



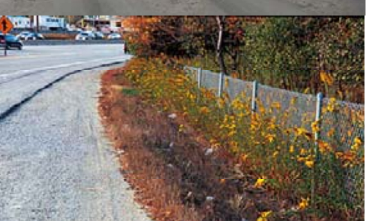

Assessing the Efficacy of Current Road Salt Management Programs

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Executive Summary

An 18 month study was conducted by a University of Waterloo research team to assess whether adoption of the Code of Practice has effectively reduced chloride inputs to the environment in response to best management practices related to salt application and snow disposal. The study is intended to 1) provide data to support the Environment Canada 2010 review of the Code of Practice 2) evaluate the degree of implementation and effectiveness of selected best management practices to mitigate chloride transfer to the environment 3) identify barriers to implementation and 4) make recommendations to improve winter maintenance practices of roadways and parking lots. The report is divided into sections corresponding to research that was designed and conducted (surveys as well as field and laboratory studies) to evaluate the effectiveness of the Transportation Association of Canada's (TAC) *Syntheses of Best Management Practices (SOBPs)* to reduce chloride transfer to the environment. The *SOBPs* evaluated in this study include TAC 1 *Salt Plans*; TAC 2 *Training*; TAC 4 *Drainage and Stormwater*; TAC 5 *Pavements and Salt Management*; TAC 7 *Design of Road Maintenance Yards*; TAC 8 *Snow Storage and Disposal* and TAC 9 *Winter Maintenance Technologies*. The results and conclusions of each study component are summarized below in relation to specific TAC SOPBs evaluated.

ROAD SALT MANAGEMENT SURVEY (TAC 1, 2, 9)

To determine the degree to which voluntary road salt management plans programs have been implemented in Ontario, information was gathered through meetings with salt management working groups (RMOW Winter Maintenance Policy and Procedures Working Group, Ontario Road Salt Management Working Group, Toronto Conservation Authority, Credit Valley Conservation Authority and Regional Municipality of Waterloo), by convening a Salt Management workshop (May, 2008) and an International Conference on Road Salt Management (May 2009) at the University of Waterloo and by conducting a survey of Ontario Road Management Authorities.

An online tool (SurveyMonkey) was used to administer a survey that was sent to 432 public works officials in Ontario that included 40 cities, 6 Regional Municipalities, 25 Counties, 85 Towns, 1 District and over 260 Townships/Villages and Municipalities. Seventy out of 432

public works officials responded to the survey resulting in a response rate of 16.3%. The survey respondents included Regional Municipalities (20%), Cities (19%), Counties (13%), Townships (19%) and Towns (29%). Results of the survey are presented below.

Survey Results. The survey indicates that the Code has been adopted by a relatively high number of Ontario Municipalities (89% of the larger municipalities have Salt Management Plans). While the release of the Code in 2004 accelerated the rate of production of Salt management Plans, a number of municipalities required several years in preparing their plans. In some cases (43%), salt management plans are not reviewed as encouraged by the Code. Salt Management Plans cover principles of safety, environmental protection and accountability well but most have inadequate provision for continual improvement, measuring progress and communications. Many authorities have not updated their plans since initially prepared but some respondents intend to review plans in the near future. An increasing effort is required to encourage review and ongoing improvement of operations. Communication of the Salt management Plans and training to contractors and seasonal staff could be improved in many municipalities. The level of salt management training has been improved considerably through the efforts of the Ontario Good Roads Association and the Ontario Road Salt Management Group. According to the survey, 63% of the respondents have annual training programs. The learning goals set out in TAC's SOBP-Training are generally covered but some key areas – the more complicated learning goals – are not adequately covered. The Code has been effective in promoting the development of training packages but implementation is should be improved. Record-keeping has improved since the publication of the Code and the requirement for Annual Reporting. However some records that are necessary to measure effective monitoring and continuous improvement are lacking.

Since the release of the Code, mapping of salt vulnerable areas has increased with 51% of respondents indicating they have identified salt vulnerable areas and developed policies in proximity to these areas. Improved guidance in this area is strongly recommended. The Synthesis of Best Management Practices for maintenance yards has improved yard planning and design, upgrading and good housekeeping practices. Since the code was developed, the greatest improvement has been in the areas of salt storage and handling but the least improved areas are management of salt impacted water and environmental monitoring. There is a lack of awareness of this SOBP and more promotion is warranted. Approximately 61% of municipalities have snow disposal sites but most of these sites are not designed in accordance with the Code or the SOBP.

The authorities' responded positively about the benefits of the Code of Practice as a measure to advance salt management and environmental protection in Ontario. The key benefits of the Code are: 1) Increased awareness of the importance of salt management to protect the environment and of best management practices that are available 2) Provided validation for best practices and the need to improve winter control operations 3) Set a framework for salt management plans and benchmarks for salt management that lead to greater standardization 4) Accelerated the rate of introduction of best management practices and the adoption of new technologies 5) Reduced salt use and associated environmental impact 6) Reduced costs through salt reduction 7) Improved monitoring and recordkeeping.

The respondents identified several concerns and challenges regarding the Code that are primarily related to implementation challenges. Code-specific concerns were 1) There is a need to provide more detail, advice and direction regarding how to comply with the Code requirements 2) Municipalities require a simple and cost-effective way to map salt vulnerable areas and guidance on developing management practices for these areas. Implementation challenges include 1) Still difficult to change old practices and get Council and senior management commitment to change 2) The lack of resources, particularly money, is one of the main barriers to implementing the Code 3) Meeting public expectations and the challenge of changing levels of service is a challenge 4) Getting staff properly trained and getting best practice implemented in a consistent way continues to be a challenge 5) Coping with changing winters is a challenge. Other challenges include a lack of understanding or acceptance of the need for salt management and the environmental impacts of this practice. Changes in personnel at the staff, management and political levels since the Code was published underscore the importance of continual re-education.

DRAINAGE AND STORMWATER (TAC 4)

Three monitoring studies were conducted to evaluate the effectiveness of BMPs to manage chloride loss from drainage and stormwater. They include studies 1) to assess chloride in the shallow vadose zone and groundwater in response to reduced road salt applications in salt vulnerable areas 2) to measure the chloride concentration and loading in roadside snow pack of salt vulnerable areas and 3) to quantify chloride transfer in two Waterloo stormwater ponds.

Chloride in the shallow vadose zone and groundwater in response to reduced road salt applications in salt vulnerable areas. In response to progressively elevated concentrations of chloride (Cl^-) in some municipal well fields within the Regional Municipality of Waterloo (RMOW), several Best Management Practices (BMPs) were initiated in 2003-2004 in the vicinity of the impacted well fields in an attempt to reduce road salt leaching the water table which included a reduction in total road salt application of 25% in urban road network. The influence of salt reduction on groundwater quality in the Greenbrook Well Field, Kitchener was assessed by conducting a series of field monitoring activities designed to compare the quantity and mobility of chloride in the vadose zone for pre (2003) and post-BMP conditions (2009).

The groundwater monitoring data show that post-BMP chloride levels in the vadose zone at most of the field locations were ~50% lower than for pre-BMP conditions. However, chloride concentrations in groundwater remained fairly constant or increased slightly at two locations where specific safety concerns (sidewalks adjacent to public schools) resulted in the application of elevated levels of sidewalk deicing salts. The data indicate that substantial improvement in shallow groundwater quality (specifically Cl^- concentrations), resulted from the implementation of road salt BMPs. A detailed comparison of the soil core data collected from the unsaturated zone as measured in 2001 and 2008 indicates a significant reduction in average soil Cl^- concentration occurred following the implementation of the BMP activities. When these data are combined with estimates of groundwater recharge rates at each of the field monitoring stations, an average reduction of 60% in road salt mass loading to the water table was observed between the initial study (2003) and the 2008 study. The data support the overall conclusion that significant reductions in road salt loads to the subsurface resulted from the implementation of the BMP strategies in 2003. The study shows that a considerably lower percentage of the total applied road salt mass is entering the subsurface under the new salt management practices as compared to historical practices. The trends observed in the groundwater Cl^- data collected from the monitoring network correlates well with the observations made from a detailed assessment of chloride occurrence and distribution in the unsaturated zone. Accordingly, monitoring of changes in groundwater quality in shallow monitoring wells provide useful quantitative assessment of the performance of different BMPs in the urban environment. The actual time lag associated with the implementation of the BMPs and an observable influence at the water table, however, will depend on the thickness of the unsaturated zone and the vertical soil water velocity. The groundwater quality data clearly illustrate that the reduction in Cl^- concentration at the water table is a transient process that will take years to be fully realized.

Distribution and mass loading of chloride in snowpack of salt vulnerable zones. A field monitoring program was designed to quantify the spatial distribution and mass loading of chloride in roadside snowpack of salt vulnerable areas. The factorial design included measuring chloride concentrations and mass loading (kg m^{-2})in 3 well field capture zones (2, 5 and 10 year travel times) for 3 road classes (2, 3 and 4) within each capture zone, for 3 cities (Waterloo, Kitchener, and Cambridge). The data show that average chloride concentrations declined with distance from the road way. Variability in the data is related to several factors that influence both the redistribution of snow in urban environments and salt demand. Chloride concentrations in snow varied considerably as a function of road class, well field and sensitivity area (capture zone travel time).

Chloride transfer in two Waterloo stormwater ponds. A field study was conducted to examine the effect of landuse and road density/type on chloride concentrations in Laurel Creek and to evaluate the role of stormwater management ponds as a chloride source to receiving waters. Ten sampling stations in Laurel Creek (from its headwaters to the central part of Waterloo) as well as both the inflow and outflow of two stormwater management (SWM) ponds (conventional design– Pond 45 and hybrid extended detention design – Pond 33) were monitored in Waterloo, Ontario during the fall 2008 and winter/spring 2009. Chloride concentrations in Laurel Creek as well as the inflow and outflow of two stormwater ponds often exceeded the CCME chronic toxicity level (250 mg L^{-1}) and occasionally exceeded the CCME acute toxicity level (750 mg L^{-1}). Mean monthly chloride concentrations increased throughout the winter and spring at most sites but were typically lower in the less urbanized headwater sites than in areas with increasing impervious cover and road density/traffic volume. Mean monthly chloride levels at two monitoring sites (Keats and 5B) were often 10 to 20 times higher than background levels in Beaver Creek (site 17). The study found that inflow concentrations of chloride were similar for the two stormwater ponds of varying design but their outflow concentrations varied considerably over the study period. In the hybrid design (Pond 33), mean monthly outflow chloride levels peaked in December (~700 mg L^{-1}) but remained at < 100 mg L^{-1} for the remainder of the winter. In contrast, chloride levels in the conventional design (Pond 45) were more variable and average monthly chloride concentrations increased steadily at the outflow from ~50 mg L^{-1} in October-08 to ~400 mg L^{-1} in April-09. The study suggests that the hybrid design pond (which consists of two settling ponds separated by a berm and a final vegetated area) was more effective at reducing chloride discharge at the outflow.

PAVEMENT AND SALT MANAGEMENT (TAC 5)

Performance of Pervious Concrete Pavement in an Accelerated Freeze-Thaw Climate: Transport and retention of water and salt within pervious concrete subjected to freezing and typical winter sanding. Pervious concrete has been shown to reduce stormwater volume and the concentration of many contaminants (with the exception of chloride) in urban runoff. In freeze/thaw environments, where the application of road salt is necessary, it is necessary to understand the impact of pervious concrete structures on the movement of water and hence, the transport of the Cl^- within the water. To accomplish this, a study was conducted to characterize the hydrologic performance of pervious concrete under frozen and thawed conditions, with varying additions of sand using both brine (23% salt solution) and fresh water. The overall impact of sand application to the surface of pervious concrete is a reduction in the speed of the movement of water through the pores, causing a delay in the peak flow received at the base of the concrete. In all experiments, the salt was transported through the pervious concrete very quickly. Salt underwent some dispersion with the application of sand and under frozen conditions, due to the more tortuous flow paths. Contrasting this is the impact of freezing water within the pores of the concrete. Although the overall impact of frozen water is similar to sand (i.e. slows water movement), the water is able to have this effect throughout the entire depth of the concrete, as water is able to freeze within the pores near to the base as well as at the surface of the concrete. This would also have consequences on the timing of salt transport, as it is a dissolved constituent within the water, and would also remain in the matrix of the concrete. However, these represent extreme conditions. Our observations indicate that the infiltration capacity of the pervious concrete structures, as tested, exceeds the probable maximum water loading rate that will be encountered in Southern Ontario, with or without sand; frozen or unfrozen.

The focus of the Ontario Clean Water Act is to reduce significant risks to drinking water by identifying vulnerable areas (wellhead protection areas, intake protection areas and other highly vulnerable areas) and developing plans to reduce significant risks to acceptable levels and prevent future significant risks. Chloride is listed as a potential threat to drinking water as indicated in Section 1.1 of Ontario Regulation 287/07. Implications of the Ontario Clean Water Act for road salt management include 1) Improved design and delivery of parking lot winter maintenance programs 2) Increased adoption of new technology 3) Improved delineation of salt vulnerable areas and refined winter maintenance procedures in intake protection zones (IPZs) 4) Increased level of training (certification) for road authorities and private contractors 5) Integration of salt management plans with source water protection committees (SPCs) objectives to delineate source waters, identify threats and develop and implement SWP Plan and 6) Improved stormwater management practices. While pervious pavement technologies can effectively reduce runoff, they can negatively impact groundwater quality when improperly located and poorly designed. To meet the future requirements of the Clean Water Act, better design guidance is required for the use of this material for parking lots located in salt vulnerable areas.

Clarkson Go Station Study. A study was conducted to measure and compare the chloride flux in runoff from two parking lots treated with different de-icing compounds (common road salt and a commercially available alternative de-icing material Mountain Organic Natural Icemelter) during the period October 2008 to April 2009. The data show that chloride losses from a parking lot treated with Mountain Organic Natural Icemelter were demonstrably higher than for a parking lot treated with road salt. More systematic study of the effectiveness (road safety) and associated environmental impacts of road salt and a range of alternative deicers are required to provide contractors with appropriate guidelines for optimal application rates and related spreading technology. Such information coupled with enhanced training, improved technology for salt application, better record keeping and reporting protocols would lead to significant reductions in the discharge of chloride from parking lots to the environment.

Parking Lot Management – Smart About Salt Program. In 2004, the Region of Waterloo developed and launched the *Smart About Salt (SAS)* Program. This locally initiated program incorporates a multi-faceted approach designed to reduce the application of salt on parking lots and sidewalks of both public and private properties by 1) working collaboratively with transportation operations staff from the municipally 2) developing guidelines and site plan design recommendations to minimize the need for de-icing on new developments 3) building public awareness through education programs and 4) implementing the *Smart About Salt* accreditation program for private snow contractors and clients to recognize and incorporate beneficial salt management practices on parking lots and sidewalks.

Given the increasing need to develop programs that further reduce the transmission of chloride to the environment, the *Smart About Salt* program is an example of a management model that can be effectively developed and administered by stakeholders to reduce the use of deicing chemicals by private contractors while achieving safe levels of service on parking lots and sidewalks. The program is based on developing partnerships and educational programs that promotes environmental leadership. If this or similar programs were widely implemented, it would likely promote optimal salt application and reduce winter maintenance costs while at the same time minimizing chloride discharge to the environment. There is some evidence to suggest that certification of contractors and improved record keeping practices may reduce liability and insurance costs.

There is a critical need to train and certify private contractors and to develop appropriate winter maintenance guidelines and practices for parking lots. The excessive addition of deicers to parking lots is in part related to the poor design of parking lots and related stormwater design of buildings. There is a real need to improve parking lot and building design standards to minimize the risk of water freezing on pavement which then necessitates additional applications of deicer.

SNOW STORAGE AND DISPOSAL (TAC 8)

Snow Storage Disposal Facilities (SSDFs) and Their Role in Urban Snow and Road Salt Management: Guidance for Design, Operation, and Maintenance. When snow is transported from urban areas to snow storage disposal facilities (SSDFs), it contains a range of particulate and dissolved constituents that can potentially be released into the environment during snowmelt. Snow removal, transport, storage and snowmelt and potential impacts of these processes on the environment are of concern in both urban and natural environments with transportation corridors. A review of recent literature on SSDFs is presented which describes current knowledge regarding 1) the basic characteristics of operation of SSDFs, 2) how such knowledge is used for developing guidance for planning, design and operation of SSDFs and 3) what is the potential role of SSDFs in the context of road salt management. Such information is necessary to improve guidance documents for the design of snow storage and disposal sites.

1. Introduction

BACKGROUND

Road salts are used as anti-icing and de-icing chemicals for winter road maintenance. It is widely recognized that chloride from road salt enters the environment (surface water, soils, and groundwater) through losses from salt storage facilities, snow disposal sites, as well as from roadway runoff (Marsalek, 2003). In 1995, a comprehensive five-year scientific assessment of the environmental impacts of road salt was conducted under the *Canadian Environmental Protection Act, 1999* (Environment Canada, 2001) to provide a comprehensive synthesis of scientific literature regarding the effects of road salt on the environment. The report concluded that significant discharges of chloride from road salt were having adverse impacts on freshwater ecosystems, drinking water supplies, soil, vegetation, wildlife and urban infrastructure.

To address the adverse impacts of road salt on the Canadian environment, a multi-stakeholder working group was formed to develop a risk management protocol for winter road maintenance. Accordingly, under the ***Canadian Environmental Protection Act (1999),*** the Government of Canada published a *Code of Practice for the Environmental Management of Road Salts* in 2004. The Code was designed primarily to help municipalities and other road authorities better manage their use of road salt and reduce the adverse environmental impacts of chloride while maintaining road safety. Two main recommendations of the Code are 1) development of salt management plans (which are based on a review of existing road maintenance operations, identification of means and goal setting to achieve the reductions of the negative impacts of salt releases) and 2) implementation of best management practices in the areas of salt application, salt storage and snow disposal as reported in the Transportation Association of Canada's (TAC) *Syntheses of Best Management Practices (SOBPs)*. The nine *SOBPs* include TAC 1 *Salt Management Plans*; TAC 2 *Training*; TAC 3 *Road and Bridge Design*; TAC 4 *Drainage and Stormwater*; TAC 5 *Pavements and Salt Management*; TAC 6 *Vegetation Management*; TAC 7 *Design of Road Maintenance Yards*; TAC 8 *Snow Storage and Disposal* and TAC 9 *Winter Maintenance Technologies*. Details of the SOBPs are found at http://www.tac-atc.ca/english/resourcecentre/roadsalt.cfm.

The primary assumption of the Code of Practice is that state-of-the-art salt management practices when applied as per Code recommendations will benefit the environment (i.e. reduce chloride levels input to the environment and improve problematic water and soil conditions) and also have potential benefits to road authorities (i.e. more efficient operations, improved roadway safety and cost savings). However, few systematic studies have been conducted to specifically quantify the environmental benefits (i.e. salt reduction) in the main areas where the Code recommendations have been applied (salt application, salt storage and snow disposal). This report presents the results of an 18 month study to assess whether voluntary adoption of the Code of Practice has effectively reduced chloride inputs to the environment in response to best management practices related to salt application and snow disposal. The study is intended to

1) provide data to support the Environment Canada 2010 review of the Code of Practice,
2) evaluate the degree of implementation and effectiveness of selected best management practices to mitigate chloride transfer to the environment,
3) identify barriers to implementation, and
4) make recommendations to improve winter maintenance practices of roadways and parking lots.

STUDY GOAL

The primary goal of the study is to assess whether voluntary road salt management programs and related *SOBPs* (as defined by the Code of Practice) have been implemented and are effectively reducing environmental chloride inputs from selected best management practices related to salt application and snow disposal. Specific objectives and associated tasks of the study are:

Objective 1: Determine the degree to which voluntary road salt management plans programs have been implemented in Ontario (TAC 1).

Task 1 a) Conduct a survey of 432 Ontario Road Management Authorities.

b) Hold meetings with salt management working groups (RMOW Winter Maintenance Policy and Procedures Working Group, Ontario Road Salt Management Working Group, Toronto Conservation Authority, Credit Valley Conservation Authority and Regional Municipality of Waterloo).

c) Convene a Road Salt Management Workshop at the University of Waterloo with consultants and winter maintenance practitioners from city, regional and provincial agencies.

Objective 2: Design and conduct field and laboratory studies to determine whether selected salt management SOBPs (salt application and snow disposal) reduce chloride transfer to the environment. Given the time and logistical constraints related to implementing this study, only selected BMPs were evaluated.

Task 2 a) Quantify changes in salt mass loadings to and chloride concentrations in groundwater related to improved road salt application practices in vulnerable areas (groundwater recharge zone)

b) Conduct a snow/chloride content survey in the Regional Municipality of Waterloo using the factorial design (3 cities by 3 zones of groundwater risk by 4 road types with varying salt applications) to quantify chloride concentrations and mass loading in salt vulnerable areas.

c) Compare chloride losses from parking lots using road salt with alternative deicers and evaluate parking lot management strategies for reducing salt use.

d) Conduct laboratory experiments in a cold room at the University of Waterloo to examine the effects of clogging and freezing on the permeability of pervious pavement to provide direction for the design, implementation and winter maintenance of pervious pavement parking lots in Ontario.

e) Monitor chloride levels at the outflow and inflow of two stormwater ponds with contrasting designs (conventional and enhanced) in Waterloo.

f) Review current literature on the design, operation, and maintenance of snow storage and disposal facilities (SSDFs).

Objective 3: Disseminate results of the study and related international studies in the scientific literature.

Task 3: Convene the *1st International Conference on Urban Drainage and Road Salt Management in Cold Climates: Advances in Best Practices* at the University of Waterloo. Goals of the conference are to (1) provide a state-of-the-art overview of urban drainage issues and practices in cold climate, including best management practices for snowmelt/stormwater management (2) provide state-of-the-art information on interactions between road salting and the environment, with respect to their understanding, measurement, modeling and management and (3) improve the scientific basis for policy decisions related to the impacts of winter maintenance and road salt on infrastructure, terrestrial and aquatic ecosystems and water resources.

Objective 4: Identify barriers to implementation of the Code of Practice SOBPs and make recommendations to improve winter maintenance practices of roadways and parking lots.

Task 4: Identify barriers to implementation of the Code of Practice SOBPs and make recommendations to improve winter maintenance practices of roadways and parking lots.

ORGANIZATION OF THE REPORT

The report is organized in sections which provide the research outcomes for specific tasks listed above.

2. Road Salt Management Survey

Objective 1 – Task 1a:
Determine the extent to which salt best management practices (TAC 1, 2, 7, 8, 9) are being applied.

INTRODUCTION

In the late 1990's, Environment Canada became increasingly concerned about the negative environmental effects resulting from excessive road salt use in Canada. A subsequent Assessment Report concluded that excessive use of road salts was having adverse effects on the environment and that actions needed to be taken (Environment Canada, 2001). In response to these concerns, Environment Canada published a document entitled "*Code of Practice for the Environmental Management of Road Salts"* in 2004. The Code of Practice, which included a Syntheses of 9 Best Management Practices for Salt Management, was based on the assumption that application of Best Salt Management Practices and their systematic adoption by road authorities would result in environmental benefits by ensuring that only enough salt would be applied to maintain safe travel conditions. The two key assumptions of the Code of Practice are 1) that the application of Best Practices will result in environmental improvement and 2) that Best Practices are being applied. The survey is intended to test the latter assumption.

PURPOSE OF THE SURVEY

Environment Canada's Code of Practice promoted the application of SOBPs as part of its salt management strategy. This survey was developed to determine the extent to which certain SOBPs have been implemented and are currently being used by Ontario road authorities and to identify barriers to their implementation. The survey focused on 5 specific SOBPs (listed below) primarily because they were considered to be the most critical best practices that would likely affect change in salt management practices in Ontario.

- #1 – Salt Management Plans
- #2 – Training
- #7 – Design and Operation of Road Maintenance Yards
- #8 – Snow Storage and Disposal
- #9 – Winter Maintenance Equipment and Technologies

The SOBPs listed below were not included in the survey since it was intended to focus primarily on Operational issues:

- #3 – Road and Bridge Design – While this is an important SOBP, it has not yet been broadly implemented by road authorities.
- #4 – Drainage and Stormwater Management - Since stormwater management is part of roadway design in Ontario, it was not addressed in the survey.
- #5 – Pavements and Salt Management – This SOBP focuses on pavement considerations during road design and construction.
- #6 – Vegetation Management – This SOBP focuses on the selection of vegetation for minimizing salt spray, plant species selection for salt impacted areas and drainage management.

METHODOLOGY

An online survey tool (SurveyMonkey) was used to administer the survey. The Ontario Good Road Association (OGRA) provided technical support to prepare and issue the survey. The Survey is provided in Appendix A and the data compiled and summarized by SurveyMonkey are provided in Appendix B. The survey was sent to 432 public works officials in Ontario that included 40 cities, 6 Regional Municipalities, 25 Counties, 85 Towns, 1 District and over 260 Townships/Villages and Municipalities.

There were some concerns with the survey response that will influence the results and their interpretation. These include:

1. Respondents were not required to self identify and therefore it is not possible to determine exactly who responded.

2. It is evident that some municipalities had more than one response and because the surveys are anonymous it is not possible to determine who the respondents are and correct for this issue.

3. Based on the answer to a previous question in the survey, some questions were skipped which resulted in a low response to one particular question that should have been answered by all participants. This made this question less informative.

Road maintenance authorities in areas with higher tax base have increased technical and human resource capacity to manage winter maintenance compared to smaller authorities. Accordingly, the response to the survey is likely biased towards authorities with enhanced technical capacity and related human resources to complete the survey.

SURVEY RESULTS AND CONCLUSIONS

The response rate as well as the survey results and conclusions are presented in the following subsections.

Response Rate. The survey was issued by email the first week of June and responses were requested within 30 days. Seventy out of 432 public works officials responded to the survey resulting in a response rate of 16.3%. The survey respondents included Regional Municipalities (20%), Cities (19%), Counties (13%), Townships (19%) and Towns (29%) which generally reflects a reasonable cross-section of Ontario road authorities. However, upon review of the respondents, the response is somewhat biased towards authorities with enhanced technical capacity and related human resources to complete the survey. It follows that the larger municipalities are those managing the overwhelming proportion of road salt application on municipal roads.

The Code of Practice resulted in the production of Salt Management Plans by a high percentage of road authorities in Ontario.

Approximately 89% of larger municipalities have produced Salt Management Plans.

Salt Management Plans. The Code of Practice (2004) encourages all road authorities using > 500 t of salt annually and applying salt in the vicinity of Salt Vulnerable Areas to prepare a Salt Management Plan. Although the Code of Practice was published in 2004, the framework for salt management plans was developed earlier and some road authorities began implementing best practices including Salt Management Plans before 2004. The first SOBP (TAC 1) provides direction for the preparation of a Salt Management Plan.

Approximately 78% of the respondents (54) were from larger municipalities which likely reflect authorities who have adopted the Code of Practice. Of the respondents, almost 70% (48) had developed a Salt Management Plan. This represents approximately 89% of larger municipalities and indicates that a high percentage of the municipalities subject to the Code of Practice have prepared Salt Management Plans. The survey shows that 5 years after the Code was published, a number of municipalities have yet to adopt and implement Salt Management Plans. The survey does not specify whether some authorities chose not to have a plan or whether they lack the capacity to do so.

Although the Code was published in 2004, almost 30% of respondents produced their salt management plan prior to 2004. Nearly half of respondents produced plans in 2004-05 and about 18% of the road authorities did not have plans in place until 2007-09. The results indicate that the Code of Practice effectively encouraged Salt Management Plans to be produced in Ontario. Many municipalities were proactive and produced plans before they were required. Based on discussions with several managers at the University of Waterloo Road Salt Management Workshop in 2007, this success is likely attributed in part to the promotional efforts of the Ontario Good Roads Association and the Transportation Association of Canada which produced a Salt Management Guide in 1999 and promoted its adoption by TAC members.

When asked whether Salt Management Plans are being or will be reviewed, 43% of the respondents had not reviewed their Plans but the remaining 57% had at least done so once or more than once. The majority of authorities reviewed their Salt Management Plans in 2007-08 and over 90% report they intend to review their plans in the future.

The Code of Practice identifies a number of critical elements that should be addressed and included in a Salt Management Plan. Respondents were asked to rate their plans with respect to nine underlying principles set out in the Code of Practice. The following identifies the 9 areas and how they are being addressed.

- ***Safety*** – A very high percentage (89%) of the respondents rate their plans high with respect to addressing safety. This is not surprising given that safety and mobility are the primary reasons for winter road maintenance.

- ***Environmental Protection*** – A high percentage (78%) rate their plans high with respect to environmental protection. This is expected given that the primary focus of the Code is to reduce the environmental impacts of road salt and that agencies need to justify their expenditures for further environmental investment. Accordingly they need to define their progress without claiming they have reached a final target.

- ***Continual Improvement*** – Only 56% rate their plans high with respect to continual improvement.

- ***Fiscal Responsibility*** – Approximately 68% rate their plans high with respect to fiscal responsibility.

- ***Efficient Transportation Systems*** - Approximately 68% rate their plans high with respect to efficiency.

- ***Accountability*** – Approximately 78% rate their plans high with respect to accountability.
- ***Measurable Progress*** – Only 46% rate their plans high with respect to measuring progress.
- ***Communications*** – Only 43% rate their plans high with respect to communicating with stakeholders.
- ***Knowledge and Skilled Workforce*** – Approximately 78% rate their plans high with respect to training.

Greater effort is needed to inform contractors and seasonal staff of the salt management plan.

The data show that four principles (safety, environmental protection, accountability and knowledge and skilled workforce) are handled well according to most of the survey respondents. However, three principles (continual improvement, measurable progress and communications) need more attention. These principles are critical to ensuring that Salt Management Plans are properly executed. A concerted effort should be directed to implementing these principles.

The Salt Management Plans deal well with safety and environment but are weak with respect to continual improvement, monitoring progress and communications.

A question focused on the subjects that are addressed in the salt management plans and is based on the content expectations laid out in the Code of Practice. The areas addressed to a high degree are the amount of salt used, application rates, electronic controllers, material storage, snow disposal, training, record keeping, and equipment calibration. The areas addressed to a low degree are pre-wetting, liquid only, RWIS, salt vulnerable areas, monitoring of progress and reporting and annual reviews.

Survey results show that good progress is being made on the introduction of best practices but the plans are less adequate with regard to more advanced technologies, adjusting practices for salt vulnerable areas and applying management rigor to ensure that the intent of the plan is being achieved and that practices are continually being improved.

Salt Management Plan Awareness. Agencies were asked two questions to determine whether contractors and seasonal staff are informed about the Salt Management Plan. About 55% of respondents reported they hire contractors and seasonal staff. Approximately 30% of contractors and 57% of seasonal staff are aware of the Salt Management Plans. There is an expectation in the Code of Practice that road authorities make contractors aware of their Salt

Management Plans. The survey suggests that few agencies are fully engaging and informing contractors of their Salt Management Plans.

Operational Changes Since the Adoption of the SMP. The Code of Practice was developed to encourage road authorities to adopt new winter operation practices that would maintain safe roads and reduce environmental impacts due to road salts. Several questions were asked to determine the extent to which best practices are being adopted. The results are summarized in the following sub-sections.

Although excellent salt management training is available in Ontario, only 63% of respondents have annual salt management training programs in place. Allow percentage of private contractors to be trained.

Salt Management Training. The Code of Practice was implemented to promote a change in winter maintenance practices by encouraging the introduction of best salt management practices. Training is believed to be a critical component of successful change management, especially when trying to replace long term practices with less familiar ones. In Ontario, a number of new training programs have been implemented because of the Code of Practice. Two notable programs are 1) a program developed by the Transportation Association of Canada, which ran aggressively for a couple of years and is still available on the TAC website for free download by agencies wishing to self-train and 2) a road school and DVD-based training program developed by the Ontario Good Roads Association. The survey asked a number of questions to determine who is being trained, the extent of training being carried out, the topics being trained and the preferred timing for salt management training. The following sub-sections discuss the training results of the survey.

Who is trained and when? Approximately 55% of the respondents have an annual training program. Approximately 63% of respondents with salt management plans have annual salt management training. This percentage could be improved given how important training is to creating effective change in winter maintenance practices. However, this comment should not diminish the fact that considerable training has occurred in agencies across Ontario since the Code was developed.

Most of the training programs cover the key learning goals. The environmental effects of salt are reportedly well covered.

Most authorities surveyed train their operators (97%), supervisors (79%) and managers (76%). Only 52% train seasonal staff (although not all seasonal staff work on winter road maintenance) and 21% train contractors. Of those who responded, 69% indicated that they monitor for compliance with the learning goals and 66% report that performance is in compliance with their learning goals. Most (86%) agencies retrain when performance is not being met and only 31% have a different training program for previously trained personnel.

All respondents (100%) conduct their salt management training program in the fall. A variety of learning techniques are used in the training programs. These include verbal presentations (100%), visual aids (72%), group discussions (79%) and hands on practical applications (76%).

Topics being covered. The Code of Practice encourages training for all personnel when managing or performing winter maintenance activities and training programs include a review of TAC's Syntheses of Best Practices. In particular, the *Synthesis of Best Practices – Training* identifies a number of learning goals that salt management training programs should include. The survey asked respondents to identify the learning goals covered in their training program. The respondents indicated that most of the learning goals are covered to a high degree (i.e. in greater than 75% of the cases). Over 95% report that training programs include a review of the environmental effects of salt on the environment and infrastructure.

Some learning goals that are addressed to a moderate extent (50% - 75%) include:

- Understanding dew point and the conditions that lead to frost and black ice (69%).
- Understand the concept of freeze point depressant (58%).
- Understanding the use of liquids (69%) which is particularly important for any organization using liquids.
- Managing Snow Disposal facilities (58%). It is not surprising that this percentage is low because many road authorities do not have snow disposal sites and any training related to these sites would most likely be directed at staff that manages these sites. However, 30 road authorities indicated that they have snow disposal sites and only 15 indicated they train in this area. The reason the percentage is a bit higher is that only 26 road authorities responded to the training goals question.
- Two thirds (66%) of respondents indicated that they make snow and ice control decisions based on pavement temperatures. Approximately the same percentage (62-65%) indicated that they include the learning goals around pavement temperatures in their training. It is

important for winter maintenance staff to understand the importance of pavement temperatures when making snow and ice control decisions.

Only three leaning goals were poorly addressed in less than 50% of respondents' training programs. They are:

- Understand the Phase Diagram (42%). This is a difficult concept to explain but is one that is important to understanding the science of salt use and should therefore be part of a training program.
- Understand how to measure brine concentration (31%) but 80% of agencies making brine teach how to measure brine concentration.
- Understanding how to read and interpret RWIS data (42%). In Ontario this is required as a pre-requisite to accessing MTO's RWIS data and should be part of any training program where supervisors are accessing these data. The OGRA has developed an excellent computer-based training program that deals with RWIS.

Many of the more complicated goals relating to best practices are not adequately covered.

Salt Vulnerable Areas. The Code of Practice applies to "*organizations that have vulnerable areas in their territory that could be potentially impacted by road salts.*" Annex B of the Code provides guidance for identifying vulnerable areas. The Annex identifies additional salt management measures that could be used in vulnerable areas. Three questions in the survey were directed at assessing how vulnerable areas are addressed. The results showed the following:

- About half of the respondents (51%) identify salt use in vulnerable areas.
- Similarly 49% of respondents indicated that they modify practices in the vicinity of salt vulnerable areas.
- The same percentage of respondents (51%) indicated that they have documented policies, procedures and guidelines for vulnerable areas.

There is indication that road authorities are identifying salt vulnerable areas and adjusting practices in vulnerable areas.

- In questions 31 and 41, respondents indicated that they have adopted special practices to reduce salt use near salt vulnerable areas, whereas only 18 responded to question 12 indicating that they modify practices in the vicinity of vulnerable areas. This discrepancy may be a function of the filtering technique used in the survey. The most frequently used practices to reduce salt use in vulnerable areas are:

- Used sand mix (58%)
- Reduced application rates (40%)
- Used pre-wetted salt (34%)
- Plowed more frequently (26%)
- Used straight liquid (16%)
- Plan roads to avoid salt sensitive areas (8%)

Record Keeping. Fifty respondents answered the question "Does your organization monitor and keep records of your winter maintenance activities". Of these, 96% said "Yes". The types of records that most respondents keep are:

- Annual salt use (87%)
- Road condition (85%)
- Air Temperatures (74.5%)
- Current Weather Conditions (68%)
- Pavement Temperatures (62%)
- Application Rates (60%)
- Daily Salt Use (55%)
- Treatment Strategies (21%)
- Pavement Temperature Trends (6%)

Although a high percentage maintain records, some key types of records are not being kept thus hampering continuous improvement.

Salt management records are not being maintained by a high percentage of respondents. The lack of attention to maintaining treatment strategy records would make it difficult to analyze practices as part of a continuous improvement program makes it difficult to defend against lawsuits. The lack of records on daily salt use and application rates will make it difficult to understand and manage the amount of salt being applied and to improve practices.

Maintenance Yards. Several questions were asked about salt usage in maintenance yards. Of 49 respondents, only 14% (7) constructed new maintenance yards. Of these, 43% conducted environmental assessments as part of the process of planning the new yard. Similarly 43% followed TAC's SOBP for the Design and Operation of Road Maintenance Yards. The reason given by 75% of

The SOBP for maintenance yards is being followed in the case of 43% of new yard development. Salt storage and handling practices are improving but management of impacted water still needs attention.

respondents for not following the TAC SOBP was a lack of awareness of the guide.

Respondents were asked about good housekeeping practices in their yards but only 7 respondents that have built new yards answered this question. The practices that are carried out to a high degree by those respondents are:

- 100% reported materials being stored undercover and on impermeable pads at all their yards.
- 100% reported that spreaders are not overloaded at most yards.
- 100% reported that spills are cleaned up at most yards.
- 86% reported that salt is unloaded directly inside the storage facility.
- 86% reported that vehicle wash water is managed.
- 43% weigh their vehicles to measure salt use.
- 14% use salt impacted water for brine production.
- 14% do environmental monitoring.

Most snow disposal sites appear to be poorly designed. The need for better snow storage practices and awareness of TAC's SOBP needs greater promotion.

Snow Disposal. The survey asked whether road authorities have snow disposal sites. Of the 49 respondents, 61% have snow disposal sites that apply the following best practices:

- 73% clean up debris in the spring and send it for proper disposal
- 17% store snow on impermeable hard surfaces
- 13% have melt water treatment by tanks or ponds before being discharged

Only one respondent developed a new snow disposal site. The respondent did not conduct an environmental assessment nor did it follow the TAC SOBP – Snow Storage and Disposal. This authority indicated it was not aware of the SOBP.

The Code of Practice – Reporting, Benefits and Challenges. The Code of Practice requires annual reporting to Environment Canada. The respondents were asked if they had or intended to complete their Environment Canada submission before the end of June. 79% of the respondents reported they would comply with Environment Canada reporting requirements. The data indicate that about 20% of the respondents did not plan to file a report. The survey asked about benefits of the Code of Practice for the Environmental Management of Road Salt and what challenges they faced in complying with it. The following two subsections summarize the responses to these two questions.

Benefits of the Code of Practice. Forty-eight respondents commented on the benefit of the Code and the results are described below.

Awareness & Knowledge

- Raised awareness of the amount of salt being used.
- Raised awareness of the negative impacts of salt on the environment.
- Raised awareness that reducing salt use can also reduce operating expenses.
- Improved understanding and use of best salt management practices.

Validation of Action

- Provided leverage with Council and management to obtain the necessary funding and commitment to implement best practices.

Set Framework and Standardized Approach

- Encouraged focus on salt management by providing a framework for best practices.
- Provided a framework for continuous improvement of salt management practices.
- Established a common benchmark that road authorities can work towards.
- Provided guidelines to reduce salt.
- Standardized the amount of salt being used.
- Provided a common understanding from which to draw.
- Provided objectives to serve as a benchmark.
- Provided a great tool for tracking salt best practices.
- Required regular review of winter control procedures and operations.

The greatest benefits of the Code are to standardize practices and advance the rate of implementation of best practices.

Implementation of Improved Practices

- Required road authorities to examine and monitor different methods of supplying winter control.
- Improved planning and control of road treatment practices and salt use.
- Encouraged better record-keeping that helps road authorities see progress.
- Resulted in more covered storage of materials.
- Resulted in improved salt handling practices.
- Advanced the adoption rate of new technologies.
- Encouraged greater use and development of better liquids.
- More methods have come forward.
- Encouraged lower sand/salt mixes.

20% of Ontario municipalities are not filing their annual reports with Environment Canada.

Environmental Improvement

- Getting environmental improvement.
- Reduced the amount of chlorides entering the environment without affecting winter control service levels to the motoring public.

Cost Savings

- Achieved cost savings by reducing the amount of salt applied and how it is applied

Improved Monitoring

- Resulted in conscious monitoring of salt use.
- Reporting requirement reminded organizations to review all salt management plans, documents, salt usage etc. annually.

Challenges of the Code of Practice. Forty-eight respondents commented on the challenges with complying with the Code. The following summarizes the challenges that were reported.

Understanding of the Code

- There is a need for clear direction and training on what is required in a salt management plan. A great deal of time was required for clarification of this issue.
- Challenges vary with constant upgrades and code changes.
- The framework is provided, but it is challenging to work out the details of how to accomplish everything necessary to effectively manage salt. Other resources (e.g. TAC, etc) are the key to meeting the Code of Practice.

Institutional Inertia/Liability

- It is difficult to convince some that there is not one good solution and that you must use the right treatment for the conditions.
- Trying to change old work practices/habits.
- Ensuring that proper records are maintained.
- Liability involved in winter maintenance.
- Need to make politicians and senior management more aware to ensure that municipalities are meeting the guidelines.

Resources

- The greatest challenge reported was obtaining sufficient money to implement the Code of Practice.
- Limited funding for continuous training of staff and buying equipment while providing expected level of service.
- Excessive cost of equipment,
- Money, staff and time to carry out the requirements under our plan. These are always challenges for municipalities.
- Initially costs to fully implement the Code of Practice were a factor. However, with council acceptance of the Salt Management Plan the avenue to secure additional funding for compliance is in place.

Many municipalities have had difficulty funding changes. Some reported a need for more explanation of the requirements of the Code.

Public Expectations for Level of Service

- Customers still want and expect the best level of service and don't seem to care as long as they have clear roads.
- Traditional Levels of service have been scaled back as a result of Salt Management Practices. This has been extremely difficult for people (both staff and citizens) to accept.

Training/Education

- There are very many treatments and the conditions are changing all the time. Education is the biggest challenge.
- Getting consistent practices/compliance by the operators.

Salt Use

- Our Township is small and maintains mostly gravel roads. Through discussions with other municipalities I have noticed that as a group we are using more salt now compared to 10 years ago due to pre-wetting and anti-icing. We are using salt at times we would not have in the past.
- Finding the right (least) amount of material while keeping the motoring public safe.
- Finding cost-effective ways to monitor salt use.

Winter Variability

- Difficult to measure effectiveness given the variability of winter.
- Some days we just can't keep up with changes in the weather.

Vulnerable Areas

- Mapping vulnerable areas.

CONCLUSIONS

The Code has been adopted by a relatively high number of Ontario Municipalities (89% of the larger municipalities have Salt Management Plans in place). The release of the Code in 2004 accelerated the production rate of Plans. However, it took a number of municipalities several years to prepare their plans. In many cases (43%), once the salt management plans were produced they were not reviewed as encouraged by the Code. Approximately 20% of municipalities did not intend to file their 2009 Annual Report with Environment Canada but reasons for this observation are unknown.

The Salt Management Plans cover the principles of safety, environmental protection and accountability well but often omit provisions for continual improvement, measuring progress and communications. Many have not reviewed their plans since initially prepared but there is an indication plans will be reviewed in the near future. An increasing effort is required to encourage review and ongoing improvement of operations.

The level of communication to contractors and seasonal staff regarding Salt Management Plans could be improved. Increasingly more contractors are involved in service delivery and it is important that they be trained as defined by Salt Management Plans and encouraged by the Code.

A commendable effort has been made to improve salt management training, particularly through the efforts of the Ontario Good Roads Association and the Ontario Road Salt Management Group. However, only 63% of road authorities have annual training programs. With some exceptions, the learning goals set out in TAC's SOBP-Training are generally covered. However, some key areas (i.e. the more complicated learning goals) are not adequately covered. The Code has been effective in promoting the development of training packages and continued implementation is strongly recommended.

Record-keeping has improved since the publication of the Code and the requirement for Annual Reporting. However some records that are necessary to measure effective monitoring and continuous improvement are lacking.

Since the release of the Code, mapping of salt vulnerable areas has increased with 51% of respondents indicating they have identified salt vulnerable areas and developed policies in proximity to these areas. Improved guidance in this area is strongly recommended.

The Synthesis of Best Practices for maintenance yards has been effective at improving yard planning and design, upgrading and good housekeeping practices. However, it is only being followed by 43% of the respondents for new yard development. Since the code was developed, the greatest improvement has been in the areas of salt storage and handling. The least improved areas are management of salt impacted water and environmental monitoring. There is a lack of awareness of this SOBP and more promotion is warranted.

Approximately 61% of municipalities reported having snow disposal sites. However, most are not designed in accordance with the Code or the SOBP. There is a fundamental need to increase awareness of the SOBP for Snow Storage and Disposal.

The respondents were very positive about the benefits of the Code of Practice as a measure to advance salt management and environmental protection in Ontario. The key benefits of the Code are:

- Increased awareness of the importance of salt management to protect the environment and of best management practices that are available.
- Validated best practices and the need to improve winter control operations.
- Set a framework for salt management plans and benchmarks for salt management that lead to greater standardization.
- Accelerated the rate of introduction of best management practices and the adoption of new technologies.
- Reduced salt use and associated environmental impact.
- Reduced costs through salt reduction.
- Improved monitoring and recordkeeping.

A number of concerns and challenges regarding implementation of the Code were identified. Most of the concerns related to implementation challenges rather than the Code or the Syntheses of Best Practices. The Code-specific concerns were:

- There is a need to provide more detail, advice and direction regarding how to comply with the Code requirements.
- Municipalities need a simple and cost-effective way to map salt vulnerable areas and guidance on developing management practices for these areas.

The implementation challenges that were mentioned include:

- The difficulty in changing old practices and securing Council and senior management resources to affect change.
- The lack of resources, particularly money, was identified as the main barrier to implementing the Code.
- Meeting public expectations and the challenge of changing levels of service is a challenge.
- Training staff properly and implementing best practices in a consistent way.
- Coping with changing winters is a challenge.

Other challenges come from a lack of understanding or acceptance of the need for salt management. Changes in personnel at the staff, management and political levels since the Code was published may negatively impact the level of commitment to salt management. There may be a need to re-introduce the Code through an enhanced awareness program.

3. Drainage and Stormwater (TAC 4)

Objective 2 – Task 2a:
Quantify changes in salt mass loadings to and chloride concentrations in groundwater related to improved road salt application practices in vulnerable areas (groundwater recharge zone).

ASSESSING CHLORIDE IN THE SHALLOW VADOSE ZONE AND GROUNDWATER IN RESPONSE TO REDUCED ROAD SALT APPLICATIONS IN VULNERABLE AREAS

Introduction.

Background. There is a significant body of literature demonstrating the impacts of deicers on the quality of both surface water (Bowen, 2000; Löfgren, 2001, Kaushal et al., 2005; Ruth, 2003) and groundwater (Howard and Beck, 1993; Coster et al., 1994; Nysten, 1998; Knutsson et al., 1998; Shelburne et al., 2000). A recent study by British Columbia researchers published by the Transportation research Board (NCHRP, Report 577) provides a tool for enabling an objective comparison of the cost, performance and environmental/infrastructure impact of 42 alternative deicers and found salt to be competitive or superior at ~ -°8C. However, very few studies have focussed directly on the impacts of road salt on groundwater supplies and the utility of best management practices (BMPs) to mitigate chloride loss to the environment. Mäkinen et al. (2006) conducted a study in southern Finland to determine whether an increase in groundwater chloride concentrations could be prevented if roadway salt application rates were reduced in sensitive groundwater areas (areas of highly conductive sands and gravels). They reported that over a 4 year period, a 55% reduction in salt application resulted in an observed decrease in groundwater chloride concentrations in a majority of 45 wells that were monitored (Mäkinen et al., 2006). The successful outcomes of this research led to the adoption of a salt reduction practice in many sensitive groundwater areas of Finland (Mäkinen et al., 2006). In a related study, Jin et al. (2006) monitored the migration of chloride from road salt in the vadose zone and groundwater along a new 10 km section of highway in Saskatchewan. The chloride data were compared to baseline chloride data collected prior to construction. The Jin et al. (2006) study is particularly unique because the concern of road salt impacts on the environment was identified before highway construction began. However, after monitoring for 10 years only a slight increase in the ion concentration was observed. The authors speculated that road salt application rates were not high enough to have a significant impact on the groundwater at the sample locations**. *Given the lack of field studies directed specifically towards understanding the effectiveness of winter road maintenance BMPs to reduce chloride transfer to groundwater resources, the present study is the first of its kind to rigorously quantify the effects of salt reduction strategies on groundwater resources. Results of the study will have direct implications for winter maintenance practices in salt sensitive areas across Ontario.***

Current Study and Goals. Historically, the Regional Municipality of Waterloo (RMOW) has experienced rapid population and infrastructure growth. Consequently, water utility managers are particularly concerned about protecting groundwater resources which supply approximately 85% of the regions total water supply (Sarwar, 2003) which is primarily supplied by 133 supply wells from 55 well fields (Frind and Molson, 2002; Terraqua 1998). Four of these well fields are designated as 'high priority' due to observed increases in chloride concentration since the 1970's (Switenky and Hodgins, 2008). Figure 1 shows a trend of increasing chloride concentrations and that in some cases chloride concentrations exceed the Ontario Drinking Water Standard of 250 mg/L, which is an aesthetic objective that defines the concentration at which the water becomes salty to the taste (Switenky and Hodgins, 2008).

The Greenbrook Well Field, within the City of Kitchener, is one of the higher priority well fields within the RMOW because chloride concentrations in several of these wells have steadily increased with the density of road networks. Because of observed increases in chloride, this well field was study area for research conducted in 2001 to assess road salt loading in the groundwater and shallow vadose zone (Sarwar, 2003). The field component of the 2001 study involved coring roadside soils, installation of monitoring wells and analysis of subsurface chloride concentration profiles at a series of representative locations within the capture zone of the well field. These data were used to evaluate the subsurface distribution of Cl^-, both in the unsaturated zone and in the shallow water table and examine the relationship between the type of road and the occurrence of road salt derivatives in the road-side environment (Sarwar, 2003).

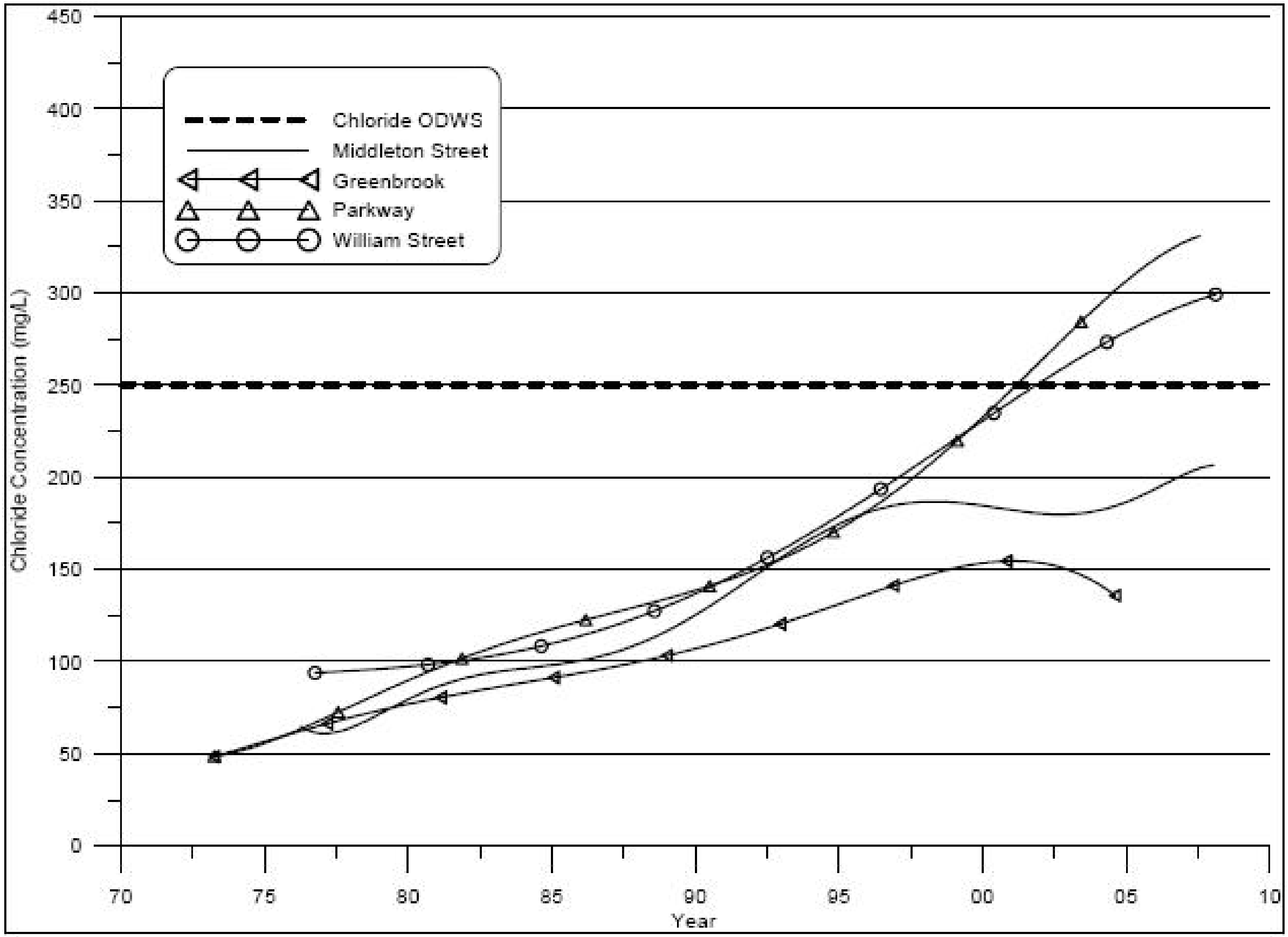


Figure 1. The Historical Chloride Concentration Trends in 5 Higher Priority Well Fields (Switenky and Hodgins, 2008)

Subsequent to the Sarwar (2003) study, a further detailed numerical analysis of the influence of historical road salt application practices on groundwater quality in the vicinity of the Greenbrook Well Field was undertaken by Bester et al. (2006). Their work demonstrated the influence of road salt loading on municipal well water quality. A model developed in the study was used to predict potential benefits associated with various salt management scenarios that involved systematic reductions in applied deicing compounds within the capture zone of the well field. The model results suggested that an overall reduction in the order of 25% in road salt application rate would be sufficient to result in the long term reductions in chloride concentrations in the municipal wells to levels below the Ontario Drinking Water Limit. Accordingly, following the work of Sarwar (2003) and Bester et al (2006), the RMOW implemented several salt reduction Beneficial Management Practices (BMPs) including: reducing salt application, upgrading winter maintenance equipment, using brine pre-wetting strategies, testing alternative deicers and motivating salt-conscious behavior in the private sector. The BMPs were adopted progressively beginning in 2003 and are described in more detail below.

The goal of the current study is to assess the effectiveness of the BMP strategies employed by the Region of Waterloo to reduce chloride transfer in salt sensitive areas and mitigate their impact on groundwater resources. A field study was designed to quantify changes in the occurrence and distribution of road salt derivatives in the subsurface following the full implementation of salt reduction strategies. The current study involved revisiting the field sites established by Sarwar (2003) and quantifying changes in stored chloride mass within the vadose zone as a metric to assess the effectiveness of the salt reduction efforts. The work also includes an examination of groundwater quality data collected from the monitoring wells originally installed at the field sites in 2001. The pre- and post-BMP data were compared to evaluate the utility of the BMP approach and potential to reduce risk to the regional groundwater quality, specifically in the Greenbrook Well Field. This report presents a description of the methodology employed in the field investigations, summaries of the data sets used to evaluate the performance of the road salt BMP strategies and a quantitative assessment of the effectiveness of the implemented BMPs to date.

Materials and Methods.

Field Site. The Greenbrook well field is located in the City of Kitchener, within the Regional Municipality of Waterloo (Figure 2). It consists of five pumping wells which extract groundwater from two aquifers within the Waterloo Moraine (Frind and Molson, 2002; Sarwar, 2003). The main aquifers are composed of glaciofluvial sands and gravels separated by till units (Sarwar, 2003). Historically, the well field has been active since the initial development of a spring fed area in 1896 (Callow, 1996). Over time, the water demand has grown with the increase in population and as a result more production wells were drilled. Today the well field has a rated capacity of about 12.3 million liters per day (RMOW, 2006). Concentrations of dissolved compounds derived from road salt (NaCl) have increased in several of the production wells since the 1970's (Switenky and Hodgins, 2008).

Because of the importance of the well field for water production and the observed increasing concentrations of sodium (Na^+) and chloride (Cl^-) in local monitoring wells, the Greenbrook well field represents an area of concern for the RMOW and therefore is an appropriate site to study the effectiveness of alternative road salt management practices on groundwater quality. Presented in Figure 3, the 10-year capture zone of the well field (Muhammad, 2000) has subsequently been the subject of BMP initiatives designed to reduce road salt impacts to groundwater quality. Accordingly, this area and the original field study sites were selected as the focus of the current study. As part of their groundwater monitoring program, the RMOW continues to monitor water quality in these wells and the data provide invaluable information regarding performance of the BMP strategies designed to mitigate the impact of road salt on groundwater.

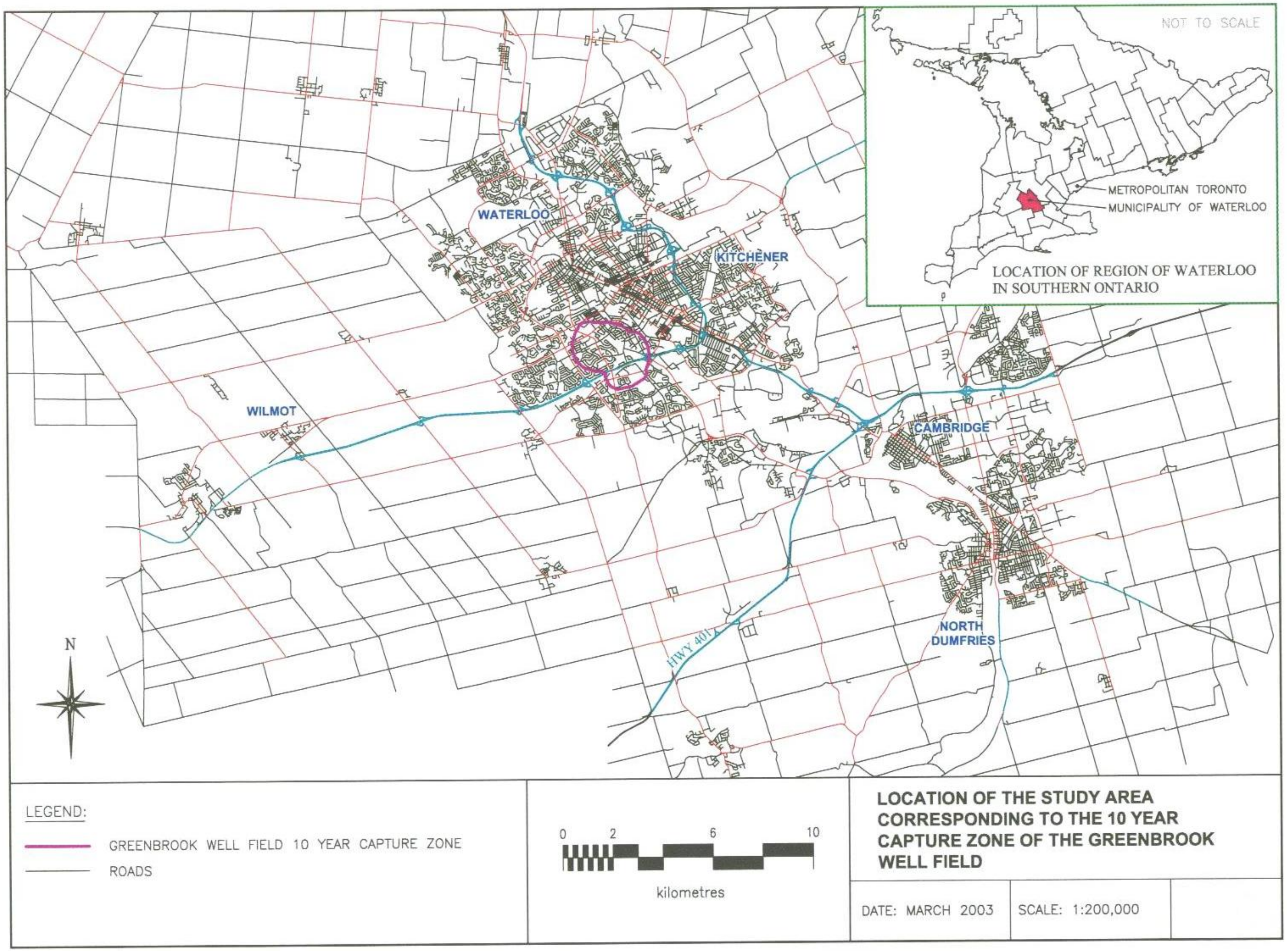


Figure 2. Location of Study Site (Sarwar, 2003)

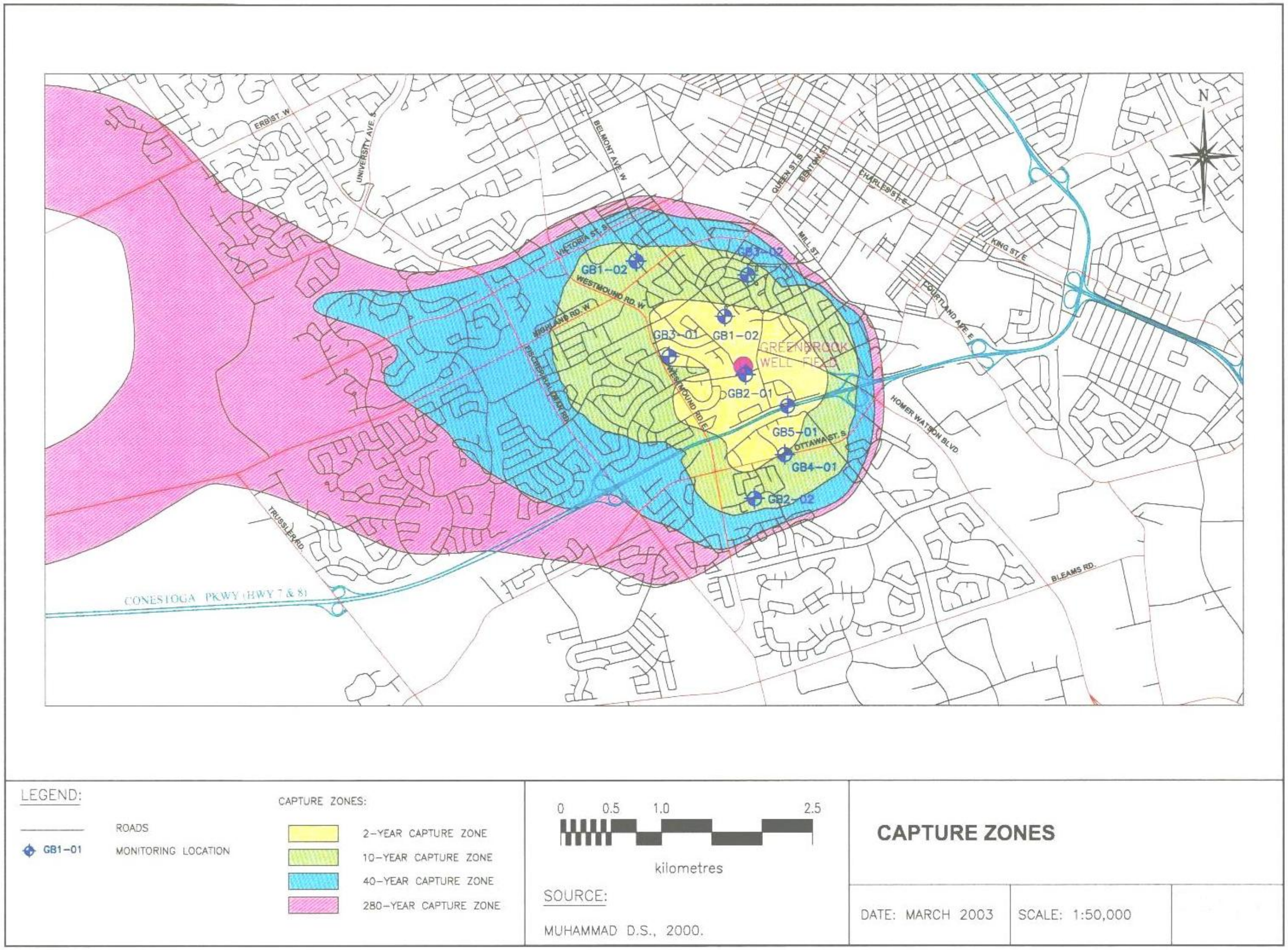


Figure 3. Greenbrook Wellfield Capture Zones (Sarwar, 2003)

BMP Implementation. To reduce chloride transfer to groundwater resources, several BMP strategies have been implemented by the RMOW (Switenky and Hodgins, 2008). During the winter of 2004, a plan was initially developed to progressively reduce road salt application rates with a target of 10% overall and 25% within the capture zones of the protected well fields; while still maintaining an appropriate level of safe driving conditions. However, a 25% reduction for all areas was later implemented. In order to quantify these reductions, the RMOW carefully tracked salt application rates in the protected well fields using an Automated Vehicle Locator/Global Positioning System. Anti-icing and alternative de-icing products were also tested as alternatives to pure dry salt application. The brine pre-wetting approach was used in an attempt to reduce the scatter of the applied road salt.

Field Activities. In the present study, the effectiveness of BMP strategies to mitigate chloride transfer to the shallow vadose zone and groundwater was investigated by comparing pre-BMP and post-BMP conditions. Seven of the eight field sites initially investigated by Sarwar (2003) were re-evaluated for post-BMP conditions. The eight original site names, locations and associated road types are described in Table 1 with site locations listed in Figure 4. Each site is located within the 10 year capture zone of the Greenbrook well field (Muhammad, 2000) and was selected based on road classification, geology, and soil type, with additional consideration given to other logistical constraints (i.e., drill rig accessibility and subsurface utilities clearance) (Sarwar, 2003; Stantec, 2002).

The shallow vadose zone at the 7 selected sites was cored May 29, 30 and June 2, 2008. Each continuous core was extracted within approximately 1 m of the existing well and approximately 1 m from the road edge. The cores were drilled to the water table in 3’ sections using the direct-push method with an Enviro-Core® sampling system (1.6” inner diameter plastic liner) then capped, labeled and sealed to prevent moisture loss. The resulting bore hole was then backfilled and sealed with bentonite. The sealed cores were then refrigerated until they could be processed.

Table 1. Monitoring Well Locations and Road Types (Sarwar, 2003)

Sr. #	Well #	Location	Coordinates		Surface Elevation (m BGS)	Road Type
			Easting	Northing		
1	GB1-01	Belmont Drive	540402.62	4809167.91	325.002	Secondary urban
2	GB2-01	Greenbrook Drive	540621.116	4808592.1	323.44	Secondary urban
3	GB3-01	Barberry Place	539863.917	4808772.41	332.033	Domestic with no salt
4	GB4-01	Ottawa Street	541008.499	4807791.91	341.761	Primary urban
5	GB5-01/07	Highway 7 & 8	541035.422	4808282.86	327.259	Primary rural
6	GB1-02/07	Lawrence Drive	539537.642	4809710.61	330.071	Secondary urban
7	GB2-02	Laurentian Drive	540704.741	4807364.58	342.155	Secondary urban
8	GB3-02	Rex Drive	540649.345	4809570.61	322.452	Secondary urban

Note: GPS survey was conducted by Stantec.

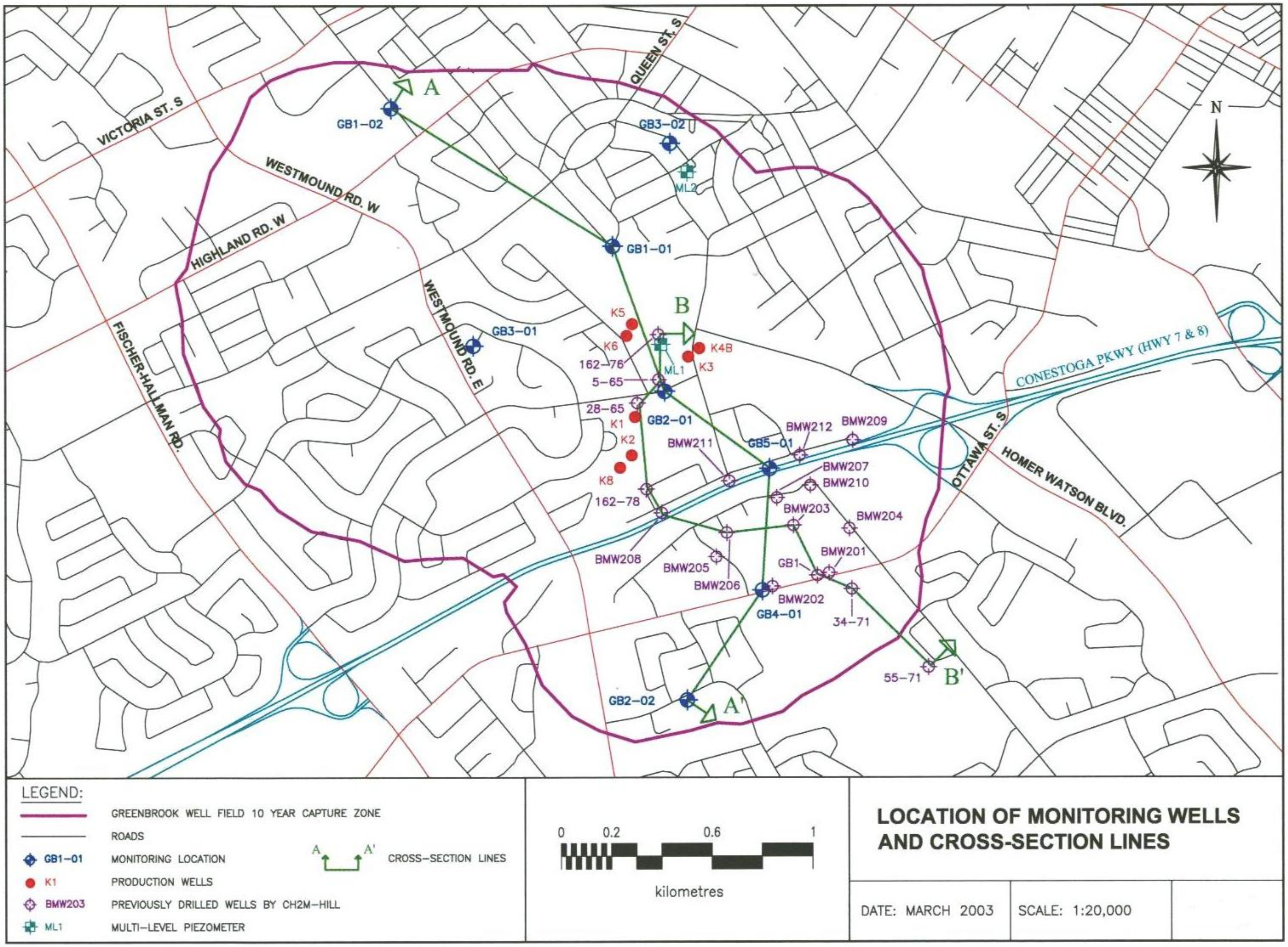


Figure 4. Location of Field Study Sites Within the 10 Year Capture Zone (Sarwar, 2003)

The RMOW conducts a shallow groundwater monitoring program at each site on a bi-annual basis in the spring and fall of each year. Water levels and water quality parameters including temperature, pH, conductivity, DO, and TDS are measured at each location. As part of the current study, groundwater samples were extracted and analyzed for various ions including chloride.

Laboratory Methods. In the laboratory, refrigerated cores were split in half and the soil characteristics (color, texture) of each core were documented. The moisture content was determined gravimetrically by drying at 100 ^{o}C for 24 hours. Soil samples were prepared for Cl^- analysis by gently breaking each sample with a mortar and pestle and passing it through a 2 mm sieve. One gram of oven dried sample was added to 10 mL of deionized water and agitated overnight using an orbital shaker then centrifuged for 15 min at 3000 rpm. The supernatant was analyzed for dissolved chloride ion (Cl^-) using a Dionex 3000 Ion Chromatograph. Results are reported in mg L^{-1}

Data Analysis. The method described by Sarwar (2003) was used to estimate the total chloride loading to the water table. According to this method, Cl^- concentrations (mgL^{-1}) are converted to soil Cl^- concentrations (mg kg^{-1} dried soil) and vertical profiles are plotted as a function of depth for each site. A Cl^- peak that represents annual salt input was evident in each profile. A single mass pulse was selected, separated into intervals bounded by core data points, and the average soil Cl^- concentration was calculated for each interval. Assuming a 1m length of road and a 2.0 m depth of impacted area for primary roads and 1.5 m for secondary roads, the total soil volume of each interval was calculated. The total mass of dry soil for each interval was calculated based on the total volume of each interval and the average dry bulk density of the soil within the pulse. The mass of chloride in each interval was then calculated based on the interval-specific average soil Cl^- concentration and total mass of dry soil. The total mass of Cl^- within a 1m length of road was calculated by summing the Cl^- mass from each interval. Finally, the total chloride loading to the water table along a 1km stretch of a two-lane roadway is estimated by multiplying the total Cl^- mass within a 1m length of road by 1000 m and 2 lanes.

Groundwater recharge rates were estimated from the core-derived data following the method described by Sarwar (2003). This approach converts soil Cl^- concentrations to pore water Cl^- concentrations which is calculated using the soil Cl^- concentration, the ratio of the mass of water to the mass of wet soil, and the average dry bulk density. The pore water Cl^- concentrations were averaged throughout the vadose zone assuming that this is the average pore water concentration which annually enters the groundwater. The total water volume available to transport the Cl^- across the water table was then calculated by dividing the total mass of Cl^- by the average pore water Cl^- concentration. The final annual average recharge rate was estimated by dividing the total available water volume by the surface area of the road salt impacted area (i.e. 2m^2 for primary roads and 1.5m^2 for secondary roads).

Profiles of cumulative stored Cl^- mass (g m^{-2}) provide visual a representation of the total Cl^- mass with depth above the water table. These profiles were calculated by summing the product of the soil Cl^- concentration, average dry bulk density, and depth interval represented by the sample for each sampling point. These profiles were not originally calculated in the Sarwar (2003) study raw data from that study were subsequently used to calculate the pre-BMP profiles for comparison with the post-BMP profiles.

Results and Discussion.

Monitoring Well Water Quality. Figure 5 depicts temporal trends of chloride concentration for the 7 monitoring wells. The maximum concentration observed over the 7 year period was 4580 mgL^{-1} in GB1-01 (Belmont Dr.) in late 2001, while the lowest observed concentration was 8 mgL^{-1} in GB3-02 (Rex Dr.) in early 2008. The second and third highest groundwater Cl^- concentrations were measured in wells GB4-01 and GB5-01/07, respectively. Compared to the other sample locations, these locations received the highest road salt loading rates. Surprisingly, well GB1-01, located beside a secondary road, consistently had the highest Cl^- concentration which suggests that site specific conditions as well as road salt application practices play an important role in the distribution and magnitude of Cl^- levels present in the subsurface environment. Well GB1-01 is located in an open area at a corner of a steep road and higher salt application rates were likely applied to increase road safety. Accordingly, the increased rates would cause Cl^- laden snow to build-up at this corner location (Sarwar, 2003). The average groundwater Cl^- concentration representing the 2 primary road locations over the 7 year period was 1400 mgL^{-1}, while the average representing the 5 secondary road locations was 900 mgL^{-1}. If GB1-01, the secondary road with the highest concentrations of any location, is removed from the average estimate, the average concentration decreases to 300 mgL^{-1}.

Overall, a decrease in chloride concentration was observed for each monitoring well over the study period with the exception of GB2-02 (Laurentian Dr.) and GB1-02/07 (Lawrence Dr.)

which showed slight increases over time. These two sites show increases in the amount of stored chloride mass, which are likely the result of continued heavy sidewalk salt application adjacent to a public school. The decreasing trend in Cl^- concentration in the shallow groundwater is gradual and this observation serves to illustrate the slow temporal response of the groundwater system to BMP implementation. Of critical interest, however, is the substantial magnitude of the Cl^- reductions in groundwater over the monitoring period. Accordingly, the data demonstrate that the salt reduction BMP program has considerably reduced the transfer of road salt to the water table at the monitored sites. Continued monitoring will be required to determine if Cl^- concentrations continue to decrease over time in response to the salt reduction BMPs.

Soil and Pore Water Cl^- Concentration Profiles and Cumulative Stored Cl^- Mass Profiles. Concentration profiles of soil and pore water Cl^- as well as cumulative stored mass profiles for pre- and post-BMP conditions are presented in Figure 6 through Figure 12.

Chloride levels in soil at the Belmont Avenue (GB1-01) site range from 4 to 515 mg kg^{-1} with an average of 163 mg kg^{-1} for post-BMP conditions compared to 8 to 744 mg kg^{-1} with an average of 369 mg kg^{-1} for the pre-BMP 2001 data (Figure 6). Chloride peaks representing annual salt pulses are present at depths of approximately 1m and 2.8m. The upper more recent peak at 1m was used to estimate mass loading estimates based on the 2.8m peak may have been influenced by the water table. Total annual Cl^- loading to the water table for a 1km length of a 2 lane road was estimated to be 0.53 t or 2% of the total amount applied. The calculated pore water Cl^- concentration profile shows a range from 21 to 3172 mgL^{-1} and an average of 1102 mgL^{-1} above the water table, which is substantially lower than the range of 43 to 5564 mgL^{-1} and average of 2890 mgL^{-1} observed during the pre-BMP period. The above estimates of average vadose zone pore water concentration and total loading represent an estimated recharge of 160 mm or 18% of the total average annual precipitation. The total cumulative stored Cl^- mass was estimated at 700 g $^-m^{-2}$.

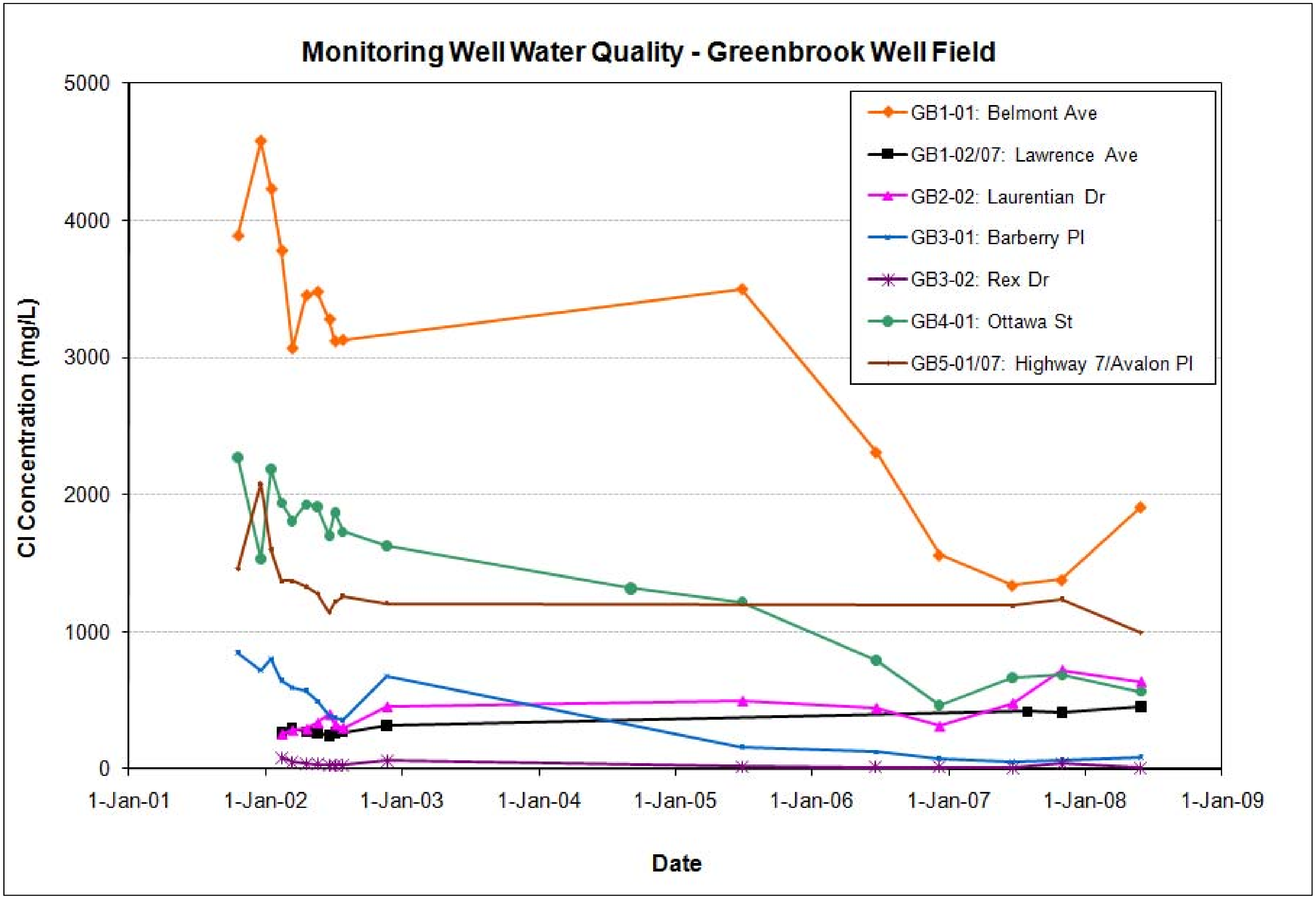


Figure 5. Temporal Variations in Chloride Concentration from Greenbrook Monitoring Wells

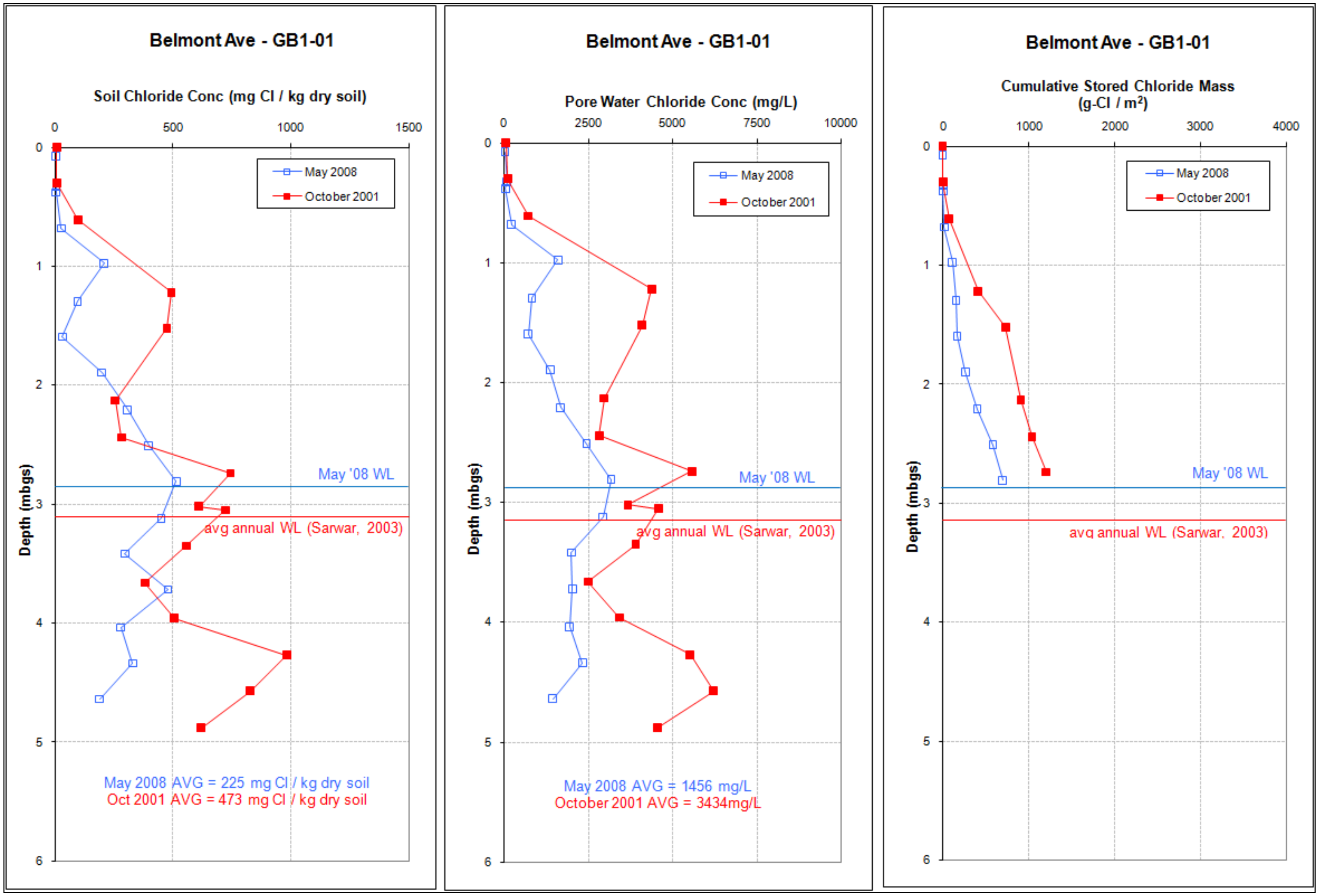


Figure 6. Belmont Ave Profiles of Soil and Pore Water Cl⁻ Concentration and Cumulative Stored Cl⁻ Mass

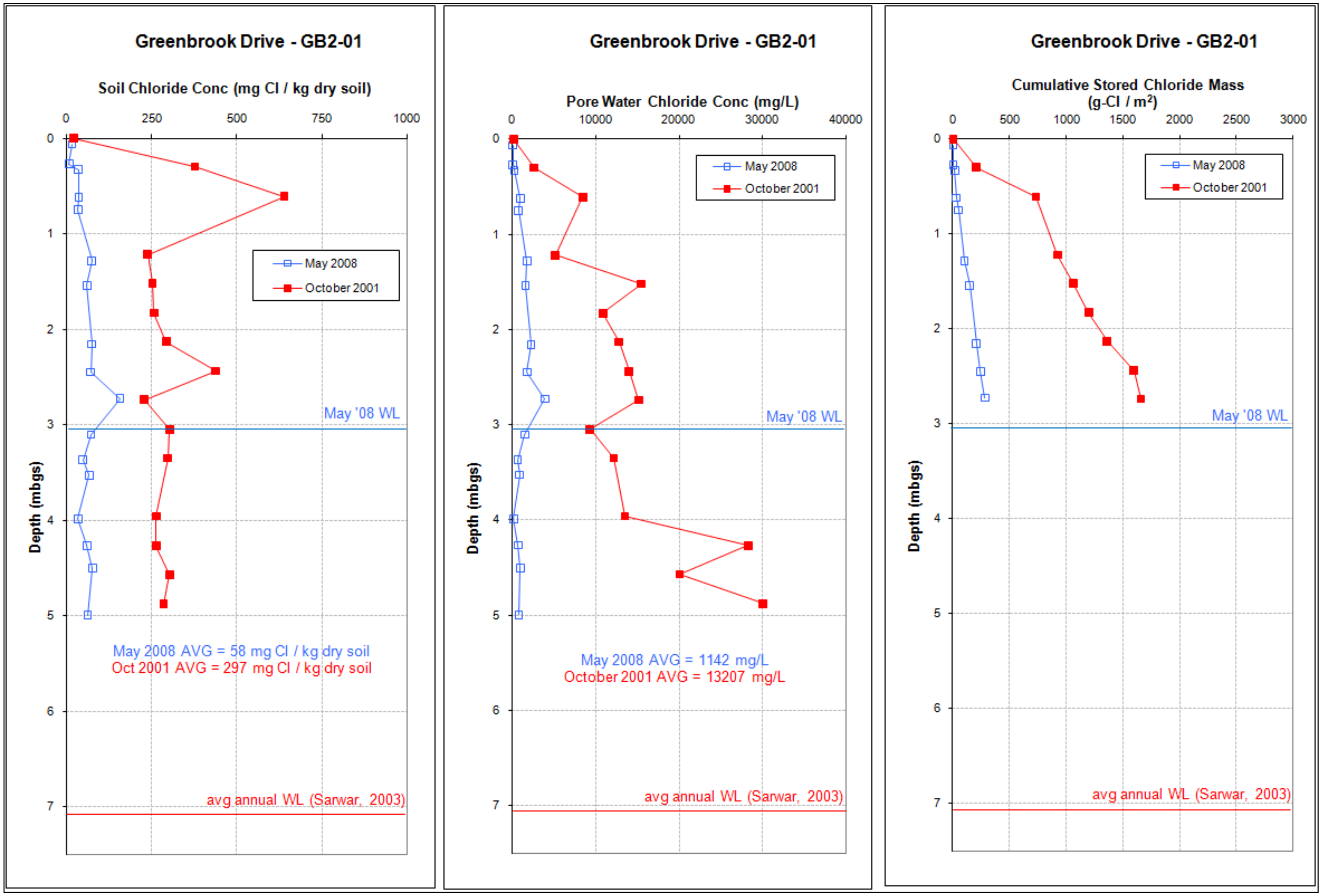


Figure 7. Greenbrook Dr. Profiles of Soil and Pore Water Cl^- Concentration and Cumulative Stored Cl^- Mass

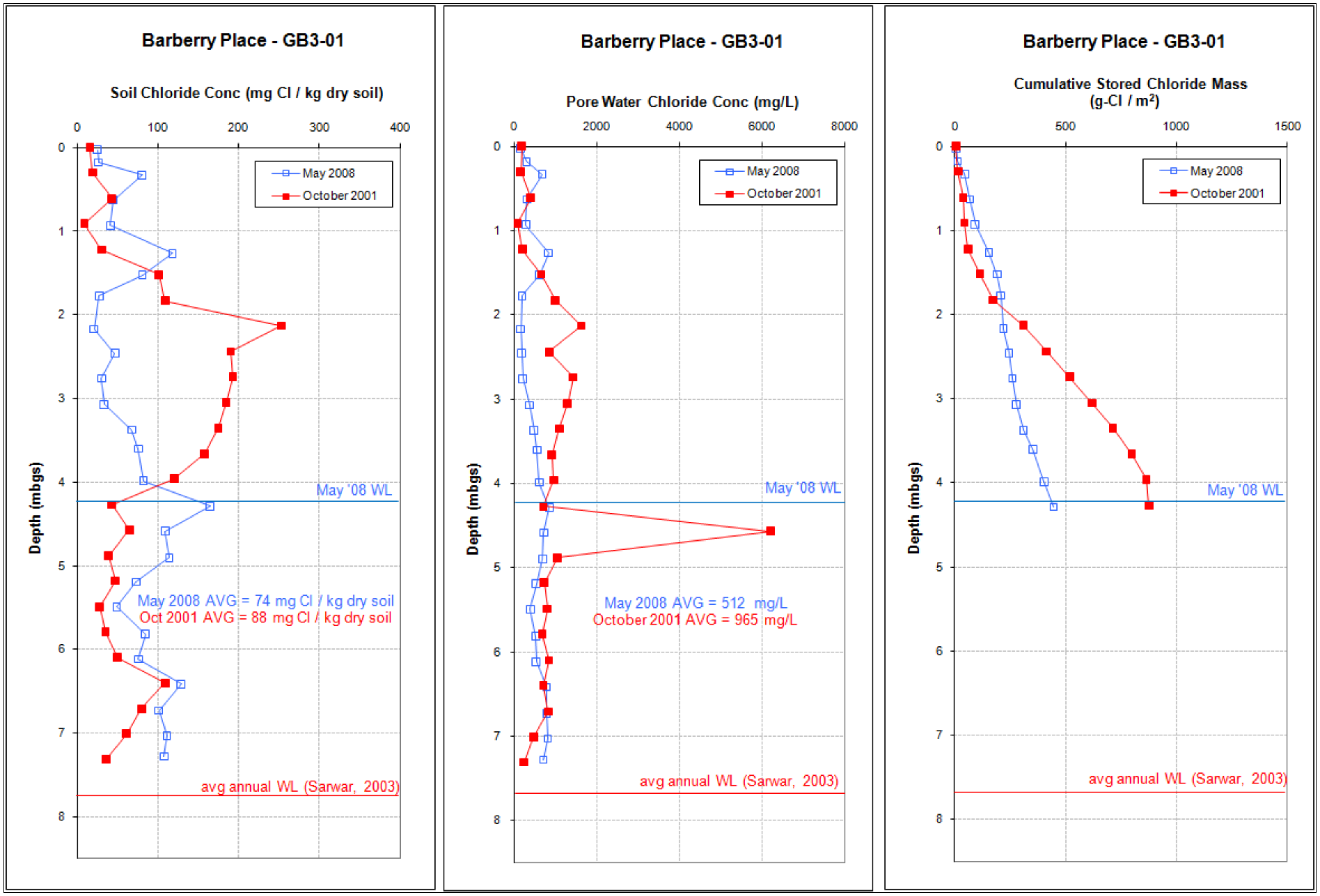


Figure 8. Barberry Pl. Profiles of Soil and Pore Water Cl⁻ Concentration and Cumulative Stored Cl⁻ Mass

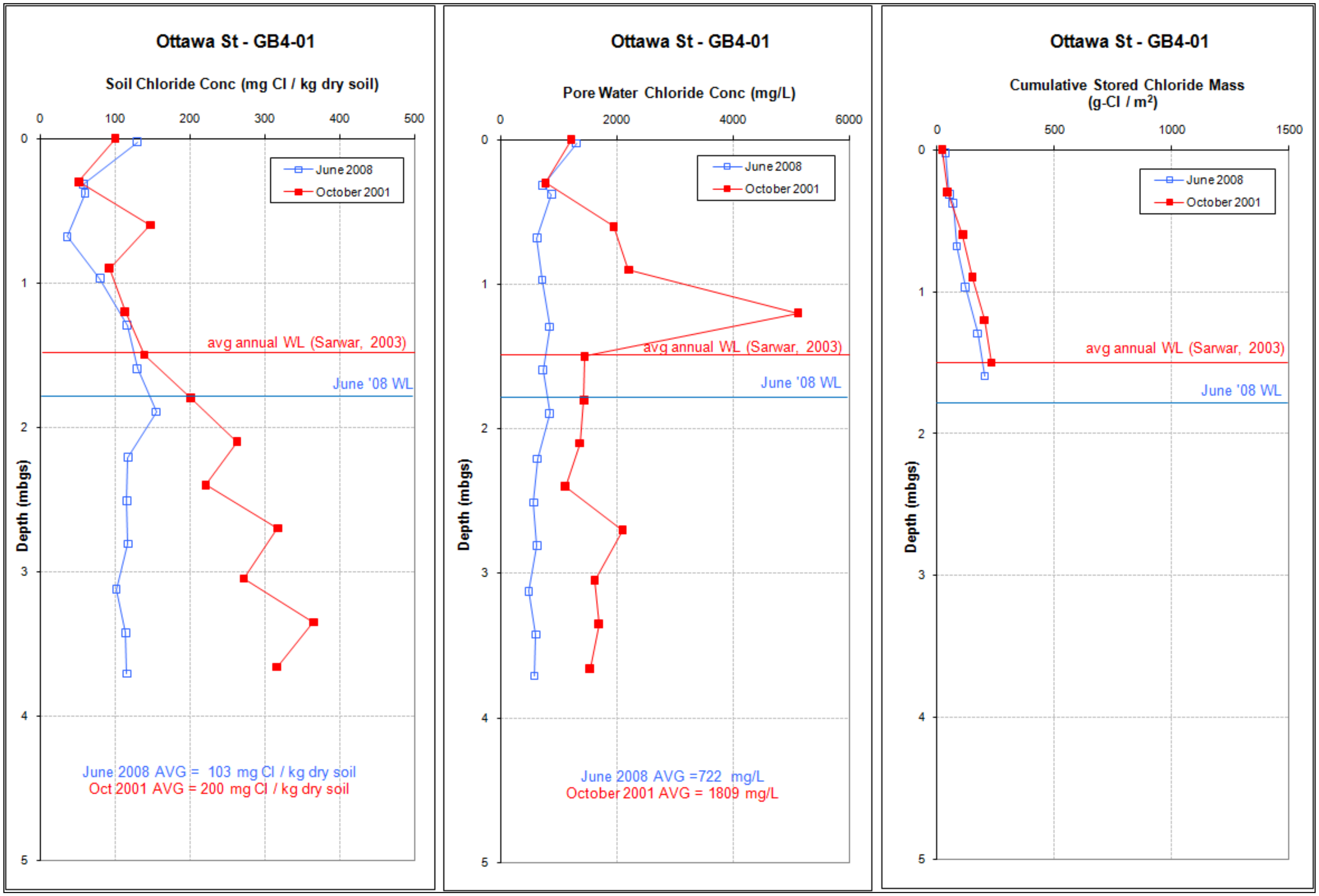


Figure 9. Ottawa St. Profiles of Soil and Pore Water Cl^- Concentration and Cumulative Stored Cl^- Mass

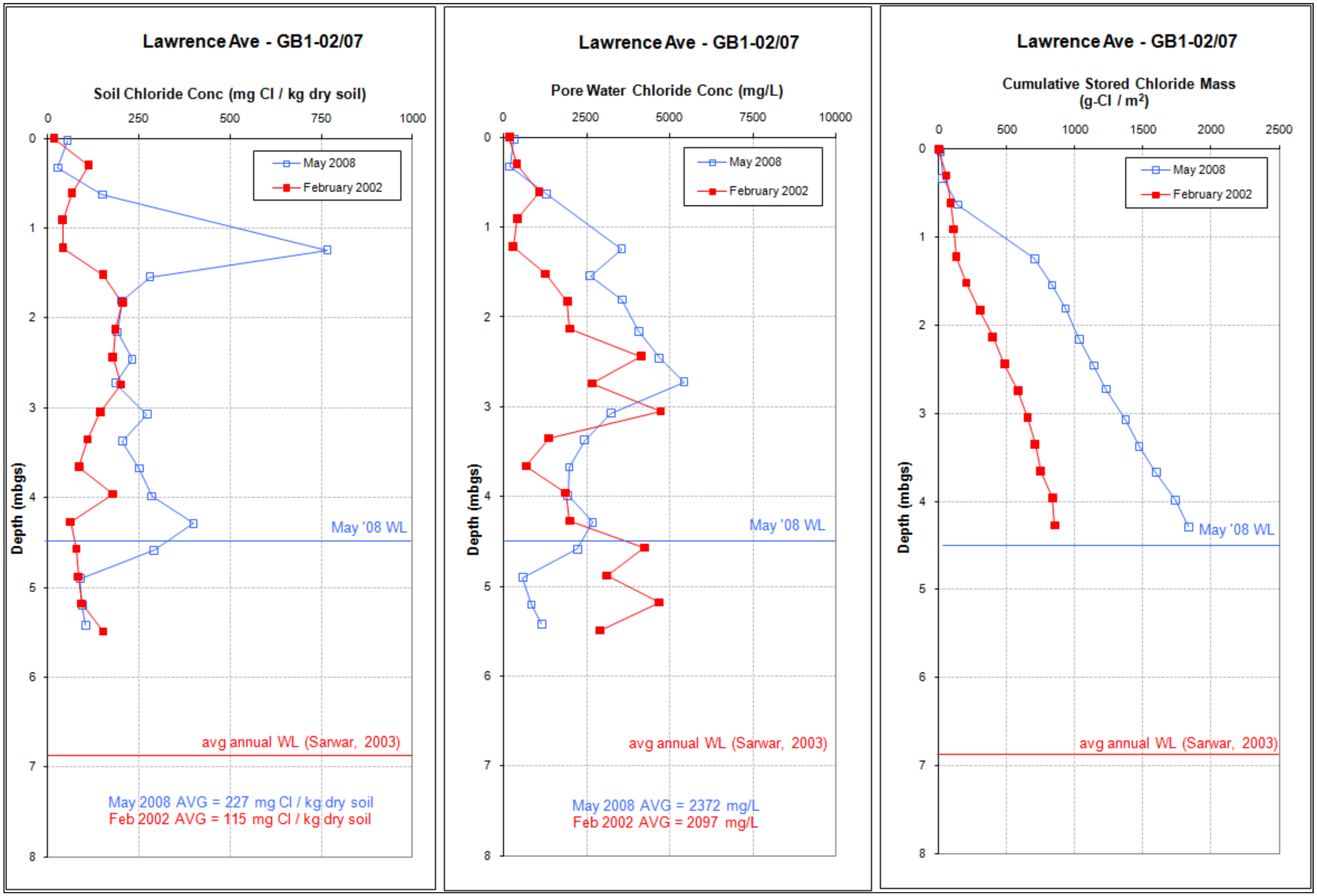


Figure 10. Lawrence Ave. Profiles of Soil and Pore Water Cl^- Concentration and Cumulative Stored Cl^- Mass

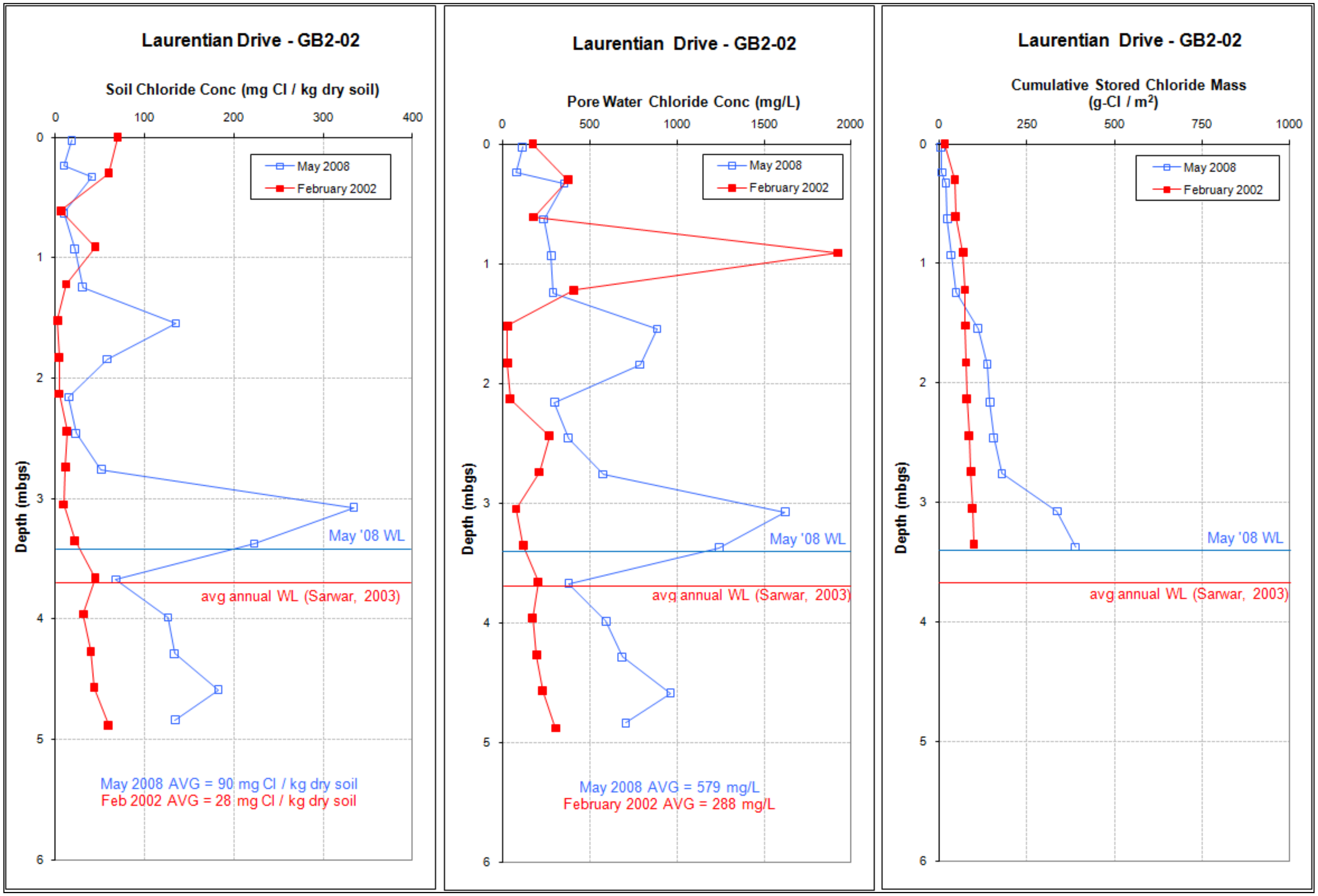


Figure 11. Laurentian Dr. Profiles of Soil and Pore Water Cl^- Concentration and Cumulative Stored Cl^- Mass

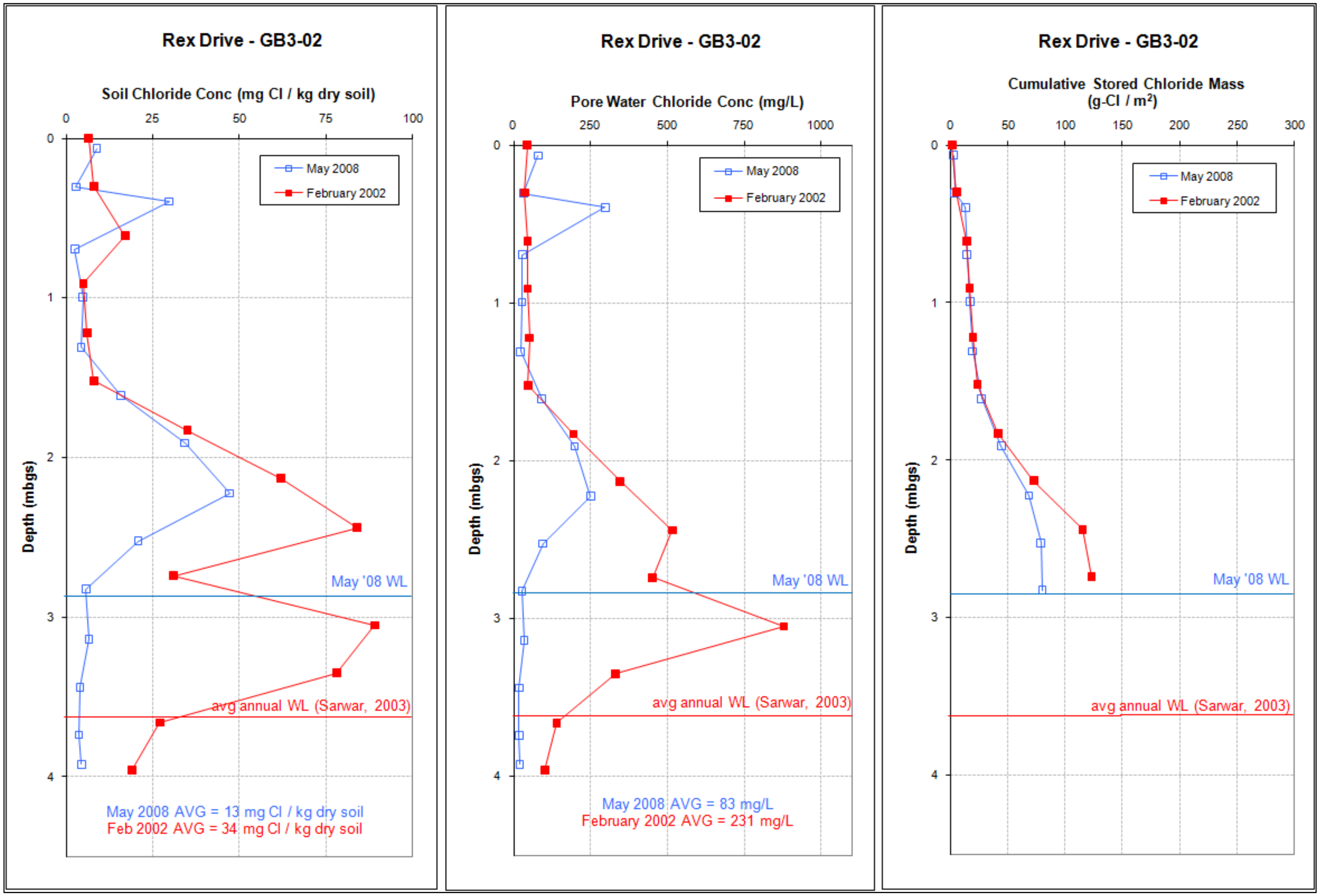


Figure 12. Rex Dr. Profiles of Soil and Pore Water Cl⁻ Concentration and Cumulative Stored Cl⁻ Mass

At Greenbrook Drive (GB2-01), the post-BMP vadose zone soil Cl^- concentrations ranged from 8 to 157 mg kg^{-1} and averaged 57 mg kg^{-1}. These levels are substantially lower than the range and average of 22 to 640 mg kg^{-1} and 237 mg kg^{-1}, measured respectively in 2001 (Figure 7). Figure 7 also shows a Cl^- peak at approximately 2.7m which is used to estimate Cl^- loading to the water table. The total Cl^- loading was ~0.55t or 2% of the total applied road salt. Pore water concentrations above the water table ranged from 77 to 3,936 mgL^{-1} and averaged 1,357 mgL^{-1} (Figure 7). Pre-BMP levels had a larger range (197 to 30,036 mgL^{-1}) and averaged 11,166 mgL^{-1}, which is related to the low moisture content in the cores. The estimated recharge was 134 mm, which is 15% of the total precipitation. The total cumulative Cl^- mass is an estimated 285 g m^{-2}, which is approximately 1/6 of the pre-BMP levels (Figure 7). Accordingly, this reduction is promising considering the close proximity of this location to the Greenbrook pumping station.

Profiles of soil and pore water Cl concentration and cumulative stored mass at the Barberry Place site (GB3-01) are generally lower than the pre-BMP conditions (Figure 8). The minimum, maximum, and average soil concentrations above the water table were 21, 165 and 60 mg kg^{-1}, respectively; while the values from the previous study were 9, 253, and 86 mg kg^{-1}. The chloride pulse centered around 1.3m was chosen to estimate a Cl^- loading of 0.5 t. The pore water minimum, maximum and average Cl^- concentrations above the water table are 156, 832 and 426 mgL^{-1} and seem to show less spatial variation than the pre-BMP levels of 83 (minimum), 6203 (maximum) and 936 mgL^{-1} (average). The estimated recharge was 393 mm and associated ratio of recharge to the total precipitation was 43%. The cumulative stored Cl^- mass was estimated to be 446 g m^{-2}, approximately half of what was present in 2001 (Figure 8).

The location adjacent to Ottawa Street (GB4-01) was the only primary road (which receives higher NaCl loading rates) that was re-studied in 2008 and associated profiles are presented in Figure 9. The water table is very shallow at this site, which makes it difficult to evaluate longer term trends in the subsurface Cl^- distributions. Overall, the soil and pore water concentrations appear to be somewhat lower for post-BMP conditions. The total stored Cl^- levels in the thin unsaturated zone section are similar between the two sampling dates. These profiles likely only reflect the current year's activities. Soil concentrations in the vadose zone ranged from 36 to 129 mg kg^{-1} and averaged 87 mg kg^{-1}, which is comparable to the range (51 to 147 mg kg^{-1}) and average 2003 value of 107 mg kg^{-1}. Pore water concentrations in the vadose zone ranged from 620 to 1299 mgL^{-1} and averaged 827 mgL^{-1}; they were much lower than the 770 to 5,115 mgL^{-1}

range and average of 2,113 mgL^{-1} measured in 2001. Unfortunately, because the water table was so shallow it was also not possible to clearly identify any distinct peaks with which to estimate mass loading to the water table. As a result, mass loading was back-calculated as 0.4 t (2% of total loading) using the average pore water Cl^- concentration above the water table and assuming the same recharge calculated in Sarwar (2003) using the bromide tracer test (120 $mmyr^{-1}$). The cumulative stored mass in the unsaturated zone profiles collected during both sampling campaigns was found to be approximately 200 g m^{-2}.

Site GB1-02/07, corresponding to Lawrence Avenue, is one of the sites that had a trend of increasing groundwater Cl^- concentrations since pre-BMP conditions (Figure 10) illustrate this increasing trend. While the minimum, maximum and average chloride soil concentrations above the water table were initially 17, 205, and 123 mg kg^{-1} respectively, the same 2008 parameters were higher with values of 27, 767, and 250 mg kg^{-1}, respectively. A well defined peak at 1.2m was used to calculate the Cl^- mass loading which was 3 t or 11% of the total Cl^- applied. For the post-BMP condition, Cl^- concentrations in pore water above the water table were only slightly higher with minimum, maximum, and average values of 185, 5,426 and 2,708 mgL^{-1} compared to 2003 concentrations of 174, 4,730 and 2807 mgL^{-1} respectively. The estimated recharge and associated ratio to the total precipitation was 370 mm and 41%, respectively. The cumulative stored Cl^- mass was 1,837 g m^{-2}. As was described for the slight increases in observed groundwater concentrations at this site, it is believed that the subsurface Cl^- distributions may have been influenced by private salt applications to the sidewalk and adjacent plaza parking lot.

Compared to pre-BMP conditions, the Cl^- concentration at GB1-02/07 increased in vadose zone profiles from the site adjacent to Laurentian Drive (GB2-02) (Figure 11). The minimum, maximum and average soil Cl^- concentrations in the vadose zone were 2, 70, and 23 mg kg^{-1}, respectively for pre-BMP conditions. However, for post-BMP conditions s minimum, maximum and average soil Cl^- concentrations (9, 334, and 74 mg kg^{-1}) were higher. An annual salt pulse at 1.5m was selected for loading estimates instead of one at 3.1m, as the deeper pulse may be influenced by the water table and represents an older winter season. Total Cl^- loading to the water table was estimated to be 0.37 t, which corresponds to 1% of the total loading at surface. The post-BMP vadose zone pore water concentrations varied from 77 to 1619 mg L^{-1} while the pre-BMP concentrations ranged from 24 to 1922 mg L^{-1}. The average post-BMP vadose zone Cl^- pore water concentration (547 mg L^{-1}), was nearly double that observed at pre-BMP conditions.

The recharge at this site was estimated to be 225 mm or 25% of the total precipitation. Figure 11 shows that the cumulative stored Cl^- increased by a factor of four compared to pre-BMP levels. These elevated levels likely result from the over application of salt to sidewalks adjacent to elementary schools.

The GB3-02 study site located on Rex Drive had the lowest chloride levels in the vadose zone (and groundwater) for both pre- and post-BMP conditions (Figure 12). Sarwar (2003) hypothesized that these low Cl^- levels may be due to local site conditions such as finer near-surface material and a slightly higher elevation relative to the road. Both of these site specific conditions would decrease infiltration rates and promote surface runoff. At this site, the average soil concentration above the water table decreased from 36 to 16 mg kg^{-1} while observed minimum and maximum concentrations decreased from 5 to 2 mg kg^{-1} and 89 to 47 mg kg^{-1}, respectively. The distinct Cl^- pulse at approximately 2.2m was used to estimate the total water table loading of 0.2 t (~1% of the total applied). Sarwar's (2003) vadose zone pore water concentrations ranged from 36 to 880 mg L^{-1} with an average of 249 mg L^{-1} while the same parameters from 2008 ranged from 23 to 298 mg L^{-1} with an average of 105 mg L^{-1}. The amount of recharge was estimated to be 623 mm (69% of the total precipitation). The cumulative stored mass of chloride at the site was ~80 g m^{-2}. This value is substantially lower than the 120 g m^{-2} measured during pre-BMP conditions.

Quantitative Comparison of Pre- and Post-BMP Conditions. The average pore water Cl^- concentration above the water table (Table 2), cumulative stored chloride mass (Table 3) and the chloride loading to the water table and recharge estimates (Table 4) are presented to compare pre- and post-BMP conditions and to evaluate the potential effectiveness of the salt reduction program. Table 2 shows that since pre-BMP conditions, the average pore water concentration above the water table decreased by 3% to 88% at 6 of the 7 sites. Similarly, the cumulative stored chloride mass (Table 3) decreased from 13% to 83% for 5 of the sites. However, chloride levels at the Lawrence Avenue site (GB1-02/07) increased by 115% while Laurentian Drive (GB2-02) increased by 292%. Total chloride mass loading to the water table (Table 4) decreased from 11% to 83% across 6 sites, while the Lawrence Avenue (GB1/0207) site showed an increase of about 24%. The observed increases at Lawrence Avenue and Laurentian Drive sites are likely due to high salt applications along private sidewalks. Stored Cl^- mass in the vadose zone decreased by ~45% on average (excluding the Lawrence Ave. and Laurentian Dr sites).

Table 2. Comparison of mean pore water Cl^- Concentration above the water table for pre- and post-BMP conditions

Location	Pre-BMP Cl^- (mgL^{-1})	Post-BMP Cl^- (mgL^{-1})	% Change
Belmont Ave: GB1-01	2890	1102	**-62**
Lawrence Ave: GB1-02/07	2807	2708	**-3**
Greenbrook Dr: GB2-01	11166	1357	**-88**
Laurentian Dr: GB2-02	308	547	**+78**
Barberry Pl: GB3-01	936	426	**-55**
Rex Dr: GB3-02	249	105	**-58**
Ottawa St: GB4-01	2113	827	**-61**

Table 3. Comparison of cumulative stored Cl^- mass above the water table for pre- and post-BMP conditions

Location	**Pre-BMP Stored Cl^- ($g\ m^{-2}$)**	Post-BMP **Stored Cl^- ($g\ m^{-2}$)**	**% Change**
Belmont Ave: GB1-01	1207	700	**-42**
Lawrence Ave: GB1-02/07	854	1837	**+115**
Greenbrook Dr: GB2-01	1659	285	**-83**
Laurentian Dr: GB2-02	99	388	**+292**
Barberry Pl: GB3-01	876	446	**-49**
Rex Dr: GB3-02	123	80	**-35**
Ottawa St: GB4-01	232	203	**-13**

Table 4. Comparisons of Cl- mass loading to the water table and estimated recharge for pre- and post-BMP conditions

Location	2001/2002				2008				% change in Cl^- Mass Loading to water table
	Mass Loading to water table (tonnes Cl^-/ 2 lane km)	% of Total Cl^- Loading at Surface[3]	Estimated Recharge (mm/yr)	% of total avg annual precipitation (904 mm[5])	Mass Loading to water table (tonnes Cl^-/2 lane km)	% of Total Cl^- Loading at Surface[4]	Estimated Recharge (mm/yr)	% of Total avg annual precipitation (904 mm[5])	
Belmont Ave: GB1-01	2.8	21	318	35	0.53	2	160	18	**-81**
Lawrence Ave: GB1-02/07	2.4	18	287	32	3.0	11	370	41	**+24**
Greenbrook Dr: GB2-01	3.2	24	94	10	0.55	2	134	15	**-83**
Laurentian Dr: GB2-02	0.41[2]	3	449[2]	50	0.37	1	225	25	**-11**
Barberry Pl: GB3-01	1.0[1]	8	360[1]	40	0.50	2	393	43	**-50**
Rex Dr: GB3-02	0.34	3	449	50	0.20	1	623	69	**-42**
Ottawa St: GB4-01	1.0[1]	3	120[1]	13	0.40[1]	2	120[1]	13	**-61**

Note: Cl^- mass loading estimates were calculated using the method described in the Data Analysis section of the above report, except for locations denoted as:

[1] - Cl^- mass loading was back-calculated using average pore water Cl^- concentrations and recharge estimates from Sarwar (2003) bromide tracer tests because no defined soil Cl- peaks could be found above the water table

[2] - Cl^- mass loading was back-calculated using average pore water Cl^- concentrations and the same Sarwar (2003) recharge estimate as Rex Dr. (due to similar road classification and site conditions) because no defined soil Cl^- peaks could be found above the water table

[3] - 2001/2002 estimated Total Cl^- Loading at Surface is 33.6 tonnes/ 2 lane km of primary road or 13.4 tonnes/ 2 lane km of secondary road (Sarwar, 2003)

[4] - 2008 estimated Total Cl^- Loading at Surface is estimated 26.3 tonnes/ 2 lane km (based on total NaCl loading of 43.4 tonnes from Switenky and Hodgins, 2008)

[5] - Seglenieks (2008)

Table 4 provides estimates of groundwater recharge rates and Cl^- mass loading to the water table and provides additional insight into the effectiveness of the implemented road salt BMP Program. Although some variability in the Cl^- loading and recharge rates can be expected, the total recharge and percent of annual precipitation estimated at each site are remarkably similar for the pre- and post-BMP surveys. Both the Cl^- mass loading rates and the percent of the total salt applied that was transferred to the roadside subsurface environment were substantially reduced in the post-BMP period. Excluding sites likely influenced by private salt use (Lawrence Ave. and Laurentian Dr.); we estimate that the total Cl^- mass loading to the water table was reduced by approximately 60% due to the salt reduction BMPs. The ratio of total Cl^- loading to the water table relative to that applied at the surface decreased for all sites (Table 4). These observations suggest that salt is being applied more effectively to the roadways and less is being transferred to roadside soils. This is likely due to the use of liquid anti-icing salt brines which suppress the amount of bounce and scatter which may otherwise occur during the application of dry road salt.

Conclusions and Implications. The present study examined the effect of salt reduction strategies on groundwater resources by measuring and comparing the Cl^- content in soil and pore water as well as cumulative mass of Cl^- stored in the vadose zone adjacent to a range of road types for pre- and post-BMP conditions in the Greenbrook well field. Conclusions of the study are:

1. At two locations adjacent to schools where significant amounts of sidewalk deicing salts were applied liberally, concentrations of Cl^- in groundwater remained fairly constant or increased slightly since pre-BMP conditions. This site specific sidewalk winter maintenance practice dampens the effects of salt reduction programs observed at other locations.
2. Compared to the pre-BMP salt reduction period, mass loading of road salt to the water table was reduced by an average of 60% in the post-BMP period. The data suggest that salt management practices in salt vulnerable areas can effectively reduce the transfer of Cl^- to groundwater.
3. Long term groundwater quality monitoring in shallow wells can provide a useful quantitative performance assessment of road salt reduction BMPs in salt vulnerable areas.

However, the actual time lag associated with the implementation of the BMPs will ultimately depend on the thickness of the unsaturated zone and the vertical soil water velocity.

4. Although a reduction of approximately 25% in total road salt application was the target over the long term, with some variability depending on climatic conditions, the measured magnitude of subsurface water quality improvement was closer to 50%. The data suggest that actual reductions in salt application exceeded the target and this could be partly responsible for the difference between the observed and expected chloride concentrations.

EVALUATING CHLORIDE CONCNETRATIONS AND MASS LOADING IN SNOW IN SALT VULNERABLE AREAS

Objective 2 – Task 2b:
Conduct a snow/chloride content survey in the Regional municipality of Waterloo using the factorial design (3 cities by 3 zones of groundwater risk by 4 road types) to evaluate the effect of reduced salt loadings in vulnerable zones.

Introduction. To improve traffic safety in cold climates, the practice of winter road maintenance typically includes a combination of snow removal and the application of de-icing materials (NCHPR, 2007). In urban landscapes, a variety of transport mechanisms cause considerable spatial and temporal variation to occur in the deposition and distribution patterns of deicing salt. For example, salt can be transported in runoff from the road (Marsalek, 2003) or by airborne mechanisms (splash and spray) to the roadside (Lundmark and Olofsson, 2007). Poor application methods and over application of deicers can increase chloride transfer to roadside areas where it may damage vegetation (Viskari and Kärenlampi, 2008) or infiltrate into the soil and potentially impact groundwater resources (Bester et al., 2006; Sarwar et al., 2002). Accordingly, the legacy effects of long-term road salt use on chloride concentration in surface waters have been reported (Kelly et al., 2008).

While chloride in splash is generally deposited in close proximity to the road, salt spray can be transported much longer distances by wind. The transport distance is influenced by various factors such as: road and traffic characteristics, type and amount of precipitation and wind conditions (Blomqvist, 1999). Lundmark and Olofsson (2007) developed a model that incorporates an exponential function for splash and spray transport mechanisms which accounts for the observed exponential decrease in the soil chloride content with distance from the road. Because the snowpack is an important reservoir for retaining and storing pollutants during winter (Bartosová & Novotny, 1999), it can be considered as a surrogate measure of how well BMPs designed to reduce salt transfer to the environment are working in salt vulnerable areas.

In 2003, the Region of Waterloo implemented a program to reduce road salt use by 25% in wellhead protection (salt vulnerable) areas. This target was achieved by adopting a range of salt reduction options such as decreasing salt application rates, upgrading winter maintenance equipment, using brine pre-wetting strategies, testing alternative deicers and motivating salt-conscious behavior in the private sector. The objective of this study is to quantify the chloride mass loading in snowpack in salt vulnerable areas and to compare these data to measurements of salt mass loading to groundwater (data previously presented in Section 3 Objective 2 Task 2a of this report). A field monitoring program was designed to measure chloride concentrations and water equivalents in roadside snow deposits at several locations across the Regional Municipality of Waterloo and to provide estimates of chloride mass loading (kg m^{-2}) from roadside snow pack in salt vulnerable areas. The factorial design of the study included measuring chloride concentrations and snow water equivalents at 3 well field capture zones (2, 5 and 10 year capture zones) for 3 road classes (2, 3 and 4) within each well field capture zone for 3 cities (Waterloo, Kitchener, and Cambridge).

Methods. The study was conducted in the Region of Waterloo during February 2008. Snow samples of were collected along transects at representative roadside locations (Table 5) that reflected various road classes (2 and 3). Road classes are defined according to function and traffic volume. These classifications typically include Class 1 - Expressways; Class 2 – Arterials (major and minor); Class 3- Collectors and Class 4 - Local Residential. Depending upon weather conditions, salt application rates for road class 1 and 2 can vary from 70 to 180 kg lane km^{-1} and from 70 to 90 kg lane km^{-1} for road class 3 and 4. Therefore based on the traffic speed, volume, weather conditions as well as salt application type and rate, it can be expected that the rates of chloride splash and salt spray will vary as a function of road type and ultimately influence the spatial and temporal distribution of chloride in roadside snowpack. In the case of the Region of Waterloo, the same rate of salt application was applied for all road classes. Sites were selected to reflect a typical range of road classes located within three well fields (William Street, Greenbrook and Middleton) in Waterloo, Kitchener and Cambridge, respectively (Table 5).

Snow samples were collected with pre-washed snow tubes along 3 to 5 transects (located approximately 100 m apart) in triplicate at a distance of 0.5, 2.5, 5.0 and 10 m from the curb. In some cases, the varying location of sidewalks/obstructions necessitated sampling at other distances reported in Table 7. Snow samples were placed in plastic bags and returned to the laboratory at the University of Waterloo where they were melted and filtered (0.45 μm) prior to analysis for chloride using the mercuric thiocyanate and ferric chloride method (AWWA 4500 CL E) with a Technicon Autoanalyzer. The data are organized and presented to compare relative differences in snow chloride concentrations within and mass loading between well fields, road type and capture zone sensitivity areas (2 year, 5 year and 10 year travel time). Because of logistical and financial constraints, no replicate samples were collected before or after February 2008.

Table 5. Snow sampling locations

City	Well Field	Road Class	Location	Number of Transects
Kitchener	Greenbrook	2	Westmount Rd between Highland Rd and Ottawa St	6
	Greenbrook	3	Victoria St between Westforest Trail and Fischer-Hallman Rd	7
Waterloo	William Street	2	King St between Erb St and Union St	7
	William Street	3	Bridgeport Rd/Caroline St between King St and Erb St	7
Cambridge	Middleton	2	Water St between Birch St Ainslee St and Myers Rd	7
	Middleton	3	St Andrews St between Cedar St and Grant Ridge Drive	

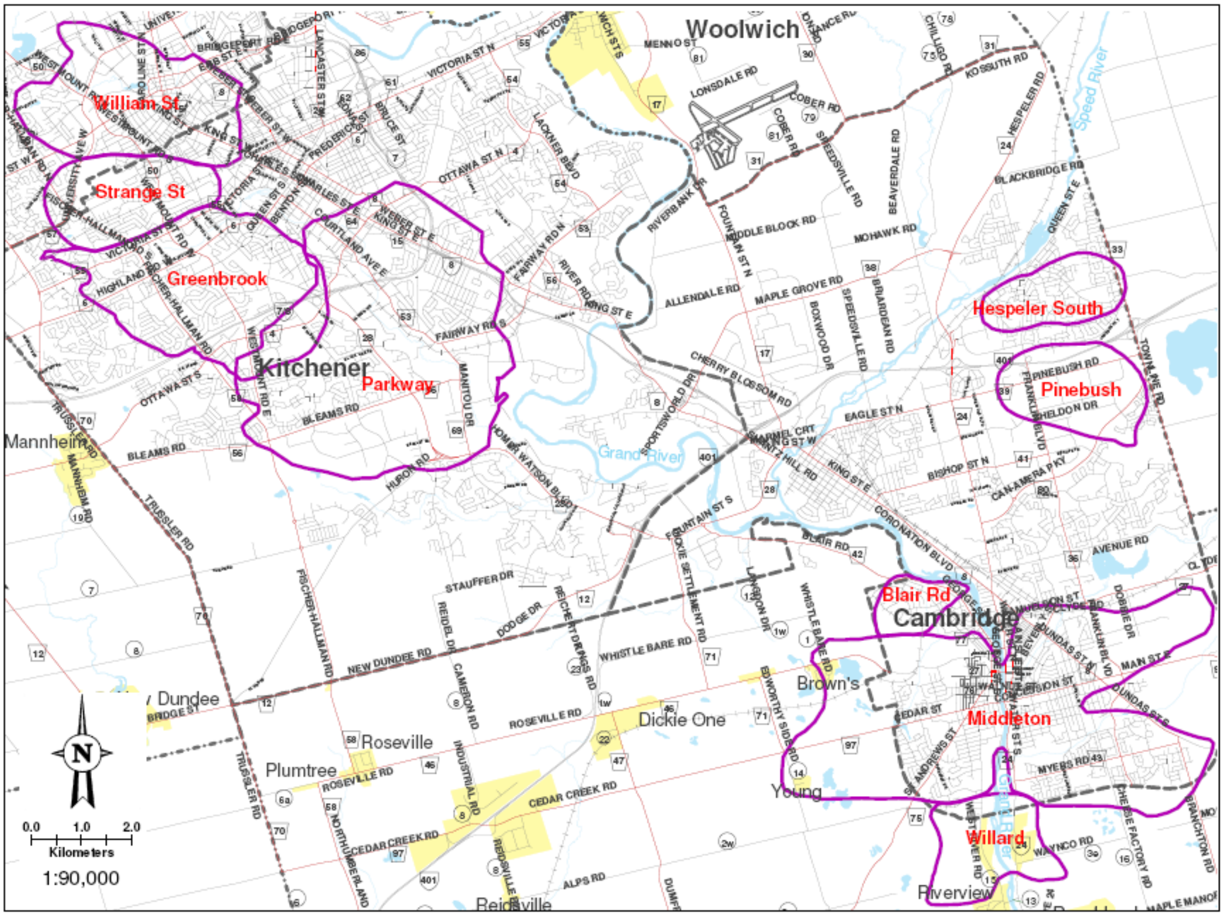


Figure 13. Well field protection areas in the Regional Municipality of Waterloo.

Results and Discussion.

Chloride concentrations in snow. Chloride in roadside snow deposits varied as a function of road class, distance from the road, well field sensitivity area (capture zone travel time) and location (Table 6). In Kitchener and Waterloo, mean chloride concentrations were generally lower in sensitivity area 1 than for sensitivity area 2 but the opposite trend was observed for the Cambridge sites. In Cambridge, the average chloride concentrations were highest (> 600 mg L^{-1}) in sensitivity area 1 for road classes 2 and 3, but declined in areas with decreasing groundwater sensitivity to < 200 mgL^{-1}).

Table 6. Average chloride concentration in roadside snow by road class and sensitivity (capture zone travel time).

Sensitivity	Road Class		[Cl] mgL^{-1} Waterloo	Kitchener	Cambridge
1	2	$\bar{X}$	378.9	385.3	606.9
		SD	456.3	605.0	810.5
		n	65	69	72
	3	$\bar{X}$	323.9	330.1	695.8
		SD	511.5	470.7	1218.2
		n	70	78	72
2	2	$\bar{X}$	604.9	311.5	111.2
		SD	656.0	334.6	197.8
		n	69	72	71
	3	$\bar{X}$	683.2	482.6	201.3
		SD	783.8	551.3	250.6
		n	84	71	68
3	2	$\bar{X}$			198.7
		SD			418.9
		n			72
	3	$\bar{X}$			12.9
		SD			22.3
		n			69
	4	$\bar{X}$			37.7
		SD			98.5
		n			70

Chloride concentration in snow varied as a function of distance and road type within various sensitivity area designations (Table 7). The data show that average chloride concentrations declined with distance from the road way. Variability in the data is related to several factors that influence both the redistribution of snow in urban environments and salt application rates. Reinosdotter and Viklander (2006) reported that chloride concentrations in roadside snow in Sundsvall Housing Area (Lulea, Sweden) ranged from 3.1 to 116 mgL^{-1}. Lundmark and Olofsson (2007) examined chloride deposition and distribution in soils along a deiced highway in Sweden. They found that the chloride deposition pattern decreased significantly with distance from the road and that chloride content in the soil decreased exponentially with distance from the road. Pedersen et al. (2000) studied the effects of road distance and protective measures on deicing

NaCl deposition and soil solution chemistry in planed median strips. They reported that damage from road salt is strongly affected by road distance. In a related study, Sarwar et al. (2002) measured chloride concentrations in snow at 0, 1, 2 and 3 m distances from the curb adjacent to primary and secondary roads in the Region of Waterloo. Their study showed that chloride concentrations in roadside snow deposits were higher in areas adjacent to primary roads than secondary roads. In their study, the range of measured chloride concentrations in snow as a function of distance from the road for primary roads was 0-1 m (800-1100 mgL^{-1}), 2-3 m (25-500 mgL^{-1}) for primary roads and 0-1 m (100-400 mgL^{-1}) and 2-3 m (0-100 mgL^{-1}) for secondary roads. In the present study, chloride concentrations in snow generally decreased with distance from the road but the maximum concentrations were 4 to 10 times higher than reported by Lundmark and Olofsson (2007) but generally lower than pre-BMP chloride levels in the Region of Waterloo previously reported by Sarwar et al (2002).

Chloride mass loading in snow. With the exception of one location (road class 2, sensitivity area 2 in Waterloo), the median mass loading of chloride in snow pack ranged from 0.1 to 1.2 kg m^{-2} and was lower in road class 3 than for road class 2 (Table 9). These loading rates are comparable to measurements of salt mass loading in soils which can be used to calculate loading to groundwater (data previously presented in Section 3 Objective 2 Task 2a of this report). Post-BMP estimates of chloride loading in roadside soils in the Region of Waterloo ranged from 0.08 to 1.8 kg m^{-2} (Table 3). While the snow pack data provide an example of the spatial range and variability of chloride mass loading, additional studies would have to be conducted to better assess temporal variability, which will be a function of road type, winter severity as well as the type and frequency of deicer applied. Regardless, the data show that chloride mass loading measurements in roadside snow pack are comparable to levels observed in roadside soils.

Conclusions.

1. Chloride concentrations in snow deposits decreased with distance from the road.
2. Chloride concentrations varied considerably as a function of road class, well field and sensitivity area (capture zone travel time).
3. Chlorides mass loading (kg m^{-2}) measurements in roadside snow pack are comparable to levels observed in roadside soils.

Table 7. Chloride concentrations (mg L^{-1}) in snow with distance (m) from the road

Sensitivity	Road Class		Waterloo								Kitchener					Cambridge						
			0.5	***2.0***	***2.5***	***3.0***	***3.5***	***5.0***	***8.0***	***10***	***0.5***	***2.0***	***2.5***	***5.0***	***10***	***0.5***	***1.0***	***2.5***	***3.0***	***3.5***	***5.0***	***10***
1	**2**	$\bar{X}$	950		365	299		130	70	14	679	691	187	360	178	1393	2288	603			199	82
		SD	443		317	247		144	43	7	580	708	215	827	397	743	1974	520			176	133
		n	17		14	3		16	3	12	16	6	12	17	18	15	3	18			18	18
	3	$\bar{X}$	1016	409	141		155	85		51	957		436	179	18	1646		1220		433	37	12
		SD	679	207	128		96	151		71	564		325	244	15	1367		1618		238	49	12
		n	15	6	9		3	16		17	16		18	18	18	18		15		3	18	18
2	**2**	$\bar{X}$	1076		880			262		189	680	417	470	84	30	330		55			36	21
		SD	543		861			286		184	268	128	348	88	37	296		45			45	32
		n	17		18			16		18	18	6	12	18	18	18		17			18	18
	3	$\bar{X}$	1587		587			266		24	932		879	129	230	548		236			29	4
		SD	818		401			306		11	332		621	197	454	169		174			45	2
		n	17		17			18		18	18		17	18	588	17		16			18	17
3	**2**	$\bar{X}$														604		161			28	1
		SD														689		97			36	1
		n														18		18			18	18
	3	$\bar{X}$														29		12	22	7	2	3
		SD														29		10	30	3	2	4
		n														17		3	12	2	17	18
	4	$\bar{X}$														116		34	12	19	6	4
		SD														179		30	1	10	4	3
		n														17		12	3	3	17	16

Table 9: Chloride mass loading (kg m^{-2}) in snow pack of salt vulnerable areas

		Road Class						
		Kitchener		Waterloo		Cambridge		
Sensitivity		2.00	3.00	2.00	3.00	2.00	3.00	4.00
	Mean	9.94	1.03	0.85	3.75	3.40	0.45	
	Median	1.14	0.68	0.79	0.60	1.17	0.37	
	StDev	22.43	1.09	0.34	5.72	6.11	0.50	
1	n	18	18	10	17	18	18	
	Mean	3.34	0.54	13.15	1.03	0.27	0.10	
	Median	0.67	0.41	5.21	0.98	0.21	0.07	
	StDev	5.77	0.36	14.71	0.71	0.19	0.07	
2	n	18	18	18	18	18	17	
	Mean					0.05	0.09	0.10
	Median					0.03	0.01	0.01
	StDev					0.05	0.15	0.09
3	n					18	18	16

ASSESSMENT OF CHLORIDE TRANSFER IN TWO WATERLOO STORMWATER PONDS

Objective 2 – Task 2b:
Monitor chloride levels at the outflow and inflow of two stormwater ponds with contrasting designs (conventional and enhanced) in Waterloo.

Introduction. Stormwater runoff in urban areas represents a major pathway for pollutant transfer to receiving waters. The combined impacts of increased flows, erosion and pollutant concentrations in urban stormwater can significantly degrade the quality of receiving waters (Paul and Meyer, 2001). To mitigate some of the adverse effects associated with urban development, a wide range of structural and vegetative Best Management Practices have been generally implemented in Ontario through the subwatershed and site management planning process (i.e. OMOE, 2003; TRCA, 2009). This planning process is typically used to implement low impact development scenarios that have Stormwater Management (SWM) practices designed to address stormwater quality, quantity and erosion concerns as an assumed part of the development form. The implementation procedure determines the management options to be used and the level of control (i.e. lot level, conveyance level, end-of-pipe) and then to test the performance of options on the key physical and biological systems of the watershed (OMEE, 1994).

Stormwater management ponds are engineered structures commonly used in urban areas to improve water quality and reduce flooding. The first ponds were designed to control flooding and erosion. However, due to inadequate storage volumes, excessive accumulation and subsequent washout of sediment and release of pollutants from accumulated sediments, these early pond designs failed to significantly reduce the impacts of surface water runoff on water quality because they were designed primarily for quantity and erosion control. Improvements in pond design (i.e. hybrid extended detention pond) have been made (OMOE, 2003) to meet water quality, flooding and erosion concerns. While newly designed facilities have the potential to remove pollutants, field research focusing on treatment performance is lacking. One of the main reasons for this discrepancy is that most of the initial experimental design and implementation research on SWM ponds was conducted either in the United States or Europe where environmental conditions vary significantly from that of Ontario. In addition, differences between observed and expected SWM pond performance are influenced by climate variability, pond design and stormwater pollutant characteristics (Van Buren et al., 1997). While SWM pond design has primarily focused on increasing storage capacity and improving water quality (i.e. sediment removal), less consideration has been directed towards managing chloride in urban runoff via SWM ponds. Despite the promotion and wide adoption of SWM ponds in Ontario, relatively little is known about the delivery, storage, export and internal cycling of chloride in SWM ponds and their impact on stream water quality.

In this study, chloride concentrations in Laurel Creek and two stormwater management (SWM) ponds with different designs (conventional – Pond 45 and hybrid extended detention – Pond 33) were monitored in Waterloo, Ontario during the fall 2008 and winter/spring 2009. The goal of the study was to examine the effect of landuse and road density/type on chloride concentrations in Laurel Creek and to evaluate the role of stormwater management ponds as a chloride source to streams.

Methods.

Laurel Creek sampling stations. A hydrometric and water quality monitoring program was developed to evaluate the spatial and temporal variation in chloride levels at several locations in the Laurel Creek (from the headwaters to the lower reaches of the basin reflecting multiple land uses, road types and densities). During periods of base flow, chloride was measured once a week at ten sampling stations (Figure 14). However, for storm events, chloride and river discharge were measured at five stations (5, 14, 17, 21, and 23) to examine variability within and between sites for base and storm flow conditions. All procedures for sample collection, storage, analytical methods and QA/QC protocol are consistent with Standard Methods.

Water Quality Sampling and Chloride Analysis. Surface water samples in Laurel Creek and samples at the inflow and outflow of SWM ponds 33 and 45 were collected as grab samples in acid washed triple rinsed bottles. The samples were immediately refrigerated then analyzed for chloride within 24 hours using the mercuric thiocyanate and ferric chloride method (AWWA 4500 CL E) with a Technicon Autoanalyzer at the University of Waterloo.

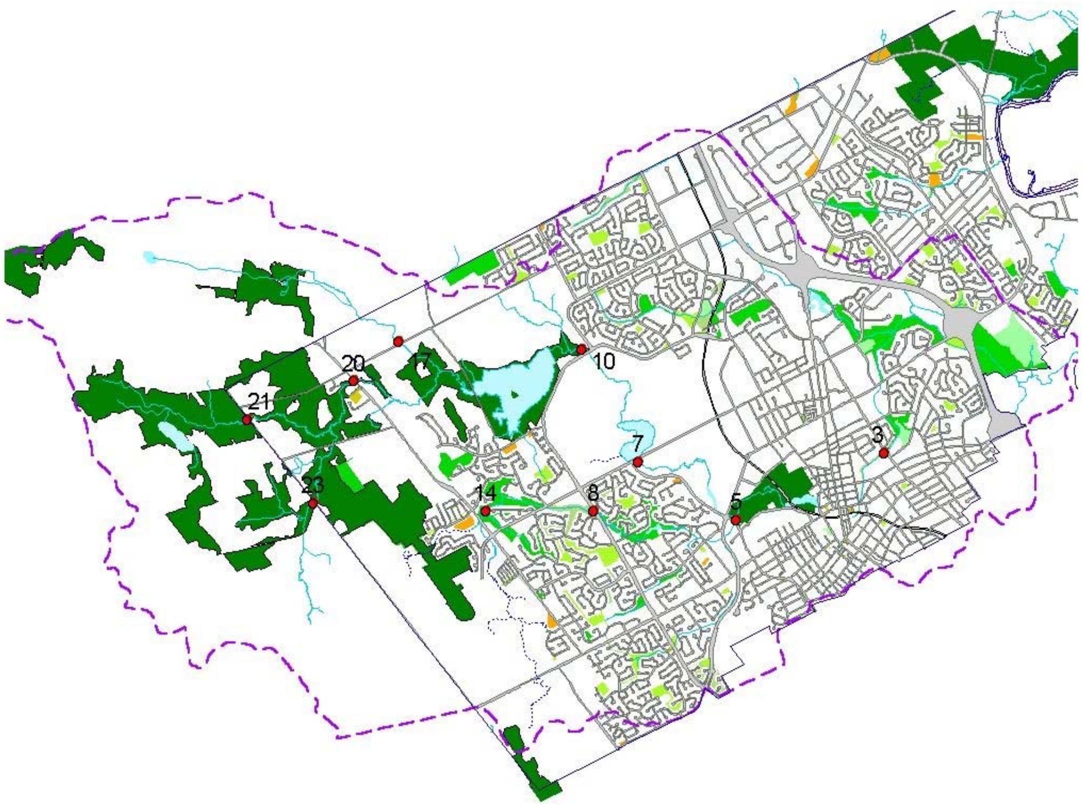


Figure 14. Location of river monitoring sites in the Laurel Creek watershed.

Description of Stormwater Management Ponds. Chloride concentrations were monitored at the inflow and outflow of two stormwater management (SWM) ponds with different designs (conventional – Pond 45 and hybrid extended detention – Pond 33) in Waterloo, Ontario from October 2008 to April 9 (Figure 15). Design characteristics of each pond are described below.

Figure 15. Aerial map indicating the proximity of Pond 33 and Pond 45 to the University of Waterloo and Laurel Creek Reservoir.

Pond 33 – Eastbridge Subdivision. Pond 33 is located on the east side of Waterloo, Ontario (Figure 16) and was designed for a suspended solids removal efficiency of 80% (Enhanced Protection). This hybrid extended detention pond has two main cells; the sediment forebay and the extended detention cell. The sediment forebay is designed to treat the first 4 $m^3 s^{-1}$. Flows above this threshold are routed via a flow splitter to an overflow channel which bypasses the sediment forebay. The permanent pond depth of the 50 m by 17 m forebay is 0.95 m. The secondary cell is divided into two compartments; the secondary settling pond and the extended detention wetland which has been heavily planted with *Typha Latifolia*. The permanent pool is 1685 m^3 and the extended detention portion increases the volume to 4242 m^3. The pond has a drawdown time of approximately 23.1 hours. Two storm sewers are connected to the outlet; one drains the treated water to the natural channel of Colonial Creek and the other drains directly to the Grand River when outlet flows are > 3.8 $m^3 s^{-1}$.

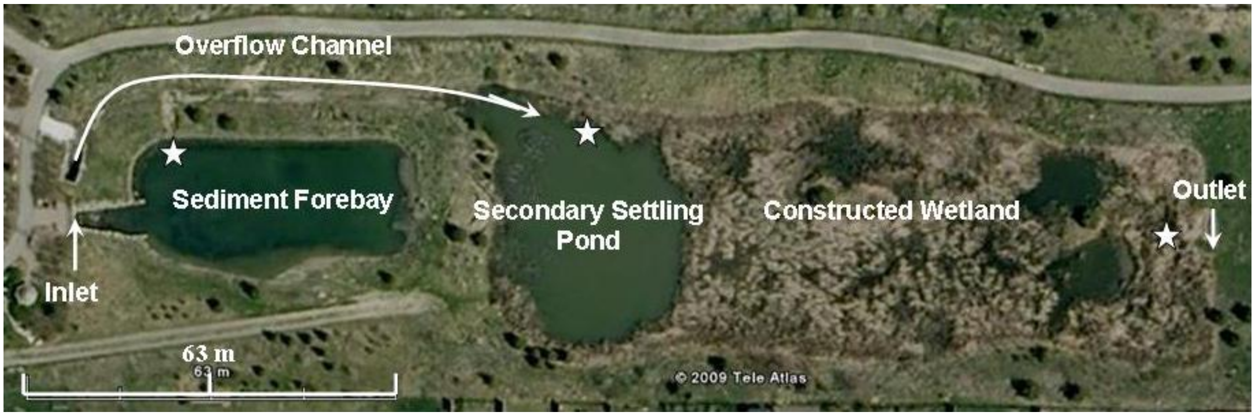


Figure 16. Aerial photograph of Pond 33.

Pond 45 – Columbia Forest Subdivision. Pond 45 was constructed in 1996 and designed to treat runoff from the Columbia Forest Subdivision in Waterloo, Ontario (Figure 17). It receives runoff from a 29.7 ha residential area with ~50% impervious surface cover. The first 20 mm of rainfall on all rooftops in the drainage area infiltrates into lot level soakaway pits to help maintain pre-urbanization infiltration rates. During summer, the first 20 mm of runoff is diverted into two infiltration galleries to maximize the amount of infiltration within the residential area. The remaining runoff drains into Pond 45. The pond was designed for a suspended solids removal efficiency of 70% (Normal Protection) and drains directly into Clair Creek at Fisher Hallman Road immediately above station 14 (Figure 14).

Figure 17. Aerial photograph of Pond 45.

Pond 45 has a storage volume of 6,925 m^3 and an extended detention area which adds another 1 m to the pond depth; totaling 12,450 m^3 of pond volume. This pond has a 48 hr drawdown rate for a 100 year storm event.

Results and Discussion.

Chloride Levels in Laurel Creek. Chloride concentrations in Laurel Creek varied considerably over time during the study period (Table 8 and Figure 18). The data show that during the months of September and October (2008) and May to August (2009), the mean monthly chloride concentrations were below the CCME chronic toxicity level of 250 mgL^{-1} (Figure 18). However, at two sample locations (Keats and 5B) mean monthly chloride concentrations exceeded the chronic toxicity level from November (2008) to April (2009) In February (2009), the mean monthly chloride concentration exceeded the acute toxicity level. These two sites receive surface runoff from class 2 high traffic volume four lane roads in Waterloo; namely, Keats Way and University Avenue, respectively.

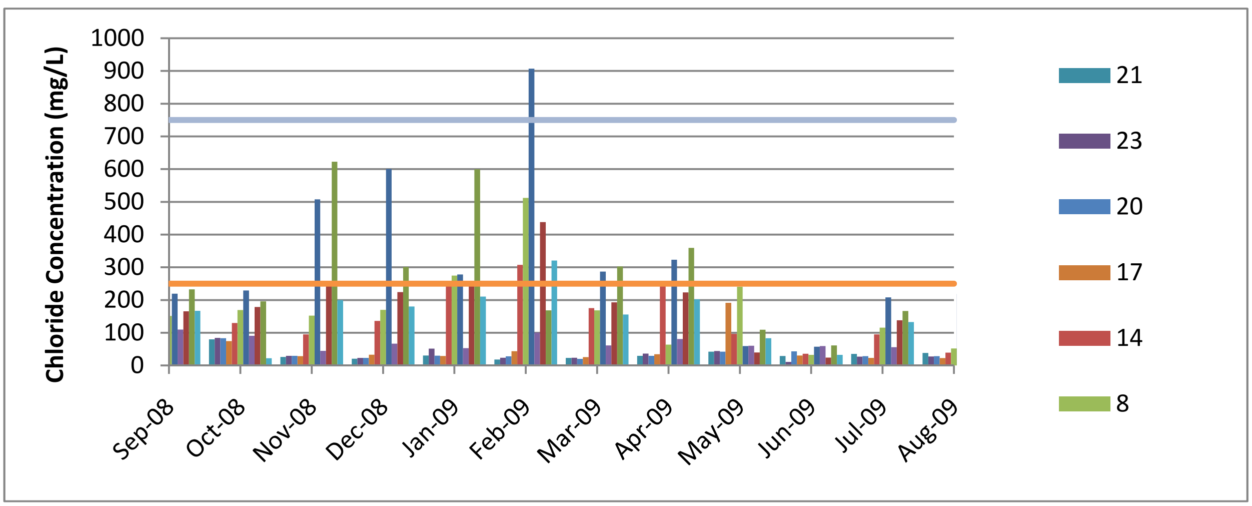


Figure 18. Mean monthly chloride concentration (mg L^{-1}) in Laurel Creek from headwaters (site 21) to downstream (site 3).

Table 8. Chloride concentrations (mean monthly ± standard deviation) in mg L^{-1}

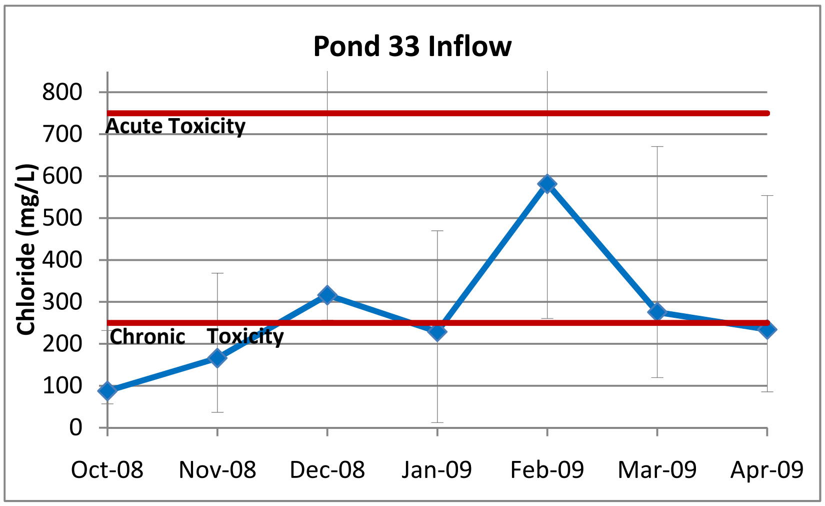
Month		Sites										
		Keats	5A	5B	23	21	17	20	14	8	7	3
Sep-08	x	219.6	165.5	232.8	102.0	94.9	97.6	96.1	121.9	151.4	110.0	167.2
	SD	51.0	25.9	85.5	58.6	54.6	59.7	54.4	52.5	28.0	62.2	14.2
	n	3	3	3	3	3	3	3	3	3	3	3
Oct-08	x	229.4	178.8	196.0	84.5	79.7	74.4	83.3	129.6	169.4	90.5	22.0
	SD	16.5	45.2	55.7	61.5	59.8	58.1	61.6	66.5	42.6	64.8	78.2
	n	4	4	4	4	4	4	4	4	4	4	4
Nov-08	x	507.5	258.0	622.6	29.7	25.9	28.5	29.4	95.0	152.1	44.6	199.6
	SD	358.7	131.6	629.1	3.3	2.2	3.7	1.8	31.1	47.4	7.7	120.2
	n	4	4	4	4	4	3	4	4	4	4	4
Dec-08	x	600.6	224.4	301.2	23.1	20.7	32.8	23.1	136.2	170.1	66.9	180.5
	SD	576.2	129.9	375.1	8.1	4.5	4.3	5.3	66.3	116.4	22.1	161.9
	n	9	9	9	9	9	9	7	7	7	7	7
Jan-09	x	278.2	251.7	599.8	51.4	30.4	28.9	29.9	252.2	274.6	53.0	210.7
	SD	29.1	22.9	164.6	0.0	6.8	2.4	3.5	12.4	61.3	2.9	63.4
	n	4	4	2	1	4	4	4	4	4	4	4
Feb-09	x	907.2	438.2	168.3	23.7	23.3	43.8	28.1	307.3	512.1	100.3	320.9
	SD	425.6	258.2	118.0	6.5	10.5	11.0	4.7	157.5	675.6	27.5	132.4
	n	8	10	9	4	9	9	10	10	10	10	10
Mar-09	x	287.2	192.9	302.7	23.4	18.3	25.7	20.4	175.3	168.6	61.4	155.5
	SD	110.5	78.3	202.2	8.2	6.7	5.7	7.7	100.0	80.8	24.1	95.6
	n	4	4	4	4	4	4	4	4	4	4	4
Apr-09	x	323.3	223.2	359.3	36.2	29.4	34.4	29.7	244.3	240.6	81.0	202.3
	SD	201.6	27.2	31.6	2.7	29.4	3.6	2.5	54.4	33.2	21.2	71.2
	n	4	4	4	4	4	4	4	4	4	4	4
May-09	x	59.2	40.0	109.3	44.4	42.2	191.4	42.1	96.5	63.7	60.4	83.2
	SD	50.7	28.3	45.1	36.7	27.4	416.9	55.3	38.5	51.0	7.0	45.4
	n	6	6	4	6	7	7	7	7	7	7	7
Jun-09	x	57.2	24.0	61.5	10.7	29.1	30.7	43.1	36.1	32.7	59.3	32.5
	SD	23.0	17.3	25.0	7.8	22.9	30.5	22.3	25.8	43.7	35.7	21.9
	n	3	4	4	4	4	4	4	4	4	4	4
Jul-09	x	208.2	138.4	166.7	26.9	35.4	23.3	28.7	95.0	115.8	56.2	132.6
	SD	100.8	69.0	80.7	12.1	3.2	11.6	14.2	37.8	54.1	4.6	68.5
	n	9	9	9	9	8	9	9	9	9	9	9
Aug-09	x	218.4	75.0	151.8	27.5	38.4	22.8	28.5	39.5	52.2	70.7	102.9
	SD	90.9	26.1	74.1	14.4	2.6	12.1	15.5	14.8	17.3	65.9	45.9
	n	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0
	AVG	351.1	196.0	247.1	35.6	35.4	51.2	36.2	149.3	189.5	70.2	166.5
	SD	359.3	165.7	249.0	30.2	26.1	130.3	30.1	110.4	283.1	36.8	113.1

In cold regions, urban stormwater runoff contains a range of pollutants (both dissolved and particulate) as well as elevated levels of chloride (Schuler, 1987; Marsalek, 1997; Marsalek et al., 2000) that significantly impact biotic health of aquatic ecosystems. In Laurel Creek, chloride concentrations were also variable in the watershed because of land use, percent imperviousness and road type/traffic density. The data in Figure 18 show that chloride concentrations were typically lower in the less urbanized headwater sites (21, 23, 20 and 17) than in areas with increasing impervious cover and road density/traffic volume such as those found at the more urbanized downstream monitoring sites (8, Keats, 5A, 5B and 3). The headwater sites (21, 23) are located on gravel roads that are not typically treated with deicer. However, in the summer these roads are treated for dust suppression with calcium chloride which might represent one possible source of chloride measured in surface waters.

The land use in the Beaver Creek watershed upstream of monitoring site 17 is predominantly agricultural and chloride concentrations at this site are relatively low compared to concentrations observed at the more urbanized downstream sites. To compare the relative magnitude of chloride concentrations in surface waters of the Laurel Creek Watershed during the study period, mean monthly chloride concentrations were normalized by dividing each value by chloride concentrations from site 17 (background levels). These ratios (Table 9) are mean monthly concentration factors relative to background levels and show that two sites (Keats and 5B) had mean monthly chloride levels that were often 10 to 20 times higher than background levels.

Chloride Levels in Two Stormwater Ponds. Stormwater ponds are widely used in the treatment of urban stormwater. They provide flow control, sedimentation, removal of dissolved and particulate associate contaminants and in some cases they provide aesthetic amenities (Schueler, 1987). Judd (1970) was the first to report densimetric chemo-stratification in SWM ponds resulting from chloride inputs. Marsalek (1997) and Marsalek et al. (2000) reported the gradual accumulation of chloride over winter and the expedient flushing of chloride in a Kingston SWM pond. Evidence from cold regions in North America has shown that the performance of stormwater ponds differs greatly between winter and summer. For example, pond hydraulics change seasonally and removal efficiency is lower during winter due to a combination of an ice cover, cold water and de-icing salts. Semadeni-Davies (2005) examined the function of a stormwater pond in southern Sweden and also found de-icing salt has a major effect on pond hydraulics through pond stratification. They reported that up to 80% of the chloride was retained by the pond but that chloride was flushed between events. Accordingly, the chloride regime in SWM ponds has been shown to have a number of environmental implications which include: 1) stratification that inhibits vertical mixing and aeration of bottom sediments 2) the reduced oxygen levels and high chloride promote chemical processes that enhance the release of pollutants from bottom sediments and 3) high chloride levels which can have toxic effects on certain biota in ponds and surface waters receiving pond effluent.

Pond 33. Temporal variability in chloride concentrations at the inflow and outflow of pond 33 is shown in Figure 19. At the pond inflow, mean monthly chloride levels increased from 88 mg L^{-1} in October to 580 mg L^{-1} in February then decreased to 234 mg L^{-1} in April. At the pond outflow, chloride levels increased from 25 mg L^{-1} in October to a maximum of 710 mg L^{-1} in December before declining to < 100 mg L^{-1} from January to April.



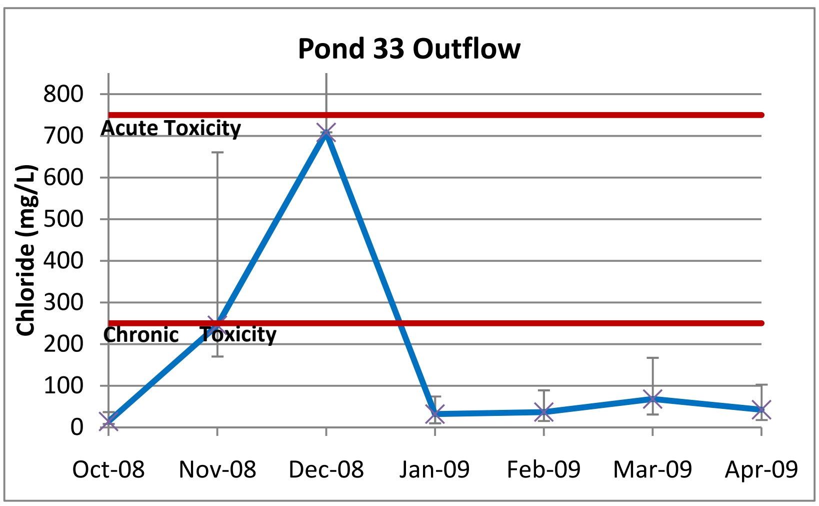


Figure 19. Chloride concentrations (mean monthly ± standard deviation) at the inflow and outflow of Pond 33.

Pond 45. Temporal variability in chloride concentrations at the inflow and outflow of pond 45 is shown in Figure 20. At the pond inflow, mean monthly chloride levels increased from 100 mg L^{-1} in October to a maximum of 500 mg L^{-1} in February then decreased to 200 mg L^{-1} in April. At the pond outflow, chloride levels steadily increased from 50 mg L^{-1} in October to a maximum of 400 mg L^{-1} in April.

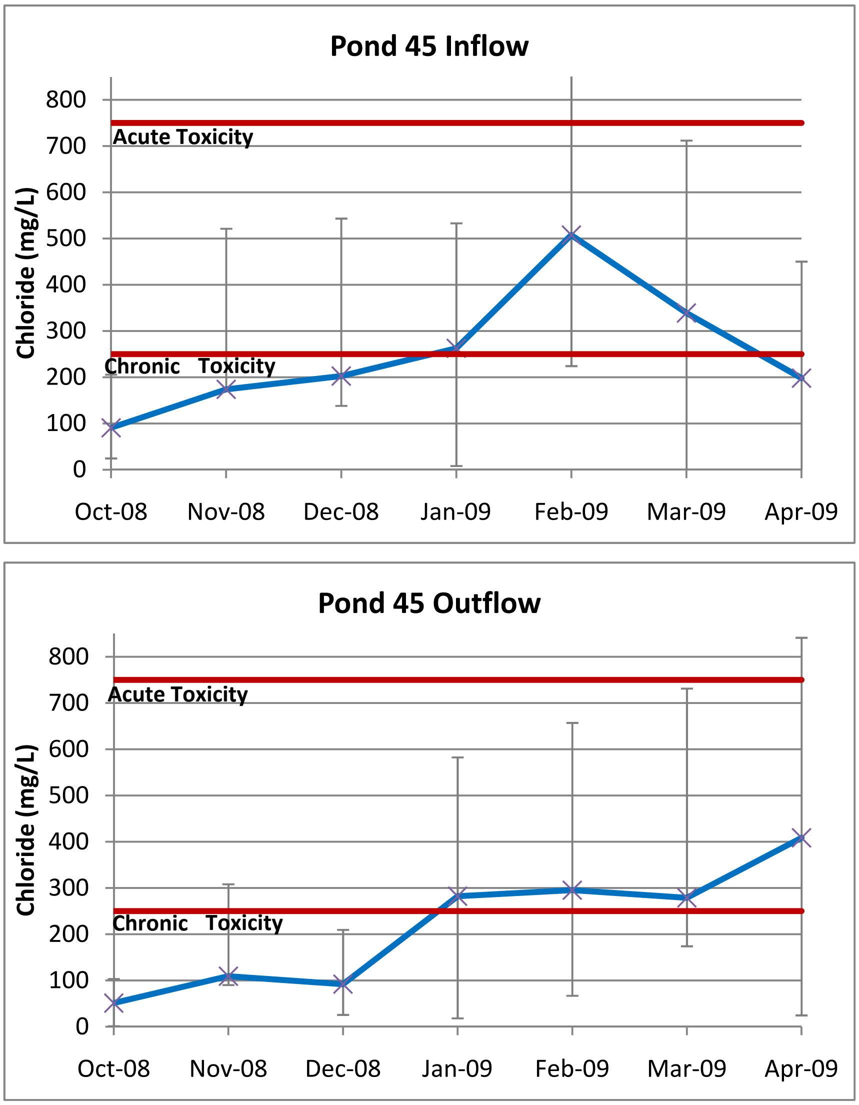


Figure 20. Chloride concentrations (mean monthly ± standard deviation) at the inflow and outflow of Pond 45.

Pond 45 drains directly into Clair Creek less than 200 m above monitoring site 14 (Figure 14). Because of logistical constraints, no monitoring equipment was deployed above site 14 to directly measure the chloride flux from upstream reaches of Clair Creek and therefore it is not possible to determine (without a considerable monitoring effort) the direct effect of pond effluent on the chloride concentration in Clair Creek. However, data in Table 9 can be used to provide some insight into the potential effect of pond effluent on chloride levels in Clair Creek by comparison with "background" levels at site 17 (Beaver Creek). The data show that relative to background levels (site 17), chloride concentrations at site 14 were similar for September and October. However, chloride concentrations at site 14 increased 3 and 4 fold in November and December, respectively. From January to April, mean monthly chloride levels increased approximately 7 fold. Effluent from Pond 45 likely influenced chloride concentrations at site 14. However, another unmonitored stormwater pond is located immediately upstream of site 14 and the contribution of chloride from that pond to the stream is unknown.

Conclusions.

1. Chloride concentrations in Laurel Creek and two stormwater ponds often exceeded the CCME chronic toxicity level (250 mg L^{-1}) and occasionally exceeded the acute level (750 mg L^{-1}).
2. Mean monthly chloride concentrations in Laurel Creek increased throughout the winter and spring at most sites but were typically lower in the less urbanized headwater sites than in areas with increasing impervious cover and road density/traffic volume.
3. Mean monthly chloride levels at two monitoring sites (Keats and 5B) were often 10 to 20 times higher than background levels in Beaver Creek (site 17) and demonstrate the effect of runoff from Class 2 roads on water quality of Laurel Creek.
4. The inflow chloride concentrations of Ponds 33 and 45 were of similar magnitude for the study period but chloride levels at the pond outflow were very different. In the conventional pond (Pond 45), chloride levels steadily increased over the study period but for the hybrid extended detention (Pond 33), chloride levels peaked (>700 mgL^{-1})in December but remained low (< 100 mgL^{-1}) for the remaining four months. Runoff to both ponds emanates from a similar landuse and road type suggesting that differences in chloride concentrations in the pond outflow are more likely related to pond design. Pond

45 has one large compartment compared to Pond 33 which has two main cells; the sediment forebay and the extended detention cell. The secondary cell of Pond 33 is divided into two compartments; the secondary settling pond and the extended detention wetland which has been heavily planted with *Typha Latifolia*. Separation of the compartments in Pond 33 by a berm and the existence of dormant vegetation in the secondary settling pond may have restricted lateral mixing in the pond resulting in lower outflow chloride levels. More research is required to better understand the effect of pond design on chloride transport and outflow dynamics.

Table 9. Monthly mean chloride levels and concentration factors relative to site 17 (background Cl concentrations)

Year /Month	Keats	5A	5B	23	21	17	20	14	8	7	3
08-Sep	219.6	165.5	232.8	102.0	94.9	97.6	96.1	121.9	151.4	110.0	167.2
	2.3	1.7	2.4	1.0	1.0	1.0	1.0	1.2	1.6	1.1	1.7
08-Oct	229.4	178.8	196.0	84.5	79.7	74.4	83.3	129.6	169.4	90.5	22.0
	3.1	2.4	2.6	1.1	1.1	1.0	1.1	1.7	2.3	1.2	0.3
08-Nov	507.5	258.0	[6]22.6	29.7	25.9	28.5	29.4	95.0	152.1	44.6	[1]99.6
	17.8	9.1	21.8	1.0	0.9	1.0	1.0	3.3	5.3	1.6	7.0
08-Dec	600.6	224.4	301.2	23.1	20.7	32.8	23.1	136.2	170.1	66.9	180.5
	18.3	6.8	9.2	0.7	0.6	1.0	0.7	4.2	5.2	2.0	5.5
09-Jan	278.2	251.7	599.8	51.4	30.4	28.9	29.9	252.2	274.6	53.0	210.7
	9.6	8.7	20.8	1.8	1.1	1.0	1.0	8.7	9.5	1.8	7.3
09-Feb	907.2	438.2	168.3	23.7	23.3	43.8	28.1	307.3	512.1	100.3	320.9
	20.7	10.0	3.8	0.5	0.5	1.0	0.6	7.0	11.7	2.3	7.3
09-Mar	287.2	192.9	302.7	23.4	18.3	25.7	*20.4*	*175.3*	*168.6*	61.4	155.5
	11.2	7.5	11.8	0.9	0.7	1.0	0.8	6.8	6.6	2.4	6.1
09-Apr	323.3	223.2	359.3	36.2	29.4	34.4	29.7	244.3	240.6	81.0	202.3
	9.4	6.5	10.4	1.1	0.9	1.0	0.9	7.1	7.0	2.4	5.9
09-May	59.2	40.0	109.3	44.4	42.2	191.4	42.1	96.5	63.7	60.4	83.2
	0.3	0.2	0.6	0.2	0.2	1.0	0.2	0.5	0.3	0.3	0.4
09-Jun	57.2	24.0	61.5	10.7	29.1	30.7	43.1	36.1	32.7	59.3	32.5
	1.9	0.8	2.0	0.3	0.9	1.0	1.4	1.2	1.1	1.9	1.1
09-Jul	208.2	138.4	166.7	26.9	35.4	23.3	28.7	95.0	115.8	56.2	132.6
	8.9	5.9	7.2	1.2	1.5	1.0	1.2	4.1	5.0	2.4	5.7
09-Aug	218.4	75.0	151.8	27.5	38.4	22.8	28.5	39.5	52.2	70.7	102.9
	9.6	3.3	6.7	1.2	1.7	1.0	1.3	1.7	2.3	3.1	4.5

> 20 times
> 10 to 20 times
> 5 to 10 times

4. Pavement and Salt Management (TAC 5)

Objective 2 – Task 2d:
Conduct laboratory experiments in a cold room at the University of Waterloo to examine the effects of clogging and freezing on the permeability of pervious pavement to provide direction for the design, implementation and winter maintenance of pervious pavement parking lots in Ontario.

PERFORMANCE OF PERVIOUS CONCRETE PAVEMENT IN AN ACCELERATED FREEZE-THAW CLIMATE

Introduction. Pervious concrete is increasingly being used as an environmentally friendly, sustainable paving material. The United States Environmental Protection Agency (USEPA) has recognized the benefits of pervious concrete (Tennis et al., 2004) because it has a high void ratio (15% to 30%) that can effectively increase percolation rates (Huffman, 2007; Bermudez, 2008). Pervious concrete is typically placed on a clear stone base that acts as a reservoir to hold water before it infiltrates into the sub-grade. In some landscapes (with coarse soil not overlying a groundwater recharge zone i.e. salt vulnerable area), pervious concrete has the potential to reduce the need for many traditional stormwater conveyance or storage systems. The structure and design of pervious concrete makes it particularly suitable for low volume, low speed applications such as residential streets, driveways, shoulders and parking lots.

Pervious concrete has been used in Europe and the southern United States (Huffman, 2007) where pavement structures are not subject to freeze-thaw conditions. However, little is known about the hydrologic performance and physical behavior of the open structure of pervious concrete in colder climates (i.e. northern United States and Canada) where freeze-thaw cycles are common. Potential benefits associated with the use of pervious concrete in cold climates include a reduction of aggregate loss and failure related to lower moisture levels which reduce the effects of water freezing. An additional benefit is that snow and slush clear quicker from the surface of permeable pavements than from conventional concrete (Henderson, 2008).

The Centre for Pavement and Transportation Technology (CPATT) at the University of Waterloo, Waterloo, ON partnered with the Cement Association of Canada (CAC) and industry members to conduct a Canada wide project to evaluate the performance of pervious concrete pavement in freeze-thaw climates. The research includes field and laboratory studies that examine the structural integrity and drainage characteristics of five test areas across Canada that reflect a range of mix designs, pavement structures, construction methods, winter maintenance techniques and rehabilitative maintenance performance. In this report, laboratory studies are conducted on pervious concrete samples cast during construction of the field sites, cores extracted from the test areas and samples prepared in the laboratory.

The objective of this study is to evaluate the effect of winter maintenance treatments including the application of salt brine and freeze-thaw cycles on the performance of pervious concrete. Winter maintenance techniques are evaluated in conjunction with representative freeze-thaw cycles and precipitation rates experienced in southwestern Ontario.

Methods. The experimental design for laboratory experiments on pervious concrete is illustrated in Figure 21. Samples were prepared in the concrete laboratory of the Civil and Environmental Engineering Department at the University of Waterloo in several batches. Each batch of concrete was used to produce two slabs and three cylinders. All concrete slabs were prepared according to method CSA A23.2-3C. Two sizes of slab moulds were used; 300mm by 300mm by 150mm and 300mm by 300mm by 200mm. Four batches of concrete were prepared each day and casting was carried out over three days in total. Figure 22 shows a slab being cast. Slabs were immediately covered in plastic, following casting. The moulds were removed after 24 hours then the slabs were covered in plastic for seven days and cured at room temperature (Figure 23).

Figure 21. Schematic of experimental design.

Figure 22. Slab consolidation.

Figure 23. Slabs covered in plastic during curing.

In total 24 slabs were prepared. Two were cast for material characterization which included coring and testing for void content, permeability and compressive strength. Four were cast for use in a related project directed by another research team under this project, using moisture instrumentation. The remaining 18 slabs were cast for six loading programs. Each loading program with identical precipitation and winter maintenance loadings was conducted in triplicate. Within the three replicate slabs, one contained a temperature sensor (designed for concrete applications and read temperature and time) to monitor freeze-thaw cycling.

The 100mm by 200mm cylinders were prepared using two methods 1) two layer method (10 drops of the Proctor Hammer added per layer) and 2) three layer method (each layer contained 20 rods according to method CSA A23.2-3C. The two methods were then subsequently evaluated for consistency and material characterization. Pervious concrete is unique from conventional concrete and therefore conventional sample consolidation methods may not represent pervious concrete conditions in the field. Cylindrical samples were cured in a moisture room. During the preparation of the samples, fresh concrete tests were conducted to ensure consistency.

Fresh Concrete Characteristics. Fresh concrete testing included slump, temperature, air content and density measurements in accordance with standard methods (CSA A23.2-5C, ASTM C 1064, CSA A23.2-3C, CSA A23.2-6C). The results of each fresh concrete test for each slab are listed in Table 10. Slabs 0A and 0B were used for material characterization and slabs 7A, 7B, 7C and 7D were supplied to the other project in the following section of this report.

Table 10. Fresh Concrete Results

Batch	Slabs	Unit Weight (kg/m^3)	Slump (mm)	Air Content (%)	Temperature (°C)
1	0A, 3A	1924.2	0	4.0	24.1
2	1A, 3B	1888.0	0	3.8	22.1
3	1B, 3C	1941.9	0	4.0	22.2
4	1C, 6A	1976.0	0	4.4	19.6
5	0B, 4A	2042.6	0	5.1	21.9
6	2A, 4B	1985.2	0	4.4	21.4
7	2B, 4C	2022.0	0	5.2	21.9
8	2C, 6B	1928.5	0	4.1	21.4
9	7A, 5A	2055.8	0	5.6	23.1
10	7B, 5B	2074.2	0	5.6	21.1
11	7C, 5C	2000.8	0	4.8	20.2
12	7D, 6C	1893.9	0	3.4	19.8
Average		1977.8	0	4.5	21.6

Each batch of concrete had a consistent slump of 0mm which is anticipated in pervious concrete because it is a “stiff mix”. Temperature remained consistent throughout the batching process (Table 10).

Testing Methods.

Cores and Cylinders. Four cores were extracted from each slab and the air void content, permeability and compressive strength testing were measured in each core. Air void content was measured using a CoreLok vacuum system and permeability was measured using a Gilson permeameter (Figure 24). Sides of the core were sealed with a latex membrane to provide pressure and reduce lateral flow. Cylinders that were cast during the preparation of the slabs were tested for compressive strength at 7 and 28 days after sample preparation.

Figure 24. Gilson Permeameter

Slabs. In total 18 slabs were prepared for accelerated freeze-thaw cycling experiments. The slabs were divided into six sub-groups. Each group received a specific sand loading rate considered typical for winter maintenance application on pervious concrete. The experimental design involved testing for various sand applications (heavy, average and no sanding) and precipitation (heavy, average) rates listed below.

1. Heavy sanding, heavy precipitation.
2. Average sanding, average precipitation.
3. Heavy sanding, average precipitation.
4. Average sanding, heavy precipitation.
5. Heavy salting, heavy precipitation.
6. No winter maintenance, heavy precipitation.

During each freeze-thaw cycle, one winter maintenance and precipitation loading test was performed. The amount of precipitation applied varied based on the average monthly precipitation in Waterloo, Ontario. The precipitation rate per freeze-thaw cycle was determined for each month based on the number of freeze-thaw cycles per month (Ho and Gough, 2006). Consecutive months with similar precipitation loadings per freeze-thaw cycle were grouped. The precipitation values and number of freeze-thaw cycles for each month used in the experiments are listed in Table 11. Ho and Gough (2006) report that on average 51 freeze-thaw cycles occur annually in Toronto, Ontario. The weather conditions of Toronto and Waterloo are similar when considering temperature ranges (EMR, 1985).

Table 11. Freeze-Thaw Cycle Precipitation Loading

Cycles	Months	Precipitation/Freeze-Thaw Cycle	
		Average (mm)	Heavy (mm)
29	January, February, March	6.5	9.75
4	April	19	28.5
1	May, June, July, August, September	423	634.5
2	October	33	49.5
6	November	14	21
9	December	8	12

According to Ho and Gough (2006), freeze-thaw cycles occur when the maximum daily temperature is 0°C or higher and the minimum daily temperature is < -1°C. To undergo freeze-thaw cycles, pervious concrete slabs were moved from an outside room at 20°C to a large freezer with a constant temperature of -15°C. According to the temperature sensors, 14 hours are required for one freeze-thaw cycle to be completed (i.e. temperature changes in the slab from above 0°C to below 0°C). The cycles generally range from at least 8°C to -12°C to test the pervious concrete under more aggressive conditions.

Figure **25** shows typical sensor data for a 200mm thick slab completing 12 cycles.

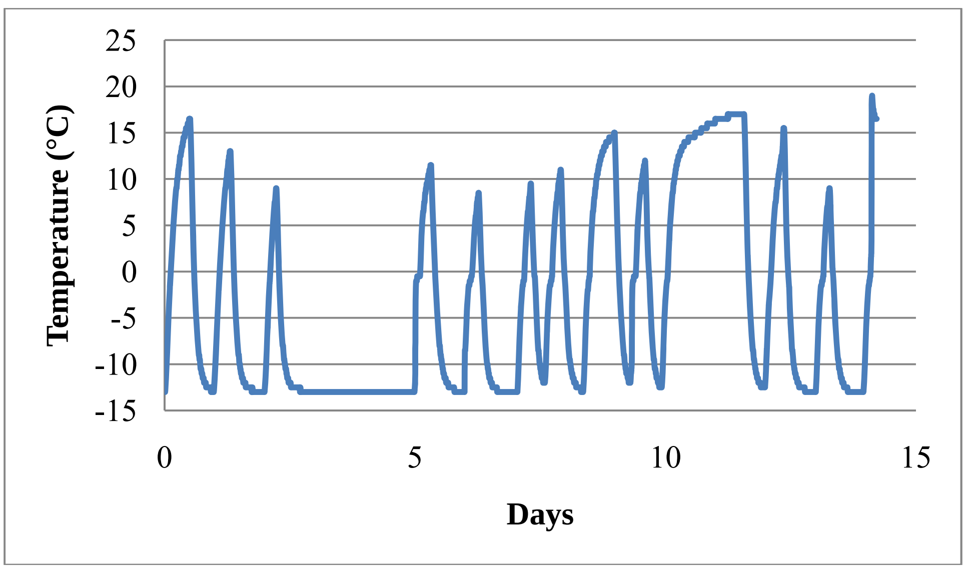


Figure 25. Freeze-thaw cycling of a 200mm thick slab.

Results. The fresh and hardened concrete slab densities are presented in Figure 26. The average fresh and hardened densities were 1978 kg/m^3 and 2017 kg/m^3, respectively. Minimal variations in densities were observed and the pervious concrete had a hardened density similar to the upper limit of light weight concrete ranging from 1600kg/m^3 to 2000kg/m^3 (NRMCA, 2009).

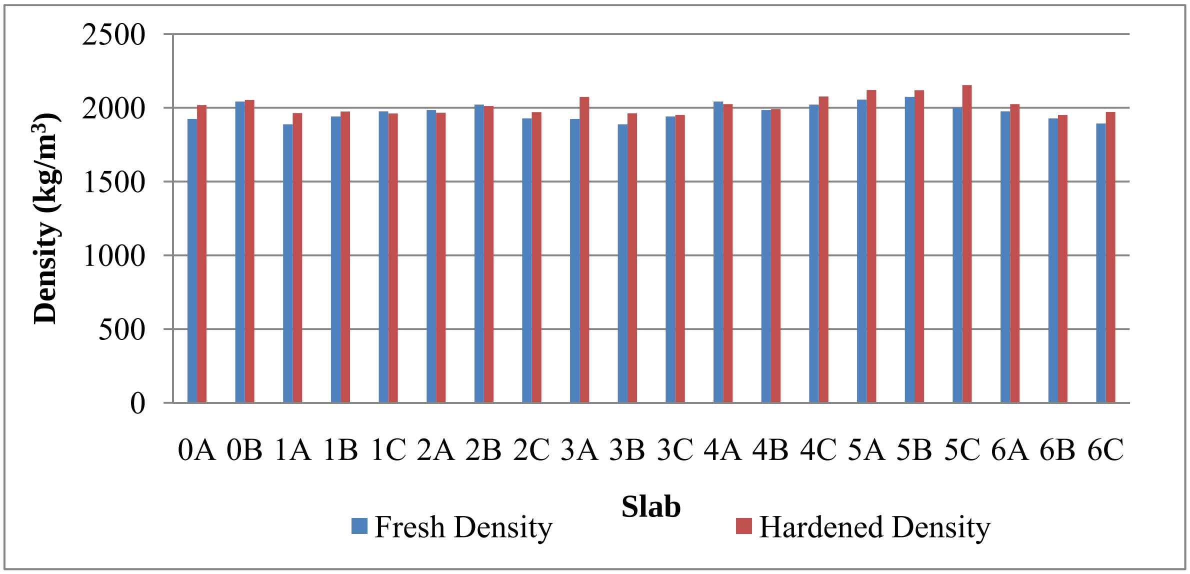


Figure 26. Density of the pervious concrete batches.

Cores. The fresh density of two 200mm slabs (0A and 0B) were comparable to the average density of the other slabs and the hardened densities were also comparable, indicating that slabs 0A and 0B were representative of the other slabs that were cast. Four cores, each 100mm in diameter were extracted from each slab, as shown in Figure 27.

Figure 27. Cores extracted from slabs for material characterization.

Permeability data for the eight cores are presented in Table 12. The permeability of the four cores from slab 0A was similar (standard deviation = ±0.12). Two of the cores from slab 0B performed similarly to 0A whereas the other two had much higher permeability rates. The permeability of the bottom face of Core 0B4 was 1.17cm/sec. However, permeability the slabs appear to be quite variable but these fluctuations are commonly observed in field trials. The measured permeability rates of all the cores exceeded the value necessary to infiltrate the maximum rainfall intensity observed in southern Ontario which is 0.0083cm/sec (EC, 2008).

Table 12. Core Permeability

Core	**Permeability (cm/s)**	**Average Permeability ± 1 Std Dev (cm/s)**
0A1	1.16	1.32 ± 0.12
0A2	1.30	
0A3	1.42	
0A4	1.41	
0B1	4.82	3.20 ± 1.79
0B2	1.73	
0B3	1.58	
0B4	4.67	

Following permeability testing the cores were end ground to measure void content and compressive strength. The void content for the core and slab combinations were consistent (Table 13). The standard deviation for all cores was 0.8% and the within slab variability was 0.8% for 0A and 0.9% for 0B.

Table 13. Void Content of Cores

Core	**Void Content (%)**	**Average Void Content (%)**
OA1	28.6	29.0
OA2	28.5	
OA3	28.7	
OA4	30.2	
OB1	29.3	29.1
OB2	29.9	
OB3	29.4	
OB4	27.9	

Compressive strength was measured on cores with an age of 5.5 months and the results of these tests are listed in Table 14.

Table 14. Compressive Strength of Cores

Cylinder	Compressive Strength (MPa)	Average Compressive Strength (MPa)
0A1	13.6	12.7
0A2	12.2	
0A3	12.1	
0A4	13.1	
0B1	16.2	14.5
0B2	14.3	
0B3	13.1	
0B4	14.4	

Table 14 shows the compressive strength for all cores were relatively consistent with the average compressive strength of 13.6MPa. This value is considered safe for low speed, low volume traffic that pervious concrete pavement is typically used for. The compressive strength measurements for slabs are presented in Table 15.

Table 15. Compressive Strength of Cylinders

Cylinder (Batch – Cylinder Number)	Preparation Method	Age (Days)	Compressive Strength (MPa)	Average Compressive Strength (MPa)	Standard Deviation (MPa)
1-1	PH	7	7.0	9.6	2.3
3-1	PH	7	8.0		
5-1	PH	7	13.0		
7-1	PH	7	9.4		
9-1	PH	7	11.7		
11-1	PH	7	8.7		
2-1	Rod	7	12.4	12.4	3.5
4-1	Rod	7	16.2		
6-1	Rod	7	8.8		
8-1	Rod	7	9.6		
10-1	Rod	7	17.1		
12-1	Rod	7	10.4		
1-2	PH	28	9.7	11.5	2.2
1-3	PH	28	10.0		
3-2	PH	28	9.7		
3-3	PH	28	9.4		
5-2	PH	28	15.6		
5-3	PH	28	14.5		
7-2	PH	28	13.1		
7-3	PH	28	11.3		
9-2	PH	28	13.5		
9-3	PH	28	12.6		
11-2	PH	28	9.6		
11-3	PH	28	9.3		
2-2	Rod	28	11.7	14.4	3.7
2-3	Rod	28	12.6		
4-2	Rod	28	15.2		
4-3	Rod	28	16.3		
6-2	Rod	28	13.6		
6-3	Rod	28	11.4		
8-2	Rod	28	15.0		
8-3	Rod	28	12.7		
10-2	Rod	28	19.0		
10-3	Rod	28	23.0		
12-2	Rod	28	10.3		
12-3	Rod	28	11.6		
PH = Proctor Hammer					

Research related to various consolidation methods for evaluating the characteristics of pervious concrete has been carried out at the University of Waterloo. This research compared the use of rods and a Proctor Hammer and found at that cylinder size, two layers and 10 Proctor Hammer drops per layer produced the optimum concrete conditions when compared to the field site (Rizvi et al., 2009). Table 15 shows increases in compressive strength between the 7 and 28 day values for the cylinders prepared with both methods of compaction. Both compaction methods produced cylinders with compressive strengths comparable to that of the cores extracted from the slabs. The average strength of the cylinders prepared using the rod method is greater than the Proctor Hammer results. However, the rod method includes the cylinders from batch 10 which have strengths much greater than the other cylinders. By removing the results of the batch 10 cylinders the 7 and 28 day compressive strength averages for the rod prepared samples change to 11.5 MPa and 13.0 MPa, respectively. For 7 and 28 day old samples, the Proctor Hammer compaction method was more consistent with a lower standard deviation. The standard deviations presented in Table 15 represent variations between the mixes. The average standard deviation for 28 day strengths between two cylinders from the same batch, such as 1-2 and 1-3, were 0.5 MPa and 1.4MPa for the proctor hammer and rod compaction methods, respectively.

The Proctor Hammer created cylinders with less variability in compressive strength. This work should be continued to include void content and permeability testing. The consistency of the compaction of the Proctor Hammer is being recognized in pervious concrete research as ASTM C1688 was released in 2009 for testing the fresh density of pervious concrete pavement and requires the pervious concrete to be placed in the density bucket in two layers and receive 20 Proctor Hammer drops per layer. This standard was available not available at the time of casting the slabs and cylinders but has been used in more recent projects.

Slabs. The slabs are monitored regularly for changes in performance including distress development on the surface, permeability and total weight. To monitor distress development photos of the surface of each slab were taken regularly. Distresses that have appeared to date include fracturing of aggregate, aggregate ravelling and paste loss. Aggregate ravelling is a pavement surface defect whereby the aggregate pops out of the pavement leaving a hole. The paste loss which can also lead to ravelling refers to the loss of the matrix or cement paste which keeps the aggregate in place. These pavement distresses can be avoided through careful mix design and proper construction. In general, minimal surface distress has occurred, which is likely a result of no traffic loading on the slabs. Table 16 shows the distresses that are present in each slab. Slabs that are not loaded with sand include estimates of the severity and density of the distress. It is not possible to view the entire surface of the slabs that are loaded with sand and therefore noticeable distresses through the sand are listed. Very slight to slight ravelling occurred in all the slabs and will be quantified in the future.

Table 16 indicates the surface distress development in the slabs for various experimental conditions. All slabs experienced some level of surface distress. However, it was very minimal in most cases where a slight paste loss occurred. Figure 28 shows slabs 2B, 5B and 6B. In the photo of slab 5B, the addition of salt solution changes the characteristics of the surface as the surface of the number 5 slab always appear darker than the others and wet. All three photos were taken at the same time of the slabs, during the same point in the same freeze-thaw cycle.

Table 16. Slab Surface Distress Development

Slab	Condition		
	A	B	C
1	Very slight paste loss	Fractured aggregate, Slight paste loss	Fractured aggregate, very slight paste loss
2	Moderate paste loss	Moderate paste loss	Moderate paste loss
3	Very slight paste loss	Fractured aggregate, Slight paste loss	Very slight paste loss
4	Very slight paste loss	Very slight paste loss	Moderate paste loss, fractured aggregate
5	<5% Fractured aggregate, <10% Moderate paste loss	<5% Fractured aggregate, 50% moderate paste loss	<5% Fractured aggregate, 50% Moderate paste loss, 10% Severe paste loss
6	<5% Fractured aggregate, 10%-20% slight paste loss	<5% Fractured aggregate, 10% - 20% moderate paste loss	<5% Fractured aggregate, <10% Moderate paste loss

Figure 28. Slab condition during cycling.

Condition Changes. The slab mass was anticipated to increase with sand loading and slabs were weighed regularly to monitor these changes. If ravelling occurs on the slab, then the weight may decrease. There is also a potential that the weight of the slabs will increase more than the weight of the sand loading due to water being trapped in the slabs. Table 17 shows the initial weight of the slabs, the weight of applied sand, the anticipated weight after one year of cycling and the true weight after one year of cycling. The initial weights are before the slabs were evaluated for permeability and were therefore naturally dried at room temperature. The weight was recorded after the slabs had dried at room temperature for 10 days.

Table 17. Slab Weight Changes with Loading

Slab	Weight (kg)				
	Initial	**Sand/Salt Loading**	**Anticipated After 1 Year**	**Recorded After 1 Year**	**Difference Between Anticipated and Recorded Year 1**
1A	35.42	2.08 (sand)	37.50	37.08	-0.42
1B	35.56	2.08 (sand)	37.64	37.22	-0.42
1C	35.32	2.08 (sand)	37.40	37.14	-0.26
2A	35.46	1.04 (sand)	36.50	36.48	-0.02
2B	36.22	1.04 (sand)	37.26	37.44	0.18
2C	35.48	1.04 (sand)	36.52	36.54	0.02
3A	28.06	2.08 (sand)	30.14	29.26	-0.88
3B	26.50	2.08 (sand)	28.58	28.06	-0.52
3C	26.34	2.08 (sand)	28.42	27.94	-0.48
4A	27.40	1.04 (sand)	28.44	28.44	0.00
4B	26.88	1.04 (sand)	27.92	27.88	-0.04
4C	28.04	1.04 (sand)	29.08	28.86	-0.22
5A	28.70	2.04 (salt solution)	28.70	28.92	0.22
5B	28.62	2.04 (salt solution)	28.62	28.84	0.22

5C	29.08	2.04 (salt solution)	29.08	29.32	0.24
6A	27.40	0	27.40	27.62	0.22
6B	26.34	0	26.34	26.58	0.24
6C	26.62	0	26.62	26.78	0.16

Slabs with less than the anticipated weight are indicated in Table 17 as having a negative difference. While great care is taken during the precipitation and permeability loadings it is possible that minimal amounts of sand are lost during these events. The other possible causes for this observation are aggregate loss and sand movement through the slab. The slabs are moved in and out of the freezer during freeze thaw cycling and loose aggregate can fall off the slab during this time. Slabs are also moved on to the scale and permeability stand which can also lead to a loss of aggregate from the slabs. It is unlikely that sand would travel through the slab with the precipitation due to the small size of the voids and the intricacy of the void network.

The slabs that are most useful in understanding water absorption or water being trapped in the voids are the number 6 slabs as they receive no winter maintenance loading, only precipitation loading. All three of the number 6 slabs showed similar increase in weight, indicating that on average the weight increased by 0.8%. From the void content results there is potential for the slab weight to increase by 29% if the slab was saturated. A 23% salt solution was applied to slab 5 which changed the appearance of the pervious concrete pavement surface (Figure 28).

Permeability. The permeability measurements for the 6 slabs using a Gilson permeameter are presented in Figure 29 for the first year of cycling.

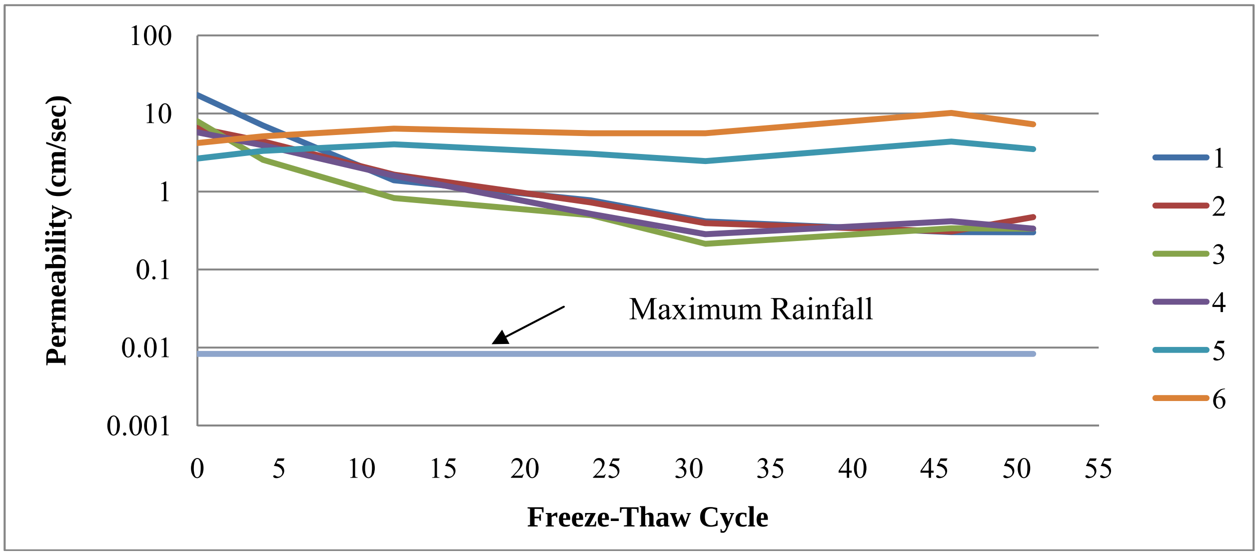


Figure 29. Permeability of slabs throughout one year of freeze-thaw cycling.

The permeability of slab groups 5 and 6 (with no sand loading) remained relatively constant over time (Figure 29). The other four slab groups (that received variable rates of sand loading) showed a decrease in permeability with time from approximately 10 to 0.5 cm/sec. Permeability was measured at various times in the freeze-thaw cycle experiments. Permeability rates at 46 freeze-thaw cycles generally increased in all slabs, whereas at 31 cycles all slabs showed a decrease in permeability. These consistent trends indicate suggest that permeability is being affected by temperature conditions. The critical element related to permeability is the comparison to the maximum rainfall rate for the region. None of the slabs have a measured permeability that approaches this rate. Figure 30 compares the initial permeability of each slab to measured density and shows that as the density of the slab increases the permeability decreases. The density of the slab may have an effect on the durability of the pervious concrete in the long term but this will be evaluated with further studies.

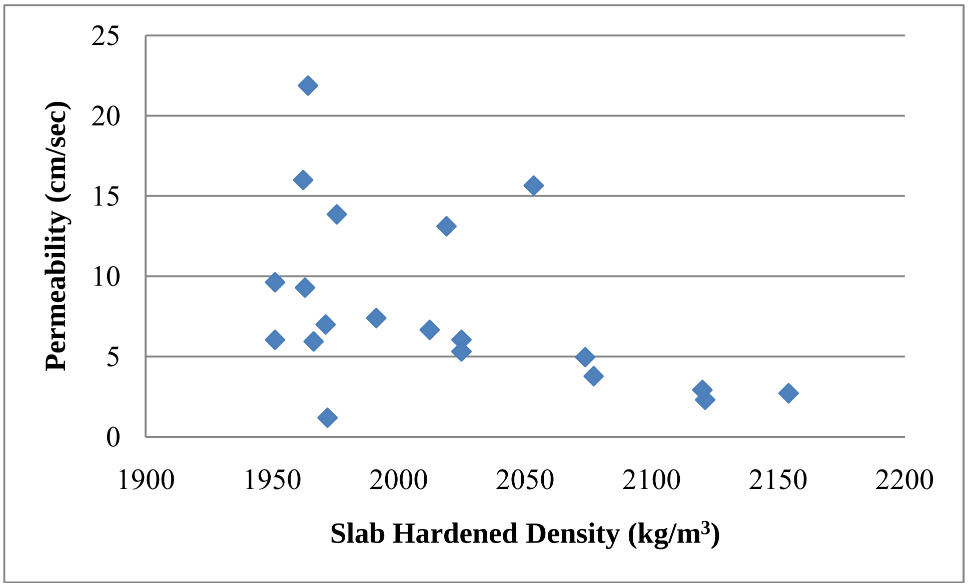


Figure 30. Comparison of permeability to hardened density of slabs.

Conclusions.

1. The fresh concrete testing demonstrated consistency between the prepared batches, slabs and cylinders. The use of the Proctor Hammer for consolidation of the cylinder samples showed less variability than the conventional rodding method.
2. The extraction of cores from the slabs for material characterization is an effective method for comparing the physical characteristics of the slabs, particularly changes in permeability as a function of sanding and freeze-thaw cycles. The cores had sufficient compressive strength for pervious concrete applications in Southern Ontario.
3. The freeze-thaw cycling system is effective and simple to implement. Minimal distress development occurred on the slabs including ravelling, slight paste loss and aggregate fracturing being present on many slabs. The permeability of the slabs treated with sand decreased but remained more than adequate to accommodate maximum rainfall rates experienced in Ontario. Permeability of slabs treated with salt solution continued to be high. However the surface of these slabs appeared wet and paste loss was more aggressive compared to slabs not treated with salt.
4. The slabs treated only with water equivalent to standard precipitation rates held a small quantity of moisture after one year of cycling. It is premature to draw any conclusions relevant to winter maintenance practices from one year of study to the

long-term as continued study of this process under field and laboratory conditions is required. While the study shows that permeability of the slabs remained well above the maximum expected rainfall after one year, further study is required to determine whether subsequent years of sanding would result in continued loss of permeability.

5. Overall, the usage of pervious concrete pavement supports the TAC 5.0 road salt management best practices as it is expected that application rates of deicing chemicals might decrease with a pervious pavement surface (TAC, 2003). This reduction would be attributed to the fact that it is highly permeable and water would immediately move through the system thus reducing the formation of ice on the pavement surface. Also the light color and higher thermal mass will cool down more slowly in comparison to conventional pavements which again would potentially reduce the usage of salt or deicing chemicals. It is not expected that pervious concrete pavement would be any more susceptible to scaling or other types of distresses typically observed with conventional concrete pavements. However, this can only verified with Canadian field performance data over time.
6. The results presented here coupled with other complimentary research conducted at the University of Waterloo indicate that the design permeability of these structures would be sufficient to maintain optimal permeability for several years prior to requiring specific maintenance to improve permeability. The need for maintenance would depend on several factors such as the pavement thickness, amount of winter maintenance, amount of precipitation, traffic loading, number of freeze thaw cycles, etc. However, for a typical parking lot or low volume road applications, it would not be expected that additional maintenance would be required. Finally, pervious concrete pavement will shed brine more quickly and thus be similar to open graded asphalt pavements or grooved concrete, it may be beneficial in areas that are vulnerable to salt spray. Conversely, this type of pavement would also result in quick movement of salt through the pavement system as compared to conventional pavements. Consequently, in areas where there are sensitivities in groundwater, these pavement structures should be designed with an impervious lower layer where the salt contaminated run off can be captured and treated.

TRANSPORT AND RETENTION OF WATER AND SALT WITHIN PERVIOUS CONCRETE SUBJECTED TO FREEZING AND TYPICAL WINTER SANDING

Background and Context. As pervious concrete surfaces become more prevalent in stormwater best management practices, there is an increasing need to understand their impact on the surrounding landscape components as a whole. These 'infiltration' practices reduce some of the increased flow volume and temperature related impacts of more traditional end-of-pipe stormwater management controls, such as ponds and wetlands (Toronto and Region Conservation Authority, 2008); however, their impact on groundwater is not well documented. Tennis *et al.* (2004) states that pervious concrete is instrumental in recharging groundwater and that the use of pervious concrete in land development provides a solution to construction that is sensitive to environmental concerns. Sediment samples extracted from beneath (within the subgrade) a permeable pavement parking lot in the Township of King indicated that the average road runoff contaminant concentrations within the permeable pavement sediments were either similar to or lower than sediment from nearby reference sites, with no obvious relationship to pavement age, design or soil type (Toronto and Region Conservation Authority, 2008). The one notable exception from this study was chloride (Cl^-), which is a dissolved constituent that does not bind to soils like most other roadway contaminants. Chloride, a component of road salt, accumulates over time, but would be expected to eventually leach from the soil into groundwater (Toronto and Region Conservation Authority, 2008). Many communities in Southern Ontario receive a portion of their drinking water supply from groundwater. The Region of Waterloo relies heavily upon groundwater resources for drinking water and for irrigation of agricultural fields. Groundwater recharge areas (e.g. the Waterloo Moraine) are salt vulnerable areas with sandy soils where the water table is located close to the surface that are vulnerable to groundwater contamination (Region of Waterloo, 2008).

Much work has been done characterizing the performance of these pervious concrete surfaces, with the general consensus that the systems perform well under high-flow (i.e. storm flow) conditions, because of their high void ratio and related high infiltration rates. However, much less is known about the water quality impacts of pervious concrete, specifically with regards to chloride from road salt application. Understanding how chloride is transported through, and retained within, the pervious matrix has long-reaching implications for the use of pervious concrete structures in freeze-thaw environments, where the application of road salt or brine solutions (typically containing high concentrations of chloride, as sodium chloride) to the surface is a safety necessity (for melting surficial ice) during the winter season. Furthermore, the performance of pervious concrete is not well-documented for freeze-thaw environments, and the implications of sand application on the infiltration capacity of the pervious surface have yet to be characterized. The objectives of this study are to: 1) determine the effect of sand application on the performance of pervious concrete, under both frozen and thawed conditions; 2) characterize the transport and retention of salt within the pervious matrix; and 3) discuss the implications for groundwater quality.

Methods and Approach. Water and salt retention were monitored for four pervious concrete slabs (7A, 7B, 7C, 7D) in the CPATT lab at the University of Waterloo. To determine volumetric water content each slab was instrumented with two Campbell Scientific CS-605 time domain reflectometery (TDR) probes, positioned 5 and 15 cm from the top surface of the slab during the slab setting. The slabs were paired for testing, with two slabs dedicated to salt (as a surrogate for chloride) characterization (herein referred to as CS) and two slabs dedicated to characterizing the hydrologic performance of the pervious concrete (HS), thus providing a basis for comparison of saline (winter) to non-saline conditions.

Prior to experimentation, characterization of each slab was completed. The dry slabs were each weighed to determine the mass of the concrete matrix only. The pore volume of each slab was determined through displacement, where the slab was slowly and carefully lowered into a tub full of water. The volume of the concrete matrix is responsible for the water being displaced from the tub, thus the pore volume is the residual of the total volume of the slab. The slabs were allowed to drip-dry and then were re-weighed to determine the volume of water retained in the matrix of the pervious concrete. Porosity was calculated as the ratio of the volume of the void space to the volume of the total concrete slab. The void space volume only includes the larger pores within the pervious matrix that could readily fill with water, and not the small air spaces that exist within the structure (fine materials) that comprises the matrix itself.

After the initial characterization, water and a 23% brine (sodium chloride) solution were applied at a constant rate to the surface of the HS and CS pervious concrete slabs, respectively, using a ‘precipitation’ apparatus (Figure 31) and a Marriott device to facilitate even application onto the surface of the slab. The slabs were subjected to varying amounts of sand clogging, under both frozen and thawed conditions, with both salt and fresh water. Accordingly, there were a total of 12 independent experimentation designs, with 2 repetitions of each (i.e. 2 HS slabs and 2 CS slabs). For the frozen runs, the slab was placed in a walk-in freezer at a temperature of -15°C for at least 24 hours. The water or brine solution to be applied to the frozen slab was placed in the same freezer for at least 2 hours prior to application, and ice cubes composed of water or brine, whichever was appropriate, were placed in the reservoir of the Marriott system to maintain a temperature near to 0°C. Slabs were tested initially under 'pristine' conditions (i.e. no sand applied), with sand applications increasing incrementally, according to a 'heavy' sand loading rate of 40 g sand m^{-2}, and 0, 10 and 50 individual sand applications (Table 18).

Table 18. Sand application quantities. Clogging levels 1 and 2 represent 10 and 50 sand applications at the 'heavy' sand application rate.

Clogging Level	# of Applications	Sand Added (g) - cumulative total
0	0	0
1	10	36
2	50	180

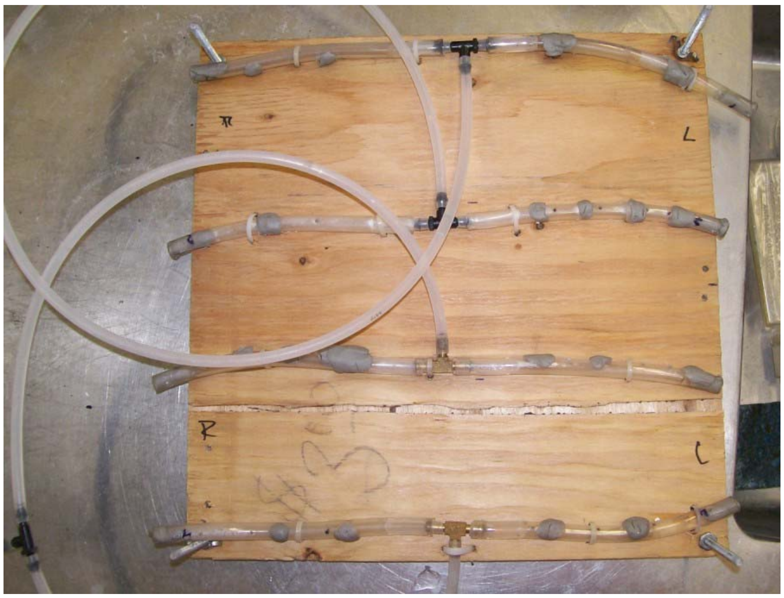


Figure 31. 'Precipitation' apparatus used for the application of the water and the brine solution evenly to the surface of the pervious concrete slab

The Marriot system is designed to provide a constant flow rate, regardless of the level of water (or brine) in the delivery system. The flow rate from this system can be altered by changing the height of the vent tube of the Marriott system and sliding it up and down for increased and decreased flow rates, respectively. A flow rate of 45 ml min^{-1} was targeted for each run, simulating a precipitation intensity of 30 mm hr^{-1}. This is equivalent to the 2 hour duration of a 10 year storm, according to the 31 year (1971 – 2003) rainfall intensity-duration frequency data for the Waterloo-Wellington region (M. Stone, personal communication). Two independent precipitation devices (one each for the CS and the HS slabs) permitted simultaneous experimental runs to be conducted (Figure 32). Upon flow initiation, water samples were collected beneath the slabs at regular time intervals to track the volume of the water flowing through the slab. A time interval of 1 minute was chosen for the beginning of the experiment, until the volume of water measured coming out of the slab was approximately equivalent to the flow rate onto the slab (i.e. 45 ml min^{-1}); then, the measurement interval was spaced further apart because the system was considered to be at steady-state flow conditions (flow rate in = flow rate out).

TDR measurements were made using a Campbell Scientific TDR-100 system and a SMDX-50 multiplexer, controlled by a CS1000 data logger that collected and recorded volumetric water contents within the slabs every 10 minutes. The empirical calibration function of Topp *et al.* (1980) was applied to relate the dielectric number from the TDR reading to the volumetric water content within the pervious concrete slab. For the CS slabs, the movement of salt was monitored through measurement of the electrical conductivity (EC) of the water flowing from the bottom of the slab at regular time intervals (similarly reduced once steady state conditions were reached) using a Thermo Scientific EC probe, with all EC measurements corrected to 25°C standard conductivity values. These tests were repeated at both frozen and thawed conditions, and with the three levels of sand clogging on the surface of the slab, producing a total of 12 independent experimentation designs, with 2 replicates of each (i.e. 2 HS slabs and 2 CS slabs).

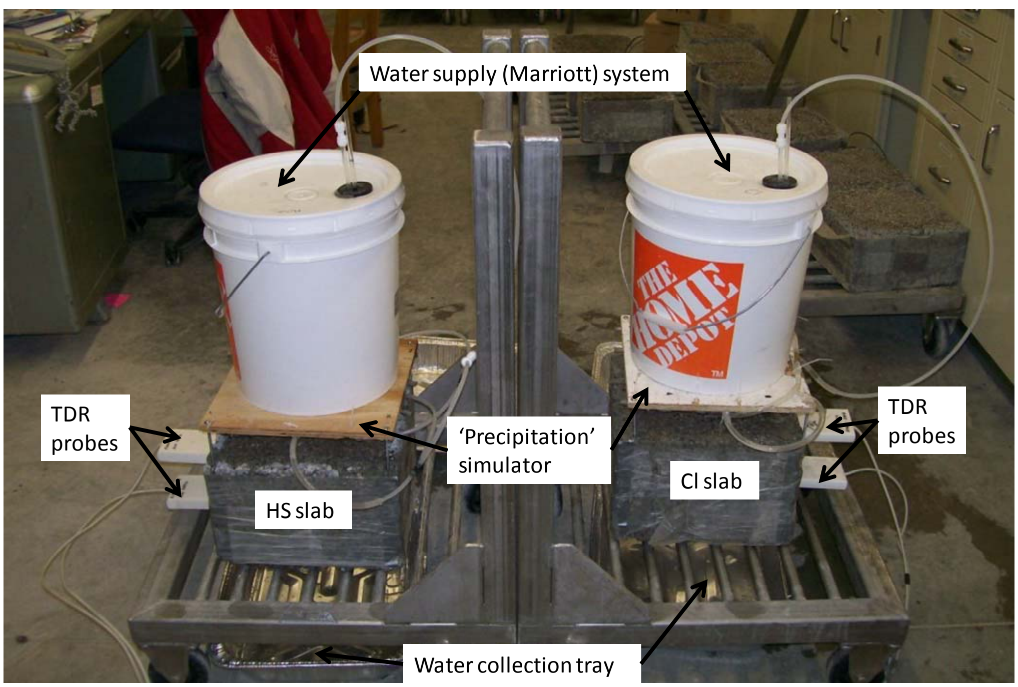


Figure 32. Experimental setup for evaluating water and salt retention in pervious concrete slabs

Results and Discussion

Slab Characteristics. Each of the slabs tested had slightly different physical characteristics (Table 19). The variability in pore volumes, and hence porosity, of the slabs is an artifact of their construction.

Table 19. Physical characteristics of the pervious concrete slabs. Wet weight was measured after dripping from the bottom of the slab had ceased.

Characteristic	**Salt Slabs (CS)**		**Hydrology Slabs (HS)**	
	7A	**7B**	**7C**	**7D**
Dry Weight (kg)	37.30	36.98	35.38	34.76
Wet Weight (kg)	38.08	37.76	36.26	35.56
Pore Volume (L)	3.44	5.59	4.06	4.40

Moisture Dynamics. Due to complications caused by the high electrical conductivity of the brine used on the CS slabs, the TDR data was deemed unreliable for the CS slabs and thus, is not used in this report. The HS slabs were not affected by these issues, so the TDR data is suitable to use. Volumetric water contents (VWC) measured within the two HS slabs ranged from 8% when the slab was dry, to 22% during the experimental runs when the slab had water flowing through it. The variability in the physical characteristics of the different slabs as a result of their independent construction and the presence of the TDR probe, as described previously, is likely responsible for differences in VWC measurements between slabs under dry conditions. Nonetheless, following the completion of an experimental run, the slabs all appear to drain (i.e. return to their pre-test VWC value) within approximately two days. Results indicate that the time required to drain the water from the slab under frozen conditions is greater than when the slab is thawed (Figure 33). In addition, when the concrete is frozen, less water drains from the pervious matrix, causing the VWC to stabilize at higher residual water contents. This trend was consistent for all of the experimental runs, regardless of sand application amounts (Figure 34). The multiple spikes in VWC in Figure 34 indicate the start of an experimental run (addition of water/brine to the slab), under differing conditions. Variations in the height of the VWC spike is likely a result of variations in the rate which water was applied to the surface of the slab, as difficulties were encountered in obtaining consistent flow rates between tests. The VWC at the bottom of the slab was consistently higher than that at the top of the slab. Although this could be partially due to the variations in slab properties with depth into the slab, where the water is drained more slowly (i.e. water is retained within the slab more effectively) at the base of the slab where the concrete is the most compact and the pores are the smallest. However, it is more probable that this is due to the preferential draining of the upper portion of the slab by gravity. As a consequence of this preferential drainage, water remains in the lower portion of the slab for longer, as it continues to drain into this layer from above. This phenomenon is magnified under frozen conditions, as the drainage from the bottom of the slab (and to this area from the upper portion of the slab) is slowed due to frozen water films within the matrix constricting the pore size, thereby reducing the efficacy of the slab to shed water.

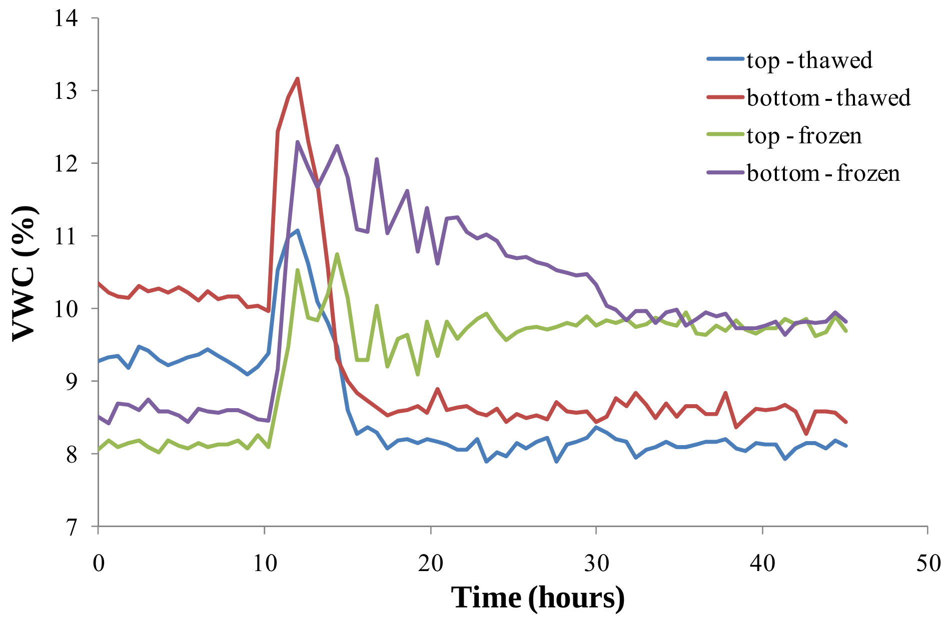


Figure 33. VWC for the 7D (HS) slab during two experimental runs (thawed and frozen), both at 'pristine' conditions (i.e. no sand application). Note: 'top' denotes the probe located 5cm from the slab surface, while 'bottom' denotes the probe located 15cm from the slab surface.

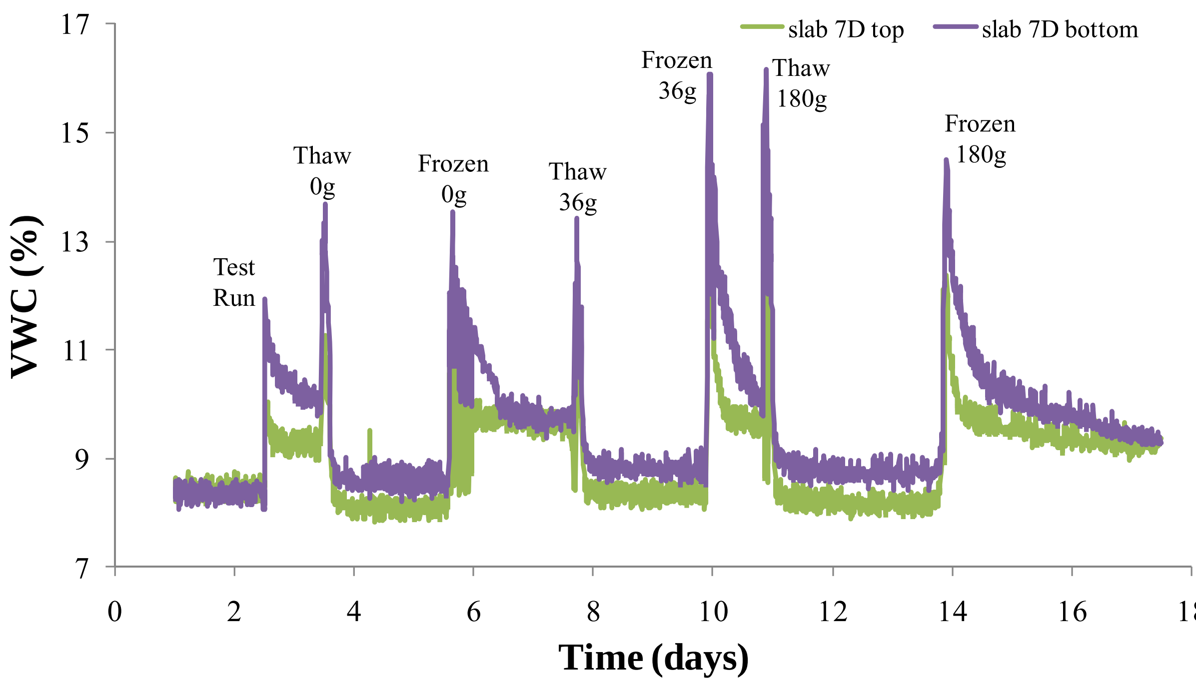


Figure 34. VWC of the 7D(HS) slab during each different experimental run. The weight in grams indicates the amount of sand applied to the slab prior to each test.

The residual VWC within the slab following drainage was typically comparable across the entire range of sand applications. It is anticipated that, under more extreme sand applications, the addition of sand particles onto the surface (and infiltration into the upper portion of the concrete) will cause additional water retention due to the sand particles reducing the average pore size within the concrete. This could have negative implications on the performance of the pervious concrete under extreme conditions (i.e. very clogged and frozen), as there is potential for the pervious concrete to suffer from reduced drainage efficiency.

Transportation of Salt. EC values of the brine solution recovered from the bottom of the CS slabs (denoted as 'C'), after having passed through the matrix of the pervious concrete, were compared to the EC of the initial brine solution (C_o) as applied to the surface of the slab. Results indicate that, under all conditions, EC measurements of the water collected from the bottom of the slab quickly (<10 minutes) reached the EC of the brine solution. In the thawed and frozen slabs only 50 to 200 ml of solution, respectively, was required to achieve $C/C_o = 0.5$ (median concentration). This is an order of magnitude less than the pore volume of this slab, so it is evident that the solute is bypassing most of the empty pore space and tracking in a preferred flow-path. It was delayed more in the frozen slab, as freezing may have blocked some of the preferential flow-paths. Even so, only a small portion of the total volume available for flow was being used. Note also that the thawed breakthrough curve (Figure 35a) exhibits greater dispersion (curve more spread out), as freezing may have increased the tortuosity of the flowpaths. A similar situation occurred with heavy sanding – a delay in breakthrough and greater dispersion (Figure 35b). It too, however, used only a small fraction of the available pore-space. This suggests a greater flow rate could be easily handled in this pavement under all sand loading and frozen/thawed conditions tested.

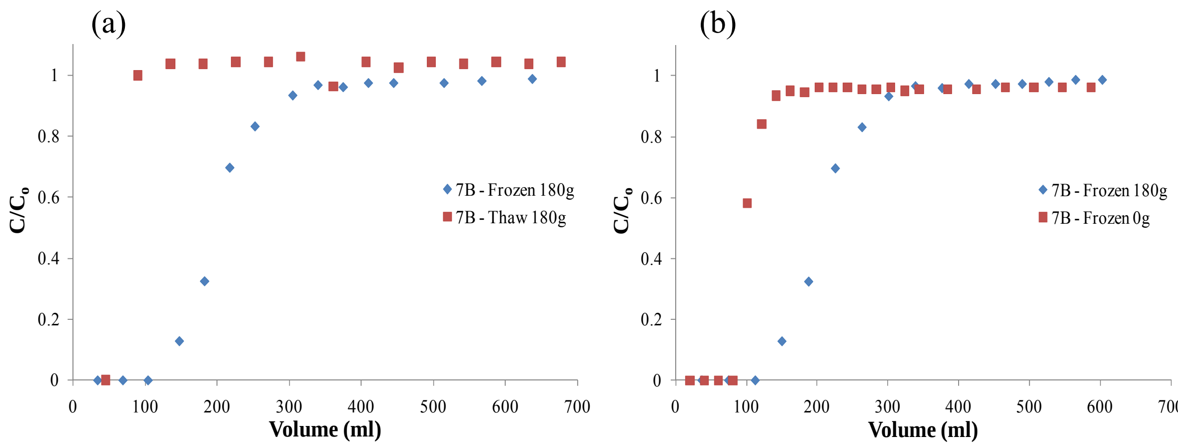


Figure 35. Breakthrough curves for EC values. 5a (left) illustrates the breakthrough curve for frozen and thawed conditions with 180g of sand; 5b (right) illustrates the breakthrough curve for 0 and 180g of sand under frozen conditions.

Sand Application and Water Movement._To determine the effect of sand application and frozen versus thawed conditions on water movement through the pervious concrete slabs, the timing of the initial water pulse was measured as it flowed through the slab, until the flow rate measured from the bottom of the slab reached a 'steady-state' flow rate. In this circumstance, 'steady-state' flow is considered to have been achieved when the water flowing out of the base of the block remains relatively constant over time. This should be equal to the rate of water application on the slab surface, which would, ideally, be consistent between tests. As mentioned previously, this was not always true. In these circumstances, an average steady-state flow rate was chosen carefully, based on the relative change in consecutive flow rates, where if three or more consecutive flow measurements (water flowing out of the base of the block) illustrated less than 5% change from the previous measurement, the system was said to be at steady-state flow conditions.

Table 20 indicates the time required for each slab to reach steady-state flow conditions under each independent experimental design. The time to reach steady-state flow conditions is related to the ability of the slab to transmit water, where longer times indicate slower movement of water through the slab. There were many inconsistencies in this dataset, which are likely due to a combination of measurement error and experimental design such as the inconsistent flow rates from the 'precipitation' simulator, as discussed above. This produced some contrasting results that cannot be easily explained. Notwithstanding, frozen conditions generally increased the length of time for the slab to reach steady-state flow, as water that was frozen in the pores of the concrete was likely impeding the movement of water through the slab. Similarly, sand application generally slowed the movement of water through the slab, as pores near the surface became slightly clogged. The presence of salt was expected to enhance water movement through the slab under frozen conditions, as a consequence of the reduced frozen water content within the CS slabs; however, the data does not support this hypothesis. These observations are reflected in the slope of the line relating the flow rate from the base of the slab to the time elapsed since the start of the experimental run (i.e. initiation of water flow onto the surface of the slab, Figure 36). A steeper slope indicates that steady-state flow conditions were reached more rapidly than a gentler slope, which would indicate that the movement of water is being impeded in the pervious matrix. In Figure 36, the steepest slope was observed for the experiment under thawed conditions and no sand application, with the slope becoming more gradual for each consecutive experimental run until the most gradual slope under frozen conditions with 180g of sand indicating the slowest movement of water through the slab under these conditions. The flow rate is expressed as a percent of the average flow rate for each experimental test independently, in an attempt to normalize for differences in flow rates between tests. Also, the trends illustrated in Figure 36 are not consistent among all of the slabs.

Table 20. Experimental treatments and the time required to reach steady state flow. Longer times indicate slower movement of water through the slab. Note: Thaw + 180g Sand slab CS (7A) was omitted due to inconsistencies in the data.

Treatment	Time Required to Reach Steady State Flow (min)			
	Salt Slabs		Water Slabs	
	CS (7A)	CS (7B)	HS (7C)	HS (7D)
Thaw + 0g Sand	4.00	5.24	14.08	71.32
Frozen + 0g Sand	6.00	10.00	50.00	4.00
Thaw + 36g Sand	9.00	7.00	14.00	10.50
Frozen + 36g Sand	7.00	17.00	8.00	8.00
Thaw + 180g Sand	****	11.00	15.00	6.00
Frozen + 180g Sand	9.00	13.00	22.32	30.55

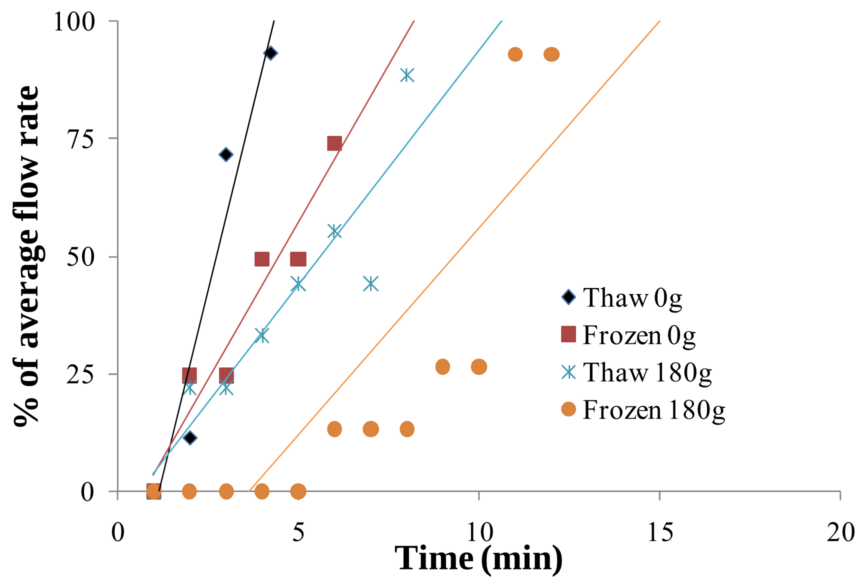


Figure 36. Average flow rate versus time for CS slab 7B, illustrating the variation in the time required to reach steady-state flow conditions as a consequence of sand application and freeze/thaw conditions. Flow rate is expressed as a percent of the average flow rate for each experimental test independently.

Summary and Conclusions.

1. In all experiments, the salt was transported through the pervious concrete very quickly. Slight dispersion of salt was observed in EC breakthrough curves; however, there is a strong potential for rapid flushing of salt through the highly permeable matrix of pervious concrete structures.
2. Dispersion increased slightly under frozen conditions and with increased sand application, due to the more tortuous flow paths.
3. The overall impact of sand application to the surface of pervious concrete is a reduction in the movement of water through the pores, causing a delay in the peak flow received at the base of the concrete. This impact is likely limited to the near-surface portion of the concrete, as the sand is unlikely to penetrate into the pore space at depth within the concrete.
4. The study demonstrated that sanding and freezing did not significantly impair the ability to transmit flow. Under extreme sand applications and frozen conditions, the drainage efficiency of the concrete is only modestly reduced. Our observations indicate that the infiltration capacity of the pervious concrete structures, as tested, exceeds the probable maximum water loading rate that will be encountered in Southern Ontario.
5. The future development, improvement and application of pervious pavement technologies as a stormwater management measure to reduce runoff have important implications for the Clean Water Act. The primary focus of the Ontario Clean Water Act is to reduce significant risks to drinking water by identifying vulnerable areas (wellhead protection areas, intake protection areas and highly vulnerable areas and developing plans to reduce significant risks to acceptable levels and prevent future significant risks. Chloride is listed as a potential threat to drinking water as indicated in Section 1.1 of Ontario Regulation 287/07. Implications of the Ontario Clean Water Act for road salt management include 1) Improved design and delivery of parking lot winter maintenance programs 2) Increased adoption of new technology 3) Improved delineation of salt vulnerable areas and refined winter maintenance procedures in intake protection zones (IPZs) 4) Increased level of training (certification) for road authorities and private contractors 5) Integration of salt management plans with source water protection committees (SPCs) objectives to delineate source waters, identify threats and develop and

implement SWP Plan and 6) Improved stormwater management practices. While pervious pavement technologies can effectively reduce runoff volume, they can negatively impact groundwater quality when either improperly located or poorly designed. To meet the future requirements of the Clean Water Act, better design guidance is required for the use of this material for parking lots located in salt vulnerable areas.

Objective 2 – Task 2c:
Compare chloride losses from parking lots using road salt and alternative deicers and evaluate parking lot management strategies for reducing salt use.

CLARKSON GO STATION STUDY

Introduction. In many regions of North America and Europe, the transfer of chloride from transportation corridors to the environment has been shown to adversely impact the quality of groundwater and surface waters (Hoffman et al., 1981: Wilcox, 1986; Goodwin et al., 2002: Marsalek, 2003; USGS, 2007). While the observed increase in surface and groundwater chloride concentrations are primarily attributed to runoff from roadways, there is an increasing awareness that the cumulative effect of runoff from parking lots in urban areas can also adversely impact the health of aquatic systems and the sustainability of groundwater resources (Meriano and Eyles, 2009). Few studies have been conducted and specifically designed to quantify chloride transfer to the environment in runoff from parking lots. To our knowledge, no studies have been conducted in Canada to determine whether there is a demonstrable difference in the mass of chloride transferred in storm drains to receiving waters from applications of alternative de-icing materials compared to standard maintenance practices using road salt.

The objective of this study was to measure and compare the chloride flux in runoff from two parking lots treated with different de-icing compounds (common road salt and a commercially available alternative de-icing material Mountain Organic Natural Icemelter) during the period October 2008 to April 2009. In this report, data are presented for a range of melt/precipitation events to illustrate differences in chloride transfer from two commuter parking lots as a function of the type of deicer used. Recommendations for improved parking lot design and winter maintenance are presented.

Methods.

Experimental Design. The quality and quantity of runoff was monitored from October 2008 to April 2009 at two Go Transit parking lots (GO 1 and GO 3) located in Mississauga, Ontario (Figure 37). The GO1 parking lot drains an area of 3,425 m^2 and was treated with Mountain Organic Natural Icemelter. Conversely, the GO 3 parking lot which drains an area of 20,058 m^2 was only treated with common road salt. Drainage outlets from each parking were instrumented to measure discharge and chloride concentrations continuously for a range of precipitation and melt events. The data were used to quantify and compare chloride fluxes (mg m^{-2} s^{-1}) and cumulative loads (kg m^{-2}) for individual events. The winter maintenance contractor estimated that on average, approximately 4 t of common road salt was typically applied (~0.2 kgm^{-2}) per event which is about 10 times the rate used on provincial roads. Depending upon weather conditions, it is estimated by the contractor that 2 to 24 (20 kg) bags of Mountain Organic Natural Icemelter (~0.01 to 0.14 kg m^2) were typically used per application. An accurate daily salt application rate was not provided by the contractor because on board computerized loggers for the spreader truck was not available.

Monitoring Instrumentation. Two Hobo Pro v2 temperature loggers were installed on site to record air temperature. Precipitation was measured with a winterized tipping bucket rain gauge located approximately 1 km north of the study site at the Clarkson Community Center, Mississauga. A compound weir (Figure 38) was installed in the storm drains of each parking lot and water level change was recorded continuously with a pressure transducer. An ISCO 2150 flow logger was installed to record water level height and a rating curve was developed to estimate discharge (Ls^{-1}). The weirs were inspected monthly to minimize water loss around the seal and flow loggers were calibrated every 2 weeks.

During melt or precipitation induced runoff events, water samples were collected in the storm drains with ISCO 6712 Auto-samplers. For each event, the ISCO samplers were programmed to collect water based on time intervals related to the intensity and duration of the precipitation/melt event. Most melt/precipitation events were between 12 to 24 hours long but some sample periods were < 6 hours. For a 6 hour event, water samples were collected every 15 minutes but samples were collected every 30 minutes for events with a duration of 6 to 12 hours. For large events (> 16 hour), samples were collected every 45 minutes and for the largest events (≥ 24 hour) samples were collected every hour. Chloride concentrations were determined with a

Technicon Autoanalyzer using standard method 4500-Cl-E (Eaton et al. eds., 1995) at the University of Waterloo.

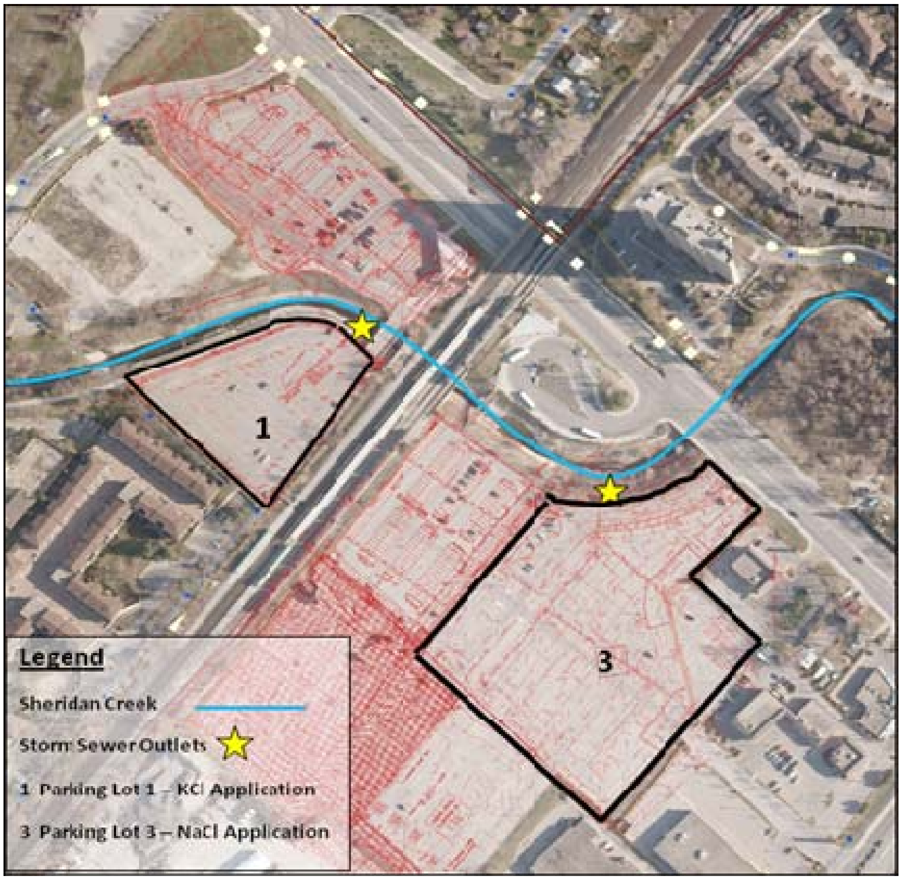


Figure 37. Location of parking lot and storm water outlets

Figure 38. Compound Weir Installed

Results and Discussion. Temporal variation in temperature, precipitation, chloride concentrations and chloride loads in runoff from the two parking lots (GO1 and GO 3) for the period of record (October 2008 to April 2009) are presented in Figure 39. The mean, maximum and minimum chloride concentrations (mg L^{-1}) and total loads (g m^{-2}) for 26 sampled runoff events are presented in Table 21. The amount and type of precipitation (snow, rainfall and a mix of snow and rain) measured during the study varied considerably which strongly influenced the timing, rate and magnitude of runoff from the parking lots which subsequently influenced the deicer demand.

The hydrologic response from both parking lots was flashy and tightly coupled with the type and amount of precipitation inputs as well as the specific processes that induced the melt (i.e. chemical melt versus temperature induced melt). The maximum discharge was 50 Ls^{-1} and 82 Ls^{-1} for the GO1 and GO 3 parking lots, respectively. The event mean chloride concentration for the 26 monitored events was 14,561 mg L^{-1} and 6,816 mg L^{-1} for the GO 1 and GO 3 parking lots, respectively. However, average chloride loads (g m^{-2}) were higher by a factor of 2.3 for GO 1 (46 gm^{-2}) compared to GO 3 (20 gm^{-2}).

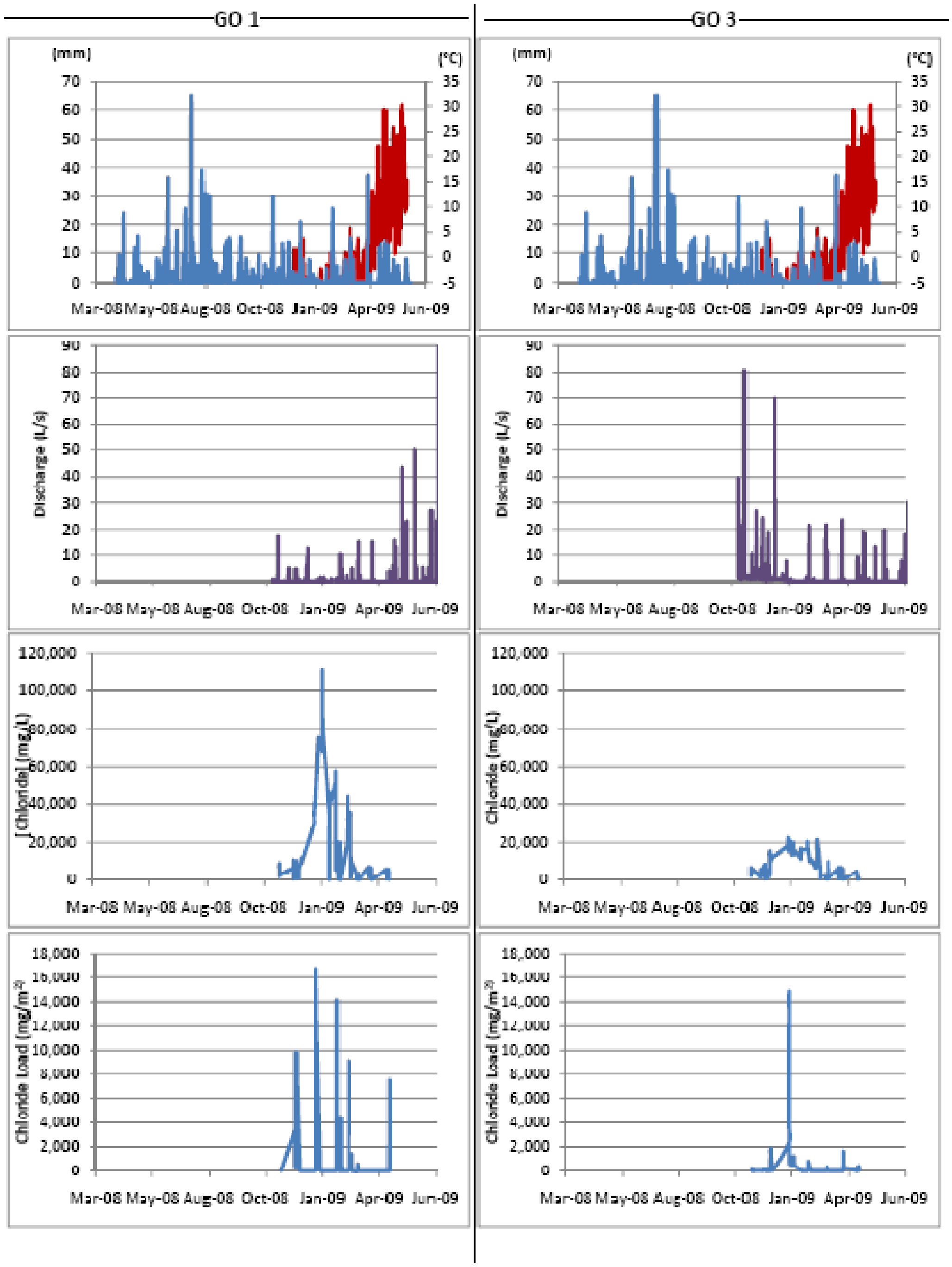


Figure 39. Temporal variation in temperature, precipitation, chloride concentrations and chloride loads in runoff from the two parking lots (GO1 left column and GO 3 right column) for the period of record (October 2008 to April 2009).

Table 21. Summary of precipitation (type and amount) and chloride concentrations and loads in the GO 1 and GO 3 parking lots

Date	Precipitation Type	Precip (mm)		Temp (°C)		GO 1				GO 3			
		Rain	Snow	Max	Min	Mean (mg/L)	Max (mg/L)	Min (mg/L)	Total Load (g/m^2)	Mean (mg/L)	Max (mg/L)	Min (mg/L)	Total Load (g/m^2)
11-Nov-08	Rainfall	3.2											
13-Nov-08	Rainfall	8.4											
14-Nov-08	Rainfall	28.6											
20-Nov-08	Snow		50			4326	9032	1709		5821	6634	1914	1.74
4-Dec-08	Rainfall/Snow	1.2	<50							2649	5522	1293	0.04
9-Dec-08	Snow	0.2	<50										
10-Dec-08	Rainfall	19.4				3135	10553	375	56.19	2279	8279	351	0.83
15-Dec-08	Rainfall	4.2				2118	5278	741		2499	5058	1113	1.99
16-Dec-08	Rainfall/Snow	2.6	10							6258	15371	2270	13.86
20-Dec-08	Snow		15	-5.4	-16.0	11840	13145	10707		4215	4939	3780	
7-Jan-09	Rain/Snow		3	2.0	-1.7	36549	41004	29666	58.03				
13-Jan-09	Snow		6	2.2	-15.1	72684	74880	70488		18089	22403	15444	126.18
18-Jan-09	Snow		10	-1.6	-8.0	84351	111175	68075		15920	20233	13073	14.94
29-Jan-09	Snow		15	-2.8	-10.2	35021	46378	21947		13021	17101	10960	
7-Feb-09	Light Rain	1		10.8	-9.9	21052	57562	4968	65.55	17663	20407	15613	1.59
11-Feb-09	Light Rain			9.1	4.1	5295	19894	561	11.14	10392	11392	9900	
18-Feb-09	Rain	12.9		1.9	-1.2					7378	9262	6558	0.01
21-Feb-09	Snow		5	0.1	-9.0	24514	44153	16973	21.84				
26-Feb-09	Heavy Rain/Snow	10	8	9.3	1.2	10905	35984	1048	4.24				
7-Mar-09	Rain	12		4.7	-1.9	554	2298	209	3.56	910	2858	319	2.27
10-Mar-09	Rain	10		3.1	0.6	892	3213	56		1705	9807	485	0.17
24-Mar-09	Dry for 7 days			3.6	-5.7	6678	7216	4128		5481	6936	552	
25-Mar-09	Rain	10		7.2	1.0	4328	7117	1155		5614	5999	4625	
29-Mar-09	Rain			11.2	4.1	3640	6417	63		3514	6067	261	6.68
18-Apr-09	Dry for 7 days			22.2	6.1	5209	5532	4985					
20-Apr-09	Rain	26.8		6.4	4.0	1462	5250	158	27.65				3.85
TOTAL									248.21				174.15

To illustrate the influence of deicer type on chloride transfer from parking lots, the fluxes and total cumulative chloride loads measured during four specific runoff events are presented in Figure 40. The data demonstrate that chloride fluxes ($mgm^{-2}s^{-1}$) and total cumulative loads (gm^{-2}) were demonstrably higher for the GO 1 parking lot. Possible reasons for the increased loss of chloride to Sheridan Creek from this parking lot are 1) a demonstrably larger mass of deicer was generally applied per unit area to GO 1 than to the GO 3 parking lot, 2) there may be additional subsurface inputs of chloride to the GO 1 storm drain from groundwater (however, because the GO 1 storm drain only experienced flow during runoff periods, it is unlikely that groundwater was a significant additional source of chloride to the storm drain), or 3) more chloride is stored in the GO 1 storm drains from the legacy of historical salt application to this lot. According to the contractor, rock salt was applied 9 times to the GO 1 lot to January 17, 2009. Because daily records of salt application rates were not available, the study team was unable to determine whether the total amounts of chloride in the deicer applied to the parking lots per unit area were significantly different. Gaps in data regarding daily mass of deicer applied is being addressed in a subsequent 2010 study

Conclusions. The study illustrates that parking lot runoff is a significant source of chloride to the environment. The data clearly show that chloride losses from a parking lot treated with Mountain Organic Natural Icemelter were demonstrably higher than for a parking lot treated with road salt. More systematic study of the effectiveness (road safety) and associated environmental impacts of road salt and a range of alternative deicers is required to provide contractors with appropriate guidelines for optimal application rates and related spreading technology. Such information coupled with enhanced training, improved technology for salt application, better record keeping and reporting protocols as well as possible certification of contractors would lead to significant reductions in the transfer of chloride to the environment from parking lots.

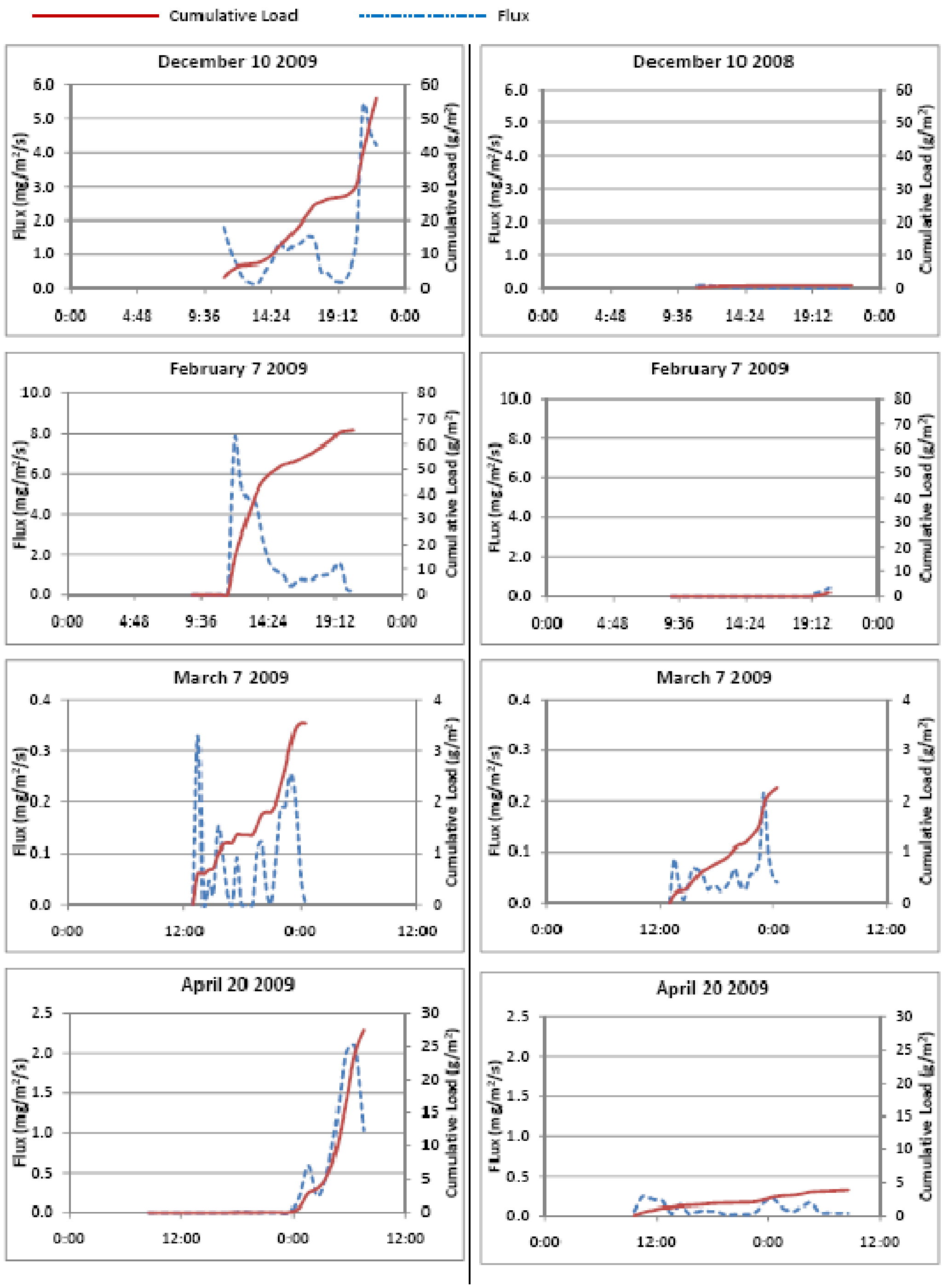


Figure 40. Fluxes and total cumulative chloride loads measured during four runoff events in 2009 (GO 1 left column and GO 3 right column).

PARKING LOT MANAGEMENT – SMART ABOUT SALT PROGRAM

Introduction. Many years of winter road maintenance experience and related research activities have resulted in the development of a range of safety standards for the application of deicers (sand road salt and other products) to Ontario roadways. The standards are flexible and depend upon weather conditions and related variables such as temperature, storm severity, length of storm, existing road conditions, type of deicer, type of road and equipment used. While such standards are available for roadways (Ontario Ministry of Transportation, 2008), no guidelines are currently available for winter maintenance of parking lots or sidewalks. Accordingly, private contractors (who predominantly manage parking lots) must rely on experience to apply deicers at sufficient rates while considering all aspects of business risk and liability. The Salt Institute estimates that North American contractors apply ~ 6 million t of salt per year. Recognizing the need to better understand salt application practices on parking lots and that salt reduction through improved best management practices is desirable and achievable, it is necessary to consider strategies that continue to encourage salt reduction (by promoting proactive strategies and best management practices to reduce icing conditions), reduce liability (through improved salt management, better record keeping and inspection procedures) and promote better design of parking lots and related infrastructure (i.e. storm drainage from buildings).

The Region of Waterloo is one of the largest Canadian municipalities to rely on groundwater as the primary source of drinking water. Over the past 30 years, monitoring studies of municipal supply wells show that chloride concentrations have risen above the Ontario Drinking Water Standard specifically for 15 municipal water supply wells and chloride concentrations over his time have been steadily increasing for the remaining 112 municipal wells. The source of the chlorides has been attributed primarily to winter applications of road salt and road salt represents approximately 90% of all salt applications. Because of its dependence on groundwater sources for drinking water supplies, the Regional Municipality of Waterloo proactively employed a range of technologies and winter maintenance procedures to mitigate salt transfer to the environment. As part of its Strategic Focus 2004-2006, the Regional Municipality of Waterloo expressed its intention to reduce road salt use by 10% overall and by 25% in wellhead protection (salt vulnerable areas) by 2006 and the 2007-2010 Strategic Focus has continued to strategically promote and implement BMPs to reduce the transfer of chloride to the environment.

While continuing to meet road condition targets and safety obligations (Region of Waterloo et al., 2002), several winter maintenance best management practices were implemented by road authorities in the Region of Waterloo to enable salt reduction (Figure 41). However, given the significance of salt impacts on municipal water sources, the Region of Waterloo began to look beyond the road sector for additional opportunities and strategies to reduce the overall impact of salt on drinking water supplies. In particular, the recognition of parking lots as an important potential source of chloride and the need to better manage these areas, represented an additional opportunity for the Region to manage salt transfer in to the environment, particularly in salt vulnerable (groundwater recharge) zones. To the study team's knowledge, there has been no systematic study of deicer requirements for parking lots, there are no data driven parking lot guidelines and no comprehensive training programs exist in Canada for contractors who provide winter maintenance for urban parking lots. While there are a few examples of guidance documents for salt management of parking lots such as those described by the Minnesota Pollution Control Agency http://www.pca.state.mn.us/programs/roadsalt.html), as well as the Snow and Ice Management Association which offers comprehensive training to Canadian and US members; they are premised on standard salt application rates for roadways which arguably are fundamentally different to manage.

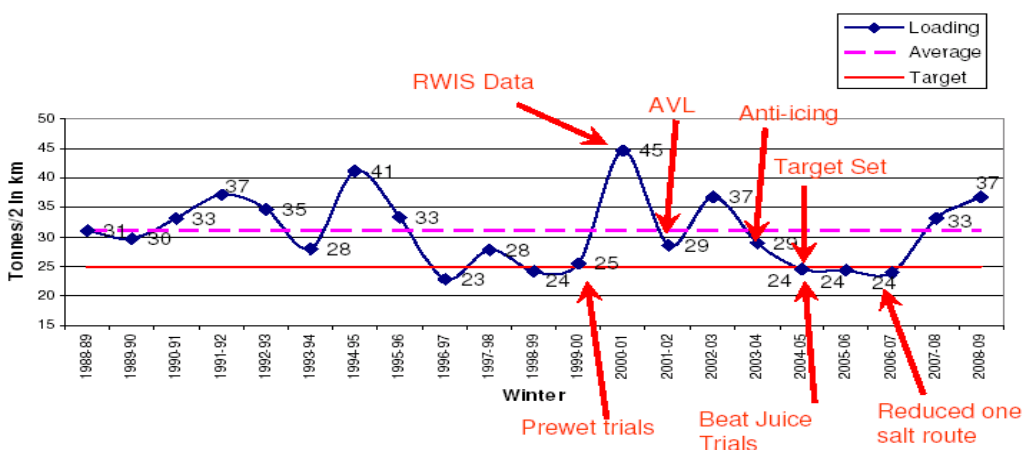


Figure 41. Historical salt loading data for the Region of Waterloo and the year when various treatment technologies and procedures to mitigate salt transfer to the environment were applied.

Implications of poor winter maintenance practice and parking lot design for salt management. The excessive addition of deicers to parking lots is related to a variety of factors that include the lack of winter maintenance guidelines/regulations for parking lots, the lack of training programs for contactors, the use of poorly designed equipment for salt application as well as improperly designed parking lots and related stormwater infrastructure. Salt application rates are also influenced by the expectations of property owners for bare pavement and the lack of understanding of how deicers function. Many contractors feel pressured by property owners to apply deicers when conditions do not warrant further application. During freeze thaw cycles typically experienced in the winter months across Canada, improperly situated drain pipes create conditions that increase rather than reduce the application of deicers (Figure 42).

Figure 42. Improperly designed drainage from entrance to nursing home.
(Photograph by Bob Hodgins)

Lot grading and its relationship to snow storage and subsequent runoff represent a second challenge for salt management of parking lots. During periods when the temperature rises above 0°C, melt water from snow piles (Figure 43) can refreeze and flow out onto the parking lot thus requiring additional salt application when temperatures fall to below freezing. Properly designed parking lots with appropriate winter maintenance and snow storage practices typically avoid this problem (Figure 44).

Figure 43. Location of snow storage related to excessive salt application
(Photograph by Bob Hodgins)

Figure 44. Good example of snow storage (Photograph by Bob Hodgins)

The surface condition of parking lots can influence the rates and magnitude of chloride discharge to the environment. Cracked pavement and potholes in parking lots (Figure 45) increase the risk of water ponding and/or infiltrating into the shallow subsurface zone where dissolution products of deicers can migrate to groundwater (Sarwar et al, 2002).

Figure 45. Poor condition of pavement promotes loss of chloride by infiltration to the subsurface. (Photograph by Bob Hodgins)

Smart About Salt Program. In 2004, the Region of Waterloo contracted Bob Hodgins formerly of Ecoplans to develop and launch the Smart About Salt (SAS) Program. This novel program incorporates a multi-faceted approach to optimize salt use on both public and private properties by 1) working collaboratively with transportation operations staff from the municipality 2) developing guidelines and site plan design recommendations to minimize the need for de-icing on new developments 3) building public awareness through education programs and 4) implementing the *Smart About Salt* accreditation program for private snow contractors and their clients to recognize and incorporate beneficial salt management practices on parking lots and sidewalks.

The *Smart About Salt* accreditation program was adopted locally by the Region of Waterloo as a voluntary accreditation program for snow and ice contractors as well as owners and managers of outdoor parking facilities but it has potential to be considered as a model of environmental stewardship for broader application. The program is designed to optimize the use of deicing chemicals by private contractors while achieving safe levels of service on parking lots and sidewalks. To become accredited, companies are required to submit an application demonstrating that employees have 1) successfully completed salt management training 2) implemented industry best management practices 3) maintained records of deicing activities and inspection procedures and 4) taken steps to eliminate on-site sources of ice. In order to maintain accreditation, an annual renewal form must be submitted, verified and approved, to demonstrate on-going compliance and continuous improvement. All accredited contractors and sites are subject to a random audit to verify compliance.

Program Achievements. Since its official launch in January 2008, the *Smart About Salt* program has made some significant achievements and developed local, provincial and national partnerships. These achievements and partnerships include:

- The accreditation of 16 contractors and 3 facilities with an additional 40 contractors and 25 facilities registered in the program;
- Several Region of Waterloo sites are to be accredited and have moved from a tender to a Request for Proposal process to hire contractors that are S*mart About Salt* registered;
- Non-profit corporations (Landscape Ontario and the Ottawa chapter of Building Owners and Managers Association) endorse and promote the program to their membership. ;

- The program has been approved and promoted by Lombard Canada, an insurance company that specializes in underwriting the snow and ice industry. This company has committed to providing a minimum 5% insurance premium reduction to *Smart About Salt* accredited snow contractors providing the program can be delivered province-wide. There is some evidence to suggest that certification of contractors and improved record keeping practices will likely reduce liability and insurance costs. Lombard Canada provided valuable input into the development of the program. Communication with contractors revealed a reluctance to implement salt reduction practices for fear of increased liability. Lombard's input has allowed the program to address those fears; thereby, removing one of the major barriers to implementation of the program.
- Canada Green Building Council and Building Owners and Managers Association ("BOMA") are considering including *Smart About Salt* accreditation in their respective building certification systems – "*LEED Canada for Existing Buildings: Operations and Maintenance*" and "*BOMA BEST*" *respectively* – which currently do not address winter maintenance practices and
- The *Smart About Salt* program has been profiled in trade magazines: Milestones (provincial), Landscape Trades (national) and Parker (national) as well as at national and international conferences and symposiums.

Smart About Salt Council. A special purpose not-for-profit corporation, *Smart About Salt Council* (SASC), is currently being developed by the Region of Waterloo in partnership with Landscape Ontario and Building Owners and Managers Association-Ottawa. This council is responsible for administration, delivery and on-going development of the program and is managed by an Executive Director who reports to the Board of Directors, with one representative from each of the three founding contributors to the SASC; namely the Region of Waterloo, Landscape Ontario and the Ottawa chapter of BOMA.

The Region of Waterloo has agreed to promote the program locally, monitor and assess the extent of local implementation and occasionally provide financial contributions as per the Region's financial/purchasing by-laws for projects and studies needed to improve the program. Region staff will also investigate the merits of developing financial incentives to local contractors and facility owners to encourage local implementation. The *Smart About Salt* program, including all print and electronic materials, trademarks, intellectual property and licenses developed by the Region has been transferred to the SASC with conditions that allow the Region to continue to promote the program locally and continued local use of the logo.

Summary. The rates and magnitude of chloride discharge from parking lots to the environment is related to a variety of factors that include the lack of winter maintenance guidelines/regulations for parking lots, the lack of training programs for contactors, the use of poorly designed equipment for salt application as well as improperly designed parking lots and related stormwater infrastructure. Salt application rates are also influenced by the expectations of property owners for bare pavement and the lack of understanding of how deicers function. In some cases, contractors feel pressured by property owners to apply deicers when conditions do not warrant further application. During freeze thaw cycles typically experienced in the winter months across Canada, improperly situated drain pipes create conditions that increase rather than reduce the application of deicers. Accordingly, there is a critical need to train and certify private contractors and to develop appropriate winter maintenance guidelines and practices for parking lots. The *Smart About Salt* Program is an example of a locally adopted management model designed to optimize salt application by private contractors while achieving safe levels of service on parking lots and sidewalks. The program is based on developing partnerships and educational programs that promote environmental leadership and has potential for broader application in other jurisdictions. Such programs if implemented widely would optimize salt application and reduce winter maintenance costs in parking lots thus minimizing chloride discharge to the environment. There is some evidence to suggest that certification of contractors and improved record keeping practices can reduce liability and insurance costs.

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5. Snow Storage and Disposal (TAC 8)

Objective 2 – Task 2f:
Evaluate the design, operation, and maintenance of snow storage and disposal facilities (SSDFs).

SNOW STORAGE DISPOSAL FACILITIES (SSDFS) AND THEIR ROLE IN URBAN SNOW AND ROAD SALT MANAGEMENT: A REVIEW OF LITERATURE RELATED TO GUIDANCE FOR DESIGN, OPERATION, AND MAINTENANCE

Introduction. Winter road and street maintenance practices in urban areas include a number of operations designed to maintain safe and relatively uninterrupted transportation during the winter months. In current practice, this process starts with anti-icing of pavements in anticipation of snowfall (a practice that inhibits the bonding of snow and ice to pavement) and continues with plowing of the snow to the sides of roads and streets or adjacent snow storage areas and application of deicing and anti-skid materials. Application of these procedures leads to bare pavement which is the stipulated level of service in the winter road maintenance policies of many communities for certain types of roads. As snow accumulates and the space for storing snow on streets fills up, safety (non-obstructing visibility) and operational considerations dictate the need for snow removal and disposal. While there are some local removal/disposal options to be considered, including in-situ melting or disposal into sewers, the earlier practice of snow dumping into open waters is no longer allowed in most jurisdictions (e.g., Environnement et Faune du Québec, 1996) and the common practice consists of hauling snow away to specially designed snow storage and disposal facilities (SSDFs).

Snow hauling to SSDFs can represent a large and operationally formidable task involving removal of hundreds of thousands of tonnes of snow from central urban areas as well as more widely dispersed suburban areas to disposal locations. Due to the magnitude of this task, snow removal does not happen immediately after fresh snowfall plowing. Instead, snow is typically removed after several days and is referred to as “used” snow which has very different physical and chemical properties than fresh snow (e.g., Viklander, 1996; Viklander, 1997; Oberts et al., 2000). Firstly, used snow has been mechanically processed by plowing (removal) to the street side, which generally involves compaction and increase in density and water content. In fact, while fresh snow has a water equivalent of < 0.10, the water equivalent of used snow at SSDFs is typically 0.60 or higher (Semadeni-Davies, 1999; Wheaton and Rice, 2003).

Snow stored on streets and roads accumulates various materials and chemicals. The former category includes sand and grit used in road maintenance, urban litter and possibly other materials related to road/land use activities (e.g., road structure materials detached from the pavement or other structures). The latter category includes chemicals originating from atmospheric deposition, road salting, traffic byproducts, and byproducts of other land use activities (e.g., heating and industrial activity). Contaminants typically measured in used snow include salts, salt additives (e.g., ferrocyanides), heavy metals (particularly Cd, Cr, Cu, Ni, Pb and Zn), oil, grease or total petroleum hydrocarbons (TPH), nutrients, bacteria and some trace organic chemicals (polycyclic aromatic hydrocarbons, PAHs, pesticides and PCBs) (Novotny et al., 1999; Oberts et al., 2000; Pierstorff and Bishop, 1980; Scott, 1980). Both solids and a range of contaminants accumulate in snow and may be moved during snow clearance activities to the roadside and snow storage space, or be hauled away with used snow (Oberts et al., 2000).

Materials and chemicals in snow can be eluted during snowmelt due to either chemical snowmelt or by warm air temperatures and heat release from urban structures (e.g., buildings) or land use processes (e.g., heat generated by traffic). Natural thermal melt of snow is further accelerated by reduced albedo, or reflectivity, of urban snow due to deposition of particulate matter on snow which often forms a dark crust on the snow surface as the snow melts. The elution process in snow storage piles (either on street sides or at the storage site) is further affected by repeated freeze-thaw cycles during which snow crystallizes and changes its physical structure (Colbeck, 1981). Snow crystallization expels impurities from ice crystals and causes them to accumulate in the space between crystals, thus making them more readily transportable in meltwater which ultimately affects the dynamics of chemical elution.

There is a significant body of literature regarding processes that govern the rates and magnitudes of snowmelt in natural environments. However, much less is known about the physical and chemical behavior of disturbed urban snow piles. Field observations do indicate that soluble chemicals, such as road salts, are eluted early from snow piles. Consequently, elevated concentrations of chloride (i.e., compared to the average concentration in the snow pile) are observed during the early phase of snowmelt. A disproportionately large amount of dissolved chemicals may leave the pile early during the melting process. Dissolved constituents are also separated over time as they fractionate within the melting snow pile. This preferential elution is caused by the earlier described expulsion of impurities from ice crystals and their availability for a quick washoff with the snowmelt wet front that propagates downward though the deposit. Some ions are excluded from ice crystals more efficiently than others and therefore can be released earlier from a melting snow pile. Westerstrom (1995) described the release of ions in snowmelt from an urban lysimeter in the following order sulfate > chloride > nitrate. A similar observation was reported by Viklander (1997) for laboratory lysimeters.

Elevated chloride concentrations in meltwater can exceed the average concentration in the snow pile by more than 5 to 7 times because of preferential elution. Thus, it can be expected that a high proportion of road salt applied in urban areas either stays on the pavement and is removed with solute transport as soon as the chemical melt starts or that salt elution will take place in snow piles on road/street sides. Consequently, when snow is collected from urban surfaces and removed to storage sites, much of the chloride load applied to snow has already been removed from the snow in runoff to receiving waters. Salt may also be lost from the road before plowing and snow collection by traffic spray to the roadside environment.

In the snowpack, solids (encompassing a broad range of sizes, from clay and silt to sand and gravel, and a broad range of materials – anti-skid materials of mineral origin, asphalt detached from road surfaces, litter, etc.) behave differently than dissolved materials. As a general rule, solids remain snow piles until they are almost entirely melted. Depending upon the particle size distribution of solids in the snow pile, particulate matter can be transported during snowmelt induced runoff or remain on site (Droste and Johnston, 1993).

When snow is transported from urban areas to snow storage sites, it contains a range of particulate and dissolved constituents that can potentially be released into the environment during snowmelt. There are many environmental concerns about snow removal, transport, storage and snowmelt and potential impacts of these processes on the environment, including road salt releases. Consequently, various jurisdictions have developed guidance documents for the design of snow storage and disposal sites. Potential impacts of snow removal and storage are addressed in this section, which focuses specifically on 1) the basic characteristics of operation of SSDFs, 2) how such knowledge is used for developing guidance for planning, design and operation of SSDFs and 3) what is the potential role of SSDFs in the context of road salt management.

Operation of Snow Storage and Disposal Facilities (SSDFs). Principles of operation of SSDFs are discussed in this section, starting with the quantity and quality of used snow, processes governing snow melt and contaminant release as well as the impacts of such releases on the environment and their implications for melt water management.

Snow mass input to SSDFs. In Ontario, large masses of used snow are typically transported to SSDFs. Some limited anecdotal data from Montreal, Ottawa, Richmond Hill and Winnipeg indicate that the annual volume of snow stored in SSDFs is 400,000 (out of 9,000,000 m^3 removed), 1,500,000, 10,000 and 400,000 m^3, respectively. The corresponding water volumes can be estimated by multiplying snow volume by the water equivalent of 0.6 (Semadeni-Davies, 1999; Wheaton and Rice, 2003). The volume of snow removed over time is a function of several variables including total annual snowfall but also the physical and chemical characteristics of the snow pile. The City of Winnipeg reports that 359,000 and 119,000 m^3 of snow were removed during 2004 and 2006, respectively, even though the annual snowfalls were quite similar: 1490 and 1520 mm (City of Winnipeg, 2009).

Typically snow mass input to the storage site is estimated by the number of truck loads multiplied by the load volume and the assumed water equivalent. The snow input mass is of interest for assessing the site performance and suitability because this mass may be multiplied by concentrations of various contaminants in snow (obtained by snow sampling) to provide an estimate of the contaminant mass at the site. Such estimates can be used as a check when undertaking mass balance assessments for water flows and contaminant fluxes.

Used snow quality. There is a paucity of published literature on the physical and characteristics of used urban snow. Although these data are of general interest and do provide a basis for SSDF design and operation, they are often poorly documented with respect to snow age (i.e., accumulation of contaminants, or depletion of contaminants by earlier elution), mechanical processing (compaction) and variation in water equivalent. Snow quality data reported by Oberts et al. (2000) for specific land uses and data from a related study is presented in Table 22. Data from a more recent study in Richmond Hill, ON are shown in Figure 46 (Exall et al., 2009).

Table 22. Mean concentrations of water quality constituents in urban snow piles summarized from Novotny et al. (1999) and Oberts et al. (2000)

Water quality constituent	***Residential land use***	***Commercial land use***	***Industrial land use (2 sites)***	***Seven other studies[a]***
TSS [mg/L]	185 - 352	231 - 595	387 – 3,199	3 – 3,100
Total solids [mg/L]	<2,000 – 7,000[b]	494 – 23,800[b]	48 – 630[b]	4,950 – 6,945
COD [mg/L]	49 - 130	114 - 627	75 – 591	22 – 1,049
BOD5 [mg/L]	---	---	---	7.5 - 18
TP [mg/L]	0.24 - 0.52	0.58 - 1.04	0.38 - 1.97	---
TKN [mg/L]	1.36 - 3.0	1.0 - 6.5	1.2 - 6.6	---
NO_2+NO_3 [mg/L]	0.25 - 1.0	0.37 - 1.3	0.25 - 1.1	0.07 - 5.2
Chloride [mg/L]	---	---	---	1 - 12,005
TCd [μg/L]	---	---	---	1 - 270
TCu [μg/L]	3 - 54	81 - 225	89 – 135	1 - 510
Sol. Cu [μg/L]	<1 - 10	3 - 13.4	3.1	---
TPb [μg/L]	50 - 103	134 - 293	46 – 213	---
Sol. Pb [μg/L]	ND - 22	ND - 77	ND <20	---
TZn [μg/L]	213 - 651	332 - 771	186 – 777	---
Sol. Zn [μg/L]	5 -319	9 - 47	5 – 25	---
pH	---	---	---	5.1 - 9.2
Cyanide [μg/L]	9-345[b]	49-270[b]	2-18[b]	---

[a]Studies conducted in Canada, Sweden and US

[b]Range (rather than mean)

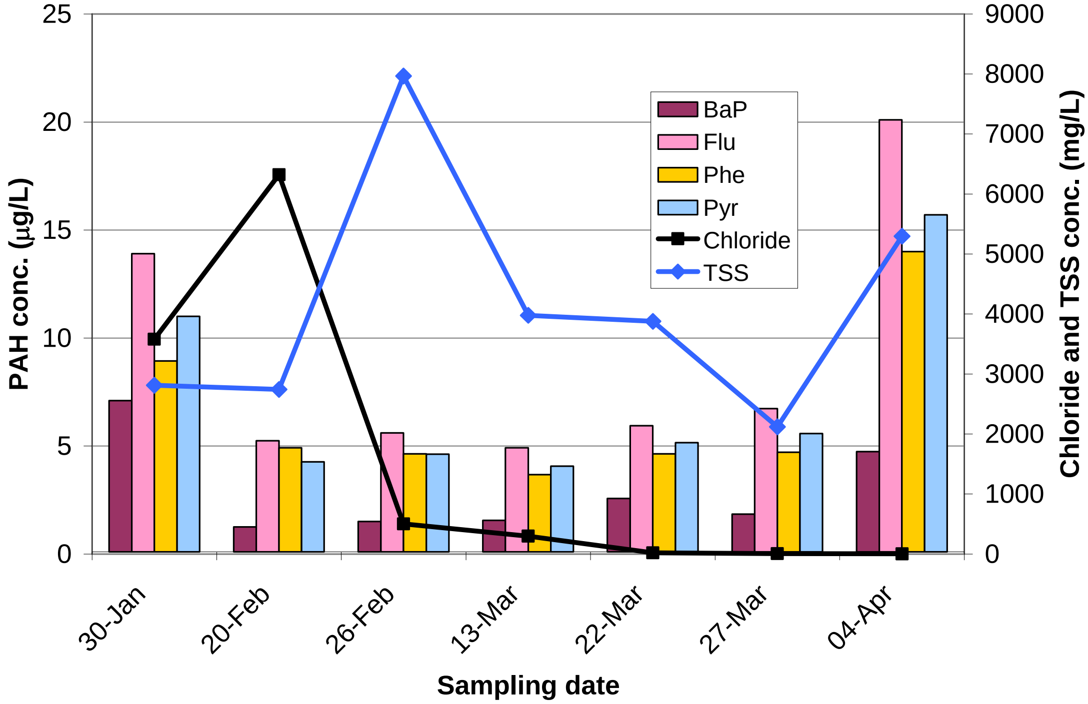

Figure 46. Concentrations of selected chemicals in snow pile samples (Richmond Hill, Ontario; source: Exall et al., 2009)

Urban snow piles are typically non-homogeneous media. Therefore, collection of representative samples to estimate total contaminant concentrations is rather difficult. However, careful snow pile sampling can provide a good estimate of pollution potential. The data in Table 22 and Figure 46 indicate the potential environmental hazard of contaminant transfer (depending on the release mechanism) with respect to chloride, cyanide (a road salt additive) and trace metals (Cu, Cd, and Zn) contributions of high loads of total solids and COD and significant loads of nutrients (various forms of P and N). Accordingly, the degree of environmental risks is strongly affected by the contaminant release mechanism, potential dilution during snowmelt and further dilution by stormwater runoff and treatment or dilution in the snowmelt treatment train.

Snow pile melting – water quantity processes. Wheaton and Rice (2003) distinguish three phases of the snowmelt process: ripening, middle melt and final melt. Ripening represents the initial phase when snowmelt starts by internal changes within the snow pile. Wheaton and Rice (2003) measured water equivalents in a SSDF located in Anchorage Alaska. They reported that water equivalents ranged from 0.6 to 0.72 and the median value was 0.60. Semadeni-Davies (1999) studied a broad range of snow piles in various urban area locations (residential suburbs, industrial areas, and downtown areas) and reported water equivalents ranging from 0.25 to 0.70. Accordingly, the actual values will depend greatly on factors such as snow processing during plowing and removal, snow age, weather conditions preceding and during snow collection, and how much ripening has already taken place on the road/street surface.

As snow piles begin to melt, meltwater typically moves downward through the snow deposit with very little perching or lateral movement. During this period, a dark crust of particulate matter can form on the pile surface. This can reduce the albedo and further accelerates snowmelt. Meltwater infiltrating into the bottom part of the pile can refreeze and form a thick ice layer at the base of the pile. Wheaton and Rice (2003) refer to this layer as the basal ice layer and noted that in Anchorage, the thickness of this layer was approximately 0.5 m. The basal ice layer maintains a relatively constant thickness and generally approximates the shape of the melt pad base.

The 'middle melt' phase represents a process where meltwater starts to emerge from the snow pile as visible flow. This flow may take two forms; mostly as an integrated flow along the basal ice surface but also as flow through conduits forming in the ice layer. On flat melting pads, discharge forms as a continuous seepage along the top surface of the basal ice layer and exits from the pile around the perimeter. Little or no flow occurs under the basal ice. By the end of the middle phase, flows are usually at their peak around 10 to 30 Ls^{-1}. During this phase, the snow pile shrinks vertically over its entire area. Wheaton and Rice (2003) reported that flow from a V-swale melt pad was concentrated and exited at a single point.

During the final melt phase, snow piles disintegrate and the basal ice layer becomes exposed locally. At this point, the direction of flow is no longer controlled by snowmelt processes but by the geometry of the melting pad. Careful melting pad design can concentrate flow to a single point thus avoiding flow over contaminated residues while at the same time allowing intentional direction of the flow to release or treatment points as needed. Other changes in the snow pile indicate collapse of the top snow layer onto the basal ice layer. Eventually the snow pile disintegrates into smaller patches and the pad surface becomes exposed.

Snow pile melting – water quality processes. Pollutant transport at SSDFs comprises three processes: elution of pollutants from the pile, snowmelt infiltration into the ground (where base conditions permit) and surface runoff from the site into receiving waters. Elution from snow piles described in the literature as freeze exclusion or preferential elution describes the phenomenon of pollutant exclusion from crystallized snow by freeze-thaw cycles and the flushing of such pollutants by the meltwater wetting front. Preferential (or early) elution applies to soluble chemicals (including chloride). In the case of pollutants attached to particulates, removal from the snow pile or pack is delayed and occurs during the final melt, if critical shear of the flows are sufficient to transport particulates. During preferential elution, concentrations of dissolved ions greatly exceed the average concentrations in bulk snow. This is usually described by the enrichment or concentration factor (CF) which can range from 2 to 17 (Westerstrom, 1995). In a study of a 200 m^2 paved parking lot, Westerstrom (1995) reported a maximum CF factor of 6 which decreased to 0.8 of the average concentration after about 30% of water was removed. Similar findings were confirmed by Viklander (1997) in a laboratory lysimeter and reported as a graph of the cumulative chloride flux vs. cumulative snowmelt (Figure 47).

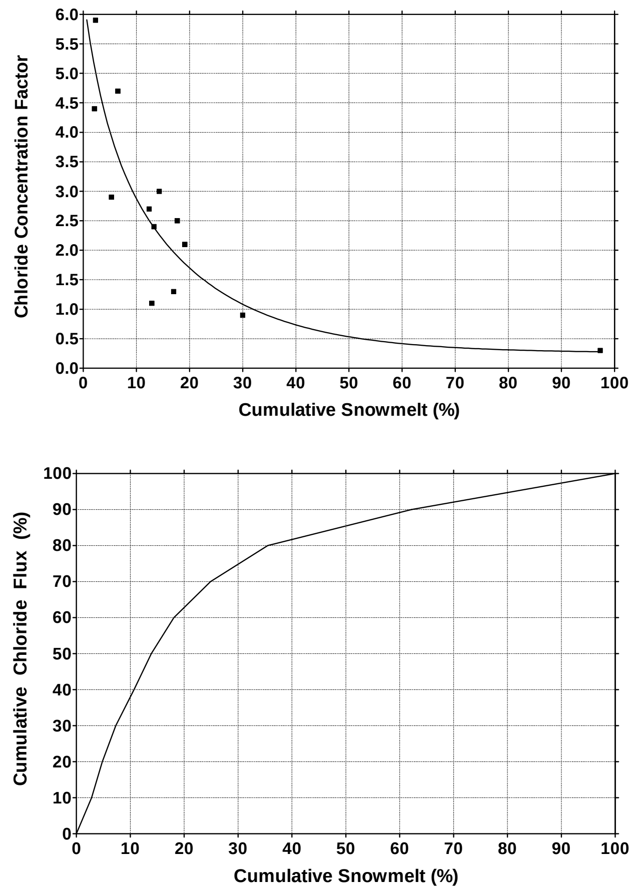

Figure 47. Preferential elution of chloride: (a) Top panel - a 200 m^2 paved parking lot (Westerstrom, 1995) and (b) Bottom panel – laboratory lysimeter (Viklander, 1997)

At the beginning of the middle melt phase, chloride concentrations in very low flows have been reported to range from 1,000 to 10,000 mgL^{-1} (Wheaton and Rice, 2003). By the end of the middle stage, flow may be at its peak but chloride concentrations can decline to 100 mgL^{-1}. Similar findings were reported by Exall et al. (2009) for the Richmond Hill site and by Droste and Johnston (1993) for four SSDFs in the Ottawa area. In the former study, about 5,000 m^3 of water was found to contain 16,200 kg of chloride which represents a concentration of ~3,240 mgL^{-1}. Whereas this number represents roughly one tenth of the peak concentration shown in Figure 48 (~30,000 mgL^{-1}). Droste and Johnston (1993) found the peak chloride concentration was about 2,300 mgL^{-1} but potentially higher values may not have been measured because sampling was infrequent.

The information on preferential elution is of great interest for snowmelt management and represents an analogous phenomenon to the so-called "first flush" phenomenon in urban stormwater runoff. This term refers to a period during the early part of runoff that often contains a disproportionately high fraction of the total pollutant load. In the case of a Richmond Hill SSDF, the highly concentrated early snow meltwater was low in volume and only about one third of the total load of chloride was released during low flow (Figure 48). The figure shows that after March 7, 2007 the remaining chloride was diluted in higher runoff volumes. Accordingly, this knowledge can be used in runoff management by developing treatment strategies that focus on the early chloride pulse when smaller volumes can be detained, diluted with cleaner water and then released. Other studies report that chloride concentrations decline to values < 100 mgL^{-1}, (Wheaton and Rice, 2003) which is similar to concentrations observed during the Richmond Hill Study (Figure 48 and 49).

The transport mechanism of solids and associated contaminants is very different than for dissolved constituents in the snow pile. Solids found in snow piles (Table 22) typically include soils and sediment removed with used snow. Some solids in used snow represent sand and grit applied to street and roads to improve traction, while others originate from sidewalk snow clearance causing removal of chunks of sod and soils during this operation as well as debris and dust and dirt that accumulates in urban areas. Solids removal from the snow pile depends on the transport capacity of the meltwater flow. If a critical shear stress for erosion is not exceeded, the solids will remain on the melting pad. Accordingly, a critical part of the management of snow piles involves reducing meltwater flows. Droste and Johnston (1993) reported a maximum TSS concentration of 7,500 mgL^{-1} in snowmelt prior to the final melt of a snow pile. Wheaton and Rice (2003) reported a similar value of 5,400 mgL^{-1} and Exall et al. (2009) reported TSS concentrations between 2,000 and 8,000 mgL^{-1}. Thus, concentrations of solids in snowmelt can be excessively high and need to be controlled, optimally by settling. Droste and Johnston (1993) characterized the snowmelt solids with respect to their settleability, tested for settling times of 1, 6, 12 and 24 hours. Settling times between 1 and 6 hours offered acceptable removals of TSS (up to 95%) and most sediment-associated metals (e.g., Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, and Zn). Their study shows that good control of sediment-associated metals in SSDF effluent can be achieved by treating meltwater in settling ponds.

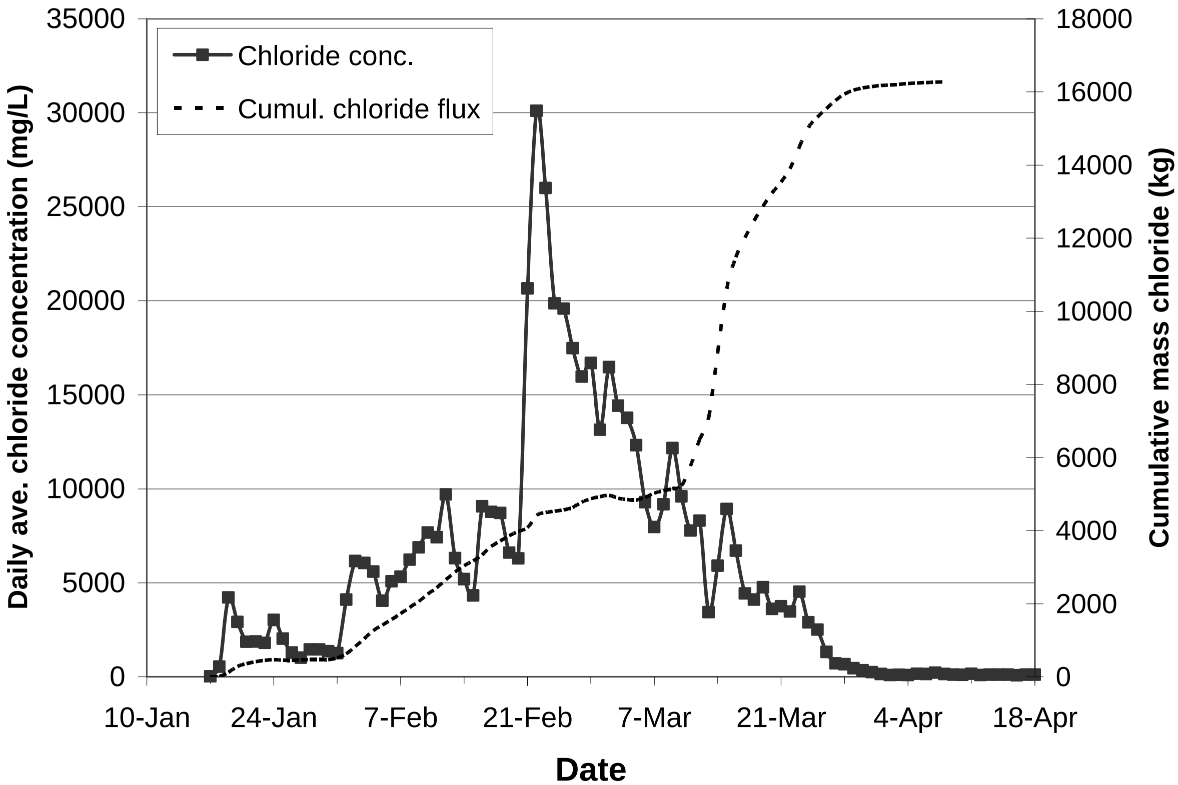

Figure 48. Average chloride concentration in and cumulative mass of chloride out in 2007 at the Richmond Hill SSDF (unpublished data).

Particles in the snow pile or on the pad surface are subject to erosion and transport during meltwater or rainfall events. As seepage exits from the pile along the upper surface of the basal layer top, it is saturated with solids from the surface of the snow pile. Mobilization of sediment is particularly high on gently sloping surfaces of snow fill. Near-vertical surfaces become self-armored as they build up thick layers of sediment. Typically, solids, debris and litter stay on the melting pad surface after the final melt and have to be cleaned or swept at the end of the melt season. Transport of solids and materials leaving the snow pile is affected by the overall site design which is discussed in detail later.

Snowmelt management. SSDF effluent can contain high levels of contaminants and should be treated prior to discharge into the environment. The treatment trains are for snow pile management are analogous to those applied to stormwater. The main constituents of concern are solids and associated contaminants (mostly heavy metals and PAHs, TPH) and deicing chemicals (i.e. chloride). While the control of solids is well established and known, controlling chloride is much more challenging because of its mobility and conservative properties. Chloride ion basically moves through the urban environment without attenuation, except by dilution, which may reduce concentrations, but does not affect the overall loads. Consequently, provincial regulations (e.g., OMOE, 1975; OMOE, 1994) do not require chloride treatment but recommend avoiding release of chloride shock loads into receiving waters by snowmelt dilution. Both issues are addressed in the following sections.

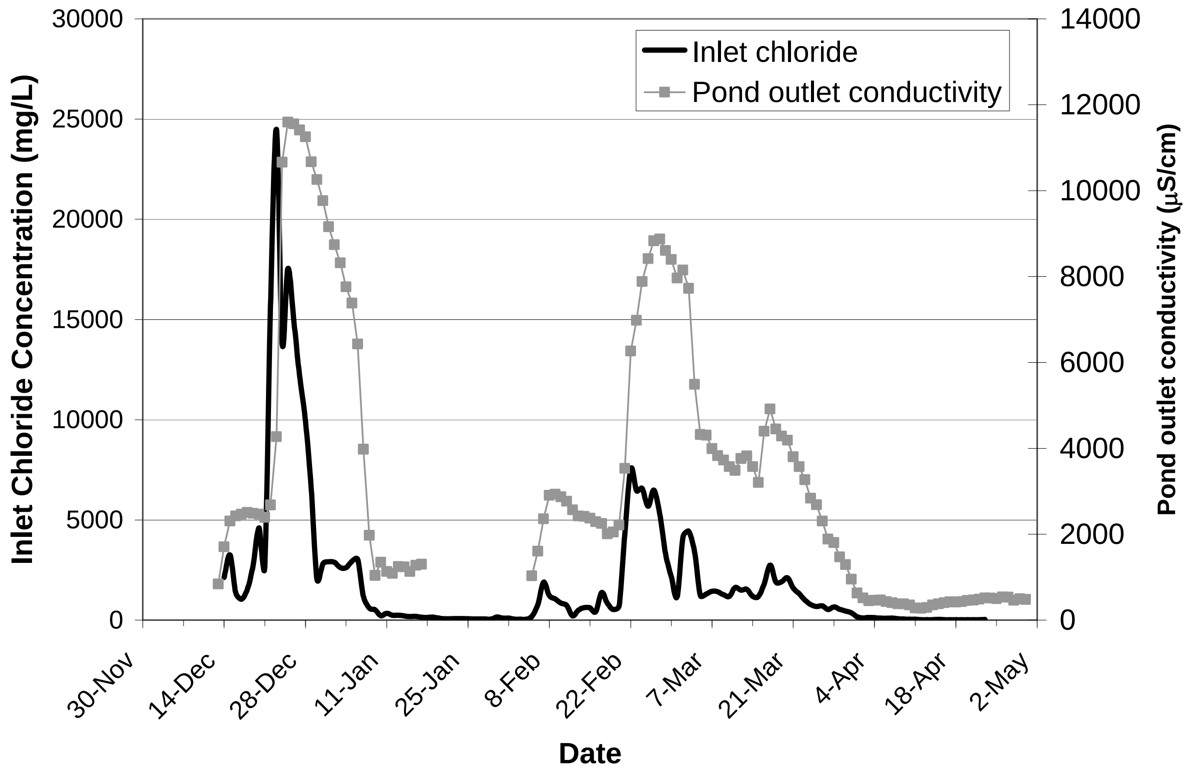

Figure 49. Buffering of chloride / conductivity peaks during passage through the Richmond Hill stormwater pond, 2008 (unpublished data).

In summary, there are increasing concerns regarding the discharge of SSDF effluent into groundwater or surface waters. These concerns originate from observations of high concentrations of solids and a range of dissolved and sediment associated contaminants but few studies have been designed and conducted to quantify these processes in snow piles. These concerns are however, serious enough to warrant careful selection of SSDF locations, particularly in salt vulnerable areas. To mitigate such potential effects, SSDF runoff should be managed prior to discharging directly into the surface or subsurface environment. When discharging into surface waters, all the chemicals/concerns discussed here apply; when allowing runoff to infiltrate into the soil, the chemicals of most concern are those that impact groundwater quality, such as road salts and additives, BTEX and phenols (MacViro, 2004; Exall et al., 2006). Hydrophobic chemicals are bound to solids that stay on the SSDF surface and would be either incorporated into SSDF base soils or be removed during annual maintenance.

SSDF Snowmelt and Runoff: Environmental Impacts. All guidance documents for planning and design of SSDFs express concerns about potential environmental impacts of runoff from such facilities (e.g., Environnement et Faune Québec, 1996). These concerns are based on protocols listing chemical substances detected in stored snow piles or snowmelt/runoff from such piles and relatively high concentrations in comparison to stormwater generated in urban areas. Urban snowpack and SSDFs are sources of various contaminants that over time are released at highly variable rates during winter snowmelt are potentially toxic to aquatic biota (Marsalek, 2003). To our knowledge, no studies have been conducted to examine the environmental impacts of runoff from SSDFs on receiving waters, outside of the snowmelt treatment train. Under these circumstances, a precautionary approach is recommended and also all relevant environmental regulations have to be followed.

The following section lists chemicals and materials of environmental concern, which are typically grouped into a number of categories (Table 23).

Table 23. SSDF environmental impacts on receiving waters

Chemicals or materials	Potential environmental impacts (hazards)
Sediments (of mineral origin) and TSS	Sediments (coarser materials) and TSS occur in SSDF runoff in high concentrations and quantities. Their main impacts include changes to fish habitat, transport of adsorbed chemicals and filling of flow and navigational channels. Some of these materials remain on the melting pad at the end of the season, others are captured in the treatment train and the rest are discharged into receiving waters. Impacts on fish habitat result mainly from reduced sunlight penetration, interfering with photosynthesis; blanketing of gravel grounds where fish spawn and rear their young, and where algal and invertebrate food sources live; filling up of pools where fish feed, take refuge from predators and rest; direct effects on aquatic organisms, including abrasion of gills and other sensitive tissues; reduction of visibility for catching food and avoiding predators; and loss of protective qualities of large woody debris (Horner et al., 1994). Transport of adsorbed chemicals is typical for hydrophobic substances and depending on particle sizes, may extend over larger segments of receiving streams. The filling of flow channels is typical for smaller streams with insufficient sediment transport capacity to move the incoming materials. This may lead to formation of sediment banks by outfalls, with other impacts on flow distribution in the receiving waters.
Solids, organic debris (grass, leaves collected with snow)	Represent a significant component of used snow and while some of these materials remain on the melting pad at the end of the season, much of this load gets into receiving waters, where it is biodegraded by bacteria. Biodegradation exerts oxygen demand leading to reduced DO levels in receiving waters, which in turn may lead to fish kills and destruction of the bottom dwelling fish forage.
Litter	Aesthetic pollution impacting stream and lake bottoms and shorelines.
Road salts (typically NaCl, although various types are employed, depending on local preferences)	Salts exert physical impacts on receiving waters (Judd, 1970), toxic effects on aquatic life (US EPA, 1988), damage to vegetation and soils, and may impact on human health via drinking water (US EPA, 2009). Physical impacts include densimetric stratification, which may impede vertical mixing in lakes and oxygen transport to bottom layers.

Road salts (typically NaCl, although various types are employed, depending on local preferences) (con't.)	Toxicity to aquatic life. Toxic effect levels for chloride have been established by the US EPA for aquatic life, at both acute and chronic levels, as 860 and 230 mg/L, respectively (US EPA, 1988). These limits are currently under review by some US states (working with new toxicity data) and the Canadian Council of Ministers of the Environment (CCME) is currently working on new chloride aquatic toxicity standards. Regardless of the magnitude of "revised" standards, concentrations of chloride in runoff from SSDF exceed the above values by such margins that this aquatic toxicity will remain to be of concern in SSDF design. Salt damage to vegetation and soils (loss of fertility) has been reported and needs to be considered in SSDF design. Salt contamination may cause vegetation stress and decreased productivity/soil fertility; sodium ion may displace essential plant nutrients in the soil; and soils deprived of vegetation are more susceptible to erosion. Drinking water concerns. Where SSDFs drain into groundwater (some are designed to drain into underlying soils), both chloride and sodium ions are of some concern. Under secondary (aesthetic) drinking water standards, chloride concentrations over 250 mgL^{-1} or sodium concentrations over 200 mgL^{-1} would impart a "salt" taste; people on a limited sodium diet should use drinking water with no more than 20 mgL^{-1} of sodium (a guidance level which is under review, according to the US EPA, and is probably too low)(US EPA, 2009).
Salt additives (anti-caking agents, ferrocyanides, and anti-corrosion agents, chromates)	Both groups of substances may contribute to SSDF runoff toxicity. Upon dissolution in water, cyanide and chromate ions form and may create some risk of toxicity. Analysis of Canadian snow and snowmelt samples indicated some may exceed CCME guidelines for cyanides (Exall et al., 2010); additional cyanide data were presented in Table 22.
Alternate deicers – CMA (calcium-magnesium acetate)	CMA is biodegradable in soils, and has a little effect on vegetation. Because of its poor mobility in soils, it is unlikely that it would reach groundwater. The main environmental concern is oxygen depletion in receiving waters during decomposition (the speed of decomposition is affected by water temperature).
Nutrients	Runoff from SSDFs contains loads of P and N; not much is known about the actual species and their potential contribution to nutrient loads. However, excessive inputs of nutrients stimulate nuisance aquatic plant and algae growth .
Heavy metals	Urban snow and particularly that removed from roadways contains heavy metals at significant levels. In general, such metals are

Heavy metals (con't.)	attached to solids and removed during settling, however, there is some evidence that in salt-laden runoff, metals become more mobile and bioavailable. Winter highway runoff seems to represent a class of potentially toxic effluents, but identification of source of toxicity (i.e., metals vs. chloride) is generally missing and currently researched. Heavy metals contribute to contamination of game fish, making them inedible.
PAHs and TPH (or oil and grease)	All of these chemicals are found in road and highway runoff, sometimes at significant levels, depending on the traffic intensity. While these substances are of general concern, again their identification as source of toxicity is generally missing. Otherwise these substances are attached to sediments and readily removed by sedimentation.
Oxygen demanding substances (measured by COD or BOD)	Snowmelt may exert significant oxygen demands, as documented in Table 22 by high COD concentrations (Pierstorff and Bishop, 1980). In the same table, BOD values are relatively low, perhaps because of interference of toxic substances with bacteria in BOD tests.
BTEX (benzene, toluene, ethylbenzene and xylenes – volatile organic compounds found in petroleum derivatives)	BTEX compounds pose risk to aquatic and terrestrial organisms, and to humans, with respect to drinking water and food production. In general, they contribute to contamination of soil and groundwater (Meyer and Wania, 2008).
Phenols	Major anthropogenic sources of phenols are industrial effluents and sewage, and also automobile exhausts; transfer to urban snow, precipitation and water is possible. There is a freshwater aquatic life water quality guideline of 4.0 μg/L; no references concerning phenols in snowmelt were found.

SSDF Treatment Train. The preceding section identified the materials or chemicals of concern. SSDF runoff must be treated to alleviate such concerns and treatment is best accomplished in a treatment train comprising two or more unit processes controlling the potentially harmful chemicals and materials. The existing SSDF facilities focus on two aspects: (a) removal of solids and (b) management of chloride concentrations in runoff. In the first case, the solids removal task is similar to that concerning stormwater and is generally accomplished by settling in a treatment pond. The second task requires dilution of high chloride concentrations resulting from preferential elution and coinciding with relatively low meltwater flows in early melts. Both tasks can be accomplished in a single facility, a stormwater pond, which is a common design solution found in many recently built SSDF facilities. Such a treatment train can be further refined by addition of other processes, e.g., pretreatment using oil and grit separators. Accordingly, an effective treatment train would comprise an oil & grit separator or a similar structure, e.g., a sediment forebay with oil absorbing boom (pretreatment is provided by capturing coarser solids and intercepting floatables, e.g., free oil) and a stormwater pond that promotes (a) settling/removal of solids and (b) dilution of chloride. There are many proprietary oil and grit separators available on the market and in general, they offer high removals of coarse solids, which may be well suited for pre-treating snowmelt runoff from a melting pad. Pretreatment of melt runoff protects the pond against sediment buildup and reduces maintenance costs. With conventional pretreatment devices, more than 90% of particles with $D \geq 0.150$ mm are generally removed (Droste and Johnston, 1993). However, removal of the remaining of the fine particle load is challenging even during extended settling in the pond.

Following pretreatment, SSDF runoff should be treated by settling in a stormwater management pond. The settling properties of solids in snowmelt was measured by Droste and Johnston (1993) on samples collected at four snow dumps in the Ottawa area for four settling times: 1, 6, 12 and 24 hours. Their results are summarized in Figure 50.

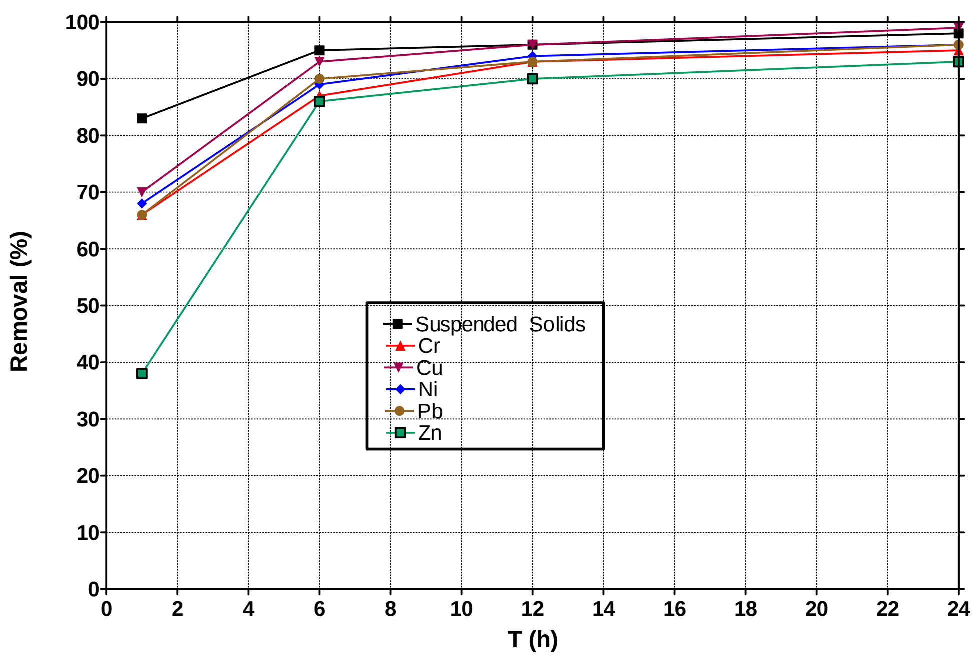

Figure 50. Percent removals of TSS, Cr, Cu, Ni, Pb, and Zn by settling of snow dump samples (data source: Droste and Johnston, 1993).

Contaminant removal for snowmelt settling with durations >6 hours provides significant benefit for the removal of TSS and adsorbed metals (Figure 50). Such detention times do not generate large demands on the pond storage volume (compared to conventional stormwater treatment), considering detention times from 24 to 48 hours for much higher rates and volumes of inflow.

Particulate matter that settles in a treatment pond will eventually need to be removed to restore its active volume and function. The literature suggests that sediment quality in stormwater management facilities is generally acceptable in facilities located in residential areas. Marsalek et al., (2006) found that the highest concentrations of heavy metals were in facilities located in industrial areas and highway corridors. Given the nature of sediment in snow piles, it can be expected that SSDF sites will contain polluted sediments, particularly where stored snow originates from roads and streets with heavy traffic. Examples of sediment quality collected in a meltwater pond at the Richmond Hill SSDF are shown in Figure 51 to Figure 54 (Exall et al., 2009).

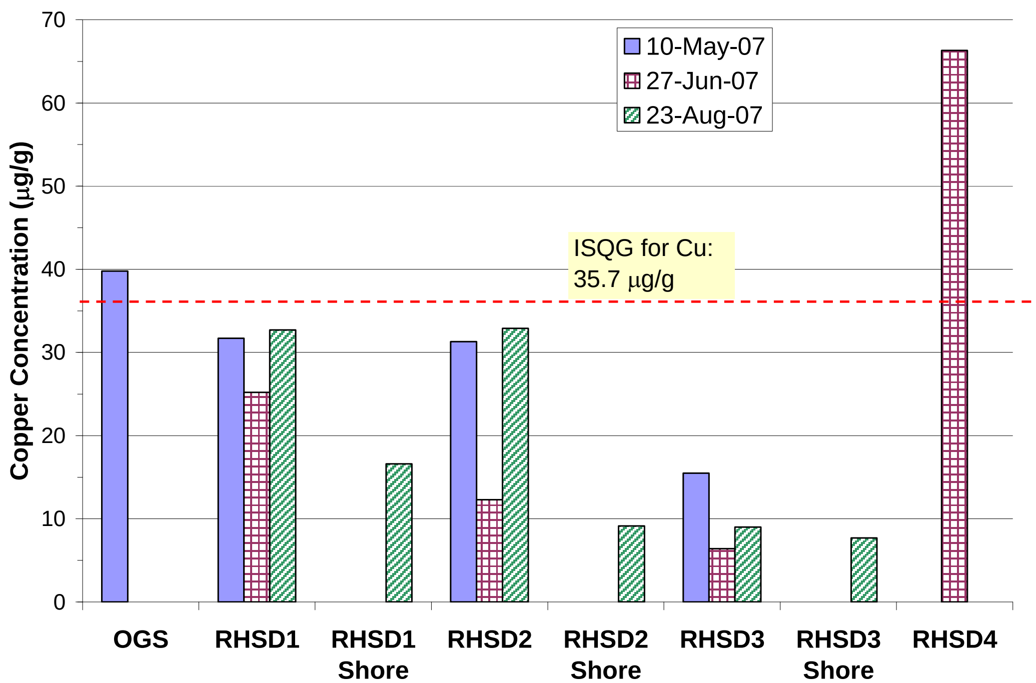

Figure 51. Copper concentrations in OGS, stormwater pond (RHSD1-pond inlet, RHSD2-pond mid-point, RHSD3 – pond outlet) and drainage ditch (RHSD4) sediments (Exall et al., 2009).

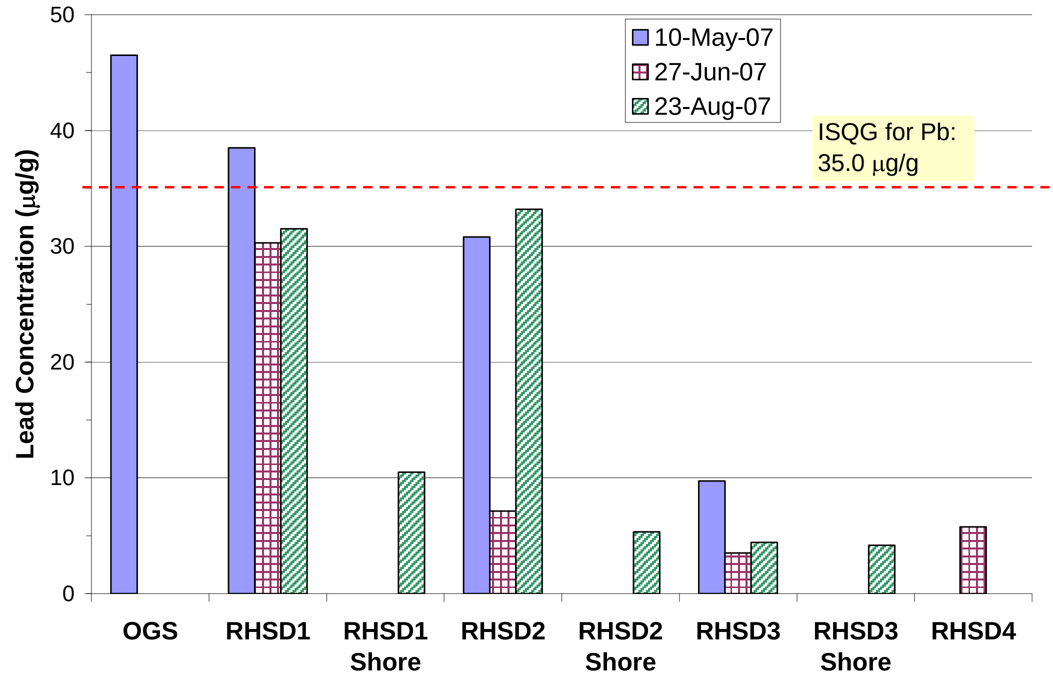

Figure 52. Lead concentrations in OGS, stormwater pond and drainage ditch sediments (Exall et al., 2009).

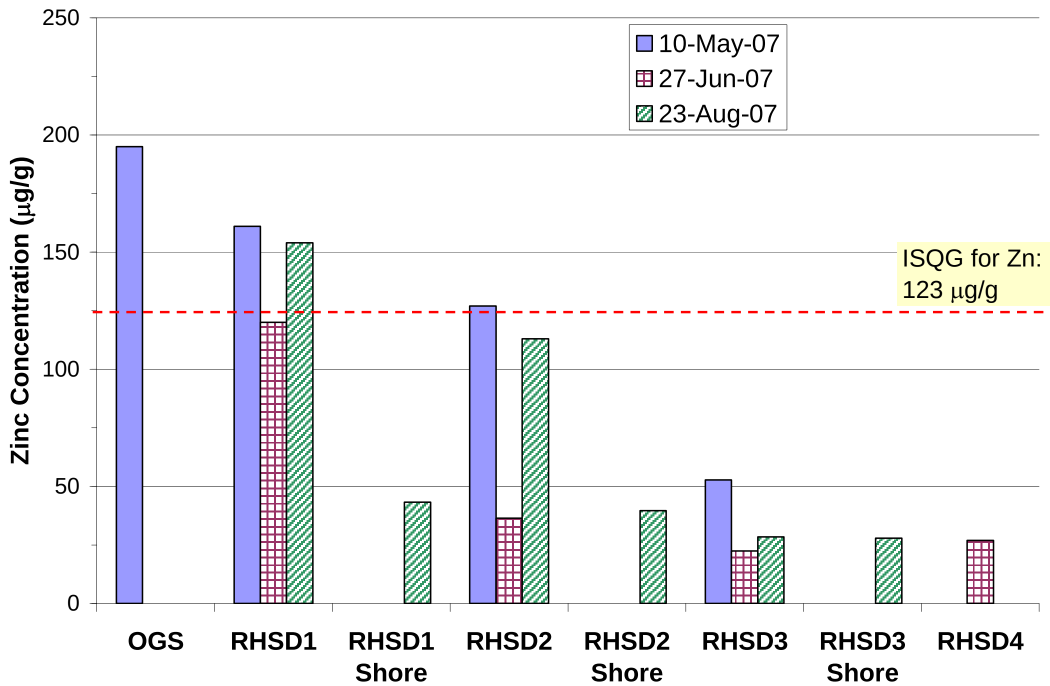

Figure 53. Zinc concentrations in OGS, stormwater pond and drainage ditch sediments (Exall et al., 2009).

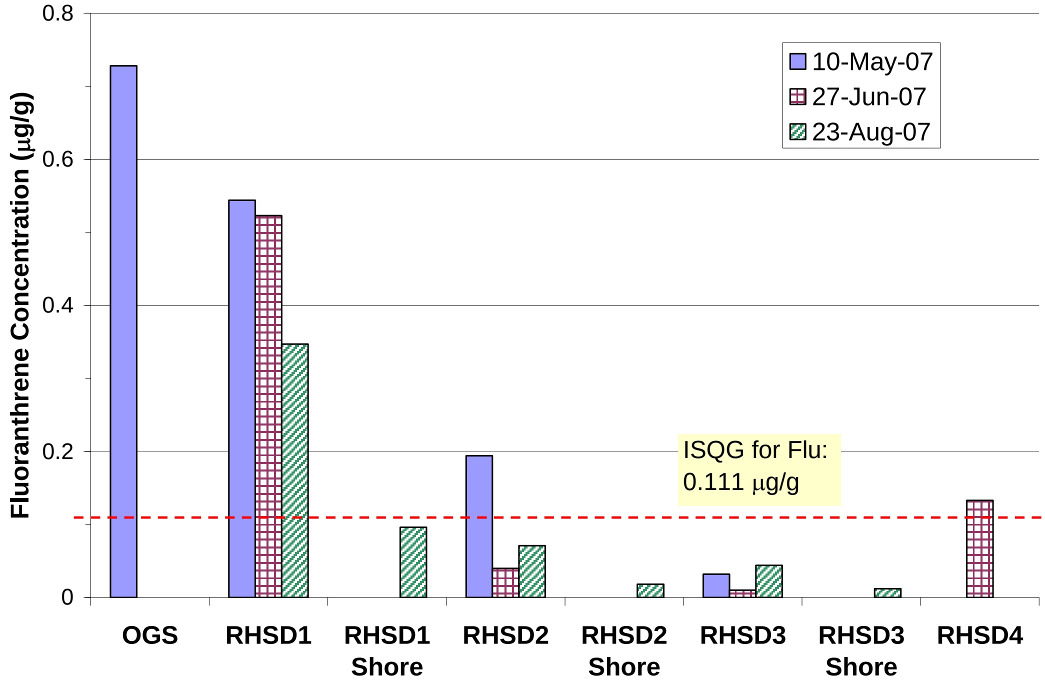

Figure 54. Fluoranthene concentrations in OGS, stormwater pond and drainage ditch sediments (Exall et al., 2009).

Several observations can be made regarding data presented in Figure 51 to Figure 54: (a) The highest contaminant levels, for both heavy metals and PAHs, are found in sediments from the oil and grit separator, which agrees with data reported earlier by Marsalek et al. (2006), (b) contaminant levels decline along the pond main streamline from inlet to outlet (in the flow direction), with the lowest levels (generally below the CCME Interim Sediment Quality Guidelines, 2002) found close to the pond outlet and (c) sediment toxicity tests (Exall et al., 2009) indicated the absence of acute sediment toxicity, except for samples from the oil and grit separator and possibly one location in the pond. Sediments from the SSDFs and particularly those from the oil and grit separator would need to be assessed for applicable disposal options (Graham and Lei, 2000).

An important treatment question which requires further study is related to whether dilution of chloride in the pond is achieved by mixing of the chloride laden inflow with the ambient pond water. A second question is related to the prevention of chloride shock loads that are released into receiving waters. This aspect requires further study and changes in the operation of existing stormwater ponds, including possible modifications of inlet and outlet structures will likely be required. Densimetric chemo-stratification of ponds in winter impedes vertical mixing and chloride laden inflows entering stratified ponds form gravity underflows that move straight to the lower strata of the pond, without much mixing (Marsalek 1997; Marsalek et al., 2000). Gravity underflows then further increase the meromictic stability of the pond water, which impairs vertical mixing. In a stratified pond, the highest chloride concentrations are observed near the bottom and decrease toward the water surface.

Concerning stormwater pond outlets, common designs employ reversed slope pipes reaching into deeper strata of pond water (OMOE, 2003) and may release water with elevated chloride concentrations. Better dilution would be achieved in ponds with weir outlets, or ponds with adjustable depths of water withdrawal. Another design feature contributing to dilution of chloride concentrations in ponds is the diversion of stormwater runoff from surfaces without stored snow (i.e., relatively chloride-free water) into the pond. Note however that such a measure increases the demand on the pond storage volume and the associated design and cost implications need to be fully evaluated.

Summary of Technical Guidance for Design of SSDFs. There is a paucity of published literature on the design of snow storage and disposal facilities (SSDFs) and the TAC guidelines are the most comprehensive (TAC, 2003) in this regard. The following is a brief summary of the TAC guidance recommendations but it should be emphasized that site designs must comply with all locally applicable regulations and municipal ordinances. An example is provided in the appendix. The following subsections address 1) planning of snow storage sites 2) design of snow storage sites 3) operation and maintenance and 4) monitoring.

Well planned, designed and operated SSDFs provide cost savings, improve traffic flow and safety in the urban area and reduce overall environmental impacts. However, there are also challenges in implementing such facilities with respect to environmental issues, social impacts and costs. Successful planning and implementation requires long-term strategic planning, including a scoping analysis, comparison of various snow removal and disposal technologies, assessment of snow storage needs and associated costs, selection of the best alternative, and securing funding; all done with public involvement and advice through structured consultations.

Evaluation of existing and planning of new snow storage sites. The planning of snow removal and disposal involves consideration of all technologies and alternatives (Environnement et Faune du Québec, 1996), which is not addressed in this section dealing with SSDFs only. Under such circumstances, the planning process includes four steps: 1) assess the disposal/storage needs, 2) identify the candidate existing and new SSDFs sites, 3) evaluate the sites, and 4) choose the preferred site or sites.

Snow removal and disposal needs. Snow disposal needs are typically assessed using a planning horizon of 15 years. In this regard, snow removal/redistribution locations and storage volumes adjacent to the cleared sites must be assessed and mitigation measures evaluated. Typical problems associated with deficient SSDFs include contamination of soils, groundwater and surface water from the release of meltwater; blowing dust and litter released from melting snow; noise from snow disposal facility operation; and visual impacts on neighborhoods caused by unsightly snow disposal operations (TAC, 2003; Wisconsin Department of Natural Resources).

A mix of permanent and temporary (emergency) sites serving specific areas should be considered together with the current costs of snow removal, transport, storage and disposal (TAC, 2003). Typical costs include load/haul/dump fees, optional dumping of snow into sewers (using sewer chutes and considering potential effects on treatment processes), snow melting (both stationary and mobile systems), capital investment costs and costs associated with maintenance and repairs of existing and/or proposed facilities.

Identification of candidate sites. As part of the planning process, municipalities typically establish one or more SSDF facilities and have contingency plans for other sites used for emergency / overflow snow storage. These temporary sites might include parking lots, parks, sports and recreation fields (pending evaluation of their suitability). Accordingly, the planning process utilizes two types of snow storage sites. These include permanent facilities and temporary (also called emergency) facilities. The former are preferred because they can be properly developed and designed to meet the necessary requirements (City of Winnipeg, 2009). Reinosdotter et al. (2003) compared local SSDF sites (within the urban area) vs. those outside (remote) and concluded that a combination of local and remote sites was the most realistic option.

The assessment of existing sites focuses on meeting both primary and secondary criteria. Primary criteria include transportation (haul distance), land use and zoning, hydrogeology and meltwater characteristics while secondary criteria include noise, property size (snow holding capacity), ownership, availability of utilities and overall economics. The assessment process offers an opportunity to review public, agency and staff concerns with existing sites and identify potential concerns that should be resolved during the planning phase (Alaska DEC, undated).

It is necessary to collect baseline information for any proposed future snow storage sites Such information should include surface water quality, flow regime and assimilative capacity; site hydrogeology and locations of groundwater recharge areas; location of salt-vulnerable areas (wetlands, sensitive vegetation, agricultural areas, drinking water supplies, shallow ponds) and locations of sensitive land uses (residential, institutional, recreational) (City of Ottawa, undated).

Identification of candidate sites should include even those which are more remote, but offer favorable physical attributes such as low permeability soils, natural gentle slopes towards a ponding area (with adequate potential to install appropriate drainage and collection systems as required), runoff discharge to a high-flow stream or river, or an optional discharge to a sanitary sewer (Massachusetts Department of Environmental Protection, 2001). In the assessment of environmental and socio-economic factors, important criteria include minimization of environmental impacts, hauling costs, roadway safety and control of traffic flows, and minimization of emissions including drainage flow, noise, dust and fumes; and practicality of the site with respect to future maintenance requirements (TAC, 2003). The types of sites considered and applicable environmental regulations will determine meltwater management needs, with respect to both water quantity and quality. Towards this end, the effectiveness of current practices in snowmelt treatment should be evaluated.

Proper evaluation of candidate sites start with an assessment of existing snow removal methods and snow storage and disposal sites (i.e., establishing a reference), accounting for such factors as snow hauling distances (striving to minimize hauling costs), snow hauling routes and site access, recognizing impacts of heavy truck traffic on the environment (noise, fumes) and road longevity, past and current site land use (a list of unsuitable sites is presented later) and presence of utilities which could limit site operation. Concerning the surrounding land use, areas with residential, institutional and recreational land uses should be avoided. In some cases, land may have to be acquired and rezoned (TAC, 2003). Because of noise concerns, it has been recommended that snow dump sites be located at least 350 m from existing or planned residential housing. Sites in hollows or other locations where natural or man-made barriers will baffle sound are preferred (Alberta Environmental Protection, 1994).

Environmental considerations address potential impacts on the environment, including soil conditions (preference is given to sites with low permeability soils with sufficient bearing capacity to handle year-round traffic) and most importantly, the protection of surface water and groundwater quality, proximity to surface waters and potential effects, meltwater discharge location into stream and rivers providing sufficient dilution (consider flow fluctuations and low flows; in some jurisdictions, discharge into streams with winter baseflow < 85 Ls^{-1} has to be avoided), avoiding discharge into salt vulnerable areas, groundwater recharge areas and areas over shallow aquifers. When discharging into sanitary sewers, there must be sufficient treatment capacity. Preference is given to the upland sites with the fewest associated environmental problems and a low risk of negative environmental impacts. Depending on the meltwater pathway, preference is given either to sites which have mild slopes and tend to slope away from surface water bodies, outside of the flood plain and well above the groundwater table, or to sites with fine structured soils allowing infiltration, and removal of contaminants by filtration, adsorption and microbial activity (Massachusetts Department of Environmental Protection, 2001). A hydrogeological study may have to be commissioned to establish site suitability. Areas with fractured bedrock near the surface, allowing easy transport of meltwater to groundwater aquifers, should be avoided.

The size of the site must be adequate to accommodate all the removed snow plus provide the space needed for operations. Land and operational costs and environmental conditions will affect the considerations of a single site vs. multiple sites. Snow storage capacity is enhanced by utilizing the vertical capacity of the site, either depositing snow in layers (typically 3 m thick), or by vertical blowing (City of Ottawa, undated). Besides snow storage capacity, the amount of snow brought to the site should serve to estimate runoff rates, meltwater quality, and potential impacts on downstream uses of the receiving water.

Practices to be avoided. There is a general consensus that the following sites/practices should be avoided (Alaska Department of Environmental Conservation, undated; Alberta Environmental protection, 1994; City of Ottawa, undated; Massachusetts Department of Environmental Protection, 2001; New Hampshire Department of Environmental Services, 2007), South Dakota Department of Water and Natural Resources, 2010; TAC, 2003; Wheaton and Rice, 2003; Wisconsin Department of Natural Resources, undated):

- Dumping used snow into open waters and wetlands; where the disposal site (usually an emergency site) is in close proximity to surface waters, which could be adversely affected, a vegetated buffer of 50 m or more and a silt fence should be provided. Where feasible, a minimum setback of 200 m from a water body is recommended.
- Avoid sites with steep slopes or highly erodible soils.
- Avoid areas where groundwater is used for drinking water supplies. Sites must not be located within wellhead protection areas (if designated); where such areas are not designated, disposal sites must be located a locally-specified minimum distance from wells and public water systems.
- Avoid dumping snow in sanitary landfills (snowmelt will enhance leachate flow and can also cause further contamination) and gravel pits, which lack opportunities for snowmelt treatment (groundwater table is too close to the land surface).
- Avoid disposing of used snow on top of storm sewer inlets (catch basins) or in stormwater drainage swales or ditches, because high loads of solids in used snow (sand sediment, litter) will increase maintenance of such facilities and create a risk of rapid transport of such materials to the receiving waters. There could also be an increased potential for flooding during melt periods or spring rainfall events, which could contribute to road safety issues.
- Avoid placing sites near high traffic areas, which are already discharging chloride and heavy metal loads to the local environment, to avoid further aggravation of such loads and congested traffic with snow dumping vehicles.
- Avoid agricultural land to eliminate the risk of soil contamination.
- Avoid public parks and recreational areas (e.g., sports fields) – contaminants in snow may contaminate soils and accidental ingestion of such soils can be detrimental to human health, especially in children. Soil compaction, the presence of debris and excessive soil moisture in the spring would also contribute to difficulties in preparing and maintaining such facilities for recreation. However, park areas not used for public recreation, such as parking lots, can serve as disposal sites.
- Avoid snow dumping on high and medium-yield aquifers.
- Other water bodies to be avoided include salt marshes, vegetated wetlands, certified vernal pools, shellfish beds, mudflats, drinking water reservoirs and their tributaries, protection zones of public drinking water wells, or areas of critical environmental concerns.
- Avoid dumping close to environmentally protected areas with ecologically sensitive, protected or threatened species.

Design. The following is intended to provide guidance for the effective design, operation, maintenance and environmental monitoring of SSDFs.

Operational considerations. SSDFs are winter maintenance facilities with a high volume of traffic during the relatively short period of time. Consequently, they need to be designed to facilitate efficient operation, minimal nuisance to the surrounding area and appropriate level of security. Efficient site operation requires a good accessibility and well-planned access routes, facilitated by proper signage. Considerations for increased truck traffic require inspection of the truck access routes and possible upgrade of roads used by hauling trucks (TAC, 2003). Vehicle movement within the dumping area needs to be well controlled with clearly marked traffic routes that avoid backing up. The site must be equipped with electrical power, which is required at the gate and elsewhere for lighting so that dumping can safely continue at night. A building may be required for monitoring operations and routine data collection. Proper site design includes an access road for repairs of collection and treatment areas/facilities (TAC, 2003). Site security and environmental controls require site boundary delineation using perimeter fencing with appropriate signage and gate with controlled access and low permeability berms around site to prevent uncontrolled offsite release of meltwater. Security measures protect against dumping of garbage and reduce risk of injury to the general public, particularly children (City of Ottawa, undated). Such measures include security fencing and lighting to limit unrestricted and unauthorized access.

Melt pad/area. Design considerations of melt pads reflect two primary options for melt water disposal; into surface waters or into the ground. In general, the facility should have a solid base providing support for truck traffic. In facilities with surface water disposal, the base should have low permeability to direct melt water to management facilities, protect groundwater, and support vehicles even after frost is gone. Some guidelines recommend building relatively impervious bases using a clay layer, or waterproof membrane, asphalt, concrete, imported clay or similar materials (Alberta Environmental Protection, 1994). Site grading should avoid runoff from surrounding areas entering the pond, and minimize snowmelt percolation into groundwater. There are however cases, where drainage of surrounding areas into the meltwater pond is encouraged to promote chloride dilution (Exall et al., 2009).

The pad should slope northward (so that the sun will melts the pile from south to north) and can be designed as a sloping plane, or as a single or multiple V-shaped pads (minimum 45 m crest to crest, 2% side slope to the central trough, 1-2% longitudinal slope), draining away from snow piles and dumping areas (in order not to interfere with traffic) into a collection facility (a pond) (Wheaton and Rice, 2003). Swale crests, drainage channels and berms should be armored. Wheaton and Rice (2003) described advantages of V-shaped pads, which provided lower turbidity and promoted meltwater movement as saturated flow within a snow pile, so that particulates are not mobilized during the early and middle stages of melt. The V-trough provides a single point of discharge and thereby improves control of flows released from the site. Other benefits were obtained by placing snow in high, compact masses with steep sides around minimizing exposure and adding snow fill receding from uphill to downhill. Melt pads should be oriented so that exposure to the afternoon sun is maximized; faster snowmelt will dry the ground faster.

Sites not draining into surface waters, but dissipating water by infiltration and evaporation, do not need detention ponds or water confinement berms, but can be constructed as field or gravel parking lots, without storm drainage, but enclosed by a snow fence. Sites draining into storm sewers need a melt management system comprising snow fence, filter berm, a small detention basin and buffer zone (between the filter berm and the sewer inlet) (South Dakota Department of Water and Natural Resources, 2010).

Meltwater quality management. Meltwater quality management should be approached in an integrated manner recognizing that it is the last step in the overall pollution control plan for a particular area. The Minnesota Stormwater Management Guidelines recommend a five-step management approach: pollution prevention, infiltration of meltwater, meltwater storage, filtration and good housekeeping practices (Minnesota Pollution Control Agency, 2005). Pollution prevention should be practiced at the catchment scale by wise use of de-icing and anti-skid chemicals and materials, limiting the use of additives like ferrocyanide, planning snow removal and meltwater discharge to less sensitive waters or to treatment facilities, designing management facilities to provide chloride dilution (to lower its impact) and practicing litter and erosion controls. Alternative deicers have been tested, but none appear to be free of environmental impacts and their runoff would still be an issue for disposal. They may also require more detailed monitoring which could further increase costs.

To reduce impacts on surface waters, the Minnesota Pollution Control Agency manual recommends infiltrating as much of the snow melt as possible, but first pre-treating it by removing sediment and attached contaminants and avoiding impacts on important groundwater aquifers. Stormwater ponds, which are commonly used in the meltwater treatment train, generate some concerns about chloride accumulation and may need structural provisions for chloride mixing and release (e.g., submerged outlets). Drainage and flow-control structures need to be functional in cold weather (even with ice cover), so their design requires special consideration. With appropriate planning, they can be designed to facilitate easy flow monitoring and sampling (as required) which helps streamline compliance monitoring (Minnesota Pollution Control Agency, 2005).

Where constructed wetlands are used to treat runoff, they require some pretreatment and halophytic plants should be used, recognizing that wetlands do retain some limited effectiveness even in cold weather. Filtration measures and hydrodynamic solids separation structures are effective for removing certain solids, but do little with respect to controlling chloride in its dissolved form (Minnesota Pollution Control Agency, 2005; Wisconsin Department of Natural Resources, undated).

A model treatment train contains source control measures in the catchment, collection of meltwater at the SSDFs site, pretreatment focusing on removal of excessive (coarser) solids, meltwater settling and chloride balancing in a pond and gradual release of chloride into a discharge channel / receiving water body. With respect to pretreatment, the common options include sediment forebays or hydrodynamic oil and grit separators. Sediment forebays serve to remove coarser solids by settling and their design is described in standard stormwater management manuals (OMOE, 2003). They are typically designed with maximum volumes between one fifth and one third of the permanent pool volume. They may be fitted with oil-absorbing booms and litter screens. Hydrodynamic oil and grit separators perform a similar function, with a smaller footprint and capture of floatables (described in design brochures provided by commercial vendors). Thus, the recommendations below focus on meltwater ponds.

In general, meltwater ponds should have an impermeable base (or even a full lining depending on local groundwater and soil conditions), forebay and a large main pond area; an absorbent boom could be placed at the forebay section. Where permitted and useful, uncontaminated drainage should be directed to the pond to provide chloride dilution. The pond volume should be capable of accommodating all of the meltwater generated plus any site drainage and precipitation runoff. Recommendations concerning hydraulic residence times vary considerably. Droste and Johnston (1993) recommend 6 h as a minimum detention time while Alberta Environmental Protection (1994) recommends a 24 h detention time but preferable detention times should be as long as 4 days. Pond outlets should be controlled to regulate chloride release into receiving waters.

In some cases, detailed chloride releases have been specified, but these depend on local regulations. For example, Wheaton and Rice (2003) suggested that ponds or other treatment measures should be designed to control chloride and sediment (total suspended solids) releases as follows: Mean concentration of chloride release per 1 day < 3,600 mgL^{-1}, 30 days < 1,200

mgL^{-1}, and season < 300 mgL^{-1} and the sediment removal > 95% for particles >100 um in diameter. Local environmental regulations may specify further reduction, depending on downstream water uses, such as fisheries and water withdrawals. In a four year study, Wheaton and Rice (2003) reported peak chloride concentrations ranging between 1,000 and 10,000 mgL^{-1}. Accordingly, flow dispersion and energy dissipation control structures may need to be installed at outfalls to the receiving waters.

A silt fence, or barrier should be placed securely on the down gradient of the disposal site (Alaska Department of Environmental Conservation, Undated; Massachusetts Department of Environmental Protection, 2001). Earthen berms, which need to be stabilized to avoid soil erosion, are used to control local drainage by directing snowmelt and surface runoff to settling ponds and minimizing seepage of contaminants into groundwater.

Some guidance documents also recommend polishing effluent from meltwater ponds (South Dakota Department of Water and Natural Resources, 2010) by passing it through a gravel and rock filter berm before discharging the effluent into receiving waters. Snow storage sites should be located far enough upstream to facilitate good functioning of the control structures; minimum distance is 30-45 m but 150 m is typically preferred. To further attenuate pollutants in the meltwater, a vegetative buffer strip (> 45 m) should be maintained between the disposal site and adjacent water bodies, or stormwater drains. Dry detention basins should be designed with a minimum operational depth of 0.6 m to limit the basin size and berms of appropriate heights. These basins are designed to filter out sediments, organic solids as well as litter and debris (South Dakota Department of Water and Natural Resources, 2010). Ponds require maintenance access. All required approvals, permits and licenses have to be applied for and obtained; conduct baseline monitoring of contaminant levels at site. It is customary to assess the meltwater treatment facility by monitoring for a period of at least 3 years. Details of monitoring requirements are presented later.

Operation and maintenance. Operation and maintenance issues for SSDFs include three types of considerations: site management, snow pile and meltwater management and off season maintenance.

Site management depends on the size of snow disposal operation. For larger sites, staff is assigned the responsibility for operating the site and 24 h security is maintained, in some cases even off season. For larger operations, vehicle management may be needed, particularly with night time dumping. As the site fills up and free space is reduced, vehicle management becomes more challenging. Management responsibilities may be extended off site, by occasionally monitoring hauling operations and making sure that drivers follow the prescribed routes. Monitoring for compliance with municipal policies is also needed (TAC, 2003).

During the snow removal season (winter), site management must focus on snow pile management, minimizing snow handling/crust breakage, blowing and ramping and lifting snow onto the pile, spreading piles in the spring to increase the exposed area, and sloping piles down south to north, with snow on high (south) melting first and running directly towards the drainage / collection system, without washing/eluting the remaining snow. Wheaton and Rice (2003) recommend to place hauled snow over the full width of each V-swale; sequence snow placement starting at the downslope side and work upslope; maintain snow in a compact mass with steep sides (2:3); maintain appropriate setbacks from all containment berms and from the discharge end of the V-swales (Wheaton and Rice, 2003); maintain pad vegetative cover and re-grade only to ensure swale functionality; and restrict access and prohibit off-season traffic and non-snow storage uses.

For placing snow in piles, various machinery is used, including bulldozers, front-end loaders, and blowers; damage to blowers can be a risk if large wooden debris is present in the dumped snow (TAC, 2003). To maximize snow storage, snow piling up as high as 15 m was recommended (City of Ottawa, undated). Site litter control is practiced on an on-going basis by collecting litter and installing a perimeter fence preventing litter being blown to adjacent properties. Particular attention is paid to large debris, which needs to be periodically checked and hauled away. As the area is being filled, the remaining site capacity is monitored. Where practical, samples of meltwater and soils are collected for testing. Records should be kept concerning snow received and quality of meltwater discharged. There is also a need to minimize any nuisance effects including noise from trucks and equipment, visual impacts of dirty snow piles and site lights (for night dumping), dust, litter and debris (TAC, 2003).

The snow pile must melt completely, preferably in the spring, when receiving water flows are high. Meltwater discharging into minimal flows, or the ponding of meltwater, should be avoided. End-of-season operations include compilation of disposed volumes for each site; cleanup and proper disposal of debris/litter; inspection, cleanout and repair of the meltwater management facilities to ensure their effectiveness; repairs to the site and access routes, and landscape and site office maintenance. In the fall, the site is prepared for winter operation by inspecting for problems, and making repairs to the working base, security and perimeter fences, and the lighting system. The soil surface is restored as required; re-grading may be needed if channelization from snowmelt or flowing water has occurred; and vegetated strips may need to be reseeded (TAC, 2003). Finally, consultations with the community or municipality regarding the snow site management and operation are encouraged. These will also serve to manage any public complaints or concerns regarding the site.

Monitoring. Monitoring of the SSDFs is important to ascertain the level of compliance with applicable regulations and municipal policies, determine whether improvements in facility performance and operation are required and collect information for design of future facilities. A summary of recommendations found in the literature follows.

In general, SSDF site monitoring deals with material balances at the site (i.e., inputs and outputs), impacts on the environment and site operation. Among material balances, those of snow/water and chloride are of the greatest importance. Snow inputs represent the volume of snow dumped, which can be converted into a water equivalent (e.g., using a coefficient of 0.6; Semadeni-Davies, 1999) and the cumulative volume of snow dumped minus losses by melting yield the storage mass balance. Besides volume, discharges from the snow pile and from the meltwater pond are also of interest for assessing potential opportunities for dilution in the pond and impacts on receiving waters. Site outputs include the volume and flow rate of meltwater, discharge of various chemicals and materials, and the volume and type of debris collected and disposed of.

Flow monitoring of facility discharges is important for determining the water balance. There can be considerable challenges with monitoring such flows under highly variable conditions (high flows during rainfall and low flows during melt, freezing and thawing conditions, etc.). These difficulties can include instrument failure due to harsh conditions and inundation as well as damage / alteration of flow structures due to ice buildup. These challenges can be significantly reduced by incorporating monitoring elements into the site design. This facilitates more accurate and robust flow measurements and protects flow control structures from freezing temperatures. Multiple instruments may provide backup for failure of certain systems, but add significantly to costs and maintenance.

With respect to chloride transport, chloride flux (i.e., flow multiplied by concentration) is also of interest and can be obtained by measuring discharge and approximating chloride concentrations with a calibrated conductivity probe. For smaller sites, this process is simplified and intensive measurements are made only during the initial period to verify performance, but infrequently in the following years. Conductivity or chloride probes can be located at the outlet from the pond – before discharging into receiving waters, in order to ensure compliance with discharge requirements. Continuous monitoring with online or data-logging capabilities is recommended. Routine maintenance (calibration, data downloading etc.) will also be required. With respect to environmental impacts, a broader list of constituents of interest may be required by local regulations, including chloride, sodium, pH, heavy metals, Total Petroleum Hydrocarbons (TPH) (or oil and grease), TSS, total dissolved solids, phenols, nutrients, BOD/COD, and BTEX (MacViro, 2004; Exall et al., 2006). Where other deicers are used, other substances pertinent to those deicers may need to be monitored as well.

For the melt water treatment train, its efficiency in attenuating basic constituents is of interest, and should be monitored over the first three years of operation. Particular attention should be directed to treatment pond efficiency; both the influent and effluent need to be monitored, recognizing that the outflow hydrographs lag in time behind the inflow hydrographs. Thus, direct comparison of inflow and outflow fluxes is not useful, but rather comparisons of integrated loads over extended time periods (ideally the whole winter and spring period) plus instantaneous concentrations of chloride in the outflow. CCME is currently working on regulations for chloride, which will be important for future operations of meltwater treatment facilities.

Where warranted, some or all of the following locations should be monitored: beneath the site (soils and groundwater), above and around the site (air quality), in the dumped snow, in the melting snow piles, in the meltwater, at the discharge from the site, upstream and downstream of the site in the receiving stream, and in the groundwater up and down gradient from the site (City of Ottawa, undated). The results of such monitoring will be affected by urban vs. rural locations, intensity of site use, size of site, and characteristics of the receiving stream.

All monitored data should be properly recorded and documented. Examples of records to be kept include records dealing with any complaints, litigation and a show of due diligence; compliance with regulations and licensing, providing information to regulatory agencies, determination of fees and payments, decommissioning and future sale of the site. Other information of interest include the volume of snow dumped and the time, estimates of the melt rate, debris volume and type, contaminant monitoring, maintenance and operation records (TAC, 2003).

Examples of monitoring of SSDFs were published by Droste and Johnston (1993) and Exall et al. (2009). Droste and Johnston (1993) monitored four dumps in the Ottawa area and reported preferential elution of chloride from the snow pile and delayed elution of TSS. Settleability tests of snowmelt effluent indicated high removals of TSS and associated chemicals for settling times from 1 to 24 hours. Consequently, they recommended settling times greater than 6 hours for removal of most contaminants to an adequate degree. Exall et al. (2009) reported on the monitoring of a relatively small SSDF, which received about 10,000 m^3 of snow during the snow removal season. Meltwater runoff contained about 16 t of chloride, which represented about 6% of the total amount applied to roads in the municipality studied. Early elution of chloride contributed to high chloride concentrations early in the melting season.

6. Barriers to Implementation of the Code of Practice

Objective 4 – Task 4:
Identify barriers to implementation of the Code of Practice SOPBS and make recommendations to improve winter maintenance practices of roadways and parking lots.

The Code of Practice for the Environmental Management of Road Salts was implemented in 2004 to help municipalities and other road authorities better manage their use of road salts and reduce environmental impacts while at the same time maintaining the highest level of road safety. Developed in consultation with a Multi-stakeholder Working Group for Road Salts, the Code recommended that road authorities prepare salt management plans that identify actions to improve their practices in the areas of salt storage, general use on roads and snow disposal.

Results of the present study suggest that the Code has been adopted widely by municipalities across Ontario. The preparation and implementation of salt management plans and the related application of best management practices in the areas of salt storage and general road use has resulted in a reduction of chloride transfer to the environment compared to pre-Code levels. There has been considerable progress in the adoption of practices that minimize salt loss to the environment from salt storage facilities. Impacts of salt application on the environment have decreased impart due to the increased use of calibrated spreader controls, higher use of liquid deicers, rapid increase in use of RWIS and wide adoption of salt management training programs. Although significant progress has been made to address the problem of winter maintenance and its impact on chloride transfer to the environment, several barriers where continued improvement is required to more fully implement the Code of Practice for the Environmental Management of Road Salts are described below.

1. **Salt Vulnerable Area Identification**: Many municipalities do not have the financial, technical or logistical support to properly delineate salt vulnerable areas and use this information to modify winter road maintenance practices accordingly.
2. **Training Concerns**: While many municipal road maintenance workers have received a high level of winter maintenance training, a concerted level of effort is required to

improve training to respond to technological advances, changes in salt application guidelines and staffing changes over time. Training for private contractors is not mandatory, yet they are increasingly used by municipalities and private industry for winter maintenance of parking lots, sidewalk and roads. Improved training for private contractors is necessary to optimize salt application rates and reduce chloride discharge to the environment.

3. **Implementation**: The pace of implementation is often slow because of the rate at which BMPs are typically adopted and turnover among elected officials and experienced snow fighting professionals.
4. **Alternative Deicers:** A recent report NCHRP (2007) published by the Transport Research Board compared the performance 42 alternate deicers and quantified the impacts of comparable quantities of deicers that would be required to replace road salt.
5. **Public Education**: Public awareness of the service impacts of winter road maintenance and the need for salt management is relatively high but the public is largely unaware of the environmental consequences of various snow fighting options.
6. **Design and Management of Stormwater Infrastructure:** There is a need to change engineering and land use planning practices through better design and maintenance in order to improve and promote best management practices for winter maintenance that reduce chloride transfer to the environment. The treatment train approach used at engineered snow disposal facilities is effective at intercepting many sediment-associated pollutants found in urban snow. However chloride is the exception and therefore requires managed release to minimize adverse effects of pond outflow to receiving waters.
7. **Capacity:** The larger agencies which are responsible for the majority of salt application have displayed financial commitment and developed technical capacity to implement BMPs. However, many small municipalities and townships have less the financial and technical capacity to fully adopt and implement the Code of practice for the Environmental management of Road Salts.

7. Conclusions and Recommendations

CONCLUSIONS

1. The Code of Practice resulted in the production of Salt Management Plans by a high percentage of road authorities in Ontario. Approximately 89% of larger Ontario municipalities have produced Salt Management Plans. Salt Management Plans generally deal well with safety and environment but are weak with respect to continual improvement, monitoring progress and communications. Greater effort is needed to inform contractors and seasonal staff of the salt management plan. Although excellent salt management training is available in Ontario, only 63% of road authorities responding to the survey have an annual salt management training program in place.

2. A very low percentage of private contractors are trained. Most of the municipal training programs cover the key learning goals and the environmental effects of salt are reportedly well covered. Many of the more complicated goals relating to best practices are not adequately covered in Salt Management Plans.

3. Although a high percentage of municipalities maintain records, some key types of records are not being kept thus hampering continuous improvement.

4. There is an indication that many road authorities are identifying salt vulnerable areas in Salt management Plans and some municipalities are beginning to adjusting winter maintenance practices in salt vulnerable areas. Progress is being hampered due to poor delineation and identification of Salt Vulnerable Areas.

5. Most snow disposal sites appear to be poorly designed. The need for better snow storage practices and awareness of TAC's SOBP requires greater promotion to the public, municipalities and private industry. The SOBP for maintenance yards is being followed in the case of 43% of new yard development. Salt storage and handling practices are improving but management of impacted water still needs attention.

6. Many municipalities have had difficulty funding changes and often lack strong and continued leadership, financial, technical and human resources to adequately implement the Code. Some municipalities reported a need for more explanation of the requirements of the Code.

7. A field study was conducted in Waterloo to evaluate the performance of the road salt BMP strategies (reduction of salt application by 25% in salt vulnerable areas) and quantitatively assess the effectiveness of the implemented BMPs to mitigate the impacts of road salt on groundwater resources. Compared to pre-BMP levels in 2001, the study found that BMPS implemented to reduce salt application resulted in a reduction of 45% in the average total mass of Cl^- stored in soil. The data clearly support the overall observation that significant reductions in road salt loads to the subsurface were achieved through the implementation of the BMP strategies in 2003.

8. Parking lot runoff is a significant source of chloride to the environment. More rigorous and systematic studies of the effectiveness (road safety) and associated environmental impacts of road salt and a range of alternative deicers are required to provide contractors with appropriate guidelines for optimal application rates and related spreading technology. Such information coupled with enhanced training, improved technology for salt application, better record keeping and reporting protocols as well as possible certification of contractors could lead to significant reductions in the chloride discharge to the environment from parking lots.

9. Given the increasing need to optimize salt application in parking lots and sidewalks, the *Smart About Salt* Program is an example of a locally developed management model that has potential to be more broadly applied in other jurisdictions. The program is based on developing partnerships and educational programs that promotes environmental leadership.

10. Pervious pavement technologies have the potential to reduce urban runoff but should not be used indiscriminately in salt vulnerable areas.

RECOMMENDATIONS

Several recommendations follow from the results of this study. They are presented below in three categories; education, salt application and research.

Education.

1. Continued education for the public, municipalities, institutions and private contractors is the key to ensure the Code is fully adopted and implemented. While considerable progress has been made by municipalities since the Code was developed considerable effort is required to train municipal workers and private contractors.

2. The Smart About Salt Program, developed by the Region of Waterloo, is a locally developed program that incorporates a multi-faceted approach to reduce the application of salt on both public and private properties by 1) working collaboratively with transportation operations staff from the municipally 2) developing guidelines and site

plan design recommendations to minimize the need for de-icing on new developments 3) building public awareness through education programs and 4) implementing the *smart about salt* accreditation program for private snow contractors and clients to recognize and incorporate beneficial salt management practices on parking lots and sidewalks. Initially developed as a voluntary accreditation program for snow and ice contractors as well as owners and managers of outdoor parking facilities, this program has tremendous potential for broad application and adoption in other jurisdictions.

Salt Application.

1. Improve parking lot and related stormwater management infrastructure design to optimize winter maintenance.
2. Provide training and guidelines for the application of road salt to parking lots.
3. Develop decision support tools to better delineate salt vulnerable areas and incorporate improved technologies to optimize the rates and magnitudes of road salt application.

Research.

1. Develop adaptation and mitigation strategies through improved design of roadways, parking lots and related stormwater infrastructure to mitigate chloride transfer to the environment.
2. Develop software to permit municipalities to calculate a local winter severity index that can be used to normalize salt application as a function of the variables that drive salt demand.
3. Conduct controlled studies to rigorously evaluate the effectiveness and environmental benefits of alternative deicers.
4. Develop regional assessment tools to identify salt vulnerable areas so that this information can be better integrated into Road Salt Management Plans and winter maintenance practice.
5. Explore a range of options to educate and improve the general awareness of the public regarding the effect of road salt on the environment, safe and responsible driving in winter conditions and installation of snow tires.
6. Conduct controlled studies to develop and provide guidance for the application of salt to parking lots and sidewalks.

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U of W Road Salt Management Survey

Winter 2009

U of W Salt Management Survey

1. Default Section

1. Your Information (This information is optional and will only be used if we need to follow up for clarification.)

Name:

Municipality

Email Address:

Phone Number:

*** 2. Please identify your municipal type:**

- Regional Municipality
- City
- County
- Town
- Other (please specify)

*** 3. Does your organization hire contractors/seasonal staff?**

	Yes	No	Don't Know
Contractors			
Seasonal Staff			

*** 4. Has your organization produced a Salt Management Plan (SMP) that uses best management practices in an effort to minimize the negative environmental impacts of road salt?**

- Yes
- No

U of W Salt Management Survey

2. Your Salt Management Plan

*** 1. What year was your plan first adopted? If you don't have one click "None".**

- ◯ 2001
- ◯ 2002
- ◯ 2003
- ◯ 2004
- ◯ 2005
- ◯ 2006
- ◯ 2007
- ◯ 2008
- ◯ 2009

*** 2. Who (what position) was responsible for creating and implementing the SMP?**

- ◯ No Plan
- ◯ Manager
- ◯ Commissioner
- ◯ Supervisor
- ◯ Director
- ◯ Other (please specify)

*** 3. Who (what position) is responsible for maintaining and updating the SMP?**

- ◯ No Plan
- ◯ Manager
- ◯ Commissioner
- ◯ Supervisor
- ◯ Director
- ◯ Other (please specify)

*** 4. If your SMP has been reviewed since it was created, please indicate the years it was reviewed.**

- ☐ Not Reviewed
- ☐ 2001
- ☐ 2002
- ☐ 2003
- ☐ 2004
- ☐ 2005
- ☐ 2006
- ☐ 2007
- ☐ 2008
- ☐ 2009

*** 5. Who is involved in the review of your SMP?**

*** 6. Are your contractors/seasonal staff aware of your Salt Management Plan?**

	Yes	No	Don't Know	Not Applicable
Contractors	◯	◯	◯	◯
Seasonal Staff	◯	◯	◯	◯

U of W Salt Management Survey

3. SMP not reviewed

*** 1. Do you plan to review your SMP in the near future?**

- ◯ Yes
- ◯ No

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4. SMP Rating

*** 1. How would you rate your organization's SMP (or best management practices) with respect to the following parameters: (1-Low means it's not addressed at all, 5-High means it's given a lot of attention)**

	1-Low	2	3	4	5-High
Safety: Your plan recognizes the importance of effective winter maintenance to the safety of roadway users and maintenance crews.	○	○	○	○	○
Environmental Protection: Your plan strives to minimize the amount of road salt entering the environment.	○	○	○	○	○
Continual Improvement: Your plan is a living document and is reviewed and updated regularly.	○	○	○	○	○
Fiscal Responsibility: Your SMP fits within the fiscal capabilities of your road authority.	○	○	○	○	○
Efficient Transportation Systems: Your Plan takes into account the effects on transportation system performance.	○	○	○	○	○
Accountability: Your plan identifies who is responsible and accountable for developing and implementing the SMP.	○	○	○	○	○
Measurable Progress: Your Plan has a mechanism for tracking and reviewing progress on its implementation.	○	○	○	○	○
Communication: Your plan contains a requirement for communicating internally and externally with key stakeholders.	○	○	○	○	○
Knowledge and Skilled Workforce: Your plan provides for training for managers, supervisors and operators.	○	○	○	○	○

*** 2. Are the following elements addressed in your salt management plan? (please check the box that applies in each case)**

	Yes	No	Don't Know
The type and amount of Chloride-based chemical used (all sources including solids, liquids and abrasive mixes)	○	○	○
The type and amount of non-chloride chemicals used	○	○	○
Current application rate for each type of material	○	○	○
Percentage of fleet with pre-wetting	○	○	○
Percentage of fleet with liquid only applications	○	○	○
Percentage of fleet with electronic spreader controls	○	○	○
Road weather information systems installation	○	○	○
Identified the location of salt use in vulnerable areas	○	○	○
Modified winter maintenance practices in the vicinity of salt vulnerable areas	○	○	○
Sand & salt storage good housekeeping practices	○	○	○
Snow storage and disposal practices	○	○	○
Training of staff in best salt management practices	○	○	○
Record keeping of salt use	○	○	○
Percentage of spreaders that are calibrated	○	○	○
Percentage of materials stored under cover	○	○	○
Documentation and record keeping	○	○	○
Monitoring of progress, anaysis and reporting to senior management	○	○	○
Annual review by senior management and corrective action	○	○	○

*** 3. Have there been any changes made to the following areas of your winter maintenance infrastructure since the adoption of the SMP?**

	Yes	No
Salt storage facilities	○	○
Snow disposal sites	○	○
Vehicles	○	○
Pavement temperature focus	○	○
Application rates	○	○
Use of liquids	○	○

Other (please specify)

*** 4. Does your road authority have documented policies, procedures and guidelines in the following areas?**

	Yes	No
Level of service for each roadway type	○	○
Salt and sand application rates	○	○
Good housekeeping practices for maintenance yards consistent with TAC's Design and Operation of Road Maintenance Yards Synthesis of Best Practices	○	○
Equipment calibration and re-calibration	○	○
Training	○	○
Snow disposal	○	○
Incorporation of salt management consideration into road & bridge design	○	○
Identification and protection of salt vulnerable areas	○	○

*** 5. To what extent are the following groups aware of your SMP? (please check the most appropriate response)**

	None	Some	Most	All
Managers	○	○	○	○
Supervisors	○	○	○	○
Operators	○	○	○	○

U of W Salt Management Survey

5. Public Information

* **1. Is the general public informed about changes to winter road maintenance practices?**

- ◯ Yes
- ◯ No
- ◯ Don't Know

U of W Salt Management Survey

6. How Pulbic Is Informed

*** 1. How do you inform the public of your Winter Maintenance Practices? (Check all that apply)**

- [ ] Internet/website
- [ ] Newspapers
- [ ] Pamphlets
- [ ] Public Meetings
- [ ] Radio
- [ ] Television
- [ ] Other (please specify)

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7. Salt Management Practices

*** 1. Has your organization implemented salt best management practices?**

- ◯ Yes
- ◯ No

U of W Salt Management Survey

8. Types of Practices

*** 1. What best management practices has your organization committed to or implemented?**

- [ ] Covered storage
- [ ] RWIS
- [ ] Anti-icing
- [ ] Good Housekeeping Practices
- [ ] Infra-red thermometers
- [ ] Dedicated weather forecasts
- [ ] Electronic spreader controls
- [ ] Calibration
- [ ] Snow drift control
- [ ] Variable application rates
- [ ] Pre-wetting
- [ ] GPS/AVL
- [ ] Other (please specify)

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9. Training

*** 1. Does your organization have annual salt managment training (either in house or outside) for any of its staff?**

- ◯ Yes
- ◯ No

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10. Training Information

*** 1. When is the training session scheduled? (Check all that apply)**

- [ ] Spring
- [ ] Summer
- [ ] Fall
- [ ] Winter

*** 2. Which of the following staff are trained in salt management?**

- [ ] Managers
- [ ] Supervisors
- [ ] Operators
- [ ] Seasonal Personel
- [ ] Contractor Personnel
- [ ] Other (please specify)

*** 3. Is the prescribed level of performance of trained personnel in compliance with the training session learning goals and is the compliance monitored?**

	Yes	No	Don't Know
Performance is in compliance with learning goals.	○	○	○
Compliance is monitored.	○	○	○

*** 4. What is done if the presecribed performance is not met?**

- [ ] Retrain
- [ ] Re-assign
- [ ] Nothing

Other (please specify)

*** 5. Is there a minimum passing grade for the salt management training? Please identify the passing grade in the comment section.**

- ○ Yes
- ○ No
- ○ Not Applicable

Passing Grade

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*** 6. Which of the following learning techniques do your salt management training sessions include? (Check all that apply.)**

- [ ] Verbal Presentations
- [ ] Visual Aids
- [ ] Group Discussions
- [ ] Hands on Practical Application
- [ ] Other (please specify)

*** 7. In your salt management training courses, what percentage of the learning comes from the following techniques? (Please assign 100 points to the techniques listed.)**

Reading

Hearing and Seeing (taught through presentation)

Discussion, Answering Questions, Group Work

Hands on Demonstrations

*** 8. Is the training session different for previously trained personnel and new personnel?**

- ( ) Yes
- ( ) No

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11. Learning Goals

*** 1. Are the following learning goals, as outlined by the Transportation Association of Canada, covered in your salt management training program?**

	Yes	No
SALT MANAGEMENT POLICY - Understand the definition and importance of Level of Service and that the goal is to achieve the prescribed level of service.	◯	◯
Understand the organization's Operating Policies and their application to winter operations.	◯	◯
Understand the organization's Salt Management Policy.	◯	◯
PRINCIPLES OF ICE FORMATION - Understand slippery road conditions are a result of water being lowered below its freezing point on the road surface.	◯	◯
Understand the sources of moisture on the road include dew, rain, and snow.	◯	◯
Understand dew point and what conditions will lead to dew forming on the road surface. Also understand what conditions will lead to frost and black ice forming on the road surface.	◯	◯
Understand the importance of pavement temperature in making snow and ice control decisions.	◯	◯
Understand why bridges freeze first.	◯	◯
SCIENCE OF FREEZE POINT DEPRESSANTS - Understand the concept of a freeze point depressant.	◯	◯
Understand that chemicals are used to prevent or break the bond between snow and ice.	◯	◯
Know the chemical composition of rock salt, and other chemicals used by your road authority.	◯	◯
Understand that brine rather than the solid chemical melts the snow and ice.	◯	◯
Understand the phase diagram for the chemicals that are used in your organization.	◯	◯
Understand the implication of chemical concentrations greater than the eutectic concentration.	◯	◯
Understand the criteria for the selection of de-icing chemicals.	◯	◯
Understand the relationship between chemical concentrations and freeze point.	◯	◯
Understand that dry chemicals and pre-wetted chemicals take time to work.	◯	◯
Understand the testing requirements and risks associated with the introduction of new snow and ice control chemicals.	◯	◯
Understand the principle of refreeze.	◯	◯
MATERIAL USE - Understand the role of traffic and crossfall of the road in forming and distributing brine.	◯	◯
Understand when to windrow and when to spin a pre-wetted solid.	◯	◯
Understand how to treat special areas such as bridges and culverts, super-elevations, intersections, hills (crests, sags, inclines), bus stops and high wind conditions.	◯	◯
Understand that chemical should not be applied to dry pavement where drifting snow is not sticking.	◯	◯
Understand when to use and not use specific chemicals, taking into account pavement temperatures, forecasts, time of day, humidity, traffic volumes etc..	◯	◯
Understand the procedure for making snow and ice control liquids from solid chemicals.	◯	◯
Understand the importance of quality control and chemical concentration.	◯	◯
Understand the benefits of using pre-wetting chemicals and abrasives.	◯	◯
Understand the difference between proactive anti-icing and reactive de-icing.	◯	◯
Understand how dry materials are pre-wetted.	◯	◯
Understand that salt and sand can bounce or be blown off the road and that this product loss can be reduced by pre-wetting.	◯	◯
Understand the concepts of liquid anti-icing.	◯	◯
Understand the benefits of a proactive anti-icing approach.	◯	◯
Understand how to fill spreaders and anti-icing units with liquid chemicals.	◯	◯

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Understand the health, safety and environmental precautions that need to be taken when handling liquid chemicals.	○	○
Understand how to measure brine concentrations.	○	○
Understand the timing of plowing operations so that chemicals are not plowed off the road prematurely.	○	○
Understand the importance of timely plowing.	○	○
Understand how to efficiently plow each beat/route.	○	○
ROAD SALT AND THE ENVIRONMENT - Understand that chlorides are mobile in the environment.	○	○
Understand that road salt may attract some wildlife to the road, potentially increasing the hazard of animal/vehicle collisions.	○	○
Understand that high salt levels can harm vegetation and agricultural crops adjacent to the roadway.	○	○
Understand that high salt levels can harm animals including fish living in streams, wetlands and lakes.	○	○
Understand that it is desirable to only use enough chemical to achieve the prescribed level of service.	○	○
MAINTENANCE YARDS - Understand that all salt and sand/salt blends should be covered to minimize salt loss.	○	○
Understand that salt spillage is wasteful and can be harmful to the environment.	○	○
Understand the salt-handling activities that result in wasteful releases of salt to the environment.	○	○
Understand how these salt-handling activities should be carried out to prevent the wasteful release of salt to the environment.	○	○
Understand that timely yard maintenance and repairs are necessary to control salt loss.	○	○
SNOW DISPOSAL - Understand how to manage the snow pile to facilitate melting.	○	○
Understand the measures to be used to control nuisance effects (noise, dust, litter).	○	○
Understand how to monitor and record chloride, metal, pH, TPH and suspended solids in meltwater discharges.	○	○
Understand how the snow disposal system has to be managed to be cost-effective and to reduce environmental and social impacts.	○	○
RECORD KEEPING - Understand the importance of timely and accurate records.	○	○
Understand the importance of good records for mounting a due diligence defence in the event of a lawsuit.	○	○
Understand how to complete your organization's activity/ storm reports.	○	○
Understand the importance of recording actions and inactions and the rationale for each.	○	○
Understand the importance of knowing your beat/route and what it takes to properly maintain it to the prescribed LOS.	○	○
SPREADERS - Understand the concept of putting out the right material, in the right amount, at the right time, and leaving it there long enough to do the job.	○	○
Understand how the electronic controller and gate settings on each spreader must be set to achieve the specified application rate.	○	○
Understand how to calibrate each spreader to ensure that the right amount of material is being spread.	○	○
Understand how to recognize when re-calibration is necessary.	○	○
DRIFT CONTROL - Understand the role and effective placement of snow drift control devices (structural snow fences, snow ridging, agricultural stubble, living snow fences).	○	○
WEATHER - Understand the kinds and sources of weather information.	○	○
Understand how to read a weather forecast.	○	○
Understand what can affect local weather conditions and why weather might vary from one location to another.	○	○
Understand lake effect snowfalls.	○	○
Understand that wind chill does not significantly affect absolute road temperatures but does affect the rate of cooling.	○	○
Understand when a forecast could be wrong.	○	○
Understand that a wind of 15 km/hr is needed to drift snow.	○	○

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Understand how wind changes can signal an approaching or passing storm.	○	○
Understand how to monitor weather conditions and anticipate changes.	○	○
Understand how to read a radar image and use the information in decision-making.	○	○
Understand how weather forecasts can be used in making snow and ice control decisions.	○	○
PAVEMENT TEMPERATURES - Understand the concept of heat balance and how it can affect pavement temperatures.	○	○
Understand how to read a pavement condition forecast.	○	○
Understand how pavement condition forecasts and real time information can be used in making snow and ice control decisions.	○	○
RWIS AND IRTS - Understand the components and purpose of RWIS installations.	○	○
Understand how to read and interpret RWIS data.	○	○
Understand how to properly mount a truck-mounted IRT so as to avoid erroneous readings.	○	○
Understand that IRT's are for measuring temperature trends, not exact temperatures.	○	○
Understand why odd readings might be obtained (e.g. interference, out of calibration, acclimatization, buried utilities, shading etc).	○	○
Understand precautions about handling and using IRT's.	○	○

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12. Salt Management Practices

*** 1. When applying road salt, does your organization:**

	Yes	No
Make snow and ice control decisions based on pavement temperatures, rather than air temperatures?	○	○
Conduct ongoing monitoring of pavement temperatures?	○	○
Use dedicated weather forecasts.	○	○

*** 2. Which, if any, measures has your organization taken to reduce salt use near salt vulnerable areas?**

- ☐ None
- ☐ Reduced application rates for solid salt
- ☐ Used pre-wetted salt
- ☐ Used straight liquid application (anti-icing)
- ☐ Used sand mix
- ☐ Plowed more frequently
- ☐ Plan roads to avoid salt sensitive areas
- ☐ Other (please specify)

*** 3. Which or the following practices if any, has your organization carried out?,**

- ☐ Planted salt tolerant plant species in areas subject to salt impact
- ☐ Use drift control measures to reduce snow accumulation on roadways
- ☐ Shield natural areas from salt spray by planting buffers of salt tolerant species
- ☐ Employed special drainage management techniques to reduce salt impacts to sensitive area.
- ☐ None of the above

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13. Record Keeping

*** 1. Does your organization monitor and keep records of your winter maintenance activities?**

- ◯ Yes
- ◯ No

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14. Record Keeping Practices

*** 1. Which of the following records do you keep?**

- [ ] Air temperatures
- [ ] Pavement temperatures
- [ ] Pavement temperature trends
- [ ] Road condition
- [ ] Current weather condition
- [ ] Application rates
- [ ] Treatment strategy
- [ ] Daily salt use
- [ ] Annual salt use
- [ ] None of the above

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15. Maintenance Yard Design & Operation

*** 1. Have you constructed a new maintenance yard in the last 5 years?**

- ◯ Yes
- ◯ No

16. Information on Maintenance Yards

* 1. When planning your new yard was an environmental assessment conducted to understand the risks associated with salt loss?

- Yes
- No

* 2. Do you use the following practices at any of your yards?

	All Yards	Some Yards	No Yards
Salt is unloaded directly inside the storage facility			
Spreaders are not washed at the yards			
Spreaders are washed at the year but wash water is managed			
All materials are stored under cover on impermeable floors			
Salt impacted water is collected and used for brine production			
Spreaders are loaded inside the facility			
Spreaders are not overloaded			
Spilled salt is cleaned up			
Facility roof and floor are inspected annually and repaired as needed			
Vehicles are weighed to measure salt use			
Environmental monitoring			

* 3. Did you follow TAC's SOBP#7.0 - Design and Operation of Road Maintenance Yards?

- Yes
- No

17. Did Not Use SOBP

*** 1. Why did you not follow TAC's SOBP #7.o - Design and Operation of Road Maintenance Yards?**

- [ ] Didn't know about it
- [ ] It was too onerous
- [ ] We didn't want to follow it
- [ ] Other (please specify)

U of W Salt Management Survey

18. Snow Disposal Site Design & Operation

*** 1. Do you have snow disposal areas**

- ◯ Yes
- ◯ No

19. Information on SDFs

*** 1. Do you use the following practices at any of your snow disposal facilities?**

	All	Some	Non
Snow stored on impermeable hard surface	◯	◯	◯
Melt water is collected and treated in a tank or pond before dishcarge	◯	◯	◯
Debris is cleaned up in the spring and sent for proper disposal	◯	◯	◯

*** 2. Have you constructed a new snow disposal facility in the last 5 years?**

◯ Yes

◯ No

U of W Salt Management Survey

20. New SDF Details

*** 1. When planning your new snow disposal site did you do an Environmental Assessment under the Environmental Assessment Act?**

- ◯ Yes
- ◯ No

*** 2. Did you follow TAC's SOBP #8.0 - Snow Storage and Disposal?**

- ◯ Yes
- ◯ No

21. No Snow Disposal Site SOBP

*** 1. Why did you not use TAC's SOBP #8.0 - Snow Storage and Disposal?**

- [ ] Didn't know about the SOBP
- [ ] It was too onerous
- [ ] We did not want to follow it
- [ ] Other (please specify)

U of W Salt Management Survey

22. General

*** 1. Will you be completing your Environment Canada submission before the end of June?**

- ◯ Yes
- ◯ No
- ◯ Does not apply because we use less than 500 tonnes of salt and do not have any salt vulnerable areas

*** 2. What do you feel have been the benefits of Environment Canada's Code of Practice?**

*** 3. What do you feel have been the challenges with meeting Environment Canada's Code of Practice?**