Recommendations for Winter Traction Materials Management on Roadways Adjacent to Bodies of Water

by

James Mark Staples, Research Assistant
Laura Gamradt, Research Assistant
Otto Stein, Ph.D., Co-Principal Investigator
Department of Civil Engineering
College of Engineering
Montana State University

and

Xianming Shi, Ph.D., Principal Investigator
Western Transportation Institute
College of Engineering
Montana State University

A report prepared for the

Montana Department of Transportation
Research Section
2701 Prospect Ave.
Helena, MT 59620-1001

Final Report • Oct. 25, 2004

TECHNICAL REPORT DOCUMENT PAGE

<table>
<tr><td>1. Report No. FHWA/MT-04-008/8117-19</td><td>2. Government Accession No.</td><td>3. Recipient's Catalog No.</td></tr>
<tr><td rowspan="2">4. Title and Subtitle
Recommendations for Winter Traction Materials Management on Roadways Adjacent to Bodies of Water</td><td colspan="2">5. Report Date Oct. 2004</td></tr>
<tr><td colspan="2">6. Performing Organization Code</td></tr>
<tr><td>7. Author(s)
James Mark Staples, Laura Gamradt, Otto Stein, and Xianming Shi</td><td colspan="2">8. Performing Organization Report No.</td></tr>
<tr><td rowspan="2">9. Performing Organization Name and Address
Western Transportation Institute
P.O. Box 174250
Montana State University - Bozeman
Bozeman, MT 59717-4250
Phone: (406) 994-6114 Fax: (406) 994-1697</td><td colspan="2">10. Work Unit No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.
MDT Project # 8117-19</td></tr>
<tr><td rowspan="2">12. Sponsoring Agency Name and Address
Research Section
Montana Department of Transportation
2701 Prospect Avenue
PO Box 201001
Helena MT 59620-1001</td><td colspan="2">13. Type of Report and Period Covered
Final, June 2003-October 2004</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code 5401</td></tr>
<tr><td colspan="3">15. Supplementary Notes Research performed in cooperation with the Montana Department of Transportation and the US Department of Transportation, Federal Highway Administration. The report can be found at: http://www.mdt.state.mt.us/research/projects/env/traction.shtml</td></tr>
<tr><td colspan="3">16. Abstract

Wherever possible, a combination of both structural and non-structural BMPs, or best management practices, should be employed to minimize the environmental impacts of winter traction materials. Structural BMPs treat or mitigate highway runoff after it goes off the roadways, and non-structural BMPs reduce the amount of traction materials applied on roadways while maintaining winter mobility and public safety. Strategies can be implemented in the domain of technology, management, or both. Strategies may vary, depending on the specific climate, site, and traffic conditions. The crux is selecting an appropriate suite of BMPs that can function most effectively for a given set of conditions.

This report focuses on the cold region and rural transportation perspective, and discusses the structural BMPs potentially applicable in Montana in greater detail, including the applicability, site criteria, engineering characteristics, safety concerns, maintenance issues, costs, effectiveness in the presence of snow, and sediment removal efficiency. Despite the challenges of winter conditions, structural BMPs such as ponds, wetlands, and vegetated swales and filter strips, can still remove high levels of sediment from runoff if designed, sited, installed, and maintained properly.

This report also summarizes the primary non-structural BMPs used to reduce the use and thus minimize the environmental impacts of winter traction materials, including: incorporating environmental staff into construction and maintenance, proper training of maintenance professionals, erosion control, snow fences, snow storage, street sweeping, improved anti-icing and de-icing practices, improved sanding practices, appropriate application rate, and snowplow technologies. Among these, anti-icing strategies, road weather information systems, the Maintenance Decision Support System, and advanced snowplow technologies are highly recommended for use in Montana.</td></tr>
<tr><td>17. Key Words
Winter maintenance, Best management practices, Highway runoff, Cold region, Sanding, De-icing, Anti-icing, Water quality</td><td colspan="2">18. Distribution Statement
Unrestricted. This document is available through the National Technical Information Service, Springfield, VA 21161.</td></tr>
<tr><td>19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified</td><td>21. No. of Pages
103</td><td>22. Price</td></tr>
</table>

DISCLAIMER

ACKNOWLEGEMENTS

The Western Transportation Institute (WTI) would like to extend its sincere appreciation to Craig Abernathy, manager of this project at the Montana Department of Transportation, for his guidance and assistance throughout the project. WTI would not have been able to develop this report without the participation of the organizations and individuals listed below.

- Montana Department of Transportation (MDT)
- Montana Department of Environmental Quality (DEQ)
- Montana Fish, Wildlife and Parks (FWP)
- Susan C. Sillick, MDT
- Eric Stimson, MDT
- Dan Williams, MDT
- Robert Ray, DEQ
- Don Skaar, FWP
- Kelly Fitch, WTI
- Wendi Chang, WTI
- Carla Little, WTI

The research team would also like to thank all the professionals who responded to our survey regarding the highway runoff BMPs, or provided valuable information that made this report possible.

TABLE OF CONTENTS

Technical Report Document Page ii
Disclaimer iii
Acknowlegements iv
Table of Contents v
List of Tables vii
List of Figures viii
Executive Summary ix
1. Introduction 1
1.1 Background 1
1.2 Environmental Concerns 2
1.3 Impacts of Chloride 2
1.4 Allowable Chloride Levels in Streams 3
1.5 Sand versus Chloride-Based Materials 4
1.6 Particle Sizes of Concern 4
1.7 Reducing the Impacts of Traction Materials 5
1.8 Problems Associated with Cold Regions 6
1.9 Information Offered by This Report 6
1.10 How This Report Is Organized 7
2. Methodology 8
3. Structural Best Management Practices 9
3.1 Terminology 9
3.2 Ponds 11
3.3 Wetlands 24
3.4 Infiltration 29
3.5 Filtration 30
3.6 Biofiltration 30
3.7 Implementing Structural BMPs for Montana 37
4. Non-Structural Best Management Practices 45
4.1 Incorporating Environmental Staff into Construction and Maintenance 45
4.2 Proper Training of Maintenance Professionals 45
4.3 Erosion Control 47

4.4 Snow Fences ... 48
4.5 Snow Storage ... 49
4.6 Street Sweeping ... 51
4.7 Improved Anti-icing and De-icing Practices ... 52
4.8 Improved Sanding Practices ... 58
4.9 Appropriate Application Rate ... 58
4.10 Snowplow Technologies ... 59
5. Conclusions and Recommendations ... 62
6. Appendix A: Summary of Survey Results ... 66
6.1 Traction Materials ... 66
6.2 Structural BMPs ... 66
6.3 Venner Consulting Survey on Stormwater Runoff ... 68
7. Appendix B: Blank Survey ... 70
8. References ... 81

LIST OF TABLES

Table 1. Estimated costs of a dry pond based on different volumes 14
Table 2. Estimated costs of a wet pond based on different volumes 17
Table 3. Sediment removal efficiencies of wet ponds 18
Table 4. Comparative removal efficiencies at three Ontario wet ponds during growing season and in wintertime conditions (Schueler 2000) 20
Table 5. Coefficients of ice growth (α) under various conditions (Ontario Ministry of Environment) 24
Table 6. Pollutant removal efficiencies (%) for filter strips (Yu et al. 1995) 35
Table 7. Meltwater character and BMP focus, corresponding to Figure 12 (Oberts 2003) 38
Table 8. Summary of selection criteria for structural BMPs 40

LIST OF FIGURES

Figure 1. Comparison of Montana traction sand sizes and detrimental particle sizes 5

Figure 2. Cross-section of a dry pond showing levels of different storm events and example drainage structure (Barr Engineering Company 2001)................................ 11

Figure 3. Example of an energy dissipater at the inlet of a detention pond (Marsalek et al. 2000) 12

Figure 4. Example layout of a wet pond with forebay and other features (Ontario Ministry of Environment 2003) 15

Figure 5. Example of a circuitous flow path in a wet pond to facilitate plug flow (Ontario Ministry of Environment 2003) 16

Figure 6. Cross-section of wet extended detention pond with different storage levels (Federal Highway Administration 1997) 19

Figure 7. Configuration of a flow splitter to limit heavy flows in a BMP (Ontario Ministry of Environment 2003) 23

Figure 8. The New Hampshire wetlands mitigation site post-establishment: Arial view (Federal Highway Administration 2004) 25

Figure 9. Design configuration of constructed wetlands as: 1) a shallow marsh, 2) a pond/wetland, 3) an extended detention wetland, and 4) a pocket wetland (Barr Engr. Co. 2001)... 26

Figure 10. Plan and section views for a vegetated swale with water levels for different design storms (CWP 2003). 31

Figure 11. Sod placed in channel for erosion control in Australia (Jimboomba Turf Group) 36

Figure 12. General progression of snowmelt and the associated pollutant loads (Oberts 2003) 37

Figure 13. MDSS live display of road and weather information (RAP 2001) 46

Figure 14. The snowplow simulator at GE Driver Development (Fraughton 2003).................... 47

Figure 15. Snow storage and collection system in Colorado (Guo 1999) 50

Figure 16. A RWIS sensor station (Boon and Cluett 2002) 55

Figure 17. Tanks for liquid deicers mounted on hoppers for granular materials.......................... 60

Figure 18. Automatic vehicle location system (Orbital TMS at www.tms-online.com).............. 61

Figure 19. Highway maintenance concept vehicle and some of its components.......................... 62

EXECUTIVE SUMMARY

Compliance with water quality regulations along with a desire to minimize adverse environmental impacts have led to the need for assessing practices to better manage winter traction materials on roadways adjacent to water bodies. Winter traction materials, if not handled properly, may have negative environmental effects on water bodies adjacent to roads. Highway runoff carrying chemicals and abrasives from winter maintenance activities has been identified as a source of non-point source pollution, and the Montana Department of Transportation is committed to minimizing the impacts of such activities. To further understand these impacts and identify ways to mitigate them, a literature review, a survey and consultations were conducted to produce this report.

Although salt and other chloride-based deicers are difficult to remove from highway runoff and can have negative impacts on water bodies, they are typically quickly diluted to concentrations for which there are little measurable effects. Sand and other suspended solids have a greater potential to cause negative impacts but are relatively easy to remove from highway runoff. As such, best management practices should focus on the reduction and removal of these particles from highway runoff.

Wherever possible, a combination of both structural and non-structural BMPs, or best management practices, should be employed to minimize the environmental impacts of winter traction materials. Structural BMPs treat or mitigate highway runoff after it goes off the roadways, and non-structural BMPs reduce the amount of traction materials applied on roadways while maintaining winter mobility and public safety. Strategies can be implemented in the domain of technology, management, or both. Strategies may vary, depending on the specific climate, site, and traffic conditions. The crux is selecting an appropriate suite of BMPs that can function most effectively for a given set of conditions.

This report focuses on the cold region and rural transportation perspective, and discusses the structural BMPs potentially applicable in Montana in greater detail, including the applicability, site criteria, engineering characteristics, safety concerns, maintenance issues, costs, effectiveness in the presence of snow, and sediment removal efficiency. Despite the challenges of winter conditions, structural BMPs such as ponds, wetlands, and vegetated swales and filter strips, can still remove high levels of sediment from runoff if designed, sited, installed, and maintained properly.

This report also summarizes the primary non-structural BMPs used to reduce the use and thus minimize the environmental impacts of winter traction materials, including: incorporating environmental staff into construction and maintenance, proper training of maintenance professionals, erosion control, snow fences, snow storage, street sweeping, improved anti-icing and de-icing practices, improved sanding practices, appropriate application rate, and snowplow technologies. Among these, anti-icing strategies, road weather information systems, the Maintenance Decision Support System, and advanced snowplow technologies are highly recommended for use in Montana.

INTRODUCTION

1.1 Background

The Montana Department of Environmental Quality (DEQ) is in the process of developing Total Maximum Daily Loads (TMDL) for all of Montana's water bodies on the 303(d) list (USEPA 2000). Defined as the greatest amounts of given pollutants that a water body can receive without violating water quality standards and designated uses, TMDL set pollution reduction goals that are necessary to improve the quality of affected aquatic resources. By taking a watershed approach, TMDL consider all potential sources of pollutants, both point and non-point sources.

As a major source of the non-point source pollution, highway runoff has adverse effects on the adjacent aquatic resources if no measures are taken to remove the excessive pollutants originating from highway construction, operation and maintenance activities. The Montana Department of Transportation (MDT) has been committed to regulating highway runoff to minimize its potential negative environmental effects. For example, engineering and management methods were recommended to minimize the intrusion of U.S. Highway 93 Evaro – Polson into adjacent natural resources and to enhance and restore damaged resources (Skillings-Connolly, Inc. 2001). This report, however, will focus on a more specific aspect of highway runoff, the impacts of winter maintenance activities on the adjacent water bodies in Montana. It is the outcome of a research project funded by MDT, in order to provide general guidance for the management of winter traction materials on roadways, which can then be used in developing portions of TMDL plans that require MDT's participation.

In the State of Montana, salting and sanding operations are essential to maintain population mobility and safety by providing safer driving surfaces in the winter season. However, traction materials applied on the roadways, including both chemicals and abrasives, may impact nearby receiving waters by increasing pollutant and sediment loads. In addition, sudden snowmelt and rain-on-snow events can produce large runoff volumes that may overwhelm roadside facilities designed to minimize these impacts.

This report will review and synthesize current technologies and management strategies to minimize highway runoff impacts on aquatic resources due to winter maintenance activities, while taking the specific needs and constraints of Montana's affected roadways into consideration. The report aims to deliver a better understanding of issues that are important for environmental resource agency officials, transportation planners, highway engineers and other stakeholders to assess and mitigate possible adverse impacts of highway winter maintenance activities on Montana's receiving waters. It is envisioned that cost savings and environmental benefits can be realized through the improved highway maintenance policies and practices, or the proper use of best management practices (BMPs) designed to mitigate highway runoff.

1.2 Environmental Concerns

The pollutants of greatest concern in highway runoff are those that accumulate from highway construction, maintenance, and use, including sediment, nutrients, heavy metals, petroleum-related compounds, deicers and other chemicals. Several factors influence the composition and concentration of highway runoff, including: surrounding land use, presence of construction activities, storm intensity, duration and days between storm events, and traffic activity during a storm (Yong et al. 1996).

Chemical deicers* (such as road salt) are usually spread out on roadways to melt ice and snow by lowering the freezing point of the snow-salt mixture, and abrasives (such as sand) are applied to increase the traction between the icy road and a vehicle's tires. In this report, we use the term *traction materials* to refer to both deicers and sand. Through repeated applications and plowings, large amounts of traction materials are deposited alongside the roadways, which can migrate to the adjacent water bodies by wind, rain, or snowmelt.

A study from the Michigan Department of Transportation (DOT) concluded that none of the studied deicers poses widespread adverse environmental threats; however, each deicer can have potentially damaging impacts depending on site-specific conditions and concentrations of deicers in the receiving environment (Public Sector Consultants, Inc. 1993). The effects of highway de-icing activities on the Peshastin Creek watershed in Washington were investigated over a 6-month period from December 1999 to May 2000. The physical, chemical, and biological parameters evaluated in the study indicated that de-icing activities using IceBAN (a magnesium chloride-based deicer) and traction sand along U.S. Highway 97 had no measurable negative impact on Peshastin Creek (Yonge and Marcoe 2001).

Nonetheless, it is extensively agreed that highway runoff, originating from salting, sanding, and other maintenance activities, potentially poses threats to water resources (Hanes et al. 1976, Sorensen et al. 1996, Missoula City-County Health Dept. 1997, Turner-Fairbank Highway Research Center 1999). One case study found decreases in the diversity and productivity of aquatic ecosystems at some sites with inflow of highway runoff containing sediment (Buckler and Granato 1999). The Michigan DOT study suggested that endangered and threatened species and the habitat on which they depend for survival could be adversely affected by the use of certain deicers. In addition, groundwater and vulnerable aquifers can be affected by any material applied or spilled on the land, including deicers and sand (Public Sector Consultants, Inc. 1993).

1.3 Impacts of Deicers

Deicers, mainly chloride-based chemicals, can be found in a wide variety of snow and ice control products used on winter roadways to either prevent the bonding of ice to the roadway (anti-icing) or break the bond between ice and the roadway (de-icing). They are also added to sand to make it easier to manage, distribute, and stay on roadways (prewetting).

---

* For simplicity, this report uses the term *deicer* to refer to all the chemicals used for de-icing, anti-icing and prewetting operations and uses the term *sand* to refer to all the abrasives.

Because most chlorides are readily soluble in water and difficult to remove, there has been considerable concern over the effects of chloride in streams. Most studies have examined the impacts of chloride on surface water, but chloride also causes great concern if it reaches groundwater used as a source of drinking water (Public Sector Consultants, Inc. 1993). However, several studies have found that chloride concentrations in highway runoff are typically low enough that chloride is quickly diluted in receiving waters. Therefore, the impacts of chemical deicers on receiving waters may be negligible in many cases, depending on the type and designated use of the receiving water, and on the drainage system used to discharge the runoff (Turner-Fairbank Highway Research Center 1999).

One study examined the use of magnesium chloride by the Colorado DOT in 1997-1998 and its impacts on several aquatic organisms. Given a dilution factor of approximately 1 to 500 of applied chemicals prior to its exit from the roadway, the use of magnesium chloride during that study period had a very limited potential to cause environmental damage more than twenty yards from the roadway (Lewis 1999). Another study conducted by the Michigan DOT concluded that deicers could be toxic to aquatic organisms, but only in streams with very low flows and in wetlands and ponds with long turnover times. The negative impact of calcium magnesium acetate (CMA) and chloride compounds are most likely to occur in areas of high deicer use, where roadway runoff is channeled directly to small water bodies. Vegetation of the most sensitive species and vegetation located immediately adjacent to roadways can also be damaged by the use of deicers [*] (Public Sector Consultants, Inc. 1993).

In addition to chloride, its associated cations such as sodium (Na^{+}), calcium (Ca^{2+}), magnesium (Mg^{2+}), and potassium (K^{+}) can have environmental effects. Na^{+} is highly soluble in water, can bind to certain clay soil particles, break down soil structure, and decrease permeability. Ca^{2+}, Mg^{2+}, and K^{+} are soluble in water and can exchange with heavy metals in soil, potentially releasing them into the environment (Public Sector Consultants, Inc. 1993). More information on the impacts of these cations can be found in the aforementioned Michigan DOT report.

1.4 Allowable Chloride Levels in Streams

The U.S. Environmental Protection Agency (EPA) specified that the one hour average (acute) and four day average (chronic) concentrations of chloride should not exceed 860 mg/L and 230 mg/L more than once in three years, respectively (USEPA 1988). It should be noted that these levels were developed for chloride associated with sodium, and chloride associated with potassium, magnesium, and calcium would be more toxic to aquatic life, and thus should be managed at lower concentrations (USEPA 1988).

However, chloride concentrations as high as these levels in rivers and streams adjacent to highways appear unlikely. Water testing done by MDT in three such streams in 2003 and 2004 indicates that chloride levels do rise in these streams during the winter maintenance months, but only reached a high of 36 mg/l in one sample. Most of the winter chloride levels in these streams

[*] The report can be found on the Michigan DOT website under the links for Maps and Publications then Reports at http://www.michigan.gov/mdot/.

were less than 15 mg/l. To reach chloride levels of 230 mg/l to 860 mg/l in these streams would entail very large increases in the quantities of chloride products applied during winter maintenance. Such significant increases are not anticipated in future highway maintenance activities.

More information on appropriate chloride concentrations for specific aquatic plants and animals can be found in the EPA Document 440588001, Ambient Water Quality Criteria for Chloride-1988, available online at http://www.epa.gov/clariton/clhtml/pubindex.html.

1.5 Sand versus Chloride-Based Materials

Unless acute levels of chloride are exceeded, the impact of road sand is a much greater concern for the Montana DEQ. The sand particles can accumulate on and around low vegetation and cause stress, or settle to stream bottoms and degrade habitat for aquatic organisms (Public Sector Consultants, Inc. 1993).

In addition to increasing turbidity and depositional loading, the sediment from sanding operations can retain and transport other pollutants to receiving water bodies and thus impair water quality (Kirk 2002). It was revealed that a reduction in individual invertebrate numbers north of Santa Fe, New Mexico was most likely caused by sedimentation from sanding operations rather than chemical changes from the input of deicers (Molles 1980). It was also suggested that during the spring, inputs of traction sand could be expected to asphyxiate the eggs of spawning trout (Molles 1980). In Montana, the use of traction sand raises concerns over endangered and threatened species such as the bull trout and their habitat.

1.6 Particle Sizes of Concern

Particulate matter from sanding operations, especially the finer particles, has a greater possibility to adversely impact aquatic systems and downstream habitats (Young et al. 1996). A study showed that the particle size distribution of traction sand is critical in terms of negative impacts to the productivity of aquatic species. When 10–20 percent (by weight) of a stream's substrate is composed of sediment less than 0.85 mm in diameter, the salmon egg viability was found to degrade significantly (Reiser and White 1988).

The Montana DEQ and Montana Fish, Wildlife and Parks (FWP) become most concerned when particle sizes are less than 6.35mm in diameter. Many of such small particles naturally occur in the mountainous streams in Montana, and these streams typically have sufficient energy to carry them. However, the streams can become overwhelmed when substantial quantities of such small particles are introduced by highway runoff or other sources.

According to expert opinions, particle sizes less than 2mm become especially problematic, as they will block the movement of oxygen into streambed gravels. This oxygen is critical for aquatic wildlife that lay eggs in the streambed gravel.

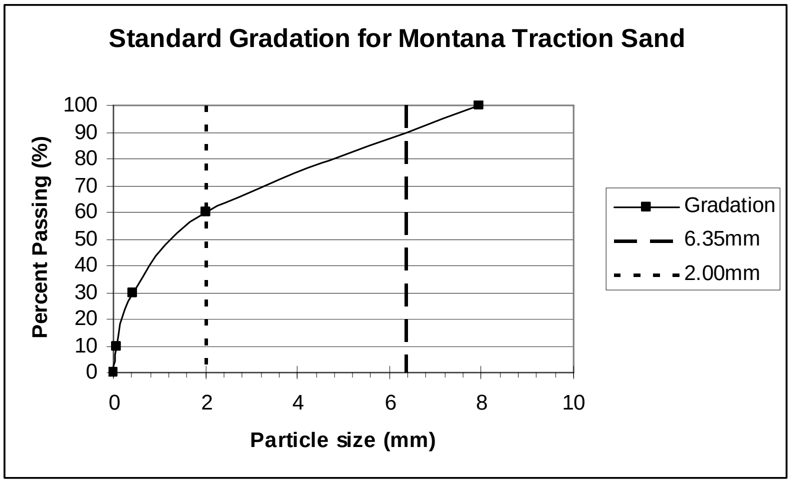

Figure 1. Comparison of Montana traction sand sizes and detrimental particle sizes

In light of data provided by MDT (shown in Figure 1), approximately 90% of particles in the Montana traction sand are smaller than 6.35mm and cause concern for the Montana DEQ and FWP. Figure 1 was derived from the upper limits of the standard gradation of sand, and it should be noted that MDT strives to obtain cleaner sand, which is sand with a larger percentage of particles of appropriately bigger sizes.

According to expert opinions, sand free of much finer particles (ones that pass through the #200 sieve, or 0.075mm in diameter) provides better traction and is easier to be captured by many structural BMPs. Furthermore, the very small particles in air can contribute to respiratory problems, leading to air quality issues especially on urban routes. Particles smaller than 10 microns (0.01mm) in diameter, known as PM-10, can be suspended in the air. Communities with excessive PM-10 particles in the air may surpass limits imposed by the Clean Air Act and be categorized as "non-attainment", and the use of sand has been curtailed (e.g. Metro Denver and Utah's Wasatch Front).

1.7 Reducing the Impacts of Traction Materials

While trying to achieve high level of service (LOS) in maintaining a safe roadway, highway agencies should balance the public safety goals with economic as well as environmental concerns. Wherever possible, they should minimize the impacts of traction materials on the environment through a combination of structural and non-structural strategies. Strategies can be implemented in the domain of technology, management, or both. Strategies may vary, depending on the specific climate, site, and traffic conditions. The crux is selecting an appropriate suite of BMPs that can function most effectively for a given set of conditions.

A. Reduce the Amount of Traction Materials Applied

The first, common sense step in reducing the impacts of traction materials is to reduce the amount of traction materials applied on the roadway. This can be difficult when it is questioned whether the public safety will be compromised. Methods to accomplish this goal are source control strategies, categorized under non-structural best management practices (BMPs).

B. Recover the Traction Materials Applied

Other non-structural BMPs attempt to recover or collect the traction materials before they migrate into adjacent bodies of water. The two primary BMPs for this purpose are street sweeping and snow storage. In some cases, traction sand recovered from the roadway may be reused.

C. Capture the Traction Materials Applied

Without jeopardizing the safety of traveling public, it is currently impossible to eliminate the use of traction materials for highway winter maintenance. It is also unlikely to recover all the traction materials applied on roadways. Highway runoff is the primary vehicle through which pollutants from winter maintenance activities reach the receiving water. Therefore, methods are needed to capture the traction materials that are carried by stormwater or meltwater runoff before they migrate into the adjacent bodies of water. In this report, such methods are defined as structural BMPs.

1.8 Problems Associated with Cold Regions

For applications in cold regions such as Montana, cold climate may complicate the selection and performance of BMPs and present additional challenges.

Frequent salting and sanding activities may increase sediment loads and produce large amounts of pollutants, and snowmelt and rain-on-snow events can produce large runoff volumes. Winter characteristics that further complicate the task of stormwater runoff mitigation in cold regions include, but are not limited to (Barr Engineering Company, Inc. 2001, Caraco and Claytor 1997):

- Frozen ground
- Ice formation
- Short growing season
- Reduced biological activity
- Pipe freezing
- Frost heave
- Deep frost line
- Reduced infiltration

Great care must be taken to ensure that structural BMPs function effectively in cold regions, especially during the winter and spring seasons. Traditional design guidelines developed in temperate regions need adjustment. If necessary, modifications to design features could be made to accommodate site-specific needs. Such modifications can be explored in six categories: feasibility, conveyance, pretreatment, treatment, maintenance, and landscaping (Caraco and Claytor 1997).

1.9 Information Offered by This Report

This report focuses on winter traction materials management on roadways adjacent to water bodies, with highway runoff mitigation as a critical component.

Most of the literature has focused on structural BMPs to mitigate stormwater runoff, especially in urban settings. These BMPs may not be applicable for treating highway runoff in cold regions and in rural settings such as Montana, even though some principles of design are transferable. Although there have been reports addressing problems associated with structural BMPs in cold regions, very little research has been done to summarize the state of practice or to provide technical guidance such as design criteria. Therefore, this report features the cold region and rural transportation perspective, and discusses the structural BMPs potentially applicable in Montana in greater detail, including the applicability, site criteria, engineering characteristics, safety concerns, maintenance issues, costs, effectiveness in the presence of snow, and sediment removal efficiency.

The two primary pollutants of concern are sand and deicers. Because deicers are difficult to remove from runoff and should pose minimal environmental impacts, structural BMPs designed to remove sand (or any suspended solid) are discussed in greater detail.

Conveyance of runoff to structural BMPs can be a problem, and the focus of current literature has been addressing the problems of ice formation in pipes. Additionally, it has focused on providing pretreatment and energy dissipation at the inlets with the assumption that runoff has already reached the entrance to the BMP. This information is presented in this report.

Cost estimates and removal efficiencies for structural BMPs have also been provided; however, such information comes from varied sources with data from BMPs that have a vast range of designs and applications.

In addition to structural BMPs, this report also summarizes the primary non-structural BMPs used to minimize the impacts of winter traction materials on the environment, including: incorporating environmental staff into construction and maintenance, proper training of maintenance professionals, erosion control, snow fences, snow storage, street sweeping, improved anti-icing and de-icing practices, improved sanding practices, appropriate application rate, and snowplow technologies.

1.10 How This Report Is Organized

Following this introductory chapter, the methodology is briefly described. Then, the chapter of structural BMPs follows. First, terminology is given for terms used in the survey. More detailed information is then provided for the primary structural BMPs, followed by a discussion on BMP selection. Although non-structural BMPs are the logical first step in managing impacts of winter traction materials on adjacent water bodies, information on them is presented in the chapter following the structural BMP chapter. In the end, appendices and references are included. Throughout the report, more details are given to the BMPs that are potentially applicable in Montana, considering the cold climate, rural setting, and other constraints.

METHODOLOGY

This report summarizes information gathered through a literature review, a survey to the snow and ice control community, and consultations with the Montana DEQ and FWP. Of these three methods, the literature review received the greatest focus, and yielded the majority of the information.

The literature review attempted to determine which structural and non-structural BMPs would be applicable in Montana, and what modifications would be necessary for successful implementation. Existing technologies, procedures, practices, and policies regarding the minimization of impacts from winter traction materials on the adjacent water bodies were reviewed. Publications and reports published by the Federal Highway Administration, state and local environmental protection agencies, state transportation centers, and state highway agencies were targeted in the review process. Sources used in this report include scientific journal articles, government documents and manuals, and reliable web-based documents.

In October 2003, a survey regarding the highway runoff BMPs was developed and sent to approximately 40 transportation professionals, mainly state DOT maintenance engineers who were identified in the preliminary literature review process. At the same time, the survey was also sent to the Snow and Ice list serve operated under the Snow and Ice Pooled Fund Cooperative Program (snow-ice@list.uiowa.edu), which has hundreds of subscribers ranging from state and local DOT personnel to private sector specialists who are interested in highway winter maintenance issues. In February 2004, the survey was distributed again to reach some DOT engineers who agreed to participate in the survey but failed to respond in the first time. The survey was also sent to a few professionals identified in the environmental protection community.

The survey attempted to gather information in regard to the state of practice. For instance, where structural BMPs could be used with respect to a roadway, how they could be successfully implemented in cold climates, how they need to be maintained in winter, how effective each is in terms of sediment removal, and other questions that were not expected to be addressed by the literature review. The collected surveys with ambiguous or incomplete answers were followed up by telephone interviews to make sure that the information obtained is reliable and appropriate. Both the blank survey and survey results are attached in the appendices of this report.

The consultations with the Montana DEQ and FWP were used to gather local information such as specific pollutant characteristics and to address specific environmental concerns in the State of Montana.

STRUCTURAL BEST MANAGEMENT PRACTICES

Structural BMPs are systems implemented along the roadside to physically trap runoff and to allow pollutants to settle out, evaporate, infiltrate or be absorbed. They are designed to treat both the velocity and the quality of highway runoff. In reducing the impacts of traction materials, the design features that treat runoff quality should be emphasized. The basic mechanisms for pollutant removal are gravity settling, infiltration of soluble nutrients through soil or filters, or biological and chemical processes (Turner-Fairbank Highway Research Center 1999).

Pollutants in runoff can be divided into two categories: suspended and dissolved. Sand particles contribute mainly to suspended solids in runoff, and deicers contribute to dissolved pollutants. Most structural BMPs are more efficient at removing one or the other. The removal of suspended solids is usually accomplished through settling, which can be very effective in removing sand particles. Removal of finer clay and silt particles is much less efficient with settling, but few of these small particles are found in traction sand. Few structural BMPs can effectively remove dissolved pollutants.

The structural BMPs potentially applicable in Montana can fall into the categories of ponds, wetlands, infiltration structures, filtration structures, and biofiltration structures. The details of these BMPs are described in this chapter.

1.1 Terminology

Dry Settling Pond – A dry settling pond holds runoff for a given period of time and releases it at a controlled rate such that the pond remains dry between storm events. The settling time for a given particle controls the design detention time of the runoff held in such a pond.

Dry Extended Detention Pond – The dry extended detention pond provides a higher level of treatment than traditional dry ponds as they are designed to hold runoff for a greater length of time. During this time, usually 24 hours (Caraco and Claytor 1997), more particles have the opportunity to settle.

Wet Settling Pond – In contrast to a dry settling pond, a wet settling pond contains a permanent pool between storm events. This permanent pool provides additional treatment for runoff. Wet ponds are designed to allow runoff from a storm event to displace the volume of water held in the wet pond from the previous storm, and runoff is treated to improve quality, not to reduce its rate.

Wet Extended Detention Pond – This structure combines qualities of both wet ponds and dry ponds. Extended detention wet ponds contain a permanent pool as well as the volume to hold and treat additional runoff so that it can provide some level of treatment for most storm events as well as reduce the velocity of runoff.

Wet Vaults and Grit Chambers – Wet vaults and grit chambers work under the same principles as ponds, except they use an underground chamber to detain runoff. The detention time controls the amount of sediment captured, and the volume can be much more limited compared with aboveground pond systems.

Constructed Wetland – Constructed wetlands take advantage of the physical and chemical processes of natural wetlands to treat the quality of runoff as well as its velocity. Such BMPs, unlike most others, have the potential to provide a high level of treatment for both suspended and dissolved pollutants. Constructed wetlands include shallow marsh and submerged gravel types.

Shallow Marsh – A shallow marsh is typically a type of constructed wetland in which most of the wetland contains very shallow, heavily vegetated, standing water with limited storage volume for larger storms.

Submerged Gravel Wetlands – Submerged gravel wetlands treat runoff flowing through a submerged rock bed with vegetation growing on its surface. They can be highly effective in removing dissolved pollutants, and inflows of suspended particles must be limited to prevent clogging. These BMPs have been most widely used to treat wastewater.

Infiltration Trench – Infiltration trenches are excavations in which runoff is collected and given adequate time for infiltration. This design reduces the volume of runoff and has the ability to treat runoff for dissolved pollutants. Suspended solids in runoff can clog infiltration trenches and either cause them to fail or require excessive maintenance.

Infiltration Basin/Infiltration Meadow – These structures function similarly to infiltration trenches, but they closely resemble a dry pond in appearance. As infiltration trenches do, infiltration basins and meadows hold runoff, giving it sufficient time to infiltrate, but unlike a dry pond or even a wet pond, they are not designed to release runoff from the design storm.

Porous Pavement – This type of paving can consist of either porous asphalt or block pavers with holes. Either option allows runoff to infiltrate through the pavement into the soil beneath. Porous pavement treats runoff and reduces the volume of runoff; however, it cannot be used to treat runoff with suspended solids as they will clog porous pavement and prevent further infiltration.

Surface Sand Filter – High levels of treatment can be obtained by sand filters, but these structures are typically more costly compared with other structural BMPs. Runoff treated by a surface sand filter must first pass through a pretreatment basin to allow particles to settle out, then it can pond above the sand filter where it will filter through a bed of sand, before it can be collected and sent to a receiving body of water.

Subsurface Sand Filter – Subsurface sand filters operate identically to surface sand filters, but they are self-contained units designed for use underground in areas where space is limited.

Bioretention – Bioretention systems look and operate very similar to infiltration basins except they collect the infiltrated runoff after it has percolated to an underdrain and discharge the treated runoff to a receiving body of water. These BMPs are often small features located as islands in parking lots. Similar to any infiltration or filtration BMP, bioretention systems treat runoff for dissolved pollutants instead of suspended solids and must have a pretreatment or high level of maintenance to avoid failure.

Dry Swale – Dry swales are also known as grassy swales or vegetated channels. These BMPs are very common and require minimal modifications for use in cold climates. They treat runoff by reducing flow velocities and providing time for particles to settle. Frequently, dry swales have check dams that temporarily pond runoff to both increase the removal of suspended solids and reduce the runoff velocity.

Wet Swale – Wet swales are almost identical to dry swales except they either have highly impermeable soils or are located close to the water table. Frequently they contain standing water, and they can function similarly to a wet pond where incoming runoff replaces the existing volume of water.

Vegetated Filter Strip – Vegetated filter strips are a different configuration of a dry swale. They are often a linear structure like swales, but the flow of water is perpendicular across their length. As with swales, they reduce water velocities to allow the deposition of suspended solids.

1.2 Ponds

3.2.1. Dry Ponds and Dry Extended Detention Ponds

A dry settling pond (Figure 2) holds runoff for a given period of time and releases it at a controlled rate such that the pond remains dry between storm events. The settling time for a given particle controls the design detention time of the runoff held in such a pond. Dry extended detention ponds provide a higher level of treatment than traditional dry ponds as they are designed to hold runoff for a greater length of time.

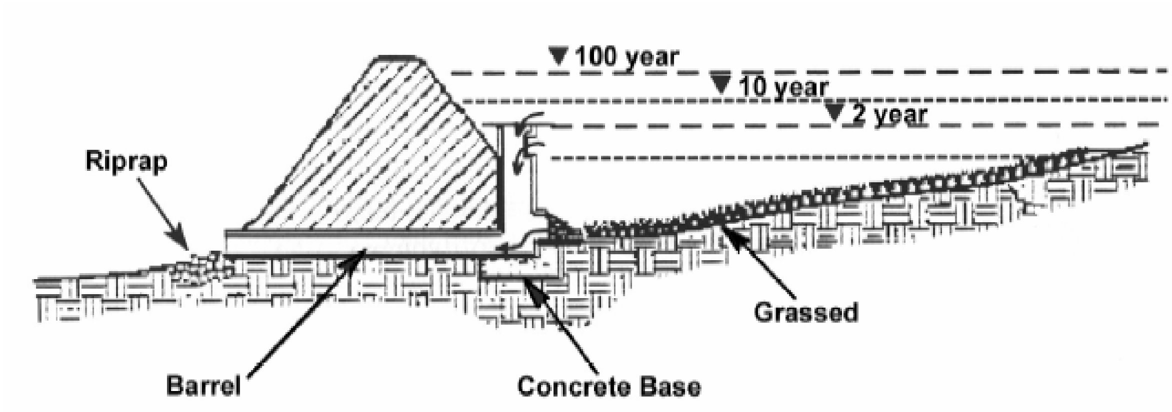

Figure 2. Cross-section of a dry pond showing levels of different storm events and example drainage structure (Barr Engineering Company 2001)

Applicability

Dry ponds, also known as detention ponds, are among the most widely applicable runoff treatment practice, and 42% of the states responding to our survey reported using dry ponds. In another survey (Venner Consulting 2003), 81% of the respondents reported using dry ponds. These basins are designed to hold a volume of runoff for a period of time before releasing it to a stream or storm sewer system. They are usually located at the end of a pipe and remain empty between storm events, with the main purpose of volume control, not water quality control. However, dry extended detention ponds are used for both volume and water quality control (Shammaa et al. 2002). The extended detention time (e.g., 24 hours) allows additional particles to settle, thus providing a higher level of treatment.

Dry ponds remove pollutants primarily by sedimentation or settling; consequently, dry ponds should be used to remove suspended solids such as sand particles. Pollutants other than suspended solids can be removed if attached to the settlable suspended solids.

Site Criteria

Few site criteria limit the use of dry ponds, and the area required can be small for small drainage areas. Because dry ponds do not increase water temperature as much as wet ponds, they can be more applicable in areas where increases in stream temperatures will impact fish habitats (CWP 2003). Dry ponds must also have relatively easy access for maintenance personnel and equipment.

Engineering Characteristics

Slopes into the dry pond should be 3:1 (horizontal to vertical) or flatter to prevent erosion and facilitate maintenance. This factor may require a larger area than anticipated.

The longer the flow path through the pond, the more effective sediment removal can be. To this end, an oval shape is preferred with the inlet located as far away from the outlet as possible. Preferred length to width ratios range from 4:1 to 5:1. Other methods for obtaining a longer flow path are installing berms or baffles. These methods require additional land to maintain the design storage capacity of the pond (Oberts 2003). Baffles can also prevent short circuiting (Shammaa et al. 2002), which is the development of a flow path that results in detention times less than the design detention time.

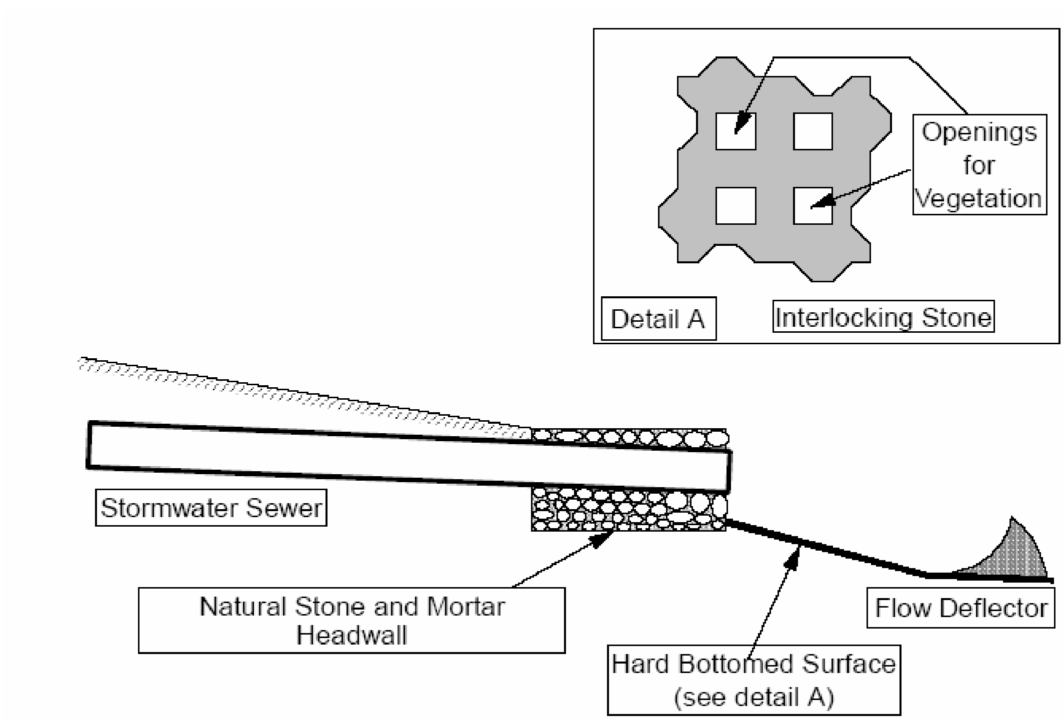

Figure 3. Example of an energy dissipater at the inlet of a detention pond (Marsalek et al. 2000)

Most dry ponds are designed to empty in a time period of less than 24 hours, resulting in lower pollutant removal than wet ponds. Longer detention time may improve removal efficiency, but may not be cost effective. The maximum recommended pond depth is 6 to 10 feet. For most sand sizes, however, the 24-hour detention time should be sufficient, and a longer detention time would be required to remove finer silt particles.

If high incoming flow velocities are anticipated, an energy dissipater (Figure 3) should be placed in the inlet to prevent washout by heavy water flows. This washout can resuspend accumulated sediment and carry it to the receiving water body. In addition to an energy dissipater, a dry pond should also contain a sediment forebay to capture large sediment particles.

The outlet should be sized according to the size of the drainage area and placed in a location that allows easy maintenance.

Safety Concerns

As with any structure designed to hold water, dry ponds have the safety issue of thin ice that should be addressed with signage or fencing. However, drawdown of water typically prevents the formation of ice.

Maintenance

Dry ponds require little maintenance. Inlet and outlet pipes should be checked routinely for clogging. The outlet pipes in many dry ponds in Colorado along I-70 became blocked by accumulated sediment. These outlet pipes were perforated, and now have a sleeve around them to facilitate maintenance (pers. comm. with Terri Tiehen, CDOT Region 1). A hard surface in the forebay can facilitate the removal of trapped sediment, as well as a hard surface in the entire dry pond; however, interlocking blocks (as shown in Figure 3) can be ripped up by machinery (Ontario Ministry of the Environment 2003).

Mowing and debris removal should be performed as needed, and sediment may need to be removed every 5 to 20 years (MOLWAP 2004, Shammaa and Zhu 2001).

Costs

Dry ponds are one of the least expensive runoff treatment practices in terms of cost per unit area treated. A study performed in 1997 (Brown and Schueler 1997) developed the following formula for the cost of a dry extended detention pond:

Equation 1. Cost of a dry extended detention pond

$C = 12.4V^{0.760}$

Where: C = Construction, design and permitting cost (1997 dollars)

V = Volume needed to control the 10-year storm (cubic feet)

Table 1. Estimated costs of a dry pond based on different volumes

Volume (of 10-year storm)	**Cost (1997 dollars) $C = 12.4V^{0.760}$**
1000 ft^3	\$2,360
5000 ft^3	\$8,030
10,000 ft^3	\$13,600

The annual cost of routine maintenance is estimated to be 3% to 5% of the construction cost. Ponds typically have life spans of greater than 20 years (CWP 2003).

Effectiveness in Snow

Dry ponds can perform well in cold climates and remain effective during the winter. Precautions can be taken to guard against freezing pipes and orifices. Weirs are recommended in place of outlet pipes to reduce the effects of ice formation; however, dry ponds require some outlet pipes to allow complete draining of the pond. Heavy spring runoff storm events can increase the potential for scour and resuspension of accumulated sediment if this possibility is not accounted for with an appropriate forebay.

A dry pond can be used as a snow storage area during the winter season. If this practice is employed, vegetation damage due to pollutants in the snowpack should be monitored and may require additional vegetation maintenance in the spring and summer months.

Sediment Removal Efficiency

Equations for sediment removal are presented in section 3.7.4, and they indicate that a greater flow length yields higher removal efficiency. This makes sense because a greater flow length would result in a greater detention time for a given flow velocity. Furthermore, a shallower depth yields higher removal efficiency. Consequently, ponds with greater flow lengths and more shallow depths will generally have higher removal efficiencies.

Dry ponds can remove significant amounts of suspended solids (sediment) if given an adequate detention time and measures to prevent short-ciruiting. Studies in Canada found that removal rates for total suspended solids (TSS) varied from zero to 60% when detention times varied from zero to 24 hours. Another study found an increase in TSS removal of 14-28% with the addition of baffles as mentioned previously (Shammaa and Zhu 2001). Baffles would decrease the average flow velocity and increase removal efficiency. Dry ponds can be paired in series or combined with other BMPs to improve their removal efficiency.

For dry ponds, enhancement options are listed as follows (Caraco and Claytor 1997):

- *Sediment Forebay*. This feature should include a deeper permanent pool to minimize potential scour and sediment resuspension by trapping larger particles near the inlet of the pond (Figure 4).

- *Extended Storage*. This feature can improve the effectiveness of dry ponds by increasing detention time. Outlet controls should be fitted with filters or weirs to dissipate energy and evenly spread flow.
- *Micropool at the Outlet*. A micropool at the outlet of the dry pond can concentrate finer sediment and reduce re-suspension.
- *Pond Shape*. Methods to increase the detention time include constructing the pond in an oval shape, installing baffles, or creating a curved flow path (as shown in Figure 5).

3.2.2. Wet Ponds

Wet ponds (Figure 4) contain a permanent pool between storm events, and this pool provides treatment for runoff beyond that of a dry pond.

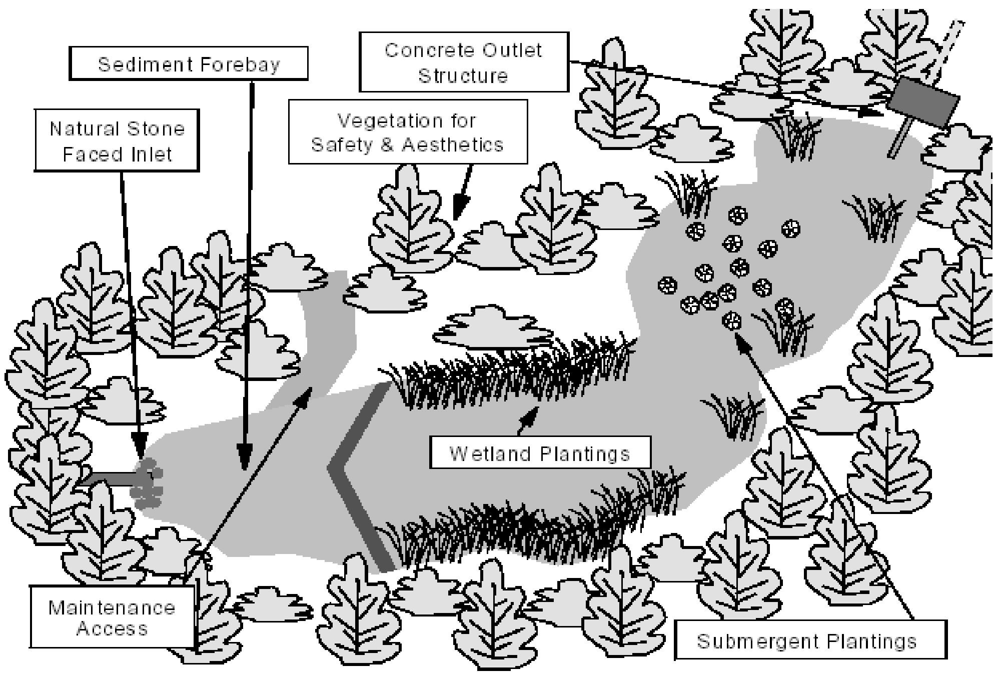

Figure 4. Example layout of a wet pond with forebay and other features (Ontario Ministry of Environment 2003)

Applicability

A wet pond uses a permanent pool of water for water quality control and provides little control of water volume. The primary treatment process is sedimentation that removes suspended solids. These structures hold runoff until the next storm provides enough runoff to displace the pool of water in the pond. This action can only occur if the wet pond has been designed so that water moves through its volume as a single plug of water.

Wet ponds are among the most cost-effective and widely used runoff practices, and 42% of the states responding to our survey reported using wet ponds. In another survey (Venner Consulting

2003), 65% of the respondents reported using wet ponds. Wet ponds score well on community acceptance, and have low maintenance and cost requirements, while meeting the requirements for channel protection, water quality, and overbank flood protection (Federal Highway Administration 2003). The greatest disadvantage of wet ponds is the high potential for increases in water temperature that may affect trout habitat.

Site Criteria

Wet pond usage can be limited in arid climates because sufficient water is needed to maintain the permanent pool, yet they have few other restrictions (Federal Highway Administration 1997). Wet ponds may require a large contributing watershed of at least 10 acres (Barr Engineering Company 2001). Additionally, depth to groundwater should be considered if groundwater contamination is a concern.

Because a wet pond can allow breeding of mosquitoes, the proximity to residential areas may limit the use of wet ponds.

Engineering Characteristics

The volume of wet ponds is typically based on a specific design storm so that the pond volume equals the volume of runoff produced by such a storm. This volume will allow a replacement of a treated volume of water with a new untreated volume of runoff moving as a single plug of water. For cold climates, the increased volume of a wet extended detention pond may be required to account for ice formation (Caraco and Claytor 1997).

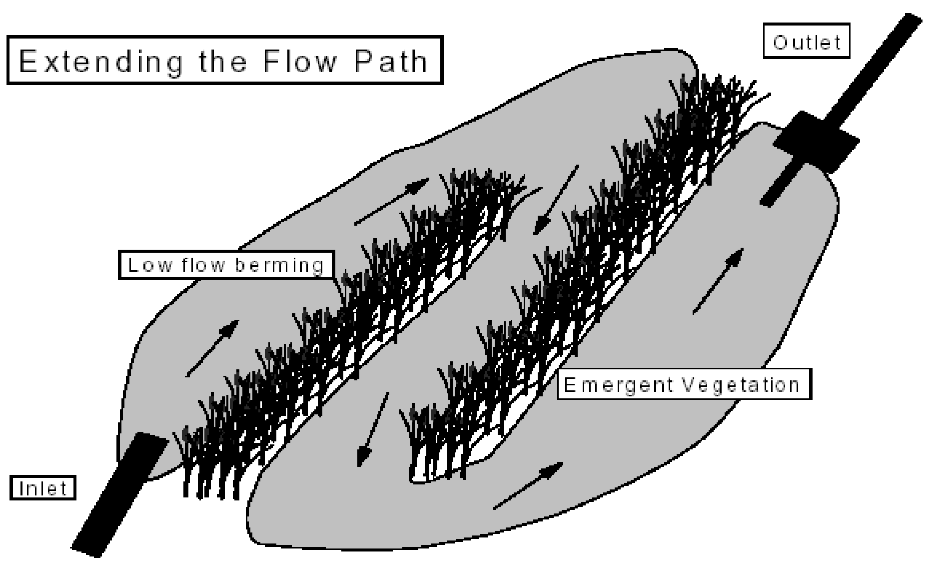

Figure 5. Example of a circuitous flow path in a wet pond to facilitate plug flow (Ontario Ministry of Environment 2003)

Long and narrow or wedge-shaped ponds can facilitate plug flow and prevent newer runoff from flowing directly to the outlet without treatment. Other designs including pools of varied depths and a circuitous flow path (Figure 5) can also encourage plug flow.

To avoid washout by heavy flows, a sediment forebay and possibly an energy dissipater (as shown in Figure 3) should be added.

In addition, plants that grow along the perimeter of the pond can help with pollutant removal and aesthetics (MOLWAP 2004). Larger plants or trees may reduce the increases in water temperature.

Safety Concerns

As with any structure designed to hold water, wet ponds have the safety issue of thin ice that should be addressed with signage or fencing. Additionally, one survey respondent included the use of wet ponds by waterfowl to be a potential hazard to motorists when such ponds are located immediately adjacent to roadways.

Maintenance

Ponds should not be drained during the winter or early spring season when stream flows are still relatively low. The possibility of high chloride concentrations in pond water mixing with low stream flow rates could cause negative downstream effects.

For regular maintenance, the design should allow for easy access by maintenance personnel and equipment. Additionally, three respondents to our survey recommended constructing hard surfaces in a forebay in order to withstand heavy flows and facilitate cleaning.

Costs

A study performed in 1997 (Brown and Schueler 1997) developed the following formula for the cost of a wet pond:

Equation 2. Cost of a wet pond

$C = 24.5V^{0.705}$

Where: C = Construction, design and permitting costs (1997 dollars)

V = Volume needed to control the 10-year storm (cubic feet)

Table 2. Estimated costs of a wet pond based on different volumes

Volume (of 10-year storm)	**Costs (1997 dollars) $C = 24.5V^{0.705}$**
1000 ft^3	\$3,200
5000 ft^3	\$9,900
10,000 ft^3	\$16,200

Effectiveness in Snow

Effectiveness of wet ponds is typically reduced in cold climates, where wet ponds can still function and effectively remove sediment. The primary loss of effectiveness stems from ice formation, and in the case of a wet pond, incoming water could potentially flow over the ice layer to the outlet and receive little or no treatment. Many factors control this ice formation, and it may not be an issue if it never forms or melts by the time spring runoff begins. Some sources suggest potential also exists for inflow to enter beneath an ice layer and scour the bottom of the wet pond. This scour could resuspend accumulated sediment; however, few studies of ponds under winter conditions exist. One study conducted in Canada is discussed in the following section on extended detention wet ponds.

Sediment Removal Efficiency

Equations for sediment removal are presented in section 3.7.4.

Wet ponds can have higher removal rates for sediment than dry ponds because of the permanent pool, which not only increases detention times, but also prevents resuspension of sediment. Two-thirds of all sediment can be removed during the first 24 hours according to some modeling (Barr Engineering Company 2001). Other reported removal efficiencies of wet ponds are presented in Table 3.

Table 3. Sediment removal efficiencies of wet ponds

Wet Pond	**Removal Efficiency of Suspended Solids**
All wet ponds have capability for: Georgia Stormwater Manual (Haubner 2001)	80%
On-line wet pond, Austin, TX (Federal Highway Administration 1997)	46%
Wet retention pond, Austin, TX (Federal Highway Administration 1997)	94%
Wet detention pond (Federal Highway Administration 1997)	78%
Wet pond: designed for water quality (Comings, Booth, and Horner 1999)	81%
Wet pond: designed to control runoff velocity and some water quality (Comings, Booth, and Horner 1999)	61%

The comparison between the last two ponds in Table 3 illustrates the importance of ensuring plug flow. The first one was designed with a horseshoe shape to prevent short-circuiting and achieved higher removal efficiency. The second one had multiple cells with rectangular shapes, and runoff was able to pass directly from the inlet to the outlet of several cells without receiving much treatment, thus achieving lower removal efficiency (Comings, Booth, and Horner 1999).

3.2.3. Wet Extended Detention Ponds

Wet extended detention ponds combine qualities of both wet ponds and dry ponds by including a permanent pool as well as the volume for additional runoff (Figure 6) to reduce the runoff velocity.

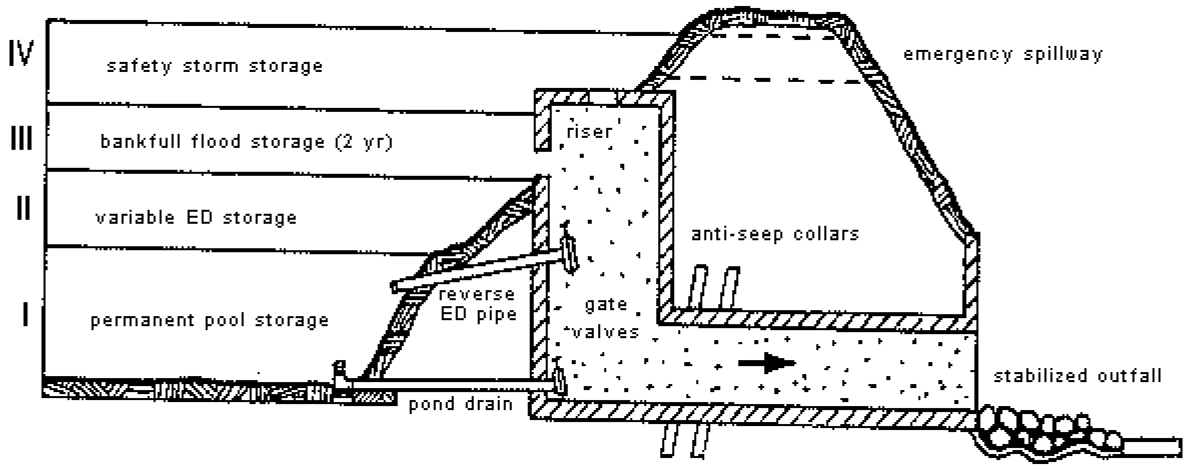

Figure 6. Cross-section of wet extended detention pond with different storage levels (Federal Highway Administration 1997)

Applicability

The wet extended detention pond combines the treatment concepts of the dry extended detention pond and the wet pond, and it can both reduce the runoff velocity and provide some level of treatment. In this design, the water quality volume is split between the permanent pool and detention storage provided above the permanent pool. During storm events, water is detained above the permanent pool and released over 12 to 48 hours. Wet extended detention ponds should be designed to maintain at least half the treatment volume in the permanent pool.

Site Criteria

Wet extended detention ponds can have limited applicability in arid climates, yet have few other restrictions (Federal Highway Administration 1997). Site criteria for wet extended detention ponds are the same as wet ponds, except they require a greater area for additional storage.

Engineering Characteristics

The volume of wet extended detention ponds is typically based on a specific design storm so that the pond volume equals the volume of runoff produced by such a storm (permanent pool volume), plus the extended detention volume, which is defined as the volume above the normal (permanent) pool elevation.

A forebay and possibly an energy dissipater (as shown in Figure 3) should be included in the design as discussed for dry ponds. Alternating areas of shallow and deep pools in wet ponds can be used to increase the sediment trapping efficiency and habitat diversity. Wetland plants introduced along the edges of the pond can help reduce erosion on the banks (Federal Highway Administration 1997), but the position or type of vegetation should account for water levels that can widely fluctuate because of the extended detention storage.

Safety Concerns

Safety concerns include thin ice and potential waterfowl hazards to motorists.

Maintenance

Maintenance requirements are low, and similar to those of wet ponds.

Costs

Costs should be similar to those for wet ponds, and Equation 2 may be applicable.

Effectiveness in Snow

Wet extended detention ponds can be effective in winter conditions just like wet ponds, and they have the added volume that can handle heavy flows during the spring runoff.

Table 4. Comparative removal efficiencies at three Ontario wet ponds during growing season and in wintertime conditions (Schueler 2000)

Parameter	Heritage Park Wet Pond	Harding Park Wet ED Pond w/ Marsh	Rouge River Wet ED Pond
Comparative Pollutant Load Reduction During Growing Season			
Total Suspended Solids (TSS)	80%	80%	87%
Total Phosphorus (TP)	80%	37%	79%
Comparative Pollutant Load Reduction in Wintertime Conditions			
Total Suspended Solids (TSS)	86%	78%	75%
Total Phosphorus (TP)	65%	56%	67%
Note: Removal efficiencies were calculated based on 10 or more paired samples at each pond.			

Some literature has suggested that the formation of ice can lead to scouring of the bed and resuspension of sediment if inflows were forced under the ice. One field study in Kingston, Ontario demonstrated that this might not be the case (Marsalek et al. 2000). The study examined an on-line wet pond with additional storage in a dry cell for high inflows. Because this pond receives inflow from a creek, ice covering the main channel for creek flow in the pond remained thin, and elevated inflows (from a rain event in February 1996 and the spring melt) were able to break through the ice. Consequently, flow velocities under the ice were never sufficient to scour the bed of the pond. The study also suggests that winter conditions for an on-line extended detention wet pond will not increase chances of washout by heavy water flows beyond what may occur during warmer conditions.

Another study of three different wet ponds in Ontario found removal rates of suspended solids did not significantly decrease during winter months (Schueler 2000). Table 4 indicates removal rates during the growing season and in winter conditions, respectively.

Sediment Removal Efficiency

Equations for sediment removal are presented in section 3.7.4.

In Table 4, removal efficiencies for the two wet extended detention ponds were 80% and 87% during the growing season, and 78% and 75% in winter conditions, respectively. Other wet ponds in Edmonton were found to provide TSS removals of up to 90% (Shammaa and Zhu 2001).

3.2.4. Wet Vaults and Grit Chambers

Wet vaults and grit chambers are structures designed to detain runoff for a given period of time to remove suspended solids. Grit chambers often include an additional chamber to remove oils. Typically wet vaults and grit chambers hold water until the next storm provides sufficient water volume to displace the previous volume in a fashion similar to wet ponds. Applications are favored in locations with limited space for traditional aboveground ponds such as dense urban areas, and costs can be high relative to detention ponds.

These BMPs can have high removal rates of suspended solids if they are sized appropriately and receive adequate maintenance. Maintenance is especially critical to prevent heavy flows from large storm events from resuspending and washing out accumulated sediment. In addition to regular maintenance, a flow splitter can be installed (see section 3.2.7: Cold Region Modifications). More detailed information on the design and use of wet vaults in temperate climates can be found in the Georgia Stormwater Manual at http://www.georgiastormwater.com/ under the link for Underground Detention.

In cold regions, during winter months, wet vaults and grit chambers need to be protected from freezing temperatures by insulation with snow cover, placement below the frost line, or placement indoors. Additionally, these structures will receive much higher loads of suspended sediment in cold regions where traction sand is applied to roadways, and they would need to be sized differently than for use in more temperate regions. Unfortunately, little research has been done in regard to their use and effectiveness in cold regions.

3.2.5. Sand Cans

In the Lake Tahoe area in California, sand cans have been used as a pretreatment device designed to trap sediment from incoming runoff. These devices act similarly to wet vaults and grit chambers. They are inverted culvert sections filled with large gravel in the bottom. Runoff enters the top of the sand can and leaves via an outlet pipe placed about one foot below the top. Sand cans have the advantage of low costs and easy installation. They have been found to be highly effective in capturing sediment in runoff as a pretreatment for other BMPs, but require regular maintenance to remove accumulated sediment. Without such maintenance, heavy flows can resuspend trapped sediment. For more information, please review the Planning Guide for Implementing Permanent Storm Water Best Management Practices in the Lake Tahoe Basin at http://www.swrcb.ca.gov/rwqcb6/BMP/Index.htm (TIRRS 2001).

3.2.6. Other Proprietary Systems

A wide variety of proprietary systems are available to remove suspended solids from runoff. Most are designed for placements below ground. Some work exactly as wet vaults and grit chambers, yet others induce hydrodynamic forces to cause particles to settle and prevent resuspension during heavy flows. Similar to wet vaults and grit chambers, these proprietary systems are most applicable in areas with limited space and can be costly for the volume of water treated and the required maintenance.

Some of these proprietary systems are Aqua-Swirl, BaySaver, StormVault, StormTreat, Vortechs, Stormceptor, Downstream Defender, and ADS Water Quality Units. For more information and reviews of these systems, please visit:

http://www.epa.gov/ne/assistance/ceit_iti/tech_cos/stor.html - This EPA site contains a list of many current technologies with descriptions and contact information.

http://www.state.ma.us/envir/step/documents/default.htm#techAssess – This site contains independent evaluations of some of the technologies listed in the EPA site.

3.2.7. Cold Region Modifications for Detention Facilities

Detention facilities are structures, such as ponds, designed to hold runoff for a given period of time. They can provide the highest levels of treatment with the least modification for cold regions although they may need an increased volume to accommodate ice formation and the accumulation of high levels of sediment from traction materials. Additionally, conveyance structures may need modification to prevent or accommodate ice formation.

Modifications for detention facilities in cold regions may include:

- *Outlets.* These can allow drawdown in the fall to prevent the formation of ice, and different outlet options can allow for higher storage volumes during the spring thaw (Oberts 2003). Outlet structures such as riser hoods can allow the constant flow of water despite the formation of an ice layer. The City of Anchorage recommends using a weir for an outlet structure in place of standpipe to avoid the problems of icing at outlets (Jokela and Bacon 1990).
- *Underdrains*. These additions can drain the soil in the bottom of the detention pond to prevent freezing and encourage infiltration during the early snowmelt when soluble pollutants dominate the melt water (Oberts 2003).
- *Oversized Pipes.* Inlet and outlet pipes can be oversized to accommodate both ice formation and design flow. For culverts in cold regions, it is recommended that they generally be oversized to account for the accumulation of ice or snow and the resulting decrease in capacity as well as an increase in flow velocity (Ashton and Griffiths 1990).

Adjustments of the hydraulic grade line and flow transitions can also reduce the impacts of ice on pipes (Jokela and Bacon 1990).

- *Deeply Buried Pipes.* Inlet and outlet pipes can be buried beneath the frost line to prevent ice formation.
- *Increased Volume.* Detention ponds should be sized for increased volumes associated ice cover and spring meltwater. Additionally, these ponds should be designed to hold at least one year's worth of sediment to avoid frequent maintenance (Cote et al. 2003).
- *Deeper Water Depth at Outlet.* Allowing a deeper water depth at the outlet would reduce potential scouring as water flows from under the ice to the outlet (Oberts 1990).

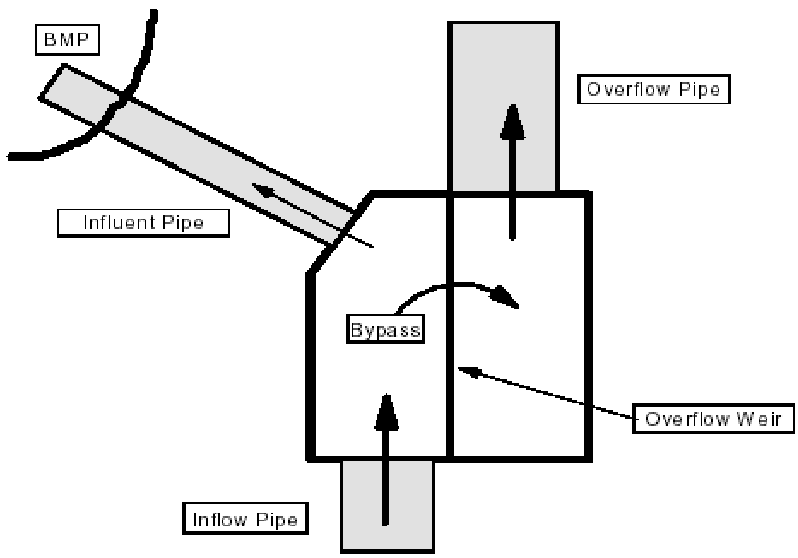

Figure 7. Configuration of a flow splitter to limit heavy flows in a BMP (Ontario Ministry of Environment 2003)

- *Installation of Flow Splitter.* This device (Figure 7) can allow heavy flows from large storms to bypass a particular BMP, limiting the rate at which runoff can flow to the BMP. The runoff that bypasses the BMP can be either treated by some less effective and less costly BMP, or does not receive any treatment. The purpose is to avoid washout of the BMP.

In the design of facilities that hold runoff, the Ontario Ministry of Environment recommends increasing the volume to equal the expected volume of ice that might form on a permanent pool. They suggest using Stefan's Equation to estimate ice thickness (Ontario Ministry of Environment):

Equation 3. Stefan's equation for determination of ice thickness

$h = \alpha(D_f)^{0.5}$

Where: h = Ice thickness in mm

α = Coefficient of ice growth

D_f = The sum of freezing degree-days

The coefficient of ice growth can range from 7 to 34 according to Table 5. The study of a wet pond in Kingston, Ontario found a coefficient of 12.4 produced values that fit measured data most closely. However, the measured values were affected by constant inflow from a creek and a one-day thaw event. The Ontario Ministry of Environment also recommends consultation with a local municipality in estimating ice thickness.

Table 5. Coefficients of ice growth (α) under various conditions (Ontario Ministry of Environment)

Condition	α (mm °C$^{-0.5}$d$^{-0.5}$)
Theoretical Maximum	34
Windy lakes with no snow	27
Average lake with snow	17-24
Average river with snow	14-17
Shelter river with rapid flow	7-14

1.3 Wetlands

3.3.1. Constructed Wetlands

Applicability

Wetlands use the natural processes of filtration, sedimentation, adsorption, and other physical removal processes to remove pollutants (Earles 1999). Through the combination of these different processes, constructed wetlands can be effective in removing both suspended and dissolved pollutants. The use of wetlands can be limited in arid regions as a result of evaporation and can be limited in cold regions as a result of limited plant growth. Limited data are available for the use of constructed wetlands for runoff mitigation, and optimal design criteria have not been identified for their use in temperate regions (Earles 1999). While little data are available for their use in cold regions, constructed wetlands are in use in latitudes as far north as the Arctic Circle.

One-third of the states responding to our survey reported using constructed wetlands. In another survey (Venner Consulting 2003), two-thirds of the respondents reported using constructed wetlands. In designing a wetlands mitigation strategy for its improvements to Route 101, New Hampshire DOT took a broad "landscape approach" to fit local ecosystem and resource management needs, which included replacing culverts with a twin-span bridge, creating and improving freshwater wetlands, and recycling sand and gravel from the wetlands site for use on the road (Federal Highway Administration 2004). The innovative initiative led to a beautiful ecosystem as shown in Figure 8. For more information on the project, please contact Den Danna at ddanna@dot.state.nh.us.

Figure 8. The New Hampshire wetlands mitigation site post-establishment: Arial view (Federal Highway Administration 2004)

Site Criteria

Site selection for constructed wetlands should include consideration of the following (Earles 1999):

- Distance from runoff source
- Availability of land
- Gentle topography
- Soils and their permeability

Groundwater and baseflow must be sufficient for vegetation to survive during dry periods, and soils must allow ponding of water, or a liner should be added during construction. In humid regions, 25 acres or more of drainage area may be needed to maintain the water level; arid regions would need more (CWP 2003). Organic matter must also exist in sufficient quantities for wetland vegetation to become established (Federal Highway Administration 1997). The site criteria of soils, depth to bedrock, and depth to groundwater can limit the areas in which a constructed wetland may be used.

Engineering Characteristics

As with most detention and retention ponds, a pretreatment such as a forebay should be added to reduce the amount of sediment that enters the constructed wetlands. Typically, the volume of the forebay should be 10% of the total volume of the wetlands (CWP 2003).

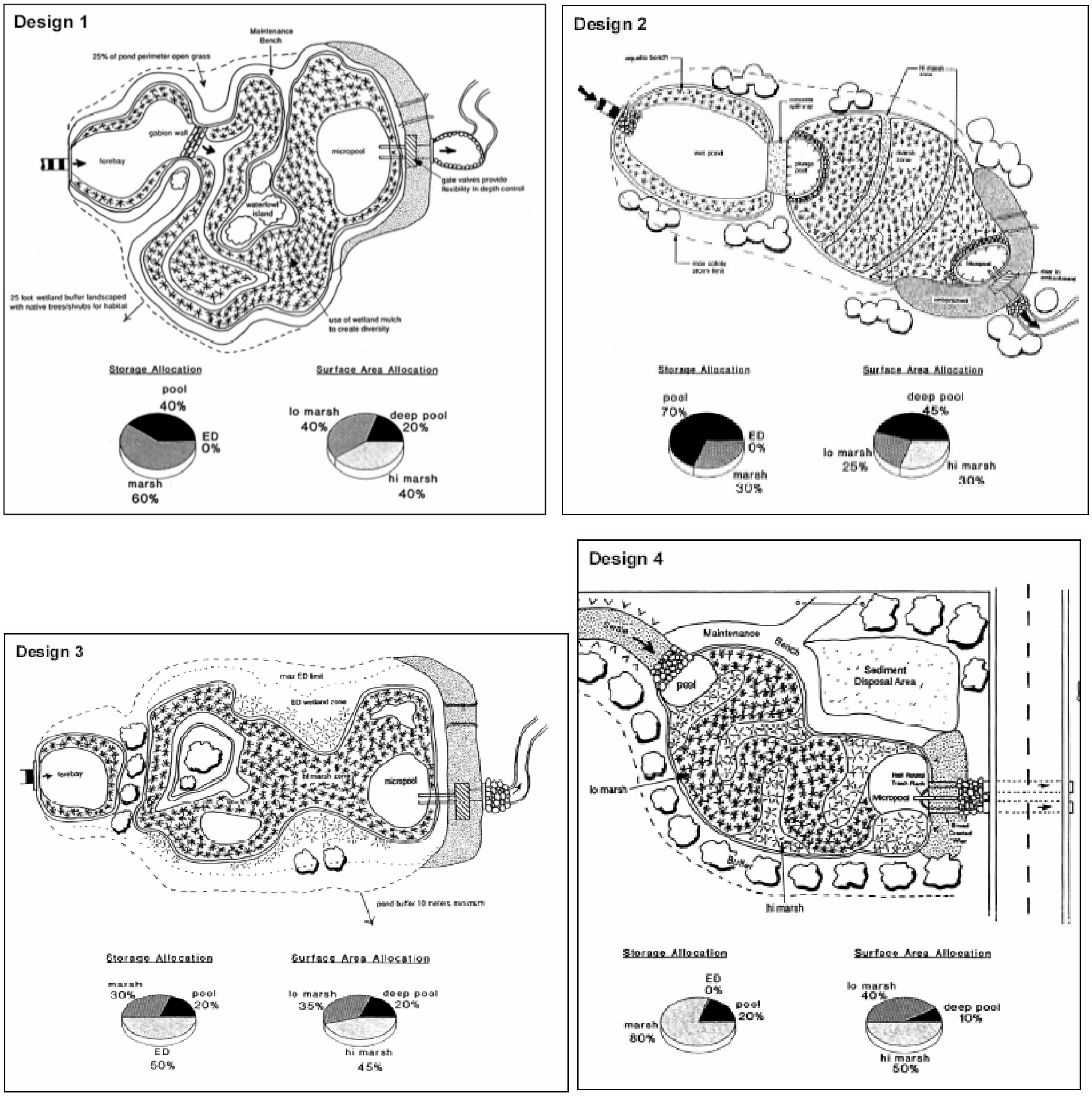

Figure 9. Design configuration of constructed wetlands as: 1) a shallow marsh, 2) a pond/wetland, 3) an extended detention wetland, and 4) a pocket wetland (Barr Engr. Co. 2001)

Four different configurations, shallow marsh systems, pond/wetland systems, extended detention wetland systems, and pocket wetland systems are shown in Figure 9 (Barr Engineering 2001). Each of these configurations includes a pool at the inlet and outlet for increased sedimentation of large particles and reductions of high incoming and outgoing flow velocities. These pools should reduce resuspension of accumulated sediment. For more information on each of these types of wetlands, please visit the link to the topic of Stormwater Wetlands at http://www.metrocouncil.org/environment/Watershed/BMP/manual.htm, as part of the Urban Small Sites Best Management Practice Manual.

Other BMPs can be used in conjunction with constructed wetlands for better treatment (Barr Engineering 2001). A non-uniform cross-section should be incorporated to provide diverse habitat for a variety of plants and other organisms (Shammaa and Zhu 2001). If the existing soils are not conducive for ponding, a liner of different soil or a synthetic material can be used (Federal Highway Administration 1997). When designed for TSS removal, constructed wetlands should have a minimum detention time of 24 hours for a 2-year storm (Shammaa and Zhu 2001). General guidelines for design include (Earles 1999):

- Simple design
- Minimal maintenance
- Design for extreme conditions and scenarios
- Use existing topography
- Mimic nearby natural systems

Safety Concerns

As with any structure designed to hold water, wetlands have the safety issue of thin ice that should be addressed with signage or fencing. Additionally, one survey respondent included the use of wet ponds by waterfowl to be a potential hazard to motorists, and one might assume constructed wetlands could attract waterfowl as well.

Maintenance

During the establishment period, constructed wetlands may require monitoring of vegetation and hydrologic conditions. Maintenance can vary depending on the location of the wetlands with respect to residential areas. A properly designed forebay that traps sediment can limit maintenance to cleaning of the forebay and not the entire wetlands.

As shown in the layout for a pocket wetland, maintenance access for vehicles should be included in the design, and as recommended in several surveys, the forebays or inlet pools could be lined with a hard surface to facilitate cleaning.

Costs

Wide variations in wetland designs prevent accurate cost estimates, and there is little data available on the costs of constructed wetlands. However, it has been suggested that they cost 25% more than runoff ponds of equivalent volumes (CWP 2003). Constructed wetlands also require greater areas than runoff ponds of equivalent volumes, and this additional land may have significant costs. Some studies have shown costs that can vary from $748.89/acre to $19,200/acre in 1990 dollars (USEPA 1993).

Effectiveness in Snow

Because few optimal design criteria have been identified for constructed wetlands in temperate regions (Earles 1999), design considerations and effectiveness in cold regions are even less understood. In addition, most guidelines have not been developed from measurable data.

However, there are some modifications suggested for the use of constructed wetlands in cold regions, which are similar to those for other structural BMPs, such as:

- Controlled outlets allowing drawdown in the fall to provide additional storage during the spring snowmelt (Oberts 2003).
- Ice-resistant outlets using steep gradients, oversized pipes, weirs, and riser hoods.
- Designed as an on-line system with continuous flow to reduce the potential ice formation (CWP 2003)
- Use of other BMPs in conjunction with a constructed wetland to enhance its effectiveness and provide more treatment than would otherwise be possible during winter months.

Sediment Removal Efficiency

Equations for sediment removal are presented in section 3.7.4.

Constructed wetlands can remove very high levels of suspended solids similar to other wet ponds, since they have very slow flow velocities and shallow flow depths. Additionally, other pollutants can be removed by constructed wetlands to a greater degree than other systems as a result of biological activities. Such activities can significantly taper off during winter months; however, some research has shown that certain species of plants can remain highly effective during winter months (Hook et al. 2003)

Pollutant removal can be increased with the following measures (Earles 1999):

- Increasing volume to increase residence time
- Increasing the ratio of surface area to volume
- Increasing the length of the flow path
- Increasing the level of pretreatment of inflow

3.3.2 Submerged Gravel Wetlands

Submerged gravel wetlands filter water through a submerged rock bed with wetland vegetation growing at the surface. This practice is most widely used for wastewater treatment and should not be used to remove suspended solids, or they can become clogged. In cold regions where highway runoff may have high concentrations of sand, submerged gravel wetlands have limited applicability. They should be considered as a tool mainly designed to treat urban runoff and to remove certain dissolved pollutants. Excessive pretreatment to remove suspended solids may be needed when used in cold regions.

1.4 Infiltration

3.4.1. Infiltration Trenches, Basins, and Meadows

Infiltration trenches, basins, and meadows all treat runoff and reduce its volume by providing a structure to promote the infiltration of runoff into the surrounding soil. The soil treats runoff in the same way that soil treats wastewater coming from a typical septic tank and drainfield system used by most rural homeowners. Similar to a wastewater system, an infiltration system designed for runoff needs a pretreatment structure similar to a septic tank to remove suspended solids. The soil will trap suspended solids in pore spaces where such solids will block the movement of water and reduce or prevent the percolation of further inputs of water.

Infiltration systems can have a limited potential to treat runoff for chlorides, but the consequences of chloride addition to groundwater should be considered. In the Lake Tahoe region, infiltration has been found to be the only effective method of removing fine silts, clays and phosphorus (TIRRS 2001).

One-third of the states responding to our survey reported using infiltration systems. In another survey (Caraco and Claytor 1997), one-fourth of the respondents recommended using infiltration trenches and basins.

3.4.2. Porous Pavement

The use of porous pavement in cold regions faces even greater challenges than other infiltration systems. Porous pavement has been traditionally limited to parking lots without heavy truck traffic, and traction materials such as sand should not be applied on porous pavement. Some porous pavements face a high potential risk of damage by snowplows. (MOLWAP 2004, CWP 2003, Caraco and Claytor 1997).

3.4.3. Bioretention

Bioretention systems receive runoff from impervious areas, and treat it very similarly as infiltration BMPs and filtration BMPs would. Water is filtered through a constructed soil bed and then collected in an underdrain system for discharge. The incorporation of vegetation allows some water to be lost through transpiration. These systems are typically smaller features such as islands in parking lots, and they may pass the runoff volume from large storms to a storm drain system, as they are typically off-line systems (Caltrans 2004).

Because bioretention systems rely on the percolation of runoff through a bed of soil, they are not well suited for removing suspended solids. If used to treat runoff, bioretention systems require pretreatment to remove such suspended solids, or the system can become clogged and fail like any infiltration system.

More information on infiltration BMPs and porous pavement can be found in the Runoff BMP Design Supplement for Cold Climates (Caraco and Claytor 1997). Information on Bioretention can be found in the Minnesota Urban Small Sites BMP Manual – Stormwater Best Management Practices for Cold Climates (Barr Engineering Company 2001).

1.5 Filtration

3.5.1. Surface and Subsurface Sand Filters

Sand filters are most useful in urban areas where a high level of runoff treatment is desired. Although they can be highly effective in removing suspended solids, sand filters can quickly clog when treating high levels of suspended solids such as sand in incoming runoff. Despite the effectiveness of sand filters in removing other pollutants, they do little to remove chloride from runoff.

The use of sand filters to treat runoff in Montana has limited application because high levels of suspended solids can clog them or thus require excessive maintenance, and they do not remove chloride. More information and detailed design criteria can be found in the Georgia Stormwater Management Manual (Haubner 2001) available at: http://www.georgiastormwater.com/.

1.6 Biofiltration

Biofiltration is the use of closely grown vegetation to filter runoff. The slow flow through the media allows particles to settle. Most biofiltration practices are also identified as open channel systems. This class of treatment systems is among the most recommended BMPs in cold climates (Caraco and Claytor 1997). One-half of the states responding to our survey reported using biofiltration practices.

The effectiveness of biofiltration treatment in Montana is limited by the short growing season when vegetation actively removes nutrients, and this limitation may also extend the time to establish a biofiltration BMP. Other limitations of applying biofiltration methods in cold climates include vegetation damage, reduced drainage due to buildup of salt and other deicers, impacts from snow storage, roadway scrapes from plowing, and heavy accumulations of sand (Watson 1994, Caraco and Claytor 1997, Davis et al. 1998). However, biofiltration methods have many advantages that make them a viable option in Montana.

Advantages of implementing natural materials in biofiltration practices include adding to the roadside aesthetics and preventing erosion while effectively treating runoff. Biofiltration is most effective when combined with other BMPs. As part of a system, a biofiltration BMP can be used as a conveyance structure that provides treatment. For instance, vegetated swales can be combined with detention ponds, infiltration trenches, constructed wetlands, etc. (Watson 1994).

3.6.1. Vegetated Swales

Applicability

A vegetated swale is a channel lined with vegetation that treats runoff as it flows through the vegetation at a shallow depth and relatively slow velocity (Figure 10). Swales can be used in place of a curb and gutter and are usually less expensive, however may require more land. Swales are usually designed for a 2-year storm event and hence cannot support large storms. They are best used as a complement to other BMPs capable of providing additional capacity for runoff (such as retention/detention ponds or infiltration trenches). If swales are used in conjunction with another such BMP, they should be placed after the BMP that controls the runoff quantity. Swales can be placed in either wet or dry formats.

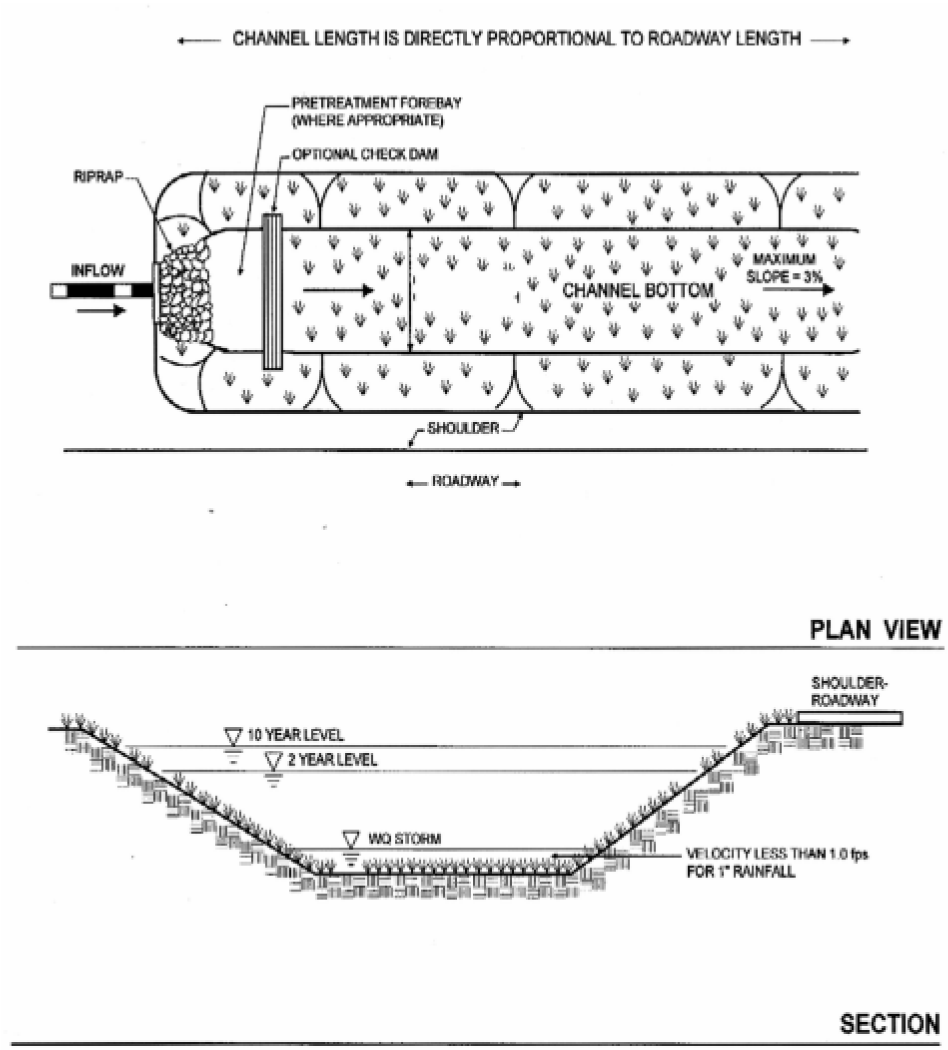

Figure 10. Plan and section views for a vegetated swale with water levels for different design storms (CWP 2003).

Site Criteria

The best locations for vegetated swales are naturally low topographic areas of uniform grade (e.g., roadside ditches). Vegetative swales are not recommended for highly arid areas where it is difficult to sustain growth (Watson 1994).

Swales are useful for runoff control in single-family residential subdivisions and on highway medians. Performance significantly diminishes for areas with higher concentrations of runoff, which consequently have higher runoff velocities (Watson 1994). To provide for additional runoff capacity, the vegetative swale could be used in addition to a pond type facility.

Engineering Characteristics

Flow in a swale is classified as open channel flow; hence, Manning's equation (see section 3.7.4) can be used to design the channel dimensions. Experiments conducted in Washington determined that a Manning n value of 0.3 was typical for grass swales mowed regularly (Colwell, Horner, and Booth 2000).

Design of a vegetated swale should meet four criteria (Watson 1994):

1. Maximum flow depth
2. Minimum retention time
3. Adequate channel capacity
4. Channel stability during high flow events

Recommended minimum swale length is 100 feet, and a study in Washington recommends that given the choice, the width of a swale should be over-designed as opposed to length to promote shallower flow (Colwell, Horner, and Booth 2000). Retention time is based on the swale length and design velocity found through Manning's Equation. Pollutant removal increases with increased retention times and ideally should be a minimum of nine minutes (Colwell, Horner, and Booth 2000). Check dams can be added to increase this retention time.

Maximum permissible velocities based on channel erosion characteristics of slope and vegetation cover were found experimentally in several studies. The velocities ranged from 2.5 feet per second for easily eroded soils with less densely spaced grasses on slopes greater than 5% to 6 feet per second for erosion-resistant soils with bluegrass turf on shallow slopes. A maximum permissible swale velocity of 4 feet per second is recommended for design considerations (Watson 1994). Recommended side slopes are 3:1 to 4:1 and a longitudinal slope between 1% and 2% (Caraco and Claytor 1997).

Details of design can be found in the Guidance for Design of Biofiltration Facilities for Stream Water Quality Control available at http://wms.geonorth.com/1999annual_report/c2.pdf, or from the Watershed Management Section, Municipality of Anchorage, Alaska.

Safety Concerns

Safety concerns for vegetated swales are the same as those for any open channel.

Maintenance

Vegetated swales require relatively low maintenance, which includes mowing and debris removal, and additional seeding and thatching as needed. Mowing is recommended as needed, usually once or twice per year (Barr Engineering Company 2001), to keep the grass an average height between 2 to 6 inches for best sedimentation (Watson 1994). If plants and woody shrubs are included in the swale vegetation design, harvesting and clearing of all decaying material should occur in the early spring.

Initial needs for the site include watering the turf area, and an irrigation line may need to be installed if the site is susceptible to dry weather (Watson 1994, Barr Engineering Company 2001).

Costs

Vegetative swales are relatively inexpensive and regenerative. Initial costs involve grading, laying topsoil, assembling seed mixes and associated planting costs, or associated costs to lay sod. Maintenance costs include initial site watering and mowing and debris removal over time. If the site is susceptible to dry weather and does not have access to irrigation, costs may involve the installation of an irrigation line. One study from Virginia and Taiwan estimated swale construction costs would range between $5 and $15 per linear foot (Yu et al. 2001).

Vegetative swales incur moderate capital costs and their effective life span is 5 to 20 years or possibly longer (Turner-Fairbank Highway Research Center 1999).

Effectiveness in Snow

Accumulation of sediment along road shoulders will prevent runoff from properly entering a swale or may bypass a filter strip (Watson 1994). Therefore, swales should be designed to account for an accumulation of sediment.

Vegetated swales are most effective during the summer months when the vegetation is actively growing. Impacts from the winter season on the swales are potentially significant and must be monitored. These impacts include vegetation damage, reduced drainage due to buildup of salt and other deicers, impacts from snow storage, roadway scrapes from plowing, and heavy accumulations of sand. The use of salt-tolerant vegetation should be considered.

Despite the loss of effectiveness of vegetated swales in the winter, they can remain effective if they have adequate vegetative cover, and they can act as permeable snow storage areas when located adjacent to highways (Caraco and Claytor 1997). This can be especially important in more urban settings. Although grass in vegetated swales can be dormant for most of the winter, it can still provide resistance to flow and cause the deposition of suspended solids. Vegetative swales can also provide some level of infiltration if located in well-drained soils (Jokela and Bacon 1990). The use of vegetated swales in this manner limits their application by soil type, depth to groundwater, and risks of frost heave to structures.

Sediment Removal Efficiency

Equations for sediment removal are presented in section 3.7.4.

One study (Barrett et al. 1998) discussed the fact that most design manuals would only recommend vegetative controls as pretreatment practices. The basis for the recommendation was low removal efficiencies for a few observational studies. However, it was suggested that those studies were not well designed and significant removal of the pollutants occurred before the runoff entered the test sections that were monitored.

A 9-minute residence time in vegetated swales generally provides slightly higher pollutant reductions over a 5-minute residence time and resulted in an 83% removal of total suspended solids (Watson 1994). In addition, vegetated swales can provide up to 99% erosion reduction (Barr Engineering Company 2001).

One study found the greatest factor for sediment removal in vegetated swales to be the addition of check dams, which increase the detention time of runoff and increase sedimentation. The same study also found that swales longer than 75 meters did not increase sediment removal regardless of slope (Yu et al. 2001).

3.6.2. Vegetated Filter Strips

Applicability

A vegetated filter strip is an evenly graded area covered by vegetation over which runoff flows at a very shallow depth. These grassy filter strips are often used as a pretreatment for other BMPs with a larger capacity, and this practice is best for smaller drainage areas as it is only able to treat low intensity rainfall events. The primary limitation in their applicability is the establishment of vegetation and the assurance of sheet flow; otherwise, filter strips are highly flexible tools (Federal Highway Administration 1997).

Site Criteria

The best locations for vegetated filter strips are naturally low topographic areas of uniform grade (e.g., roadside ditches), and filter strips can easily be placed along roadsides. Vegetative filter strips may be difficult to establish in arid areas where it is difficult to sustain growth, but they can be used almost anywhere else.

Engineering Characteristics

Vegetated filter strips should have a minimum length of 25 feet, slopes between 2% and 6% (Caraco and Claytor 1997), and the slope of the contributing drainage area should not exceed 10% (Watson 1994). To allow for uniform sheet flow, the maximum recommended impervious drainage area for vegetated filter strips is 5 acres (Watson 1994). A flow-spreading device should be installed to uniformly distribute flow across the filter strip. If the flow is entering from a curb, allow 1-foot curb cuts per every 5 feet of curb length (Watson 1994). The primary goal in filter strip design is a shallow, uniform, sheet flow of runoff with a slow velocity that allows the settling of suspended particles such as sand.

The majority of pollutant removal has been noted to occur at the pavement edge; hence, the length of the filter strip did not directly affect the amount of removal (Barrett et al. 1998). Another study found the first 30 cm of grass trapped the largest amount of sediment (Deletic 1999). The accumulation of sediment near the start of a filter strip should be considered in the design.

Details of design can be found in the Guidance for Design of Biofiltration Facilities for Stream Water Quality Control available at http://wms.geonorth.com/1999annual_report/c2.pdf, or from the Watershed Management Section, Municipality of Anchorage, Alaska.

Safety Concerns

Accumulated sediment near the edge of a roadway could block the flow of water and puddle water onto the roadway.

Maintenance

Vegetated filter strips require similar maintenance to vegetated swales (section 3.6.1). They require mowing, debris removal, and possible re-seeding (Barr Engineering Company 2001). Additionally, vegetation damage and sediment accumulation should be monitored.

Costs

Vegetated filter strips are a relatively low-cost practice, and costs can be similar to those of vegetated swales. Vegetated filter strips can easily be placed along roadsides at a low cost and with a longer effective life (20 to 50 years) than a vegetated swale (Schueler 1987).

Effectiveness in Snow

Vegetated filter strips are most effective during the summer months when the vegetation is actively growing, but not limited to use during such months. Healthy vegetation can still promote sedimentation despite winter conditions.

Impacts from the winter season on the filter strips can be significant and must be monitored. These impacts include vegetation damage, reduced drainage due to buildup of salt and other deicers, impacts from snow storage, roadway scrapes from plowing, and heavy accumulations of sediment that may induce channelized flow.

Vegetated strips have potential to be used as valuable permeable snow storage areas that allow for some meltwater infiltration (Caraco and Claytor 1997).

Sediment Removal Efficiency

Equations for sediment removal are presented in section 3.7.4.

One study found that the pollutant removal efficiencies for vegetated filter strips vary, depending on their length. The details are listed in Table 6.

Table 6. Pollutant removal efficiencies (%) for filter strips (Yu et al. 1995)

Filter Length	TSS	TP	NO_3	Lead	Zinc
18-foot	27	22	6	2	17
50-foot	67	22	8	18	46
150-foot	68	33	9	20	50

Another study concluded that vegetated filter strips can trap a substantial percentage of all particles above 0.06mm, and they trap very few particles less than 0.006mm (Deletic 1999). It should be noted that the survey as part of this report found that DOT's within the US reported about 8% of their sand passing through the #200 sieve, which corresponds to particle sizes smaller than 0.075mm. Thus, vegetated filter strips have the potential to remove most of the sand that washes off roadways.

3.6.3. Native grass sod

Highway construction projects and newly constructed water conveyance features often contribute large amounts of sediment to nearby lakes and streams. Traditionally, vegetation is established to prevent the erosion that contributes this sediment. However, the establishment of vegetation requires time before it becomes effective in limiting erosion and the movement of sediment. During this establishment, non-native weed species have the opportunity to take hold, overcome the desired native, and require the application of herbicides.

In Montana, California and other parts of the world, researchers are studying the use of native grass sod for erosion control and water quality protection. This emerging technology will have direct application to biofiltration treatments. It has been estimated that despite high initial costs native grass sod will be very cost-effective because of reduced maintenance, reduced herbicide use, and increased environmental benefits.

.

Figure 11. Sod placed in channel for erosion control in Australia (Jimboomba Turf Group)

In Australia, the Jimboomba Turf Group produces a sod called STAYturf specifically for use in channels and other locations with high erosive forces (Figure 11). More information on this product can be found at http://www.jimboombaturf.com.au.

Native grass sod has been successfully implemented in Montana for erosion control on high slope highway sections. Recently, California DOT has funded a new research project to evaluate the efficiency and cost-effectiveness of the reinforced native grass sod for vegetated swales, strips and sediment control and to address the issues related to its preparation, installation, establishment, and maintenance. For more information on the ongoing research in California, please contact Dr. Xianming Shi at the Western Transportation Institute, (406) 994-6486.

Using native grass sod has the potential to provide immediate erosion control and sediment reduction. Given proper installation and site conditions, it can be established in a much shorter time frame than traditional seeding methods, and it has minimal maintenance requirements once established. As a result of quick establishment, weed species have limited opportunities for establishment and growth. Sod has been shown to remove up to 99 percent of total suspended solids in runoff, with a significant improvement compared with traditional seeding methods (USEPA 2002).

1.7 Implementing Structural BMPs for Montana

3.7.1. Timing of Pollutant Load in Snowmelt

Selection of an appropriate BMP requires knowledge of the interaction of the precipitation and the pollutants. Throughout the winter, snow and pollutants accumulate along highways. In the early stages of snowmelt, a first flush of meltwater and runoff, driven by a lower energy input resulting in lower water volumes, will contain high levels of soluble pollutants. During the mid-stages of snowmelt as energy and water volume increase, concentrations of soluble pollutants decrease and concentrations of solids increase. In the latter stages of snowmelt, water volume decreases, and the remaining solids are exposed to transport by rainfall. Understanding this process can provide aid in choosing appropriate BMPs (Oberts 2003). These stages of snowmelt are shown in Figure 12.

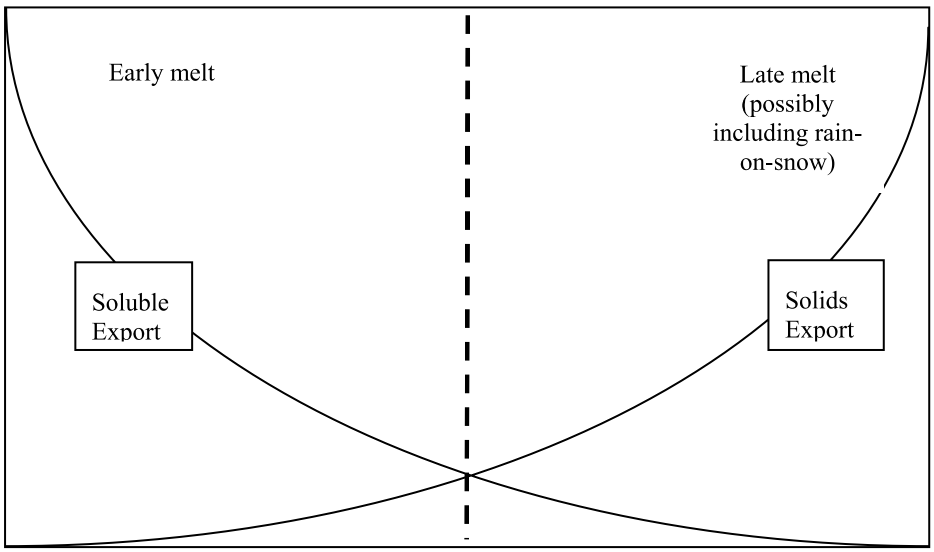

Figure 12. General progression of snowmelt and the associated pollutant loads (Oberts 2003)

A study of water quality in 2001, along I-70 in Colorado, led to results in agreement with the progression shown in Figure 12. Dissolved sodium and chloride concentrations were higher during snowmelt events than rainfall events, and suspended sediment concentrations were found to be as much as an order of magnitude higher during rainfall events than during snowmelt events (Clear Creek Consultants, Inc. and JF Sato & Associates 2002).

This general sequence illustrates a significant problem associated with winter maintenance. Early in the spring thaw, when flow rates are lower, dissolved pollutants may be transported by lower volumes and lower velocities. At this stage, receiving waters may be more vulnerable to the impacts of these soluble pollutants. Later, suspended pollutants such as sand may be carried by runoff with higher velocities and higher volumes that may reduce the efficiency of the structural BMP. These problems should be considered when choosing a structural BMP for a given site.

3.7.2. Criteria for Selecting Structural BMPs

Each structural BMP has its own characteristics and each site has its own challenges. Therefore, the structural BMP should be selected to adapt to these site-specific conditions. The consensus is that no single BMP option can be applied to all situations and a one-size-fits-all approach could result in spending resources for unnecessary or inappropriate treatment (Turner-Fairbank Highway Research Center 1999).

In order to select the right structural BMP, the character of stormwater or meltwater runoff should be taken into consideration. Table 7 provides information describing the meltwater and the criteria for selecting a BMP.

Table 7. Meltwater character and BMP focus, corresponding to Figure 12 (Oberts 2003)

Character of Meltwater	
High soluble content	High solids content
Low runoff volume, early infiltration	Large runoff volume (especially if rain-on-snow occurs), saturated soils
Initiated by chemical addition and/or solar radiation	Solar driven
BMP Focus	
Infiltration	Filtration
Dilution	Volume control
Pollution prevention (salt, chemical application)	Pollution prevention (anti-skid application)
Retention	Detention/settling
Wetlands/vegetation (infiltration, biological and soil uptake)	Wetlands/vegetation (filtration, settling)

After considering the pollutant of concern and its quantity, one should look more closely at other characteristics of the runoff such as its volume and velocity and determine the potential structural BMP options available to mitigate such runoff.

From these options, the selection of appropriate BMPs will be determined by site conditions, including physical characteristics and community and environmental factors. The placement of any structural BMP with respect to the roadway will be dependent on those conditions. These conditions include (Barr Engineering Company, Inc 2001 and TIRRS 2001):

- Topography
- Soils
- Local climatic conditions
- Runoff hydrology
- Drainage area

- Water table
- Factors affecting construction costs
- Winter maintenance needs and the associated pollutant load
- Proximity to wells
- Characteristics of adjacent water bodies
- Access for maintenance

The physical characteristics will determine whether there are physical constraints at the site that may restrict or preclude the use of a particular BMP, whereas the community and environmental factors will determine how the selected BMP mesh with the surrounding environment and any nearby community (Barr Engineering Company 2001).

Error! Reference source not found. provides a summary of selection criteria for structural BMPs, with a focus on the removal of suspended solids or dissolved pollutants, the characteristics of structural BMPs and their applicability in cold regions.

3.7.3. Common Problems with Structural BMPs

To address the challenges of implementing structural BMPs in cold regions, traditional design guidelines developed in temperate regions need adjustment. Several reasons for BMP failure in the northeastern U.S. (Cote et al. 2003) are:

1. *Undersized*: Many BMPs require excessive maintenance for adequate treatment of runoff as they are not sized to accommodate volume of suspended solids for a year's worth of traction sand. Unrealistic sizing can lead to high velocities of flow that can scour the bottom of the BMP and resuspend sediment.
2. *Lacking pretreatment*: Most BMPs need some sort of pretreatment such as a forebay to capture easily settled particles. This is especially important for wetlands and infiltration BMPs. These pretreatments should have easy access for cleaning or be designed appropriately to accommodate the accumulation of sediment.
3. *Using same design for all situations*: BMPs need to be designed for variations in hydraulics, hydrology, and pollutant loading on a case-by-case basis.
4. *BMPs not designed for worst-case scenario*: Beyond the volume of runoff, many designs are overly optimistic about the effectiveness of the BMP or other issues such as growth of vegetation, groundwater levels, or level of maintenance and inspection.

In addition to proper design, structural BMPs must also be sited, installed, and maintained appropriately in order to function effectively. The importance of proper maintenance of structural BMPs cannot be overestimated. All the structural BMPs, if they function properly, require both time and budget commitments for maintenance in order to continue to function and to be successful over time. Many structural BMPs fail due to the lack of continued support for maintaining the installed facilities.

Table 8. Summary of selection criteria for structural BMPs

Structural BMP	**Removal of Suspended Solids**	**Removal of Dissolved Pollutants**	**Relative Costs**	**Relative Maintenance**	**Difficulty of Use in Cold Climates**	**Other Requirements and Concerns**
Dry Pond	Medium/High	N/A	Low	Low	Low	-
Wet Pond	High	Low	Low/Medium	Low	Low/Medium	Needs year round water
Wet Extended Detention Pond	High	Medium	Low/Medium	Low	Low/Medium	Needs year round water
Wet Vault	Medium	N/A	Medium/High	High	Medium	Needs regular cleaning
Sand Can	Low	N/A	Low	Medium	Low	Primary use as pretreatment
Proprietary Wet Vaults	Medium/High	N/A	High	Medium	Variable	Can be expensive
Constructed Wetland	High	Medium/High	Medium	Low/Medium	Medium	Monitor development of vegetation
Submerged Gravel Wetland	N/A	High	High	Medium	High	Needs pretreatment
Infiltration	N/A	High	Medium	Medium	High	Needs pretreatment
Porous Pavement	N/A	High	High	Medium	Medium	Cannot use traction sand
Bioretention	N/A	High	High	Medium	High	Needs pretreatment
Filtration	N/A	High	High	High	High	Needs pretreatment
Vegetated Swale	Medium	Low	Low	Low	Low	Check dams improve performance
Vegetated Filter Strip	Medium	Low	Low	Low	Low	Ensure sheet flow

3.7.4. Sediment Removal Factors

To properly design and develop a structural BMP with realistic performance expectations, the sediment removal factor needs to be considered. The governing equations include Manning's equation, Stokes' law, and the removal efficiency equation. Manning's equation defines flow in an open channel, Stokes' law defines the settling velocity for discrete particles, and the removal efficiency equation defines the fraction of a given particle size that can be removed by settling under specific conditions.

The following inputs are required to determine sediment removal or delivery: flow velocity, flow depth, flow length, and settling velocity of the design particle size.

Flow velocity is determined by Manning's equation, using the geometric parameters:

Equation 4. Manning's Equation

$$V = 1.49/n\,(R^{2/3})\,(S^{1/2})$$

Where: *V = Open channel flow velocity (ft/s)*

n = Manning roughness coefficient (0.3 for regularly mowed grassy swale)

R = Hydraulic radius = A/P_w *(ft)*

A = Cross-sectional area (ft^2)

P_w *= Wetted perimeter (ft)*

S = Slope (ft/ft)

From the survey conducted as part of this report, DOTs within the U.S. reported as much as 8% of their sand passing through the #200 sieve, which corresponds to particle sizes smaller than 0.075mm (very fine sands and smaller). These sizes tend to be of the most environmental concern, as larger particles will be removed in larger quantities if the smaller particle size is selected for design. Stokes' law can give the settling velocity for particles smaller than 0.075mm.

Equation 5. Stoke's law for settling velocity

$$V_s = \frac{g(\rho_{Particle} - \rho_{Water})d_P^2}{18\mu}$$

Where: Vs = Settling velocity of a discrete particle (ft/s)

g = Acceleration due to gravity (ft/s^2)

ρ *= Density* $(slug/ft^3)$

D_p *= Diameter of particle (ft)*

μ *= Dynamic viscosity of water* $(lb*s/ft^2)$

Assuming a water temperature of 5°C (40°F), the settling velocity for a very fine sand particle (particle sizes equal to 0.0625mm) would be 0.0023 m/s, and the settling velocity for a silt particle (particle sizes equal to 0.031mm) would be 0.0006 m/s. These velocities can be used to calculate the theoretical removal efficiencies for structural BMPs such as dry ponds.

Equation 6. Removal efficiency equation for flowing water

$$\text{Removal Efficiency} = 1 - e^{-XV_s / hV}$$

Where: X = Length of flow path (ft)

V_s = Settling velocity of a discrete particle (ft/s)

h = Flow depth (ft)

V = Average flow velocity (ft/s)

(Adapted from literature: Julien 1998)

It should be noted that Equation 6 calculates the removal efficiency for a specific particle size, not an entire range of suspended particles. Most reported values of removal efficiency for BMPs include the entire range of sizes.

In the removal efficiency equation, a greater flow length yields higher removal efficiency. This makes sense because a greater flow length would result in a greater detention time for a given flow velocity. Also, a smaller value for h yields higher removal efficiency. Consequently, ponds with greater flow lengths and more shallow depths will generally have higher removal efficiencies.

3.7.5. Sediment Delivery Factors

Equation 6 determines the removal efficiency of suspended sediment, and thus is useful for determination of design parameters for many structural BMPs. However, there may be times when sediment delivery is desired over sediment removal so that suspended solids can remain suspended until reaching a desired location. This location may be a structural BMP, or a location where such sediment can be easily cleaned by sweepers or heavy machinery. The exact opposite set of criteria from sediment removal can be applied and the appropriate equation is found by simply subtracting the removal efficiency from 1 or using Equation 7:

Equation 7. Delivery efficiency equation for flowing water

$$\textit{Delivery Efficiency} = e^{-XV_S / hV}$$

Where X, V_s, h, and V are the same variables as in Equation 6

To increase the rate of sediment delivery, or decrease sediment removal, the following factors can be adjusted as needed.

- Increase flow velocity (V), slope (S), hydraulic radius (R), or flow depth (h)
- Decrease flow length (X) or roughness (n)

From Manning's equation, it can be seen that changing any one of these parameters will affect other parameters. This set of factors will have to be balanced in order to optimize the delivery of sediment to a desired location. Additionally, changing factors such as flow velocity and depth will have to be balanced with concerns that include erosion and public safety.

3.7.6. Role of Vegetation

Vegetation increases the roughness of a slope or a channel; therefore, it slows down the flow velocity by increasing the n-value in Manning's equation. The Handbook of Channel Design for Soil and Water Conservation, SCS-TP-61, provides information on different n-values for different vegetation under different flow regimes (Stillwater Outdoor Hydraulic Laboratory 1954). Vegetated surfaces interrupt and divert the flow of runoff and help permeable surfaces perform a filtering function. In addition to preventing or reducing soil erosion, vegetation can also remove nutrients and other pollutants through plant uptake and adsorption (Hyman and Vary 1999).

In addition to roughness, other major factors that determine suitable vegetation include: resistance to drought, native vs. non-native species, required maintenance, and tolerance to salt.

Many DOTs have developed successful programs such as integrated roadside vegetation management (IRVM) that results in many benefits including: safety, economic, flexibility, environmental, appearance, and public relations (Henderson 2004).

3.7.7. Example Selection of Structural BMP

While other structural BMPs may be acceptable, final selection of BMPs should be based on site-specific conditions, as described in section 3.7.2. The following scenarios illustrate two conditions typical in Montana and possible structural BMP selections are provided for each.

Scenario A: A segment of interstate highway through a high pass with heavy winter precipitation

Possible BMP: Because this scenario includes heavy winter precipitation on an interstate highway with a high level of service, heavy use of both sand and deicers should be expected. In the spring, heavy flows from snowmelt could also be expected. Hard surfaces should be used wherever possible to facilitate sediment removal in the spring and to provide resistance to erosion from heavy flows. The use of vegetated swales and filter strips should be limited, as the establishment of vegetation may be difficult in a high pass, and these vegetated practices may be overwhelmed from the heavy use of sand. However, after initial treatment, a vegetated swale may be an appropriate conveyance structure that would have limited impacts from ice formation in contrast to pipes and other conduits.

One appropriate structural BMP might be a wet extended detention pond. The permanent pool in this pond might capture chlorides early in the spring thaw and hold them long enough for some treatment or, more likely, dilution following heavier flows. The extended detention capacity should provide sufficient volume for these heavier flows, and it could be designed with a detention time to remove most of the incoming suspended solids such as sand. Section 1.2 provides more information and suggested modifications for ponds and other detention facilities in cold climates.

Scenario B: A segment of a two-lane rural route through a broad valley

Possible BMP: This route may have a lower level of service than an interstate highway, and the expected winter precipitation should be lower than that of a mountainous pass. With a lower level of service and lower precipitation, the use of less sand and deicers should be expected. In a broad valley with gentle topography, vegetated swales and filter strips could provide sufficient treatment of the highway runoff. Flow velocities could be lower than those of scenario A, as the area of paved roadway, the volume of snow, and the average slope of the surrounding land would be less. Potentially better soils, lower flow velocities, and lower amounts of sand would all allow relatively easy use of vegetated structural BMPs. These BMPs are expected to achieve high levels of sediment removal, as even unconstructed vegetative areas were estimated to provide an average 69% sediment removal efficiency by respondents to our survey. Section 1.6 provides more information on vegetated swales and filter strips.

NON-STRUCTURAL BEST MANAGEMENT PRACTICES

Non-structural BMPs are preventative measures designed to reduce the amount of traction materials applied on roadways, which thus can reduce the need for, or dependence on, many structural BMPs*. Often, non-structural BMPs can reduce the costs of winter maintenance in addition to minimizing the environmental impacts while preserving public safety as a priority. They are procedures, protocols, and other management strategies that would help keep pollutants out of drainage courses or aquatic ecosystems.

Non-structural BMPs are usually not limited by the weather or land use. If issues related to implementation are addressed well, non-structural BMPs can be easily adopted. The details of major non-structural BMPs are described in this chapter.

1.1 Incorporating Environmental Staff into Construction and Maintenance

Several state DOTs have added environmental staff to assist maintenance personnel in meeting environmental goals and implementing planned improvements. New York and Virginia DOTs provide the most far-reaching and staff-rich models. The environmental specialists enhance communication, while providing training, oversight, quality assurance, and technical advice. They are involved in supporting construction and maintenance operations and monitoring erosion and sediment control activities. They spend approximately 50 percent of their time in the field working directly with maintenance and construction staff, developing new beneficial practices, and promoting hands-on environmental stewardship (Rentch 2004).

1.2 Proper Training of Maintenance Professionals

Proper training for maintenance personnel is imperative, serving as the key to technology implementation. Providing guidelines to managers and operators for winter traction materials application and equipment handling is an important step in ensuring the best possible practices to be employed. For instance, New York State DOT trains staff in salt management reduction techniques and has documented usage reductions over several seasons.

It may be beneficial to conduct training courses early in the fall months, which serve as a refresher course for seasoned personnel or as an introduction of winter maintenance and snow removal tactics to new employees (The Salt Institute 1999). The meeting can also be useful in reviewing operations to find areas in which efficiency can be improved.

4.2.1. MDSS

The Federal Highway Administration has been developing a Maintenance Decision Support System (MDSS) designed to collect and interpret weather and mapping data from many sources. With the right information, winter maintenance managers can respond proactively by managing the infrastructure and deploying resources in real time. The anticipated benefits include reduced

* While one could argue that the proper maintenance of structural BMPs should be considered as an important non-structural BMP, this report does not elaborate on it.

operating expenses, a higher level of service, and more efficient use of chemicals which reduces impacts on the environment (Federal Highway Administration 2003, Pisano et al. 2004).

The MDSS was designed with the needs of state DOTs in mind and allows state winter maintenance managers to view predicted weather conditions throughout the state, predict impacts of weather on road conditions, plan treatment scenarios based on available resources, and receive treatment recommendations based on proven rules of practice.

The prototype MDSS allows state DOTs to customize the system and a live display of the Iowa MDSS is shown in Figure 13 (RAP 2001). The Current shortcomings for the MDSS software include difficulty with blowing snow, limitations in the 24hr to 48hr forecast, and a lack of a scheduling component for personnel. However, it proves to be a highly useful tool in integrating weather data and forecasts with maintenance decisions. For more information, please visit http://ops.fhwa.dot.gov/weather/index.asp or contact Paul Pisano at Road Weather Management, FHWA, Office of Operations, (202) 366-1301, paul.pisano@fhwa.dot.gov.

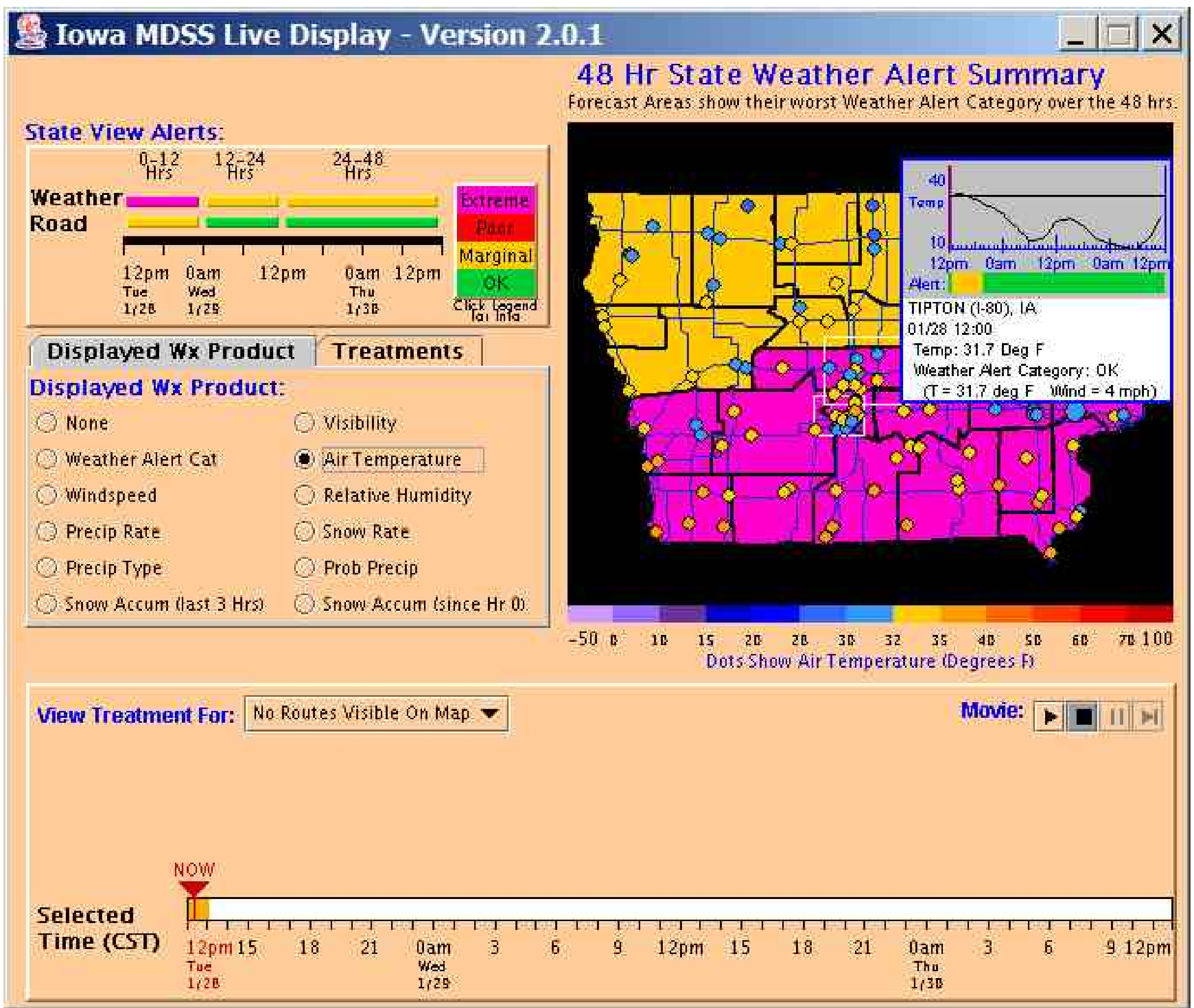

Figure 13. MDSS live display of road and weather information (RAP 2001)

4.2.2. Computer Based Training

Lack of effective and scientifically based training has hampered progress in the implementation of anti-icing and road weather information system (RWIS) technologies. In order to take advantage of the many new technologies available, a computer based training (CBT) program has been developed by the Snow and Ice Pooled Fund Cooperative Program, and a generic version was distributed in April 2003 to be adjusted by receiving states.

This highly interactive software was designed for both supervisors and field operators, and it will be updated to remain consistent with the MDSS software and other new technologies. It also has the flexibility to allow the user to work through the training from start to finish or to reference certain sections individually. More information on the status of this software can be obtained from Leland Smithson, Bureau of Research and Technology Transfer, Iowa Department of Transportation, leland.smithson@dot.state.ia.us (Smithson 2003).

4.2.3. Simulator Training

Utah DOT successfully completed a pilot snowplow driver training with the GE Driver Development using snowplow simulators. The snowplow simulator (as shown in Figure 14) presents drivers with simulated winter environments, allowing them to hone their skills (Fraughton 2003). For more information, please contact Darrell A. Rupp, Operations Performance Manager, (801) 303-5696 or Darrell.rupp@ge.com.

Figure 14. The snowplow simulator at GE Driver Development (Fraughton 2003)

1.3 Erosion Control

Erosion is the process of separating and transporting soil away from its base by water, wind, or gravity. Although erosion control is a particular concern for new construction, maintenance activities can lead to erosion as well. Removal of vegetation, disturbance of topsoil, compaction, and creation of steep slopes are among the many causes of erosion (Hyman and Vary 1999).

Effective erosion control requires a systematic approach, which takes into account government regulations and permitting requirements; design, construction, and maintenance considerations;

various temporary and permanent erosion control methods; and new technologies (Johnson et al. 2003).

The common devices for temporary erosion control include: earth diversions and swales; erosion control blanket and stabilization mats; mulching and turf establishment; ditch checks; sandbag barrier; silt fence; soil berms; temporary slope stabilization and pipe downdrain; and triangle silt dikes (Johnson et al. 2003).

The common devices for temporary sediment control include: biorolls; drainage swales; inlet protection; perimeter control; sediment basins; sediment traps; silt curtain; silt fence; standpipes; and treatment basins (Johnson et al. 2003).

The common devices for permanent erosion control include: design elements; ditches and liners; detention pond; riprap; runoff spreaders; soil bioengineering; and turf establishment. It should be noted that many erosion problems could be simply avoided by good design practices (Johnson et al. 2003).

A combination of adequate drainage, installation of protective devices and elements, and establishment of desirable vegetation offer the best means for soil conservation. For instance, staged seeding as areas of a project are complete can reduce erosion by 90% (Johnson et al. 2003).

A large amount of detailed information is available in the MDT manual, *Erosion and Sediment Control Best Management Practices*[*] (CDM 2004), or the Minnesota Local Road Research Board manual, *Erosion Control Handbook for Local Roads* (Johnson et al. 2003).

1.4 Snow Fences

Snow fences are an old technology designed to capture wind-blown snow before it accumulates on a roadway[+]. They work in a way very similar to many of the structural BMPs designed to remove suspended solids in runoff. A snow fence reduces the velocity of wind to the point at which it can no longer carry snow; consequently, the wind deposits snow at or near the snow fence. In many areas along roadways, the wind consistently forms drifts of snow year after year. These areas are ideal locations for snow fences.

Research has shown that areas protected by snow fences can be 10°F or more warmer than adjacent unprotected road pavement, and the dramatic effect of snow fences on road surface conditions provides a compelling argument for mitigating blowing snow with roadside vegetation as well as fences (Tabler 2004).

[*] Available under the MDT's Research Program at http://www.mdt.state.mt.us/research/projects/env/erosion.shtml.

[+] Complete design guidelines can be found in the SHRP Publication SHRP-W/FR-91-106 available at: http://www4.trb.org/trb/onlinepubs.nsf/web/Highway_Operations_Reports.

By reducing or eliminating wind-deposited snow on roadways, snowplows have less snow to plow, and they can use less traction materials. Less wind-deposited snow means less money spent on winter maintenance. Typically, snowplowing costs 100 times more than the construction of snow fences (Tabler 1991). Snow fences reduced snow removal costs by more than one-third over a 45-mile section of I-80 in Wyoming in the 1970's (Tabler 1991). In addition to cost savings and environmental benefits, snow fences can improve driving conditions under certain winter conditions and make roads safer.

4.4.1. Living Snow Fences

Some states such as Minnesota use living snow fences, which are snow fences made of trees or shrubs. These living snow fences can cost less, require less maintenance, and be more aesthetically pleasing than traditional constructed snow fences. However, they require an establishment period before they can become effective. Additionally, they are difficult to adjust if designed incorrectly or wind patterns change.

The Minnesota DOT has produced a manual for design, installation, and maintenance of living snow fences, "Catching the Snow with Living Snow Fences", item #MI-07311[*]. Minnesota also purchases crops such as corn to act as temporary living snow fences. In 2003, they purchased standing corn that protected 20 miles of highway[+].

1.5 Snow Storage

Snow piles containing sand, salt, trash and debris generate concentrated releases of pollutants during spring thaw and rain events. For this reason, it is important to properly store snow removed from roadways in adequately prepared areas. Actions can be taken to minimize negative impacts of sediments and litter found in a snow pile on surrounding surface waters. Considerations for a snow disposal site include (TAC 2003):

- Ensure roadway safety will not be affected.
- Clearly identify boundaries that will be visible under adverse winter conditions.
- Minimize the effects on surrounding environment.
- Manage the volume of meltwater.
- Remove debris, litter, and sediment that accumulate after each winter.
- Select a location that does not require excessive maintenance.
- Isolation from drinking water well supplies (USEPA 1988), at least 75 feet from private wells and 200 feet from community wells (TIRRS 2001).

---

[*] Available from the University of Minnesota Extension Service at 405 Coffey Hall, University of Minnesota, St. Paul, MN 55108-6068.

[+] For more information on this program, please contact Dan Gullickson, Mn/DOT Living Snow Fence Coordinator at (651) 284-3763 or Daniel.Gullickson@dot.state.mn.us.

The management of meltwater should include (TAC 2003):

- Collection of contaminated meltwater to a pond for treatment.
- Drainage of meltwater away from snow piles.
- Reduction of meltwater volume with permeable soils (CWP 2003).
- Possible dilution of meltwater with uncontaminated runoff.
- Sufficient volume of pond to handle maximum probable meltwater volumes.
- Regulated release from the pond.
- Easy access for maintenance such as the removal of sediment.

Road construction can incorporate snow storage in its design for the purpose of sand recovery. Such a system was constructed on Berthoud Pass, Colorado on Highway 40 (Figure 15). This system allowed snow to be piled along the roadway in storage areas with similar cross-sections to a swale. These storage areas were configured parallel to the roadway so that plows would deposit snow in them throughout the winter. A drain system was placed under the storage areas to collect the snowmelt and any sediment and carry it to detention ponds (Guo 1999).

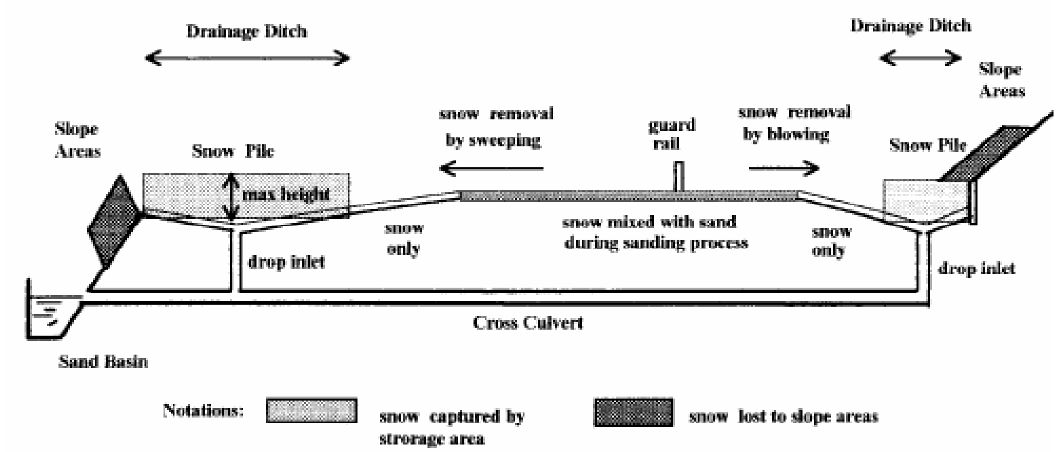

Figure 15. Snow storage and collection system in Colorado (Guo 1999)

Such a system could have a high cost; however, it demonstrates the incorporation of snow storage and sand recovery into roadway design. Another key component of the design in Figure 15 that is not shown is the isolation of "clean" runoff, coming from the cut slope on the right side of the figure, from highway runoff. This runoff separation reduces the runoff volume that requires treatment. More detailed information on this can be found in the Sediment Control Action Plan (SCAP) for both the Black Gore Creek and Straight Creek I-70 Corridors (CDOT 2002). Questions on the SCAPs can be directed to Terri Tiehen, Water Quality Program Manager, (303) 757-9285, Theresa.Tiehen@dot.state.co.us, or Mike Crouse, Clear Creek Consultants, (303) 215-0040, clearcr@ecentral.com.

Utah has used storage areas at some of their maintenance yards that allow for evaporation, as the climate has very low humidity. For more information, please contact Lynn Bernhard, P.E., Methods Engineer, Utah DOT, Maintenance Planning Division, (801) 964-4597.

For snow disposal, the following practices should be considered: location and construction of the sites to take into account operational and environmental factors, drainage management, training of personnel and monitoring of the effectiveness of the facility (Environment Canada 2004).

1.6 Street Sweeping

The implementation of adequate street sweeping practices can aid in the prevention of inadvertent pollutant transportation to, and filling of, adjacent water bodies.

Timing and frequency of street sweeping are critical to obtaining adequate removal rates, and a well-planned schedule for street sweepings can optimize pollutant removal. In order to remove the greatest amount of winter sand and salt debris, sweeping should occur when materials on roadways are at their peak, in the early spring shortly after snowmelt but before any significant rainfall events occur. The percent reduction of TSS loading has been shown to be dependent on the number of cleanings per year, with optimal cleaning and removal occurring from weekly sweeping.

In the past few years, research has shown street sweeping to effectively reduce pollutant loads from roadways due to improvements in equipment and sweeping methods. Compared with traditional broom and conveyor belt (mechanical) sweepers, vacuum-assisted and regenerative air sweepers are more effective at picking up fine particulates. Improved methods, such as tandem sweeping, consisting of mechanical sweeping followed immediately by a vacuum-assisted sweeping, has dramatically increased particulate removal efficiency. A recent study in Wisconsin found that street sweeping can be highly effective in reducing sediment in runoff; however, it noted the need for high speed sweepers for use on highways and the development of a street sweeping program with maintenance guidelines (Martinelli et al. 2002). Although the cost of high-end sweepers (i.e., regenerative air sweepers or combined broom and vacuum in one) may be 2 to 2.5 times the cost of a traditional sweeper, the operation costs and service life are shown to be comparable (Dupuis 2002).

Street sweepings may be tested for pollutants such as total petroleum hydrocarbons, polynuclear aromatic hydrocarbons, and metals such as lead, chromium, and cadmium. The sweeping disposal options include: land-applied, landfill, bio-treatment, and thermo-treatment. According to the Iowa DOT, land-applied, or recycled street sweeping, is the most inexpensive option, followed by landfill (Hyman and Vary 1999).

Reuse of road sanding materials, for applications such as construction aggregates, may also be considered. Because road sand may contain salts and other residuals, quality controls may need to be applied. Proper placement of storage and disposal sites is critical to reuse planning and careful attention should be paid to the proximity of these sites to wetlands, watercourses, and wells, in addition to accessibility of these locations throughout all seasons (MOLWAP 2004).

Requirements for angular sand particles as traction materials limit the reuse of sand for winter maintenance. The Colorado DOT found that vehicle traffic significantly reduces the angularity of sand particles, thus making them unsuitable for reuse (CDOT 2002).

4.6.1. Sand Accumulation around Barriers

Barriers along a roadway can allow sand to accumulate around their base, where street sweepers and heavy equipment such as front-end loaders are unable to reach such sand. No innovative methods were discovered in the research for this report. Current methods for removing this sand include the use of shovels and small skid steer loaders. Many vacuum-assisted sweepers have attachments for a hose that could be used as a vacuum in some situations to remove this sand. Other options include the use of water to wash out such sand to a location where a sweeper or structural BMP could collect it, and the redesign or replacement of such barriers.

Snow storage in areas easily accessible by sweepers and other machinery can also aid in reducing the amount of sand accumulated around roadside barriers. Snow storage is discussed in more detail in section 1.5.

With the reduced use of sand, there is little need to deal with the sand accumulated around barriers. A reduction in the use of sand during the winter in Utah has decreased the amount of sand to be removed in the spring. Street sweepers can now cover fifteen lane miles instead of six lane miles before needing to empty their load (pers. comm. with Lynn Bernhard, P.E., Utah DOT).

1.7 Improved Anti-icing and De-icing Practices

Traditionally, de-icing is the approach followed by agencies with responsibility for snow and ice removal. After snowfall, the de-icing process uses granular materials that penetrate accumulated snow and ice in order to break the bond that has formed with the roadway. Once the bond is broken, snowplows can remove the layer of snow and ice. As a reactive strategy, the de-icing practice is generally reliable and well understood.

However, in the past decade or so, a new approach termed anti-icing has been adopted by winter maintenance personnel, which aims to prevent the bonding of ice to the roadway by spreading chemicals before the snowfall. While it is possible and appropriate under certain circumstances to use solid chemicals for anti-icing, liquids are more commonly used (Nixon and Williams 2001). As a proactive strategy, successful use of anti-icing chemicals requires application immediately prior to a storm, especially regarding to the onset, type, intensity and duration of winter storms, and thus entails accurate weather forecasts.

The benefits from appropriate anti-icing include: improved level of service, cost savings, better maintenance response, improved environmental quality, and indirect or other benefits (Bosely 2001). When applied correctly, anti-icing can reduce the required plowing and decrease the quantity of chemicals used (USEPA 1999). In many conditions, anti-icing eliminates the need for abrasives because it eliminates the cause for slipperiness (Williams 2001).

The benefits of anti-icing were demonstrated in a comparison between two maintenance divisions in Montana between the years 1997 and 2000. One division used anti-icing operations to a greater degree and achieved a higher level of service with a 37% cost savings per lane mile (Goodwin 2003). Anti-icing programs also led to success stories in many other states, including Idaho, Minnesota, Oregon, Washington, and Colorado.

De-icing typically requires much larger quantities of material than an appropriately timed anti-icing application. However, de-icing is still an appropriate technique for roadways with lower priority service levels (Ketchum et al. 1996), and it does not require accurate weather forecasts. Additionally, it can be used in situations when the weather forecasts were inaccurate, or anti-icing was ineffective.

4.7.1. Chemicals for Anti-icing and De-icing

For anti-icing and de-icing purposes, chemical deicers (such as road salt) are usually spread out on roadways to melt ice and snow by lowering the freezing point of the snow-salt mixture. The widely used deicers include: sodium chloride, calcium chloride, magnesium chloride, potassium acetate, calcium magnesium acetate, and biobased deicers. These chemicals can all be effective in snow and ice removal, and each product has its own advantages and disadvantages.

Concerns have risen regarding the negative impacts that chemical deicers pose on the environment, motor vehicles, and infrastructures. One study estimates that road salt imposes infrastructure costs of at least $615 per ton, vehicle corrosion costs of at least $113 per ton, aesthetic costs of $75 per ton if applied near environmentally sensitive areas, plus uncertain human health costs (Vitaliano 1992).

Sodium Chloride

Sodium chloride ($NaCl$), or salt, is one of the most commonly used deicers, as it has been traditionally abundant and cheap (Fischel 2001). 83% of the states responding to our survey reported using sodium chloride. It can be used as either rock salt (for de-icing) or as salt brine (for anti-icing), and it is rarely used and minimally effective below pavement temperatures of 10°F (Transportation Research Board 1991). Salt is often added to sand and other abrasives to prevent freezing. Most sand used by MDT in the western portion of the state has 5-7% salt added to sand (Williams 2004).

The primary advantage of salt is its abundance and relatively low cost, and the chloride associated with sodium is less toxic to aquatic life than those with calcium and magnesium (TIRRS 2001).

Calcium Chloride and Magnesium Chloride

Many DOTs use calcium chloride ($CaCl_2$) or magnesium chloride ($MgCl_2$) in a brine solution for anti-icing, which work at lower temperatures than salt brine. 58% and 75% of the states responding to our survey reported using $CaCl_2$ and $MgCl_2$, respectively. However, these chemicals are more costly than salt, and they can be difficult to handle. At low relative humidity, calcium and magnesium chloride residue on roads can attract more moisture than salt, resulting in dangerous, slippery conditions under certain circumstances (CWP 2003). Granular calcium chloride can be combined with salt to increase the effectiveness of salt in cold conditions, as calcium chloride acts quickly, gives off heat, and forms initial brine with moisture in the air (Wisconsin Transportation Information Center 1996).

Magnesium chloride is less corrosive and less expensive than calcium chloride, yet remains effective down to -22°F as opposed to 10°F for salt and -60°F for calcium chloride (Ketchum et al. 1996).

Salt, calcium chloride, and magnesium chloride all contribute chloride to surrounding environments, and this chloride can have detrimental effects. Despite the potential damaging effects of chlorides, the use of chloride-based deicers can reduce the use of sand, cost less if used appropriately, and minimally affect surrounding environments.

Calcium Magnesium Acetate (CMA) or Potassium Acetate (KA)

CMA and KA offer attractive alternatives to chloride-based deicers due to their non-corrosive characteristics, benign impacts on surrounding soils and ecosystems, and their lack of adverse human health effects. CMA works as a deicer similar to salt, yet it can require 50% more by weight than salt to achieve the same results. Air quality impacts and costs are the greatest challenges for the use of CMA. Other challenges associated with CMA include poor performance in thick accumulations of snow and ice and in temperatures below 23°F (Wegner and Yaggi 2001). Only 17% of the states responding to our survey reported using CMA.

Despite the difficulties in using CMA, it is less toxic to fish, less harmful to most plants, and less corrosive to vehicles, pavement, and bridge materials than salt. For these reasons, CMA has been used in various parts of the U.S. where the surrounding artificial or natural environment is particularly sensitive to the use of salt (Transportation Research Board 1991). CMA can exert a high oxygen demand on small water bodies, but its use in New Zealand over a 5-year study period has not shown any significant impacts on streams, soils, or vegetation (Burkett and Gurr 2004).

Potassium acetate (KA) can also offer an alternative to salt with fewer detrimental effects on the surrounding environment. It can affect the surrounding environment similarly to CMA, but less research has studied its impacts (Wegner and Yaggi 2001). KA is more costly than CMA, yet performs quickly at much lower temperatures, and it is frequently used at airports on runways. A few DOTs have also used KA for automated anti-icing systems on bridges with various levels of success.

Biobased Deicers

Biobased deicers, mainly those from agricultural byproducts and wastes, have begun to offer new options for snow and ice control applications. Such byproducts are non-corrosive and offer great performance in significantly lowering the freezing point and enhancing the melting capacity. In addition, they are designed to be biodegradable and environmentally friendly. It is envisioned that biobased deicers may gradually replace traditional deicers to a great extent, and minimize the negative impacts of snow and ice control activities to the environment.

Biobased deicers often come from the processing of beet juice, corn, molasses, and other agricultural products (Better Roads 2001). They can be expensive if used alone; however, they are frequently mixed with other common deicers to lower their freezing point and inhibit their corrosiveness. The common biobased deicers include trade names such as IceBan, Caliber, and Dow Armor.

There are potential environmental concerns of Biological Oxygen Demand (BOD) related to the use of biobased deicers, especially when they are applied near low volume waterways. In addition, MDT is concerned with Nitrogen and Nitrates contained in such deicers and the city of Missoula has maximum limits on these for any chemicals used in the city limits.

4.7.2 Anti-icing

An anti-icing manual entitled *Manual of Practice for an Effective Anti-icing Program: A Guide for Highway Winter Maintenance Personnel* is available from the Federal Highway Administration at http://www.fhwa.dot.gov/reports/mopeap/mop0296a.htm. For an anti-icing manual for low volume roads, the *Manual of Practice for Anti-icing of Local Roads* from the University of New Hampshire Technology Transfer Center is available at http://www.t2.unh.edu/ under the link for publications.

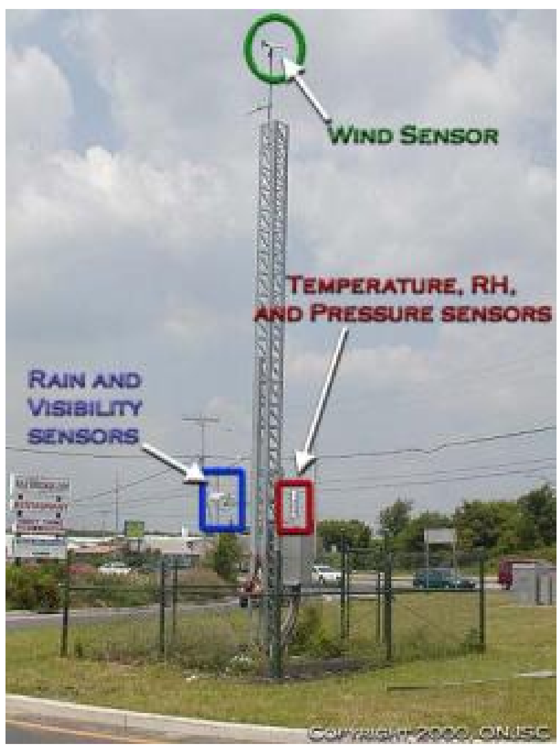

Figure 16. A RWIS sensor station (Boon and Cluett 2002)

Road Weather Information Systems (RWIS)

A road weather information system (RWIS) is a network of weather stations, forecasting services, and the supporting infrastructure (Ballard 2004). The components of RWIS can include meteorological sensors, pavement sensors, site-specific forecasts, temperature profiles of roadways, a weather advisor, communications, and planning (USEPA 1999). The roadside equipment for RWIS is also defined as environmental sensor stations (as shown in Figure 16), or ESS, in which the remote processing units combine data from atmospheric sensors with data from pavement sensors, typically temperature (Ketchum et al. 1996).

The use of RWIS can provide useful information for current and oncoming winter weather and assist the DOT winter maintenance managers to plan snow and ice control operations, especially when the anti-icing strategy is employed. With higher quality observational data for improved weather forecasting, RWIS makes it possible for winter maintenance to be proactive, and thus enable maintenance personnel to cost-effectively provide a higher level of service. In addition, RWIS can provide travelers with better information for safe and efficient travel. However, nearly all of these benefits result only when winter maintenance practices are significantly changed to take advantage of RWIS capabilities (Boon and Cluett 2002).

According to a study done in California and Montana (Ballard 2004), the following items are critical to optimize the RWIS use:

- Better forecasts
- Better training
- Appropriate siting and coverage
- Appropriate maintenance of the systems
- Improvement on the user interface
- Sharing of information

Partially due to the inaccurate forecasts that may lead to spreading liquid chemical on roadways with no storm occurring, MDT has adopted an approach termed just-in-time anti-icing, which holds the anti-icing operations until the storm starts to occur.

Improved Weather Forecasting

FORETELL* is a multi-state advanced road and weather condition forecasting system developed by the Castle Rock Corp., which integrates satellite, radar and surface observations with RWIS data, using state-of-the-art weather models and decision support displays. It provides a web-based, one-stop information source for maintenance crews and the traveling public.

In FORETELL, the data are provided at 10-km grid resolution, increasing the ability to pinpoint which areas are affected by winter weather conditions. Grid atmospheric weather nowcasts and forecasts (four times each day and 24 hours into the future) are mapped to Interstates and state highways to predict pavement conditions. The evaluation in the upper Mississippi valley indicated that most elements of the program were working well, but forecast accuracy needed some improvement (Smithson 2004).

* A brief video demonstrating the value of the FORETELL system is available at itspubs@fhwa.dot.gov.

Among weather forecasting for surface transportation, there is a particularly strong need for improved pavement temperature forecasts. Pavement temperature plays a key role in the highway winter maintenance activities. A forecasting model chain for pavement temperature in topographically varied terrain was developed and is being tested on Interstate 90 in Montana. The chain was initiated with the continental-scale meteorological forecast model calculated on 20-km spacing, then refined to a 1-km spacing using a mesoscale model. Results were then interpolated to provide a 30-m resolution weather forecast. Finally, a Radiation Thermal Model for Road Temperature (RadTherm/RT) was implemented to calculate terrain or pavement temperature. Comparisons of the pavement temperature calculated and measured at a RWIS station were quite good when the meteorological forecasts used as inputs to the model were accurate (Adams et al. 2004).

Automated Sprayers

Some anti-icing operations can be conducted remotely using automated sprayers. Such systems have been used mostly on bridge decks that are more prone to icing, and may need more frequent application of anti-icing or de-icing applications. Several of these systems have been installed in Minnesota and Utah on bridges, and more information on their performance can be obtained from Cory Johnson, Minnesota DOT, Office of Metro Maintenance Operation, 651-583-1431, or from Robert Stewart, Utah DOT, Research Division, 801-965-4333.

For a complete list of automated sprayers in use by various DOTs around the country, please visit the SICOP web site http://www.sicop.net/FAST%20Project.pdf. Manufacturers of such sprayers include: Boschung America (www.boschungamerica.com), Odin (www.odin.com), Energy Absorption (www.energyabsorption.com/products/freezeFree/freezefree.htm), and All Weather, Inc.(www.allweatherinc.com/html/qmfast.html).

A New Technology: Anti-icing Smart Overlays

A recently developed anti-icing pavement overlay has the potential to greatly reduce the amount of chemicals needed for snow and ice control operations. Research in Michigan* has combined an epoxy with an aggregate of limestone that can retain anti-icing chemicals for extended periods. With the overlay, it is difficult to wash off the deicers applied on the surface, and the anti-icing chemicals retained on the surface can prevent ice from bonding to that surface.

Recent tests of this overlay on a bridge in Wisconsin found monthly anti-icing treatments were more than adequate to retain the anti-icing properties. The potential exists for this overlay to receive only one anti-icing treatment each winter season. In addition to reducing the required frequency of anti-icing and de-icing operations, the greatest benefit from this technology will be less reliance on weather forecasting for effective anti-icing.

* For the latest information on this new technology, please contact Russ Alger, Director of the Institute of Snow Research, Michigan Technological University at rgalger@mtu.edu.

1.8 Improved Sanding Practices

By selecting an appropriate particle size and shape for use as traction sand, it is possible to minimize negative impacts resulting from such winter abrasives. Materials larger than a #50 sieve (approximately 300 microns in diameter) have been found to be most effective for enhanced traction. To further ensure efficiency of abrasives, use of materials with crushed or angular particles is recommended, since rounded particles are less effective (Haubner 2001).

Use of a "clean" sand source is highly recommended in order to reduce pollution from sand application. "Clean" sand refers to sand free of fine materials, which carry a majority of pollutants and can increase stream turbidity (Caraco and Claytor 1997). This type of sand is often used in non-attainment areas where PM-10 particles have impaired air quality.

A variety of non-structural BMPs for road sanding can be implemented to optimize application and removal of sanding debris. These include: reducing quantity and application rate of sanding in applicable areas; using physical barriers in specific locations, such as along drainage or streams, to route materials away from watercourses; reduced plowing speed in sensitive areas; cleaning inlets prior to first rain; and modifying blade angles and blower hoppers in sensitive areas.

4.8.1. Pre-wetted Sand

Another innovative practice in highway winter maintenance is termed prewetting, i.e., the application of liquid chemicals to abrasives prior to use on the roadway. It can reduce the quantity of sand that is kicked off the roadway by passing vehicles.

Abrasives can be pre-wetted on the stockpile, or when the abrasives are loaded into the truck, or when they are delivered at the spinner or tailgate (Nixon 2001). If cold, the pre-wetted abrasives will quickly refreeze to the road surface and create a sandpaper-type surface, which can cut abrasive use by 50% in cold temperatures. If warm, chemicals can accelerate break-up of snowpack while providing a traction aid to the public (Williams 2001).

Often, sand is pre-wetted with a liquid deicer; however, research in Norway has found sand pre-wetted with hot water can be highly effective. Dry sand may be removed from a roadway by the passage of as few as 50 vehicles, but pre-wetted sand with hot water can remain after the passage of as many as 2,000 vehicles. Using hot water (between 194°F and 203°F) and sand, roads maintained satisfactory friction values for as long as seven days on roads with an average annual daily traffic (AADT) volume of 1,000-1,500 vehicles (Vaa 2004). Conditions where this method is particularly useful include: hard blue ice, high volumes of heavy trucks, and thin ice or frost (Vaa 2004). New spreaders were developed in Norway for this technique. However, it should be noted that mounting boilers on plow trucks is not possible at this time in the United States.

1.9 Appropriate Application Rate

Reducing the application rate of deicers and sand can significantly reduce the environmental impacts, but this must be considered secondary to traveler safety. The objective is to deliver the right amount of traction materials in the right place at the right time. Therefore, it is desirable to use the most recent advancements in the application of winter maintenance anti-icing and de-icing materials, winter maintenance equipment, and road weather information and other decision support systems (Environment Canada 2004). For instance, the information provided by RWIS and improved weather forecasting (discussed in section 4.7.2) can be highly valuable in choosing the appropriate application rate. In addition, spreaders need calibration to ensure that the chosen application rate is actually implemented. The training of personnel and the monitoring of the effectiveness of application techniques should also be considered.

Under the National Cooperative Highway Research Program, Project 6-13 (http://www4.nas.edu/trb/crp.nsf/All+Projects/NCHRP+6-13), guidelines for snow and ice control materials and methods have been developed. A pavement snow and ice condition (PSIC) index was developed to evaluate the effectiveness of within-storm and end-of-storm winter maintenance strategies and tactics, which along with field tests has been used in developing a set of application rate guidelines. The application rates were derived for dry salt, pre-wetted salt, and salt brine, based on the dilution potential, pavement temperature, and presence of an ice/pavement bond. The adjusted dilution potential level accounts for precipitation type and rate, snow and ice conditions on the road, and the treatment cycle time and traffic conditions. Application rates for calcium chloride, magnesium chloride, potassium acetate, and CMA were developed from analytical work (Blackburn et al. 2004).

1.10 Snowplow Technologies

The technologies for snowplows are constantly evolving, and they range from low-tech calibrated spreaders to high-tech vehicle guidance systems.

4.10.1. Controlling the Application Rate of Spreaders

Simply calibrating spreaders begins the process of applying less traction materials. With calibrated spreaders, operators can apply a precise amount of material for a given condition. Other spreaders have groundspeed controls to apply a consistent amount of material regardless of the truck's speed. In the past, materials were overly applied as trucks slowed for curves or intersections or other obstacles. Newer spreaders can discharge material with a rearward velocity equal to the truck's forward velocity so that the material lands on the roadway with zero velocity, and less will bounce out of the travel lane (Transportation Association of Canada 2003).

4.10.2. Switching between Liquid and Granular Materials

Many configurations of hoppers allow snowplows to carry and spread both liquid and granular materials in different amounts. Many V-box type sand spreaders (as shown in Figure 17) can accommodate tanks for liquid deicers in a saddle bag arrangement. These systems can easily allow drivers to switch between different materials that can be applied at different rates.

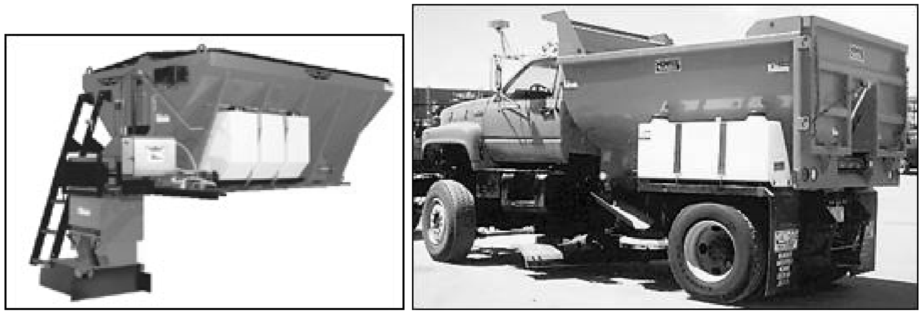

Figure 17. Tanks for liquid deicers mounted on hoppers for granular materials

For snowplows, viable options include: sand spreaders, liquid spreaders, different combinations of the two to allow the application of sand, pre-wetted sand, or deicer. The snowplows allowing the switch between liquid and granular materials are desirable, especially when certain stretches of the highway are very sensitive to the use of sand and only the application of deicers is allowed. Some systems can also use the liquid material to pre-wet the granular material to help the granular material "stick" to the snow or ice covered roadway. To aid drivers in deciding which material to apply, plow trucks can be equipped with infrared sensors that detect the pavement temperature. These technologies can help reduce the negative environmental effect of snow and ice control operations.

Major companies that offer systems that can switch between liquid and granular materials include: Henderson Manufacturing, Monroe Truck Equipment, and Swenson Spreader.

4.10.3. GPS and AVL Technologies

Global Positioning Systems (GPS) have been used as part of Automated Vehicle Location (AVL) technology (Figure 18) to track and provide real time information on winter maintenance operations and material application. With AVL and winter maintenance specific data, DOTs have another powerful tool in creating winter maintenance strategies. Winter maintenance specific data include: type of applied material, material application rate, position of plow blade, pavement temperature, etc.

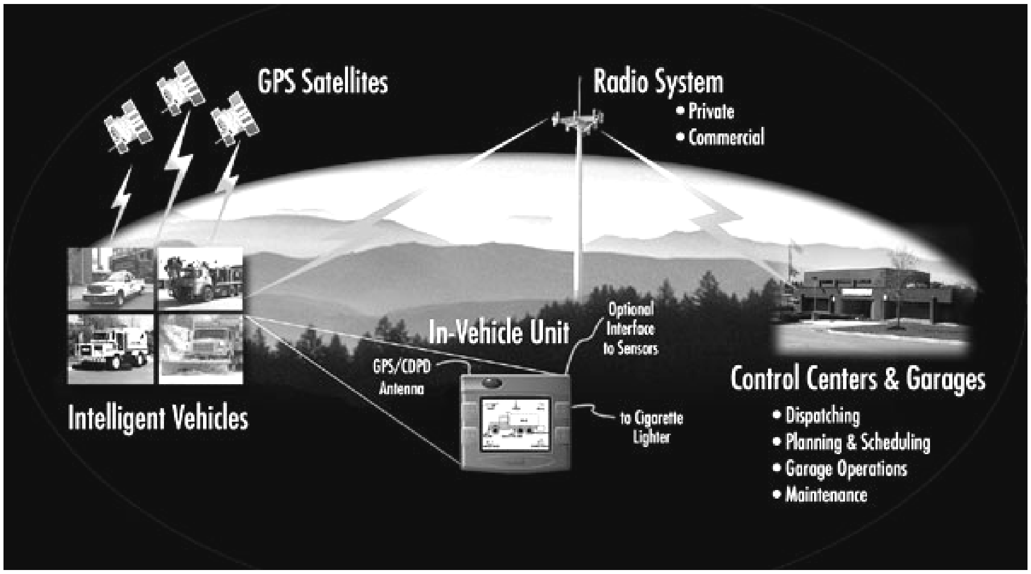

Figure 18. Automatic vehicle location system (Orbital TMS at www.tms-online.com)

Fort Collins, Colorado* has installed an AVL system on their snowplows and street sweepers, providing the additional data of type of chemicals being applied, application rate, position of plow blade, and position of sweeper. This information is available in real time to the crew chief who can give instructions to the drivers via a text messaging system. Currently this information is recorded in a geographic information system (GIS).

The Wisconsin DOT has equipped its winter maintenance vehicles with GPS and sensors that record environmental data, equipment status data, and material usage data. A GIS software application was developed to process such data to generate reports and provide decision management tools. The software can be used to analyze the computed performance measures and relationships among performance measures presented in reports, charts, and maps (Vonderohe et al. 2004).

4.10.4. Vehicle Guidance and Collision Avoidance

Research in Minnesota* has been developing technologies to assist snowplow drivers in low visibility conditions. These systems use highly accurate GPS units combined with radar sensors, magnetic sensors, and a geospatial database to provide information that can be relayed to the driver in several ways including a head-up display. This head-up display overlays information from the multiple sensing units and the database with the driver's field of vision; consequently, the driver can see obstacles and road boundaries that would otherwise be obstructed by poor visibility. Through a cost-benefit analysis, this technology seems to be most beneficial on high

* For more information on the system in Fort Collins, please contact Scott Oman at the Fort Collins Streets Department, (970) 221-6615.

* More information is available through the Minnesota Specialty Vehicle Initiative, Intelligent Transportation Systems Institute at the University of Minnesota, 612-626-1077, http://www.its.umn.edu/research/ivifieldtest/.

volume roads that experience a high level of road closures from winter weather (Kack and Cuelho 2004).

4.10.5. Highway Maintenance Concept Vehicle

Over a 6-year period, several state DOTs have been developing a highway maintenance concept vehicle[+] (Figure 19).

Figure 19. Highway maintenance concept vehicle and some of its components

The project aims to improve the efficiency and safety of winter maintenance vehicle operations by incorporating many of the latest technologies to the snowplow. These technologies include temperature sensors, a friction sensor, a freeze point sensor (Frensor), high intensity lights, GPS/AVL, a ground speed spreader, prewetting equipment, liquid spreaders, a power booster, an underbody plow, and a front plow. The latest version of this vehicle cost an additional $40,000 for all of these advanced technologies (Kroeger and Sinhaa 2004). It is important to note that many of these technologies can be used alone and could offer significant benefits.

CONCLUSIONS AND RECOMMENDATIONS

This report has reviewed best management practices for managing winter traction materials and for reducing their impacts on adjacent bodies of water through a literature review, a survey, and appropriate consultations. Because highway runoff is the primary vehicle through which pollutants from winter maintenance activities impact adjacent water bodies, this report has focused on the structural BMPs designed to capture traction materials carried by such runoff. To

[+] For more information, please contact Dennis Kroeger at (515) 296-0910, kroeger@iastate.edu, or visit http://www.ctre.iastate.edu/research/conceptv/index.htm.

reduce the amount of traction materials applied on roadways, non-structural BMPs have also been reviewed.

Environmental Concerns

The detrimental impacts of sand generally outweigh the negative impacts of chlorides. This conclusion provides good news because chlorides are generally difficult to remove from highway runoff, whereas suspended solids such as sand are much easier to remove.

The Montana DEQ and Montana FWP become most concerned when particle sizes are less than 6.35mm in diameter. According to expert opinions, particle sizes less than 2mm become especially problematic, as they will block the movement of oxygen into streambed gravels and thus endanger the aquatic wildlife. Sand free of much finer particles (ones that pass through the #200 sieve, or 0.075mm in diameter) provides better traction and is easier to capture with many structural BMPs.

Best Management Practices

BMPs can be categorized as either structural or non-structural, of which some may be more applicable for use in Montana and other rural areas with cold climates.

Geographical and climatic conditions on Montana’s roadways present the challenge of providing winter mobility while balancing traveler safety with economical and environmental concerns. High volumes and high velocities of spring runoff, combined with freezing winter conditions, hinder the effective use of many structural BMPs. Although much data and research is available on structural BMPs in temperate regions, limited quantitative data are available for structural BMPs in cold regions. More research is needed in this area to develop specific design criteria and to justify the investment of structural BMPs in cold regions. For instance, for many of the BMPs mentioned in this paper, no cost-benefit analysis has been done.

The most applicable structural BMPs for use along Montana’s highways seem to be dry ponds, wet ponds, wet extended detention ponds, constructed wetlands, vegetated swales, and vegetated filter strips. It is mainly because of their resistance to freezing conditions and their ability to effectively trap suspended solids, yet they may need protection from and additional storage for heavy flows and high sediment loads. In certain situations, under specific site conditions, other BMPs such as sand filters or infiltration trenches may be applicable; however, their use is limited in Montana and may require excessive modifications at high costs.

Non-structural BMPs have the added benefit of potential cost savings in winter maintenance activities; however, they often require an initial investment in new technology. Non-structural BMPs are rapidly evolving as new technologies are developed, and keeping track of these technologies will require a continuous effort.

Anti-icing, Road Weather Information Systems (RWIS), and the Maintenance Decision Support System (MDSS) in conjunction with advanced snowplow technologies are expected to provide the most efficient use of traction materials on winter roadways in Montana. With further testing, the anti-icing smart overlay technology may reduce or eliminate the dependence on accurate weather forecasting for anti-icing operations, and it is potentially highly useful for bridges that require more frequent anti-icing or de-icing than the associated roadway.

Wherever possible, highway agencies should minimize the impacts of traction materials on the environment through a combination of non-structural and structural strategies. Strategies can be implemented in the domain of technology, management, or both. Strategies may vary, depending on the specific climate, site, and traffic conditions. The crux is selecting an appropriate suite of BMPs that can function most effectively for a given set of conditions.

Benefits of This Report

This report has provided a toolbox of structural and non-structural BMPs that can minimize the environmental impacts of highway winter maintenance activities. The ones most applicable for use in Montana have been described in greater detail than those less applicable.

The following two scenarios provide examples of how one might use a combination of structural and non-structural BMPs. However, the final selection of BMPs should always be determined by site-specific conditions, on a case-by-case basis.

Scenario A: High dilution potential, high runoff velocities and volumes, and rapid discharge to adjacent water bodies; similar to an interstate highway passing over a high mountain pass with high precipitation.

Possible BMPs: The high dilution potential, high precipitation, and high level of service would require the application of large amounts of sand and deicer. Effective anti-icing could reduce the use of both sand and deicer, though de-icing and sanding will still be necessary for some situations. For especially sensitive areas, other deicers such as CMA or some biobased deicers may be useful. To maximize the effectiveness of snow and ice control operations, some of the latest snowplow technologies, such as friction and freeze point sensors, pavement temperature sensors, and spreaders capable of spreading both liquid and granular materials could be used. In addition to these technologies, the latest MDSS and CBT can help managers and operators more effectively integrate these new technologies and tactics into their winter maintenance practices. Because structural BMPs can be more costly and less flexible than non-structural BMPs, their selection deserves a more thorough review of site-specific conditions.

The chosen non-structural BMPs may affect which structural BMPs to be employed. For instance, if the use of sand was eliminated from a stretch of highway, a structural BMP may not be necessary for more than regulating the velocity of highway runoff. This may be an option in areas where implementing other structural BMPs is too costly.

Or, when sand is used, a wet extended detention pond as discussed in section 1.7 could be used with an inlet designed for energy dissipation. The high runoff velocities and potential large amounts of sand would preclude the use of many vegetated practices that could be easily eroded or overwhelmed, and hard surfaces and a snow storage/collection system (section 1.10) should be added to the roadway to convey the runoff and its suspended solids to the pond.

Although the abovementioned non-structural and structural BMPs may provide a theoretical mitigation of traction material impacts, their use in this situation would require continued monitoring and possible modifications to remain effective.

Scenario B: Low dilution potential, low runoff velocities and volumes, slow discharge to water body; similar to a two-lane roadway passing through an area of low elevation and gentle topography with low precipitation.

Possible BMPs: With the low dilution potential and low precipitation, much lower amounts of sand and deicer would be required than in scenario A. The possible lower level of service for this roadway may not warrant the time and expense of implementing an extensive anti-icing program using sophisticated software and weather forecasting models. However, anti-icing should remain in the toolbox for this roadway with appropriate levels of training for effective use. De-icing and sanding could be employed with equal success as a result of the low dilution potential, and the latest MDSS and CBT could increase the effectiveness and reduce the applied amounts of traction materials.

Vegetated swales and filter strips, as discussed in section 1.7, could effectively capture much of the sand and suspended particles in highway runoff from this scenario. This section of roadway may already have such features that would only need slight modifications to meet the design specifications such as sheet flow across a filter strip. With minimal investments in BMPs, the effects of traction materials in this scenario could be effectively minimized.

APPENDIX A: SUMMARY OF SURVEY RESULTS

As described in the Methodology chapter, a survey was sent to approximately 40 transportation professionals, mainly state DOT maintenance staff located in cold regions, as well as to all subscribers of a winter maintenance list serve (snow-ice@list.uiowa.edu) with over 500 subscribers. Eighteen responses were received from 12 states; however, little useful information was gathered, especially with respect to structural BMPs. It seems that this lack of information was partly due to an overall lack of knowledge of the use and effectiveness of structural BMPs in cold regions.

1.11 Traction Materials

Among the 12 states surveyed, 92% of states reported using sand, 83% reported using anti-icing materials, and 100% reported using de-icing materials. The usage of various chemicals for snow and ice control operations is summarized in the following table.

Material	$MgCl_2$	NaCl	$CaCl_2$	CMA	Other
States reported using	75%	83%	58%	17%	25%

All responses that included information on the gradation of sand material used on roadway included the % passing the #200 sieve, which corresponds to 0.075mm (as shown in the following table). These particles are the most difficult to capture with structural BMPs and can have significant impacts on streams. For some states there is considerable variability in sand gradation depending on the source of sand and the intended use. Idaho, for example, uses different standards depending on the usage area (mountain, black ice, PM-10 standard, etc.).

State	AK	ID	MO	VT	WA	WI	Alberta
Sand passing #200 sieve	0-2%	0-5%	0-8%	0-6%	0-4%	0-5%	0-10%

1.12 Structural BMPs

Thirteen responses reported an estimated efficiency of unconstructed vegetative areas for sediment removal. The average estimated value for this efficiency was 69%.

For various types of structural BMPs, relevant information gathered from the survey is summarized in the following table.

Structural BMP Type	% of States reported using BMP	When BMP is most effective	Regularity of Maintenance
Dry Settling Pond	42%	No information	No information
Wet Settling Pond	42%	Spring & Summer (AK), all year (UT)	When sediments accumulate, or every 10 years
Dry Ext. Detention Pond	8%	No information	No information
Wet Ext. Detention Pond	8%	No information	No information
Constructed Wetland	33%	No sediment removal in winter	As needed, remove invasive species, every 10yrs
Shallow Marsh	0%	No information	No information
Infiltration Trench	33%	When no frost	As needed
Infiltration Basin	8%	Summer, when no frost	As needed
Infiltration Meadow	8%	Summer	
Porous Pavement	17%	No information	No information
Surface Sand Filter	0%	No information	No information
Subsurface Sand Filter	0%	No information	No information
Submerged Gravel Wetlands	0%	No information	No information
Bioretention	8%	During vegetation growth	As needed, and mowing
Other Retention System	8%	No information	No information
Dry Swale	33%	Summer, during vegetation growth	As needed, and mowing
Wet Swale	17%	Summer, during vegetation growth	As needed, and mowing
Vegetated Filter Strip	50%	During vegetation growth	As needed, and mowing

Information was also collected addressing safety concerns and other problems related to successful structural BMP selection and use:

- The ponding/puddling of water behind a lip of sediment or backing up from a BMP was a safety concern for pedestrians and vehicles.
- Mud slides, sloughing, and excessive soil movement or tracking onto a road from a construction site.
- Some ponds remain ice free and attract waterfowl that can be a hazard to drivers.
- Grassy swales do not provide much infiltration during the winter in AK as it is too cold, and the storm drains remain frozen all winter.
- Slope, soil characteristics, springs or seepage, aspect, terrain and condition, temperature and climate, depth to ground water, and timing of BMP construction are all aspects of structural BMP selection and use.

1.13 Venner Consulting Survey on Stormwater Runoff

The complete Venner Consulting survey on stormwater runoff can be found at http://www.vennerconsulting.com with detailed information and links for certain questions.

Based on the survey results, the usage of various types of structural BMPs is summarized in the following table.

Structural BMP type	% of States reported using BMP
Dry ponds	81%
Wet ponds	65%
Wet vaults	19%
Constructed wetlands	67%
Vegetated Swales and filter strips	90%
Porous pavement	11%
Infiltration basins/trenches	68%
Sand filters	32%

The Venner Consulting survey also investigated the perceived importance of various issues related to structural BMPs, and the results are summarized in the following table.

Question/Issue	High Priority	Med. Priority	Low Priority	No Priority
Feasibility of BMPs	60%	28%	6%	6%
Costs of construction BMPs	58%	24%	14%	4%
Construction BMP efficiencies	74%	16%	6%	4%
Ops. and maintenance of BMPs	72%	20%	4%	4%
Compliance with water quality standards	28%	30%	34%	8%
Quantify BMP benefits and costs	54%	34%	8%	4%
Performance of BMP retrofits	42%	28%	20%	10%
Selection of BMPs & process	36%	36%	18%	10%
Optimization of detention basin	32%	40%	24%	4%
Deicer Selection	28%	26%	38%	8%
Removal of traction sand in snow areas	24%	24%	36%	16%

APPENDIX B: BLANK SURVEY

Survey of Highway-Runoff
Best Management Practices

Purpose

Highway-runoff may have adverse effects on adjacent aquatic resources if no measures are taken to remove potential contaminants before runoff reaches the receiving waters. The impairment of highway-runoff to the environment can be mitigated through structural or non-structural best management practices (BMPs), or through a combination of both. In cold regions, the climate may complicate the selection and performance of BMPs, requiring modifications to BMPs to accommodate site-specific needs. This survey seeks to identify current highway-runoff BMPs throughout North America, especially those effective for areas climactically similar to Montana.

Contact Information

Please complete the following information to aid in the processing of this survey:

Name: ____

Agency/Title: ____

Mailing Address: ____

City: ____________________ State: ___________ Zip Code: ____________________

E-mail Address: ____

Phone Number: _____ - _____ - ________ Ext. ______________

Fax Number: _____ - _____ - ________

Please return survey and any supporting documents to:

Xianming Shi, Ph.D., Research Associate
P.O. Box 174250, Western Transportation Institute
Montana State University
Bozeman, MT 59717-4250
(406) 994-6486
(406) 994-1697 *fax*

Or email completed surveys to Xianming_S@erc.montana.edu. The survey results will be available upon request.

Deadline for submission of survey is November 20th, 2003.

THANK YOU FOR YOUR PARTICIPATION IN THIS IMPORTANT SURVEY!

Please attach additional sheets if additional space is needed.

1. What traction materials do you currently use to maintain snow- and ice-free roadways in the winter?
   - ❑ **Sand**: please give a brief technical description (i.e. particle size distribution) of this material and where materials come from. ____

     ____
   - ❑ **Anti-Icing Materials**: please give a brief description of the anti-icing product you use. ________________

     ____

     ____
   - ❑ **De-Icing Materials**
     - ❑ Salt (sodium chloride)
     - ❑ Calcium chloride
     - ❑ Calcium magnesium acetate (CMA)
     - ❑ Magnesium chloride (Freezgard, Ice-Stop, Caliber M1000, etc.)
     - ❑ Other (please specify): ____

   If you use one or more of these materials in any combination, please briefly describe the combinations *(when do you use them, for what purposes, how much of each component, etc.):*

   ____

   ____

   ____

2. Please estimate the efficiency of unconstructed vegetative area (natural vegetation) in terms of sediment removal (% reduction). ____

3. Do you currently use any structural BMPs to minimize the migration of traction materials to nearby receiving waters? ___ Yes ___ No

   *If you answered yes, please proceed to Question 4. Otherwise skip ahead to Question 7.

4. What structural BMPs do you employ to contain highway-runoff? *(If there are **cold climate modifications** that you have made to any of these mechanisms, briefly describe them after the corresponding mechanism)*

   <u>Detention Systems</u>:
   - ❑ Dry Settling Pond ____
   - ❑ Wet Settling Pond ____
   - ❑ Dry Extended Detention Pond ____________________________________
   - ❑ Wet Extended Detention Pond ____________________________________
   - ❑ Constructed Wetland ____
   - ❑ Shallow Marsh ____
   - ❑ Other (please specify): ____

Infiltration:

- ❑ Trench ____
- ❑ Basin ____
- ❑ Meadow ____
- ❑ Porous Pavement ____
- ❑ Other (please specify): _ ____________________________________

Filtering Systems:

- ❑ Surface Sand Filter ____
- ❑ Underground Sand Filter ____________________________________ ___
- ❑ Submerged Gravel Wetland ____________________________________
- ❑ Other (please specify): ______________________________________

Retention Systems:

- ❑ Bioretention ____
- ❑ Other (please specify): ____

Biofiltration:

- ❑ Dry Swale ____
- ❑ Wet Swale ____
- ❑ Vegetated Filter Strip ____
- ❑ Other (please specify): ______________________________________

* Please refer to and complete the attached table with respect to the selected structural BMPs.

5. For each of the selected structural BMPs, how can the design feature be engineered to best enable its maintenance and repair? How can it be engineered to force the entry of water and associated sediment load? How can it be engineered to avoid washout by heavy water flows?

____

____

____

____

6. Please list any safety concerns for vehicle traffic or maintenance personnel associated with the selected structural BMPs (such as a possible increase of water or ice on the roadway).

____

____

____

____

7. Please list any additional problems (related to climate, geography/land characteristics, etc.) that should be addressed for the selected structural BMPs. ____

____

____

____

____

8. What non-structural BMPs do you employ to minimize the accumulation of traction materials near roadways and the resulting transport of these materials to adjacent water bodies? (If there are cold climate modifications that you have made to any of these practices, briefly describe them after the corresponding practice)

- ❑ Roadside Snow Storage ______________________________
- ❑ Storage of Traction Materials ______________________________
- ❑ Using Homogeneous/Pure/Fine Sanding Materials ______________________________
- ❑ Timely Street Sweeping ______________________________
- ❑ Ongoing/Updating Operator Training ______________________________
- ❑ Appropriate Application Rate of Anti- and De-Icing Materials ______________________________
- ❑ De-Icing/Sanding Material Recycling ______________________________
- ❑ Modification of Existing Snow Plow Vehicles ______________________________
- ❑ Other, Please describe briefly:

  ____

  ____

9. For each of the selected non-structural BMPs, please address the issues related to successful implementation.

____

____

____

10. Please feel free to add other comments or refer to/attach any guidance materials regarding highway-runoff BMPs. ____

____

____

THANK YOU FOR TAKING THE TIME TO COMPLETE THIS SURVEY!

	Where can it be best used? Inside curves? Outside curves? Off the roadway?	Can it be added to existing roadways or only during initial construction?	How small a space can it be built and still be effective & usable?	Under which conditions (e.g. location, time of year, temperature, etc.) it is most effective?	How efficient is it in terms of sediment removal (% reduction), during Winter? Spring? Other seasons?	How often should it be maintained to make it most effective, during Winter? Spring? Other seasons?	How is it maintained during the winter? How effective is it in the presence of snow?	What are the approximate costs of Construction? Annual maintenance?
DRY SETTLING POND					W: S: O:	W: S: O:		C: M:
WET SETTLING POND					W: S: O:	W: S: O:		C: M:
DRY EXTENDED DETENTION POND					W: S: O:	W: S: O:		C: M:

	Where can it be best used? Inside curves? Outside curves? Off the roadway?	Can it be added to existing roadways or only during initial construction?	How small a space can it be built and still be effective & usable?	Under which conditions (e.g. location, time of year, temperature, etc.) it is most effective?	How efficient is it in terms of sediment removal (% reduction), during Winter? Spring? Other seasons?	How often should it be maintained to make it most effective, during Winter? Spring? Other seasons?	How is it maintained during the winter? How effective is it in the presence of snow?	What are the approximate costs of Construction? Annual maintenance?
WET EXTENDED DETENTION POND					W: S: O:	W: S: O:		C: M:
CONSTRUCTED WETLAND					W: S: O:	W: S: O:		C: M:
SHALLOW MARSH					W: S: O:	W: S: O:		C: M:

	Where can it be best used? Inside curves? Outside curves? Off the roadway?	Can it be added to existing roadways or only during initial construction?	How small a space can it be built and still be effective & usable?	Under which conditions (e.g. location, time of year, temperature, etc.) it is most effective?	How efficient is it in terms of sediment removal (% reduction), during Winter? Spring? Other seasons?	How often should it be maintained to make it most effective, during Winter? Spring? Other seasons?	How is it maintained during the winter? How effective is it in the presence of snow?	What are the approximate costs of Construction? Annual maintenance?
INFILTRATION TRENCH					W: S: O:	W: S: O:		C: M:
INFILTRATION BASIN OR MEADOW					W: S: O:	W: S: O:		C: M:
POROUS PAVEMENT					W: S: O:	W: S: O:		C: M:

	Where can it be best used? Inside curves? Outside curves? Off the roadway?	Can it be added to existing roadways or only during initial construction?	How small a space can it be built and still be effective & usable?	Under which conditions (e.g. location, time of year, temperature, etc.) it is most effective?	How efficient is it in terms of sediment removal (% reduction), during Winter? Spring? Other seasons?	How often should it be maintained to make it most effective, during Winter? Spring? Other seasons?	How is it maintained during the winter? How effective is it in the presence of snow?	What are the approximate costs of Construction? Annual maintenance?
SURFACE OR UNDER-GROUND SAND FILTER					W: S: O:	W: S: O:		C: M:
SUBMERGED GRAVEL WETLAND					W: S: O:	W: S: O:		C: M:
WET VAULT					W: S: O:	W: S: O:		C: M:

	Where can it be best used? Inside curves? Outside curves? Off the roadway?	Can it be added to existing roadways or only during initial construction?	How small a space can it be built and still be effective & usable?	Under which conditions (e.g. location, time of year, temperature, etc.) it is most effective?	How efficient is it in terms of sediment removal (% reduction), during Winter? Spring? Other seasons?	How often should it be maintained to make it most effective, during Winter? Spring? Other seasons?	How is it maintained during the winter? How effective is it in the presence of snow?	What are the approximate costs of Construction? Annual maintenance?
BIO-RETENTION					W: S: O:	W: S: O:		C: M:
DRY OR WET SWALE					W: S: O:	W: S: O:		C: M:
VEGETATED FILTER STRIP					W: S: O:	W: S: O:		C: M:

	Where can it be best used? Inside curves? Outside curves? Off the roadway?	Can it be added to existing roadways or only during initial construction?	How small a space can it be built and still be effective & usable?	Under which conditions (e.g. location, time of year, temperature, etc.) it is most effective?	How efficient is it in terms of sediment removal (% reduction), during Winter? Spring? Other seasons?	How often should it be maintained to make it most effective, during Winter? Spring? Other seasons?	How is it maintained during the winter? How effective is it in the presence of snow?	What are the approximate costs of Construction? Annual maintenance?
CHANNELS OR DIKES					W: S: O:	W: S: O:		C: M:
OTHER:					W: S: O:	W: S: O:		C: M:
OTHER:					W: S: O:	W: S: O:		C: M:

REFERENCES

Adams, E.E., L.R. McKittrick, P. Gauer, and A.R. Curran, 2004. A First Principles Pavement Thermal Model for Topographically Complex Terrain. SNOW04-035. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 422-432.

Arnold, J.A., D.E. Line, S.W. Coffey, and J. Spooner, 1993. Stormwater Management Guidance Manual. North Carolina Cooperative Extension Service and North Carolina Division of Environmental Management, Raleigh, NC.

Ashton, W.S. and L.A. Griffiths, 1990. Culverts. Cold Regions Hydrology and Hydraulics. ASCE Technical Council on Cold Regions Engineering.

Ballard, L. Analysis of Road Weather Information System Users in California and Montana. SNOW04-060. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 190-207.

Barr Engineering Company, 2001. Minnesota Urban Small Sites BMP Manual – Stormwater Best Management Practices for Cold Climates, prepared for the Metropolitan Council, at http://www.metrocouncil.org/environment/Watershed/bmp/manual.htm.

Barrett, M.E., P.M. Walsh, J.F. Malina Jr., and R.J. Charbeneau, 1998. Performance of Vegetative Controls for Treating Highway Runoff. *Journal of Environmental Engineering*, Vol. 124, Issue 11, pp. 1121-1128.

Better Roads, 2001. Agricultural byproduct deicers are here to stay. *Better Roads for the Government/Contractor Project Team*. July 2001, available at: http://www.betterroads.com/sitemap.htm.

Blackburn, R.R., D.E. Amsler, Sr., and K. M. Bauer, 2004. Guidelines for Snow and Ice Control Material and Methods. SNOW04-059. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 31-49.

Boon, C.B and C. Cluett, 2002. Road Weather Information Systems: Enabling Proactive Maintenance Practices in Washington State. http://www.its.dot.gov/JPODOCS/REPTS_TE/13660.html.

Boselly, S.E., 2001. Benefit/Cost Study of RWIS and Anti-icing Technologies. Final report prepared for NCHRP.

Brown, W. and T. Schueler. 1997. The Economics of Stormwater BMPs in the Mid-Atlantic Region. Prepared for: Chesapeake Research Consortium. Edgewater, MD. Center for Watershed Protection. Ellicott City, MD.

Buckler, D.R. and G.E. Granato, 1999. Assessing Biological Effects from Highway runoff Constituents. U.S. Department of Interior and U.S. Geological Survey Open-File Report 99-240.

Burkett, A. and N. Gurr, 2004. Icy Road Management with Calcium Magnesium Acetate to Meet Environmental and Customer Expectations in New Zealand. SNOW04-050. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 267-277.

California Department of Transportation. Storm Water Treatment BMP New Technology Report. April 2004. SW-04-069.04.02. http://www.dot.ca.gov/hq/env/stormwater/index.htm.

Caraco, D. and R. Claytor, 1997. Stormwater BMP Design Supplement for Cold Climates. United States Environmental Protection Agency, Office of Wetlands, Oceans and Watersheds and US EPA Region 5, at http://www.cwp.org/cold-climates.htm.

CDM, 2004. Erosion and Sediment Control Best Management Practices: Report. Revised May 2004. http://www.mdt.state.mt.us/research/projects/env/erosion.shtml.

Center for Watershed Protection, Inc. (CWP). The Stormwater Manager's Resource Center, Stormwater Management Fact Sheets. http://www.stormwatercenter.net/. Updated June 2003.

Cheng, K.C. and T.F. Guthrie, 1998. Liquid Road De-icing Environment Impact. Levelton Engineering Ltd., Richmond, BC. available at http://www.wsdot.wa.gov/partners/pns/ as the "Levelton Report".

Clear Creek Consultants, Inc. and JF Sato & Associates, 2002. Data Evaluation Report, Interstate 70 Storm Event/Snowmelt, Water Quality Monitoring – 2001. December 2002. Colorado Department of Transportation, Region 1.

Colorado Department of Transportation (CDOT), 2002. Sediment Control Action Plan, Black Gore Creek I-70 Corridor. Prepared in cooperation with Clear Creek Consultants, Inc. and J.F. Sato & Associates. May 2002.

Colorado Department of Transportation (CDOT), 2002. Sediment Control Action Plan, Straight Creek -70 Corridor. Prepared in cooperation with Clear Creek Consultants, Inc. and J.F. Sato & Associates. May 2002.

Colwell, S.R., R.R. Horner, and D.B. Booth, 2000. Characterization of Performance Predictors and Evaluation of Mowing Practices in Biofiltration Swales. Center for Urban Water Resources Managenment, Department of Civil Engineering, University of Washington, Seattle, WA, August 2000.

Comings, K.J., D.B. Booth, and R.R. Horner, 1999. Stormwater Pollutant Removal by Two Wet Ponds in Bellevue, Washington. Center for Water and Watershed Studies, University of Washington, Seattle, WA.

Cote, R.C., M. Lundsted, R. Balke, and E. Pannetier, 2003. Designed to Fail: Why Most Commonly Used Designs Fail and How to Fix Them. Comprehensive Environmental Inc. Cold Climate Conference, Portland, ME. November 2003.

Davis, A., M. Shokouhian, H. Sharma, and C. Henderson, 1998. Optimization of Bioretention Design for Water Quality and Hydrologic Characteristics. Department of Civil Engineering, University of Maryland, College Park

Deletic A.,1999. Sediment Behaviour in Grass Filter Strips. *Water Science and Technology*, Vol. 39, No. 9, pp. 129-136.

Dupuis, T.V., 2002. Assessing the Impacts of Bridge Deck Runoff Contaminants in Receiving Waters; Volume 2: Practitioner's Handbook. NCHRP Report 474, Transportation Research Board, Washington, D.C., 2002.

Earles, T.A. 1999. Mitigated Wetlands for the Treatment of Stormwater Runoff: Monitoring and Management. PhD Dissertation, University of Virginia, Department of Civil Engineering.

Environment Canada, 2004. Code of Practice for the Environmental Management of Road Salts. EPS 1/CC/5.

Federal Highway Administration, 1997. Stormwater Best Management Practices in an Ultra-Urban Setting: Selection and Monitoring. United States Department of Transportation, http://www.fhwa.dot.gov/environment/ultraurb/.

Federal Highway Administration, 2003. Maintenance Decision Support System. FHWA Publication Number: FHWA-OP-03-010.

Federal Highway Administration, 2004. New Hampshire Department of Transportation's Route 101 Ecological Protection and Enhancement Features. Last modified on April 22, 2004. http://www.fhwa.dot.gov/environment/ecosystems/nh.htm.

Fischel, M., 2001. Evaluation of Selected Deicers Based on a Review of the Literature. The SeaCrest Group. Louisville, CO. Report Number CDOT-DTD-R-2001-15. October 2001.

Fraughton, P. 2003. Tuning Up Skills for A Snow Job. The Salt Lake Tribune. http://www.sltrib.com/2003/nov/11202003/utah/112576.asp.

Goodwin, L.C., 2003. Best Practices for Road Weather Management. Road Weather Management Program, Office of Transportation Operations, Federal Highway Administration. Report number FHWA-OP-03-081.

Guo, J.C.Y., 1999. Sand Recovery for Highway Drainage Designs. *Journal of Irrigation and Drainage Engineering*. Vol. 125, No. 6, pp. 380-384.

Hanes, R.E., L.W. Zelazny, and R.E. Blaster, 1976. Effects of De-icing Salts on Water Quality and Biota – Literature Review and Recommended Research. National Cooperative Highway Research Program Report 91.

Haubner, S. (editor in chief), 2001.Georgia Stormwater Management Manual. Volume 2: Technical Handbook, First Edition – August 2001. http://www.georgiastormwater.com/.

Henderson, K., 2004. Integrated Roadside Vegetation Management: A Quick Glance Around the Country. http://www.forester.net/ec_0004_integrated.html.

Hook, P.B., O.R. Stein, W.C. Allen and J.A. Biederman. 2003. Plant Species Effects on Seasonal Performance Patterns in Model Subsurface Wetlands. Constructed Wetlands for Wastewater Treatment in Cold Climates Ü. Mander and P.D. Jenssen (Eds.). pp. 87-106. WTI Press, England.

Hyman, W.A. and D. Vary, 1999. Best Management Practices for Environmental Issues Related to Highway and Street Maintenance. Synthesis of Highway Practice 272. National Academy Press. Washington, D.C.

Johnson, A., A. Moffatt, and E. Slattery, 2003. Erosion Control Handbook for Local Roads. Minnesota Local Road Research Board (LRRB) Manual Number 2003-08.

Jokela, J.B. and T.R. Bacon, 1990. Design of Urban Sedimentation Basins in Anchorage. Cold Regions Hydrology and Hydraulics. ASCE Technical Council on Cold Region Engineering.

Julien, P.Y., 1998. Erosion and Sedimentation. Cambridge University Press. New York, NY.

Kack, D. and E. Cuelho, 2004. Needs Assessment and Cost-Benefit Analysis of RoadView™ Advanced Snowplow Technology System. SNOW04-006. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 332-347.

Keating, J., 2001. De-icing Salt, Still on the Table. *Stormwater*, Vol. 2, No 4.

Ketchum, S.A., L.D. Minsk, R.R. Blackburn, and E.J. Fleege. Manual of Practice for and Effective Anti-Icing Program, A Guide for Highway Winter Maintenance Personnel. U.S. Army Cold Regions Research and Engineering Laboratory. Report Number FHWA-RD-95-202. June 1996.

Kings County Department of Natural Resources, 1998. King County, Washington Surface Water Design Manual. September 1998.

Kirk P.S., 2002. Effectiveness of Three Best Management Practices for Highway runoff Quality along the Southeast Expressway, Boston, Massachusetts. Water-Resources Investigations Report 02-4059.

Kroeger, D.A. and R. Sinhaa, 2004. Business Case for Winter Maintenance Technology Applications, Highway Maintenance Concept Vehicle. SNOW04-034. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 323-331.

Landry, M.S. and T.L. Thurow, 1997. Function and Design of Vegetation Filter Strips: An Annotated Bibliography. Texas State Soil and Water Conservation Board Bulletin No. 97-1.

Lewis, W.L. Jr, 1999. Studies of Environmental Effects of Magnesium Chloride Deicer in Colorado. November 1999. Received electronically from author.

Mangold, T., 2000. Road Salt Use for Winter Maintenance – A Review of Impacts, Alternatives, and Recommendations for the St. Paul Campus Stormwater Management Plan. NRES5061. December 200.

Marsalek, P.M., W.E. Watt, J. Marsalek, and B.C. Anderson, 2000. Winter Flow Dynamics of an On-Stream Stormwater Management Pond. *Water Quality Research Journal of Canada*. Vol. 35, No. 3, pp. 505-523.

Martinelli, T.J., R. Waschbusch, R. Bannerman, and A. Wisner. 2002. Pollutant Loading to Stormwater Runoff from Highways: The Impact of a Freeway Sweeping Program. Final Report Number: WI-11-01. WISDOT Highway Research Study #97-01. Project I.D. #0092-45-82. Wisconsin Department of Transportation, Division of Transportation Infrastructure Development, Bureau of Highway Operations.

Ministry of Land, Water, and Air Protection (MOLWAP). Best Management Practices to Protect Water Quality. Water, Air, and Climate Branch, Government of British Columbia. http://wlapwww.gov.bc.ca/wat/wq/nps/BMP_Compendium/BMP_Introduction/bmphome.htm. Last accessed: June 2004.

Missoula City-County Health Department, 1997. Storm and Ground Water Quality Impacts of Chemical Deicer Usage in Missoula, Montana. State Report prepared for the Montana Department of Environmental Quality.

Molles, M.C., 1980. Effects of Road Salting on Aquatic Invertebrate Communities. USDA Forest Service, Eisenhower Consortium Bulletin 10.

Nixon, W.A. and A.D. Williams, 2001. A Guide for Selecting Anti-icing Chemicals. Version 1.0. IIHR Technical Report No. 420.

Nixon, W.A., 2001. The Use of Abrasives in Winter Maintenance. Prepared for the Iowa DOT.

Oberts, G.L., 1990. Design Considerations for Management of Urban Runoff in Wintry Conditions. In Proceedings – International Conference on Urban Hydrology Under Winter Conditions, March 19-21, 1990, Norvik, Norway.

Oberts, G.L., 2003, Cold Climate BMPs: Solving the Management Puzzle. *Water Science and Technology*. Vol. 48, No. 9, pp.21-32.

Ontario Ministry of the Environment, 2003. Stormwater Management Planning and Design Manual.. Queen's Printer for Ontario. http://www.ene.gov.on.ca/envision/gp/4329eindex.htm. Last modified April 2004.

Pisano, P.A., A.D. Stern, W.P. Mahoney, W.L. Myers, and D. Burkheimer, 2004. Winter Road Maintenance Decision Support System Project: Overview and Status. SNOW04-005. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 3-17.

Public Sector Consultants, Inc., 1993. The Use of Selected De-icing Materials on Michigan Roads: Environmental and Economic Impacts. Prepared for the Michigan Department of Transportation. http://www.michigan.gov/mdot/.

Reiser, D. W. and R.G. White, 1988. Effects of Two Sediment Size-classes on Survival of Steelhead and Chinook Salmon Eggs. *North American Journal of Fisheries Management* 8(4): 432-437.

Rentch, R., 2004. Day-to-Day Integration of Stewardship and Efficiency. *Successes in Streamlining*. http://environment.fhwa.dot.gov/strmlng/newsletters/apr04nl.htm. Last modified on April 5, 2004.

Research Applications Program (RAP), National Center for Atmospheric Research. Road Weather MDSS. http://www.rap.ucar.edu/projects/rdwx_mdss/mdss_description.html. Last updated in June 2001.

The Salt Institute, 1999. The Snowfighter's Handbook: A Practical Guide for Snow and Ice Control. Alexandria, VA.

Schueler, T.R., 1987. Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs. Metropolitan Washington Council of Governments, Publication No. 87703.

Schuler, T.R., 2000. Pollutant Removal Dynamics of Three Wet Ponds in Canada. *The Practice of Watershed Protection*. The Center for Watershed Protection, Ellicott City, MD.

Schueler, T.R. and R.A. Claytor, 2000. Maryland Stormwater Design Manual. Maryland Department of the Environment. Baltimore, MD.

Shammaa, Y. and D.Z. Zhu, 2001. Techniques for Controlling Total Suspended Solids in Stormwater Runoff. *Canadian Water Resources Journal*. Vol. 26, No. 3, pp. 359-375.

Shammaa, Y., D.Z. Zhu, L.L. Gyurek, and C.W. Labatiuk, 2002. Effectiveness of dry ponds for stormwater total suspended solids removal. *Canadian Journal of Civil Engineering*. Vol. 29, pp. 316-324.

Shaver, E. and R. Baldwin, 1991. Sand Filter Design for Water Quality Treatment. Delaware Department of Natural Resources and Environmental Control, Dover, DE.

Skillings-Connolly, Inc., 2001. Montana Department of Transportation Draft Environmental Re-evaluation of F 5-1(9)6 U.S. Highway 93 Evaro – Polson Final Environmental Impact Statement and Section 4(f) Evaluation.

Smithson, L.D., 2003. Training – the Key to Technology Implementation. Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa, August 2003.

Smithson, L.D., 2004. Proactive Snow and Ice Control Toolbox. SNOW04-061. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 153-157.

Sorensen, D.L., V. Mortenson, and R.L. Zollinger, 1996. A Review and Synthesis of the Impacts of Road Salting on Water Quality. Utah Department of Transportation Final Report UT-95.08.

Stillwater Outdoor Hydraulic Laboratory, 1954. Handbook of Channel Design for Soil and Water Conservation. Soil Conservation Service, United States Department of Agriculture. SCS-TP-61.

Tabler, R.D., 1991. Snow Fence Guide. Strategic Highway Research Program, National Research Council, Washington D.C. SHRP-W/FR-91-106.

Tabler, R.D., 2004. Effect of Blowing Snow and Snow Fences on Pavement Temperature and Ice Formation. SNOW04-030. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 401-413.

Tahoe Interagency Roadway Runoff Subcommittee, 2001. Planning Guide for Implementing Permanent Storm Water Best Management Practices in the Lake Tahoe Basin. http://www.swrcb.ca.gov/rwqcb6/BMP/Index.htm.

Transportation Association of Canada, 2003. Synthesis of Best Practices – Road Salt Management. http://www.tac-atc.ca.

Transportation Research Board, 1991. Highway De-icing: Comparing Salt and Calcium Magnesium Acetate. National Research Council, Special Report 235. http://trb.org/publications/sr/sr235.html.

Turner-Fairbank Highway Research Center. Is Highway Runoff a Serious Problem? FHWA Environmental Technology Brief, updated in 1999 at http://www.tfhrc.gov/hnr20/runoff/runoff.htm.

United States Environmental Protection Agency, 1988. Ambient Water Quality Criteria for Chloride -1988. Office of Research and Development, Environmental Research Laboratory. Duluth, MN. EPA 440588001.

United States Environmental Protection Agency, 1993. Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. EPA 840-B-92-002.

United States Environmental Protection Agency, 1999. Stormwater Management Fact Sheet – Minimizing Effects from Highway De-icing. Office of Water. EPA 832-F-99-016

United States Environmental Protection Agency, 2000. Section 303(d) List Fact Sheet for MONTANA. http://oaspub.epa.gov/waters/state_rept.control?p_state=MT.

United States Environmental Protection Agency, 2002. Construction Site Stormwater Runoff Control. http://cfpub1.epa.gov/npdes/stormwater/menuofbmps/site_31.cfm.

Vaa, T., 2004. Implementation of New Sanding Method in Norway. SNOW04-025. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 473-486.

Venner Consulting, 2003. Stormwater Research Survey. http://www.vennerconsulting.com/.

Vitaliano, D., 1992. Economic Assessment of the Social Costs of Highway Salting and the Efficiency of Substituting a New Deicing Material. Journal of Policy Analysis and Management, Vol. 11, No. 3, pp. 397-418.

Vonderohe, A., T. Adams, C. Blazquez, J. Maloney, and T. Martinelli, 2004. GIS-Based Analysis of Intelligent Winter Maintenance Vehicle Data. SNOW04-029. Sixth International Symposium on Snow Removal and Ice Control Technology. Transportation Research Circular E-C063: Snow and Ice Control Technology. June 2004. pp. 348-360.

Watson, M., 1994. Guidance for Design of Biofiltration Facilities for Stream Water Quality Control. Municipality of Anchorage Watershed Management Program Document No. CPg96002.

Wegner, W. and M. Yaggi, 2001. Environmental Impacts of Road Salt and Alternatives in the New York City Watershed. *Stormwater*, Vol. 2, No. 5.

Williams, D., 2001. Past and Current Practices of Winter Maintenance at the Montana Department of Transportation (MDT). White Paper.

Williams, D., 2004. "Deicer" Is a Solid, Not a Liquid. Montana Department of Transportation. January 2004.

Wisconsin Transportation Information Center. 1996. Using Salt and Sand for Winter Road Maintenance. Wisconsin Transportation Bulletin No. 6. http://tic.engr.wisc.edu/publications.html.

Yonge, D. and N. Marcoe, 2001. An Evaluation of the Impacts of Highway Deicers on Peshastin Creek. Washington State Transportation Center Research Report T1804-2.

Young, G.K., S. Stein, P. Cole, T. Kammer, F. Graziano, and F. Bank, 1996. Evaluation and management of highway runoff water quality. Federal Highway Administration Final Report FHWA-PD-96-032.

Yu, S.L., S.L. Barnes, and V.W. Gerde, 1993. Testing of Best Management Practices for Controlling Highway Runoff. Virginia Transportation Research Council, Charlottesville, VA.

Yu, S.L. and R.J. Kaighn, 1995. The Control of Pollution in Highway Runoff Through Biofiltration. Virginia Transportation Research Council, Final Report VTRC 95-R29.

Yu, S.L., J. Kuo, E.A. Fassman, and H. Pan, 2001. Field Test of Grassed-Swale Performance in Removing Runoff Pollution. *Journal of Water Resources Planning and Management*, Vol. 127, No. 3, pp. 168-171.