and gaskets properly installed		
2. Anti-seep collars properly spaced and having watertight connections to pipe		
3. Backfill placed and tamped by hand under "haunches" of pipe		
4. Remaining backfill placed in max. 8 inch lifts using small power tamping equipment until 2 feet cover over pipe is reached		
Concrete pipe		
1. Pipe set on blocks or concrete slab for pouring of low cradle		
2. Pipe installed with rubber gasket joints with no spalling in gasket interface area		
3. Excavation for lower half of anti-seep collar(s) with reinforcing steel set		
4. Entire area where anti-seep collar(s) will come in contact with pipe coated with mastic or other approved waterproof sealant		
5. Low cradle and bottom half of anti-seep collar installed as monolithic pour and of an approved mix		
6. Upper half of anti-seep collar(s) formed with reinforcing steel set		
7. Concrete for collar of an approved mix and vibrated into place (protected from freezing while curing, if necessary)		
8. Forms stripped and collar inspected for honeycomb prior to backfilling. Parge if necessary.		
C. Backfilling		
Fill placed in maximum 8 inch lifts		

Stormwater Pond/ Wetland Construction Inspeciton Checklist

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
Backfill taken minimum 2 feet above top of anti-seep collar elevation before traversing with heavy equipment		
4. Riser / Outlet Structure Installation		
Riser located within embankment		
A. Metal riser		
Riser base excavated or formed on stable subgrade to design dimensions		
Set on blocks to design elevations and plumbed		
Reinforcing bars placed at right angles and projecting into sides of riser		
Concrete poured so as to fill inside of riser to invert of barrel		
B. Pre-cast concrete structure		
Dry and stable subgrade		
Riser base set to design elevation		
If more than one section, no spalling in gasket interface area; gasket or approved caulking material placed securely		
Watertight and structurally sound collar or gasket joint where structure connects to pipe spillway		
C. Poured concrete structure		
Footing excavated or formed on stable subgrade, to design dimensions with reinforcing steel set		
Structure formed to design dimensions, with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place (protected from freezing while curing, if necessary)		
Forms stripped & inspected for honeycomb prior to backfilling; parge if necessary		
5. Embankment Construction		
Fill material		
Compaction		
Embankment		
1. Fill placed in specified lifts and compacted with appropriate equipment		
2. Constructed to design cross-section, side slopes and top width		

Stormwater Pond/ Wetland Construction Inspeciton Checklist

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
3. Constructed to design elevation plus allowance for settlement		
6. Impounded Area Construction		
Excavated / graded to design contours and side slopes		
Inlet pipes have adequate outfall protection		
Forebay(s) constructed per plans		
Pond benches construction per plans		
7. Earth Emergency Spillway Construction		
Spillway located in cut or structurally stabilized with riprap, gabions, concrete, etc.		
Excavated to proper cross-section, side slopes and bottom width		
Entrance channel, crest, and exit channel constructed to design grades and elevations		
8. Outlet Protection		
A. End section		
Securely in place and properly backfilled		
B. Endwall		
Footing excavated or formed on stable subgrade, to design dimensions and reinforcing steel set, if specified		
Endwall formed to design dimensions with reinforcing steel set as per plan		
Concrete of an approved mix and vibrated into place (protected from freezing, if necessary)		
Forms stripped and structure inspected for honeycomb prior to backfilling; parge if necessary		
C. Riprap apron / channel		
Apron / channel excavated to design cross-section with proper transition to existing ground		
Filter fabric in place		
Stone sized as per plan and uniformly place at the thickness specified		
9. Vegetative Stabilization		
Approved seed mixture or sod		

Stormwater Pond/ Wetland Construction Inspeciton Checklist

Construction Sequence	Satisfactory/ Unsatisfactory	Comments
Proper surface preparation and required soil mendments		
Excelsior mat or other stabilization, as per plan		
10. Miscellaneous		
Drain for ponds having a permanent pool		
Trash rack / anti-vortex device secured to outlet structure		
Trash protection for low flow pipes, orifices, etc.		
Fencing (when required)		
Access road		
Set aside for clean-out maintenance		
11. Stormwater Wetlands		
Adequate water balance		
Variety of depth zones present		
Approved pondscaping plan in place and budget for additional plantings		
Plants and materials ordered 6 months prior to construction		
Construction planned to allow for adequate planting and establishment of plant community (April-June planting window)		
12. Final Inspection		
Construction sediment removed from settling basin		
Contributing drainage area stabilized		
Vegetation established per specifications		
Inlet and outlet structures operational		
Comments:		
Actions to be Taken:		

Stormwater Pond/ Wetland Construction Inspeciton Checklist

BIORETENTION - Operation & Maintenance Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	
Inspector:	

MAINTENANCE ITEM	SATISFACTORY / UNSATISFACTORY	COMMENTS
1. Debris Cleanout (Monthly)		
Contributing areas clean of litter and vegetative debris		
No dumping of yard wastes into practice		
Bioretention area clean of litter and vegetative debris		
2. Vegetation (Monthly)		
Plant height taller than design water depth		
Fertilized per O&M plan		
Plant composition according to O&M plan		
Undesirable vegetation removed		
Grass height less than 6 inches		
No evidence of erosion		
3. Check Dams/Energy Dissipators/Sumps (Annual, After Major Storms)		
No evidence of sediment buildup		
Sumps should not be more than 50% full of sediment		
No evidence of erosion at downstream toe of drop structure		
4. Dewatering (Monthly)		
Dewaters between storms within 48 hours		
No evidence of standing water		
5. Sediment Deposition (Annual)		
Pretreatment areas clean of sediments		

Bioretention Operation, Maintenance and Management Inspection Checklist

Maintenance Item	Satisfactory / Unsatisfactory	Comments
Contributing drainage area stabilized and clear of erosion		
Winter sand deposition evacuated every spring		
6. Outlet/Overflow Spillway (Annual, After Major Storms)		
Good condition, no need for repair		
No evidence of erosion		
No evidence of any blockages		
7. Integrity of Filter Bed (Annual)		
Filter bed has not been blocked or filled inappropriately		

Comments:

Actions to be Taken:

Bioretention Operation, Maintenance and Management Inspection Checklist

Media Filter System - Operation & Maintenance Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	

Maintenance Item	Satisfactory / Unsatisfactory	Comments
1. Debris Cleanout (Monthly)		
Contributing areas clean of litter and vegetative debris		
Filtration facility clean		
Inlet and outlets clear		
2. Oil and Grease (Monthly)		
No evidence of filter surface clogging		
Activities in drainage area minimize oil and grease entry		
3. Vegetation (Monthly)		
Contributing drainage area stabilized		
Undesirable vegetation removed		
No evidence of erosion		
Area mowed and clipping removed		
4. Sediment Traps and Forebays (Monthly)		
Water holding chambers at normal pool		
No evidence of leakage		
Obviously trapping sediment		
Greater than 50% storage volume remaining		
5. Sediment Deposition (Annual)		
Filter chamber free of sediments		
Contributing drainage area stabilized and free of erosion		
6. Structural Components (Annual)		
Media Filter Operation, Maintenance and Management Inspection Checklist		

Maintenance Item	Satisfactory / Unsatisfactory	Comments
No evidence of structural deterioration		
Any grates are in good condition		
No evidence of spalling or cracking of structural parts		
7. Outlet/Overflow Spillway (Annual)		
Good condition, no need for repairs		
No evidence of erosion (if draining into a natural channel)		
No evidence of blockages		
8. Overall Function of Facility (Annual)		
Evidence of flow bypassing facility		
No noticeable odors outside of facility		

Comments:

Actions to be Taken:

Media Filter Operation, Maintenance and Management Inspection Checklist

Vegatative Filter System - Operation & Maintenance Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	
Inspector:	

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
1. Debris Cleanout (Monthly)		
Contributing areas clean of litter and vegetative debris		
Inlet and outlet clear		
Filtration facility clean		
2. Check Dams or Energy Dissipators (Annual, After Major Storms)		
No evidence of flow going around structures		
No evidence of erosion at downstream toe		
3. Vegetation (Monthly)		
Mowing done per O&M plan		
Minimum mowing depth not exceeded		
Undesirable vegetation removed		
No evidence of erosion		
Fertilized per O&M plan		
4. Dewatering (Monthly)		
Dewaters between storms within 48 hours		
5. Sediment deposition (Annual)		
Clean of sediment		
Winter accumulation of sand removed each spring		
Contributing drainage area stabilized and free of erosion		
6. Outlet/Overflow Spillway (Annual)		
Good condition, no need for repairs		
No evidence of erosion		

Vegetative Filter Operation, Maintenance and Management Inspection Checklist

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
No evidence of blockage		
Comments:		
Actions to be Taken:		

Vegetative Filter Operation, Maintenance and Management Inspection Checklist

Infiltration Trench/ Basin - Operation & Maintenance Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	
Inspector:	

Maintenance Item	Satisfactory / Unsatisfactory	Comments
1. Debris Cleanout (Monthly)		
Contributing drainage area clear of litter and vegetative debris		
Trench surface clean		
Inflow pipes clear		
Overflow spillway clear		
Inlet area clean		
2. Sediment Traps or Forebays (Annual)		
Obviously trapping sediment		
Greater than 50% of storage volume remaining		
3. Dewatering (Monthly)		
Trench dewaters between storms		
4. Vegetation (Monthly)		
Mowing done per O&M plan		
Minimum mowing depth not exceeded		
Undesirable vegetation removed		
No evidence of erosion		
Fertilized per O&M plan		
5. Sediment Cleanout of Trench (Annual)		
No evidence of sedimentation in gravel filter		
Sediment accumulation doesn't yet require cleanout		
6. Sediment deposition of Basin (Annual)		
Clean of sediment		
Infiltration Trench/ Basin Operation, Maintenance, and Management Inspection Checklist		

Maintenance Item	Satisfactory / Unsatisfactory	Comments
Winter accumulation of sand removed each spring		
Contributing drainage area stabilized and free of erosion		
7. Inlets (Annual)		
Good condition		
No evidence of erosion		
8. Outlet/Overflow Spillway (Annual)		
Good condition, no need for repair		
No evidence of erosion		
9. Aggregate Repairs (Annual)		
Surface of aggregate clean		
Top layer of stone does not need replacement		
Trench does not need rehabilitation		

Comments:

Actions to be Taken:

Infiltration Trench/ Basin Operation, Maintenance, and Management Inspection Checklist

Stormwater Pond/ Wetland Operation & Maintenance Checklist

Project:	
Location:	
Site Status:	
Date:	
Time:	
Inspector:	

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
1. Embankment and emergency spillway (Annual, After Major Storms)		
1. Vegetation and ground cover adequate		
2. Embankment erosion		
3. Animal burrows		
4. Unauthorized planting		
5. Cracking, bulging, or sliding of embankment		
a. Upstream face		
b. Downstream face		
c. At or beyond toe		
downstream		
upstream		
d. Emergency spillway		
6. Pond, toe & chimney drains clear and functioning		
7. Seeps/leaks on downstream face		
8. Slope protection or riprap failure		
9. Vertical/horizontal alignment of top of dam “As-Built”		
10. Emergency spillway clear of obstructions and debris		
11. Other (specify)		
Stormwater Pond/ Wetland Operation, Maintenance, and Management Inspection Checklist		

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
2. Riser and principal spillway (Annual)		
Type: Reinforced concrete _______ Corrugated pipe _______ Masonry _______ 1. Low flow orifice obstructed		
2. Low flow trash rack. a. Debris removal necessary		
b. Corrosion control		
3. Weir trash rack maintenance a. Debris removal necessary		
b. corrosion control		
4. Excessive sediment accumulation insider riser		
5. Concrete/masonry condition riser and barrels a. cracks or displacement		
b. Minor spalling (<1")		
c. Major spalling (rebars exposed)		
d. Joint failures		
e. Water tightness		
6. Metal pipe condition		
7. Control valve a. Operational/exercised		
b. Chained and locked		
8. Pond drain valve a. Operational/exercised		
b. Chained and locked		
9. Outfall channels functioning		
10. Other (specify)		
Stormwater Pond/ Wetland Operation, Maintenance and Management Inspection Checklist		

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
3. Permanent Pool (Wet Ponds) (Monthly)		
1. Undesirable vegetative growth		
2. Floating or floatable debris removal required		
3. Visible pollution		
4. Shoreline problem		
5. Other (specify)		
4. Sediment Forebays		
1.Sedimentation noted		
2. Sediment cleanout when depth < 50% design depth		
5. Dry Pond Areas		
1. Vegetation adequate		
2. Undesirable vegetative growth		
3. Undesirable woody vegetation		
4. Low flow channels clear of obstructions		
5. Standing water or wet spots		
6. Sediment and / or trash accumulation		
7. Other (specify)		
6. Condition of Outfalls (Annual , After Major Storms)		
1. Riprap failures		
2. Slope erosion		
3. Storm drain pipes		
4.Endwalls / Headwalls		
5. Other (specify)		
7. Other (Monthly)		
1. Encroachment on pond, wetland or easement area		
2. Complaints from residents		
3.Aesthetics a. Grass growing required		
b. Graffiti removal needed		
c. Other (specify)		
4. Conditions of maintenance access routes.		
5. Signs of hydrocarbon build-up		
6. Any public hazards (specify)		
8. Wetland Vegetation (Annual)		

Stormwater Pond/ Wetland Operation, Maintenance and Management Inspection Checklist

Maintenance Item	Satisfactory/ Unsatisfactory	Comments
1. Vegetation healthy and growing Wetland maintaining 50% surface area coverage of wetland plants after the second growing season. (If unsatisfactory, reinforcement plantings needed)		
2. Dominant wetland plants: Survival of desired wetland plant species Distribution according to landscaping plan?		
3. Evidence of invasive species		
4. Maintenance of adequate water depths for desired wetland plant species		
5. Harvesting of emergent plantings needed		
6. Have sediment accumulations reduced pool volume significantly or are plants "choked" with sediment		
7. Eutrophication level of the wetland.		
8. Other (specify)		

Comments:

Actions to be Taken:

Stormwater Pond/ Wetland Operation, Maintenance and Management Inspection Checklist

BIORETENTION DEVICE
COST ESTIMATE WORKSHEET
2005 Prices

Project Title ______________________

Owner ______________________

Location ______________________

Project Number ______________________

Date ______________________

Description	Units	Quantity	Unit Cost	Total Estimated Price
Site Preparation				
Tree removal - up to 12" diameter	each		$350.00	$0.00
Clear and grub brush	square yard		$1.50	$0.00
Tree protection - temp. fence	lineal foot		$3.00	$0.00
Topsoil - salvage	square yard		$4.50	$0.00
Site Formation				
Excavation - 4' average depth	square yard		$10.00	$0.00
Grading	square yard		$1.50	$0.00
Hauling off-site	square yard		$6.50	$0.00
Structural Components				
Underdrain - with pea gravel and geotextile	lineal foot		$30.00	$0.00
Inlet structure	each		$1,500.00	$0.00
Outlet structure	each		$2,500.00	$0.00
Site Restoration				
Filter strip	square yard			$0.00
Soil preparation	square yard		$30.00	$0.00
Seeding - above outlet elevation	square yard		$0.50	$0.00
Planting - below outlet elevation	square yard		$30.00	$0.00
Mulch	square yard		$5.00	$0.00
			Subtotal	$0.00
			10% Contingencies	$0.00
			Subtotal	$0.00
			Apply MN Location Factor	
			TOTAL CONSTRUCTION COST	$0.00

Description	Units	Quantity	Unit Cost	Total Estimated Price
Annual Operation and Maintenance				
Debris removal	per visit		$50.00	$0.00
Weed control	per visit		$50.00	$0.00
Sediment removal	per year		$500.00	$0.00
Replace planting media	square yard		$12.00	$0.00
Replace plants	per plant		$5.00	$0.00
Mow filter strips	per visit		$50.00	$0.00
Erosion repair	square yard		$75.00	$0.00
Inspection	per visit		$125.00	$0.00
			Subtotal	$0.00
			Apply MN Location Factor	
			TOTAL ANNUAL O&M COST	$0.00

Minnesota Location Factors	
Bemidji	0.963
Brainerd	1.003
Detroit Lakes	0.962
Duluth	0.991
Mankato	0.990
Minneapolis	1.035
Rochester	0.983
St. Paul	1.000
St. Cloud	1.002
Thief River Falls	1.042
Willmar	0.961
Windom	0.935

Note: Suggested unit costs are based on RSMeans prices for Spring, 2005, then factored into an area basis based on typical design features for Bioretention BMPs. To be used for preliminary cost estimation.

SURFACE SAND FILTER
COST ESTIMATE WORKSHEET
2005 Prices

Project Title ______________________

Owner ______________________

Location ______________________

Project Number ______________________

Date ______________________

Description	Units	Quantity	Unit Cost	Total Estimated Price
Site Preparation				
Tree removal - up to 12" diameter	each		$350.00	$0.00
Clear and grub brush	square yard		$1.50	$0.00
Tree protection - temp. fence	lineal foot		$3.00	$0.00
Topsoil - 6" depth, salvage on site	square yard		$4.50	$0.00
Site Formation				
Excavation - 6' depth	square yard		$8.00	$0.00
Grading	square yard		$1.50	$0.00
Hauling off-site - 6' depth	square yard		$10.00	$0.00
Structural Components				
Underdrain - with pea gravel and geotextile	square yard		$400.00	$0.00
Inlet structure	each		$1,500.00	$0.00
Sand filter media - 18" depth	square yard		$15.00	$0.00
Outlet structure	each		$3,000.00	$0.00
Site Restoration				
Sod filter strip	lineal foot		$1.50	$0.00
Soil preparation	square yard		$5.00	$0.00
Seeding	square yard		$0.50	$0.00
			Subtotal	$0.00
			10% Contingencies	$0.00
			Subtotal	$0.00
			Apply MN Location Factor	
			TOTAL CONSTRUCTION COST	$0.00

Description	Units	Quantity	Unit Cost	Total Estimated Price
Annual Operation and Maintenance				
Debris removal	per visit		$50.00	$0.00
Mowing	per visit		$150.00	$0.00
Sediment removal	per year		$500.00	$0.00
Gate / valve operation	per visiit		$125.00	$0.00
Erosion repair	square yard		$75.00	$0.00
Inspection	per visit		$125.00	$0.00
			Subtotal	$0.00
			Apply MN Location Factor	
			TOTAL ANNUAL O&M COST	$0.00

Minnesota Location Factors	
Bemidji	0.963
Brainerd	1.003
Detroit Lakes	0.962
Duluth	0.991
Mankato	0.990
Minneapolis	1.035
Rochester	0.983
St. Paul	1.000
St. Cloud	1.002
Thief River Falls	1.042
Willmar	0.961
Windom	0.935

Note: Suggested unit costs are based on RSMeans prices for Spring, 2005, then factored into an area basis based on typical design features for Media Filtration BMPs. To be used for preliminary cost estimation.

INFILTRATION BASIN
COST ESTIMATE WORKSHEET
2005 Prices

Project Title ______________________

Owner ______________________

Location ______________________

Project Number ______________________

Date ______________________

Description	Units	Quantity	Unit Cost	Total Estimated Price
Site Preparation				
Tree removal - up to 12" diameter	each		$350.00	$0.00
Clear and grub brush	square yard		$1.50	$0.00
Tree protection - temp. fence	lineal foot		$3.00	$0.00
Infiltration area protection - silt fence	lineal foot		$2.00	$0.00
Topsoil - 6" depth, salvage on site	square yard		$4.50	$0.00
Site Formation				
Excavation - 6' depth	square yard		$8.00	$0.00
Grading	square yard		$1.50	$0.00
Hauling off-site - 6' depth	square yard		$10.00	$0.00
Structural Components				
Inlet structure	each		$1,500.00	$0.00
Multi-stage outlet structure	each		$2,500.00	$0.00
Site Restoration				
Sod filter strip	lineal foot		$1.50	$0.00
Soil preparation	square yard		$5.00	$0.00
Seeding	square yard		$0.50	$0.00
Planting - below outlet elevation	square yard		$30.00	$0.00
Mulch	square yard		$2.00	$0.00
			Subtotal	$0.00
			10% Contingencies	$0.00
			Subtotal	$0.00
			Apply MN Location Factor	
			TOTAL CONSTRUCTION COST	$0.00

Annual Operation and Maintenance				
Replace planting media	square yard		$12.00	$0.00
Debris removal	per visit		$50.00	$0.00
Mow filter strips	per visit		$50.00	$0.00
Sediment removal	per year		$500.00	$0.00
Replace plants	per plant		$5.00	$0.00
Erosion repair	square yard		$75.00	$0.00
Gate / valve operation	per visit		$125.00	$0.00
Inspection	per visit		$125.00	$0.00
			Subtotal	$0.00
			Apply MN Location Factor	
			TOTAL ANNUAL O&M COST	$0.00

Minnesota Location Factors	
Bemidji	0.963
Brainerd	1.003
Detroit Lakes	0.962
Duluth	0.991
Mankato	0.990
Minneapolis	1.035
Rochester	0.983
St. Paul	1.000
St. Cloud	1.002
Thief River Falls	1.042
Willmar	0.961
Windom	0.935

Note: Suggested unit costs are based on RSMeans prices for Spring, 2005, then factored into an area basis based on typical design features for Infiltration Basin BMPs. To be used for preliminary cost estimation.

STORMWATER POND
COST ESTIMATE WORKSHEET
2005 Prices

Project Title	
Owner	
Location	
Project Number	
Date	

Description	Units	Quantity	Unit Cost	Total Estimated Price
Site Preparation				
Tree removal - up to 12" diameter	each		$350.00	$0.00
Clear and grub brush	square yard		$1.50	$0.00
Tree protection - temp. fence	lineal foot		$3.00	$0.00
Topsoil - 6" depth, salvage on site	square yard		$4.50	$0.00
Site Formation				
Excavation - 8' depth	square yard		$10.00	$0.00
Grading	square yard		$1.50	$0.00
Hauling off-site - 8' depth	square yard		$10.00	$0.00
Structural Components				
Inlet structure	each		$2,000.00	$0.00
Overflow structure	each		$3,500.00	$0.00
Site Restoration				
Sod - above vegetative bench	square yard		$4.50	$0.00
Soil preparation	square yard		$5.00	$0.00
Seeding - vegetative bench	square yard		$0.50	$0.00
Mulch	square yard		$1.00	$0.00
			Subtotal	$0.00
			10% Contingencies	$0.00
			Subtotal	$0.00
			Apply MN Location Factor	
			TOTAL CONSTRUCTION COST	$0.00

Annual Operation and Maintenance				
Debris removal	per visit		$100.00	$0.00
Remove invasive plants	per visit		$500.00	$0.00
Replant wetland vegetation	per plant		$10.00	$0.00
Repair erosion	square yard		$75.00	$0.00
Sediment removal and disposal	cubic yard		$10.00	$0.00
Mow	per visit		$150.00	$0.00
Gate / valve operation	per visit		$125.00	$0.00
Inspection	per visit		$125.00	$0.00
			Subtotal	$0.00
			Apply MN Location Factor	
			TOTAL ANNUAL O&M COST	$0.00

Minnesota Location Factors	
Bemidji	0.963
Brainerd	1.003
Detroit Lakes	0.962
Duluth	0.991
Mankato	0.990
Minneapolis	1.035
Rochester	0.983
St. Paul	1.000
St. Cloud	1.002
Thief River Falls	1.042
Willmar	0.961
Windom	0.935

Note: Suggested unit costs are based on RSMeans prices for Spring, 2005, then factored into an area basis based on typical design features for Stormwater Ponds BMPs. To be used for preliminary cost estimation.

STORMWATER WETLAND
COST ESTIMATE WORKSHEET
2005 Prices

Project Title ______________________

Owner ______________________

Location ______________________

Project Number ______________________

Date ______________________

Description	Units	Quantity	Unit Cost	Total Estimated Price
Site Preparation				
Tree removal - up to 12" diameter	each	------------	$350.00	$0.00
Clear and grub brush	square yard	------------	$1.50	$0.00
Tree protection - temp. fence	lineal foot	------------	$3.00	$0.00
Topsoil - 6" depth, salvage on site	square yard	------------	$4.50	$0.00
Site Formation				
Excavation - deepwater zone - 4' average depth	square yard	------------	$5.00	$0.00
Excavation - marsh zone - 1' average depth	square yard	------------	$1.00	$0.00
Grading	square yard	------------	$1.50	$0.00
Hauling off-site - 5' depth	square yard	------------	$5.00	$0.00
Structural Components		------------		
Inlet structure	each	------------	$2,000.00	$0.00
Outlet structure	each	------------	$3,500.00	$0.00
Site Restoration				
Sod - above vegetative bench	square yard	------------	$4.50	$0.00
Soil preparation	square yard	------------	$25.00	$0.00
Seeding - vegetative bench	square yard	------------	$0.50	$0.00
Planting	square yard	------------	$30.00	$0.00
			Subtotal	$0.00
			10% Contingencies	$0.00
			Subtotal	$0.00
			Apply MN Location Factor	
			TOTAL CONSTRUCTION COST	$0.00

Description	Units	Quantity	Unit Cost	Total Estimated Price
Annual Operation and Maintenance				
Debris removal	per visit	------------	$100.00	$0.00
Remove invasive plants	per visit	------------	$500.00	$0.00
Replant wetland vegetation	per plant	------------	$10.00	$0.00
Repair erosion	square yard	------------	$75.00	$0.00
Sediment removal and disposal	cubic yard	------------	$10.00	$0.00
Mow	per visit	------------	$150.00	$0.00
Gate / valve operation	per visit	------------	$125.00	$0.00
Inspection	per visit	------------	$125.00	$0.00
			Subtotal	$0.00
			Apply MN Location Factor	
			TOTAL ANNUAL O&M COST	$0.00

Minnesota Location Factors	
Bemidji	0.963
Brainerd	1.003
Detroit Lakes	0.962
Duluth	0.991
Mankato	0.990
Minneapolis	1.035
Rochester	0.983
St. Paul	1.000
St. Cloud	1.002
Thief River Falls	1.042
Willmar	0.961
Windom	0.935

Note: Suggested unit costs are based on RSMeans prices for Spring, 2005, then factored into an area basis based on typical design features for Constructed Wetlands BMPs. To be used for preliminary cost estimation.

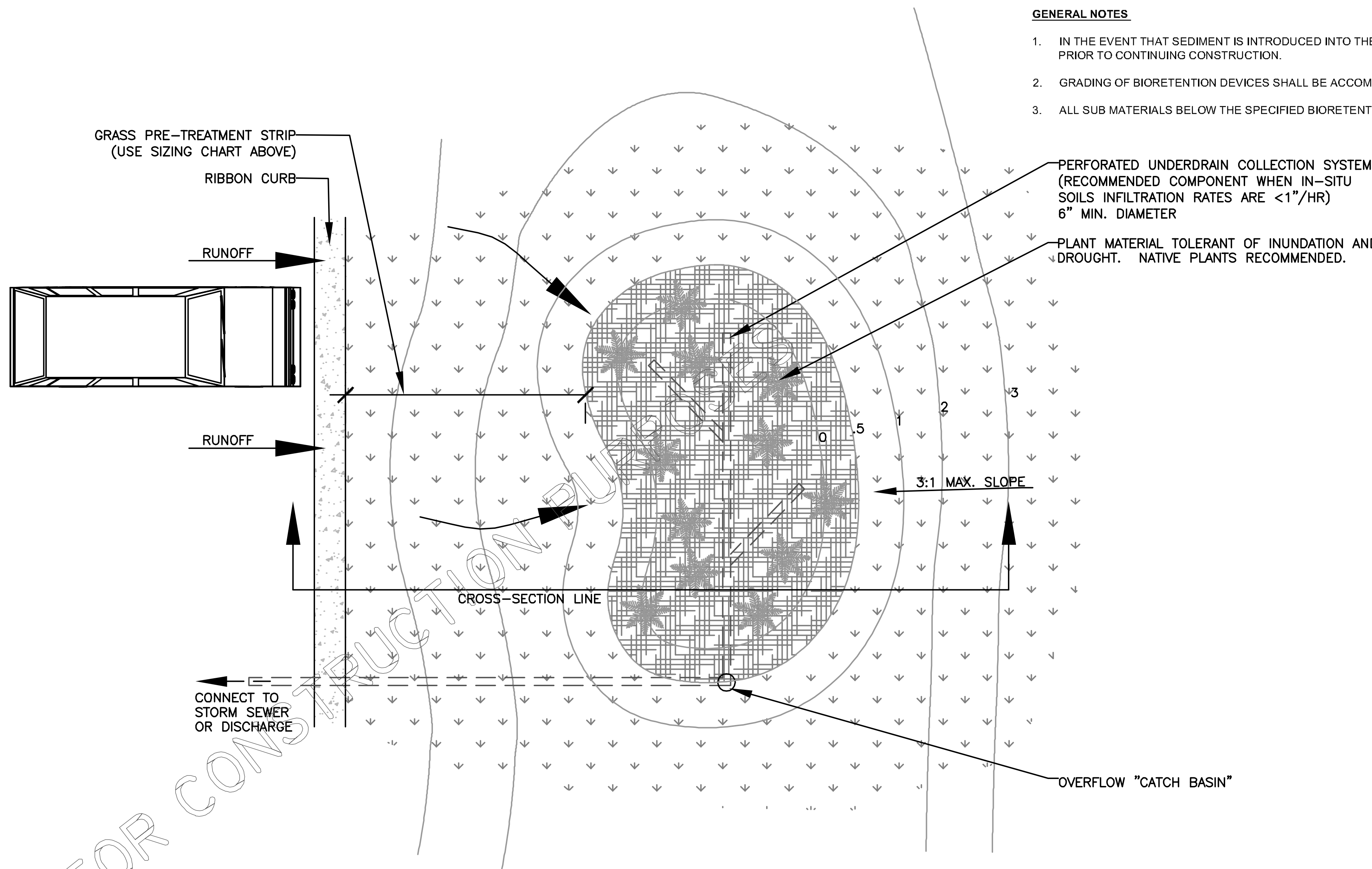
CONSTRUCTION SEQUENCING

1. INSTALL SILT FENCE AND/OR OR OTHER APPROPRIATE TEMPORARY EROSION CONTROL DEVICES TO PREVENT SEDIMENT FROM LEAVING OR ENTERING THE PRACTICE DURING CONSTRUCTION.
2. ALL DOWN-GRADIENT PERIMETER SEDIMENT CONTROL BMP'S MUST BE IN PLACE BEFORE ANY UP GRADIENT LAND DISTURBING ACTIVITY BEGINS.
3. PERFORM CONTINUOUS INSPECTIONS OF EROSION CONTROL PRACTICES.
4. INSTALL UTILITIES (WATER, SANITARY SEWER, ELECTRIC, PHONE, FIBER OPTIC, ETC) PRIOR TO SETTING FINAL GRADE OF BIORETENTION DEVICE.
5. ROUGH GRADE THE SITE. IF BIORETENTION AREAS ARE BEING USED AS TEMPORARY SEDIMENT BASINS LEAVE A MINIMUM OF 3 FEET OF COVER OVER THE PRACTICE TO PROTECT THE UNDERLYING SOILS FROM CLOGGING.
6. PERFORM ALL OTHER SITE IMPROVEMENTS.
7. SEED AND MULCH ALL AREAS AFTER DISTURBANCE.
8. CONSTRUCT BIORETENTION DEVICE UPON STABILIZATION OF CONTRIBUTING DRAINAGE AREA.
9. IMPLEMENT TEMPORARY AND PERMENATE EROSION CONTROL PRACTICES.
10. PLANT AND MULCH BIORETENTION DEVICE.
11. REMOVE TEMPORARY EROSION CONTROL DEVICES AFTER THE CONTRIBUTING DRAINAGE AREA IS ADEQUATELY VEGETATED.

GENERAL NOTES

1. IN THE EVENT THAT SEDIMENT IS INTRODUCED INTO THE BMP DURING OR IMMEDIATELY FOLLOWING EXCAVATION, THIS MATERIAL SHALL BE REMOVED FROM THE PRACTICE PRIOR TO CONTINUING CONSTRUCTION.
2. GRADING OF BIORETENTION DEVICES SHALL BE ACCOMPLISHED USING LOW-COMPACTION EARTH-MOVING EQUIPMENT TO PREVENT COMPACTION OF UNDERLYING SOILS.
3. ALL SUB MATERIALS BELOW THE SPECIFIED BIORETENTION DEPTH (ELEVATION) SHALL BE UNDISTURBED, UNLESS OTHERWISE NOTED.

GRASS PRE-TREATMENT STRIP SIZING CHART



BIORETENTION FACILITIES GENERAL PLAN

NOT TO SCALE

NO.	REVISION DESCRIPTION	DATE	BY

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Print Name:

Sign Name:

Date ____ License No.

Date

Designed By

Drawn By

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520 Lafayette Road
St. Paul, MN 55155-4194
Phone: (651)-296-6300
TTY: (651)-282-5332
WEBSITE:www.pca.state.mn.us/

2005 MINNESOTA STORMWATER MANUAL

BIORETENTION FACILITIES GENERAL PLAN

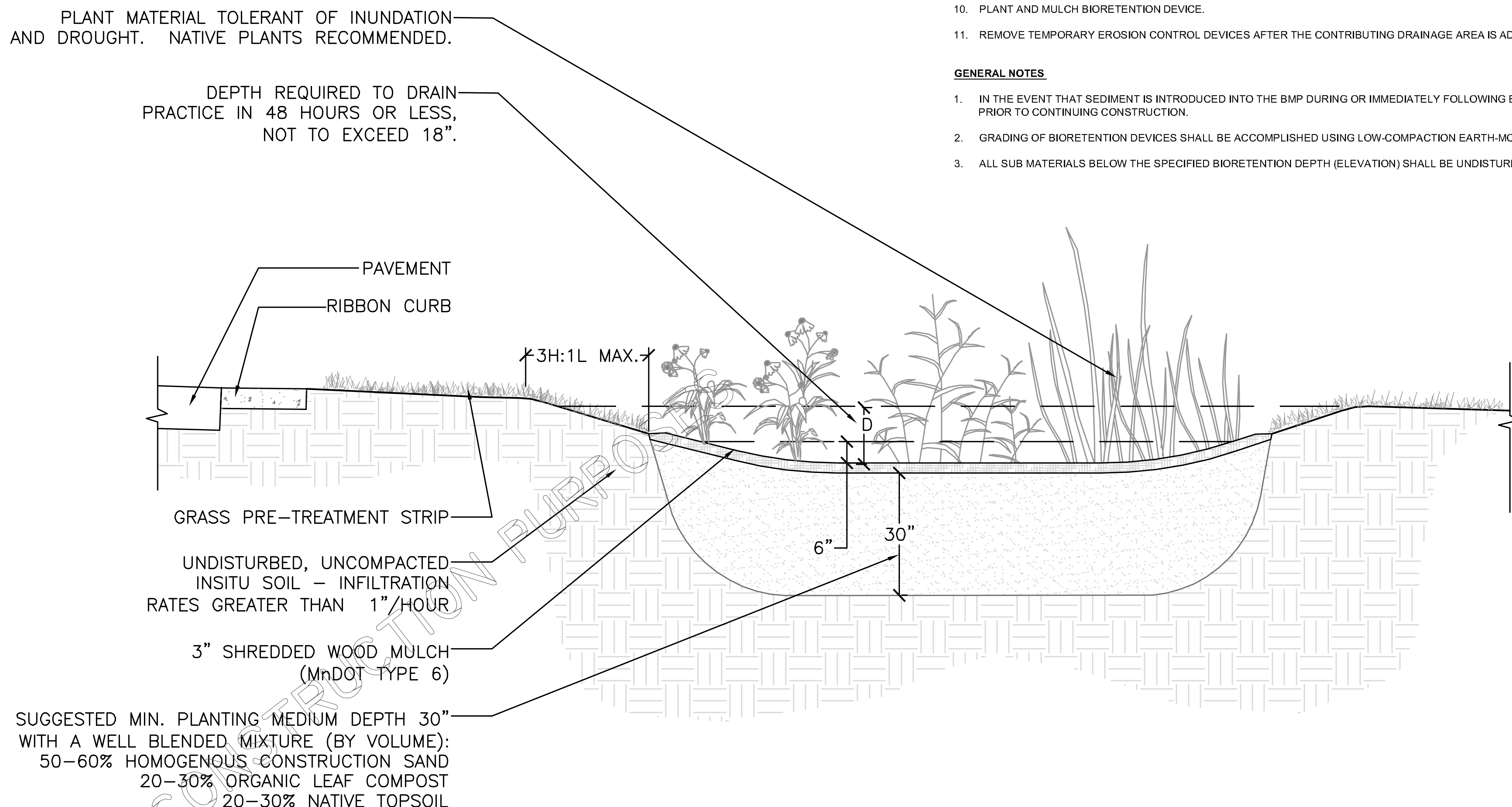
Sheet No. of Sheets

CONSTRUCTION SEQUENCING

1. INSTALL SILT FENCE AND/OR OR OTHER APPROPRIATE TEMPORARY EROSION CONTROL DEVICES TO PREVENT SEDIMENT FROM LEAVING OR ENTERING THE PRACTICE DURING CONSTRUCTION.
2. ALL DOWN-GRADIENT PERIMETER SEDIMENT CONTROL BMP'S MUST BE IN PLACE BEFORE ANY UP GRADIENT LAND DISTURBING ACTIVITY BEGINS.
3. PERFORM CONTINUOUS INSPECTIONS OF EROSION CONTROL PRACTICES.
4. INSTALL UTILITIES (WATER, SANITARY SEWER, ELECTRIC, PHONE, FIBER OPTIC, ETC) PRIOR TO SETTING FINAL GRADE OF BIORETENTION DEVICE.
5. ROUGH GRADE THE SITE. IF BIORETENTION AREAS ARE BEING USED AS TEMPORARY SEDIMENT BASINS LEAVE A MINIMUM OF 3 FEET OF COVER OVER THE PRACTICE TO PROTECT THE UNDERLYING SOILS FROM CLOGGING.
6. PERFORM ALL OTHER SITE IMPROVEMENTS.
7. SEED AND MULCH ALL AREAS AFTER DISTURBANCE.
8. CONSTRUCT BIORETENTION DEVICE UPON STABILIZATION OF CONTRIBUTING DRAINAGE AREA.
9. IMPLEMENT TEMPORARY AND PERMENATE EROSION CONTROL PRACTICES.
10. PLANT AND MULCH BIORETENTION DEVICE.
11. REMOVE TEMPORARY EROSION CONTROL DEVICES AFTER THE CONTRIBUTING DRAINAGE AREA IS ADEQUATELY VEGETATED.

GENERAL NOTES

1. IN THE EVENT THAT SEDIMENT IS INTRODUCED INTO THE BMP DURING OR IMMEDIATELY FOLLOWING EXCAVATION, THIS MATERIAL SHALL BE REMOVED FROM THE PRACTICE PRIOR TO CONTINUING CONSTRUCTION.
2. GRADING OF BIORETENTION DEVICES SHALL BE ACCOMPLISHED USING LOW-COMPACTION EARTH-MOVING EQUIPMENT TO PREVENT COMPACTION OF UNDERLYING SOILS.
3. ALL SUB MATERIALS BELOW THE SPECIFIED BIORETENTION DEPTH (ELEVATION) SHALL BE UNDISTURBED, UNLESS OTHERWISE NOTED.



INFILTRATION/ RECHARGE FACILITY CROSS-SECTION

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BIORETENTION INFILTRATION/ RECHARGE FACILITIY

Sheet No. of Sheets

CONSTRUCTION SEQUENCING

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3. PERFORM CONTINUOUS INSPECTIONS OF EROSION CONTROL PRACTICES.
4. INSTALL UTILITIES (WATER, SANITARY SEWER, ELECTRIC, PHONE, FIBER OPTIC, ETC) PRIOR TO SETTING FINAL GRADE OF BIORETENTION DEVICE.
5. ROUGH GRADE THE SITE. IF BIORETENTION AREAS ARE BEING USED AS TEMPORARY SEDIMENT BASINS LEAVE A MINIMUM OF 3 FEET OF COVER OVER THE PRACTICE TO PROTECT THE UNDERLYING SOILS FROM CLOGGING.
6. PERFORM ALL OTHER SITE IMPROVEMENTS.
7. SEED AND MULCH ALL AREAS AFTER DISTURBANCE.
8. CONSTRUCT BIORETENTION DEVICE UPON STABILIZATION OF CONTRIBUTING DRAINAGE AREA.
9. IMPLEMENT TEMPORARY AND PERMENATE EROSION CONTROL PRACTICES.
10. PLANT AND MULCH BIORETENTION DEVICE.
11. REMOVE TEMPORARY EROSION CONTROL DEVICES AFTER THE CONTRIBUTING DRAINAGE AREA IS ADEQUATELY VEGETATED.

GENERAL NOTES

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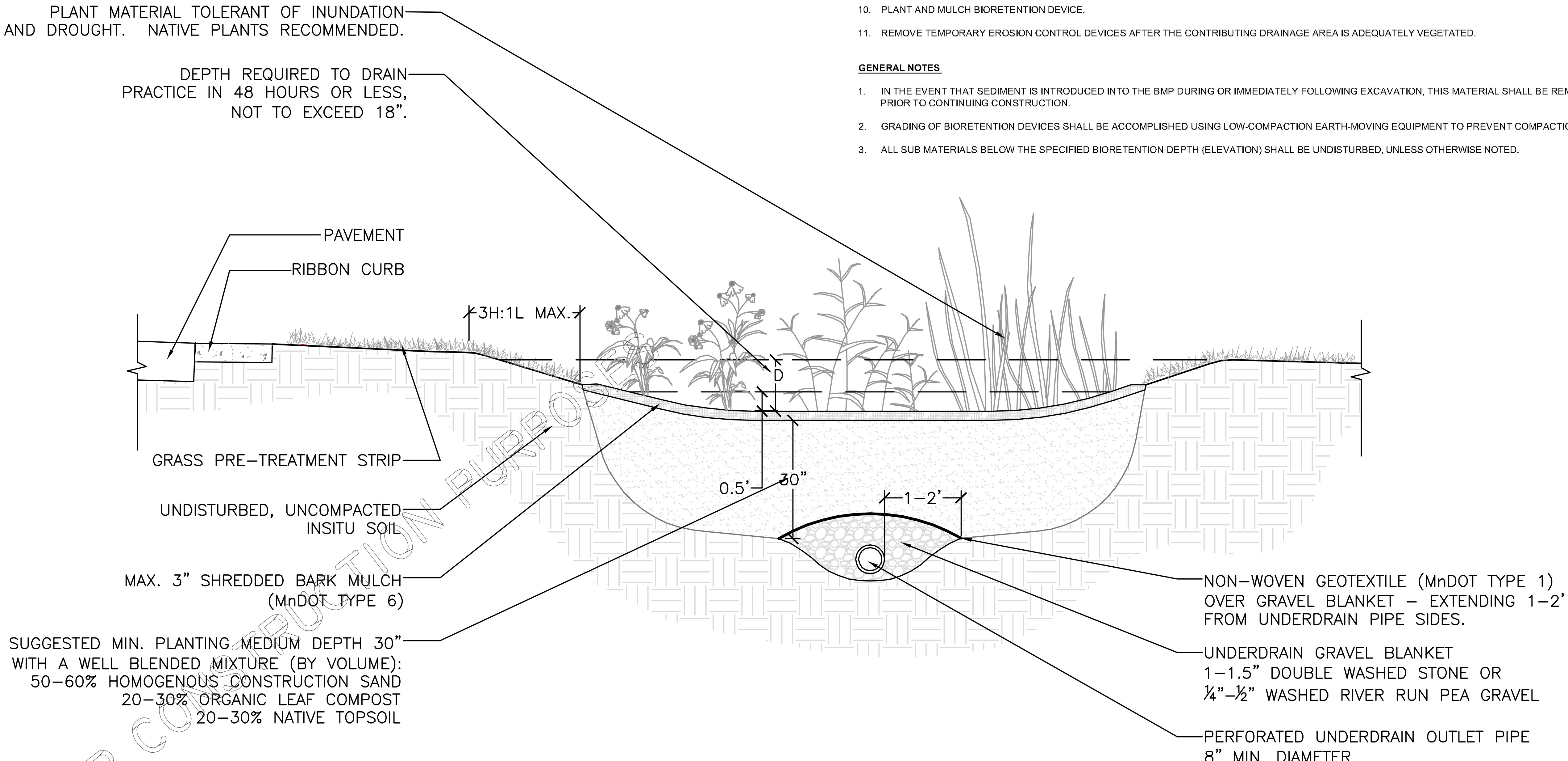
2. GRADING OF BIORETENTION DEVICES SHALL BE ACCOMPLISHED USING LOW-COMPACTION EARTH-MOVING EQUIPMENT TO PREVENT COMPACTION OF UNDERLYING SOILS.
3. ALL SUB MATERIALS BELOW THE SPECIFIED BIORETENTION DEPTH (ELEVATION) SHALL BE UNDISTURBED, UNLESS OTHERWISE NOTED.



FILTRATION/ PARTIAL RECHARGE FACILITY CROSS-SECTION

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BIORETENTION FILTRATION/ PARTIAL RECHARGE FACILITY

Sheet No. of Sheets

CONSTRUCTION SEQUENCING

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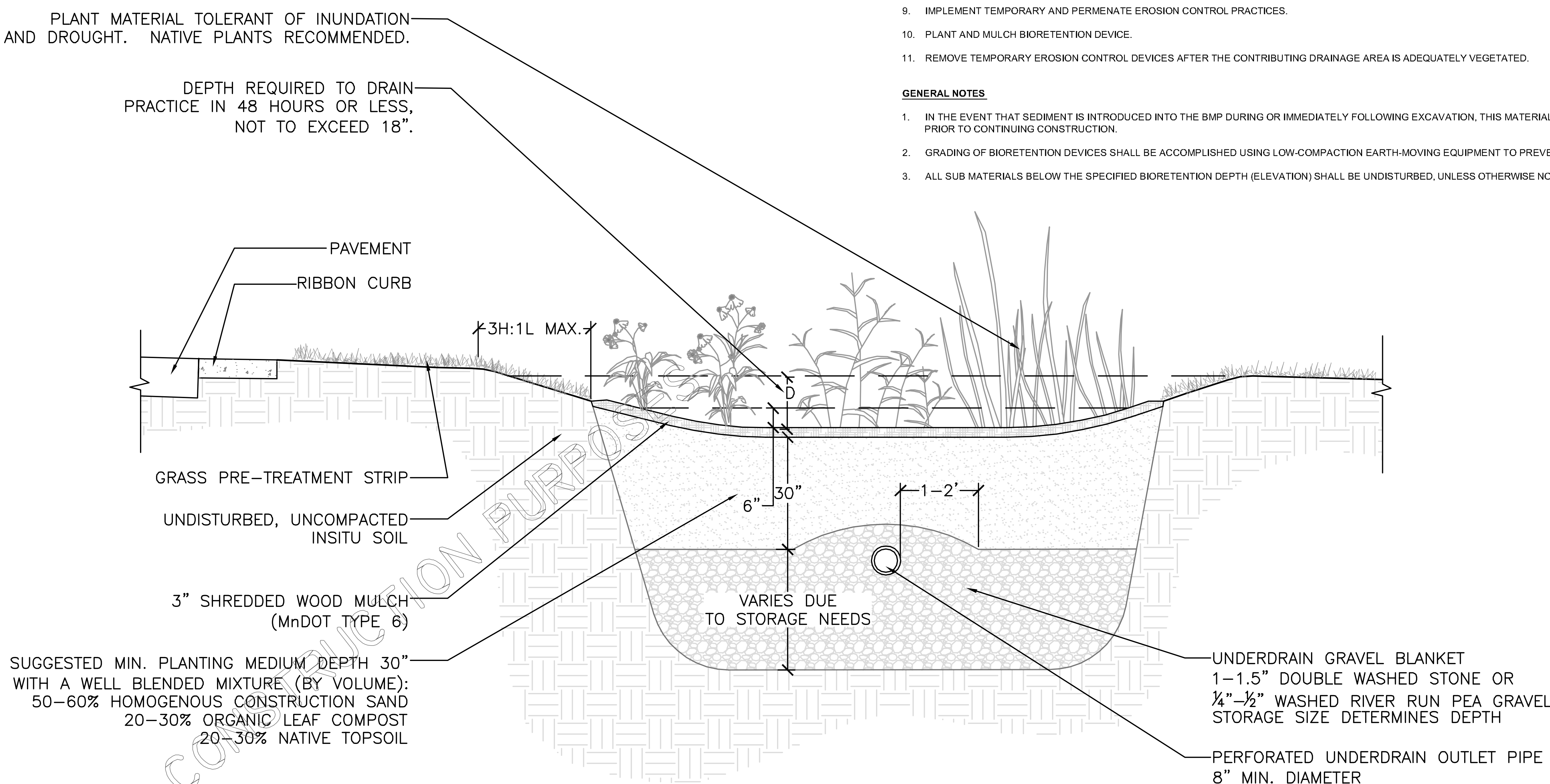
3. PERFORM CONTINUOUS INSPECTIONS OF EROSION CONTROL PRACTICES.
4. INSTALL UTILITIES (WATER, SANITARY SEWER, ELECTRIC, PHONE, FIBER OPTIC, ETC) PRIOR TO SETTING FINAL GRADE OF BIORETENTION DEVICE.
5. ROUGH GRADE THE SITE. IF BIORETENTION AREAS ARE BEING USED AS TEMPORARY SEDIMENT BASINS LEAVE A MINIMUM OF 3 FEET OF COVER OVER THE PRACTICE TO PROTECT THE UNDERLYING SOILS FROM CLOGGING.
6. PERFORM ALL OTHER SITE IMPROVEMENTS.
7. SEED AND MULCH ALL AREAS AFTER DISTURBANCE.
8. CONSTRUCT BIORETENTION DEVICE UPON STABILIZATION OF CONTRIBUTING DRAINAGE AREA.
9. IMPLEMENT TEMPORARY AND PERMENATE EROSION CONTROL PRACTICES.
10. PLANT AND MULCH BIORETENTION DEVICE.
11. REMOVE TEMPORARY EROSION CONTROL DEVICES AFTER THE CONTRIBUTING DRAINAGE AREA IS ADEQUATELY VEGETATED.

GENERAL NOTES

1. IN THE EVENT THAT SEDIMENT IS INTRODUCED INTO THE BMP DURING OR IMMEDIATELY FOLLOWING EXCAVATION, THIS MATERIAL SHALL BE REMOVED FROM THE PRACTICE PRIOR TO CONTINUING CONSTRUCTION.
2. GRADING OF BIORETENTION DEVICES SHALL BE ACCOMPLISHED USING LOW-COMPACTION EARTH-MOVING EQUIPMENT TO PREVENT COMPACTION OF UNDERLYING SOILS.
3. ALL SUB MATERIALS BELOW THE SPECIFIED BIORETENTION DEPTH (ELEVATION) SHALL BE UNDISTURBED, UNLESS OTHERWISE NOTED.



INFILTRATION/FILTRATION/RECHARGE FACILITY CROSS-SECTION

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BIORETENTION INFILTRATION/ FILTRATION FACILITY

Sheet No. of Sheets

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4. INSTALL UTILITIES (WATER, SANITARY SEWER, ELECTRIC, PHONE, FIBER OPTIC, ETC) PRIOR TO SETTING FINAL GRADE OF BIORETENTION DEVICE.
5. ROUGH GRADE THE SITE. IF BIORETENTION AREAS ARE BEING USED AS TEMPORARY SEDIMENT BASINS LEAVE A MINIMUM OF 3 FEET OF COVER OVER THE PRACTICE TO PROTECT THE UNDERLYING SOILS FROM CLOGGING.
6. PERFORM ALL OTHER SITE IMPROVEMENTS.
7. SEED AND MULCH ALL AREAS AFTER DISTURBANCE.
8. CONSTRUCT BIORETENTION DEVICE UPON STABILIZATION OF CONTRIBUTING DRAINAGE AREA.
9. IMPLEMENT TEMPORARY AND PERMENATE EROSION CONTROL PRACTICES.
10. PLANT AND MULCH BIORETENTION DEVICE.
11. REMOVE TEMPORARY EROSION CONTROL DEVICES AFTER THE CONTRIBUTING DRAINAGE AREA IS ADEQUATELY VEGETATED.

GENERAL NOTES

1. IN THE EVENT THAT SEDIMENT IS INTRODUCED INTO THE BMP DURING OR IMMEDIATELY FOLLOWING EXCAVATION, THIS MATERIAL SHALL BE REMOVED FROM THE PRACTICE PRIOR TO CONTINUING CONSTRUCTION.
2. GRADING OF BIORETENTION DEVICES SHALL BE ACCOMPLISHED USING LOW-COMPACTION EARTH-MOVING EQUIPMENT TO PREVENT COMPACTION OF UNDERLYING SOILS.
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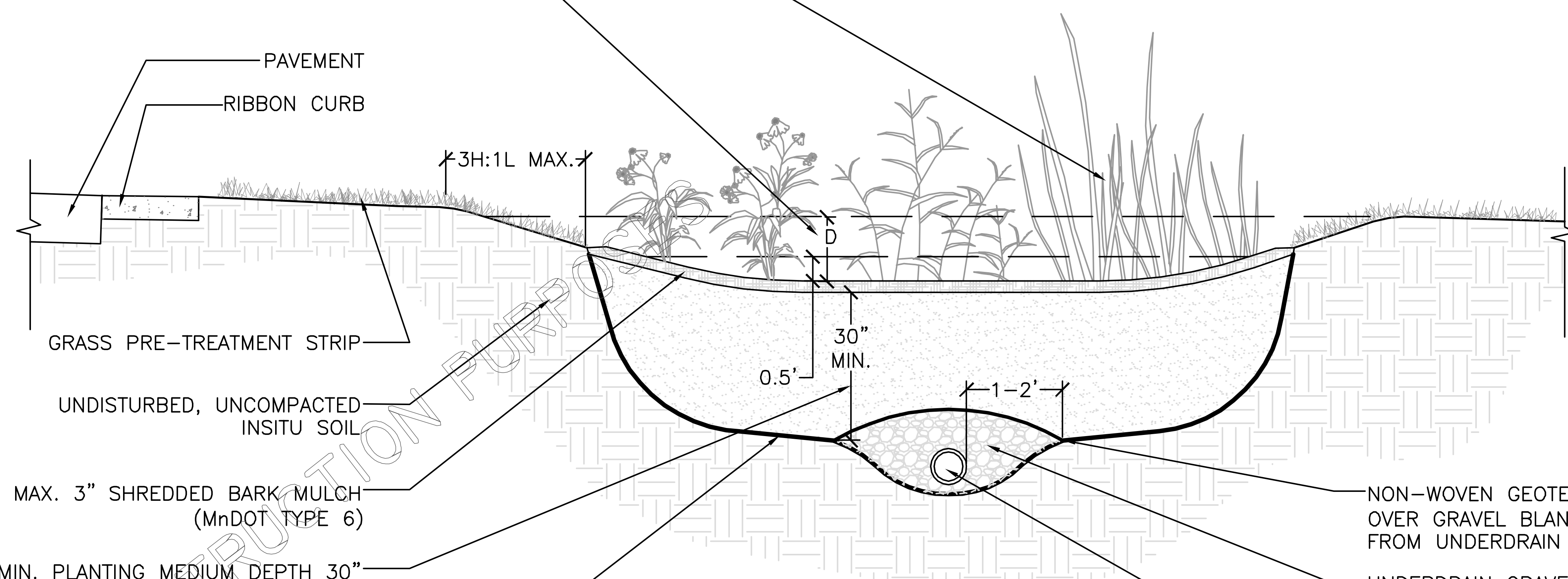

FILTRATION ONLY FACILITY CROSS-SECTION

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BIORETENTION FILTRATION ONLY FACILITY

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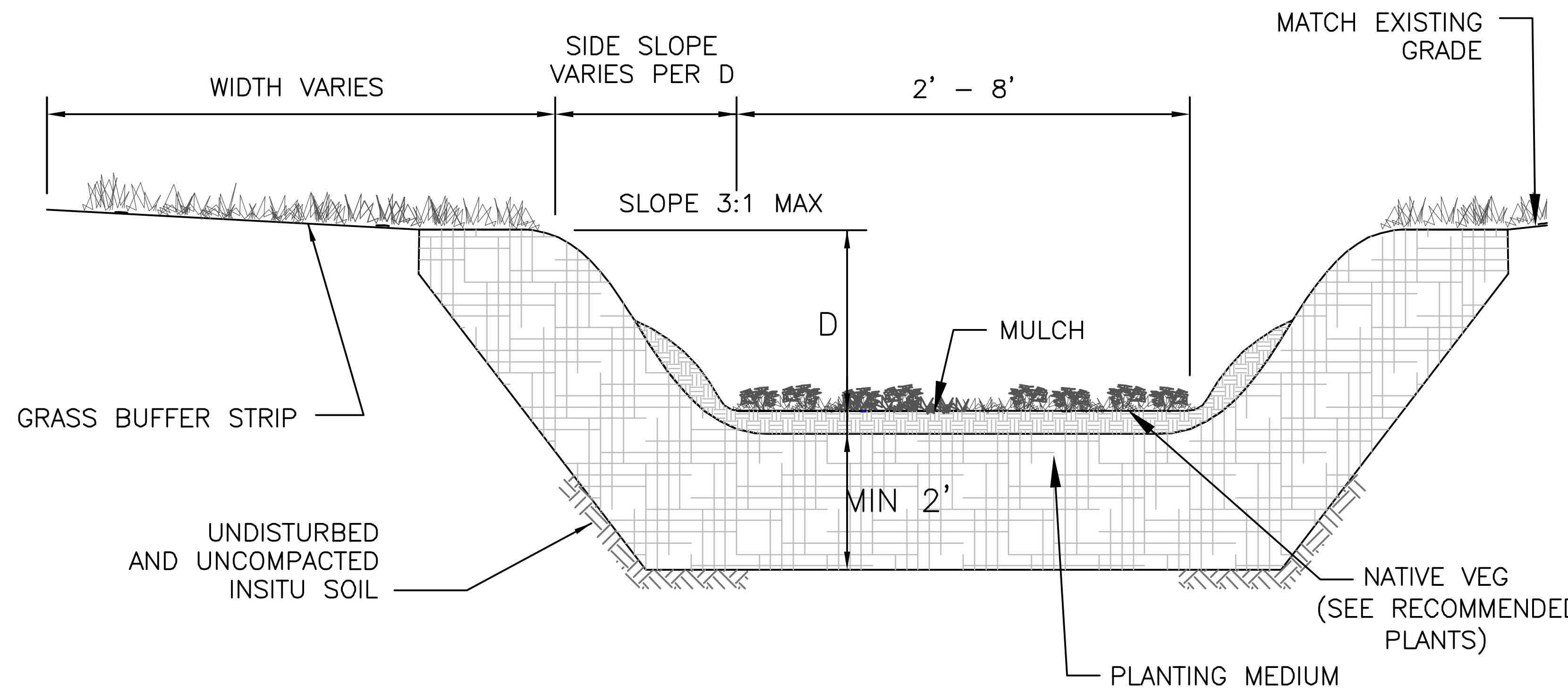
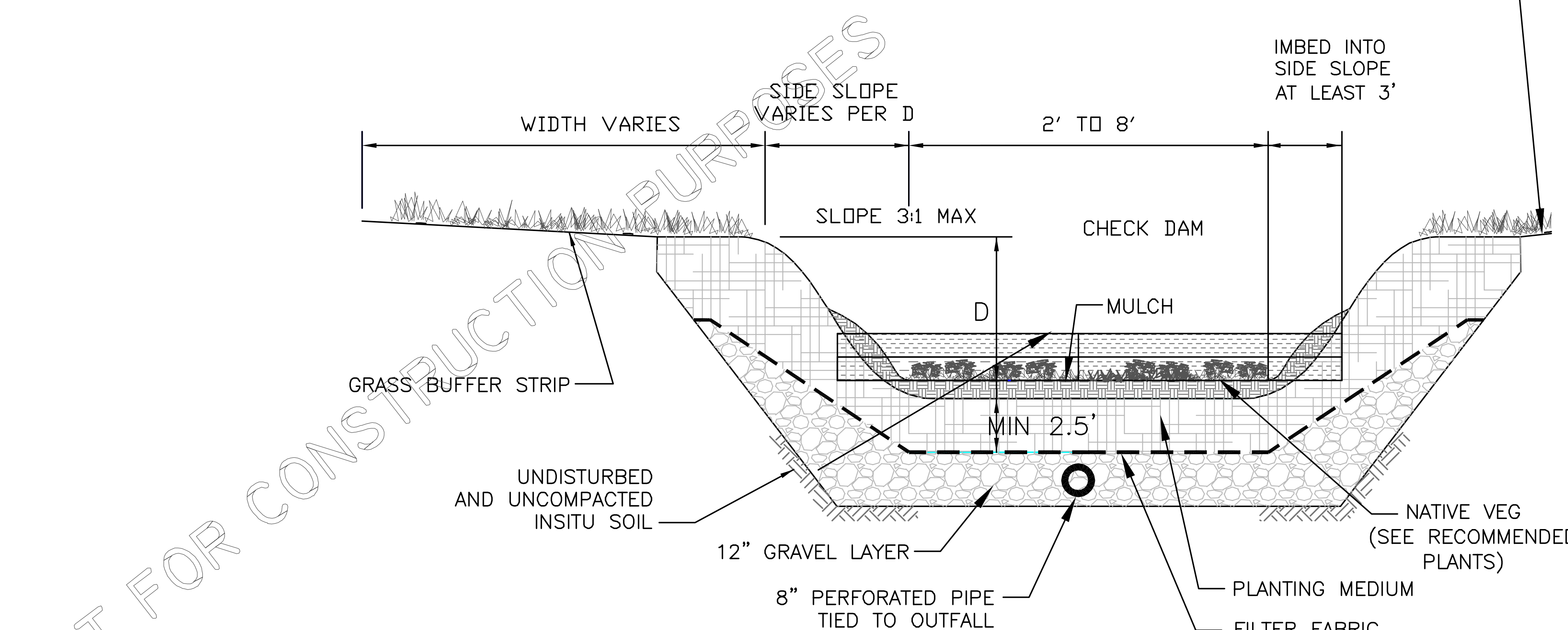


TYPICAL WET SWALE CROSS-SECTION

NOT TO SCALE



TYPICAL DRY SWALE CROSS-SECTION (WITH CHECKDAM)

NOT TO SCALE

CONSTRUCTION SEQUENCING:

1. PERFORM CONTINUOUS INSPECTIONS OF EROSION CONTROL PRACTICES.
2. INSTALL SILT FENCE ALONG THE PERIMETER OF THE SITE TO PREVENT SEDIMENT FROM LEAVING THE SITE DURING THE CONSTRUCTION PROCESS.
3. ALL DOWNGRADIENT PERIMETER SEDIMENT-CONTROL BMPS MUST BE IN PLACE BEFORE ANY UP GRADIENT LAND-DISTURBING ACTIVITY BEGINS.
4. REMOVE TOPSOIL FROM THE SITE AND PLACE IN TEMPORARY STOCKPILE LOCATION. TEMPORARY SEED THE STOCKPILE.
5. INSTALL UNDERGROUND UTILITIES (WATER, SANITARY SEWER, ELECTRIC AND PHONES) TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.
7. SEED AND MULCH DISTURBED AREAS ON SITE.
8. CONSTRUCT THE ROADS TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.
9. PERFORM ALL OTHER SITE IMPROVEMENTS TAKING THE LOCATION AND FUNCTION OF THE STORM WATER BMPS INTO CONSIDERATION.
10. FINAL GRADE THE SITE.
11. STABILIZE THE SITE BY IMPLEMENTING THE NATIVE SEEDING AND PLANTING PORTION OF THE LANDSCAPING PLAN.
12. INSTALL THE EROSION CONTROL BLANKET AND COIR ROLL/CHECK DAMS.
13. REMOVE THE SILT FENCE AFTER THE SITE IS STABILIZED PER PROJECT ENGINEER APPROVAL.

GENERAL NOTES:

1. INSTALL ALL TEMPORARY EROSION CONTROL MEASURES (IN ACCORDANCE WITH MnDOT GENERAL CONDITIONS 2573) PRIOR TO THE START OF ANY CONSTRUCTION OPERATION THAT MAY CAUSE ANY SEDIMENTATION OR SILTATION AT THE SITE.
2. INSTALL STORM DRAIN INLET PROTECTION TO PREVENT CLOGGING OF THE STORM SEWER AND SEDIMENT LOADS TO DOWNSTREAM STORM WATER FACILITIES OR WATERBODIES.
4. GRADING OF THE SWALE SHALL BE ACCOMPLISHED USING LOW-IMPACT EARTH-MOVING EQUIPMENT TO PREVENT COMPACTION OF THE UNDERLYING SOILS. SMALL TRACKED DOZERS AND BOBCATS WITH RUNNER TRACKS ARE RECOMMENDED.
5. EXCAVATE THE SWALE TO THE SPECIFIED DEPTH (ELEVATION). IT IS RECOMMENDED THAT ALL SUB MATERIAL BELOW THE SPECIFIED ELEVATION SHALL BE LEFT UNDISTURBED, UNLESS OTHERWISE DIRECTED BY THE ENGINEER.
6. GRADE TO THE DEPTH (ELEVATION) SPECIFIED IN THE CONSTRUCTION DOCUMENTS UNLESS OTHERWISE DIRECTED BY THE ENGINEER.
7. IN THE EVENT THAT SEDIMENT IS INTRODUCED INTO THE BMP DURING OR IMMEDIATELY FOLLOWING EXCAVATION, THIS MATERIAL WILL NEED TO BE REMOVED FROM THE SWALE PRIOR TO INITIATING THE NEXT STEP IN THE CONSTRUCTION PROCESS. THIS IS ESPECIALLY IMPORTANT IF THE SWALE HAS BEEN DESIGNED TO INFILTRATE STORM WATER: SEDIMENT THAT HAS BEEN WASHED INTO THE SWALE DURING THE EXCAVATION PROCESS CAN SEAL THE PERMEABLE MATERIAL, SIGNIFICANTLY REDUCING THE INFILTRATION CAPACITY OF THE SOILS.
8. MATERIAL EXCAVATED FROM THE SWALE(S) SHALL BE DISPOSED OF ON-SITE AT LOCATIONS (STOCKPILE AREAS) DESIGNATED BY ENGINEER.
9. **NON-STANDARD COMPONENT:** CLEAN, WASHED 1.5 TO 3.5-INCH GRAVEL SHALL BE PLACED IN THE BOTTOM OF THE SWALE TO THE DEPTH SPECIFIED IN THE CONSTRUCTION DOCUMENTS. GRAVEL SHOULD BE PLACED IN LIFTS AND LIGHTLY COMPACTED WITH PLATE COMPACTORS.
10. **NON-STANDARD COMPONENT:** THE PERFORATED PIPE (UNDERDRAIN) SHALL BE LAID DIRECTLY ON THE GRAVEL BED. GRADE AND ALIGNMENT SHALL NOT VARY FROM THE PRESCRIBED GRADE BY MORE THAN 0.03 FEET (9 MM) AT ANY POINT. THE JOINTS BETWEEN SECTIONS OF PIPE SHALL BE CONNECTED IN A FASHION ACCEPTABLE TO ENGINEER. ONCE THE PIPE IS IN PLACE, IT SHALL BE COVERED IMMEDIATELY WITH GRANULAR MATERIAL AS SPECIFIED IN THE CONSTRUCTION DOCUMENTS. THE GRANULAR MATERIAL SHALL BE OF UNIFORM DEPTH ON BOTH SIDES OF THE PIPE. SPECIAL INLETS AND SPECIAL DEVICES AT THE OUTLET END OF THE PIPE SHALL BE CONSTRUCTED AS SHOWN IN THE PLANS.
12. PORTIONS OF SWALE TO BE PLANTED SHALL RECEIVE 3" OF WOODCHIP MULCH (MnDOT TYPE 6).
13. PORTIONS OF SWALE TO BE SEEDED SHALL BE MULCHED WITH CLEAN GRAIN STRAW (MnDOT TYPE 3) AT A RATE OF 2 TONS PER ACRE.
14. SEEDING AND INSTALLATION OF EROSION CONTROL BLANKET SHALL BE COMPLETED WITHIN 48 HOURS OF FINAL GRADING.

NO.	REVISION DESCRIPTION	DATE	BY

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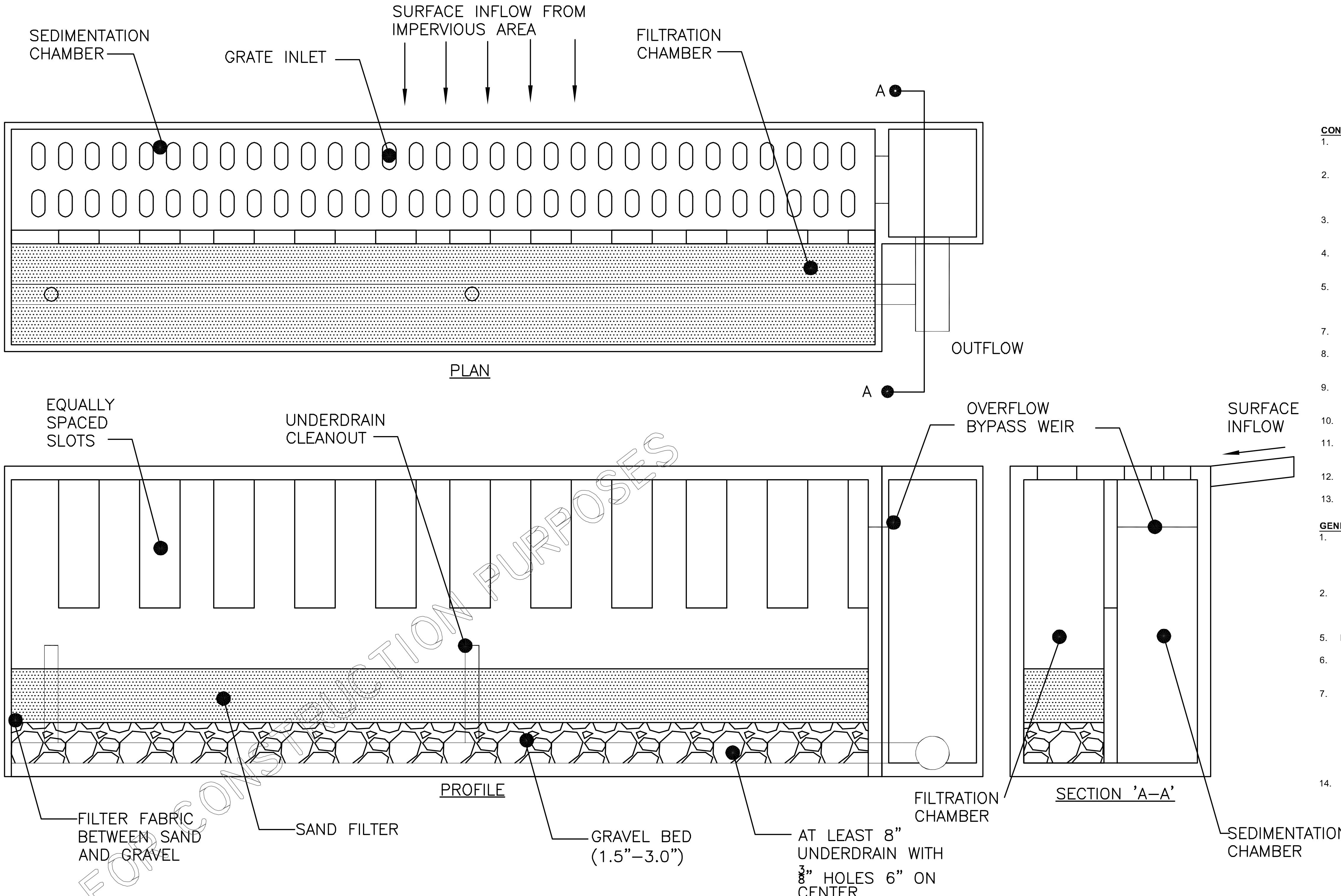
2005 MINNESOTA STORMWATER MANUAL

WET AND DRY SWALES

Sheet No.

of

Sheets



CONSTRUCTION SEQUENCING:

1. PERFORM CONTINUOUS INSPECTIONS OF EROSION CONTROL PRACTICES.

2. INSTALL SILT FENCE ALONG THE PERIMETER OF THE SITE TO PREVENT SEDIMENT FROM LEAVING THE SITE DURING THE CONSTRUCTION PROCESS.

3. ALL DOWNGRADIENT PERIMETER SEDIMENT-CONTROL BMPS MUST BE IN PLACE BEFORE ANY UP GRADIENT LAND-DISTURBING ACTIVITY BEGINS.

4. REMOVE TOPSOIL FROM THE SITE AND PLACE IN TEMPORARY STOCKPILE LOCATION. TEMPORARY SEED THE STOCKPILE.

5. INSTALL UNDERGROUND UTILITIES (WATER, SANITARY SEWER, ELECTRIC AND PHONES) TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.

7. SEED AND MULCH DISTURBED AREAS ON SITE.

8. CONSTRUCT THE ROADS TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.

9. PERFORM ALL OTHER SITE IMPROVEMENTS TAKING THE LOCATION AND FUNCTION OF THE STORM WATER BMPS INTO CONSIDERATION.

10. FINAL GRADE THE SITE.

11. STABILIZE THE SITE BY IMPLEMENTING THE NATIVE SEEDING AND PLANTING PORTION OF THE LANDSCAPING PLAN.

12. INSTALL THE EROSION CONTROL BLANKET

13. REMOVE THE SILT FENCE AFTER THE SITE IS STABILIZED PER PROJECT ENGINEER APPROVAL.

GENERAL NOTES:

1. INSTALL ALL TEMPORARY EROSION CONTROL MEASURES (IN ACCORDANCE WITH MnDOT GENERAL CONDITIONS 2573) PRIOR TO THE START OF ANY CONSTRUCTION OPERATION THAT MAY CAUSE ANY SEDIMENTATION OR SILTATION AT THE SITE.

2. INSTALL STORM DRAIN INLET PROTECTION TO PREVENT CLOGGING OF THE STORM SEWER AND SEDIMENT LOADS TO DOWNSTREAM STORM WATER FACILITIES OR WATERBODIES.

5. EXCAVATE THE FILTER TO THE SPECIFIED DEPTH (ELEVATION).

6. GRADE TO THE DEPTH (ELEVATION) SPECIFIED IN THE CONSTRUCTION DOCUMENTS UNLESS OTHERWISE DIRECTED BY THE ENGINEER.

7. IN THE EVENT THAT SEDIMENT IS INTRODUCED INTO THE BMP DURING OR IMMEDIATELY FOLLOWING EXCAVATION, THIS MATERIAL WILL NEED TO BE REMOVED FROM THE BASIN PRIOR TO INITIATING THE NEXT STEP IN THE CONSTRUCTION PROCESS. SEDIMENT THAT HAS BEEN WASHED INTO THE BASIN DURING THE EXCAVATION PROCESS CAN SEAL THE PERMEABLE MATERIAL, SIGNIFICANTLY REDUCING THE INFILTRATION CAPACITY OF THE SOILS.

14. SEEDING AND INSTALLATION OF EROSION CONTROL BLANKET SHALL BE COMPLETED WITHIN 48 HOURS OF FINAL GRADING.

PERIMETER SAND FILTER DETAILS

NOT TO SCALE

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PERIMETER SAND FILTER DETAILS

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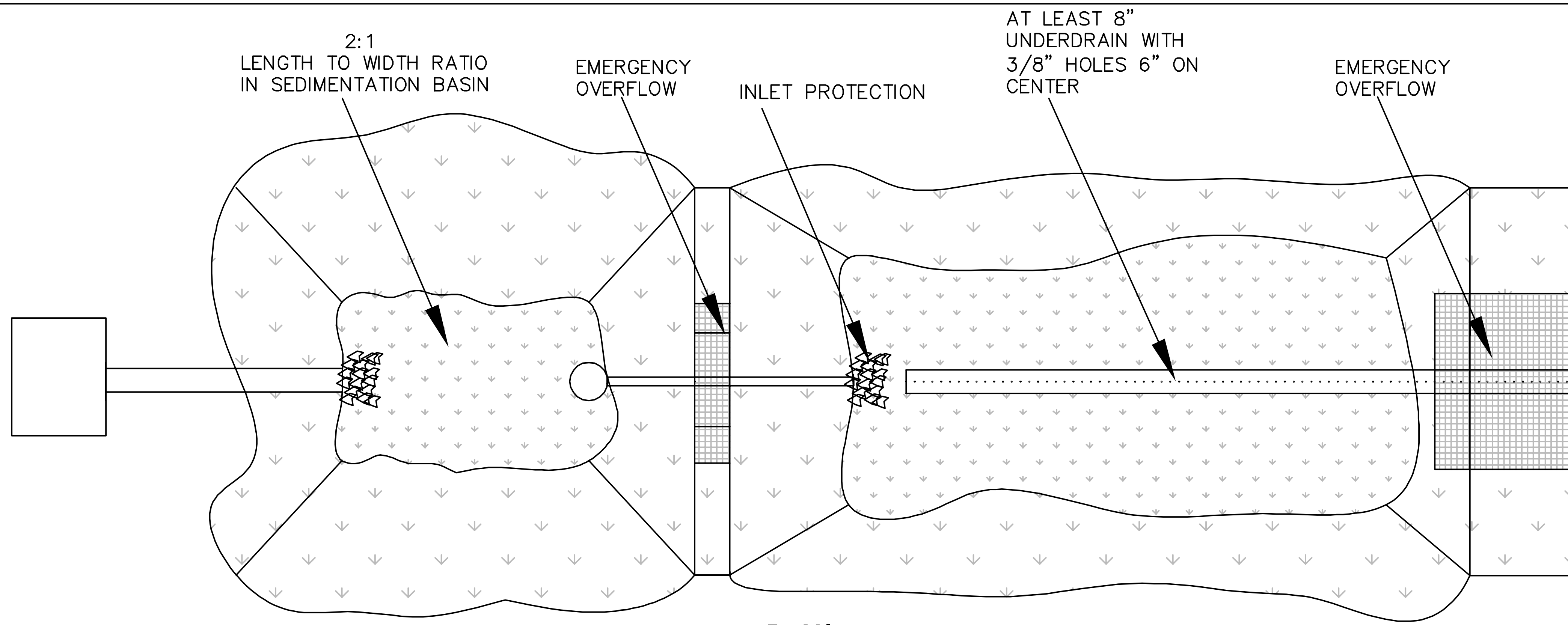
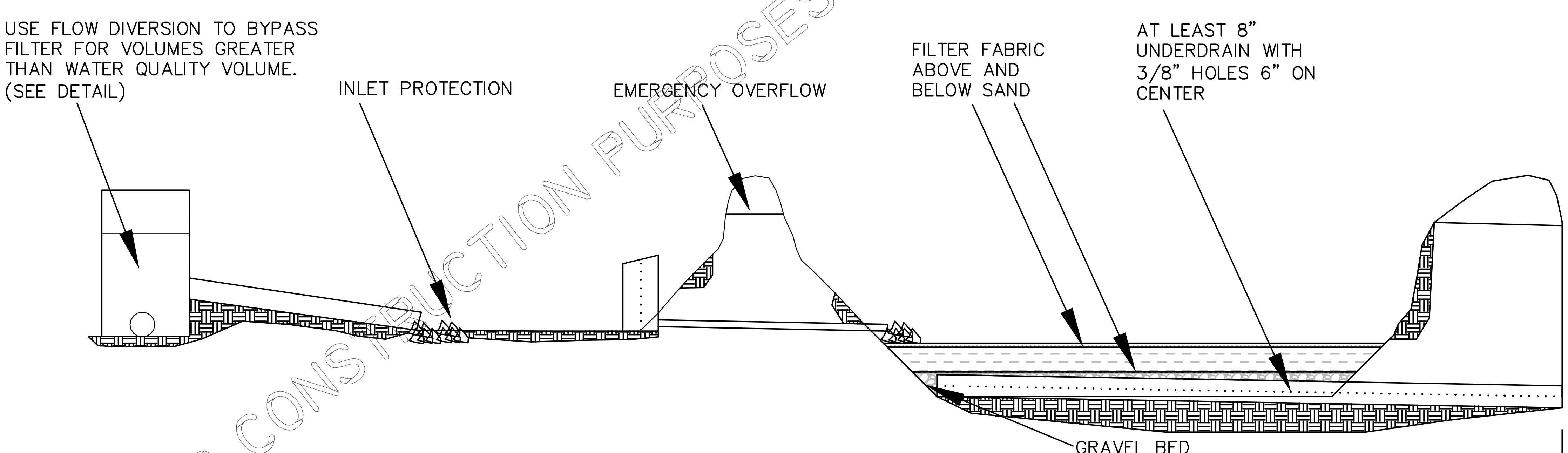


PLAN



PROFILE

SURFACE SAND FILTER DETAILS

NOT TO SCALE

CONSTRUCTION SEQUENCING:

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2. INSTALL SILT FENCE ALONG THE PERIMETER OF THE SITE TO PREVENT SEDIMENT FROM LEAVING THE SITE DURING THE CONSTRUCTION PROCESS.
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4. REMOVE TOPSOIL FROM THE SITE AND PLACE IN TEMPORARY STOCKPILE LOCATION. TEMPORARY SEED THE STOCKPILE.
5. INSTALL UNDERGROUND UTILITIES (WATER, SANITARY SEWER, ELECTRIC AND PHONES) TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.
7. SEED AND MULCH DISTURBED AREAS ON SITE.
8. CONSTRUCT THE ROADS TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.
9. PERFORM ALL OTHER SITE IMPROVEMENTS TAKING THE LOCATION AND FUNCTION OF THE STORM WATER BMPS INTO CONSIDERATION.
10. FINAL GRADE THE SITE.
11. STABILIZE THE SITE BY IMPLEMENTING THE NATIVE SEEDING AND PLANTING PORTION OF THE LANDSCAPING PLAN.
12. INSTALL THE EROSION CONTROL BLANKET
13. REMOVE THE SILT FENCE AFTER THE SITE IS STABILIZED PER PROJECT ENGINEER APPROVAL.

GENERAL NOTES:

1. INSTALL ALL TEMPORARY EROSION CONTROL MEASURES (IN ACCORDANCE WITH MnDOT GENERAL CONDITIONS 2573) PRIOR TO THE START OF ANY CONSTRUCTION OPERATION THAT MAY CAUSE ANY SEDIMENTATION OR SILTATION AT THE SITE.
2. INSTALL STORM DRAIN INLET PROTECTION TO PREVENT CLOGGING OF THE STORM SEWER AND SEDIMENT LOADS TO DOWNSTREAM STORM WATER FACILITIES OR WATERBODIES.
5. EXCAVATE THE INFILTRATION BASIN TO THE SPECIFIED DEPTH (ELEVATION). IT IS RECOMMENDED THAT ALL SUB MATERIAL BELOW THE SPECIFIED ELEVATION SHALL BE LEFT UNDISTURBED, UNLESS OTHERWISE DIRECTED BY THE ENGINEER.
6. GRADE TO THE DEPTH (ELEVATION) SPECIFIED IN THE CONSTRUCTION DOCUMENTS UNLESS OTHERWISE DIRECTED BY THE ENGINEER.
7. IN THE EVENT THAT SEDIMENT IS INTRODUCED INTO THE BMP DURING OR IMMEDIATELY FOLLOWING EXCAVATION, THIS MATERIAL WILL NEED TO BE REMOVED FROM THE BASIN PRIOR TO INITIATING THE NEXT STEP IN THE CONSTRUCTION PROCESS. SEDIMENT THAT HAS BEEN WASHED INTO THE BASIN DURING THE EXCAVATION PROCESS CAN SEAL THE PERMEABLE MATERIAL, SIGNIFICANTLY REDUCING THE INFILTRATION CAPACITY OF THE SOILS.
9. **NON-STANDARD COMPONENT:** CLEAN, WASHED 1.5 TO 3.5-INCH GRAVEL SHALL BE PLACED IN THE BOTTOM OF THE BASIN TO THE DEPTH OF AT LEAST 12 INCHES OR AS SPECIFIED IN THE CONSTRUCTION DOCUMENTS. GRAVEL SHOULD BE PLACED IN LIFTS AND LIGHTLY COMPACTED WITH PLATE COMPACTORS.
10. **NON-STANDARD COMPONENT:** THE PERFORATED PIPE (UNDERDRAIN) SHALL BE LAID DIRECTLY ON THE GRAVEL BED. GRADE AND ALIGNMENT SHALL NOT VARY FROM THE PRESCRIBED GRADE BY MORE THAN 0.03 FEET (9 MM) AT ANY POINT. THE JOINTS BETWEEN SECTIONS OF PIPE SHALL BE CONNECTED IN A FASHION ACCEPTABLE TO ENGINEER. ONCE THE PIPE IS IN PLACE, IT SHALL BE COVERED IMMEDIATELY WITH GRANULAR MATERIAL AS SPECIFIED IN THE CONSTRUCTION DOCUMENTS. THE GRANULAR MATERIAL SHALL BE OF UNIFORM DEPTH ON BOTH SIDES OF THE PIPE. SPECIAL INLETS AND SPECIAL DEVICES AT THE OUTLET END OF THE PIPE SHALL BE CONSTRUCTED AS SHOWN IN THE PLANS.
14. SEEDING AND INSTALLATION OF EROSION CONTROL BLANKET SHALL BE COMPLETED WITHIN 48 HOURS OF FINAL GRADING.

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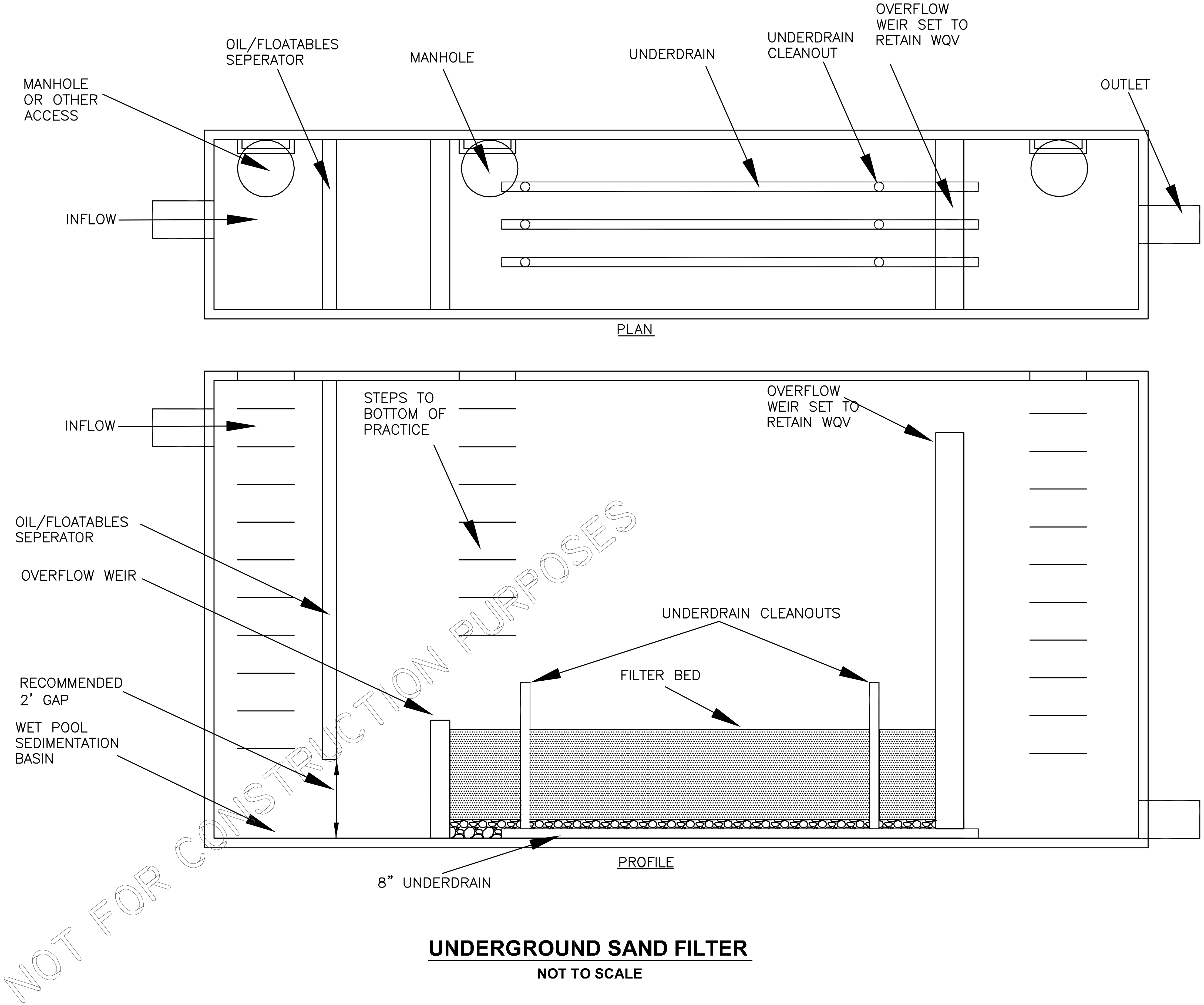
SURFACE SAND FILTER DETAILS

Sheet No. of Sheets



UNDERGROUND SAND FILTER

NOT TO SCALE

CONSTRUCTION SEQUENCING:

1. PERFORM CONTINUOUS INSPECTIONS OF EROSION CONTROL PRACTICES.
2. INSTALL SILT FENCE ALONG THE PERIMETER OF THE SITE TO PREVENT SEDIMENT FROM LEAVING THE SITE DURING THE CONSTRUCTION PROCESS.
3. ALL DOWNGRADIENT PERIMETER SEDIMENT-CONTROL BMPS MUST BE IN PLACE BEFORE ANY UP GRADIENT LAND-DISTURBING ACTIVITY BEGINS.
4. REMOVE TOPSOIL FROM THE SITE AND PLACE IN TEMPORARY STOCKPILE LOCATION. TEMPORARY SEED THE STOCKPILE.
5. INSTALL UNDERGROUND UTILITIES (WATER, SANITARY SEWER, ELECTRIC AND PHONES) TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.
7. SEED AND MULCH DISTURBED AREAS ON SITE.
8. CONSTRUCT THE ROADS TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.
9. PERFORM ALL OTHER SITE IMPROVEMENTS TAKING THE LOCATION AND FUNCTION OF THE STORM WATER BMPS INTO CONSIDERATION.
10. FINAL GRADE THE SITE.
11. STABILIZE THE SITE BY IMPLEMENTING THE NATIVE SEEDING AND PLANTING PORTION OF THE LANDSCAPING PLAN.
12. INSTALL THE EROSION CONTROL BLANKET
13. REMOVE THE SILT FENCE AFTER THE SITE IS STABILIZED PER PROJECT ENGINEER APPROVAL.

GENERAL NOTES:

1. INSTALL ALL TEMPORARY EROSION CONTROL MEASURES (IN ACCORDANCE WITH MnDOT GENERAL CONDITIONS 2573) PRIOR TO THE START OF ANY CONSTRUCTION OPERATION THAT MAY CAUSE ANY SEDIMENTATION OR SILTATION AT THE SITE.
2. INSTALL STORM DRAIN INLET PROTECTION TO PREVENT CLOGGING OF THE STORM SEWER AND SEDIMENT LOADS TO DOWNSTREAM STORM WATER FACILITIES OR WATERBODIES.
3. GRADE TO THE DEPTH (ELEVATION) SPECIFIED IN THE CONSTRUCTION DOCUMENTS UNLESS OTHERWISE DIRECTED BY THE ENGINEER.
4. IN THE EVENT THAT SEDIMENT IS INTRODUCED INTO THE BMP DURING OR IMMEDIATELY FOLLOWING CONSTRUCTION, THIS MATERIAL WILL NEED TO BE REMOVED FROM THE PRACTICE PRIOR TO INITIATING THE NEXT STEP IN THE CONSTRUCTION PROCESS. SEDIMENT THAT HAS BEEN WASHED INTO THE PRACTICE CAN SEAL THE PERMEABLE MATERIAL, SIGNIFICANTLY REDUCING THE FILTRATION CAPACITY OF THE SOILS.
5. CLEAN OUT SETTLING BASIN WHEN 1' OF SEDIMENT HAS ACCUMULATED.

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UNDERGROUND SAND FILTER DETAILS

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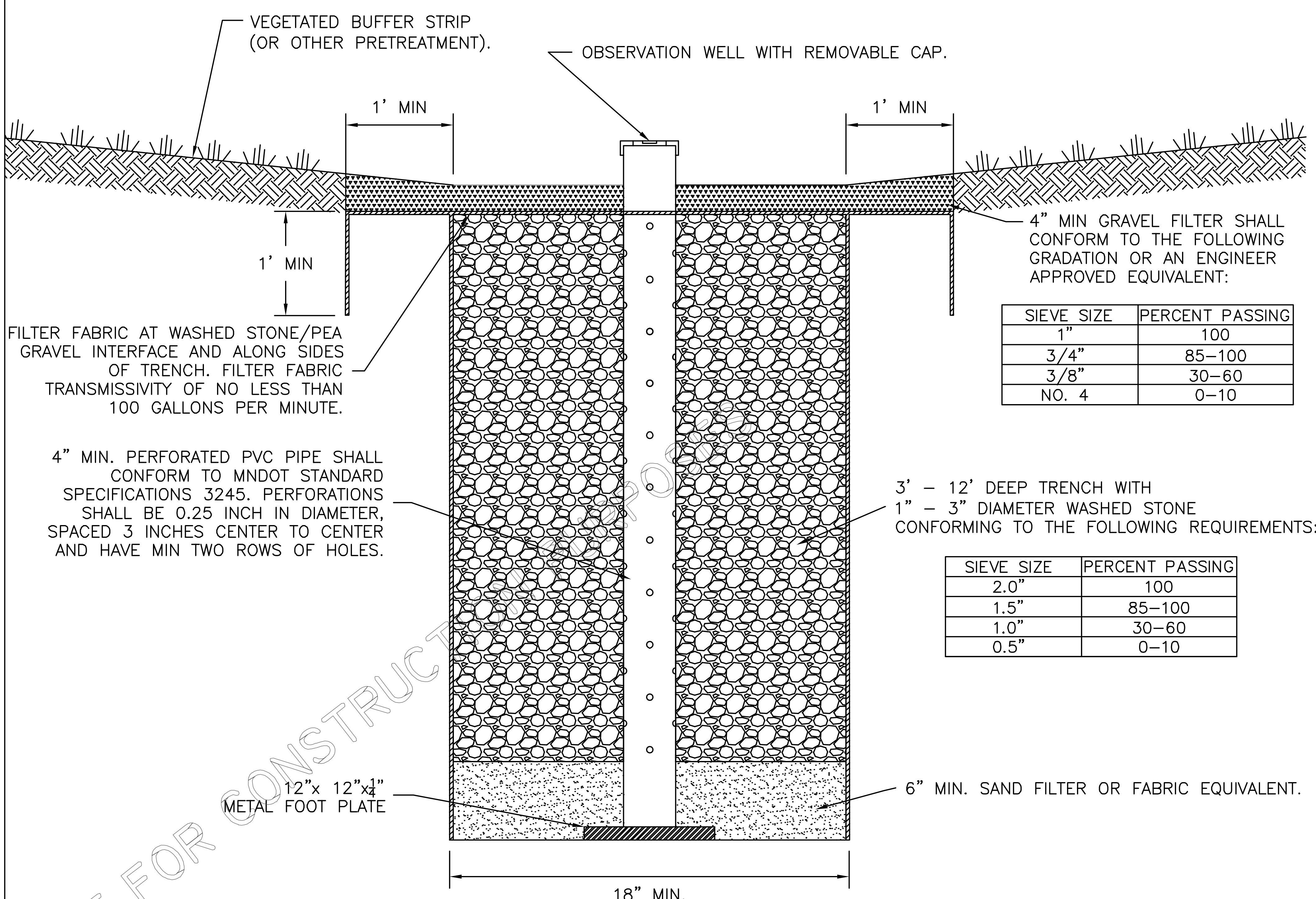

SIEVE SIZE	PERCENT PASSING
1"	100
3/4"	85–100
3/8"	30–60
NO. 4	0–10

SIEVE SIZE	PERCENT PASSING
2.0"	100
1.5"	85–100
1.0"	30–60
0.5"	0–10

TYPICAL INFILTRATION TRENCH CROSS–SECTION

NOT TO SCALE

CONSTRUCTION SEQUENCING:

1. PERFORM CONTINUOUS INSPECTION OF EROSION CONTROL PRACTICES.
2. INSTALL SILT FENCE ALONG THE PERIMETER OF THE SITE TO PREVENT SEDIMENT FROM LEAVING THE SITE DURING THE CONSTRUCTION PROCESS.
3. ALL DOWNGRADIENT PERIMETER SEDIMENT-CONTROL BMPS MUST BE IN PLACE BEFORE ANY UP GRADIENT LAND-DISTURBING ACTIVITY BEGINS.
4. REMOVE TOPSOIL FROM THE SITE AND PLACE IN TEMPORARY STOCKPILE LOCATION. TEMPORARY SEED THE STOCKPILE.
5. INSTALL UNDERGROUND UTILITIES (WATER, SANITARY SEWER, ELECTRIC AND PHONES) TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.
6. ROUGH GRADE THE SITE. IF THE INFILTRATION TRENCH IS GOING TO BE USED FOR TEMPORARY SEDIMENT CONTROL, GRADE THE INFILTRATION TRENCH TO WITHIN THREE (3) FEET OF FINAL GRADE TO PREVENT CLOGGING OF INSITU SOIL.
7. SEED AND MULCH DISTURBED AREAS ON SITE.
8. CONSTRUCT THE ROADS TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.
9. PERFORM ALL OTHER SITE IMPROVEMENTS TAKING THE LOCATION AND FUNCTION OF THE STORM WATER BMPS INTO CONSIDERATION.
10. FINAL GRADE THE SITE.
11. STABILIZE THE SITE BY IMPLEMENTING THE NATIVE SEEDING AND PLANTING PORTION OF THE LANDSCAPING PLAN.
12. REMOVE THE SILT FENCE AFTER THE SITE IS STABILIZED PER PROJECT ENGINEER APPROVAL.

GENERAL NOTES:

1. INSTALL ALL TEMPORARY EROSION CONTROL MEASURES (IN ACCORDANCE WITH MnDOT GENERAL CONDITIONS 2573) PRIOR TO SITE DISTURBANCE.
2. INSTALL STORM DRAIN INLET PROTECTION TO PREVENT CLOGGING OF THE STORM SEWER AND SEDIMENT LOADS TO DOWNSTREAM STORM WATER FACILITIES OR WATERBODIES.
3. IF THE STORM WATER BMP IS BEING DESIGNED TO SERVE AS A TEMPORARY SEDIMENT BASIN, GRADE THE BMP TO WITHIN THREE (3) FEET OF FINAL GRADE TO PREVENT CLOGGING OF INSITU SOIL. ONCE CONSTRUCTION IN THE CONTRIBUTING DRAINAGE AREA HAS BEEN COMPLETED AND THE SITE IS STABILIZED, EXCAVATE THE INFILTRATION TRENCH TO FINAL GRADE AND COMPLETE CONSTRUCTION OF THE INFILTRATION TRENCH.
4. GRADING OF THE INFILTRATION TRENCH SHALL BE ACCOMPLISHED USING LOW-IMPACT EARTH-MOVING EQUIPMENT TO PREVENT COMPACTION OF THE UNDERLYING SOILS. WIDE TRACKED VEHICLES SUCH AS BACK HOES, SMALL DOZERS AND BOBCATS ARE RECOMMENDED.
5. EXCAVATE THE INFILTRATION TRENCH TO THE SPECIFIED DEPTH (ELEVATION). ALL SUB MATERIAL BELOW THE SPECIFIED ELEVATION SHALL BE LEFT UNDISTURBED, UNLESS OTHERWISE DIRECTED BY THE ENGINEER.
6. GRADE TO THE DEPTH (ELEVATION) SPECIFIED IN THE CONSTRUCTION DOCUMENTS UNLESS OTHERWISE DIRECTED BY THE ENGINEER.
7. IN THE EVENT THAT SEDIMENT IS INTRODUCED INTO THE BMP DURING OR IMMEDIATELY FOLLOWING EXCAVATION, THE SEDIMENT WILL NEED TO BE REMOVED FROM THE INFILTRATION TRENCH PRIOR TO INITIATING THE NEXT STEP IN THE INFILTRATION TRENCH CONSTRUCTION PROCESS.
8. MATERIAL EXCAVATED FROM THE INFILTRATION TRENCH SHALL BE DISPOSED OF ON-SITE AT LOCATIONS (TEMPORARY STOCKPILE AREAS) DESIGNATED BY ENGINEER.
9. CLEAN, WASHED 1 TO 3-INCH GRAVEL SHALL BE PLACED IN THE BOTTOM OF THE INFILTRATION TRENCH TO THE DEPTH SPECIFIED IN THE CONSTRUCTION DOCUMENTS. GRAVEL SHOULD BE PLACED IN LIFTS AND LIGHTLY COMPACTED WITH PLATE COMPACTORS.

NO.	REVISION DESCRIPTION	DATE	BY

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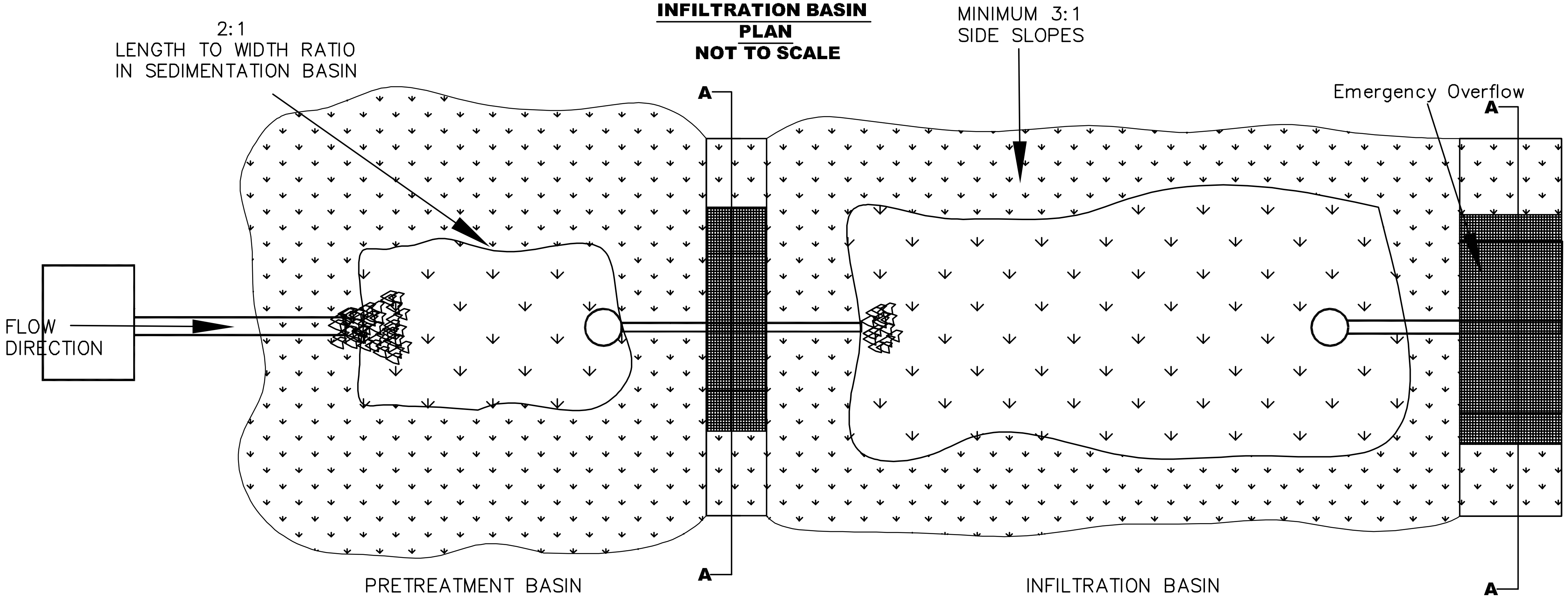
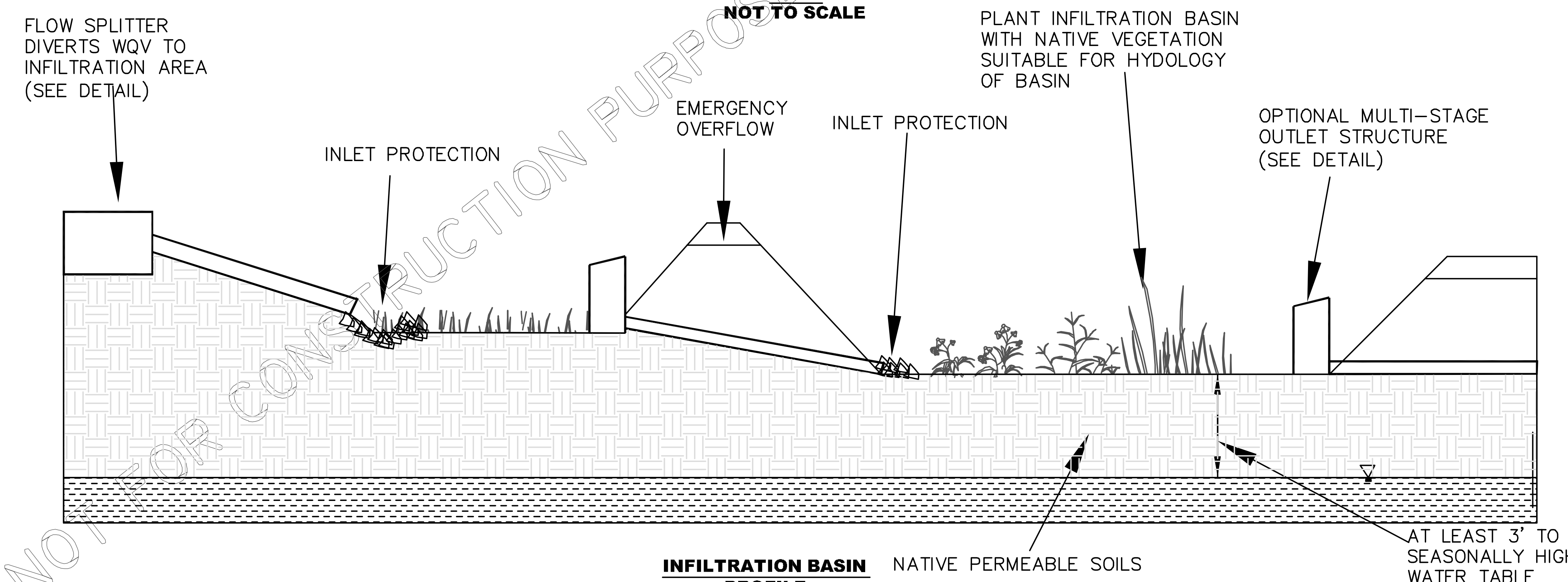
TYPICAL INFILTRATION TRENCH CROSS–SECTION

Sheet No. of Sheets

INFILTRATION BASIN
PLAN
NOT TO SCALE



INFILTRATION BASIN
PLAN
NOT TO SCALE



INFILTRATION BASIN
PROFILE
NOT TO SCALE

CONSTRUCTION SEQUENCING:

1. PERFORM CONTINUOUS INSPECTIONS OF EROSION CONTROL PRACTICES.
2. INSTALL SILT FENCE ALONG THE PERIMETER OF THE SITE TO PREVENT SEDIMENT FROM LEAVING THE SITE DURING THE CONSTRUCTION PROCESS.
3. ALL DOWNGRADIENT PERIMETER SEDIMENT-CONTROL BMPS MUST BE IN PLACE BEFORE ANY UP GRADIENT LAND-DISTURBING ACTIVITY BEGINS.
4. REMOVE TOPSOIL FROM THE SITE AND PLACE IN TEMPORARY STOCKPILE LOCATION. TEMPORARY SEED THE STOCKPILE.
5. INSTALL UNDERGROUND UTILITIES (WATER, SANITARY SEWER, ELECTRIC AND PHONES) TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.
7. SEED AND MULCH DISTURBED AREAS ON SITE.
8. CONSTRUCT THE ROADS TAKING THE LOCATION AND FUNCTION OF STORM WATER BMPS INTO CONSIDERATION.
9. PERFORM ALL OTHER SITE IMPROVEMENTS TAKING THE LOCATION AND FUNCTION OF THE STORM WATER BMPS INTO CONSIDERATION.
10. FINAL GRADE THE SITE.
11. STABILIZE THE SITE BY IMPLEMENTING THE NATIVE SEEDING AND PLANTING PORTION OF THE LANDSCAPING PLAN.
12. INSTALL THE EROSION CONTROL BLANKET
13. REMOVE THE SILT FENCE AFTER THE SITE IS STABILIZED PER PROJECT ENGINEER APPROVAL.

GENERAL NOTES:

1. INSTALL ALL TEMPORARY EROSION CONTROL MEASURES (IN ACCORDANCE WITH MnDOT GENERAL CONDITIONS 2573) PRIOR TO THE START OF ANY CONSTRUCTION OPERATION THAT MAY CAUSE ANY SEDIMENTATION OR SILTATION AT THE SITE.
2. INSTALL STORM DRAIN INLET PROTECTION TO PREVENT CLOGGING OF THE STORM SEWER AND SEDIMENT LOADS TO DOWNSTREAM STORM WATER FACILITIES OR WATERBODIES.
3. IF THE STORMWATER BMP IS BEING DESIGNED TO SERVE AS A TEMPORARY SEDIMENT BASIN, GRADE THE BMP TO WITHIN THREE (3) FEET OF FINAL GRADE TO PROTECT THE UNDERLYING MATERIAL FROM CLOGGING. ONCE CONSTRUCTION IN THE CONTRIBUTING DRAINAGE AREA HAS BEEN COMPLETED AND THE SITE IS STABILIZED, EXCAVATE THE INFILTRATION BASIN TO FINAL GRADE AND COMPLETE CONSTRUCTION OF THE BMP.
4. GRADING OF THE INFILTRATION BASIN SHALL BE ACCOMPLISHED USING LOW-IMPACT EARTH-MOVING EQUIPMENT TO PREVENT COMPACTION OF THE UNDERLYING SOILS. SMALL TRACKED DOZERS AND BOBCATS WITH RUNNER TRACKS ARE RECOMMENDED.
5. EXCAVATE THE INFILTRATION BASIN TO THE SPECIFIED DEPTH (ELEVATION). IT IS RECOMMENDED THAT ALL SUB MATERIAL BELOW THE SPECIFIED ELEVATION SHALL BE LEFT UNDISTURBED, UNLESS OTHERWISE DIRECTED BY THE ENGINEER.
6. GRADE TO THE DEPTH (ELEVATION) SPECIFIED IN THE CONSTRUCTION DOCUMENTS UNLESS OTHERWISE DIRECTED BY THE ENGINEER.
7. IN THE EVENT THAT SEDIMENT IS INTRODUCED INTO THE BMP DURING OR IMMEDIATELY FOLLOWING EXCAVATION, THIS MATERIAL WILL NEED TO BE REMOVED FROM THE BASIN PRIOR TO INITIATING THE NEXT STEP IN THE CONSTRUCTION PROCESS. SEDIMENT THAT HAS BEEN WASHED INTO THE BASIN DURING THE EXCAVATION PROCESS CAN SEAL THE PERMEABLE MATERIAL, SIGNIFICANTLY REDUCING THE INFILTRATION CAPACITY OF THE SOILS.
8. SEEDING AND INSTALLATION OF EROSION CONTROL BLANKET SHALL BE COMPLETED WITHIN 48 HOURS OF FINAL GRADING.
9. INFILTRATION AREA SHALL BE STAKED OFF DURING CONSTRUCTION TO RESTRICT HEAVY EQUIPEMENT TRAFFIC FROM COMPACTING NATIVE SOILS.

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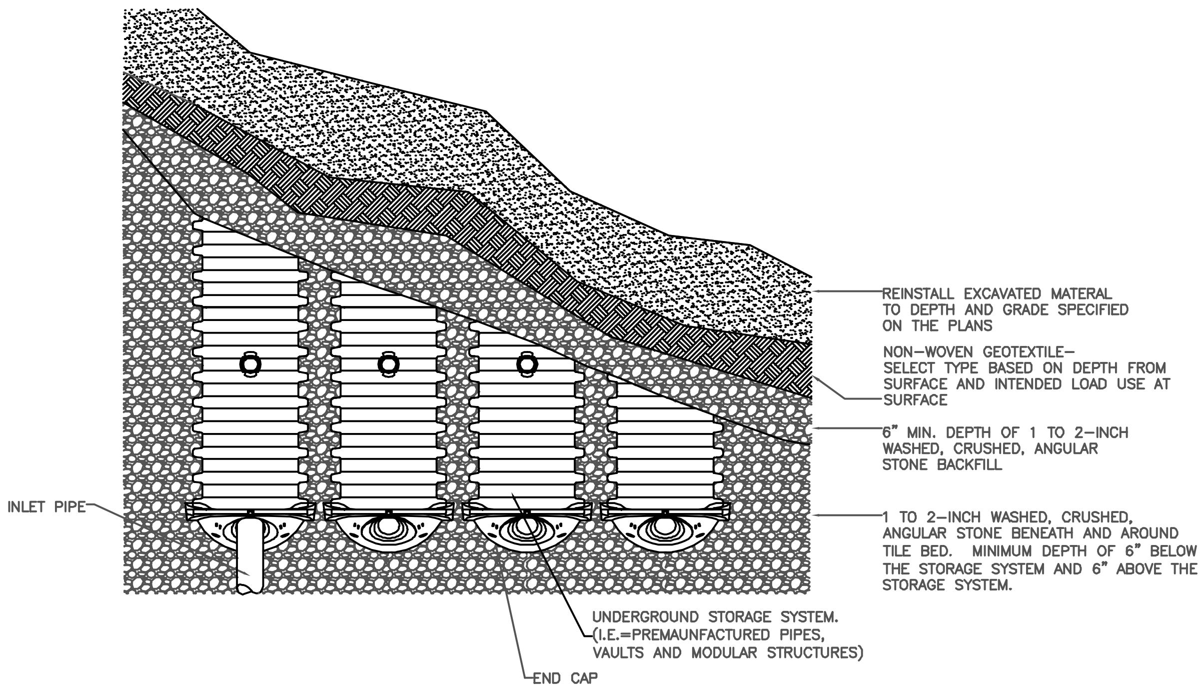
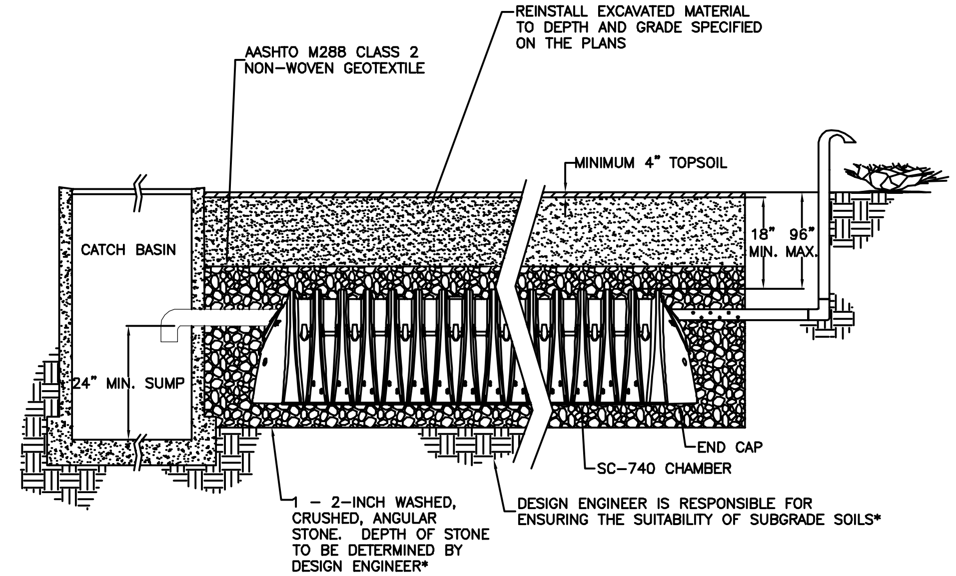
INFILTRATION BASIN PLAN AND PROFILE

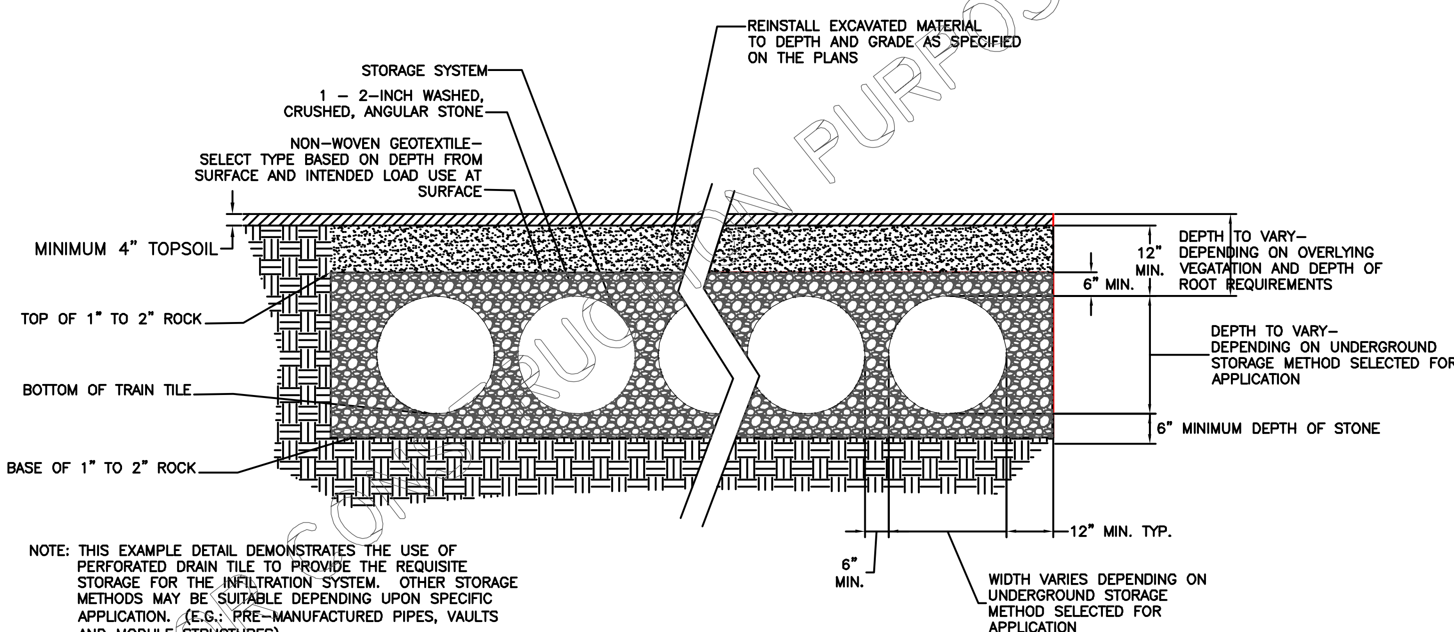
Sheet No.
of
Sheets



UNDERGROUND INFILTRATION SYSTEM
PLAN VIEW DETAIL
NOT TO SCALE



UNDERGROUND INFILTRATION SYSTEM
VENT DETAIL
NOT TO SCALE



NOTE: THIS EXAMPLE DETAIL DEMONSTRATES THE USE OF PERFORATED DRAIN TILE TO PROVIDE THE REQUISITE STORAGE FOR THE INFILTRATION SYSTEM. OTHER STORAGE METHODS MAY BE SUITABLE DEPENDING UPON SPECIFIC APPLICATION. (E.G.: PRE-MANUFACTURED PIPES, VAULTS AND MODULE STRUCTURES)

UNDERGROUND INFILTRATION SYSTEM
TYPICAL CROSS SECTION DETAIL
NOT TO SCALE

INFILTRATION SUBSURFACE PLANS & PROFILE

NOT TO SCALE

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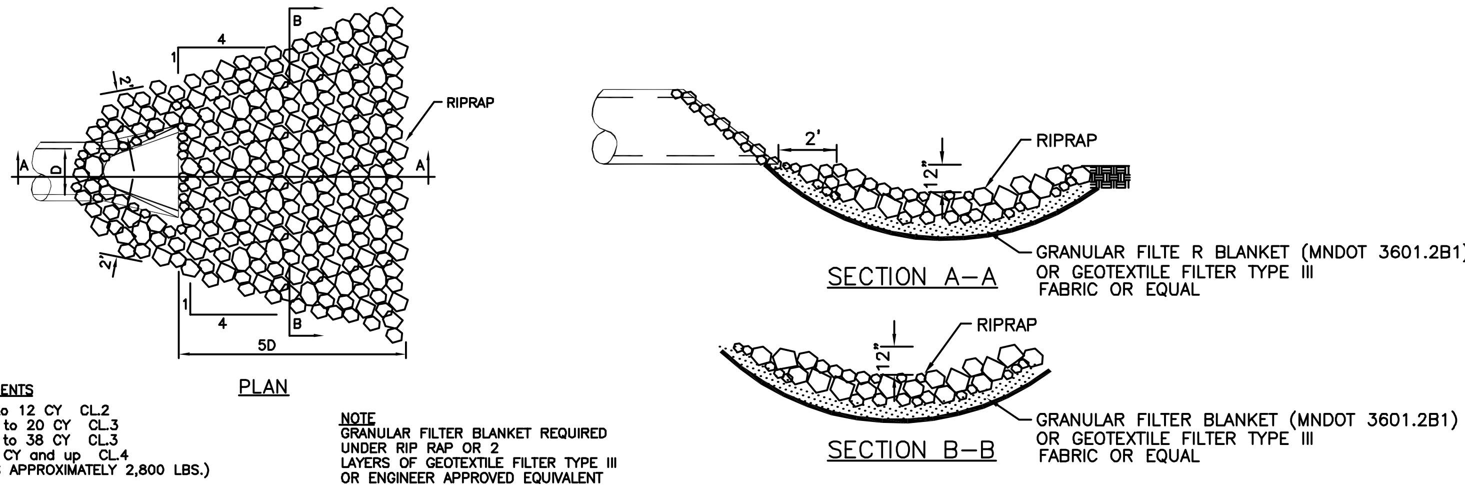
INFILTRATION SUBSURFACE PLANS AND SECTIONS

Sheet No. of Sheets



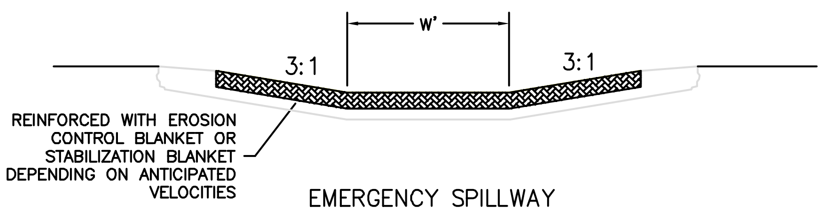
RIPRAP REQUIREMENTS

12" TO 24"	8 to 12 CY	CL.2
27" TO 33"	14 to 20 CY	CL.3
36" TO 48"	23 to 38 CY	CL.3
54" AND UP	62 CY and up	CL.4

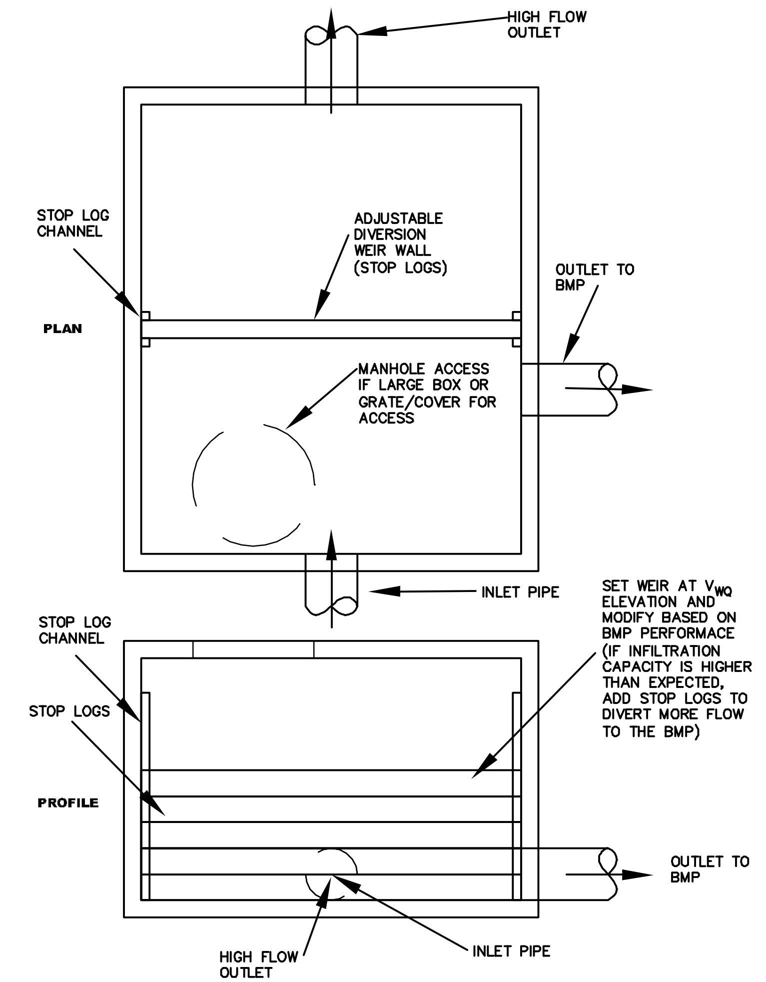
(ONE CUBIC YARD IS APPROXIMATELY 2,800 LBS.)

NOTE
GRANULAR FILTER BLANKET REQUIRED UNDER RIP RAP OR 2 LAYERS OF GEOTEXTILE FILTER TYPE III OR ENGINEER APPROVED EQUIVALENT

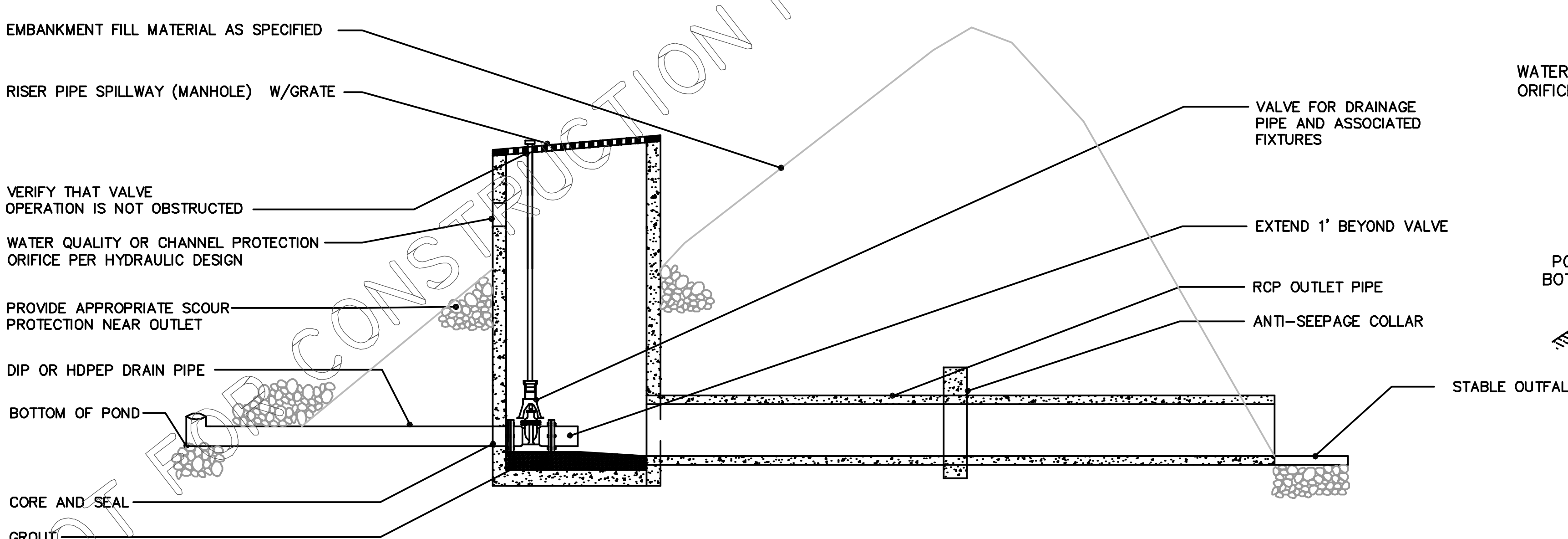
POND INLET DETAIL
NTS



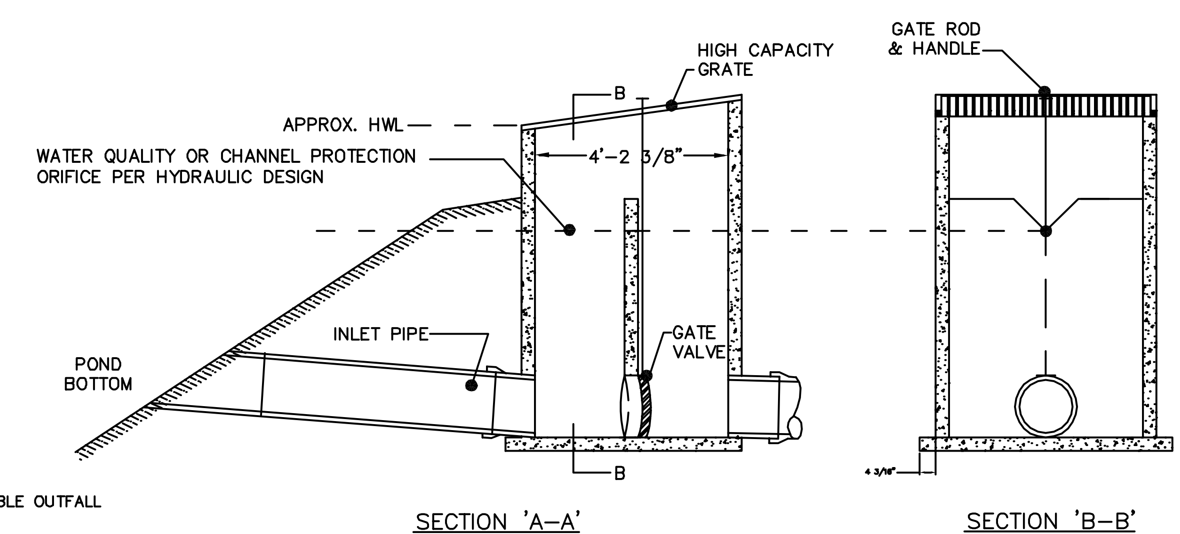
EMERGENCY SPILLWAY
CROSS—SECTION
A ———— A



ADJUSTABLE DIVERSION
NTS



MULTI—STAGE OUTLET STRUCTURE (ORIFICE EXAMPLE)
NTS



MULTI—STAGE OUTLET STRUCTURE (WEIR EXAMPLE)
NTS

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2005 MINNESOTA STORMWATER MANUAL

OUTLET STRUCTURE DETAILS

Sheet No. of Sheets

Appendix E

Minnesota Plant List and Application

Appendix E

Minnesota Plant List and Application

Contents

I. Sources for Stormwater BMP Plant Material Selection

The following agencies provide up to date information on plant material selection for vegetated stormwater BMPs .

- Minnesota Pollution Control Agency: http://www.pca.state.mn.us/publications/manuals/stormwaterplants.html
- Rice Creek Watershed District: http://www.ricecreek.org and click on the Best Management Practices browser (See also Figure E.1)
- Minnesota Department of Transportation: http://www.dot.state.mn.us/environment/pdf_files/SeedingManual2003.pdf
- Minnesota Board of Water and Soil Resources: http://www.bwsr.state.mn.us/wetlands/publications/nativewetveg.pdf Seed Mix: BWSR W4 for ditches and wet swales

There are two specific situations in which these above sources should not be used: high salt concentrations (in spray and soil) and green roofs. Recommendations on salt tolerant and green roof plant material selection are given below.

II. Salt Tolerance

Locations where salt tolerance is a concern include roadsides receiving frequent winter snowmelt spray, vegetated swales or basins where snowmelt runoff infiltrates the soil, and water bodies receiving relatively large volumes of snowmelt. This discussion is limited to selection of vegetation for constructed stormwater BMPs and vegetated areas receiving runoff from high use transportation routes and parking lots, wet and dry infiltration basins associated with regional ponding, county and state roadway swales and filter strips, and winter road snow dumping areas.

Salt tolerance is not a concern for stormwater BMPs such as rain gardens and infiltration swales in low to moderate use local streets and catchments with little or no salt-laden snowmelt runoff.

Salt tolerance is common to many plants of coastal marshy areas. These species are reliable on the east and west coast in their indigenous ranges. Some of these species are very widespread. The populations found in the Midwest are not necessarily salt tolerant. For inland areas the availability of naturally occurring populations of salt tolerant species is limited.

Salt tolerance has been shown in some of the dry grassland species of the west. The range of these species may include Minnesota. The local populations may exhibit salt tolerance and are recommended.

Salt tolerance has also been shown in some of the aggressive and invasive species found in the Midwest. These species, although amenable to the high salt areas are not recommended because of the stress that may be introduced to native plant communities. Depending on the species, their seeds may travel fairly far by wind or water and are not recommended for rural or urban areas, even if native plant communities are not adjacent.

Stormwater BMPs with high salt concentrations will be susceptible to invasion by exotic and invasive species due to multiple stressors from the salt, along with sedimentation and high phosphorus concentrations and petroleum products. Common buckthorn, one of the aggressive Midwest exotic species of saturated soils, has high salt tolerance. Box elder, a native of lowlands, but often a colonizer in disturbed sites also has high tolerance. Reed-canary grass has moderate tolerance, and purple loosestrife has high tolerance.

Table E.1 lists species and plant seed mixes which should be reliable in soils with high salt concentrations. The tolerance to salt spray may vary, and is shown in parentheses if known. The plant materials listed do not include highly aggressive and invasive species.

Salt tolerance ratings can vary across the country and between investigators, depending on the ways the data are collected and the ratings categories selected. Rating systems are not standardized between various investigators for different plant types (trees, shrubs, herbs) and uses (agriculture, horticulture). The sources sited here were used to represent as best as possible recent research, regional evaluations, and results from specialized salinity testing laboratories.

Note that information on salt tolerance for Minnesota plants warrant some interpretation. Much of the salt tolerance information published nationally is oriented toward agriculture rather than

Figure E.1 Recommended Plants for Rain garden Infiltration Basins and Vegetated Swales (Source: Rice Creek Watershed District)

Recommended Plants for Raingarden, Infiltration Basins and Vegetated Swales

Each site and Best Management Practice (BMP) application is unique. When determining plant material for BMP's take into account the suitability of the plant material to site conditions and BMP function. Use the following tables as guidelines for selecting plant material for BMP's.

Use the soil moisture gradient tool to help determine the siting of plant material in relation to the designed hydrology of the BMP. Note: Not all BMP's will have an distinct emergent community.

You are encouraged to customize your plant pallet. For more information on species characteristics and tolerances see the following sources:

Henderson, C., Dindorf, C., Rozumalski., F. 1999. Landscaping for Wildlife and Water Quality. Minnesota Department of Natural Resources. St. Paul, MN 55155-4040 USA.

Minnesota Department of Natural Resources. 2004. Native plant suppliers and landscapers in Minnesota. (http://www.dnr.state.mn.us/gardens/nativeplants/suppliers.html). St. Paul, MN 55155-4040 USA.

Shaw, D., and Schmidt R., 2003. Plants for Stormwater Design: Species Selection for the Upper Midwest. Minnesota Pollution Control Agency.

University of Minnesota Extension Services. 2004. Sustainable Urban Landscape Information Series - Plant Selection. (http://www.sustland.umn.edu/plant/index.html). St. Paul, MN 55108-6068 USA.

USDA, NRCS. 2004. The PLANTS Database, Version 3.5 (http://plants.usda.gov). National Plant Data Center, Baton Rouge, LA 70874-4490 USA.

University of Minnesota Extension Services. 2004. Sustainable Urban Landscape Information Series - Plant Selection. (http://www.sustland.umn.edu/plant/index.html). St. Paul, MN 55108-6068 USA.

Herbaceous Plants

Common Name	Scientific Name	Exposure
Prairie Phlox	*Phlox pilosa*	SUN
Little Bluestem	*Schizachyrium scoparium*	SUN
Bergamot	*Monarda fistulosa*	SUN
Meadow Blazing Star	*Liatris ligulistylis*	SUN
Virginia Bluebells	*Mertensia virginica*	SHADE
Ostrich Fern	*Matteuccia struthiopteris*	PARTIAL
Big Bluestem	*Andropogon gerardii*	Full
Canada Anemone	*Anemone canadensis*	SUN
Switchgrass	*Panicum virgatum*	SUN
Sensitive Fern	*Onoclea sensibilis*	SHADE
Obedient Plant	*Physostegia virginiana*	PARTIAL
Blue Lobelia	*Lobelia siphilitica*	PARTIAL
Golden Alexander	*Zizia aurea*	SUN
Tall Meadow Rue	*Thalictrum dasycarpum*	SUN
New England Aster	*Aster novae-angliae*	SUN
Queen of the Prairie	*Filipendula rubra*	SUN
Mountain Mint	*Pycnanthemum virginianum*	SUN
Ironweed	*Vernonia fasciculata*	SUN
Sneezeweed	*Helenium autumnale*	SUN
Blue Vervain	*Verbena hasta*	SUN
Culvers Root	*Veronicastrum virginicum*	SUN
Marsh Milkweed	*Asclepias incarnata*	SUN
Boneset	*Eupatorium perfoliatum*	SUN
Caterpillar Sedge	*Carex crinita*	PARTIAL
Cardinal Flower	*Lobelia cardinalis*	PARTIAL
Canada Blue-joint Grass	*Calamagrostis canadensis*	SUN
Joe Pye Weed	*Eupatorium maculatum*	SUN
Turtlehead	*Chelone glabra*	SUN
Woolgrass	*Scirpus cyperinus*	PARTIAL
Soft Rush	*Juncus effusus*	SUN
Porcupine Sedge	*Carex hystricina*	PARTIAL
Tussock Sedge	*Carex stricta*	SUN
Fox Sedge	*Carex vulpinoidea*	SUN
Blueflag Iris	*Iris versicolor*	SUN
Bottlebrush Sedge	*Carex comosa*	SUN
Three-squared Bulrush	*Scirpus pungens*	SUN
Water Plantain	*Alisma triviale*	SUN
Sweet Flag	*Acorus calamus*	SUN
Giant Bur-reed	*Sparganium eurycarpum*	SUN
Arrowhead	*Sagittaria latifolia*	SUN
Green Bulrush	*Scirpus atrovirens*	SUN
River Bulrush	*Scirpus fluviatilis*	SUN
Softstem Bulrush	*Scirpus validus*	SUN

Trees and Shrubs

Common Name	Scientific Name	Exposure
Low Bush Honeysuckle	*Diervilla lonicera*	PARTIAL
Red-berried Elder	*Sambucus pubens*	SUN
Hackberry	*Celtis occidentalis*	SUN
Red Osier Dogwood	*Cornus sericea*	PARTIAL
Silver Maple	*Acer saccharinum*	SUN
Steeplebush	*Spiraea tomentosa*	SUN
Black Chokeberry	*Aronia melanocarpa*	PARTIAL
High Bush Cranberry	*Viburnum trilobum*	SUN
Winterberry	*Ilex verticillata*	PARTIAL
Black Ash	*Fraxinus nigra*	SUN
Cottonwood	*Populus deltoides*	SUN
Swamp White Oak	*Quercus bicolor*	SUN
Meadow Sweet	*Spiraea alba*	SUN
Speckled alder	*Alnus incana*	SUN
Indigobush	*Amorpha fruticosa*	SUN
Pussy Willow	*Salix caprea*	PARTIAL
Buttonbush	*Cephalanthus occidentalis*	SUN

Cardinal Flower
Lobelia cardinalis

Native Seed List

		Side Slope Temporary Saturation	Wet Meadow Semi-permanent Saturation	Emergent Permanent Saturation
MNDOT SEED MIXES	25B Sedge Meadow			
	26B Stream Bank & Prairie Meadow			
	310 Ponds & Wet Areas			
	340 Sandy/dry Areas - Mid-height Grasses			
	350 General Roadside			
MN STATE SEED MIXES	W2 Native Sedge/Wet Meadow			
	W3 Native Wet Prairie			
	W4 Native Swale/Ditch			
	W5 BWSR Native Wetland Fringe			
	W6 BWSR Native Wet Prairie			
	R2 Native Riparian-Stream Bank			

EMMONS & OLIVIER RESOURCES
RCWD

stormwater BMPs. Table E.1 attempts to interpret data from the references noted at the end of this Appendix for applicability to Minnesota. Table E.2 provides sources for seed mixes.

Some common Midwest species are known to be intolerant of high salt soil concentrations. Avoid planting these species or seed mixes when salt is expected to be a stressor.

- Grey dogwood (*Cornus racemosa*)
- Red-osier dogwood (*Cornus stolonifera*)
- Silver maple (*Acer saccharinum*)
- Sugar maple (*Acer saccharum*)
- Basswood (*Tilia Americana*)

Table E.1. Cold Climate Plant Materials of the Upper Midwest with Known Salt Tolerance, Listed from Wet to Dry Soil Moisture (Sources: See Refernece Section at End of Appendix)

Plant Material	Soil Moisture	Salt Tolerance in Soil	Growth Form	Notes on Use
American elm (*Ulmus Americana*)	Always Wet/ Frequently Saturated	Medium/Low*	Tree	
Green ash (*Fraxinus pennsylvanica*)	Always Wet	Medium*	Tree	
Canada wild rye (*Elymus canadensis*)	Frequently Saturated	Medium	Herbaceous-grass	
Meadow foxtail (*Alopecurus pratensis*)	Frequently Saturated	Low	Herbaceous-grass	
Karl Foerster reed grass (*Calamogrostis acutifolia* 'Karl Foerster')	Frequently Saturated/ Mostly Drained	High	Herbaceous-grass	This is a cultivar for landscaping
White ash (*Fraxinus Americana*)	Frequently Saturated/ Mostly Drained	High*	Tree	
Poplars (*Populus* spp.)	Frequently Saturated/ Mostly Drained	Medium*	Tree	Including aspen, cottonwood, black and silver-leaved poplar; fast growing; also provide good streambank stabilization; highly tolerant to salt spray
Hackberry (*Celtis occidentalis*)	Frequently Saturated/ Mostly Drained	Medium	Tree	

Table E.1. Cold Climate Plant Materials of the Upper Midwest with Known Salt Tolerance, Listed from Wet to Dry Soil Moisture (Sources: See Refernece Section at End of Appendix)				
Plant Material	**Soil Moisture**	**Salt Tolerance in Soil**	**Growth Form**	**Notes on Use**
Jack pine (*Pinus banksiana*)	Mostly Drained	High*	Tree	
Smooth sumac (*Rhus glabra*)	Mostly Drained	Medium	Shrub	Colonizes and spreads in high sun
Staghorn sumac (*Rhus typhina*)	Mostly Drained	High	Shrub	
Cutleaf sumac (*Rhus trilobata*)	Mostly Drained	High	Shrub	
Rugosa rose (*Rosa rugosa*)	Mostly Drained	Low	Shrub	
Perennial ryegrass (*Lolium perenne*)	Mostly Drained	Medium	Herbaceous - grass	
Blue grama grass (*Bouteloua hirsuta*)	Mostly Drained	High	Herbaceous-grass	Selections being made for strongly salt-tolerant varieties; see University of Minnesota for latest
Little bluestem (*Schizachyrium scoparium*)	Mostly Drained	High	Herbaceous-grass	
Alkali grass (*Puccinella distans*)	Mostly Drained	High	Herbaceous-grass	
Tall wheatgrass (*Agropyron elongatum*)	Mostly Drained	High	Herbaceous-grass	
Western wheat grass (*Elytrigia smithii*)	Mostly Drained	High	Herbaceous - grass	
Seed Mix: MNDOT urban prairie	Mostly Drained	High	Herbaceous-grasses	
Seed Mix: MNDOT western tall grass prairie	U	M	Herbaceous-grass	
*trees with some tolerance to spray				

Table E.2 Recommended Salt Tolerant Mixes (Source: Mn/DOT 2005 Seed Mixes from Shooting Star Native Seeds Web site)

DESCRIPTION: Combination native and turf mix. Reaches a height of approximately 18 inches. For use in urban areas where conditions may be saline, droughty, & generally poor soils. Oats to be substituted for Winter Wheat in spring plantings at a ratio of 1 to 1.

RATE: 60 lbs/acre (67.2 kg/ha)

COMMON NAME	SCIENTIFIC NAME	# LBS	%AGE
GRAMA SIDEOATS	*BOUTELOUA CURTIPENDULA*	4.80	8.00%
GRAMA BLUE	*BOUTELOUA GRACILIS*	3.60	6.00%
PRAIRIE CLOVER PURPLE	*DALEA PURPUREUM*	1.20	2.00%
WILDRYE CANADA	*ELYMUS CANADENSIS*	2.40	4.00%
WHEAT GRASS SLENDER	*ELYMUS TRACHYCAULUS*	3.60	6.00%
RYE GRASS ANNUAL	*LOLIUM ITALICUM*	4.80	8.00%
WHEAT WINTER	*TRITICUM AESTIVUM*	15.60	26.00%
BLUEGRASS CANADA	*POA COMPRESSA*	7.20	12.00%
GRASS ALKALI	*PUCCINELLA DISTANS*	9.60	16.00%
BLUESTEM LITTLE	*SCHIZACHYRIUM SCOPARIUM*	6.00	10.00%
DROPSEED SAND	*SPOROBOLUS CRYPTANDRUS*	1.20	2.00%
	TOTALS	60.00	100.00%

POUNDS OF COVER CROP TO BE BAGGED SEPERATELY (TECH MEMO 04-09-ENV-02) 78.00

MIXTURE 10B (WESTERN TALL GRASS PRAIRIE)
GRASSES ARE PLS, FORBS & INTRODUCED ARE BULK, YELLOW TAG WHEN AVAILABLE

DESCRIPTION: Native mix. Reaches a height of 36 to 48 inches. For use in western Minnesota. Oats to be substituted for Winter Wheat in spring plantings at a ratio of 1 to 1.

RATE: 30 lbs/acre (33 kg/ha)

COMMON NAME	SCIENTIFIC NAME	# LBS	%AGE
BLUESTEM BIG	*ANDROPOGON GERARDI*	1.80	6.00%
GRAMA SIDEOATS	*BOUTELOUA CURTIPENDULA*	2.40	8.00%
WILDRYE CANADA	*ELYMUS CANADENSIS*	1.80	6.00%
WHEAT GRASS SLENDER	*ELYMUS TRACHYCAULUS*	1.20	4.00%
WHEAT GRASS WESTERN	*ELYTRIGIA SMITHII*	0.60	2.00%
RYE GRASS ANNUAL	*LOLIUM ITALICUM*	3.00	10.00%
WHEAT WINTER	*TRITICUM AESTIVUM*	10.20	34.00%
FORBS F-1 OR F-2	*N/A*	1.50	5.00%
SWITCHGRASS WILD TYPE	*PANICUM VIRGATUM*	0.30	1.00%
BLUESTEM LITTLE	*SCHIZACHYRIUM SCOPARIUM*	3.00	10.00%
INDIAN GRASS	*SORGHASTRUM NUTANS*	3.00	10.00%
NEEDLE GRASS GREEN	*STIPA VIRIDULA*	1.20	4.00%
	TOTALS	30.00	100.00%

POUNDS OF COVER CROP TO BE BAGGED SEPERATELY (TECH MEMO 04-09-ENV-02) 51.00

III. Green Roofs

The green roof BMP has the most specialized circumstances for plant materials and thus requires a very different list of materials compared to on-the-ground BMPs. More than any other BMP, it is unwise to proceed on selecting green roof plant materials without full knowledge of the entire green roof structural design system. This has to do with the very constrained growing conditions for this highly engineered BMP. Note that the following discussion relates to plant selection for green roofs and is not a design sheet for green roof BMPs.

The first consideration on plant material selection is the basic green roof design type. Extensive green roofs (EGRs) have been commonly using xeriscape types of plantings in a shallow, draughty growing medium. These are more appropriate for urban rooftops (See Table E.3 for planting recommendations). Intensive green roofs (IGR) include earth-bermed structures and tend to be heavier and reliant on richer, deeper substrates and may also have shrubs and trees (See also Chapter 12 Guidance Sheet on Green Roofs). As such, the plant materials for extensive and intensive green roof systems are not usually the same. For example, the selections for an earth-berm IGR planting may be quite different from an EGR system.

Secondly, the plant material selection, through biological processes and nutrient cycling, may effect whether the BMP exacerbates or mitigates the function of nutrient storage. Research to date comparing EGRs and control (nongreen) roofs shows that green roofs are a poor BMP for nutrient storage and removal from precipitation. In evidence from both southern and northern climates, total phosphorus concentrations are higher in runoff leaving a green roof compared to control roofs, although the mass loading is the same as the control (Moran *et al.*, 2004). Nitrogen losses from a green roof do not differ significantly from control roofs. So for nutrient loading and design of removal systems, other BMP tools should be located 'further down the runoff path' from the rooftop BMP to trap runoff from green roofs. It is unclear how the IGRs function for nutrient storage.

Extensive green roofs are definitely a reliable BMP for reducing peak runoff rates. This has been demonstrated in several controlled studies in both southern and northern climates. Intensive green roofs provide the same function. It is not clear if the plant material plays a significant role in this or whether it is related to the design of the planting medium and underlying roof runoff system. To date it has always been assumed that the overall design should support plant materials that are tolerant of drought conditions and not prolonged saturated soil.

There is plenty of opportunity for experimentation on green roof plant material. Most controlled experiments have been limited in the kinds of plant material tested. The Genus *Sedum* has been widely used in extensive green roof plantings. It is unknown whether plantings dominated by other and widely different plant groups will yield the same results. As such, the function of a green roof as a stormwater BMP may vary: nutrient storage may not be an issue with some plant materials. Until further case studies and experiments are conducted on the nutrient storage function of this BMP, it is wise to assume that all plant material selections will yield added nutrient runoff, particularly if the plants are fertilized. Thus, the green roof system should be designed in series with other BMPs which are expected to function in this respect.

The variety of choices of EGR plant material for warm and cold climates is generally limited in the following ways:

- ► Water and nutrients from precipitation
- ► Substrate - often at least partially synthetic and droughty
- ► Limited organic matter buildup – isolated from organic debris, leaf build-up, sediment-laden runoff
- ► Shallow rooting zone – less than one foot

Plant selection is restricted to materials which will be successful in very shallow substrates, perhaps 6 inches, up to 12 inches deep. Long-lived, perennial drought tolerant species commonly display deep taproot growth or deep fibrous root systems. This is the main reason that the Genus *Sedum* is so commonly relied upon. In contrast, many of the prairie forbs and grasses valued for infiltration BMPs may not be appropriate for green roofs.

The plant material selection for any one specific green roof is also dependent on the substrate content and depth. Intensive and extensive systems were already defined, and will significantly effect the substrate choices. The plant material selections provided here have been limited to those for EGRs. Even within an extensive system, in which the substrate is in general droughty, the specific design of each system will significantly effect plant productivity. Experiments in which the same plant material was grown on several different substrates demonstrates the importance of this. As such, one of the main criteria for selecting EGR plants is the substrate design. And often, this is limited by the structural integrity of the building, particularly for retrofit designs.

For EGRs, irrespective of the specific design, one general consideration applies to establishing plant material. The material will usually be introduced as young plants, and to reduce transplant shock and provide an enriched environment for further growth, an organic substrate such as compost should be used as the immediate transplant medium.

Table E.3 Plant Materials for Use in Extensive Green Roof Systems (Sources: Federal Energy Management Program, September 2004. Green Roofs. DOE/EE-0298)

Botanical Name	Common Name	Height (Inches)	Flower Color	USDA Zone	Bloom Time
Antennaria diocia*	Pink Pussy Toes	3"	Pink		
Armeria juniperifolia*	Spanish Thrift	2"	Pink	2	June
Armeria maritima 'Pride of Dusseldorf'*	Common Thrift	5"	Pink	2	April-June
Aubrieta 'Argenteo-variegata'*	Rock Cress	4"	Purple	4	April-June
Campanula 'Birch Hybrid'	Bellflower	4"	Blue	4	June-Sept
Sedum acre 'Aureum'	Golden Stonecrop	3"	Yellow	3	June-August
Sedum aizoon		4"	Yellow	5	July-August
Sedum album 'Murale'		1"	White	4	
Sedum cyaneum 'Rose Carpet'		2"	Pink		
Sedum dasyphyllum		3"	White	5	June
Sedum dasyphyllum 'Blue Cadet'		1.5"	White	5	
Sedum dasyphyllum 'Blue Carpet'		1"	White/Pink	5	
Sedum divergens	Old Man Bones	4-6"	Yellow	5	July-August
Sedum ewersii	Pink Stonecrop	6"	Rose-Pink	3	Late Summer
Sedum 'Jelly Bean'	Jellybean Sedum	4"			
Sedum kamtschaticum	Russian Stonecrop	6"	Yellow	3	June-July
Sedum linare 'Variegatum'		5"	Yellow		
Sedum lineare 'Golden Teardrop'		3"	Yellow	3	May-June
Sedum matrona		24"	Pink	6	Sept
Sedum 'Mentha Requein'	False artillery fern	2"		4	
Sedum pinifolium 'Blue Spruce'		8"	Yellow	4	June-July
Sedum reflexum		4"	Yellow		
Sedum sexangulare		4"	Yellow	4	
Sedum spurium 'Fuldaglut'	Dragon's Blood Sedum	6"	Red	3	Fall
Sedum spurium 'Roseum'		6"	Pink	3	
Sedum spurium 'Tri-Color'		6"	Pink	3	
Sedum spurium 'White Form'		6"	White	3	
Sedum ternatum 'Larinem Park'	Shale Barrens	2"	White	3	May-June
Sedum tetractinum		4"		5	
Sedum floriforum 'Weihenstephaner Gold'			Yellow		
Sedum 'Arthur Branch'		18"	Red	4	August-Sept
Sempervivum arachnoideum 'Sparkle'	Spider-web Hen & Chicks				
Thymus praecox 'Coccineus'	Red Creeping Thyme	1"	Red/Purple	2	July-August
Thymus praecox 'Elfin'	Miniature Thyme	1/2"	Pink	2	July-August
Thymus praecox 'Pseudolanuginosus'	Woolly Thyme	1"	Pink	2	July-August

Note: Invasive sedum species—such as Sedum sarmentosum, a native of China—should be avoided on green roof applications. Delosperma, or ice plant, is also difficult to control on some roofs.

* These require about 4 inces of soil.

IV. References

Salt Tolerance

Colorado State University Cooperative Extension Tri River Area. 2003. Salt Tolerance of Various Temperate Zone Ornamental Plants. Curtis E. Swift.

Johnson, Gary R. and Ed Sucoff. 2000. Minimizing De-Icing Salt Injury to Trees. University of Minnesota Extension Service.

Minnesota Department of Transportation. 2003 Seeding Manual. Office of Environmental Services, Erosion Control Unit.

University of California, Riverside. George E Brown Jr Salinity Laboratory

University of Wiscsonsin-Extension.1999. Salt Injury to Landscape Plants. Delahaut, K.A. and E.R. Hasseljus. Cooperative Extension Publishing.

Green Roof Plant Material Selection

Bengtsson, L. 2004. Hydrological Response of Sedum-Moss Roof. American Geophysical Union, Fall Meeting 2004, abstract #H41A-0285.

DeNardo, J.C., A.R. Jarrett, H.B. Manbeck, D.J. Beattie, and R.D. Berghage. 2003. Stormwater Detention and Retention Abilities of Green Roofs. World Water and Environmental Resources Congress 2003. Paul Bizier, Paul DeBarry - Editors, June 23–26, 2003, Philadelphia, Pennsylvania, USA

Federal Energy Management Program. September 2004. Green Roofs. DOE/EE-0298.

Moran, Amy, Bill Hunt, Greg Jennings. 2004. Greenroof Research of Stormwater Runoff Quantitiy and Quality in North Carolina. NCSU Water Quality Group Newsletter August 2004.

Shooting Star Native Seeds, 2005. Mn/DOT 2005 Seed Mixes. http://www.shootingstarnativeseed.com/mndot_mixes.htm

Uhl, M, Schiedt, L, Mann, G, Henneberg, M. 2003. Long-term study of rainfall runoff from green roofs. Wasser und Boden. Vol. 55, no. 3, pp. 28-36. Mar. 2003

Appendix F

Special Waters and Other Sensitive Receiving Waters

wq-strm8-14j

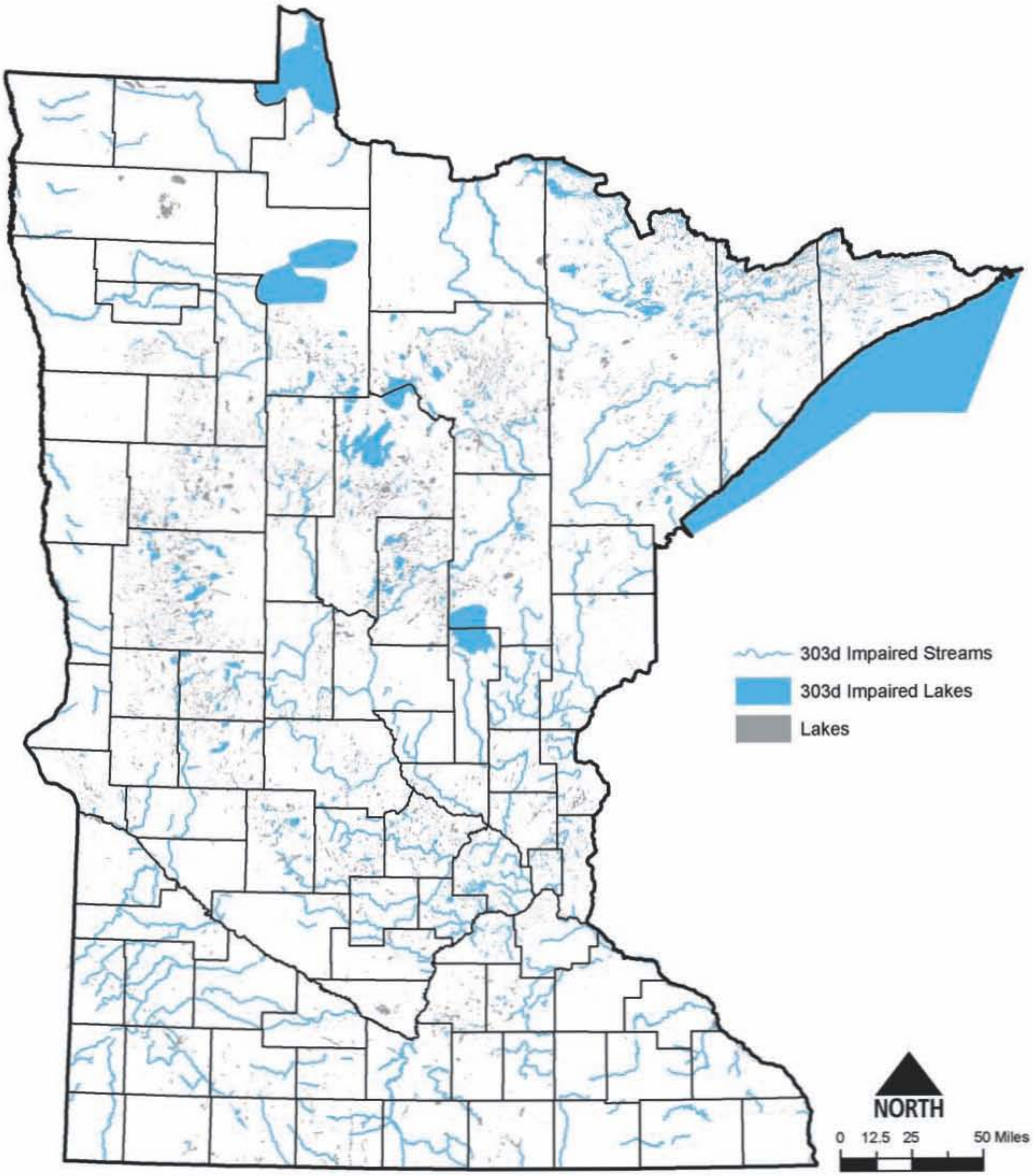
APPENDICES

Appendix F

Special Waters and Other Sensitive Receiving Waters

Contents

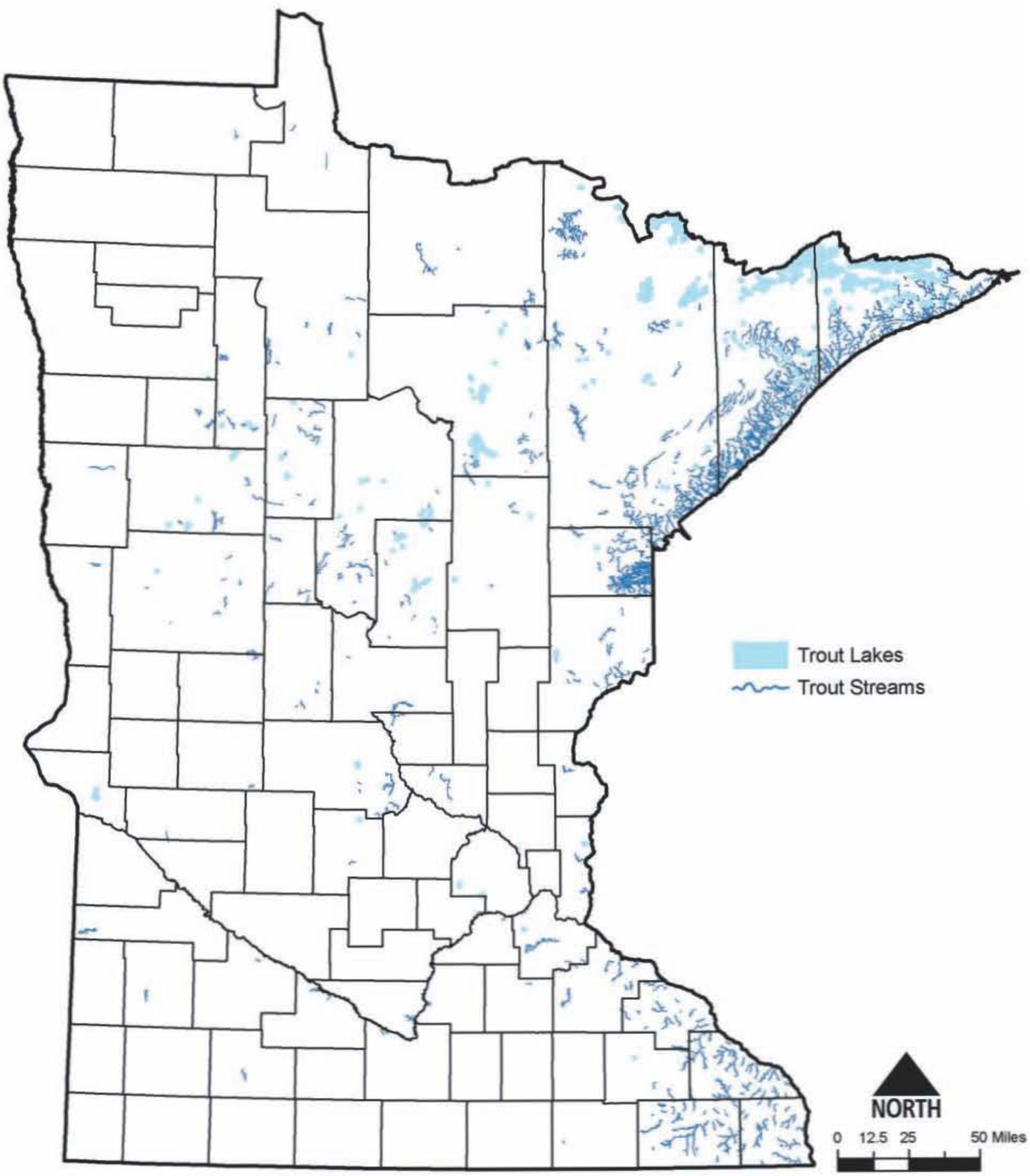
Figure F.1 Impaired Waters



October, 2005

Sources: MPCA (GIS data available at http://www.pca.state.mn.us/water/tmdl/index.html), DNR (GIS data available at http://deli.dnr.state.mn.us/)
More information on impaired waters available at http://www.pca.state.mn.us/water/tmdl/index.html

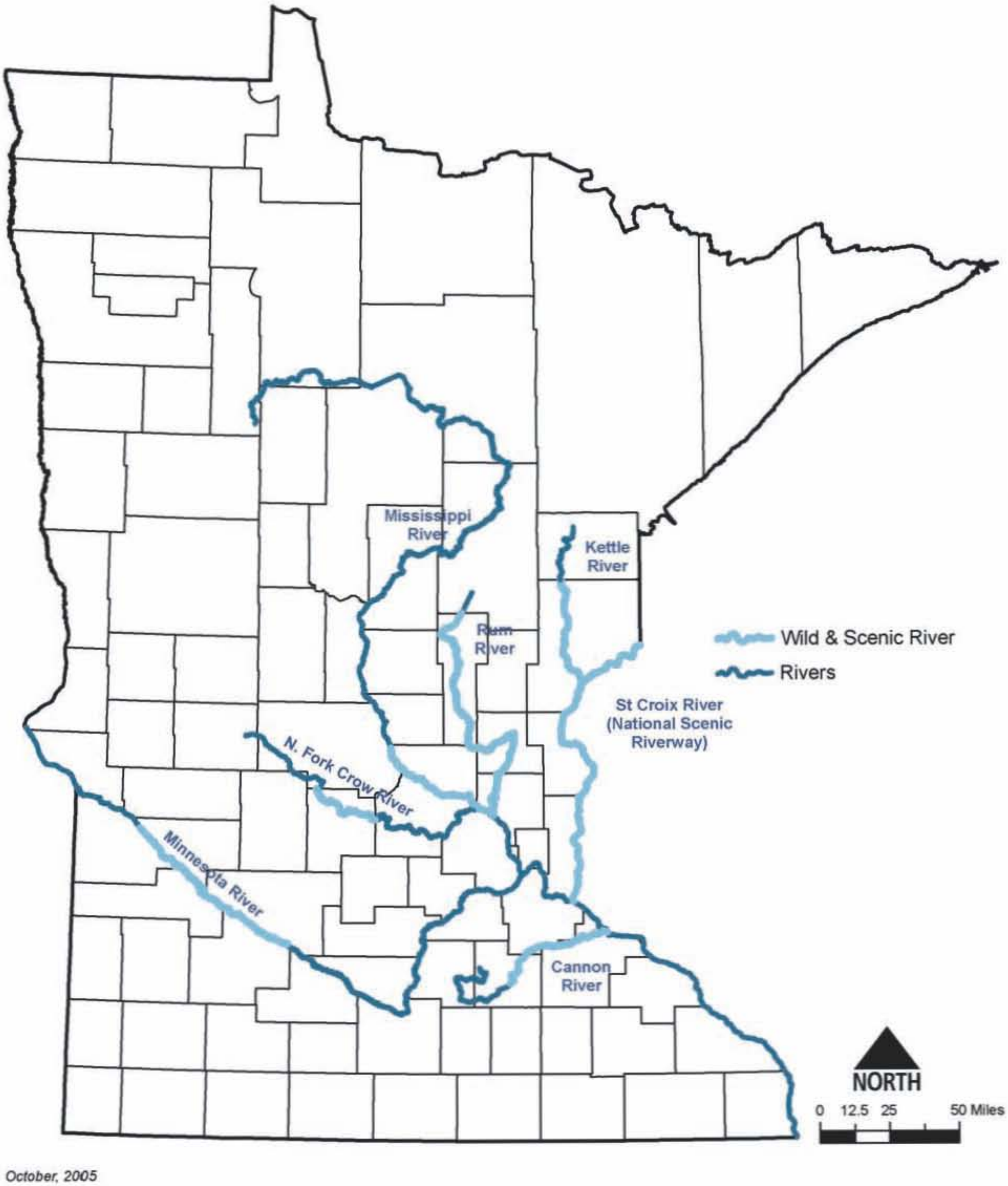
Figure F.2 Trout Resources



October, 2005

Sources: DNR (GIS data available at http://deli.dnr.state.mn.us)

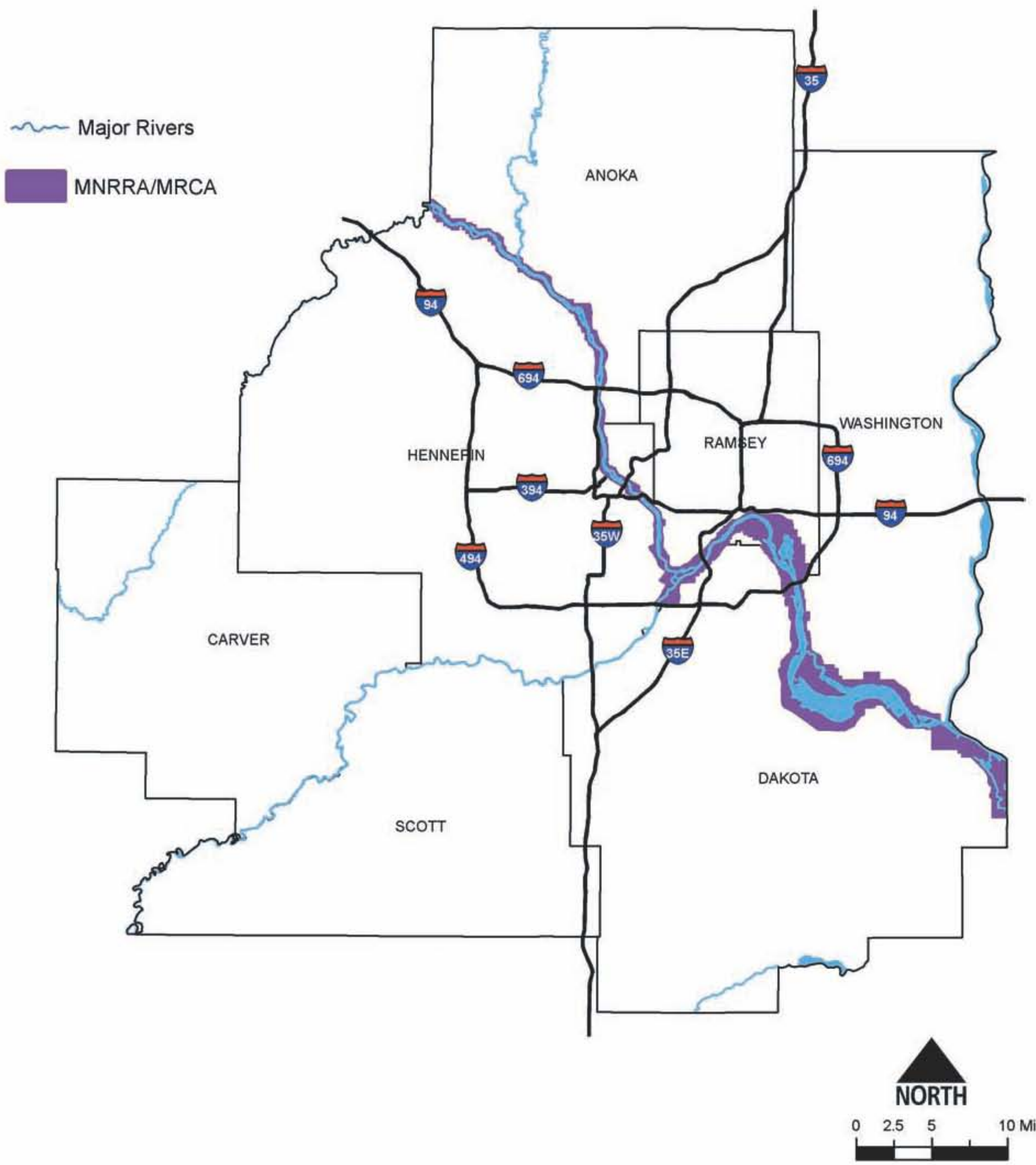
Figure F.3 Wild, Scenic and Recreational Rivers



October, 2005

Sources: DNR (GIS data available at http://deli.dnr.state.mn.us)
More information on Wild and Scenic Rivers is available at http://www.dnr.state.mn.us/waters/watermgmt_section/wild_scenic/index.html

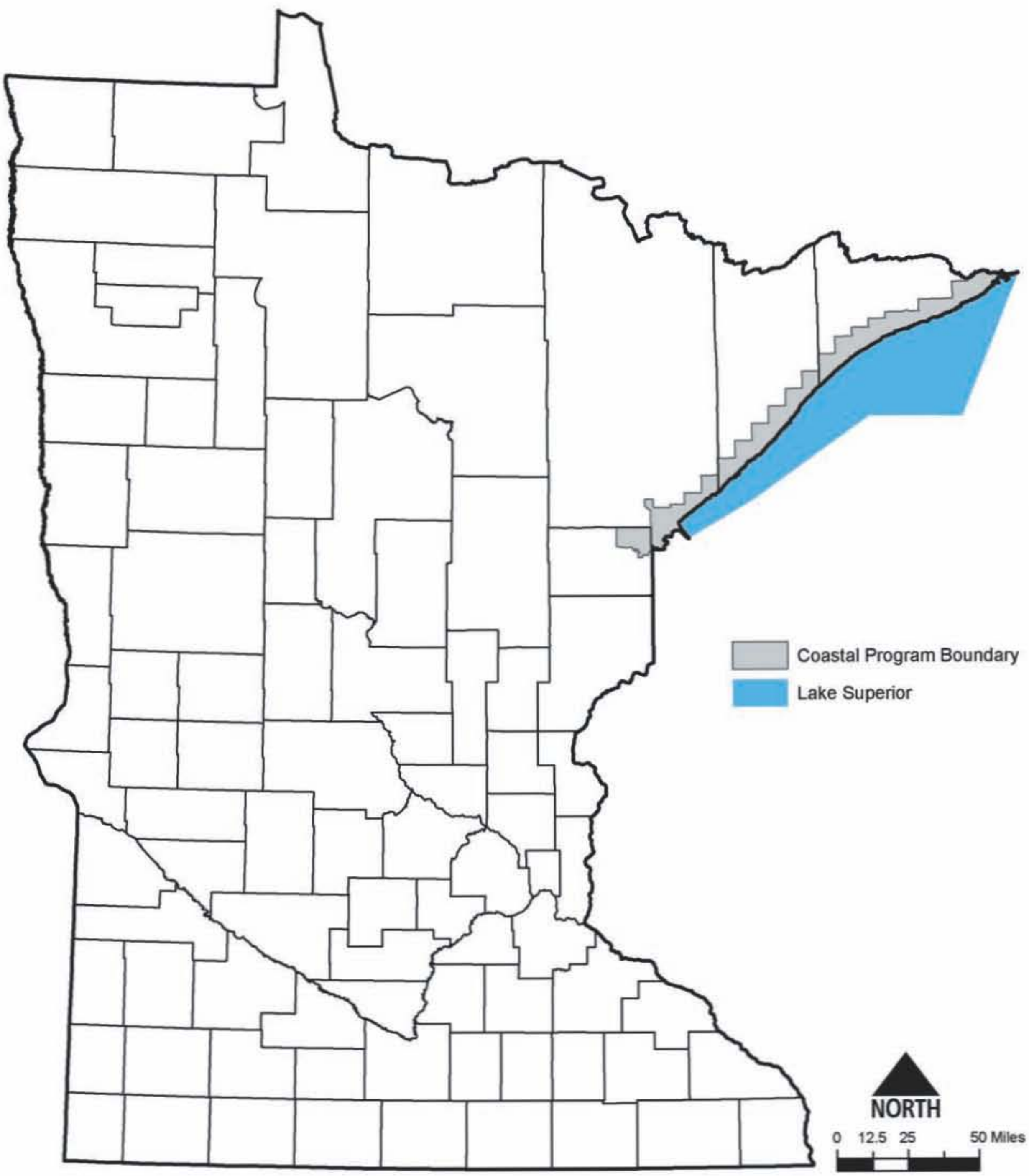
Figure F.4 Mississippi National River and Recreation Area/ Mississippi River Critical Area



October, 2005

Sources: MetroGIS (GIS data available at http://www.datafinder.org/index.asp), DNR (GIS data available at http://deli.dnr.state.mn.us)

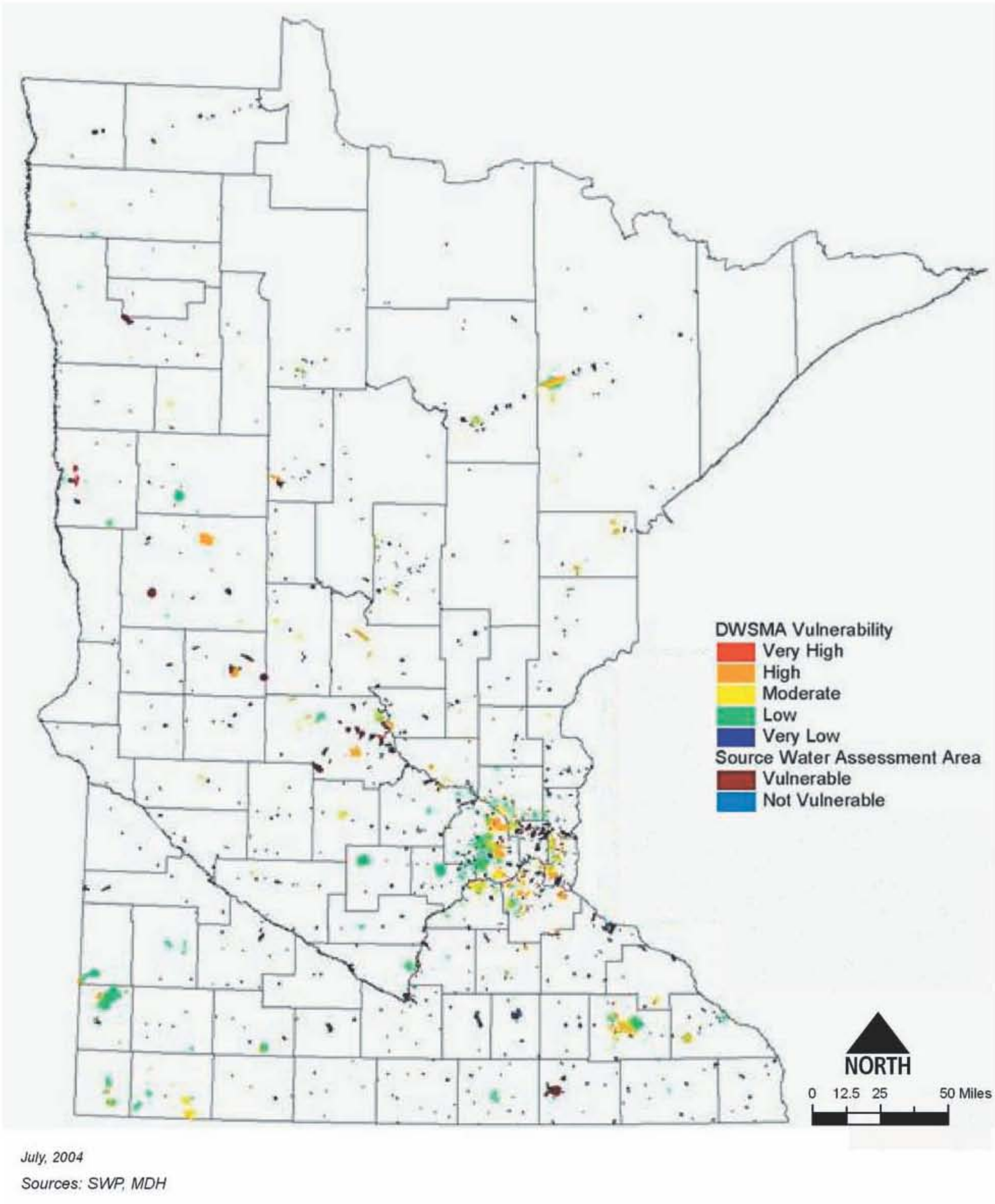
Figure F.5 Coastal Program Boundary



October, 2005

Sources: NRRI (GIS data available at http://www.nrri.umn.edu/coastalgis/basemaps.html), DNR (GIS data available at http://deli.dnr.state.mn.us/)

Figure F.6 Source Water Protection Areas



July, 2004

Sources: SWP, MDH

Table F.1 Links to Special Waters, ORVWs, and Other Sensitive Receiving Waters	
Water	**Link**
Calcareous Fens	http://www.pca.state.mn.us/publications/wq-strm1-06.xls
Impaired Waters (303d List)	http://www.pca.state.mn.us/publications/reports/tmdl-list-2004.pdf
Metropolitan Council Priority Lakes	http://www.metrocouncil.org/planning/environment/WRMPP/WRMPPMay2005_Appendi-ces2.pdf
Mississippi National River and Recreation Area (MNRRA)	http://www.dnr.state.mn.us/waters/watermgmt_section/mnrra/index.html
Mississippi River Critical Area	http://www.dnr.state.mn.us/waters/watermgmt_section/critical_area/index.html
Outstanding Resource Value Waters (ORVW)	http://www.revisor.leg.state.mn.us/arule/7050/0180.html
Public Waters	http://www.dnr.state.mn.us/waters/watermgmt_section/pwi/maps.html
Scientific and Natural Area	http://www.dnr.state.mn.us/snas/list.html
Special Waters List	http://www.pca.state.mn.us/publications/wq-strm1-05.xls
Trout Lakes	http://www.dnr.state.mn.us/fishing/trout_lakes/list.html
Trout Streams	http://www.dnr.state.mn.us/fishing/trout_streams/index.html
Wetlands	http://wetlands.fws.gov/mapper_tool.htm
Wild, Scenic, Recreational Rivers	http://www.dnr.state.mn.us/waters/watermgmt_section/wild_scenic/index.html

Appendix G

Additional Regulatory Information

wq-strm8-14k

Appendix G

Additional Regulatory Information

Contents

I. Agencies and Stormwater Authorities

Federal

Federal Emergency Management Agency (FEMA)

An agency of the US government established to provide leadership and support for the nation's emergency management system so that States, local governments, and others can effectively prepare for, respond to, recover from, and mitigate the effects of natural disasters. It consists of a national office and ten regional offices.

Federal Emergency Management Agency
Region 5
536 South Clark St.
Chicago, IL 60605
Telephone: (312) 408-5500
Web: http://www.fema.gov/regions/v/

National Oceanic and Atmospheric Administration (NOAA)

An agency of the US government established to conduct research and gather data about the global oceans, the atmosphere, space, and the sun. NOAA warns of dangerous weather, charts the seas and skies, guides the use and protection of ocean and coastal resources, and conducts research to improve understanding and stewardship of the environment. It consists of five major organizations: the National Weather Service, the National Ocean Service, the National Marine Fisheries Service, the National Environmental Satellite, Data, and Information Service, and NOAA Research.

National Oceanic and Atmospheric Administration
14th Street & Constitution Avenue, NW
Room 6217
Washington, DC 20230
Telephone: (202) 482-6090
Web: http://www.noaa.gov/

National Park Service (NPS)

A bureau of the U.S. Department of the Interior that preserves the natural and cultural resources and values of the national park system for the enjoyment, education, and inspiration of this and future generations. The NPS cooperates with partners to extend the benefits of natural and cultural resource conservation and outdoor recreation.

National Park Service
Voyageurs National Park
3131 Highway 53 South
International Falls, MN 56649-8904
Telephone: (218) 283-9821
Web: http://www.nps.gov/voya/index.htm

National Park Service
Mississippi River National River and Recreation Area
Headquarters
Suite 105, 111 Kellogg Blvd. E.
St. Paul, MN 55101
Telephone: (651) 290.4160
Web: http://www.nps.gov/miss/

United States Army Corps of Engineers (USACE)

An agency of the US government established to provide engineering services to the United States, including: planning, designing, building and operating dams and other civil engineering projects; designing and managing the construction of military facilities for the Army and Air Force; providing design and construction management support for other Department of Defense and federal agencies. It consists of a national office, eight divisions in the US, 41 district offices in the US, Asia and Europe, and field offices throughout the world.

United States Army Corps of Engineers
St. Paul District
190 Fifth Street East
St. Paul, MN 55101-1638
Telephone: (651) 290-5200
Web: http://www.mvp.usace.army.mil/

United States Environmental Protection Agency (USEPA)

An agency of the US government established to enforce federal pollution abatement laws and to implement various pollution prevention programs. The agency supervises environmental quality and seeks to control the pollution caused by solid wastes, pesticides, toxic substances, noise, and radiation and has established special programs in air and water pollution, hazardous wastes, and toxic chemicals. It also sponsors research in the technologies of pollution control. Ten regional offices facilitate coordination of pollution control efforts with state and local governments.

United States Environmental Protection Agency
Region 5
77 West Jackson Boulevard
Chicago, IL 60604
Telephone: (312) 353-2000
Web: http://www.epa.gov/Region5/

State

Minnesota Board of Water and Soil Resources (BWSR)

An administrative agency of the state for 91 soil and water conservation districts, 46 watershed districts, 23 metropolitan watershed management organizations, and 80 county water managers. The agency's purpose, working through local government, is to protect and enhance the state's irreplaceable soil and water resources by implementing the state's soil and water conservation policy, comprehensive local water management, and the Wetland Conservation Act. It consists of a central office and eight field offices statewide.

Board of Water and Soil Resources
Central Office
520 Lafayette Road North
St. Paul, MN 55155
Telephone: (651) 296-3767
Web: http://www.bwsr.state.mn.us/index.html

Minnesota Department of Agriculture (MDA)

An agency of the state government whose purpose is to work toward a diverse agricultural industry that is profitable as well as environmentally sound; to protect public health and safety with regard to food and agricultural products; and to ensure orderly commerce in agricultural food products. It consists of a central office and over 80 offices/work sites throughout Minnesota.

Minnesota Department of Agriculture
90 West Plato Boulevard,
St. Paul, MN 55107
Telephone: (651) 297-2200
Web: http://www.mda.state.mn.us/phonelist/default.htm

Minnesota Department of Health (MDH)

A public health agency of the state government that works with local public health agencies, federal health agencies, and other organizations to operate programs that protect and improve the health of entire communities, and programs that promote clean water, safe food, quality health care, and healthy personal choices. It consists of four locations in the Twin Cities metropolitan area and seven district offices in greater Minnesota.

Minnesota Department of Health
P.O. Box 64975
St. Paul, MN, 55164-0975
Telephone: (651) 215-5800
Web: http://www.health.state.mn.us/about/direct.html

Minnesota Department of Natural Resources (DNR)

An agency of the state government whose purpose is conserve and manage the state's natural resources, to provide outdoor recreation opportunities, and to provide for commercial uses of natural resources in a way that creates a sustainable quality of life. It consists of a central office and four regional offices statewide.

Department of Natural Resources
Central Office
Division of Waters
500 Lafayette Road
St. Paul, MN 55155-4032
Telephone: (651) 296-4800
Web: http://www.dnr.state.mn.us/waters/orgchart.html

Minnesota Department of Transportation (Mn/DOT)

An agency of the state government whose purpose is to develop and implement policies, plans and programs for aeronautics, highways, motor carriers, ports, public transit and railroads. It consists of a central office and eight districts statewide.

Minnesota Department of Transportation
Transportation Building
395 John Ireland Boulevard
St. Paul, MN 55155
Telephone: (651) 296-3000
Web: http://www.dot.state.mn.us/information/talk.html

Minnesota Pollution Control Agency (MPCA)

An agency of the state government whose purpose is to protect Minnesota's environment through monitoring environmental quality and enforcing environmental regulations. It consists of eight offices in six regions statewide.

Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, MN 55155-4194
Telephone: (651) 296-6300 or 800-657-3864 (in Minnesota only)
Web: http://www.mpca.state.mn.us

Industrial Stormwater Permit Program
Telephone (651) 297-2274 or 800-646-6247 (in Minnesota only)
Web: http://www.pca.state.mn.us/water/stormwater/stormwater-i.html

Construction Stormwater Program
Telephone (651) 297-2274 or 800-646-6247 (in Minnesota only)
Web: http://www.pca.state.mn.us/water/stormwater/stormwater-c.html

Municipal Separate Storm Sewer System Program
Telephone (651) 297-2274 or 800-646-6247 (in Minnesota only)
Web: http://www.pca.state.mn.us/water/stormwater/stormwater-ms4.html

Regional/Local

Counties

A political division of local level government that is smaller than a state but generally larger than a city or town. In greater Minnesota, counties are often responsible for creation, implementation and enforcement of local water management plans. There are 87 counties in Minnesota.

Association of Minnesota Counties
125 Charles Avenue
St. Paul, MN 55103-2108
Telephone: (651) 224-3344
Web: http://www.mncounties.org

Metropolitan Council

A regional planning agency serving the Twin Cities seven-county metropolitan area. The Council establishes regional growth policies, plans for transportation, aviation, water resources and regional recreation open space. It also provides essential services, including transit and wastewater treatment, to the region. The council consists of 16 districts in the seven-county metro area.

Metropolitan Council
Mears Park Center
Environmental Services
230 East 5th Street
St. Paul, MN 55101
Telephone: (651) 602-1000
Web: http://www.metrocouncil.org/services/environmental.htm

Municipalities and Townships

Minnesota municipalities and townships have regulatory authority over activities within that municipality or township that are in addition to federal, state, county, and other local regulations and ordinances. The municipality or township in which the activities are to occur should be contacted for more information about specific regulations and permits required for any activity undertaken that may impact land use, stormwater, wetlands and other bodies of water, zoning, planning, grading or any land altering activity.

Minnesota North Star Local Government
Web:http://www.state.mn.us/cgi-bin/portal/mn/jsp/content.do?subchannel=-536879913&id=-8494&agency=NorthStar

League of Minnesota Cities
145 University Ave. West
St. Paul, MN 55103
Telephone: (651) 281-1200 or 1-800-925-1122
Web: http://www.lmnc.org/

Soil and Water Conservation Districts (SWCD)

A political subdivision of the state whose boundaries generally coincide with county boundaries and whose purpose is to encourage private landowners to conserve soil and water resources through technical assistance, funding and educational services. Districts may delegate responsibility for creation, implementation, and enforcement of local water management plans to the SWCD.

Minnesota Association of Soil and Water Conservation Districts
790 Cleveland Avenue South
Suite 201
St. Paul, MN 55116
Telephone: (651) 690-9028
Web: http://www.maswcd.org

Watershed Districts (WD)

Watershed districts are local units of government that work to solve and prevent water-related problems including flood control and water quality protection. The boundaries of the districts follow those of a natural watershed and are governed by a board of managers appointed by the boards of commissioners of the counties that have land in the district. Any activity that will impact land use, stormwater, wetlands and other bodies of water, zoning, planning, grading or any land altering activity should consult with the local watershed organization to determine the local regulations.

Minnesota Association of Watershed Districts
540 Diffley Road
St. Paul, MN 55123
Phone: (651) 452-8506
Web: http://www.mnwatershed.org/

Watershed Management Organizations (WMO)

A watershed management organization is a watershed district wholly within the metropolitan area or a joint powers entity established wholly or partly in the metropolitan area by special law or agreement to perform some or all of the functions of a watershed district. Any activity that will impact land use, stormwater, wetlands and other bodies of water, zoning, planning, grading or any land altering activity should consult with the local watershed organization to determine the local regulations.

II. Enabling Legislation

The following Federal and State legislation enables the creation of, and delegates authority for, stormwater programs and regulations.

Federal Enabling Legislation

Clean Water Act (CWA)

The Federal Water Pollution Control Act Amendments of 1972 (Clean Water Act) established the basic structure for regulating discharges of pollutants into the waters of the United States. It gave USEPA the authority to implement pollution control programs and establish standards. The CWA made it unlawful for anyone to discharge any pollutant into navigable waters from a point source unless a permit was first obtained. It funded the construction of sewage treatment plants under the construction grants program and recognized the need for planning to address the critical problems posed by nonpoint source pollution. Sections 303, 319, 401, 402, and 404 of the CWA specifically address USEPA's and the state's/tribe's authority and responsibility in managing pollution of the nation's waters:

Section 303, Water Quality Standards and Implementation Plans

States are required every two years to publish an updated list of streams and lakes that are not meeting their designated uses because of excess pollutants. The list, known as the 303(d) list, is based on violations of water quality standards and is organized by river basin. For each pollutant that causes a water body to fail to meet state water quality standards, the CWA requires the MPCA to conduct a Total Maximum Daily Load (TMDL) study.

Section 319, Nonpoint Source Management Program

States, territories, and delegated tribes are required to develop nonpoint source pollution management programs if they wish to receive funds under the Section 319 program.

Section 401, Water Quality Certification

Anyone who wishes to obtain a federal permit for any activity, which may result in a discharge, must first obtain a state 401 water quality certification. The MPCA is the delegated authority to issue Section 401 water quality certifications in Minnesota. A Section 401 water quality certification may be granted if the applicant demonstrates that an activity will not result in a discharge that violates state water quality standards or results in adverse long- or short-term impacts on water quality. Such impacts can be direct or cumulative in nature.

Section 402, National Pollutant Discharge Elimination System (NPDES)

USEPA, in coordination with States, the regulated community, and the public develops, implements, and conducts oversight of the National Pollutant Discharge Elimination System (NPDES) permit program based on statutory requirements contained in the CWA and requirements contained in the NPDES regulations. Regulatory authority in the State of Minnesota is through the MPCA.

Section 404, Discharge of Dredge or Fill Material into Waters of the U.S.

Section 404 regulates placement of dredged or fill material into “waters of the United States”. Wetlands are one component of “waters of the United States;” however, there are numerous other types including intermittent streams, small perennial streams, rivers, lakes, bays, estuaries, and portions of the oceans. The 404 permit program is administered jointly by USEPA and the U.S. Army Corps of Engineers (USACE). The USACE handles the actual issuance of permits (both individual and general); it also determines whether a particular plot of land is a wetland or water of the United States. The USACE has primary responsibility for ensuring compliance with permit conditions, although USEPA also plays a role in compliance and enforcement

Coastal Zone Management Act of 1990, Section 6217

Section 6217 of the Coastal Zone Management Act requires the 29 states and territories with approved Coastal Zone Management Programs to develop Coastal Nonpoint Pollution Control Programs. In its program, a state or territory describes how it will implement nonpoint source pollution controls, known as management measures, that conform with those described in Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. This program is administered jointly at the national level with USEPA and the National Oceanic and Atmospheric Administration (NOAA).

Dam Safety Act

The Dam Safety and Security Act of 2002 addresses safety and security for dams through the coordination by the FEMA of federal programs and initiatives for dams and the transfer of federal best management practices in dam security to the states. The Act includes resources for the development and maintenance of a national dam safety information network and the development by the National Dam Safety Review Board of a strategic plan that establishes goals, priorities, and target dates to improve the safety and security of dams in the United States.

National Flood Insurance Act of 1968

Federally subsidized flood insurance was made available to owners of flood-prone property through this act. Administered by the Federal Emergency Management Agency (FEMA), participating communities are required to adopt certain minimum floodplain management standards, including restrictions on new development in designated floodways, a requirement that new structures in the 100-year flood zone be elevated to or above the 100-year flood level (known as base flood elevation), and a requirement that subdivisions are designed to minimize exposure to flood hazards.

Safe Drinking Water Act

The Safe Drinking Water Act (SDWA) was originally passed by Congress in 1974 to protect public health by regulating the nation’s public drinking water supply. The law was amended in 1986 and 1996 and requires many actions to protect drinking water and its sources: rivers, lakes, reservoirs, springs, and ground water wells. USEPA sets national standards for drinking water to protect against health risks, taking into consideration available technology and costs. These National Primary Drinking Water Regulations set enforceable maximum contaminant levels for particular contaminants in drinking water or required ways to treat water to remove contaminants. Each standard also includes requirements for water systems to test for contaminants in the water to make sure standards are achieved. In addition to setting these standards, USEPA provides guidance, assistance, and public information about drinking water, collects drinking water data, and oversees state drinking water programs.

The most direct oversight of water systems is conducted by state drinking water programs. States can apply to USEPA for primacy, the authority to implement SDWA within their jurisdictions, if they can show that they will adopt standards at least as stringent as USEPA's and make sure water systems meet these standards. Minnesota has received primacy and the Minnesota Department of Health oversees implementation of the Safe Drinking Water Act in the state. States ensure that water systems test for contaminants, review plans for water system improvements, conduct on-site inspections and sanitary surveys, provide training and technical assistance, and take action against water systems not meeting standards.

Section 10 of the Rivers and Harbors Act of 1899

Under Section 10 of the Rivers and Harbors Act of 1899, the USACE regulates the construction of any structure in, over, or under any navigable water of the United States, the excavation/dredging or deposition of material in these waters or any obstruction or alteration in a navigable water. A Section 10 permit is required from the USACE if the structure or work affects the course, location, condition, or capacity of the water body.

Wild and Scenic Rivers Act

The National Wild & Scenic Rivers Act was enacted in 1968 to balance the building of dams on rivers for water supply, power, and other benefits, with protection of the free flowing character and outstanding values of selected rivers and streams for the benefit and enjoyment of present and future generations. This designation prohibits the federal government from licensing or permitting hydroelectric dams or major diversions or assisting any water resource projects that may directly affect designated rivers. Public lands within an average of 1/4 mile corridor on both sides of the streams are managed to protect their outstanding scenic, recreational, historical/cultural, fish, wildlife, ecological, geological, and hydrological values.

State Enabling Legislation

At the State level, water law is organized into a series of Statutes and Rules. MN Statutes 103A through 103G constitute Water Law in Minnesota. These Statutes and their associated Rules are the enabling legislation related to stormwater at the State level. Links to 2004 statutes are provided.

M.S. 84 – Department of Natural Resources

This chapter includes the powers and duties of the Department of Natural Resources commissioner and addresses issues related to public lands, parks, timber, waters, minerals, and wild animals of the state.

M.S. 103A – Water Policy Information

Regulatory policy is defined within this chapter. Policy related to wetlands, hydropower, ground water management, rainwater conservation, soil and water conservation, floodplain management, scenic river protection, marginal and erodable land, and water law policy are defined and addressed in this statute. Term definitions, jurisdiction, petition for intervention rules, authority, court referral, hearings, procedure, and statewide water information systems are defined and addressed.

M.S. 103B – Water Planning and Project Implementation

Water planning and project implementation are addressed in this statute. It specifically creates and defines plans, programs, districts, commissions, organizations and boards to protect water resources. Statutes cover issues such as taxing authority, planning, levies, capital improvements, dispute resolution and project implementation.

The following Acts, Programs and Laws applicable to stormwater are included within M.S. 103B:

Lake Improvement District Law (103B.501 – 103B.581)

This law addresses a DNR coordinated local-state program for the establishment of lake improvement districts by counties.

Comprehensive Local Water Management Act (103B.301 – 103B.355)

This act encourages counties to develop and implement local water management plans. Local water management plans, which must be updated periodically, are countywide plans which address water problems in context of watershed units and ground water systems.

M.S. 103C – Soil and Water Conservation Districts

This chapter, which is known as Soil and Water Conservation District Law, addresses soil and water conservation policy. Statutes cover issues such as the formation of soil and water conservation districts, consolidation and division of districts, cooperation between districts and other public agencies, powers and duties of the Board of Water and Soil Resources, and project determination and assessments. The soil and water conservation policy of the state is to encourage land occupiers to conserve soil, water, and the natural resources they support through the implementation of practices that control or prevent pollution, ensure soil productivity, protect water quality, prevent impairment of dams and reservoirs, reduce flood damage, preserve wildlife, protect public lands and waters and preserve the tax base.

M.S. 103D – Watershed Districts

Chapter 103D, which is known as Watershed Law, addresses the establishment and termination of Watershed Districts, consolidation and boundary changes of districts, watershed management plans, project procedure and implementation, general provisions and the funding of watershed districts and projects.

M.S. 103E – Drainage

This chapter addresses general provisions, petitions for drainage projects, preliminary surveying and hearings, detailed surveying and viewing, drainage outlets, drainage construction, funding and payment of drainage system costs, and procedure to repair drainage systems.

M.S. 103F – Protection of Water Resources

This chapter addresses the protection of water resources, specifically the Southern Minnesota Rivers Basin Area, shoreland development, the Wild Scenic Rivers Act, Mississippi Headwaters Planning and Management, the Minnesota River Basin Joint Powers Board, Project Riverbend, soil erosion, the water bank program, lake preservation and protection, and the Wetland Establishment and Restoration Program.

The following Acts and Laws applicable to stormwater are included within M.S. 103F:

Floodplain Management Law (103F.101 – 103F.155)

This law addresses the reduction of flood damages through floodplain management activities. It stresses nonstructural measures such as floodplain zoning and flood proofing, flood warning practices, and other indemnification programs that reduce public liability and expense for flood damages. It provides for state coordination through the Department of Natural Resources and assistance to local government units in floodplain management planning and activities.

Minnesota Wild and Scenic Rivers Act (103F.301 – 103F.345).

This Act was passed to preserve and protect select rivers in the state that have outstanding scenic, recreational, natural, historical, scientific and similar values. It addresses which rivers could be eligible; designated three protected classes: wild, scenic, or recreational; and outlined the procedure that should be followed in the development of a management plan.

Clean Water Partnership Law (103F.701 – 103F.761)

This law addresses the protection and improvement of surface and ground water in the state through financial and technical assistance to local units of government. The purpose of this law is to control water pollution associated with land use and land management activities and to provide a legal basis for state implementation of federal laws controlling nonpoint source water pollution."

M.S. 103G – Waters of the State

The waters of the state are addressed in this chapter. The statute includes the commissioner's authority, public water designation and use, wetlands, work affecting public waters, water diversion and appropriation, permit procedure, water level establishment and control, Big Stone Lake, Mississippi Headwater Lakes, dam construction and maintenance, flowage easements, water aeration and deicing, harvest and control of aquatic plants, sunken log recovery, and streams.

M.S. 103H – Ground Water Protection

This chapter addresses ground water issues including sensitive area protection, development of best management practices, quality monitoring requirements, health risk limits, and pollution management.

M.S. 103I – Wells, Borings, and Underground Uses

This chapter addresses well construction, repair, and sealing; regulations related to wells and borings; and licensing requirements.

M.S. 115 – Water Pollution Control; Sanitary Districts

Chapter 115 addresses issues concerning water pollution control, sanitary districts, municipal water pollution control, individual and alternative discharging sewage treatment systems, regional sanitary sewer districts, water supply systems, and wastewater treatment facilities.

The following Acts and Laws applicable to stormwater are included within M.S. 115:

State Water Pollution Control Act (M.S. 115.01 – 115.09)

This Act specifically addresses stormwater issues and the National Pollutant Discharge Elimination System (NPDES). The addresses MPCA authority to perform necessary acts including the establishment and application of standards, procedures, rules, orders, variances, stipulation agreements, schedules of compliance, and permit conditions, consistent with the provisions of the federal CWA, including the NPDES. It outlines public notice for NPDES permit applications, provisions for stormwater permits, general permits, compliance with non-degradation and mitigation requirements of agency water quality rules, and regulation of stormwater discharges.

Regional Sanitary Sewer District Law (M.S. 115.16 – 115.67)

Provision for the establishment of sanitary sewer districts as a municipal corporation and subdivision of the state responsible for acquiring, constructing, improving, extending, operating, and maintaining facilities for the collection, treatment, and disposal of sewage and industrial and other wastes received from the sewer systems of all municipalities within its corporate limits.

M.S. 116 – Pollution Control Agency

This chapter addresses the creation and powers of the MPCA, the Water Pollution Control Program, nutrients in cleaning agents and water conditioners, storage tanks, and waste facility training and certification. NPDES permitting requirements for feedlots are specifically addressed in this chapter.

M.S. 116A – Public Water and Sewer Systems

This chapter outlines the purpose of the establishment of public water and sewer systems and addresses the power of county boards to construct and maintain such facilities.

M.S. 144 – Department of Health

This chapter also known as the Safe Drinking Water Act of 1977, describes the purpose and authority of the Department of Health. It addresses safe drinking water, approval of design, construction, and alteration of all public water supplies, testing, inspection, emergency plans and record keeping of facilities.

M.S. 473 – Metropolitan Government

This chapter includes the creation of the Metropolitan Council and addresses regional issues including transportation, recreational open space, solid waste disposal, aviation, water supply, comprehensive planning, and housing and redevelopment.

Minnesota Rules Chapter 4410

Environmental Quality Board environmental review rules and procedures.

Minnesota Rules Chapter 4720

Minnesota Department of Health public water supplies rules including wellhead protection plan content and procedural requirements.

Minnesota Rules Chapter 4725

Minnesota Department of Health wells and borings rules.

Minnesota Rules Chapter 6105

Minnesota Department of Natural Resources wild, scenic, and recreational rivers rule. Provide minimum statewide requirements for the selection, classification, management, and control of wild, scenic, and recreational rivers and their land use districts.

Minnesota Rules Chapter 6115

Minnesota Department of Natural Resources public water resources rules.

Minnesota Rules Chapter 6120

Minnesota Department of Natural Resources shoreland and floodplain management rules including standards and criteria to guide local governments in the adoption and implementation of shoreland and floodplain management controls.

Minnesota Rules Chapter 6135

Minnesota Department of Natural Resources utility crossing rules. Concerning utility crossings over public lands and waters, sets fees, standards, and criteria for minimizing the environmental impact of the crossings.

Minnesota Rules Chapter 7001

Minnesota Pollution Control Agency permits and certifications including the NPDES permits application procedures, issuance and conditions of approvals and the Section 401 certifications.

Minnesota Rules Chapter 7020

Minnesota Pollution Control Agency animal feedlot permit requirements and rules addressing storage, transportation, disposal, and utilization of animal manure and process wastewaters.

Minnesota Rules Chapter 7050

Water quality standards and related provisions are found in several Minnesota rules, but the primary rule for state-wide water quality standards is Chapter 7050. Included in this rule are:

- A classification system of beneficial uses for both surface and ground waters
- Numeric and narrative water quality standards
- Nondegradation provisions
- Provisions for the protection of wetlands
- Treatment requirements and effluent limits for wastewater discharges
- Other provisions related to the protection of Minnesota's water resources from pollution.

Minnesota Rules Chapter 7052

This rule outlines water quality standards, nondegradation provisions, and methods for setting water quality-based effluent limits for point sources applicable only to waters in the Lake Superior basin. This rule, called the Great Lakes Initiative (GLI), was mandated by an amendment to the Clean Water Act in 1987. All eight Great Lakes states have adopted the GLI. The GLI rules provide a common approach across state lines for the control and minimization of the discharge of persistent and bioaccumulative pollutants into the Great Lakes system.

Minnesota Rules Chapter 7090

The MPCA's stormwater rules for the construction, industrial, and municipal stormwater permitting programs. It describes who, what, and when joint NPDES/SDS stormwater permits are required.

The rules address the requirements of both the Phase I and Phase II federal stormwater regulations by integrating these regulations into one state Stormwater Regulatory Program under a new chapter of Minnesota Rules, Chapter 7090, adopted in 2005.

Minnesota Rules Chapter 7090 includes the following:

- NPDES permit requirements for regulated MS4s, construction and industrial activities
- MS4 designation process and criteria
- Notification of construction stormwater general permit coverage
- Industrial activity no-exposure exclusion

Minnesota Rules Chapter 8410

Board of Water and Soil Resources local water management rules including required content for watershed management plans, joint powers agreements establishing a watershed management organization, and local comprehensive plans.

Minnesota Rules Chapter 8420

Board of Water and Soil Resources wetland conservation rules implementing the Wetland Conservation Act and regulating impacts to wetlands caused by draining, excavating, or filling. The rules include exemption standards, sequencing requirements, replacement requirements and local government procedures.

III. Model Ordinances

Table G.1 contains a list of links to sources for model ordinances on a variety of stormwater management issues, including: general stormwater management, erosion and sediment control, growth management, floodplain management, shoreland management, neighborhood design,

Table G.1 Model Ordinance Sources

Source	Model Ordinance	Link
Center for Watershed Protection	Various	http://www.stormwatercenter.net/
		http://www.cwp.org/COW_worksheet.htm
Department of Natural Resources	Shoreland	http://files.dnr.state.mn.us/waters/watermgmt_section/shoreland/1999_model_ordinance.pdf
		http://files.dnr.state.mn.us/waters/watermgmt_section/shoreland/Shoreland_Ordinance_Review_Checklist
	Floodplain	http://www.dnr.state.mn.us/waters/watermgmt_section/floodplain/sample_ordinances.html
US Environmental Protection Agency	Various	http://www.epa.gov/owow/nps/ordinance/
Metropolitan Council	Stormwater Management	www.metrocouncil.org/environment/Watershed/model_sw_ord.pdf
Northland NEMO	Various	http://www.mnerosion.org/nemo.html (available by request)
Minnesota Pollution Control Agency	Urban Stormwater Pollution Control	http://www.pca.state.mn.us/publications/wq-sw1-03.pdf
		http://www.pca.state.mn.us/water/pubs/1-01.pdf
		http://www.pca.state.mn.us/publications/wq-strm2-06.pdf

effective building, elicit discharge detection and elimination, ground water protection, operations and maintenance and more.

These model ordinances may be used as a starting point for communities to work from in developing and adapting ordinances to local conditions and jurisdictions.

Appendix H

Acronyms, Symbols, and Glossary

Appendix H

Acronyms, Symbols, and Glossary

Contents

I. Acronyms

BASINS – Better Assessment Science Integrating Point and Nonpoint Sources

BMP – best management practice

BSD – better site design

BOD – biological oxygen demand

BWCA – Boundary Waters Canoe Area

BWSR – Board of Water and Soil Resources

cfs – cubic feet per second

C.F.R. - Code of Federal Regulations

CGP – construction general permit

CMP – corrugated metal pipe

CN – curve number

CN – cyanide

COD – chemical oxygen demand

C/O – commercial/office

CWA – Federal Clean Water Act

CWP – Center for Watershed Protection

CZMA – Coastal Zone Management Act

DA – drainage area

DDT – dichlorodiphenyltrichloroethane

DHS – Department of Homeland Security

DNR – Minnesota Department of Natural Resources

DO – dissolved oxygen

DRC – distributed runoff control

du – dwelling units

DWSMA – Drinking Water Source Management Area

ED – extended detention

EGR - extensive green roof

EOR – Emmons and Olivier Resources, Inc.

EPA – U.S. Environmental Protection Agency

ETV Program – U.S. EPA’s Environmental Technology Verification Program

FEMA – Federal Emergency Management Agency

fps – feet per second

GLI – Great Lakes Initiative

GP – Minnesota Construction General Permit (2003)

GW – ground water

HDR – high density residential

HEC–1 – Hydrologic Engineering Center–1 model

HEC–2 – Hydrologic Engineering Center–2 model

HSG – hydrologic soil group

HS – hotspot

I&M – inspection and maintenance

IDF – intensity–duration–frequency curves

IGR - intensive green roof

IP – Issue Paper

IPM - integrated pest management

LDR – low density residential

LGU – local governmental unit

LID – low impact development

MCWD - Minnehaha Creek Watershed District

MDH – Minnesota Department of Health

MDR – medium density residential

MGS - Minnesota Geological Survey

MMCD - Metropolitan Mosquito Control District

Mn/DOT – the Minnesota (state) Department of Transportation.

MNRRA – Mississippi National River and Recreation Area

MPCA – Minnesota Pollution Control Agency

M.S. - Minnesota Statutes

MS4 – Municipal Separate Storm Sewer System under the Phase II NPDES program

MSC – the Minnesota Stormwater Steering Committee's Manual Sub–Committee

NaCl – sodium chloride or common table salt used for roadway deicing.

NEMO– Non–point Education for Municipal Officials

NFIP – National Flood Insurance Program

NOAA – National Oceanic and Atmospheric Administration

NPDES – National Pollutant Discharge Elimination System

NRCS – U.S. Department of Agriculture, Natural Resource and Conservation Service (formerly the SCS – Soil Conservation Service)

NSMPP – Nonpoint Source Management Program Plan

NWI– National Wetlands Inventory

NWL – normal water level

NWS – National Weather Service

NURP – Nationwide Urban Runoff Program

O&M – operation and maintenance

OHWL – Ordinary High Water Level

OMEE – Ontario Ministry of Environment and Energy

P – Phosphorus

P–8 – Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds

PAH – polycyclic aromatic hydrocarbon

PCB – polychlorinated biphenyl

PSH – Potential stormwater hotspot

PWI – Public Waters Inventory

RCP – reinforced concrete pipe

RFS – rainfall frequency spectrum

ROW – right of way

SD – separation distance

SCS – Soil Conservation Service (now the Natural Resource and Conservation Service)

SDS – State Discharge System

SDWA – Safe Drinking Water Act

Sol P – soluable phosphorus

SFR – single family residential (land use)

SIC – Standard Industrial Classification

SLAMM – Source Loading Assessment and Management Model

SNA – Scientific and Natural Area

SPT – standard penetration test

SSC – the Minnesota Stormwater Steering Committee

SW – surface water

SWAMP – Stormwater Assessment Monitoring and Preformance Program of the Toronto and Region Conservation Authority

SWCD – Soil and Water Conservation District

SWMM – Storm Water Management Model

SWPPP – storm water pollution prevention plan/program

TDS – total dissolved solids

THMs – trihalomethanes

TMDL – total maximum daily load

TN – total nitrogen

TP – total phosphorus

TP–40 – Technical Publication 40

TR–20 – Technical Release Number 20: Computer Program for Project Formulation Hydrology

TR–55 – Technical Release Number 55: Urban Unit Hydrology for Small Watersheds

TSS – total suspended solids

TURM – Thermal Urban Runoff Model

USACE – United States Army Corps of Engineers

U.S.C. - United States Code

USC – unified sizing criteria

WCA– Minnesota Wetland Conservation Act

WD – Watershed District

WLF – water level fluctuation

WMO – Water Management Organization

WNV - West Nile Virus

WQ – water quality

WSEL – water surface elevation

II. Symbols

A – watershed area

AB – total allowable drainage area to buffer

AC – natural area conserved

AD – area disconnected

A_r – filter bed area

A_s – surface area, sedimentation basin

BMP_{RE} – BMP removal efficiency for total phosphorus

C – flow–weighted mean concentration of the pollutant in urban runoff

Ca – calcium

$CaCl_2$ – calcium chloride

Cl – chloride

CMA – calcium magnesium acetate

V_{cp} – ED – extended detention of the 1–year post–development runoff

Cu – copper

DA % Served – fraction of the drainage area served by the BMP

d_f – depth of filter bed

f_c – soil infiltration rate

FCN – free cyanide

Fe – iron

h_f – head above filter bed

Hg – mercury

I – impervious cover

I_a – initial abstraction

IC – percent new impervious cover

I_{post} – post–development site imperviousness

K – coefficient of permeability

KAc – potassium acetate

KFo – potassium formate

L – pollutant loading

L_{post} – average annual load of total phosphorus exported from the post–development site

L_{pre} – average annual load of total phosphorus exported from the site prior to development

LR – annual total phosphorus load removed by the proposed BMP

Mg – magnesium

$MgCl_2$ – magnesium chloride

N – nitrogen

Na – sodium

NaCl – sodium chloride

NH_3 – ammonium

NO_x – nitrogen oxides

P – precipitation depth

P – phosphorus

P_j – fraction of rainfall events that produce runoff

Q_f – extreme flood storage volume

Q_i – peak inflow discharge

Q_o – peak outflow discharge

Q_{p10} – overbank flood control storage rate

Q_{p100} – extreme storm control storage rate

q_p – water quality peak discharge

q_u – unit peak discharge

r – volume of stormwater runoff

Re_a – recharge area requiring treatment

Re_v – recharge volume

RR – pollutant removal requirement

R_v – volumetric runoff coefficient expressing fraction of rainfall that is converted to runoff

S – soil specific recharge factor

t_c – time of concentration

t_t – time to drain filter bed

V_{cp} -- channel protection volume

V_{p10} – overbank flood control storage volume

V_{p100} – extreme storm control storage volume

V_{pp} - permanent pool volume

V_r – rainfall runoff volume

V_{re} - recharge volume

V_s – snowmelt runoff volume

V_t – total volume

V_{ts} - total storage volume

V_v – volume of voids

V_{wq} – water quality volume

V_{wq}– ED – extended detention water quality volume

Zn – zinc

III. Glossary

A – B – C – D – E – F – G – H – I – J – K – L – M – N – O – P – Q – R – S – T – U – V – W – XYZ

A

access and egress control reinforced or rocked entrance and exit points to the site to deter tracking of sediment off the site onto adjacent streets

active karst areas underlain by carbonate bedrock with less than 50 feet of sediment cover

adsorption the adhesion of an extremely thin layer of molecules to the surfaces of solid bodies or liquids with which they are in contact

aggrade the build up of sediment or eroded material

anaerobic condition operating in a system where there is the absence of free oxygen available for biologic use.

animal waste management practices and procedures which prevent the movement of animal wastes or byproducts from feeding or holding areas into the wider environment.

annual load quantity of pollutants, sediment, or nutrients carried by a water body over the period of a year

antecedent soil moisture the water content held by a soil before a storm event. This has an effect on the amount of water that will runoff due to that event.

atmospheric controls reducing or removing wind erosion, dust, or statutory emissions regulations

B

baffle weir A structure used in measuring the rate of flow fitted with a grating or plate across a channel or pipe which makes the flow more uniform in different parts of the cross section of the stream.

bankfull flow in a stream or river where the water level is to the top of its bank. This is considered to be the channel forming flow and has a recurrence interval of around 2.5–years.

bank stabilization activities undertaken to shore up or ensure the integrity of a stream or river bank and protect it from erosion and slumping.

base flow the flow coming from ground water inputs to a stream or river system

basin a depression in the surface of the land that holds water

bed load the sand, gravel or rocks which are transported along the stream bottom by traction, rolling, sliding or saltation

Best Management Practice (BMP) one of many different structural or non–structural methods used to treat runoff, including such diverse measures as ponding, street sweeping, filtration through a rain garden and infiltration to a gravel trench.

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) a multipurpose environmental analysis system developed by the U.S. Environmental Protection Agency for water quality modeling purposes.

better site design (BSD) — the application of non–structural practices at residential and commercial sites to reduce impervious cover, conserve natural areas, and use pervious areas to more effectively treat stormwater runoff.

biological additives — products which are formulated with specialized bacteria, enzymes, or other living components that can be added to boost pollution treatment efficiencies, eg. chitosan

biological oxygen demand(BOD) — a measure of the amount of oxygen required to biologically degrade organic matter in the water.

bioretention — a soil and plant–based stormwater management best management practice (BMP) used to filter runoff

bog — a poorly drained, surface water fed, acidic area rich in accumulated plant material

bounce — water level fluctuations due to topography, soils, and runoff inputs during and after precipitation events.

buffers — a vegetative setback between development and streams, lakes, and wetlands whose aim is to physically protect and separate the resource from future disturbance or encroachment.

C

calcareous fen — a peat–accumulating wetland dominated by distinct ground–water inflows which is circum–neutral to alkaline and has high concentrations of calcium and low dissolved oxygen. The rarest wetland plant community in Minnesota.

catch basin — an inlet to the storm drain system that typically includes a grate or curb inlet.

catch basin insert — devices that attach to the entrance of a catch basin or mount inside the catch basin. They are designed to improve stormwater quality by either preventing debris and pollutants from entering the basin, or by retaining or treating the water in the basin.

channel protection — actions taken to prevent habitat degradation and erosion that may cause downstream enlargement and incision in urban streams due to increased frequency of bankfull and sub–bankfull stormwater flows.

chemical controls — includes such activities as salt management, fertilizer/pesticide management, and spill prevention and containment

chemical oxygen demand — The quantity of oxygen used in biological and non–biological oxidation of materials in water; a measure of water quality.

chemical treatment — removal of pollutant from the water column via chemical means, eg. Ferric chloride, alum, polyacrylamides

cistern — a technique which captures and temporarily stores rooftop runoff at confined sites, gradually releasing it over pervious areas.

cluster design — a reduction of average lot size within a residential development in exchange for greater conservation of natural areas.

coincident peaks — upstream peak discharge arriving at the same time a downstream structure releases its peak discharge thus increasing the total discharge well above what it was on the pre-development hydrograph.

cold climate sizing	sizing of stormwater practices to accommodate snowmelt. This is larger than rainfall–based criteria sizing in Minnesota since snowfall represents more than 10% of the annual precipitation.
computable pollutant	a pollutant for which enough runoff concentration and BMP performance data is available to perform a site–based pollutant load calculation documenting no increase in loading.
conservation easement	a restriction placed on a piece of property to protect the resources associated with the parcel. The easement is either voluntarily sold or donated by the landowner, and constitutes a legally binding agreement that prohibits certain types of development from taking place on the land.
construction sequencing	a specified work schedule that coordinates the timing of land–disturbing activities and the installation of erosion–protection and sedimentation–control measures
conveyance	a structure or feature used for transferring water from one location to another
covered karst	areas underlain with carbonate bedrock with more than 100 feet of sediment cover
curb and gutter system	edging along the side of streets meant to quickly convey stormwater runoff from the street and adjacent areas into the stormwater system
curve number	an index combining hydrologic soil group, land use factors, treatment, and hydrologic condition. Used in a method developed by the SCS to determine the approximate amount of runoff from a rainfall event in a particular area

D

dead storage	the permanent storage volume of a pond
degrade	downcutting where softer material is present in a stream channel
densimetric stratification	impairment of vertical mixing and oxygenation of bottom water layers
design storm	streamflow from a storm event used as a standard for which performance of stormwater management practices are measured.
detention time	the theoretical calculated time that a small amount of water is held in a settling basin.
disconnection	technique to spread runoff generated from rooftops or impervious surfaces into adjacent pervious areas where it can be filtered and infiltrated.
drainageway	a course or channel along which water moves in draining an area
dry pond	a water bearing stormwater management facility that controls peak runoff flows to receiving bodies such as rivers and streams which is typically free of water during dry periods, but filled during times of rainfall
dry well	a deep covered hole acting as an underground storage facility for stormwater until it seeps into the surrounding soil.

E

elution	washing out of ions in solution from a snowpack
erosion	the wearing down or washing away of the soil and land surface by the action of water, wind or ice
erosion control	any efforts to prevent the wearing or washing away of the soil or land surface
erosion control blanket	a natural or geotextile mat placed in areas susceptible to erosion to hold the soil in place until it can be permanently stabilized through vegetation or armoring
eutrophic	an environment which has an excessive concentration of nutrients
evaporation	the process of changing from a liquid state into a gas
evapotranspiration	loss of water to the atmosphere as a result of the joint processes of evaporation and transpiration through vegetation
event–based load	quantity of pollutants, sediment, or nutrients carried by a water body for particular magnitude storm events
exfiltration	uncontrolled outward leakage through cracks and interstices
extensive green roof	xeriscape type plantings in shallow, draughty growing medium typically on urban rooftops
extreme event	an 100–year, 24–hour rain event or an 100–year, 10–day snowmelt event or greater
extreme flood control	for the 100–year, 24–hour or larger events, to maintain the boundaries of the pre-development 100–year floodplain, reduce flooding risks to life, reduce property damage, and protect the physical integrity of the stormwater management practices.

F

fen	a peat accumulating wetland that receives some drainage from surrounding mineral soils and usually supports marsh–like vegetation. Richer in nutrients and less acidic than bogs due to ground water inflows.
ferrocyanide	an anti–caking additive to road salt; when converted to its free cyanide form (FCN) becomes extremely toxic to aquatic life
filter bed	a sand or gravel bottomed treatment used to filter stormwater
filtration	a series of processes that physically removes particles from water
first flush	the majority of pollutants carried in urban runoff are carried in the first ½" of runoff from a site
floodplain	land adjacent to a waterbody which is inundated when the discharge exceeds the conveyance capacity of the normal channel. Often defined in a regulatory sense as the extent of the 100–year flood.
flow control	controlling the rate and volume of water leaving a site
forebay	an extra storage space or small basin located near the inlet to settle out incoming sediments before water moves on into a pond or detention area

freeze–thaw cycle	the alternation between freezing and thawing in the snowpack. This cycle changes the composition and characteristics of the snowpack and can effect its pollutant carrying ability and the amount of runoff generated
frequency curve	A derivative of the probability curve that expresses the relation between the frequency distribution plot, with the magnitude of the variables on one axis and the number of occurrences of each magnitude in a given period as the other
frost heave	a phenomenon in cold areas in which water that is trapped in soil or cracks in rocks alternately freezes and thaws. This causes the water to expand and contract which can cause significant movement and upheaval of the soil or rock
functional components approach	an approach where basic BMP components are selected and pieced together to achieve a desired outcome

G

geomorphology	the study of the form and development of the landscape
gleyed	a blue–gray, sticky, compacted soil, usually indicative of saturated conditions
global warming	the progressive gradual rise of the Earth's surface temperature thought to be caused by the greenhouse effect, which may be responsible for changes in global climate patterns
grade breaks	point where the ground slope changes
grass channels	a natural open channel conveyance system which is preferable to curb and gutter where development density, soils, and slopes permit
green roof	a rooftop treatment practice where a thin planting media is established on roof surfaces and then planted with hardy, low–growing vegetation
ground water	water occupying the sub–surface saturated zone
ground water mounding	the localized rise in water table or potentiometric surface caused by the addition or injection of water
gully erosion	the widening, deepening and head cutting of small channels and waterways (rills) due to erosion by water or snowmelt, typified by channels one foot or more deep

H

head	the difference in elevation between two points in a body of water and the resulting pressure of the fluid at the lower point
HEC–1	a rainfall–runoff model developed by the U.S. Army Corps of Engineers
HEC–2	a rainfall–runoff model developed by the U.S. Army Corps of Engineers to compute steady–state water surface elevation profiles in natural and constructed channels.
high density residential	a high concentration of housing units in a specific area or on a specific property, typical of urban areas
hotspot	point source potential pollution generating land uses such as gas stations, chemical storage facilities, industrial facilities, etc

housekeeping (BMP)	any of a number of BMPs designed to keep pollutants from entering the waste stream by maintaining clean conditions, including street sweeping, litter pick–up and animal clean–up
hybrid rule	current MPCA water quality volume criteria in the General Permit, so called due to encompassing four different rules depending on the type of BMP used and whether the receiving water is indicated as a Special Water
HydroCAD	a computer aided design program for modeling the hydrology and hydraulics of stormwater runoff
hydrograph	graphical representation of stage or discharge at a point in a drainage as a function of time
hydrologic soils groups	an NRCS designation to give different soil types to reflect their relative surface permeability and infiltrative capability. Rankings for from high infiltration rates in Group A to very low infiltration rates in Group D
hydrology	the science dealing with the properties, distribution, and circulation of water
hydroperiod	the length of time an area is inundated or saturated by water

I

impaired waters	streams or lakes that do not meet their designated uses because of excess pollutants or identified stressors
impervious surface	a surface in the landscape that impedes the infiltration of rainfall and results in an increased volume of surface runoff
infiltration	flow of water from the land surface into the subsurface
individual permit	necessary if activities are not covered under one of the state's general permit provisions
industrial materials or activities	include but are not limited to material handling equipment or activities, industrial machinery, raw materials, intermediate products, by-products, final products, or waste products
inlet protection	preservation of the integrity and protection from the erosion of the area where water enters into a treatment area usually by vegetation or armoring
intensity–duration–frequency curves (IDF)	graphical representation of the intensity, duration, and frequency of a differing rainfalls over time
intensive green roof	rooftop systems including earth-bermed structures which ar reliant on rich, deep substrates and may include shrubs or trees
interflow	water that travels laterally or horizontally through the aeration zone during or immediately after a precipitation event and discharges into a stream or other body of water
interstitial water	water in the pore spaces of soil or rock
isopluvial	line on a map along which an equal percentage of the total annual precipitation falls in a given season or month
Issue Paper	one in a series of nine decision papers on key topics developed by CWP and EOR during production of the manual

J

K

karst	a type of topography that results from dissolution and collapse of carbonate rocks such as limestone characterized by closed depressions, sinkholes, caves, and underground drainage

L

large storm hydrology	a 10–year or greater storm event
lattice blocks	a form of pervious pavers consisting of interlocking components having an open space in the middle for vegetation or gravel
live storage	the portion of a storage basin or reservoir that is at or above the outlet and used for temporary water storage
low density residential	a low concentration of housing units in a specific area or on a specific property, typical of rural areas
low impact development (LID)	the application of non–structural practices at residential and commercial sites to reduce impervious cover, conserve natural areas, and use pervious areas to more effectively treat stormwater runoff

M

media filters	filtration of stormwater through a variety of different filtering materials whose purpose is to remove pollution from runoff
medium density residential	a moderate concentration of housing units in a specific area or on a specific property, typical of suburban areas
mesotrophic	waters containing an intermediate level of nutrients and biological production
micropool	similar to wet ponds except there is a small micropool at the outlet to prevent resuspention of previously settled materials and prevents clogging of low–flow orifice
minimum control measures	six required components of SWPPPs for MS4 communities. The six minimum control measures are: public education/ outreach; public participation/ involvement; illicit discharge detection and elimination; construction site runoff control; post–construction site runoff control; and pollution prevention/ good housekeeping.
mobilization	the release and movement of bound chemicals, nutrients, or pollutants into the environment
mottled	soil marked with irregular brown and gray/black colors indicative of poor drainage and routine saturation cycles

municipal separate storm sewer systems (MS4)	A municipal separate storm sewer system is a conveyance or system of conveyances, owned or operated by a state, city, town, county, district, association, or other public body having jurisdiction over disposal of sewage, industrial wastes, stormwater, or other wastes that discharges to waters of the United States. There are three categories of regulated small MS4s: mandatory, discretionary and petition. MS4s are required to develop and implement a Stormwater Pollution Prevention Program (SWPPP which must cover six minimum control measures and identify best management practices (BMPs) and measurable goals associated with each of these minimum control measures.

N

native vegetation	plants that are adapted to and occur naturally in a specific location
natural area conservation	the identification and protection of natural resources and features that maintain the pre-development hydrology at a site by reducing runoff, promoting infiltration, and preventing soil erosion.
90% capture rule	the design of stormwater treatment practices to capture and treat 90% of the annual rainfall from runoff producing events
no exposure	all industrial materials or activities are protected by a storm resistant shelter to prevent exposure to rain, snow, snowmelt, or runoff
Noncomputable pollutant	a pollutant for which there is not enough runoff concentration and BMP performance data available to perform a site–based pollutant load calculation documenting no increase in loading
Non–point Education for Municipal Officials (NEMO)	a University of Connecticut educational program for land use decision makers that addresses the relationship of land use to natural resource protection
nonpoint source pollution	pollution that enters a water body from diffuse origins on the watershed and does not result from discernable, confined, or discrete conveyances

O

oligotrophic	water bodies or habitats with low concentrations of nutrients
one–half inch rule	based on the first flush concept stating that the majority of the pollutants in urban runoff are carried in the first one–half inch of runoff. The half–inch rule defines the water quality volume as one–half inch times the impervious area.
orifice	outlet

Outstanding Resource Value Waters (ORVW) — defined in Minnesota Rule 7050.0180 as waters within the Boundary Waters Canoe Area Wilderness, Voyageur's National Park, and Department of Natural Resources designated scientific and natural areas, wild, scenic, and recreational river segments, Lake Superior, those portions of the Mississippi River from Lake Itasca to the southerly boundary of Morrison County that are included in the Mississippi Headwaters Board comprehensive plan dated February 12, 1981, and other waters of the state with high water quality, wilderness characteristics, unique scientific or ecological significance, exceptional recreational value, or other special qualities which warrant stringent protection from pollution.

overbank flood protection — prevention of flood damage to conveyance systems and infrastructure and reduction of minor flooding caused by an increased frequency and magnitude of floods exceeding the bankful capacity of a channel and spilling out over the floodplain.

over–control — originally proposed by McCuen in 1979, the practice of designing a system with more controls in place than it is strictly computed to be necessary for the 2–year design storm to afford some measure of channel protection

P

peak flow control — controlling the timing and magnitude of the largest flow either leaving the site or flowing through the watershed utilizing stormwater management techniques to avoid flooding and damage downstream.

perimeter control — activities or practices designed to contain sediments on a project site

permanent storage pool — the volume in a pond or reservoir below the lowest outlet level, designed for water quality purposes to settle out particles and nutrients

permeable paver — a range of products that enable some fraction of rainfall to be infiltrated into a sub–base underneath the paver

Phase II — A 1987 amendment to the federal Clean Water Act required implementation of a two–phase comprehensive national program to address stormwater runoff. Phase I regulated large construction sites, 10 categories of industrial facilities, and major metropolitan MS4s. On March 10, 2003 the program broadened to include smaller construction sites, municipally owned or operated industrial activity, and many more municipalities

Pitt Method — means of calculating the treatment depth of rainfall based on Dr. Robert Pitt's work on rainfall and pollutant distribution as part of the 1983 NURP program

pollution load — the product of flow volume times pollutant concentration

pollution prevention practices — pro–active activities and strategies instituted to avoid introducing pollution into the environment

pollutograph — graphical representation of pollution at a point in a drainage as a function of time

polycyclic aromatic hydrocarbon (PAH)	organic compound resulting from combustion of petrochemical fuel
PONDNET	an empirical model developed by William W. Walker in 1987 to evaluate flow and phosphorus routing in pond networks
pre–treatment	processes used to reduce, eliminate, or alter pollutants before they are discharged into publicly owned sewage treatment systems
primary treatment	the first stage of wastewater treatment, including removal of floating debris and solids by screening, skimming and sedimentation
Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds (P–8)	a physically–based model developed by William W. Walker to predict the generation and transport of stormwater runoff pollutants in urban watersheds.
proprietary devices	stormwater treatment devices which are privately developed and owned

Q

quiescent periods	periods of rest or inactivity

R

rain barrel	a container used to collect and store rainwater that is usually placed below the downspout of a roof gutter. The collected water is used to water the landscape
rainfall distribution	describes how the rain fell in a 24–hour period, ie. whether the precipitation occurred over a 1–hour period or over the entire 24–hour period
rainfall frequency spectrum	describes the average frequency of the depth of precipitation events (adjusted for snowfall) that occur during a normal year
rain garden	a landscaping feature that is planted with native perennial plants and is used to manage stormwater runoff from impervious surfaces such as roofs, sidewalks, and parking lots
rate control	controlling the rate that stormwater is released from localized holding areas into larger conveyance systems
receiving water	a body of water such as a stream, river, lake, or ocean, which receives stormwater and wastewater
recessional limb	the portion of the hydrograph after the peak where flows are returning to lower or baseflow levels
recharge	the addition of water to an aquifer by natural infiltration or artificial means
recurrence interval	the inverse probability that a certain flow will occur. It represents a mean time interval based on the distribution of flows over a period of record
redevelopment	any construction, alteration, or improvement that disturbs greater than or equal to 5,000 square feet of existing impervious cover performed on sites where the existing land use is commercial, industrial, institutional, or residential
removal rate	the rate at which a pollutant is removed from the water column

retention	the permanent or temporary storage of stormwater to prevent it from leaving the development site
retrofit	the introduction of a new or improved stormwater management element where it either never existed or did not operate effectively
return interval	the inverse probability that a certain flow will occur. It represents a mean time interval based on the distribution of flows over a period of record
rill erosion	an erosion process in which numerous small channels several inches deep are formed
riparian areas	areas adjacent to a water body acting as transition zones between terrestrial and aquatic systems
riser	a vertical assembly of pipe and fittings that generally distributes water upward
roof leader	a downspout or other conveyance for runoff that has been collected from roof tops routing stormwater down to the ground surface or to a sewer service
rooftop runoff storage	installation of practices to capture and temporarily store rooftop runoff at confined sites and gradually release it over pervious areas for use for irrigation
runoff	the portion of rainfall or snowmelt not immediately absorbed into the soil that drains or flows off the land and becomes surface flow
runoff volume minimization	reducing as much as possible the amount of water running off surfaces or leaving a site
runoff management	techniques, practices and strategies for dealing with runoff and minimizing its impact to the greater environment

S

secondary treatment	biological and mechanical processes that remove dissolved or suspended material from wastewater
sedge meadow	wetland vegetative communities dominated by sedges (Cyperaceae) growing on saturated soils
sediment	any particulate matter that can be transported by fluid flow and which eventually is deposited as a layer of solid particles on the bed or bottom of a body of water
sediment control basins	a designed depression in the landscape utilized to settle out sediments from the water column before discharge into other drainages
sediment removal	the removal, usually by settling or filtering, of suspended sediments from the water column
sediment yield	The amount of sediment removed from a watershed over a specified period of time
settling	a technique to remove sediment from wastewater by slowing the water flow velocity allowing the sediments to sink to the bottom
shrub–carr	wetland plant community composed of tall, deciduous shrubs growing on saturated or seasonally flooded soils

silt curtain	a natural or synthetic fabric suspended by floats and weighted at the bottom which is stretched across a water feature and used to trap and retain sediments on site
silt fence	fence constructed of wood or steel supports and either natural (eg burlap) or synthetic fabric stretched across an area of non–concentrated flow during site development to trap and retain on–site sediment due to rainfall runoff
Simple Method	a technique for estimating storm pollutant export delivered from urban development sites
site constraints	conditions unique to the site that that serve to restrain, restrict, or prevent the implementation of proposed or desired design features
site reforestation	reforestation of existing turf or barren ground at the development site with the explicit goal of establishing a mature forest canopy or prairie condition that intercepts rainfall, and maximizes infiltration and evapotranspiration
skimmer	device used to take up or remove floating matter from the water's surface
slope stabilization	activities or techniques employed to maintain the integrity or stop the degradation of sloped areas
small storm hydrology	a less than 10–year event
snowmelt	the sudden release of accumulated snow and ice with the advent of warm weather
snowpack	a horizontally layered accumulation of snow from snowfall events which accumulates and persists through the winter and may be modified by meteorological conditions over time
soakaway pit	small, excavated pits, backfilled with aggregate, used to infiltrate good quality stormwater runoff, such as uncontaminated roof runoff
soil amendment	tilling and composting of new lawns and open spaces within a development site to recover soil porosity, bulk density, and reduce runoff
sorbent	material which extracts one or more materials from the water via absorption or adsorption
source water protection area	an identified area with restricted or modified land use practices designed to protect the public drinking water supply from the introduction of contaminants
Special Waters	waters receiving special protections as defined in Minnesota Rules
spring snowmelt event	large amount of melting of the winter's accumulated snow over a short period of time (~2 weeks). Large flow volumes typical and may be the critical water quality design event
standpipe	a vertical pipe or reservoir for water used to secure a uniform pressure
stage	the height of a water surface above an established reference point
storm distribution	a measure of how the intensity of rainfall varies over a given period of time

stormwater	water that is generated by rainfall or snowmelt which causes runoff and is often routed into drain systems for treatment or conveyence
stormwater credits	activities that can be undertaken in order to reduce the sizing or requirements for stormwater management at a site
Storm Water Management Model (SWMM)	a dynamic rainfall–runoff simulation model developed by the U.S. Environmental Protection Agency in 1971 for analysis of quantity and quality problems associated with urban runoff
stormwater planter	self–contained landscaping areas which capture and temporarily store a fraction of rooftop runoff and filter it through the soil media
stormwater pollution prevention plan (SWPPP)	a plan for preventing or minimizing pollution generated at construction sites
stormwater pollution prevention program (SWPPP)	a program that is required to be developed by MS4 communities to incorporate applicable best management practices, measureable goals and which must include the six minimum control measures
stormwater treatment train	a suite of stormwater management practices incorporating aspects of pollution prevention, volume control and water quality controls
streambank stabilization	activities or techniques employed to maintain the integrity or stop the degradation of streambanks due to erosion and sedimentation
sublimation	the process of transforming from a solid directly into a gas without passing through a liquid phase
subwatershed	a subdivision based on hydrology corresponding to a smaller drainage area within a larger watershed
swale	a wide, shallow, vegetated depression in the ground designed to channel drainage of water

T

Technical Publication 40 (TP–40)	U.S. Weather Bureau publication that is the standard reference for frequency analysis in Minnesota
Technical Release Number 20 (TR–20)	a single–event rainfall–runoff computer model developed by the U.S. Soil Conservation Service in 1964.
Technical Release Number 55 (TR–55)	a simplified procedure to calculate storm runoff, volume, peak rate of discharge, hydrographs and storage volumes developed by the U.S. Natural Resource Conservation Service in 1975
temporary construction sediment control techniques	practices employed on an active construction site to control movement of sediment within or off of the site until permanent vegetation or sediment controls can be established

ten percent rule	the downstream point where the development site represents 10% of the total contributing drainage area of a watershed. Downstream hydraulic and hydrologic analysis for the effects of coincident peaks should extend to this point
thermal impact	the impact to streams and water bodies of stormwater runoff addition which are higher in temperature than the ambient stream or water body temperature. This causes stress or may result in the death of temperature–sensitive organisms such as trout
thermal protection	techniques and practices such as infiltration and shading which act to preserve and protect the ambient temperatures of streams and waterbodies from temperature–raising effects of stormwater runoff
total maximum daily load (TMDL)	the amount of a pollutant from both point and nonpoint sources that a waterbody can receive and still meet water quality standards
total phosphorus (TP)	a nutrient that can also be a contaminant because of its use by nuisance algae
total suspended solids (TSS)	a measure of the amount of particulate material in suspension in a water column
transitional karst	areas underlain by carbonate bedrock covered by 50-100 feet of sediment
transpiration	the passage of water vapor into the atmosphere through the vascular system of plants
trash rack	a structural device used to prevent debris from entering a pipe spillway or other hydraulic structure
treatment	any method, technique, or practice used for management purposes
trench	a long steep–sided depression in the ground used for drainage or infiltration
turbidity	the cloudy appearance of water caused by the presence of suspended and colloidal matter

U

ultra–urban	highly developed urban land which has limited space and disturbed soils
under drain	An underground drain or trench with openings through which the water may percolate from the soil or ground above
unified sizing criteria	statewide criteria for the sizing of stormwater management systems

V

vegetative filters	the removal of sediment, nutrients, or pollutants by plant structures
volume control	controlling the overall volume or amount of stormwater that is released from a site or localized holding area into the larger conveyance system

W

Walker Method	a method for determining sizing for water detention ponds, developed in the upper Midwest to maximize phosphorus removal to protect sensitive lakes from eutrophication
water balance	A hydrological formula used by scientists and land managers to determine water surpluses and deficits in a given area. Includes inputs such as precipitation; outputs such as evapotranspiration, infiltration, and runoff; and storage within the system
water quality sizing	tied to the volume of stormwater runoff
water quality volume	the permanent pool in a water detention pond
watershed	a topographically defined area within which all water drains to a particular point
watershed inch	a unit of measure corresponding to the volume of water spread out over the entire watershed area at a depth of one inch
waters of the State	All streams, lakes, ponds, marshes, watercourses, waterways, wells, springs, aquifers, irrigation systems, drainage systems, and all other bodies or accumulations of water surface or underground, natural or artificial, public or private, which are contained within, flow through or under the state or any portion thereof
waters of the United States	those waters coming under federal jurisdiction
weir	a spillover dam–like device used to measure or control water flow
wellhead protection area	an identified area with restricted or modified land use practices designed to protect the well supply area from the introduction of contaminants
wetland	land that is transitional between aquatic and terrestrial ecosystems and must: have a predominance of hydric soils, be inundated or saturated by surface water or ground water at a frequency and duration sufficient to support a prevalence of hydrophytic vegetation typically adapted for life in saturated soil conditions, and under normal circumstances support a prevalence of hydrophytic vegetation. To be a wetland the area must meet wetland criteria for soils, vegetation, and hydrology as outlined in the 1987 U.S. Army Corps of Engineers Wetland Delineation Manual.
wetland systems	hydrologically interconnected series of wetlands which includes the interrelatedness of habitat, wetland functions, and biology
wet pond	a permanent pool of water for treating incoming stormwater runoff
wet vault	A wet vault is a vault stormwater management device with a permanent water pool, generally 3 to 5 feet deep

XYZ

Appendix I

Bibliography

APPENDICES

Appendix I Bibliography

Contents

I. Bibliography

Aichinger, C., 2004. *Understanding the West Nile Virus.* Woodbury Bulletin (newspaper opinion page), August 11, 2004. Contact Ramsey-Washington Metro Watershed District, North St. Paul, MN.

Alexander, E.C. and Y. Gao, 2002. Copyrighted graphic of Minnesota Karst Lands.

Allen P. and R. Narramore. 1985. Bedrock controls on stream channel enlargement with urbanization, North Central Texas. Water Resources Bulletin. 21(6): 1037-1048.

American Society of Civil Engineers (ASCE). 2003. International database on pollutant removal performance of stormwater best management practices.

Andrews, W.J., J.R. Stark, A.L. Fong and P.E. Hanson, 1999. Ground-water quality along a flowpath in surficial outwash aquifer in the Upper Mississippi River Basin - The influence of land use. Hydrological Science and Technology, 15(1-4):66-75. Special Issue: 4thUSA/CIS Joint Conference, November 7-10, 1999, San Francisco. American Institute of Hydrology.

Aplikowski, S., J. Hafner, and B. Wilson. 2005. Minneapolis Chain of Lakes: A decade of Watershed Rehabilitation. Lakeline. Spring 2005.Aquafor Beech Ltd. 1999. Draft Final Stormwater Management Planning and Design Manual. OntarioMinistry of the Environment.

Arendt, R. 1997. Designing Open Space Subdivisions. Natural Lands Trust. Media, PA

Avinmelich, Y., J. McHenry and J. Ross. 1984. Decomposition of Organic Matter in Lake Sediments. Environmental Science and Technology.

Bäckström, M., 2002. Series of Papers in Doctorate Thesis, Luleå University of Technology.

Bäckström, M., 1999. Series of Papers in Licentiate Thesis, Luleå University of Technology.

Baker, D.G., W.W. Nelson and E.L. Kuehnast, 1979. *Climate of Minnesota: Part XII – The Hydrologic Cycle and Soil Water.* University of Minnesota, Agricultural Experiment Station, St. Paul, MN.

Baker, J.M., 1997. Vanishing Ponds Not a Sure Sign of Spring. Agricultural Research, April, p.9.

Barodziej, W. and S. Blood. 2004. Shore Restoration of a High-use Urban Lake.

Bengtsson, L., 1981. Snowmelt-Generated Runoff in Urban Areas. In Proceedings, Second International Conference on Urban Storm Drainage, Urbana, Illinois, June 14-19, 1981, pp.444-451.

Bledsoe, B. 2001. Relationships of stream response to hydrologic changes. Linking Stormwater BMP Designs and Performance to Receiving Water Impacts Mitigation Proceedings. Snowmass, CO.

Booth, D. and P. Henshaw. 2001. Rates of channel erosion in small urban streams. Water Science and Application 2:17-38.

Booth, D. 1990. Stream channel incision following drainage basin urbanization. Water Resources Bulletin. 26(3): 407-417.

Bouwer, H. and R. C. Rice. 1989. Effect of Water Depth in Ground-water Recharge Basins on Infiltration. Journal of Irrigation and Drainage Engineering, Vol. 115, No. 4, pp. 556-567.

Brown, E., D. Caraco and R. Pitt, 2004. Illicit Discharge Detection and Elimination: AGuidance Manual for Program Development and Technical Assessment. Center for Watershed Protection, Ellicott City, MD.

Brown, T. and J. Simpson. 2001. “Managing Phosphorus Inputs Into Lakes I: Determining the Trophic State of Your Lake.” Watershed Protection Techniques. 3 (4): 771-781. Center for Watershed Protection. Ellicott City, MD.

Brown, W. and T. Schueler, 1997. Economics of stormwater best management practices in the Mid-Atlantic region. Center for Watershed Protection, Ellicott City, MD.

Burton, G. and R. Pitt. 2002. Stormwater effects handbook: a toolbox for watershed managers, scientists and engineers. CRC/Lewis Publishers, Boca Raton, FL.

Busacker, G. 2004. Protecting Water Resources Based on a Collaborative Community Effort. AASHTO National Environmental Stewardship Competition Application.

Buttle, J.M., 1990. Effect of suburbanization upon snowmelt runoff. Hydrol. Sci. Jour.,

35(3):285-302.

Buttle, J.M. and F. Xu, 1988. Snowmelt Runoff in Suburban Environments. Nordic Hydrology, 19:19-40.

Cappiella, K. 2005. Urban Watershed Forestry Manual Part 1: Conserving Trees at the Watershed Scale. Prepared for: USDA Forest Service. Center for Watershed Protection. Ellicott City, MD.

Capiella, K, T. Schueler and T. Wright. 2005. Conserving and planting trees at development sites. USDA Northeastern Area State and Private Forestry. Center for Watershed Protection. Ellicott City, MD

Cappiella, K., Schueler, T.R. and T. Wright. 2005. Urban Watershed Forestry Manual. Part 1: Methods for Increasing Forest Cover in a Watershed. USDA Forest Service, Northeastern Area State and Private Forestry. Newtown Square, PA.

Cappiella, K., Schueler, T.R. and T. Wright. 2005. Urban Watershed Forestry Manual. Part 2: Conserving and Planting Trees at Development Sites. USDA Forest Service, Northeastern Area State and Private Forestry. Newtown Square, PA.

Capuccitti, D and W. Page, 2000. Stream response to stormwater management best management practices in Maryland. Maryland Department of the Environment. Final Deliverable for a US EPA 319 Grant.

Caraco, D. 2001. “Managing Phosphorus Inputs Into Lakes III: Evaluating the Impact of Watershed Treatment.” Watershed Protection Techniques. 3 (4): 791-796. Center for Watershed Protection. Ellicott City, MD.

Caraco, D. and R. Claytor, 1997. Stormwater BMP Design Supplement for Cold Climates. Center for Watershed Protection, Ellicott City, Maryland.

Caraco, D. and T. Brown. 2001. “Managing Phosphorus Inputs Into Lakes II: Crafting an Accurate Phosphorus Budget for Your Lake.” Watershed Protection Techniques. 3 (4): 782-790. Center for Watershed Protection. Ellicott City, MD.

Carroll County, MD. 1996a. Draft Water Resource Management Manual.

Carroll County, MD. 1996b. Draft Water Resource Management Ordinance.

Center for Watershed Protection (CWP). 1998. Better Site Design: a handbook for changing development rules in your community. US EPA. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 1998. Nutrient Loading From Conventional and Innovative Site Development. Prepared for: Chesapeake Research Consortium. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 1999. Nutrient loading from conventional and innovative site development. Chesapeake Research Consortium. Center for Watershed Protection. Ellicott City, MD.

Center for Watershed Protection (CWP). 2001. Special Issue on Urban Lake Management: Watershed Protection Techniques 3(4): 745-820.

Center for Watershed Protection (CWP). 2003. The impacts of impervious cover on aquatic systems. Watershed Protection Research Monograph No. 1. Center for Watershed Protection. Ellicott City, MD. 142 pp. 11: 165-206.

Chang, M., M. McBroom, R. Beasley. 2004. Roofing as a source of nonpoint water pollution. Journal of Environmental Management. 73: 307-315.

Chicago Wilderness and Northeastern Illinois Planning Commission, 2003. Conservation Design Resource Manual. Available at http://www.chicagowilderness.org/pubprod/miscpdf/CD_Resource_Manual.pdf.

Chollak, T and R. Rosenfield 1998. Guide for landscaping with compost amended soils. Department of Public Works. City of Redmond, WA

City of Minneapolis. 2004. City of Minneapolis Heritage Park: Near North Wetlands and Stormwater Management 2005 CIP Budget Documentation (and associated educational flyers).

City of Portland. 2004. Portland's Stormwater Management Manual. Bureau of Environmental Services. Portland Oregon. www.cleanrivers-pdx.org/tech_resources/2004_swmm.htm

City of Seattle, 2003. How soil amendments and compost can aid in Salmon recovery. http://depts.washington.edu/cuwrm/publictn/s4s.pdf

Colbeck, S.C., 1981. A simulation of the enrichment of atmospheric pollutants in snow cover runoff. Water Res. Research, 17(5): 1383-1388.

Colbeck, S.C., 1991. The layered character of snow covers. Rev. Geophys., 29(1):81-96.

Commonwealth of Virginia, 2003. *Vector Control: Mosquitoes and Storm Water Management.* Stormwater Management Technical Bulletin No 8.

Conservation Toronto and Region, 2001. *The Storm Water Pollution Prevention Handbook.* Copublished with the Ontario Ministry of the Environment. Available at http://www.ene.gov.on.ca/envision/water/stormwaterpph.htm

Covington, M. 2002. Modified Sand Filter Design (The Herring/Frock Method). Presented at Delaware Sediment and Stormwater 2002 Conference – The Race for Clean Water. Dover, DE.

Debo, T. and A. Reese. 1992. Determining downstream analysis limits for detention facilities. Proceedings from International Conference on Innovative Technologies in the Domain of Urban Stormwater Drainage.

Delaware Department of Natural Resources and Environmental Conservation (DE DNREC). 1997. Conservation Design for Stormwater Management. Dover, DE.

Dreher, D, and T. Price. 1994. Reducing the Impact of Urban Runoff: The Advantages of Alternative Site Design Approaches. Northeastern Illinois Planning Commission. Chicago, IL.

Dewberry and Davis, Inc. 1990. Toxicity of Sediments from BMP Ponds. Final Report. Northern Virginia Planning District Commission. 42 pp.

Dorman, M., J. Hartigan, R. Steg, and T. Quaserbarth. 1989. Retention, Detention, and Overland Flow for Pollutant Removal from Highway Stormwater Runoff. Federal Highway Administration Report No. RD-89-202. 179 pp.

Duke, D. and K. Shaver. 1999. "Widespread Failure to Comply with U.S. Storm Water Regulations for Industry-Part II: Facility-Level Evaluations to Estimate Number of Regulated Facilities." Environmental Engineering Science. Vol. 16(4).

Duke, D., K. Patel, and B. Masek. 1999. "Widespread Failure to Comply with U.S. Storm Water Regulations for Industry-Part I: Publicly Available Data to Estimate Number of Potentially Regulated Facilities." Environmental Engineering Science. Vol. 16(4).

Dunne, T. and R.D. Black, 1971. Runoff Processes during Snowmelt. Water Resources Research, 7(5): 1160-1172.

Emmons & Olivier Resources, Inc. (EOR). 2000. Brown's Creek Second Generation Watershed Management Plan.

Emmons and Olivier Resources, Inc. 2004. Trout Habitat Preservation Project (THPP) 2004 MAWD Project and Program of the Year Nomination Form.

Ferguson, B. and T. Debo. 1990. On-site Stormwater Management: Applications for Landscape and Engineering. 2nd Edition. Van Nostrand Reinhold, New York.

Fillmore Soil and Water Conservation District. 1998. City of Wykoff Sinkhole/Stormw Water Discharge Project. MN BWSR FY 99 State Cost Share Special Project Application.

Finkenbine, J., J. Atwater and D. Mavinic. 2000. Stream health after urbanization. Journal of the American Water Resources Association 36(5): 1149-1160.

Fish, W. 1988. Behavior of Runoff-Derived Metals in a Well-Fined Paved Catchment/Retention Pond System. Water Resources Research Institute Report No. 103. Oregon State University. 54 pp.

Galli, J. 1988. A limnological Study of an Urban Stormwater Management Pond and Stream Ecosystem. M.S. Thesis. Department of Biology. George Mason University. Fairfax, Virginia.

Galli, J. 1990. Thermal Impacts Associated with Urbanization and Stormwater Management Best Management Practices. Metropolitan Washington Council of Governments. Washington, D.C.

Galli, J. 1993. Analysis of Urban Best Management Practice Performance and Longevity in Prince George's County, Maryland. 202 pp.

Gavens, A., D. Revitt, and J. Ellis. 1982. Hydrocarbon Accumulation in Freshwater Sediments of an Urban Catchment. Hydrobiologia (91): 285-292.

Georgia (State of), 2001. *Stormwater Management Manual*. Available at http://www.georgiastormwater.com.

Giesy, J. and R. Hoke. 1991. Freshwater Sediment Quality Criteria: Toxicity Bioassessment in Sediments: Chemistry and Toxicity of In-Place Pollutants. R. Baudo, R. Giesy, and H. Muntau, Editors. Lewis Publishers.

Granger, R.J., D.M. Gray and G.E. Dick, 1984. Snowmelt Infiltration to Frozen Soils. Canadian Journal of Earth Science, 21:669-677.

Great Lakes Association. Percent Bedrock Outcrop of Landtype Associations of Northern Minnesota Map.

Grizzard, etal. 1983. Final Monitoring Report for Washington Metropolitan Area Nationwide Urban Runoff Project. Chapter 7. Occuquan Watershed Monitoring Lab. Metropolitan Washington Council of Governments.

Grizzard, T. 1989. Memorandum dated 22 March 1989. Detention Basin Spoil Disposal Near Twin Beech Court. OWML. Manassas, Virginia. 5 pp.

Haan, C., B. Barfield, J. Hayes, 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press, San Diego.

Hammer, T. 1972. Stream channel enlargement due to urbanization. Water Resources Research 8(6): 1530-1540.

Harper, H. 1988. Effects of Stormwater Management Systems on Groundwater Quality. Final Report. Environmental Research and Design, Inc. Florida Department of Environmental Regulation. 460 pp.

Hershfield, D.M., 1961. Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years. U.S. Weather Bureau, Technical Publication 40.

Hogland, W., M. Marques, and V. Karlaviciene. 2003. Stormwater Runoff From Industrial Areas and Pollution Transport. Proceedings from 1st International Conference on Urban Drainage and Highway Runoff in Cold Climate. Riksgränsen, Sweden.

Hollis, F. 1975. The effects of urbanization on floods of different recurrence intervals. Water Resources Research, 11:431-435.

Holmgren, etal. 1993. Cadmium, Lead, Zinc, Copper and Nickel in Agricultural Soils (USA)> Journal of Environmental Quality. 22:335-348.

Horner, R., D. Booth, A. Azous, and C. May. 1996. Watershed Determinants of Ecosystem Functioning. In L. A. Roesner (ed.), Effects of Watershed Development and Management on Aquatic Ecosystems: Proceedings of an Engineering Foundation Conference. Snowbird, UT: American Society of Civil Engineers.

Horsely, S. 1996. Memorandum dated July 10, 1996. Methods for Calculating Pre and Post Development Recharge Rates. Prepared for State of Massachusetts Stormwater Technical Advisory Group.

Huff and Angels, 1992. Bulletin 71. Midwest Climate Center.

Illinois Conservation Foundation and Chicago Wilderness, 2005. Changing Cost Perceptions: An Analysis of Conservation Development. Prepared by the Conservation Research Institute. http://www.nipc.org/environment/sustainable/conservationdesign/cost_analysis/

Institute of Transportation Engineers Transportation Planning Council Committee

Isabelle, P.S., L.J. Fooks, P.A. Kenny and S.D. Wilson, 1987. Effects of roadside snowmelt on wetland vegetation: An experimental study. Jour. of Envir. Management, 25:57-60.

Jeffries, D.S., 1988. Snowpack release of pollutants. National Water Research Institute (Burlington, Ontario, Canada), Report No. 88-06.

Johnson, K. 1995. Urban Storm Water Impacts on a Coldwater Resource. Presentation to the Society of Environmental Toxicology and Chemistry (SETAC) Second World Congress. Vancouver, B.C., Canada.

Jones, J., S. Anderson, J. Fognani, F. R. MacGregor, and T. Axley. 1996. “Stormwater Best Management Practices: When is Sediment Considered Hazardous?” Water Environment & Technology.

Laughland, J. C. Stormwater Management Design in Karst Terrain: Adjusting Hydrology Models and Using Karstic Features. http://www.planetrussell.net/fdg/fdg_demo_green.html.

Leersnyder, H. 1993. The Performance of Wet Detention Basins for the Removal of Urban Stormwater Contaminants in the Aukland (NZ) Region. M.S. Thesis. Department of Environmental Science and Geography. University of Auckland. 118 pp.

Leopold, L. B. 1994. A View of a River. Harvard University Press. Cambridge, MA.

Leopold, L., M. Wolman, and J. Miller. 1964. Fluvial Processes in Geomorphology. W.H. Freeman and Company. San Francisco, CA.

Liptan, T. and C. Brown. 1996. A Cost Comparison of Conventional and Water Quality-based Stormwater Designs. City of Portland. Portland OR.

MacRae, C. 1993. An alternate design approach for the control of instream erosion potential in urbanizing watersheds. pp. 1086-1091. In Proceedings of the Sixth International Conference on Urban Storm Drainage. Niagra Falls, Ontario. Marsalek and Torno (eds.).

MacRae, C. 1996. Experience from morphological research on Canadian streams: is control of the two- year frequency runoff event the best basis for stream channel protection? In Effects of Watershed Development and Management on Aquatic Systems . L. Roesner (ed.) Engineering Foundation Conference. Proceedings. Snowbird, UT. August 4-9, 1996. pp. 144-160.

MacRae C. and A. Rowney. 1992. The role of moderate flow events and bank structure in the determination of channel response to urbanization. 45th Annual Conference. Resolving Conflicts and Uncertainty in Water Management. Proceeding of the Canadian Water Resources Association. June 1992. Kingston, Ontario.

MacRae, C. and M. DeAndrea. 1999. Assessing the Impact of Urbanization on Channel Morphology. Second International Conference on Natural Channel Systems. Niagra Falls, OT.

Marsalek, J., 2003. Road salts in urban stormwater: An emerging issue in stormwater management in cold climate. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.65-74.

Marsalek, J., G.L. Oberts, K. Exall and M. Viklander, 2003. Review of the operation of urban drainage systems in cold weather: Water quality considerations. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.1-11.

Marsalek, P.M., W.E. Watt, J. Marsalek, and B.C. Anderson, 2000. Winter flow dynamics on an on-stream stormwater management pond. Water Qual. Res. Jour. Canada,35(3): 505-523.

Marsh, P. and M-K. Woo, 1984. Wetting front advance and freezing of meltwater within a snow cover - 1. Observations in the Canadian Arctic. Water Res. Research, 20(12): 1853-1864.

Maryland Department of the Environment (MDE). 2000. 2000 Maryland Stormwater Design Manual. MDE. Baltimore, MD.

Matheussen, B.V. and S.T. Thorolfsson, 2003. Estimation of snow-covered areafor an urban catchment using image processing and neural networks. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.315-326.

Maurer, G. 1996. A Better Way to Grow: For More Livable Communities and a Healthier Chesapeake Bay. Chesapeake Bay Foundation. Annapolis, MD.

McCuen, R. 1979. Downstream effects of stormwater management basins. Journal of the Hydraulics Division, ASCE, Vol. 105, No. HY11.

McCuen R. and G. Moglen. 1988. Multicriterion stormwater management methods. Journal of Water Resources Planning and Management. (114) 4.

McDonald, F. 1999. Ecologically Sound Lawn Care for the Pacific Northwest: Findings from the Scientific Literature and Recommendations from Turf Professionals. City of Seattle Public Works. Seattle, WA.

Messer, D.F., 2003. *Mosquitoes in Structural Stormwater BMPs: A Case Study.* In Proceedings of the StormCon Conference of 2003, San Antonio, Texas. Published by Forester Communications, Santa Barbara, CA.

Metropolitan Council, 1995. Precipitation Frequency Analysis.

Metropolitan Council (MC). 2001. Minnesota Urban Small Sites BMP Manual: Stormwater best management practices for cold climates. Metropolitan Council Environmental Services. St. Paul. MN.

Metzger, M.E., 2003. *Mosquito Control Challenges Presented by Stormwater Treatment Devices in the United States.* In Proceedings of the StormCon Conference of 2003, San Antonio, Texas. Published by Forester Communications, Santa Barbara, CA.

Metzger, M.E., D.F. Messner, C.L. Beitia, C.M. Meyers, and V.L. Kramer, 2002. The Dark Side of Stormwater Runoff Management: Disease Vectors Associated with Structural BMPs. Stormwater, 3(2):24-39.

Minnehaha Creek Watershed District (MCWD), 2001. Benefits of Wetland Buffers: A Study of Functions, Values, and Size. Prepared for MCWD by EOR. Oakdale, MN. 41pp.

Minnehaha Creek Watershed District, 2003. Hydrologic, Hydraulic, and Pollutant Loading Study.

Minnesota Department of Natural Resources. 2003. Field Guide to the Native Plant Communities of Minnesota: The Laurentian Mixed Forest Province. Ecological Land Clasificaiton Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program, MNDNR St. Paul, MN.

Minnesota Department of Natural Resources. 2005. Field Guide to the Native Plant Communities of Minnesota: The Eastern Broadleaf Forest Province. Ecological Land Clasificaiton Program, Minnesota County Biological Survey, and Natural Heritage and Nongame Research Program, MNDNR St. Paul, MN.

Minnesota Department of Natural Resources. 2006. Field Guide to the Native Plant Communities of Minnesota: The Prairie Parkland and Tallgrass Aspen Parklands Province. Ecological Land Clasificaiton Program, Minnesota County Biological Surve, and Natural Heritage and Nongame Research Program, MNDNR St. Paul, MN.

Minnesota Department of Transportation, 1998. Intensity of Extreme Rainfall over Minnesota.

Minnesota Department of Transportation. 2005. Highway 23 Reconstrustion Website. http://www.dot.state.mn.us/d8/projects/23/

Minnesota Department of Transportation, 2005. The Cost and Effectiveness of Stormwater Management Practices. Report 2005-23, St. Paul, MN. http://www.lrrb.org/pdf/200523.pdf

Minnesota Forest Resources Council. 1999. Sustaining Minnesota Resources: Voluntary Site-Level forest Management Guidelines for Landowners, Loggers, and Resource Managers. (General Guidelines pp. 22-23). Minnesota Forest Resources Council, St. Paul, MN.

Minnesota Pollution Control Agency, March, 2000. Protecting Water Quality in Urban Areas. Best Management Practices for Dealing with Storm Water Runoff from Urban, Suburban and Developing Areas of Minnesota. St. Paul, Minnesota.

Minnesota Pollution Control Agency (MPCA). 2002. Protecting Water Quality In Urban Areas. St Paul, MN.

Minnesota Pollution Control Agency (MPCA). 2004. 2004 Final List of Impaired Waters. http://www.pca.state.mn.us/water/tmdl/index.html.

Minnesota State Climatology Office and Minnesota Department of Natural Resources. 2003. Normal Annual Precipitation.

Morisawa, M and E. La Flure. 1979. Hydraulic geometry, stream equalization and urbanization. In the Proceedings of the Tenth Annual Geomorphology Symposia Series entitled “Adjustments of the Fluvial System” held in Binghampton, NY. September 21-22, 1979. Kendall/Hunt Publishing Company, Dubuque, IA.

Natural Resources Conservation Service. 1975. Minnesota Hydrology Guide. http://www.mn.nrcs.usda.gov/technical/eng/pdf/mhgweb.pdf

Natural Resources Conservation Service (NRCS), 1984. Engineering Field Manual for Conservation Practices. U.S. Department of Agriculture, Washington, D.C.

Natural Resources Conservation Service, 1986. Urban Hydrology for Small Watersheds, Technical Release 55 (TR-55). ftp://ftp.wcc.nrcs.usda.gov/downloads/hydrology_hydraulics/tr55/tr55.pdf

Natural Resource Conservation Service. 2005. Status of Soil Survey Digitizing (SSURGO) Minnesota.

Novotny, V., 1988. Modeling Urban Runoff Pollution during Winter and Off-Winter Periods. In Advances in Environmental Modeling, A. Marani (Editor), Elsevier Publishing, Amsterdam, pp.43-58.

Novotny, V., D.W. Smith, D.A. Kuemmel, J. Mastriano and A. Bartošová, 1999. Urban and Highway Snowmelt: Minimizing the Impact on Receiving Water. Water Environment Research Foundation (WERF), Project 94-IRM-2.

Oberts, G.L., 2003. Cold climate BMPs: Solving the Management Puzzle. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.13-31.

Oberts, G., and R. Osgood. 1988. final Report on the Function of the Wetland Treatment Systems and the Impacts on Lake McCarrons. Metropolitan Council. Publ. No. 590-89-062(a).

Oberts, G.L., P.J. Wotzka and J.A. Hartsoe, 1989. The Water Quality Performance of Select Urban Runoff Treatment Systems, Metropolitan Council, Publication No.

590-89-062a, 170 p.

Pitt, R., 1989. Small Storm Hydrology: The integration of flow and water quality for management practices University of Alabama-Birmingham.

Pitt, R., 1989. Source Load Assessment and Management Model (SLAMM).

Pitt, R. 2001. Methods for Detection of Inappropriate Discharges to Storm Drainage Systems: Background Literature and Summary of Findings. Tuscaloosa, AL.

Pitt, R., 2004. National Stormwater Quality Database.

Polta, R., 2004. A Survey of Regulations Used to Control the Use and Disposal of Stormwater Pond Sediments in the United States and Canada. EQA Report 04-542, Metropolitan Council Environmental Services, St. Paul, MN.

Pitt, R., A. Maestre, and R. Morquecho, 2004. The National Stormwater Quality Database (NSQD, Version 1.1). Department of Civil and Environmental Engineering. University of Alabama, Tuscaloosa.

Prince George's County Maryland. 2002. Prince George's County Bioretention Manual. Department of Environmental Resources.

Pronold, M., 2000. Administering the NPDES Industrial Storm Water Program in Proceedings: National Conference on Tools for Urban Water Resource Management and Protection. U.S. EPA, Office of Research and Development, EPA/625-R-00-001.

Ramsey-Washington Metro Watershed District. 2001. Tanners Lake Water Quality Improvement Project. Project Report.

Rawls, W., D. Brakensiek, and N. Miller, 1983. Green-Ampt infiltration parameters from soils data. Journal of Hydraulic Engineering. Vol. 109, No. 1, pp. 62 – 70.

Rawls, W., D. Brakensiek, and K. Saxton, 1982. Estimation of Soil Water Properties. Transactions of the American Society of Agricultural Engineers. Vol. 25, No. 5, pp. 1316 – 1320 and 1328.

Rawls, W., D. Giminez, and R. Grossman, 1998. Use of Soil Texture, Bulk Density and Slope of water Retention Curve to Predict Saturated Hydraulic Conductivity. ASAE. Vol. 41(2), pp. 983 – 988.

Roa-Espinosa, A., T. Wilson, J. Norman, and K. Johnson. 2003. Predicting the Impact of Urban Development of Stream Temperature using a Thermal Urban Runoff Model (TURM). National Conference on Urban Storm Water: Enhancing Programs at the Local Level. Proceedings. Chicago, IL.

Sansalone, J.J. and S.G. Buchberger, 1996. Characterization of metals and solids in urban highway winter snow and spring rainfall-runoff. Trans. Res. Record, 1523:147-159.

Schiffer, D. 1989. Effects of Highway Runoff on the Quality of Water and Bed Sediments in Two Wetlands in Central Florida. U.S. Geological Survey Publication No. 88-4200. Florida Department of Transportation.

Schueler, T. 1987. Controlling urban runoff: a practical manual for planning and designing urban best management practices. Metropolitan Washington Council of Governments.Washington, D.C.

Schueler, T. 1992. Design of Stormwater Wetland Systems. Metropolitan Washington Council of Governments. Washington, D.C.

Schueler, T. 1994. Design of Stormwater Pond Systems. Center for Watershed Protection. Ellicott City, MD.

Schueler, T. 1994. Hydrocarbon Hotspots: Can They Be Controlled? Watershed Protection Techniques. (1)1:3-5.

Schueler, T., 2000. Pollutant Dynamics of Pond Muck. Watershed Protection Techniques, 1(2): 39-46. Center for Watershed Protection, Ellicott City, MD.

Schueler, T. and D. Shepp. 1993. The Quality of Trapped Sediments ad Pool Water within Oil Grit Separators in Maryland. MWCOG. Maryland Department of Environment. 42 pp.

Schueler, T. 1995. Site Planning for Urban Stream Protection. Center for Watershed Protection. Ellicott City, MD

Schueler, T. and K. Brown. 2004. Manual 4: Urban Stream Repair Practices. Urban Subwatershed Restoration Manual Series. Center for Watershed Protection. Ellicott City, MD.

Schueler, T., C. Swann, T. Wright, and S. Sprinkle. 2004. Urban Subwatershed Restoration Manual No. 8: Pollution Source Control Practices, Version 1.0. Center for Watershed Protection. Ellicott City, MD.

Shaver, E. 1991. Sand Filter Design for Water Quality Treatment.

Shaw, D. and R. Schmidt, 2003. Plants for Stormwater Design. Minnesota Pollution Control Agency, 369 p.

Soil Conservation Service, 1975. Hydrology Guide for Minnesota.

South St. Louis Soil and Water Conservation District. 2001. Miller Creek Diagnostic Study and Implementation Plan: Clean Water Partnership Phase I Report

Stanek, S. (no date). *West Nile Virus and Stormwater Management.* Brochure prepared for the Minnehaha Creek Watershed District, Deephaven, MN.

State of Maryland. 2000. Maryland Stormwater Design Manual. Volume I and II. Maryland Department of Environment. Baltimore, MD.

State of Minnesota Storm-Water Advisory Group. 1997. Storm-Water and Wetlands: Planning and Evaluation guidelines for Addressing Potential Impacts of Urban Storm-Water and Snow-Melt Runoff on Wetlands. Minnesota Pollution Control Agency. St. Paul, MN.

State of New Jersey. 2004. New Jersey Stormwater Best Management Practices Manual. Watershed Management Division. Department of Environmental Protection. Trenton, NJ www.njstormwater.org

State of New York. 2003. Stormwater Management Design Manual. New York State Department of Environmental Conservation. Albany, NY.

State of Pennsylvania. 2005. Pennsylvania Stormwater Best Management Practices Manual. Bureau of Stormwater Management Department of Environmental Protection. Harrisburg, PA

State of Vermont, 2002. The Vermont Stormwater Management Manual-Final Draft. Vermont Agency of Natural Resources, Waterbury, VT. UNESCO, 2000. Urban Drainage in Specific Climates: Vol.II. Urban Drainage in Cold Climates. ed. by S. Saegrov, J. Milina and S.T. Thorolfsson. IHP-V, Technical Documents in Hydrology, No. 40, Vol. II, Paris.

State of Washington. 2004. Stormwater Management Manual For Water Quality in Western Washington, Volume III. Hydrologic Analysis and Flow Control Procedures. Washington Department of Ecology, Olympia, WA.

State of Wisconsin. 2000. Wisconsin storm water manual; technical design guidelines for storm water management practices. University of Wisconsin-Extension. Madison, WI .

State of Wisconsin. 2004. NR-151: Runoff management: Non-agricultural Performance Standards. Wisconsin Department of Natural Resources. July, 2004. No. 583.

St. Johns River Management District (SJRMD). 2001. Applicant's Handbook: Regulation of Stormwater Management Systems. Palatka, FL.Semadeni-Davies, A., 2003. Response surfaces for climate change impact assessments in urban areas. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.269-279.

Stenlund, D. 2005. Meeting Stormwater Discharge Requirements Using Compost Along Silver Cliff Creek Trail, SWPPP Development and Implementation with Compost as a Primary Best Management Practice. Powerpoint Presentation Presented at the 2005 Minnesota Air, Water, and Waste Conference, February 12, 2005.

USDA. 1986. TR-55 Urban Hydrology for Small Watersheds.

U.S. EPA (no date). *Wetlands and West Nile Virus* brochure.

United States Environmental Protection Agency (US EPA). 1980. Our Nation's Lakes. Office of Water. Washington, D.C. EPA-440-5-80-009.

U.S. Environmental Protection Agency (US EPA). 1993. Natural Wetlands and Urban Storm water: Potential Impacts and Management.

U.S. Weather Bureau (D.M. Hershfield), 1961. *Rainfall Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years.* USWB Technical Publication 40 (TP 40).Walker, W. W., 1987. Design Calculations for Wet Detention Ponds. Prepared for the St. Paul Water Utility and Vadnais Lake Area Water Management Organization, St. Paul, Minn.

Walker, 1987. Design calculations for Wet Ponds. Prepared fro St. Paul Water Utility and Vadnais Lake Area Water Management Organization, St Paul, MN

Walker Jr., W. W., 2000. P8 Urban Catchment Modal (Version 2.4), IEP, Inc. and Narrangansett Bay Project USEPA/RIDEM. http://wwwalker.net/p8/

Washington County Water Consortium (WCWC). 2003. Comparative review of watershed district rules and recommendations for standardization. Washington County Office of Administration

Wass, R.D., 2003. *Mosquito Management Do's and Don'ts in an Engineered Arizona Treatment Wetland System.* In Proceedings of the StormCon Conference of 2003, San Antonio, Texas. Published by Forester Communications, Santa Barbara, CA.

Weiss, P.T., Gulliver, J.S., Erickson, A.J., 2005.   *The Cost and Effectiveness of Stormwater Management Practices.* Prepared for the University of Minnesota.

Westerström, G., 1984. Snowmelt runoff from Porsön residential area, Luleå, Sweden.In Proceedings of the Third International Conference on Urban Storm Drainage, Gothenburg, Sweden, June 4-8, 1984, pp. 315-324.

Wheaton, S.R. and W.J. Rice, 2003. Siting, design and operational controls for snow disposal sites. In Proceedings - Urban Drainage and Highway Runoff in Cold Climate, March 25-27, 2003, Riksgränsen, Sweden, pp.85-95.

Wigington, P., C. Randall, And T. Grizzard. 1986. Accumulation of Selected Trace Metals in Soils of Urban Runoff Swale Drains. Water Resources Bulletin. 22(1): 73-79.

Willott, E. 2004. “Restoring nature, without mosquitoes?” Restoration Ecology 12(2): 147-153. http://research.biology.arizona.edu/mosquito/Willott/Pubs/Restore.html

Winer, R. 2000. National Pollutant Removal Performance Database for Stormwater Treatment Practices. 2nd Edition. Center for Watershed Protection. Ellicott City, MD.

Winer, R. and J. Zielinski. 2003. Critical Area 10% Rule Guidance Manual: Maryland Chesapeake and Atlantic Coastal Bays. Center for Watershed Protection. Critical Area Commission, Annapolis, MD.

Wright, T., C. Swann, K. Cappiella, and T. Schueler. 2004. Urban Subwatershed Restoration Manual No. 11: Unified Subwatershed and Site Reconnaissance: A User’s Manual, Version 1.0. Center for Watershed Protection. Ellicott City, MD.

Yousef, Y., M. Wanielista, J. Dietz, L. Yin, and M. Brabham. 1990. Final Report-Efficiency Optimization of Wet Detention Ponds for Urban Stormwater Management. University of Central Florida. Florida Department of Environmental Regulation. 200 pp.

Yousef, Y., L. Lin, J. Sloat, and K. Kaye. 1991. Maintenance Guidelines for Accumulated Sediments in Retention/Detention Ponds Receiving Highway Runoff. University of Central Florida. Florida Department of Transportation. 210 pp.

Yousef, Y. 1994. Personal communication. University of Central Florida, Orlando.

Zielinski, J., 2001. The Benefits of Better Site Design in Residential Subdivisions. Watershed Protection Techniques, 3(2):633-646. Center for Watershed Protection. Ellicott City, MD.

II. Web References

Agency Web References

Federal Emergency Management Agency (FEMA)

FEMA’s Introduction to NFIP, last updated October 22, 2004, http://www.fema.gov/nfip/intnfip.shtm.

Metropolitan Council (Met Council)

Met Council Environmental Services: Industrial Waste Forms, 2003, http://www.metrocouncil.org/environment/IndustrialWaste/forms.htm.

Met Council Environmental Services: Industrial Wastes web page, 2003, http://www.metrocouncil.org/environment/IndustrialWaste/.

Met Council Environmental Services: Watershed planning: 2003, http://www.metrocouncil.org/environment/Watershed/planning/index.htm.

Met Council Home Page, retrieved April 4, 2005, http://www.metrocouncil.org/.

Minnesota Board of Water and Soil Resources (BWSR)

BSWR 404 Permit (joint state and federal permit) Application Forms, retrieved April 4, 2005, http://www.bwsr.state.mn.us/wetlands/wcaforms/index.html.

BWSR and SWCD Supervisors Handbook retrieved April 4, 2005, http://www.bwsr.state.mn.us/aboutbwsr/publications/supervisorshandbook.pdf.

BWSR Home Page: retrieved April 4, 2005,
http://www.bwsr.state.mn.us/index.html.

BWSR Metropolitan Area Surface Water Management retrieved April 4, 2005,
http://www.bwsr.state.mn.us/watermgmt/metroareasurface.html.

BWSR Permit Application Forms, retrieved, April 4, 2005,
http://www.bwsr.state.mn.us/wetlands/wcaforms/index.html.

BWSR Wetland Conservation Act, retrieved, April 4, 2005,
http://www.bwsr.state.mn.us/wetlands/wca/index.html.

Minnesota Cities and Local Government

League of Minnesota Cities Home Page, retrieved April 4, 2005,
http://www.lmnc.org/.

Minnesota North Star Local Government, retrieved April 4, 2005,
http://www.state.mn.us/cgi-bin/portal/mn/jsp/content.do?subchannel=-536879913&id=-8494&agency=NorthStar.

Minnesota Counties

Minnesota Association of Counties Home Page, retrieved April 4, 2005,
http://www.mncounties.org/.

Minnesota Department of Agriculture (MDA)

Minnesota Department of Agriculture: Ask MDA, retrieved April 4, 2005,
webinfo@mda.state.mn.us.

Minnesota Department of Health (MDH)

MDH Addresses, Phone Number and Directions, last updated March 16, 2005,
http://www.health.state.mn.us/about/direct.html.

MDH Drinking Water Protection About Our Programs, last updated March 9, 2005,
http://www.health.state.mn.us/divs/eh/water/org/programdesc.html.

MDH Drinking Water Protection, last updated March 29, 2005,
http://www.health.state.mn.us/divs/eh/water/index.html.

MDH Drinking Water Protection Contact List, last updated March 9, 2005,
http://www.health.state.mn.us/divs/eh/water/org/contactlst.html.

MDH Health Risk Limits for Groundwater, last updated March 15, 2005,
http://www.health.state.mn.us/divs/eh/groundwater/hrlrule.html.

MDH Source Water Assessments of Public Water Systems, last updated March 9, 2005,
http://www.health.state.mn.us/divs/eh/water/swp/swa/index.htm.

MDH Source Water Protection General Information, last updated March 9, 2005,
http://www.health.state.mn.us/divs/eh/water/swp/index.htm.

MDH Well Head Protection, last updated March 9, 2005,
http://www.health.state.mn.us/divs/eh/water/swp/whp/index.htm.

Minnesota Department of Natural Resources (DNR)

DNR Coastal Nonpoint Pollution Control Program, 2005,
http://www.dnr.state.mn.us/waters/lakesuperior/cnp/index.html.

DNR Division of Water, 2005,
http://www.dnr.state.mn.us/waters/orgchart.html.

DNR Do I Need a Permit, 2005,
http://www.dnr.state.mn.us/permits/water/needpermit.html.

DNR Floodplain Management Program, 2005,
http://www.dnr.state.mn.us/waters/watermgmt_section/floodplain/index.html

DNR Floodplain Management Program history, 2005,
http://www.dnr.state.mn.us/waters/watermgmt_section/floodplain/history.html.

DNR Forms related to Division of Waters programs, 2005,
http://www.dnr.state.mn.us/waters/forms.html.

DNR Guide for Buying and Managing Shoreland, 2005
http://www.dnr.state.mn.us/shorelandmgmt/guide/standards_tables.html.

DNR Lake Management Program, 2005,
http://www.dnr.state.mn.us/waters/watermgmt_section/lake/index.html.

DNR Lake Superior Coastal Program, 2005,
http://www.dnr.state.mn.us/waters/lakesuperior/index.html

DNR Lake Superior Coastal Program Final Environmental Impact Statement (FEIS), 2005,
http://www.dnr.state.mn.us/waters/lakesuperior/feis/part5_ch2.html

DNR Mississippi National River & Recreation Area, 2005,
http://www.dnr.state.mn.us/waters/watermgmt_section/mnrra/index.html.

DNR Mississippi River Critical Area Program, 2005,
http://www.dnr.state.mn.us/waters/watermgmt_section/critical_area/index.html

DNR Mississippi River Management – Navigation, 2005,
http://www.dnr.state.mn.us/waters/watermgmt_section/river/miss_mgmt.html.

DNR Public Waters Works Permit Programs, 2005,
http://www.dnr.state.mn.us/waters/watermgmt_section/pwpermits/index.html.

DNR River Resource Management Program, 2005,
http://www.dnr.state.mn.us/waters/watermgmt_section/river/index.html.

DNR Water Use Permits, 2005
http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/permits.html

DNR Wild and Scenic Rivers Program, 2005,

http://www.dnr.state.mn.us/waters/watermgmt_section/wild_scenic/index.html.

Minnesota Department of Transportation (Mn/DOT)

Minnesota Department of Transportation, Drainage Manual, 2000.
http://www.dot.state.mn.us/bridge/Hydraulics-Internet-Web site/Hydraulics-Internet-DrainageManual.html

MnDOT: Contact Mn/DOT, 2005,
http://www.dot.state.mn.us/information/talk.html.

Minnesota Pollution Control Agency (MPCA)

MPCA Clean Water Partnership Section 319 Combined Application 2004 Electronic and Paper Submittals, retrieved April 4, 2005,
http://www.pca.state.mn.us/publications/wq-cwp7-02.doc.

MPCA Coastal Nonpoint Pollution Program, last updated August 1, 2001,
http://www.pca.state.mn.us/water/basins/superior/coastalnp.html.

MPCA Feedlots program, last updated February 15, 2005,
http://www.pca.state.mn.us/hot/feedlots.html#forms.

MPCA Home Page, last updated March 29, 2005,
http://www.pca.state.mn.us/.

MPCA Minnesota 2001 - 2005 Nonpoint Source Management Program Plan (NSMPP), last updated August 1, 2001,
http://www.pca.state.mn.us/water/nonpoint/mplan.html.

MPCA Minnesota's Impaired Waters and Total Maximum Daily Loads (TMDL), last updated March 22, 2005,
http://www.pca.state.mn.us/water/tmdl/index.html.

MPCA More about section 319 information (MPCA), last updated March 10, 2003
http://www.pca.state.mn.us/water/319.html.

MPCA More about the Clean Water Partnership Program CWP, last updated June 24, 2004,
http://www.pca.state.mn.us/water/cwp.html.

MPCA Nonpoint Source Issues, last updated November 18, 2002,
http://www.pca.state.mn.us/water/nonpoint/index.html.

MPCA Stormwater Program, last updated March 8, 2005,
http://www.pca.state.mn.us/water/stormwater/index.html

MPCA Stormwater Program for Construction Activity, last updated March 24, 2005,
http://www.pca.state.mn.us/water/stormwater/stormwater-c.html.

MPCA Stormwater Program for Industrial Facilities NPDES, last updated March 24, 2005
http://www.pca.state.mn.us/water/stormwater/stormwater-i.html.

MPCA Stormwater Program for MS4s, last updated March 29, 2005,
http://www.pca.state.mn.us/water/stormwater/stormwater-ms4.html.

MPCA Water Quality Standards, last updated October 29, 2003,
http://www.pca.state.mn.us/water/standards/index.html.

MPCA Water Quality Standards: Beneficial use designations, last updated October 29, 2003,
http://www.pca.state.mn.us/water/standards/index.html#beneficial.

MPCA Water Quality Standards: Non-degradation policy: last updated October 29, 2003,
http://www.pca.state.mn.us/water/standards/index.html#nondegradation.

MPCA Water Quality Standards: Numerical and narrative standards and criteria: last updated October 29, 2003,
http://www.pca.state.mn.us/water/standards/index.html#nnstandards.

Minnesota Soil and Water Conservation Districts (SWCD)

Minnesota Association of Soil and Water Conservation Districts (MASWCD) Home Page, last updated March 30, 2005,
http://www.maswcd.org/index.htm.

SWCD directory, retrieved April 4, 2005,
http://www.bwsr.state.mn.us/directories/SWCDs.pdf.

Minnesota Watershed Districts and Water Management Organizations

Minnesota Association of Watershed Districts, retrieved April 4, 2005,
http://mnwatershed.govoffice.com/index.asp?Type=B_BASIC&SEC={1F1ACEE4-3C71-468E-8830-469FA9E1C8CE

National Oceanic and Atmospheric Administration (NOAA)

NOAA, last updated April 4, 2005,
http://www.noaa.gov/

NOAA's Coastal Nonpoint Pollution Control Program web site, Revised May 04, 2004,
http://www.ocrm.nos.noaa.gov/czm/6217/.

National Park Service (NPS)

History of Critical Area, last updated September 1, 2004,
http://www.nps.gov/miss/programs/critical/cahist.htm

National Park Service Program at a glance, Partnership Wild and Scenic Rivers, last updated March 24, 2003,
http://www.nps.gov/nero/rivers/wildandscenic.htm.

National Wild and Scenic Rivers Act, last updated January 7, 2005,
http://www.nps.gov/rivers/wsract.html.

National Wild and Scenic Rivers Act Enabling Legislation, last updated January 7, 2005,
http://www.nps.gov/rivers/wsract.html.

National Wild and Scenic Rivers System home page, last updated January 7, 2005,
http://www.nps.gov/rivers/.

U.S. Army Corps of Engineers (USACE)

Sacramento District Regulatory Branch, retrieved April 6, 2005,
http://www.spk.usace.army.mil/organizations/cespk-co/regulatory/index.html

Overview of the Corps' Permit Programs, retrieved April 6, 2005,
http://www.mvp.usace.army.mil/regulatory/default.asp?pageid=799.

U.S. Army Corps of Engineers' Permit website:
http://www.nwp.usace.army.mil/op/g/Regs/Permit_req.htm

U.S. Army Corp of Engineers' Recognizing Wetlands an informational pamphlet:
http://www.sac.usace.army.mil/permits/rw-bro.html

U. S. Army Corp of Engineers, St. Paul District, retrieved April 4, 2005,
http://www.mvp.usace.army.mil/.

U.S. Army Corp of Engineers' wetland information web site:
http://www.sac.usace.army.mil/permits/wet.html

U.S. Environmental Protection Agency (EPA)

EPA's Clean Water Act, last updated April 4th, 2005
http://www.epa.gov/region5/water/cwa.htm.

EPA's Clean Water Act module, last updated March 13th, 2003,
http://www.epa.gov/watertrain/cwa/index.htm.

EPA's Clean Water Act module Section 319 page, last updated March 12th, 2003,
http://www.epa.gov/watertrain/cwa/cwa52.htm.

EPA's Clean Water Act module Section 401 page, last updated October 28th, 2002
http://www.epa.gov/watertrain/cwa/cwa58.htm.

EPA's Clean Water Act module Section 402 page, last updated on Wednesday, March 12th, 2003,
http://www.epa.gov/watertrain/cwa/cwa37.htm.

EPA's Clean Water Act module Section 404 page, last updated on Monday, October 28th, 2002,
http://www.epa.gov/watertrain/cwa/cwa55.htm.

EPA's Coastal Zone Act Reauthorization Amendments Section 6217, last updated April 4th, 2005,
http://www.epa.gov/owow/nps/czmact.html.

EPA's NPDES, last updated December 08, 2003,
http://cfpub.epa.gov/npdes/index.cfm.

EPA's Region 5, retrieved April 4, 2005,
http://www.epa.gov/Region5/.

EPA's Safe Drinking Water Act 30th Anniversary Understanding the Safe Drinking Water Act, last updated April 4th, 2005,
http://www.epa.gov/safewater/sdwa/30th/factsheets/understand.html

EPA's Source Water Assessment Page, last updated, April 6, 2005,
http://www.epa.gov/ogwdw/protect/assessment.html

EPA's TMDL definition, last updated April 4th, 2005,
http://www.epa.gov/owow/tmdl/intro.html#definition.

Source Water Assessment Program, last updated February 14, 2005,
http://www.epa.gov/safewater/protect/swap.html

U.S. Fish and Wildlife Service (FWS)

U.S. Fish and Wildlife Service, Great Lakes-Big Rivers Region Regional Office, retrieved April 4, 2005,
http://www.fws.gov/midwest/regionaloffice/.

US Forest Service

U.S. Forest Service Eastern Region, last updated March 21, 2005,
http://www.fs.fed.us/r9/.

US Forest Service Mississippi National River & Recreation Area, revised 3/31/05,
http://www.nps.gov/miss/index.html.

Other Web References

American Mosquito Control Assoc.
http://www.mosquito.org/

BMPs and Mosquitoes National Information by Marco Metzger
http://www.forester.net/sw_0203_dark.html - 71k - 28 Oct 2003

California IPM for Mosquito Series, UC ANR Communication Services
http://www.ipm.ucdavis.edu/

CDC statement on stormwater and mosquitoes
http://www.cdc.gov/nceh/ehs/Docs/Stormwater-Factsheet.pdf

Center for Watershed Protection's Stormwater BMP Design Supplement for Cold Climates (Caraco and Claytor, 1997) and revision session in Maine (2003)
http://www.cwp.org/cold-climates.htm .

Eastern Snow Conference
http://www.easternsnow.org/

"Managing Mosquitoes in Surface-flow Constructed Treatment Wetlands" by William Walton
http://anrcatalog.ucdavis.edu/pdf/8117.pdf

"Management of Mosquitoes in Stormwater Treatment Devices" by Marco Metzger
http://anrcatalog.ucdavis.edu/pdf/8125.pdf

Metropolitan Mosquito Control District
http://www.mmcd.org/wnvfaq.html

Minnesota Shoreland Management Resource Guide, last updated July 3, 2001,
http://www.shorelandmanagement.org/.

Minnesota Statutes 2004 Table of Chapters, retrieved April 4, 2005,
http://www.revisor.leg.state.mn.us/stats/103E/.

Rutgers University Mosquito Links
http://www-rci.rutgers.edu/~insects/links.htm

Stormwater Management in Cold Climates, November 3-5, 2003, Portland, Maine
http://www.cascobay.usm.maine.edu/proceed.html

University of Minnesota Extension, retrieved April 4, 2005,
http://www.extension.umn.edu/index.html.

The U.S. Army Cold Regions Research and Engineering Laboratory (CRREL)
CRREL(http://www.crrel.usace.army.mil/

U.S. Department of Health and Human Services, Centers for Disease Control and Prevention
http://www.cdc.gov/ncidod/dvbid/westnile/index.htm

USEPA Mosquito Factsheet
http://www.epa.gov/pesticides/factsheets/mosquito.htm

USEPA Publication with References on How Specific Changes in Wetlands Changed Mosquito Populations
http://www.epa.gov/owow/wetlands/pdf/WestNile_pr.pdf

Appendix J

Issue Papers

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APPENDICES

Appendix J

Issue Papers

This series of Issue Papers were prepared by the consultant team for Manual Sub-Committee issue identification and discussion purposes only.

Neither the Manual Sub-Committee nor the Minnesota Stormwater Steering Committee approved the material within these Issue Papers. The papers are provided here as background material to help describe the process that the Manual Sub-Committee followed in developing Manual content. Any reference to recommendations reflects the consultant team recommendations, as guided by the Manual Sub-Committee, but does not imply either Sub-Committee or Steering Committee approval.

Issue Papers topics are as follows:

A- BMP List and Selection Matrix

B- Precipitation Frequency Analysis and Use

C- Stormwater Regulatory Framework

D- Unified Stormwater Sizing Criteria for Minnesota

E- Watershed Based Stormwater Criteria

F- Stormwater Credits

G- Cold Climate Considerations for Surface Water Manangement

H- Potential Stormwater Hotspots, Pollution Prevention, Groundwater Concerns, and Related Issues

I- Engineering and Design Criteria

J- Stormwater Maintenance and Cost Considerations

The issue papers may be accessed through the above links to the MPCA Manual Web site:

http://www.pca.state.mn.us/water/stormwater/stormwater-manual.html.

Stormwater Research and Education

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Appendix K

Stormwater Research and Education

Contents

I. Introduction

During the course of *Minnesota Stormwater Manual* preparation, it became obvious that there were many areas of stormwater management in need of better data or information. In addition, many comments were received in various venues on the need for better research. The following list is *not* a comprehensive list of everything needed, but rather an attempt to capture thoughts collected during this round of stormwater discussions. Many additional needs are no doubt obvious to others. We encourage readers to send their thoughts on research needs to the Minnesota Pollution Control Agency along with their comments on the Manual.

II. Research Needs

- **Performance of Emerging and Non-Traditional Best Management Practice (BMPs)** – Data on the water quantity and quality performance of new BMPs or those not commonly used is desperately needed for the Minnesota climate. Such practices as bioretention, pervious pavement, green roofs, infiltration, and proprietary sediment removal devices are included in this need. Of particular need are the long-term performance data that validate some of the short-term data that do exist.

- **Cold Climate Adaptations** – Many of the suggested adaptations for cold climate BMP installation have not been adequately tested with installed system research. Building modified BMPs and collection of performance behavior is essential is we ever hope to truly address year-round water resource management.

- **Cold Climate Simulation Tools** – MPCA is in the process of developing a new predictive tool for runoff and sediment from construction sites with funds provided by Mn/DOT, LRRB, and MPCA. It is expanding the model to iinclude watershed scale (with more support by Mn/DOT and LRRB). It already provides an upgrade to the TP-40 approach. More work is needed for cold climate routines.

- **Pathogen and Toxin Treatment** – Few data exist on the effectiveness of BMPs on the removal of pathogens and many toxins of concern. Data collection on in-place effectiveness of various BMPs relative to these pollutants is needed.

- **Outdoor Labs Dedicated to Stormwater Study** – MPCA staff has been promoting an outdoor laboratory at UMore Park. Long-term progress in understanding the performance of different stormwater systems require that inflow (rainfall and runoff) be controlled in carefully designed experiments. This facility could provide that opportunity if properly developed

- **LID/BSD Construction and Maintenance** – Low Impact Development (LID) and Better Site Design (NSD) techniques outlines in this Manual are common sense approaches to minimizing the impact of development, yet little research based guidance is available on the design features and follow-up maintenance needed to keep them functional. Maintenance techniques and frequency are especially needed.

- **The Impact of Infiltration Practices** – One of the themes of this Manual and of the changing field of stormwater management is soaking precipitation into the ground before it gets a chance to concentrate and mobilize surface pollutants. It has gone further and promoted infiltration as one of the major BMP processes that can effectively address stormwater. Unfortunately, many of the conclusions drawn on the water quality benefits of infiltration are anecdotal or based on research done in climates much different than Minnesota's. Comprehensive data collection on what happens in the ground water as a result of increased urban area infiltration is essential, especially in those many parts of the state where ground water is used as a sole drinking water source. Long-term monitoring of infiltration rate performance for both quality and quantity is atop priority need.

- **The Impact of Salt** – The application of NaCl to our roads and parking areas has had a negative impact on water quality. The public's need for safety, which absolutely must come first, directly conflicts with the judicious use of salt to keep road and parking surfaces ice-free. Recent data have shown increases in both shallow ground water and lake chloride (Cl) levels – a condition that has been detected in other cold climate portions of the world. Minnesota (Mn/DOT) has been a national leader on anti- and de-icing research, but we need continued research on the nature of the Cl contamination, as well as salt management and alternative methods to keep surfaces ice-free.

- **Precipitation Patterns** – TP 40 has been criticized for being out of date because of the changes that have occurred over the past 20 years in Minnesota's climate. Some effort has been started to update precipitation frequency tables for the state, and many reviewers of the Manual support this effort.

III. Research Centers

Notable research into nonpoint source/stormwater behavior and BMP performance, particularly for cold climates, is under way at the following locations:

- University of Minnesota/MPCA – Stormwater Management Practices Assessment Team. Contact John Gulliver (gulli003@umn.edu), Jim Anderson (ander045@umn.edu) and Bruce Wilson (bruce.wilson@pca.state/mn.us)
- Minnesota Cooperative Cold Climate/LID Study. Participants include Dakota SWCD, Washington Conservation District, Ramsey-Washington Metro Watershed District, Emmons and Olivier Resources, University of Minnesota. Contact Jim Davidson (jim.davidson@co.dakota.mn.us)
- University of New Hampshire, Stormwater Center. Contact Rob Roseen (rroseen@cisunix.unh.edu)
- Norwegian University of Science and Technology (NTNU), Trondheim, Norway. Contact Sveinn Thorolfsson (sveinn.thorolfsson@bygg.ntnu.no)
- Wisconsin Department of Natural Resources, Madison, WI. Contact Roger Bannerman (banner@dnr.state.wi.us)
- Luleå University of Technology, Luleå, Sweden. Contact Maria Viklander (maria@sb.luth.se)
- Lund University, Lund, Sweden. Contact Annette Semadeni-Davies (annette.davies@tvrl.lth.se)

IV. Educational Resources on Stormwater Management

In addition to the Research Centers listed above, users are urged to contact the following education centers for more information on stormwater management:

- University of Minnesota Erosion and Sediment Control Training. Contact John Chapman (chapm155@umn.edu) Web site: http://erosion.coafes.umn.edu/
- Northland NEMO. Contact Jay Michels (jmichels@skypoint.com) Web site: http://www.mnerosion.org/nemo.html
- Builders Association of the Twin Cities. Contact Remi Stone (remi@batc.org) Web site: http://www.batconline.org/batc/index.po
- League of Minnesota Cities. Contact Craig Johnson (cjohnson@lmnc.org) Web site: http://www.lmnc.org/
- University of Minnesota Extension-. Contact Ron Struss (rstruss@umn.edu) Web site: http://www.extension.umn.edu/
- Watershed Partners. Contact Ron Struss (rstruss@umn.edu) Web site: http://cgee.hamline.edu/watershed/
- Hamline University Center for Global Environmental Education. Contact Tracy Fredin (tfredin@hamline.edu) Web site: http://cgee.hamline.edu/

- Minnesota Pollution Control Agency and Minnesota Office of Environmental Assistance. Contact Phillip Muessig (Philipp.Muessig@state.mn.us) Web site: http://www.moea.state.mn.us/

Appendix L

Simple Method for Estimating Phosphorus Export

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Appendix L

Simple Method for Estimating Phosphorus Export

Contents

I. The Simple Method

The Simple Method is a technique used for estimating storm pollutant export delivered from urban development sites. The method was developed to provide an easy yet reasonably accurate means of predicting the change in pollutant loadings in response to development. This information is needed by planners and engineers to make rational non-point source pollution decisions at the site level.

The Simple Method Calculation is intended for use on development sites less than a square mile in area. As with any simple model, the method to some degree sacrifices precision for the sake of simplicity and generality. Even so, the Simple Method is still reliable enough to use as a basis for making non-point pollution management decisions at the site level.

Phosphorus pollutant loading (L, in pounds per year) from a development site can be determined by solving the equation displayed in Table L.1.

Depth of Rainfall (P)

The value of P represents the number of inches of precipitation that falls during the course of a normal year of rainfall. Long-term weather records around the state of Minnesota suggest that the average annual rainfall depth is about 26 inches. This can be used to estimate P or a user can substitute the average annual rainfall depth from the closest National Weather Service long-term weather station or other suitable locations for which a reliable record can be demonstrated (> 10 years).

Correction Factor (P_j)

The P_j factor is used to account for the fraction of the annual rainfall that does not produce any measurable runoff. Many of the storms that occur during the year are so minor that all of the rainfall is stored in surface depressions and eventually evaporates. As a consequence, no runoff is produced. An analysis of regional rainfall/runoff patterns indicates that only 90% of the annual rainfall volume produces any runoff at all. Therefore, P_j should be set at 0.9.

Runoff Coefficient (R_v)

The R_v is a measure of the site response to rainfall events, and in theory is calculated as:

R_v = r/p, where r and p are the volume of storm runoff and storm rainfall, respectively, expressed as inches.

The R_v for the site depends on the nature of the soils, topography, and cover. However, the primary influence on the R_v in urban areas is the amount of imperviousness of the site. Impervious area is defined as those surfaces in the landscape that cannot infiltrate rainfall consisting of building rooftops, pavement, sidewalks, driveways, etc. In the equation:

$R_v = 0.05 + 0.009(I)$

"I" represents the percentage of impervious cover expressed as a whole number. A site that is 75% impervious would use I = 75 for the purposes of calculating R_v.

Site Area (A)

The total area of the site (in acres) can be directly obtained from site plans. If the total area of the site is greater than one square mile (640 acres), the Simple Method may not be appropriate and applicants should consider utilizing other approaches, such as modeling or monitoring.

Pollutant Concentration (C)

Statistical analysis of several urban runoff monitoring datasets has shown that the average storm concentrations for total phosphorus do not significantly differ between new and existing development sites. Therefore, a pollutant concentration, C, of 0.30 mg/l should be used in this equation as a default. However, if good local data are available or an adjustment is needed, this factor can be customized for local condition.

Chapter 8 contains a range of C values for those interested in conducting a more detailed analysis of phosphorus export.

The Simple Method equation listed in Table L.1 can be simplified to the equation shown in Table L.2. Applicants with verified data indicating alternative values may choose to use the original Simple Method equation as represented in Table

Table L.1 Phosphorus Pollutant Export Calculation
$$L = [(P)(P_j)(R_v)/12]\ (C)\ (A)\ (2.72)^*$$ Where: L = Load of a pollutant in pounds per year P = Rainfall depth per year (inches) P_j = Fraction of rainfall events that produce runoff R_v = Runoff coefficient, which expresses the fraction of rainfall which is converted into runoff. $R_v = 0.05 + 0.009(I)$ C = Flow-weighted mean concentration of the pollutant in urban runoff (mg/l) A = Area of the development site (acres) *12 and 2.72 are unit conversion factors

Table L.2 Simplified Pollutant Loading Calculation
$$L = (P)\ (R_v)\ (C)\ (A)\ (0.20)^*$$ Where: L = Load of a pollutant in pounds per year P = Rainfall depth per year (inches) R_v = Runoff coefficient, which expresses the fraction of rainfall which is converted into runoff = 0.05 + 0.009(I) I = Site imperviousness (i.e., I = 75 if site is 75% impervious) C = Flow-weighted mean concentration of the pollutant (total phosphorus) in urban runoff (mg/l) = 0.30 mg/l** A = Area of the development site (acres) *0.20 is a regional constant and unit conversion factor ** The C factor can be customized if good local water quality data exist or if an adjustment in the 0.30 mg/l term is needed.

1; otherwise, Table L.2 represents the revised Simple Method equation and associated values.

II. Calculating Pre-Development and Post-Development Phosphorus Load

The methodology for comparing annual pre-development pollutant loads to post-development pollutant loads is a six-step process (Table L.3).

Step 1: Calculate Site Imperviousness

In this step, the applicant calculates the impervious cover of the pre-development (existing) and post-development (proposed) site conditions.

Impervious cover is defined as those surfaces in the landscape that impede the infiltration of rainfall and result in an increased volume of surface runoff. As a simple rule, human-made surfaces that are not vegetated will be considered impervious. Impervious surfaces include roofs, buildings, paved streets and parking areas and any concrete, asphalt, compacted dirt or compacted gravel surface.

Table L.3 Process For Calculating Pre- and Post-Development Pollutant Loads	
Step No.	**Task**
1	Calculate Site Imperviousness
2	Calculate the Pre-Development Phosphorus Load
3	Calculate Post-Development Pollutant Load
4	Calculate the Pollutant Removal Requirement
5	Identify Feasible BMPs
6	Select Off-Site Mitigation Option

Step 2: Calculate Pre-Development Phosphorus Load

In this step, the applicant calculates stormwater phosphorus loadings from the site prior to development. Depending on the development classification, the applicant will use one of two equations (Table L.4). The equation to determine phosphorus loading in a redevelopment situation is based on the Simple Method. The equation to determine phosphorus loading in a new development situation utilizes a benchmark load for undeveloped areas, which is based on average phosphorus loadings for a typical mix of undeveloped land uses.

Step 3: Calculate Post-Development Pollutant Load

In this step, the applicant calculates stormwater phosphorus loadings from the post-development, or proposed, site. Again, an abbreviated version of the Simple Method is used for the calculations, and the equation is the same for both new development and redevelopment sites (Table L.5).

Table L.4 Method For Calculating Pre-development Phosphorus Loading

New Development Phosphorus Loading, $L_{pre} = 0.5\ (A)$

Where:

- L_{pre} = Average annual load of total phosphorus exported from the site prior to development (lbs/year)
- 0.5 = Annual total phosphorus load from undeveloped lands (lbs/acre/year)
- A = Area of the site (acres)

Redevelopment Phosphorus Loading, $L_{pre} = (P)\ (R_v)\ (C)\ (A)\ (0.20)$

Where:

- L_{pre} = Average annual load of total phosphorus exported from the site prior to development (lbs/year)
- P = Rainfall depth over the desired time interval (inches)
- R_v = Runoff coefficient, which expresses the fraction of rainfall which is converted into runoff = $0.05 + 0.009(I_{pre})$
- I_{pre} = Pre-development (existing) site imperviousness (i.e., I = 75 if site is 75% impervious)
- C = Flow-weighted mean concentration of the pollutant (total phosphorus) in urban runoff (mg/l) = 0.30 mg/l
- A = Area of the development site (acres)

*0.20 is a regional constant and unit conversion factor

Step 4: Calculate the Pollutant Removal Requirement

The phosphorus load generated from the post-development site must be reduced so that it is 90% or less of the load generated prior to development, In this example, a 10% reduction in phosphorus loading from pre-development conditions is used. This should not be construed as a recommended reduction for the State of Minnesota. Applicants should check with local stormwater authorities to determine if specific pre- to post-development phosphorus reduction requirements exist. The amount of phosphorus that must be removed through the use of stormwater BMPs is called the Pollutant Removal Requirement (RR). The equation in Table L.6 expresses this term numerically.

Step 5: Identify Feasible BMPs

Step 5 looks at the ability of the chosen BMP to meet the site's pollutant removal requirements. The pollutant load removed by each BMP (Table L.7) is calculated using the average BMP removal rate (Table L.8), the computed post-development load, and the drainage area served.

Table L.5 Method For Calculating Post-Development Phosphorus Loading

$$L_{post} = (P)\ (R_v)\ (C)\ (A)\ (0.20)$$

Where:

L_{post}	=	Average annual load of total phosphorus exported from the post-development site (lbs/year)
P	=	Rainfall depth over the desired time interval (inches)
R_v	=	Runoff coefficient, which expresses the fraction of rainfall which is converted into runoff = 0.05 + 0.009(I_{post})
I_{post}	=	Post-development (proposed) site imperviousness (i.e., I = 75 if site is 75% impervious)
C	=	Flow-weighted mean concentration of the pollutant (total phosphorus) in urban runoff (mg/l) = 0.30 mg/l
A	=	Area of the development site (acres)

*0.20 is a regional constant and unit conversion factor

Table L.6 Computing Pollutant Removal Requirements

$$RR = L_{post} - 0.9(L_{pre})$$

Where:

RR*	=	Pollutant removal requirement (lbs/year)
L_{post}	=	Average annual load of total phosphorus exported from the post-development site (lbs/year)
L_{pre}	=	Average annual load of total phosphorus exported from the site prior to development (lbs/year)

*0.90 is suggested post-development phosphorus load reduction. Local requirements may vary.

Table L.7 Estimate of Pollutant Load Removed by Each BMP

$$LR = (L_{post})\ (BMP_{RE})\ (\%\ DA\ Served)$$

Where:

LR	=	Annual total phosphorus load removed by the proposed BMP (lbs/year)
L_{post}	=	Average annual load of total phosphorus exported from the post-development site prior to development (lbs/year)
BMP_{RE}	=	BMP removal efficiency for total phosphorus, Table 8 (%)
% DA Served	=	Fraction of the drainage area served by the BMP (%)

Table L.8 General Summary of Comparative BMP Phosphorus Removal Performance [a]				
BMP Group[e]	BMP Design Variation	Average TP Removal Rate	Maximum TP Removal Rate[c]	Average Soluble P Removal Rate[d]
Bioretention	Underdrain	50%	65%	60%
	Infiltration	60	75	70
Filtration	Media Filters	50	60	0
	Vegetative Filters (dry)	65	75	70
Infiltration	Infiltration Trench	65	90	80
	Infiltration Basin	65	90	80
Stormwater Ponds[f]	Flow-Through (Wet) Pond	50	70	60
	Wet ED Pond[b]	55	70	70
	Micropool ED Pond	40	75	30
Constructed Stormwater Wetlands	Shallow Wetland	45	65	50
	Pond/Wetland	55	75	65
	ED Shallow Wetland	40	75	30

[a] Removal Rates Shown in this Table are a composite of four sources: Caraco (2001), MDE (2000), and Winer (2001). They apply only to the volume of water that passes through the BMP and does *not i*nclude water that bypasses the practice.
[b] Average removal efficiency expected under MPCA V_{wq} sizing Rules 1 and 3
[c] Upper limit on phosphorus removal with increased sizing and design features, based on national review
[d] Average rate of soluble phosphorus removal in literature
[e] See Issue Paper A (Appendix J)
[f] Does not include dry ponds as a water quality BMP

⚠ IMPORTANT NOTE: Removal rates shown here are composite averages intended solely for use in comparing performance between BMP designs and for use in calculating load reduction in site-based TP models. They have been adapted, rounded and slightly discounted from statistical values published in BMP performance databases.

If the load removed is equal to or greater than the pollutant removal requirement computed in Step 4, then the on-site BMP complies. If not, the designer must evaluate alternative BMP designs to achieve higher removal efficiencies, add additional BMPs, design the project so that more of the site is treated by the proposed BMPs, or design the BMP to treat runoff from an off-site area.

Step 6: Select Off-Site Mitigation Option

If the pollutant removal requirement has been met through the application of on-site stormwater BMPs, the process is complete.

In the event that on-site BMPs cannot fully meet the pollutant removal requirement and on-site design cannot be changed, an offset fee should be charge (e.g. $X per pound of phosphorus).

III. References

Caraco, D. 2001. "Managing Phosphorus Inputs Into Lakes III: Evaluating the Impact of Watershed Treatment." *Watershed Protection Techniques*. 3 (4): 791-796. Center for Watershed Protection. Ellicott City, MD.

Maryland Department of the Environment (MDE). 2000. 2000 Maryland Stormwater Design Manual. MDE. Baltimore, MD.

Winer, R. 2000. National Pollutant Removal Performance Database for Stormwater Treatment Practices. 2nd Edition. Center for Watershed Protection. Ellicott City, MD.

Channel Protection Methods

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Appendix M

Channel Protection Methods

Contents

COMPUTING V_{cp}

[Note: The material in Appendix M complements the section on channel protection in Chapter 10]

Channel Protection Method for Ponds

Step 1

Compute the runoff volume produced from the post-development 1-year, 24-hour design storm event, using TR-55, or equivalent.

Step 2

Use the "kerplunk" method which assumes the pond volume above the permanent pool instantaneously fills up. Determine storage volume and V_{cp} maximum invert elevation using the short-cut method (described below).

Step 3

Set the V_{cp} orifice invert at the permanent pool elevation and size initial diameter to drain the entire V_{cp} volume in 24 hours

Step 4

Compute the average peak discharge rate for the V_{cp} event (i.e., $V_{cp}/24$)

Step 5

Using TR-20, or equivalent, route the runoff through the pond and check to make sure that peak discharge for V_{cp} does not exceed twice the average discharge.

Step 6

Evaluate whether V_{cp} meets water quality (live storage) requirements

6a. Compute the runoff volume for live storage using appropriate MPCA pond sizing equation.

6b. Assume kerplunk conditions, where live storage volume instantaneously fills above the permanent pool.

6c. Using TR-20, route the live storage volume through the channel protection orifice to ensure it satisfies the 5.66 cfs/acre release.

6d. If the answer is YES (as it will be in most cases), the V_{cp} will be considered to meet the live storage requirement for water quality (V_{cp} can be substituted for live storage volume).

6e. If the answer is NO (which may rarely happen for very low density development sites in sensitive waters), then designers choke down the V_{cp} orifice to meet minimum V_{wq} release requirements, and repeat steps 3 to 6. If new answer is YES, then V_{cp} will again be considered to meet live-storage water quality requirement.

6f. If answer is NO, then the designer must account for V_{wq} and V_{cp} separately, and designed using two separate orifices.

Step 7 (optional)

For areas with 1-year and 2-year peak controls use TR-20 or equivalent to route the 2-year storm through the V_{cp} orifice. Check 2-year peak rate of discharge. If discharge is equal to or less than pre-development discharge rates, then outlet sizing is complete. If not, then raise the elevation of the V_p10 to an elevation that fully contains the volume of the 2-year storm below the V_p10 orifice and re-route the flows as a check. (This is rarely needed since two-year peak discharge control is usually waived when V_{cp} is provided).

Channel Protection Method for Non-Pond BMPs

Note: No permanent pool is involved in design (although a micropool is recommended to keep orifice from clogging).

In most cases, an extended detention basin is incorporated into the treatment train after the non-pond BMP to provide storage for channel protection and flood control design storms. In some cases, temporary channel protection storage can be incorporated into the non-pond BMP if adequate pretreatment is provided, and if an outlet structure is sized to ensure that the infiltration or filtration basins are empty 48 hours after the storm (e.g., infiltration basin or bioretention in the pond floor).

Channel protection within the extended detention pond is designed following Steps 1 to 5, as outlined above.

Additional Notes

It is strongly recommended that two-year peak discharge control be waived when channel protection is provided.

The effect of channel protection on total required volume of stormwater storage is modest when the local reviewing authority already requires 50- or 100-year peak discharge control.

Shortcut Sizing for Channel Protection

This method presents the TR-55 "short-cut" sizing technique, used to size practices designed for extended detention, slightly modified to incorporate the flows necessary to provide channel protection.

Storage Volume Estimation

This section presents a modified version of the TR-55 (NRCS, 1986) shortcut sizing approach. The method was modified by Harrington (1987) for applications where the peak discharge is very small compared with the uncontrolled discharge. This often occurs in the 1-year, 24-hour detention sizing.

Using TR-55 guidance, the unit peak discharge (q_u) can be determined based on the Curve Number and Time of Concentration (Figure 1). Knowing q_u and T (extended detention time), q_o/q_i (peak outflow discharge/peak inflow discharge) can be estimated from Figure 2.

Then using q_o/q_i, Figure 3 can be used to estimate V_s/V_r. For a Type II or Type III rainfall distribution, V_s/V_r can also be calculated using the following equation:

$$V_s/V_r = 0.682 - 1.43\,(q_o/q_i) + 1.64\,(q_o/q_i)2 - 0.804\,(q_o/q_i)3$$

Where:

V_s = required storage volume (acre-feet)
V_r = runoff volume (acre-feet)
q_o = peak outflow discharge (cfs)
q_i = peak inflow discharge (cfs)

The required storage volume can then be calculated by:

$$V_s = \frac{(V_s/V_r)(Q_d)(A)}{12}$$

Where:

V_S and V_r are defined above
Q_d = the developed runoff for the design storm (inches)
A = total drainage area (acres)

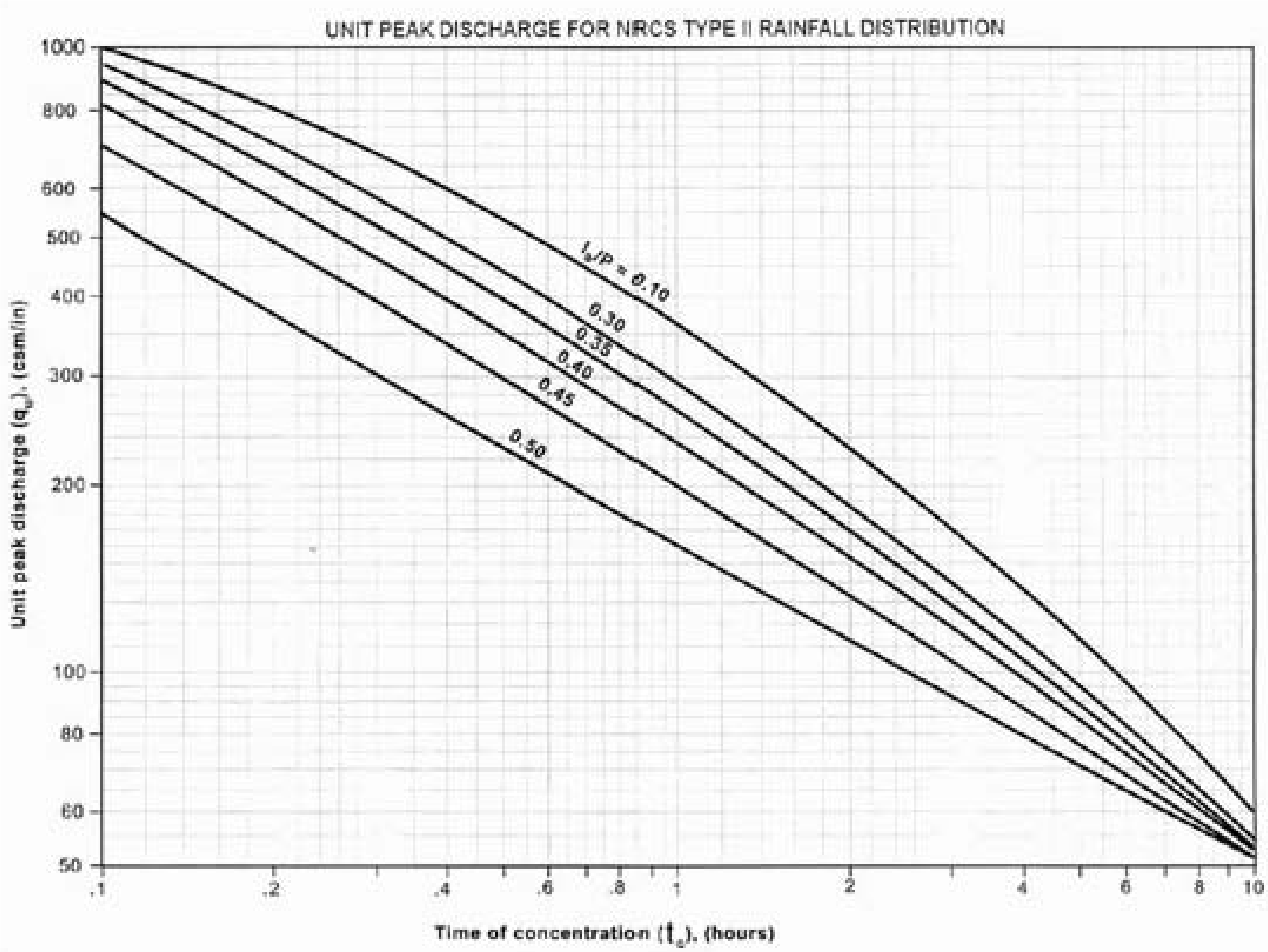

Figure 1 Unit Peak Discharge for Type II Rainfall Distribution (Source: NRCS, 1986)

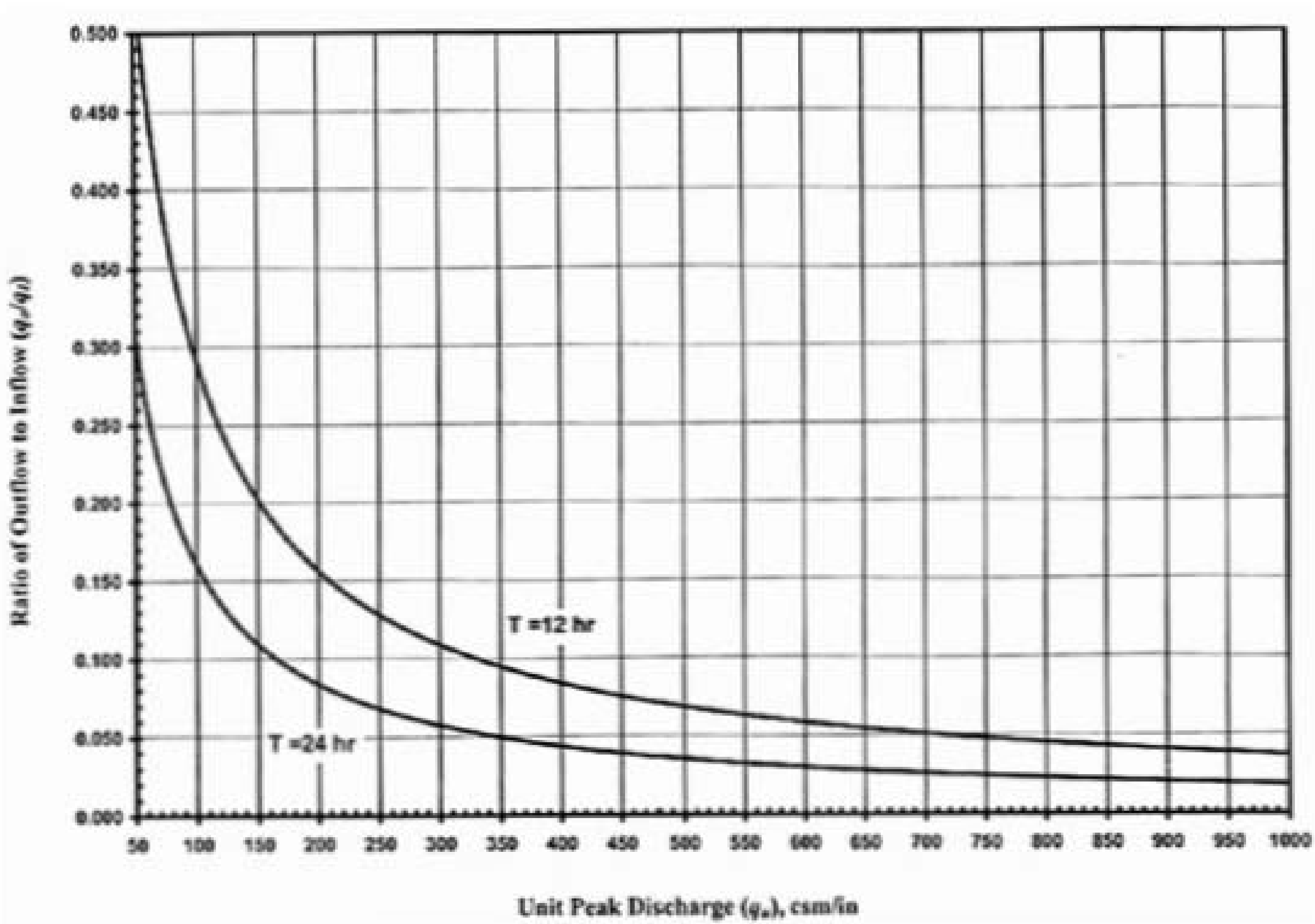

Figure 2 Detention Time vs. Discharge Ratios (Source: adopted from Harrington, 1987)

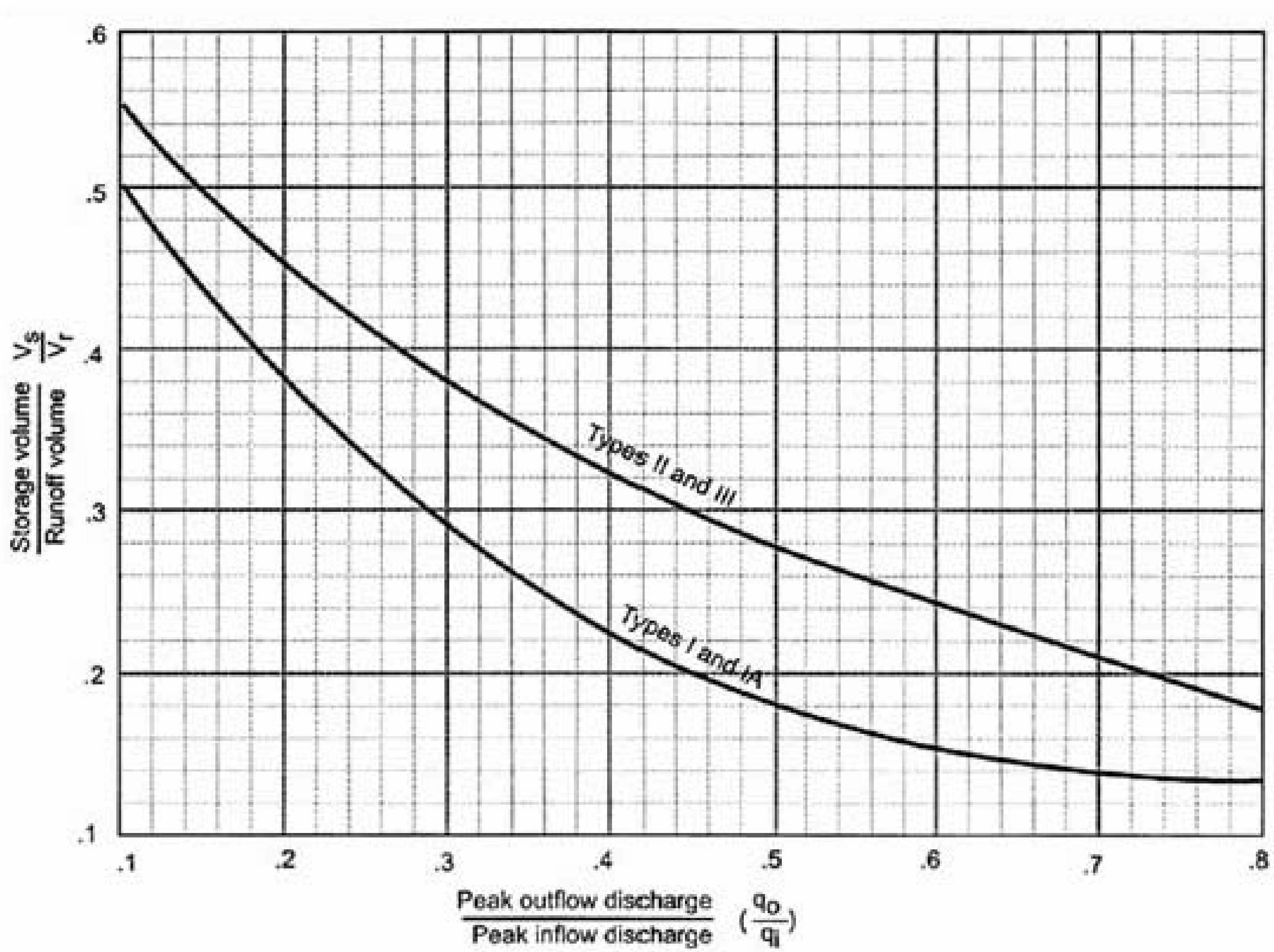

Figure 3 Approximate Detention Basin Routing For Rainfall Types I, IA, II, and III. (Source: NRCS, 1986)