Appendix F:
Source Water Protection Technical Memorandum

Technical Memorandum

From: David Ketcheson, Azimuth Environmental Consulting, Inc.
To: Daniel Twigger, C.C. Tatham & Associates Limited

Re: Drainage Master Plan
Source Water Protection Considerations

Project: 17-092
Date: November 27, 2018

The purpose of this document is to provide a technical briefing of source water protection considerations that might be factored into the overall Drainage Master Plan for the City of Barrie. Key considerations are highlighted in the upfront section of the briefing. The technical support for these considerations can be found in the appended materials.

The key considerations are premised on competing interests that primarily evolve around the benefits of enhanced infiltration recharge versus the consequences of potential contaminant flux created by the infiltrating waters. Thus, the central theme is whether it is advantageous or detrimental to limit infiltration opportunities in order to address contaminant loading to the ground water system.

In our opinion, this fundamental concern about infiltration has many contributing factors which obfuscate the correct resolution to this question. What is apparent is that the competing interests are poorly aligned toward a preferred strategy. In that regard, the solution is likely to be a balancing of opposing influences to achieve the optimum outcome. It is felt that further evaluation of these contributing factors could assist this assessment and some recommendations regarding the scope of the future work being contemplated have been included for consideration.

Key Considerations
In no order of importance:

- from a geologic context, the City is spatially quite different. The Drainage Master Plan should address this situation;
    - the Kempenfelt Bay tunnel channel area of the City is highly vulnerable and has been impacted by anthropogenic contaminants including winter salt uses;
    - the municipal wellfield in this geologic unit should be protected by prohibiting to the extent possible any and all impaired water infiltration;
    - in contrast, the upland areas north and south of the Kempenfelt Bay tunnel channel have a low aquifer vulnerability and the ground water resources beneath these areas are well protected; even the most sensitive wellhead areas (*i.e.,* WHPA-A zones);

- some past operational plans may not have fully embraced the differences in the geologic setting;

- a significant data gap exists which prevents a knowledgeable opinion from being rendered;
  - further assessment is recommended to provide the insights needed to address Source Water Protection issues as they pertain to the Drainage Master Plan;
  - numerical evaluation of the historic winter salt mass loading influences on the ground water and surface water resources need to be determined using a contaminant transport model;
  - the future direction of the City's drinking water resource development strategy would be useful to determine. Knowledge of this strategy could afford a superior source water protection plan having regard for the dominant resource to be used in the City's long term development plans (*e.g.,* surface or ground water);

- an effective interim strategy developed by the City of Barrie is recommended until the above noted data gaps in knowledge can be resolved;
  - the principles of the City's "infiltration low impact development screening process" (City of Barrie, 2017) provide a sound interim rationale for the Drainage Master Plan;
  - given the geologic setting present in the upland areas of the City and the associated low aquifer vulnerability index (AVI), Azimuth suggests that there is some latitude that could be afforded for the application of some the above noted infiltration LID screening processes as has been discussed in the appended attachment.

Rationale Discussion

Low-impact development (LID) practices are central to contemporary drainage / stormwater management (SWM) practices. When the source water is pristine then there is a strong desire to infiltrate this excess flow into the underlying soils. This is a central theme to LID-based SWM.

Conversely, when excess waters are (chemically) impaired to some degree then introduction of these waters into the ground water flow system as recharge can be greatly diminished to the point where the activity is deemed to be more detrimental than beneficial. Azimuth was tasked with assessing the "source water protection" implications to this issue. In dealing with this issue it has become apparent that the issue is much more complex than just the source water protection implications. Thus, a central question to this evaluation is how can this assessment be objectively weighed. This presentation attempts to identify the myriad of considerations to this question as it applies to this specific application.

Source Water Protection Issue

The City of Barrie (the "City") uses both ground water and surface water resources to provide a potable drinking water supply. The tenets of "source water protection" are to safeguard all municipal drinking water resources. Through the use of the multiple barrier approach advocated by Justice O'Connor, municipalities are to keep contaminants from reaching the public (O'Connor, 2002).

This situation poses a unique dilemma to the City in developing a drainage master plan. Simply stated do you divert impaired storm water to the receiving surface water body used for drinking water in order to minimize the influence this impaired excess water has on the ground water resources used for drinking water.

Source water protection policies do not specifically address SWM issues; although it could be argued that through provincial instruments these concepts may be considered. Regardless, source water protection seeks to eliminate contaminant threats and in that context the drainage master plan could consider strategies that achieve that goal.

In their technical SWM guideline, the Lake Simcoe Region Conservation Authority (LSRCA, 2016) highlight the various contaminants addressed in SWM. These include: oil, grease, metals, pesticides, fertilizers, winter salt and sediment which tend to build up on surfaces in urbanized areas. It is suggests that these contaminants come from sources such as pavement deterioration, tire and brake pad wear, vehicle emissions, spills, construction and road maintenance and also come from yard and garden care. Stormwater runoff picks up these contaminants and can transfer them to streams or ground water. Degradation of water quality can result in a decline in plant and animal diversity. It may also affect drinking water supplies and recreational uses of water such as swimming (MOE, 2003[*sic*]).

While all of these considerations can be important to SWM and hence the Drainage Master Plan, this discussion will focus on winter salt impacts because of the implications to the City's Source Water Protection program as highlighted below.

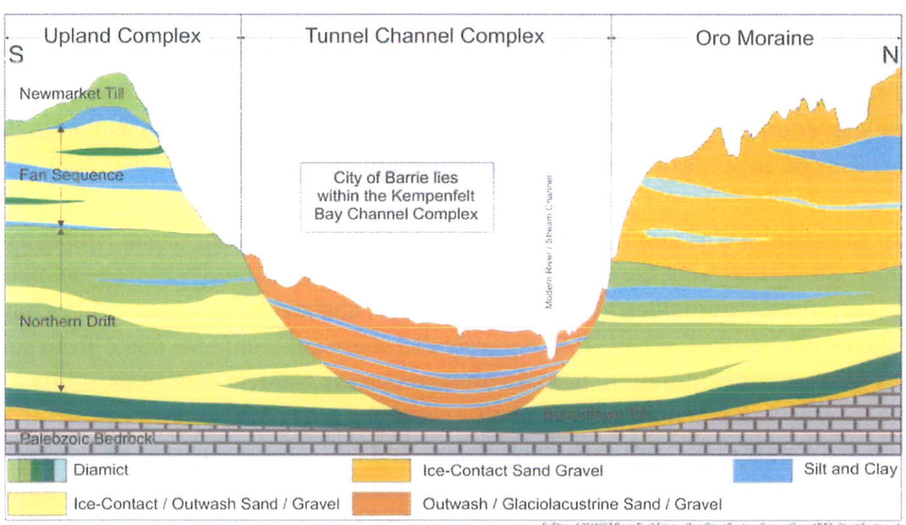
Drinking Water Systems

The City has relied on the local ground water resources to provide a potable municipal drinking water supply for decades. However, a Class Environmental Assessment completed in the 2000s advocated the development of a surface water resource to address future population needs. In 2011, the City's first surface water treatment plant was commissioned and began to supply the City along with its existing ground water network.

In the long term it would be beneficial to understand whether the surface water resource is likely to replace the ground water resource as the primary drinking water supply for the City. Understanding the timeframe for such infrastructure changes would also assist in evaluating long term objectives to source water protection and could dovetail into the ancillary master plan development. It is speculated that enhanced protection of the resource likely to be used into the future or to become the dominate resource for the City in the long term is worth considering and a factor in the longer term planning initiatives.

Ground Water Supply Issues

The City's ground water resource situated west of Kempenfelt Bay has been influenced by the long term use of winter salt on the surrounding environment. The surface geologic setting as depicted below is granular in nature and readily promotes surface water infiltration.



Source: AquaResource *et al*, 2013

The Kempenfelt Bay tunnel channel complex is a significant linear geologic feature which represents a former glaciofluvial channel cut through the local geology from the Minesing wetlands through to the Trent-Severn glacial drainage channel. It was the primary drainage channel for Lake Algonquin during the last glacial retreat and in that capacity eroded a tunnel channel through the Barrie area and eventually deposited outwash sediments within this feature over its lifespan.

The uniqueness and alignment of the feature is important in understanding how the aquifer complex has been impacted by winter salt influences. Infiltrating waters impaired by the applied winter salt have percolated into the deep ground water system over time to the extent where this influence is readily discernible in the deep municipal water supply well drawing from this aquifer complex. The depiction of the Kempenfelt Bay tunnel channel shows an alternating sequence of outwash sediments and silts and clays. In realty, material deposition in the fluvial channel shifted over time depending upon the rates of flow through this feature. Hence, finer-grainer materials are depicted in the channel corridor as well as outwash granular seams. The deepest aquifer system has traditionally yielded the greatest quantities of water and where most municipal well screens are situated. The layering of the finer grain sediments is considered imperfect and potentially undermined by stream braiding when the glacial flows were diminished.

Sodium and chloride for certain municipal supply wells within the Kempenfelt Bay tunnel channel sediments of the City are trending to exceed Ontario Drinking Water Quality Standards within the next 50 years (City of Barrie, 2016). This salt trend is sufficiently high enough to demarcate an "issues contributing area (ICA)" within the South Georgian Bay Lake Simcoe (SGBLS) Source Protection Plan for the City within the Kempenfelt Bay tunnel channel area (SGBLS, 2017). The intent of the ICA is to facilitate the implementation of enhanced source protection strategies to abate this observed trend.

Surface Water Issues

A potential ground water mitigation strategy to the winter salt infiltration issue is to route all impaired surface waters within the Kempenfelt Bay tunnel channel area to Lake Simcoe. However, the strategy is unbalanced with respect to surface water impairment issues.

The Lake Simcoe Protection Plan notes that for "... [t]he last four decades of research, monitoring, and scientific studies show how human-related activities, including urban and rural uses, recreation and agriculture, have impaired the health of the Lake Simcoe watershed through direct and indirect changes. The threats include: degraded water quality due to excessive nutrient, such as phosphorus, contaminants, and pathogens, that directly or indirectly affect the health of the ecosystem and the suitability of the water for recreational uses ...", (MOE, 2009).

In essence the same contaminants of concern for the ground water resources are also of concern to the lake.

More recently the LSRCA Technical Guideline for SWM Submissions (2016) has stated:

> "...[w]inter salt is detrimental to freshwater aquatic species, in particular, Redside Dace (*Clinostomus elongatus*) which have endangered species status the Ontario Endangered Species Act, 2007. The South Georgina Bay Lake Simcoe Source Protection Plan (2017[*sic*]) has also identified road salt as a prescribed drinking water threat.
>
> Winter salt dissolves in water and enters natural water systems via infiltration to groundwater, runoff to surface water and through storm drains. The salt remains in solution and there are currently no viable options for removal from stormwater ...".

The LSRCA indicate that mitigation of winter salt is best achieved through improved road and parking lot design in concert with a salt management plan (LSRCA, 2016). To that end, LSRCA has commissioned a parking lot design guideline to promote salt reduction (GHD Limited, 2017). The document attempts to point out design elements which could reduce winter salt use for parking lot areas and provides several examples of favoured design. The strategies tend to provide permeable surfaces to mitigate overland flow and in essence promote infiltration techniques as part of this overall strategy.

Data Gap to Design Resolution

As can be seen above, concerns about winter salt impaired water handling exist whether in terms of ground water or surface water receptors. There is no clear understanding whether one resource should be protected over the other (to the extent possible). The resolution of this question is critical to several strategies including the Drainage Master Plan.

Azimuth suggests a viable means to resolving this issue is through the use of a numerical contaminant transport model evaluation of the Kempenfelt Bay tunnel channel aquifer complex. The numerical model for this area has already been developed for the Tier Three Water Budget Evaluation (AquaResource *et al*, 2013). The modeling exercise would permit the City to understand how the past winter salt program is influencing this wellfield and move forward whether the protection of one resource over the other is warranted to optimize the risk mitigation to both drinking water resources.

An analogous study to that suggested above was completed for the Region of Waterloo in 2005. In summary the following was noted:

> "The impact of road salt on a wellfield in a complex glacial moraine aquifer system is studied by numerical simulation. The moraine underlies an extensive urban and industrial landscape, which draws its water supply from >20 wellfields, several of which are approaching or have exceeded the drinking water limit for chloride. The study investigates the mechanisms of road salt infiltration, storage, and transport in the subsurface and assesses the effectiveness of mitigation measures designed to reduce the impact. The three-dimensional transport model accounts for increases in salt loading, as well as growth of the urbanized area and road network over the past 50 years. The simulations, which focus on one impacted wellfield, show chloride plumes originating mainly at arterial roads and migrating through aquitard windows into the water supply aquifers. The results suggest that the aquifer system contains a large and heterogeneously distributed mass of chloride and that concentrations in the aquifer can be substantially higher than the concentrations in the well water. Future impact scenarios indicate that although the system responds rapidly to reductions in salt loading, the residual chloride mass may take decades to flush out, even if road salting were discontinued. The implications with respect to urban wellfields in typical snow-belt areas are discussed ...", (Bester *et al*, 2006 - see Attachments)

The findings of this study were revealing in that there existed a contaminant mass moving through the system which cannot be easily mitigated. It points out the limitations to Source Water Protection strategies in that it could take decades to realize the benefits to the efforts and even then these could be limited depending upon the degree of reduction that can be facilitated.

The greatest shortfall to this proposal is that the existing model is not well coupled to a basin surface water / lake model. Thus, in the absence of this situation there will be a need to carefully assess the surface water impairments. Boundary conditions need to be carefully assessment in order not to skew the numerical results within Kempenfelt Bay. Even then the insights obtained from the numerical modeling are anticipated to be invaluable in making risk mitigation decisions about the Kempenfelt Bay tunnel channel aquifer complex and the protection of this resource for drinking water supplies[1].

---

1 In stating this it is also recognized that the City is also address chlorinated solvent plumes that are also influence the ground water drinking water system which may also need to be assessed as part of this overall contaminant transport assessment program. There may be little worth in address the winter salt issue in isolation of the dissolved phase solvent plume especially if changes to the deep flow system are being made to mitigate winter salts that could have implications to the stability of the dissolved phase plume migration in this same aquifer system.

Interim Strategy

Decisions about the Drainage Master Plan are needed immediately. To deal with this, an interim strategy is to be used. This strategy is to mirror the "Infiltration Low Impact Development Screening Process" (City or Barrie, 2017).

Considerable effort has been expended in developing the LIDs rationale for SWM in the City of Barric through this proccss. In doing so it is rccognizcd that input from thc Risk Management Official (RMO) has occurred. The document references Source Water Protection principles in several locations in addressed the process that is being considered. This presentation will highlight parts of the document; but it should be fully reviewed and thoroughly referenced as part of the Drainage Master Plan strategy development.

<u>Linear Development Strategy</u>

For linear developments the City of Barrie has developed that following strategy:

Table 1.1 City of Barrie requirements for the implementation of infiltration type LIDs for linear developments based on Source Water Protection Vulnerable Area and road classification

Road Classification	Vulnerable Area	Requirement
Arterial & Collector	*Issues Contributing Area*	Infiltration based practices not permitted
	Wellhead Protection Area A and B	
	Wellhead Protection Area C and D	
	Intake Protection Zone-1 and Zone-2	Infiltration based practices are permitted with conditions
	Lake Simcoe Protection Plan Significant Groundwater Recharge Areas	
	Highly Vulnerable Aquifers	
	Not Vulnerable	
Local	*Issues Contributing Area*	Infiltration based practices are permitted with conditions
	Wellhead Protection Area A and B	Infiltration based practices are not permitted
	Wellhead Protection Area C and D	Infiltration based practices are permitted
	Intake Protection Zone-1 and Zone-2	
	Lake Simcoe Protection Plan Significant Groundwater Recharge Areas	Infiltration based practices are permitted with conditions
	Highly Vulnerable Aquifers	Infiltration based practices are permitted
	Not Vulnerable	

As noted above, the recommendation differentiates between arterial, collector and local roads. This philosophy is consistent with the Bester *et al* (2006) findings for the Region of Waterloo.

It would be our recommendation to adopt this interim strategy within the Kempenfelt Bay tunnel channel lands. Azimuth is less convinced of its need outside of the central portion of the City. For example, the wellfields within the Nottawasaga watershed may not need to enforce this prescriptive standard to the degree that it is needed within the tunnel channel lands.

The basis for this rationale is that the deep aquifer systems outside of the Kempenfelt Bay tunnel channel area are much more protected than those permeable lands within the tunnel channel. Consider the geologic cross section depiction above (AquaResource, 2013) where uplands on either flank of the central Kempenfelt Bay tunnel channel are much thicker with more significant aquitard layers. Water taking from depth is potentially more influenced by lateral flow from the tunnel channel sediment then from vertical migration overhead. The original aquifer vulnerability assessment of the deep aquifer system (Figure 8a-2 - SGBLS, 2017 - Chapter 8) by Golder Associates revealed that the "aquifer vulnerable index (AVI)" score was in the range of 180.

The AVI method uses a scoring system that reflects the thickness and the type of overburden material. Aquifers of high vulnerability have an AVI score less than 30, meaning the overlying material is thin and/or permeable. While aquifers of a low vulnerability have an AVI score greater than 80, meaning the overlying material is thicker and/or less permeable (SGBLS, 2017 - Chapter 4). The large AVI score of the deep aquifer system attests to the extensive sediment thickness above this confined aquifer complex as well as the impervious nature of the aquitard materials that are protecting the resource. At twice the "low vulnerability" threshold, the AVI scoring speaks to the protected nature of the aquifer systems in these upland areas (*i.e.,* Municipal Well No.: 9, 13 and 16).

Major and Non-Major Development Strategy

The LID screening process also addresses major and non-major development. Azimuth is in agreement that vegetated areas and rooftop runoff are considered to be clean and suitable for infiltration strategies.

The LID screening process also identified two other runoff considerations being: pollution hot spots and paved areas (*e.g.,* parking lots and walkway, *etc.*). The City has adopted a precautionary approach in addressing "hot spots" in prohibiting LID infiltration strategies due to the ground water contamination potential. This interim strategy seems reasonable for a City dependent in part on ground water resources.

The City's LID screening process for paved areas stated that there is "... particular concern to Source Water Protection is the fact that land-use will have a significant influence on the amount of road salt that is applied on these paved surfaces. As such runoff from paved areas, given its location within a Source Water Protection vulnerable area, will be assigned a recommendation similar to those for linear projects ...", (City of

Barrie, 2017). Following this philosophy the following table addresses paved areas (below).

Table 1.2 Infiltration LID requirements for **paved area** runoff for major and non-major development

Note: This table outlines requirements for paved area runoff only. Runoff from vegetated areas and rooftop are always permitted to be infiltrated, while runoff from pollution hot spot is never permitted.

<table>
<tr><th>Land Use</th><th>Vulnerable Area</th><th>Requirement</th></tr>
<tr><td rowspan="7">Low Density Residential</td><td>Wellhead Protection Area A and B</td><td>Infiltration based practices are not permitted</td></tr>
<tr><td>Issues Contributing Area</td><td rowspan="6">Infiltration based practices are permitted</td></tr>
<tr><td>Wellhead Protection Area C and D</td></tr>
<tr><td>Intake Protection Zone-1 and Zone-2</td></tr>
<tr><td>Lake Simcoe Protection Plan Significant Groundwater Recharge Areas</td></tr>
<tr><td>Highly Vulnerable Aquifers</td></tr>
<tr><td>Not Vulnerable</td></tr>
<tr><td rowspan="7">Commercial & Institutional</td><td>Wellhead Protection Area A and B</td><td rowspan="2">Infiltration based practices are not permitted</td></tr>
<tr><td>Issues Contributing Area</td></tr>
<tr><td>Wellhead Protection Area C and D</td><td>Infiltration based practices are permitted with conditions</td></tr>
<tr><td>Intake Protection Zone-1 and Zone-2</td><td>Infiltration based practices are permitted</td></tr>
<tr><td>Lake Simcoe Protection Plan Significant Groundwater Recharge Areas</td><td rowspan="2">Infiltration based practices are not permitted</td></tr>
<tr><td>Highly Vulnerable Aquifers</td></tr>
<tr><td>Not Vulnerable</td><td>Infiltration based practices are permitted</td></tr>
<tr><td rowspan="7">Industrial</td><td>Wellhead Protection Area A and B</td><td rowspan="7">Infiltration based practices are not permitted</td></tr>
<tr><td>Issues Contributing Area</td></tr>
<tr><td>Wellhead Protection Area C and D</td></tr>
<tr><td>Intake Protection Zone-1 and Zone-2</td></tr>
<tr><td>Lake Simcoe Protection Plan Significant Groundwater Recharge Areas</td></tr>
<tr><td>Highly Vulnerable Aquifers</td></tr>
<tr><td>Not Vulnerable</td></tr>
<tr><td rowspan="7">Mixed Use and High Density Residential</td><td>Wellhead Protection Area A and B</td><td>Infiltration based practices are not permitted</td></tr>
<tr><td>Issues Contributing Area</td><td rowspan="2">Infiltration based practices are permitted with conditions</td></tr>
<tr><td>Wellhead Protection Area C and D</td></tr>
<tr><td>Intake Protection Zone-1 and Zone-2</td><td>Infiltration based practices are permitted</td></tr>
<tr><td>Lake Simcoe Protection Plan Significant Groundwater Recharge Areas</td><td rowspan="2">Infiltration based practices are permitted with conditions</td></tr>
<tr><td>Highly Vulnerable Aquifers</td></tr>
<tr><td>Not Vulnerable</td><td>Infiltration based practices are permitted</td></tr>
<tr><td rowspan="7">Open Spaces and Environmental Protection Areas</td><td>Wellhead Protection Area A and B</td><td rowspan="6">Infiltration based practices are permitted with conditions</td></tr>
<tr><td>Issues Contributing Area</td></tr>
<tr><td>Wellhead Protection Area C and D</td></tr>
<tr><td>Intake Protection Zone-1 and Zone-2</td></tr>
<tr><td>Lake Simcoe Protection Plan Significant Groundwater Recharge Areas</td></tr>
<tr><td>Highly Vulnerable Aquifers</td></tr>
<tr><td>Not Vulnerable</td><td>Infiltration based practices are permitted</td></tr>
</table>

Azimuth's recommendation would differ slightly with the City's for low density residential development in that we would also promote LID infiltration in the WHPA-A and WHPA-B regions of the City; especially for any upland lots due to the significant separation between the ground surface and well screen depth as indicated by the AVI assessment. The same would be advocated for open spaces and environmentally protected areas where LID infiltration is in keeping with the natural ecological functions of these areas.

Finally, for the upland areas outside of the Kempenfelt Bay tunnel channel area Azimuth would suggest that mixed use and high density residential development should also consider the overall benefits to LID infiltration strategies given the low aquifer vulnerability for these areas of the City.

DRK:

Attach:

M:\17 Projects\17-092 City of Barrie Drainage Master Plan\05.0 - Reporting\Source Water Protection\05.3 - Final\Files\181127 - SWP for Drainage Master Plan Study - Azimuth - Issued.doc

References

AquaResource, International Water Consultants and Golder Associates, 2013
City of Barrie Tier Three Water Budget and Local Area Risk Assessment
prepared for the Lake Simcoe Region Conservation Authority
Final Report, Breslau, July, p. 112 plus appendices

Bester, M.L., E.O. Frind, J.W. Molson and D.L. Rudolph, 2006
Numerical Investigation of Road Salt Impact on an Urban Wellfield
Groundwater, 44(2), pp: 165-175

City of Barrie, 2017
Infiltration Low Impact Development Screening Process
issued May 2, p. 18

City of Barrie, 2016
Salt Optimization Strategy
p. 20

GHD Limited, 2017
Parking Lot Design Guidelines to Promote Salt Reduction
prepared for Lake Simcoe Region Conservation Authority
issued February 2, p. 109

Lake Simcoe Region Conservation Authority, 2016
LSRCA Technical Guideline for Stormwater Management Submissions
issued September 1, 2016, p. 130

Ministry of the Environment, 2009
Lake Simcoe Protection Plan
Queen's Printer for Ontario, July, p. 45

Ministry of the Environment and Climate Change, 2003
Understanding Stormwater Management: An Introduction to Stormwater Management Planning and Design - Major concepts and environmental concerns to consider in the Ministry of the Environment's Stormwater Management Planning and Design Manual
https://www.ontario.ca/page/understanding-stormwater-management-introductionstormwater-management-planning-and-design

O'Connor, Dennis. R., 2002
Report of the Walkerton Inquiry
A Strategy for Safe Drinking Water - Part Two
Queen's Printer for Ontario, pp. 588

South Georgian Bay Lake Simcoe Source Water Protection Committee, 2017
Lakes Simcoe and Couchiching-Black River SPA Assessment Report
Chapter 8: City of Barrie
p. 65 plus appendices

Attachment

Bester, M.L., E.O. Frind, J.W. Molson and D.L. Rudolph, 2006
Numerical Investigation of Road Salt Impact on an Urban Wellfield
Groundwater, 44(2), pp: 165-175

ground water

Numerical Investigation of Road Salt Impact on an Urban Wellfield

by M.L. Bester[1,2], E.O. Frind[1], J.W. Molson[1,3,4], and D.L. Rudolph[1]

Abstract

The impact of road salt on a wellfield in a complex glacial moraine aquifer system is studied by numerical simulation. The moraine underlies an extensive urban and industrial landscape, which draws its water supply from >20 wellfields, several of which are approaching or have exceeded the drinking water limit for chloride. The study investigates the mechanisms of road salt infiltration, storage, and transport in the subsurface and assesses the effectiveness of mitigation measures designed to reduce the impact. The three-dimensional transport model accounts for increases in salt loading, as well as growth of the urbanized area and road network over the past 50 years. The simulations, which focus on one impacted wellfield, show chloride plumes originating mainly at arterial roads and migrating through aquitard windows into the water supply aquifers. The results suggest that the aquifer system contains a large and heterogeneously distributed mass of chloride and that concentrations in the aquifer can be substantially higher than the concentrations in the well water. Future impact scenarios indicate that although the system responds rapidly to reductions in salt loading, the residual chloride mass may take decades to flush out, even if road salting were discontinued. The implications with respect to urban wellfields in typical snow-belt areas are discussed.

Introduction

As urban populations throughout the world continue to grow, increasing demands are being placed on transportation networks. One consequence is that in northern regions such as eastern Canada, Finland, and the northeastern United States, it has become standard practice over the past 50 years to keep roads and highways free of snow and ice by applying deicing chemicals. The chemical of choice is, in most cases, road salt, or sodium chloride (NaCl). Consequently, millions of tons of road salt are being applied annually, often without proper documentation of application rates, distribution, or frequency. In Canada during the late 1990s, estimates show that ~4.9 million tons of road salt were released to the environment each year, equivalent to 3 million tons of chloride (Environment Canada 2001). In the United States, between 10 and 20 million tons/year of road salt are applied nationwide (Envirocast Newsletter 2003). Application practices differ greatly from community to community. Where fear from legal liability is a motivation, application rates may exceed what would be necessary for road safety. Unfortunately, the environmental consequences of road salting are not yet well understood by the public and the decision makers.

The environmental impact of road deicing salt has become a growing concern over the past decade. Road salt has been linked, for example, to contamination of surface water and ground water, damage to trees and structures, and degradation of local ecosystems (Howard et al. 1993; Jones et al. 1986). In particular, ground water contamination by road salt can have a serious impact in areas that are dependent on ground water for their drinking water supply (Stantec 2001). Thus, cost-effective and defensible management tools are needed to evaluate the impact and risk to ground water from winter road salting. To develop the necessary scientific basis, a thorough understanding of the mechanisms that link the application of road salt to the contamination of ground water must be developed.

[1]Department of Earth Sciences, University of Waterloo, Waterloo, Ontario, Canada N2L 3G1.

[2]Currently at the University of Stuttgart, Germany.

[3]Department of Civil, Geological and Mining Engineering, École Polytechnique, P.O. Box 6079, Station Centre-ville, Montréal, Quebec, Canada H3C 3A7.

[4]Corresponding author: (514) 340-4711 x5189; fax (514) 340-4477; john.molson@polymtl.ca

Received November 2004, accepted May 2005.

doi: 10.1111/j.1745-6584.2005.00126.x

Across North America, there are numerous documented cases of ground water contamination from road salt including those by Huling and Hollocher (1972), Pilon and Howard (1987), Locat and Gélinas (1989), Pollock (1992), Howard et al. (1993), Howard and Haynes (1993), Gutiw and Jin (1998), and Novotny et al. (1999). One of the earliest studies in Canada was by Paine (1979), who performed a chloride mass balance on the Don River watershed in Toronto, Ontario, and found that as little as 50% of the NaCl being applied to the watershed was being removed by surface water flow, with the rest infiltrating to ground water. The fraction of road salt that infiltrates to shallow ground water has also been estimated by McConnell and Lewis (1972) as 25% to 50%, and by Environment Canada (2001) as 10% to 60%. Also within the Greater Toronto Area, Pilon and Howard (1987) reported chloride concentrations as high as 14,000 mg/L in shallow subsurface water adjacent to a salted urban Toronto highway, with evidence of road salt contamination at distances of up to 100 m from major urban roads. In the cities of Kitchener-Waterloo in southern Ontario, Sarwar et al. (2002) found average chloride concentrations of 2700 mg/L in shallow ground water below primary and secondary roadways. In their Road Salt Assessment Report, Environment Canada (2001) found chloride concentrations up to 18,000 mg/L in road runoff, 4000 mg/L in wetlands and watercourses, and 2800 mg/L in shallow ground water adjacent to salt storage yards.

Road salt contamination is also a concern in several European countries. In Finland, for example, where road salt contamination is a particular risk, 43% of the 2200 ground water areas mapped as important for water supply are traversed by roads that receive heavy applications of deicing chemicals (Nystén 1998). In a detailed hydrogeological investigation to assess impacts of road salt applications on a large aquifer system in Finland, Coster et al. (1994) used field data collected over a period of 2 years, as well as historical data, to calibrate a flow and transport model and to correlate changes in chloride migration with changes in pumping rates and recharge. Most recently, Finnish research has focused on assessing risk and evaluating alternative deicers (Gustafsson and Nystén 2000; Nystén and Gustafsson 2000; Hellstén and Nystén 2003). Hellstén et al. (2004), for example, show that the use of potassium formate (at 5400 kg/km) instead of sodium chloride reduced sodium and chloride concentrations in nearby ground water by >40% within 2 years. In the shallow subsurface, potassium formate was shown to rapidly degrade to carbon dioxide and water (plus potassium), none of which are environmentally harmful (the significance of the resulting CO_2 as a greenhouse gas remains to be investigated).

The Government of Canada now recognizes road salt as a toxic environmental contaminant (Canada Gazette 2001) and has recently released a Code of Practice recommending road authorities implement road salt management plans (Canada Gazette 2004). The code contains directives for monitoring road salt usage and storage, and for identifying environmentally sensitive receptors including ground water and surface water. The Code of Practice was developed under the *Canadian Environmental Protection Act* (1999), the cornerstone of federal legislation for protecting the health of Canadians and their environment.

While considerable work has been done to address road salt concerns, the focus up to now has been on field monitoring, small-scale modeling test cases, and statistical assessment of prevention measures. In the light of recent concerns about legacy sources of road salt derived from >50 years of application, there is a need for a comprehensive and quantitative assessment of surface loadings and subsequent comparative impacts on municipal water supplies. In addition, the significance of complex hydrostratigraphy that is common in the snow-belt regions, such as Canada, the northeastern United States, and Nordic countries such as Finland, should be investigated in connection with salt impact on ground water.

Our objective here is to investigate the mechanisms of road salt infiltration, storage, and transport in a complex glacial moraine aquifer-aquitard system, to evaluate the impact on a typical wellfield, and to assess the effectiveness of mitigation measures designed to reduce the impact. The Greenbrook wellfield, which supplies ~10% (~13,000 m^3/d) of the drinking water for the Regional Municipality of Waterloo (RMOW), is used as a demonstration case.

Background

The RMOW, with a population of >400,000, is located in southwestern Ontario and includes the cities of Kitchener, Waterloo, and Cambridge, as well as several municipal townships (Figure 1). Local ground water

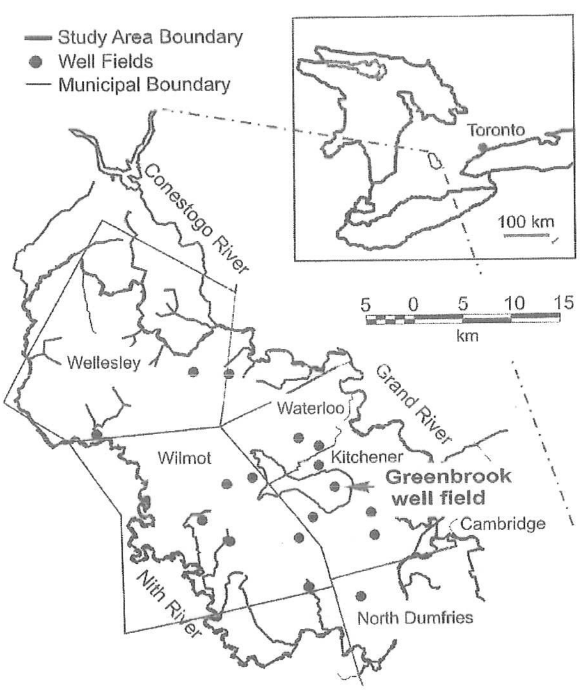


Figure 1. Location of the Greenbrook wellfield within the RMOW. The local outline around the Greenbrook wellfield is the 280-year ground surface capture zone (Frind et al. 2002).

resources provide ~80% of the drinking water from 10 major wellfields, the first of which (Greenbrook) was installed more than a century ago. All were originally situated outside the city limits, but as the urban area rapidly expanded over the past 50 years, most of the wellfields are now surrounded by residential suburbs, light industry, and dense road networks. Lying within a snow belt, the municipality began applying salt to highways and city streets in the late 1940s in order to provide safe driving conditions during the winter months.

The local topography of the Waterloo region is dominated by the Waterloo Moraine, which was formed through a dynamic period of glacial activity that left behind a complex interlaying of till sheets and coarse glaciofluvial material (Karrow 1993). The sediments range in texture from fine clay to coarse cobbled gravels and form a complex stratigraphy with a heterogeneous distribution of hydraulic conductivity ranging from 10^{-4} to 10^{-10} m/s (Béland 1977). As a result of the irregular glacial deposition processes and subsequent reworking of the surficial sediments through fluvial action, many of the individual stratigraphic units are highly nonuniform in thickness and locally discontinuous in lateral extent (Karrow 1993). Hydrogeologically, a number of aquifers separated by aquitards can be identified, with each of these units being of variable thickness and composed of a mix of materials. Some of these aquifers may be hydraulically connected through what are often referred to as hydrogeologic windows in the aquitards, which represent potential conduits for contaminants entering the aquifer system at ground surface (Martin and Frind 1998; Muhammad 2000; Frind et al. 2002).

The Greenbrook wellfield (Figure 1), on the eastern flanks of the Waterloo Moraine, was the primary source of water for the City of Kitchener prior to the addition of other wellfields in the 1950s. The wellfield now consists of five wells (K1, K2, K4b, K5a, and K8; Figures 2 and 9) that are all screened within an intermediate aquifer and currently provide ~10% of the drinking water for the municipality. Over the past few decades, water pumped from the Greenbrook wells has been showing steadily increasing chloride concentrations, with wells K1, K4b, and K5a already exceeding the drinking water limit of 250 mg/L(Cl) (Figure 2). Sodium, which is a health concern above 20 mg/L, has shown similar increasing trends, with wells K1, K4b, and K5a all above 120 mg/L(Na).

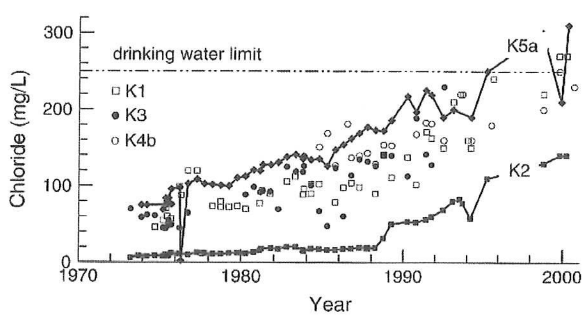


Figure 2. Observed chloride concentrations in the Greenbrook production wells. See Figure 9 for well locations.

Earlier studies by Farvolden and Weitzman (1980), Woeller and Farvolden (1989), and Fritz et al. (1991) have suggested that the high chloride concentrations found in the Greenbrook wells most likely originates from a nearby salt dump and/or local road salting, although a nearby landfill and mineralized water from a deeper aquifer have also been identified as potential sources. The suspicion of road salt as the likely source is reinforced by the tremendous growth in the urbanized area surrounding Greenbrook over the past 50 years, with the addition of local and arterial roads, as well as an expressway to the south of the wellfield in 1970 (Figure 3), all adding to the salt loading. Recent transport modeling by Muhammad (2000) confirmed that road salt is the most likely source.

Because of the importance of the ground water resource to the community, the RMOW initiated a comprehensive source water protection strategy in 1994, and wellhead protection areas have now been delineated for all wellfields (RMOW 2000) based on the methodology described by Frind et al. (2002). The three-dimensional (3D) capture zones were characterized by their maximum lateral extent (with respect to depth) and by their intersection with the ground surface. The surface capture zone for the Greenbrook wellfield is shown in Figures 3b and 4, and again for scale in Figures 6 and 9a.

With road salt identified as a major threat to the water supply, the RMOW is now facing the challenge of balancing the quality of the water supply with winter road safety. In response, the RMOW initiated a Road Salt Management and Chloride Reduction Study to determine the preferred option for stabilizing or reducing the concentrations of chloride in drinking water at all of the municipal wellfields (Stantec 2001, 2003). As part of this

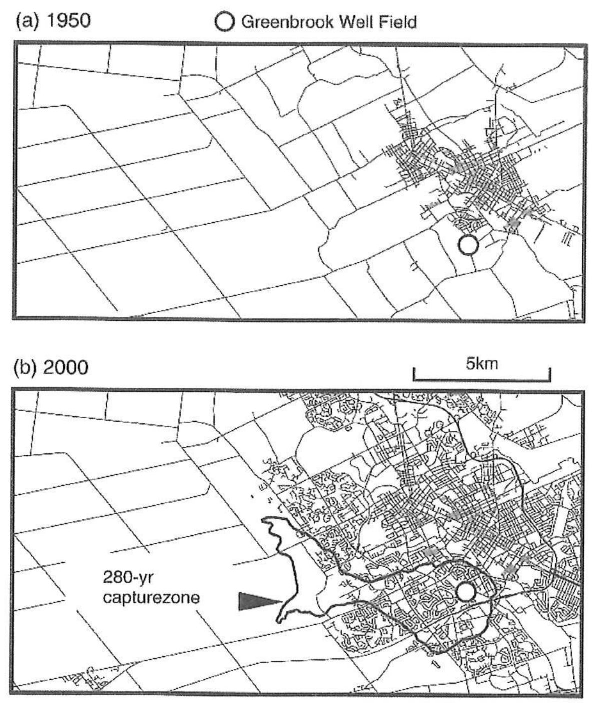


Figure 3. Road network in the area of the Greenbrook wellfield showing growth from (a) 1950 to (b) 2000.

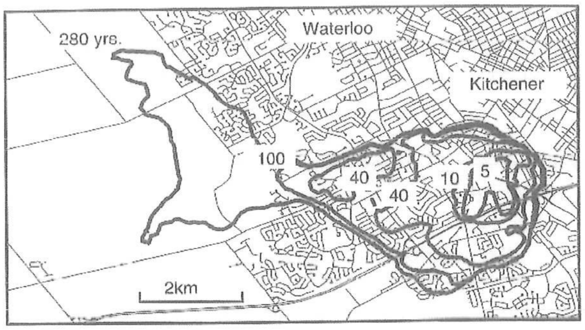


Figure 4. Ground surface capture zones for the Greenbrook wellfield at various times (after Frind et al. 2002).

study, several wellfields, including Greenbrook, were identified as high priority.

Conceptual Model and Numerical Simulation Approach

Martin and Frind (1998) developed a 3D conceptual model for the highly complex Waterloo Moraine, consisting of four aquifers interconnected with four aquitards (Figure 5). The same conceptual model was later used by Frind et al. (2002) to develop the 3D capture zone delineation methodology. The Greenbrook wells pump from the confined middle aquifer (aquifer 2).

The finite-element model WATFLOW (Molson et al. 2002) was used in both studies to simulate the 3D flow field for the major wellfields. WATFLOW is well suited for solving large watershed-scale systems, as it uses a simplified form of the unsaturated flow equation (Beckers and Frind 2001). Inclusion of the unsaturated zone is generally desirable because it allows placement of the top boundary of the model at ground surface, but it is also computationally expensive if the standard approach based on solving the Richards equation is used. The simplified and far more efficient approach used here is based on the assumption of steady-state flow, which is justified in this case because the effect of seasonal variations in ground water recharge and mass loadings dampens out below the water table, as shown by Bester (2002).

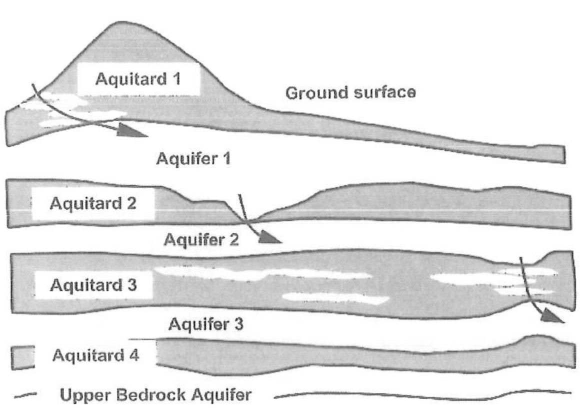


Figure 5. Hydrogeologic conceptual model of the Waterloo Moraine showing aquitard windows and possible flow paths (adapted from Martin and Frind 1998).

The regional flow model encompasses an area of >700 km^2 and is bounded by the Nith River to the west and by the Grand River to the east (Figure 1). The 3D system is resolved using 30 continuous layers of deformable triangular prisms (Figure 6), which follow the stratigraphy. The top layer at ground surface is designated as a thin (<0.1 m) and conductive ($K = 10^{-2}$ m/s) recharge-spreading layer (RSL), which diverts recharge from low-permeability surficial units to higher-permeability infiltration zones or directly to surface water, thus eliminating unrealistic water table mounding over low-conductivity material. The matrix equations are solved using a conjugate gradient algorithm optimized to handle large interlayer permeability contrasts. The finite-element mesh for the Waterloo Moraine model is shown in Figure 6.

The road salt transport simulations were completed using the 3D finite-element model Waterloo Transport Code (WTC, Molson and Frind 2003). The model solves for advective-dispersive transport according to:

$$\frac{\partial}{\partial x_i}\left[D_{ij}\frac{\partial c}{\partial x_j}\right] - \frac{\partial}{\partial x_i}(v_i c) = \frac{\partial c}{\partial t} \qquad (1)$$

where c is the aqueous salt concentration (ML^{-3}), D_{ij} is the hydrodynamic dispersion tensor (L^{2}T^{-1}), and v_i is the average linear ground water velocity (LT^{-1}). Boundary conditions for Equation 1 can be either first type (specified concentration), second type (specified concentration gradient), or third type (specified mass flux).

The WTC model is fully compatible with the WATFLOW flow model and uses the same mesh and

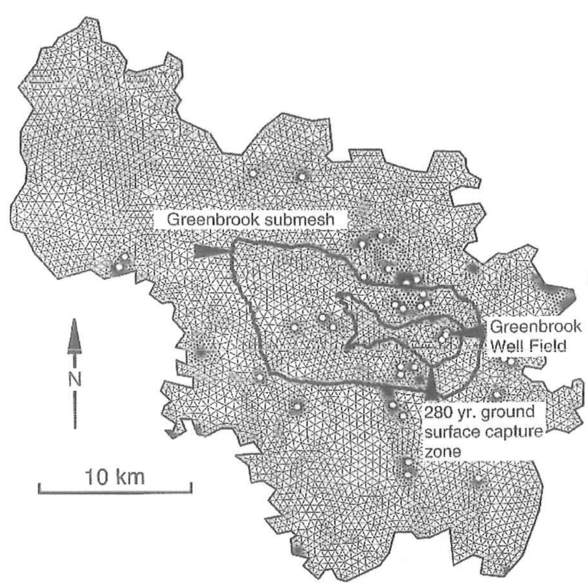


Figure 6. Plan view of the finite-element mesh for the Waterloo Moraine model (after Martin and Frind 1998) and extracted Greenbrook submesh used for the salt transport simulations. The submesh was further refined (not shown) to satisfy the accuracy and stability constraints. The 280-year ground surface capture zone is shown for reference.

numerical solution approach. To save memory and computation time, the transport model was run on a 115-km^2 subgrid with a length about twice that of the steady-state capture zone for Greenbrook (Figure 6). The final 3D transport mesh includes a total of 560,310 nodes and 1,068,969 elements in 30 mesh layers.

The transport simulations were run with dispersivities of 20, 5, and 0.02 m in the longitudinal, transverse horizontal, and transverse vertical directions, respectively, a diffusion coefficient of 10^{-10} m^2/s, and a time step of 10 d. The dispersivities are consistent with the spatial transport scale of ~10 to 15 km (Gelhar et al. 1992; Engesgaard et al. 1996) and satisfy the constraints for the control of numerical dispersion and stability. The initial (background) chloride concentration within the study area was set at 10 mg/L, based on observed data from monitoring wells in the Greenbrook area (Johnston 1994; Stantec 2001) and from other sites in southern Ontario (Jones et al. 1986; Howard and Beck 1992), which showed natural ground water chloride concentrations varying from ~5 to 20 mg/L. The simulation approach assumes a uniform temperature and fluid density since natural thermal gradients are low, and maximum chloride source concentrations are on the order of 2000 mg/L (<10% that of sea water), which will not significantly affect the flow field.

Salt Loading and Transport Model Calibration

Across the top ground surface boundary of the transport model, chloride loading is assigned as a third-type, mass-flux boundary condition. Consistent with the steady-state flow assumption, the mass influx is taken to be an annual average value. Local recharge to the subsurface was obtained from the existing 3D flow model calibration (Frind et al. 2002), which applied a uniform surface recharge (precipitation less evapotranspiration) of 530 mm/year. Of this potential recharge, Frind et al. (2002) estimated that ~280 mm/year discharges directly to streams through the RSL. The rest, being spatially variable but on average ~250 mm/year, recharges naturally through higher-permeability pathways to the underlying aquifers. In the transport model, the thin RSL is removed from the grid and the local road salt sources are placed on the next underlying nodal layer. A zero-concentration gradient is applied at all other boundaries of the model domain. The local mass influx of chloride thus depends on the space- and time-variable source concentrations representing the roads, as well as on the local recharge across the ground surface.

Because of incomplete records on salt application, the assignment of historical salt loading represented a challenge. Spatial variations of salt loading were incorporated by first using Geographical Information System (GIS)-based data to identify the geometry of the growing road network, and estimated source concentrations were then assigned to each of the five types of road systems: private, municipal, regional, township, and provincial. The concentrations were scaled for each road type by using road salt application records for 2000 (Stantec 2001). The salt loadings were based on earlier work by Muhammad (2000), who assumed an average annual application rate of 30 tons NaCl per 2–lane km road length for all road types and estimated that 20% of this reaches the water table. This salt is ~60% by mass chloride; therefore, the average application rate is 3.6 tons of chloride per 2–lane km per year. The average salt concentration at the ground surface can then be estimated based on recharge and road source area. For example, assuming an average recharge of 250 mm/year and an effective road width (including shoulders) of 10 m, the chloride concentration at ground surface would be ~1400 mg/L.

These estimates were then adjusted via calibration to the observed chloride concentration in the Greenbrook well water in 2002. Using the previous loading estimate as the initial condition, the spatial distribution of the salt loading was systematically adjusted until a reasonable match with the observed chloride concentrations at the wells was achieved. As a calibration target, the flux-averaged concentrations were calculated at each time period from the sum of the products of well concentration and pumping rate, normalized by the total pumping rate. Although this approach raises the question of nonuniqueness, it makes sense from the practical point of view because it represents the actual concentration of chloride in the common storage reservoir holding the water pumped from the five wells at the Greenbrook wellfield. Calibration to individual wells was considered but rejected as impractical. The final calibrated chloride source concentrations for each road type and year vary from 75 to 2163 mg/L (Figure 7). The flux-weighted average of the simulated concentration in the wells closely agrees with the weighted average of the observed concentrations (Figure 8).

Simulation Results: Historical Development of Chloride Plumes

Figures 9 and 10 present the simulated chloride distribution for the calibration year 2002. Figure 9a, which shows the salt distribution in plan view near ground surface, reveals an extensively contaminated system with the highest concentrations along heavily treated arterial roads and lower concentrations in the residential areas. Maximum concentrations in the near-surface ground water along arterial roads are in the 900 to 1000 mg/L range, about half the calibrated maximum chloride source

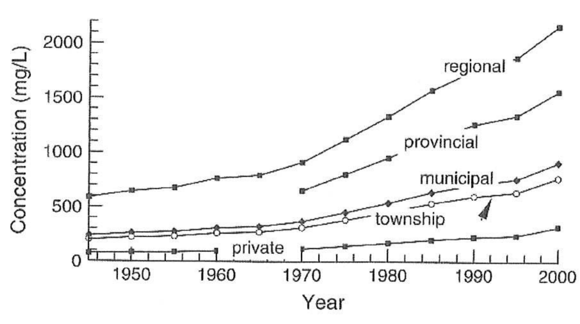


Figure 7. Calibrated road salt source loading functions.

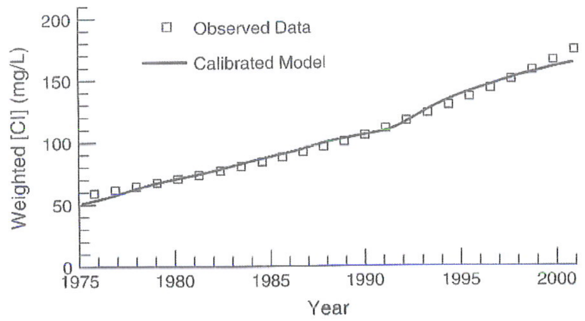


Figure 8. Model calibration showing observed and simulated breakthrough curves of flux-weighted average concentrations at the Greenbrook wells.

concentrations for 2000 (Figure 7). (The contours themselves are somewhat irregular due to the spatial discretization of the numerical model.) The white areas in the figures represent areas where the chloride concentration does not exceed the background value of 10 mg/L. As the wellfield itself is situated in an urban park, the shallow ground water is relatively free of chloride within this area (Figures 9b and 10).

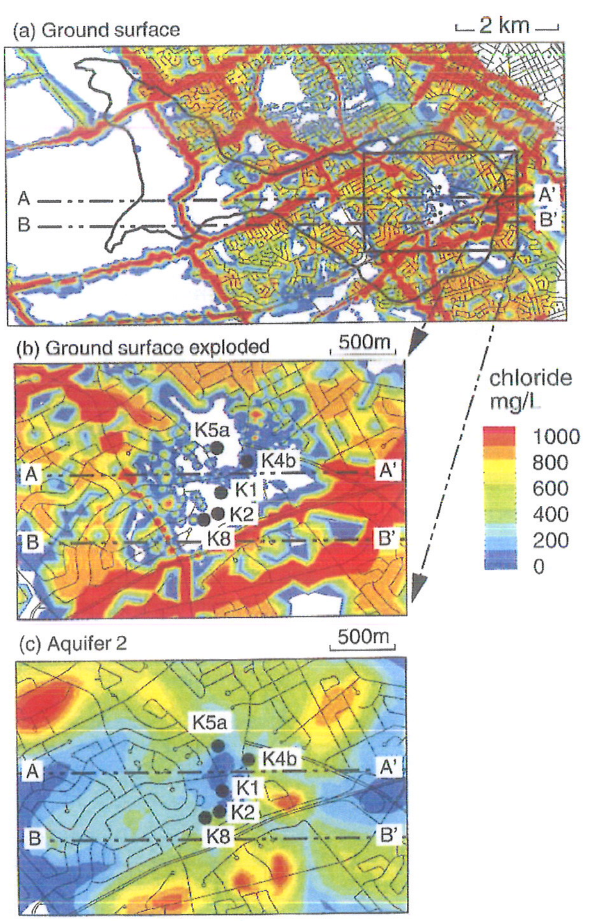


Figure 9. Simulated chloride concentrations at (a, b) ground surface and (c) in pumped aquifer 2, year 2002, base case calibration. The 280-year ground surface capture zone is superimposed in (a) for reference. Contour flood cut-off is 10 mg/L.

Figure 9c shows the plumes in plan view within the pumped aquifer. At this level, the chloride plumes no longer reflect ground surface source concentrations, as they have moved laterally under the influence of the flow system, which is controlled by aquitard windows and other primary pathways. Plume tips are seen approaching the wells from all directions, with concentrations in the range of 300 to 500 mg/L in the immediate vicinity of the wells, but also with higher concentrations up to 1000 mg/L farther from the wells. There is a small area of near-background concentration in the middle of the wellfield, which is connected to the salt-free zone at ground surface around the wellfield.

In cross sections A-A′ and B-B′ (Figure 10), the salt plumes originating at arterial roads are seen to migrate mainly vertically downward through the unsaturated zone and through aquitard 1 (the surficial layer), and then more or less horizontally within aquifer 1. Thereafter, the plumes cross aquitard 2 mainly through windows or areas with higher conductivity to reach aquifer 2, the pumped aquifer, where they follow the hydraulic gradient toward the wells. Since the two sections do not necessarily follow the flow direction, some plumes enter the section transversely (see, for example, cross section B-B′). The area of near-background concentrations in the middle of the wellfield is also evident in cross section A-A′. Chloride concentration gradients generally decrease with depth as the plumes become dispersed and as plumes from different roads merge. These trends are consistent with those simulated under similar conditions in Finland (Niemi 1998). It is evident that the present concentrations observed in the wells represent only the leading edge of the plumes; the highest concentrations have yet to appear at the wells.

Although all wells at Greenbrook are situated within a 1-km^2 area, the contamination in each well differs significantly. In cross section A-A′ (Figure 10), for example, one group of chloride plumes can be seen approaching the wellfield from the west, while another plume approaches from the east. Other plumes, such as those located in the shallow zone near the Conestoga Parkway in section B-B′, reveal small local-scale flow systems with easterly flow directions induced by another wellfield further downgradient. The controlling influence of the windows in the confining layers is reflected by the patterns of plume migration as they reach the lower aquifers. For instance, chloride reaching wells K2 and K8 from the south (Figure 9c) has arrived at these wells not because it is located in a highly salted area but because of the proximity of a high-conductivity window in the overlying aquitard. Evidence of additional conductive windows in aquitard 2 can be seen in Figure 10, section B-B′, where the salt plumes from Fischer-Hallman and Highland roads are migrating vertically downward through this aquitard before being diverted horizontally toward the wells screened in aquifer 2. The locations for these windows were inferred from the 3D kriging of the observed hydraulic conductivity data.

The cumulative chloride mass input to the aquifer system in the Greenbrook submesh area (Figure 6) up to the end of the calibration period (2002) is ~1.5 × 10^8 kg,

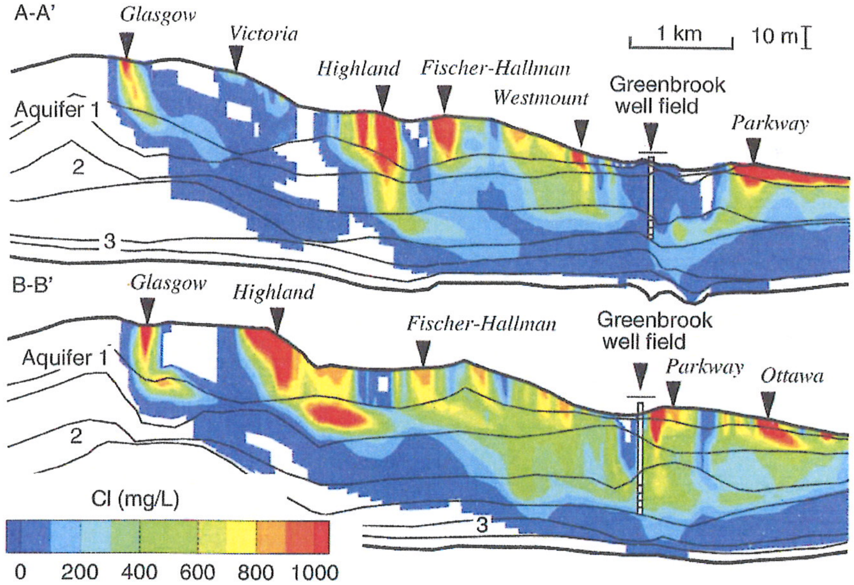


Figure 10. Simulated chloride concentrations along cross sections A-A′ and B-B′, year 2002, base case calibration. Section locations are shown in Figure 9 (note wells do not fall directly on sections); road names identified in italics. Vertical exaggeration is 20×; contour flood cut-off is 10 mg/L.

or, on average, 1.3 kg/m^2 (~30 g/m^2/year) over the 115-km^2 submesh area. Local values in the more heavily salted areas will be much higher. Most of this chloride mass input is still stored in the aquifers and aquitards of the system at the end of 2002, as significant mass discharge has not yet occurred by this time. This high salt loading should be a cause for environmental concern.

As is evident from Figures 9 and 10, chloride concentrations in both shallow and deep aquifers are highly heterogeneous, ranging from background (10 mg/L) to ~1000 mg/L. While source heterogeneity is a factor, the main reason for the strong heterogeneity of concentration at depth is the heterogeneity of the glacial hydrogeology, with aquitard windows that control flow and transport. This inherent heterogeneity has important implications for designing monitoring systems or placing new water supply wells in aquifers subjected to similar road salt contamination.

A further important point is that concentrations in the aquifer system can be substantially higher than concentrations observed in the well water, which is diluted by cleaner water being drawn in along with the contaminated water. Thus, the quality of the well water, while of primary interest from the user's point of view, is not necessarily a good indicator of water quality in the aquifer. This inherent characteristic should be kept in mind when assessing aquifer vulnerability.

Assessment of Salt Reduction Scenarios

The calibrated model was used to predict the impact of six different salt reduction scenarios over the next 40 years (2003 to 2041). This forecasting was carried out using the existing road network and road salt loadings from 2002. Any post-2002 growth of the road network within the Greenbrook capture zone was neglected. This assumption is reasonable because the road network is already at a mature stage over most of the capture zone (except for the western part), with limited potential for future growth. Breakthrough curves of the weighted average chloride concentrations for scenarios 1 to 6 are presented in Figure 11.

Scenario 1: Base Case

The base case projection represents the "do-nothing" approach where salt input is assumed to continue at 2002 levels. The concentrations within cross section A-A′ for 2041 (Figure 12a) again show chloride plumes reaching the well screens in aquifer 2 through windows in the low-conductivity layers. High chloride concentrations are also encroaching from the underlying aquifer 3 toward the wellfield, possibly entering this aquifer from a direction perpendicular to the cross section. The breakthrough curve

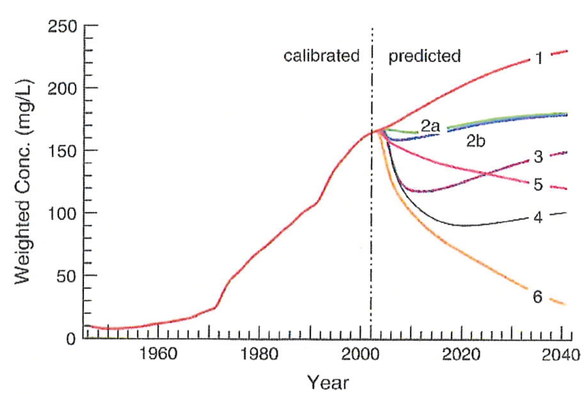


Figure 11. Breakthrough curves of flux-weighted chloride concentrations for simulation scenarios 1 to 6.

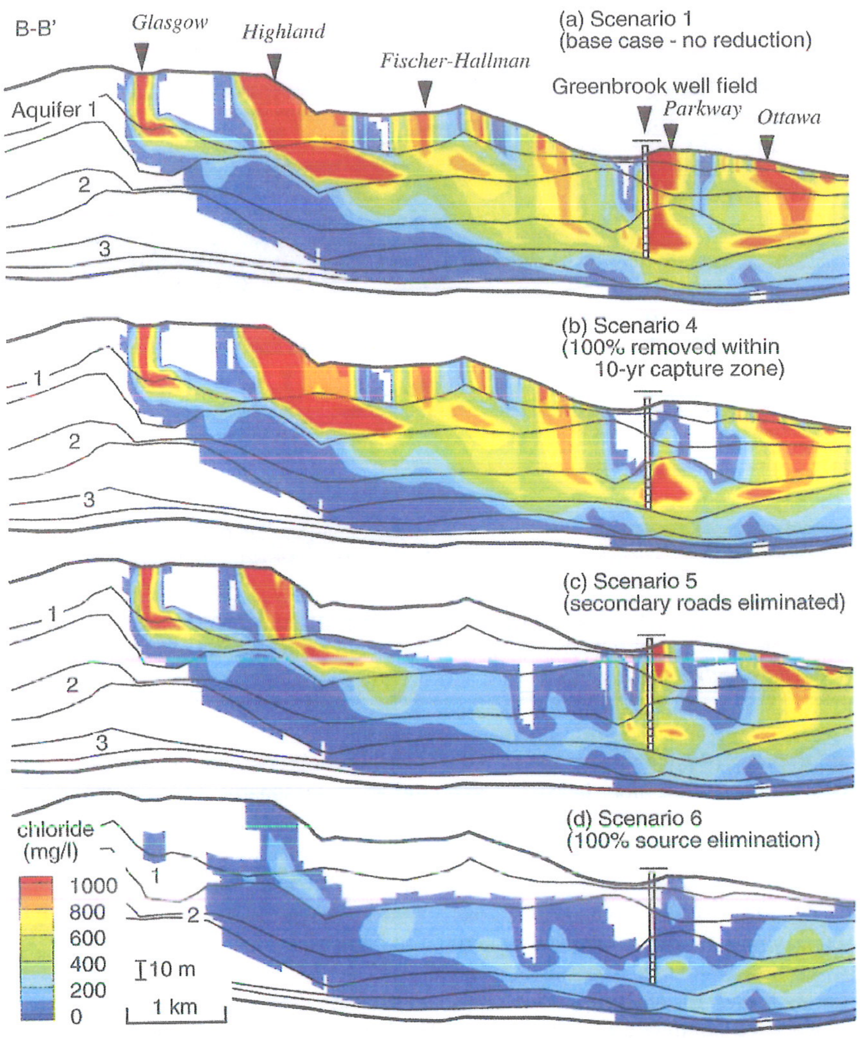


Figure 12. Predictive scenarios 1, 4, 5, and 6 showing simulated chloride concentrations along cross section B-B′, year 2041. Source changes occur in 2002; road names identified in italics. Vertical exaggeration is 20×; contour flood cut-off is 10 mg/L.

for scenario 1 (Figure 11) shows a steadily increasing concentration of chloride, with the flux-weighted concentration approaching the drinking water limit by 2041. The simulation suggests that, even assuming no change in current road salt application rates, the system will still not reach steady state with respect to well impacts by 2041 and concentrations will continue to rise.

Scenario 2: 25% Reduction within Study Area

In this scenario, the chloride mass loading is reduced by 25% within the entire study area. The reduction begins in 2002, which corresponds to the commencement of salt reduction measures by the municipality. These measures include better recordkeeping (thus avoiding dual applications), conservation, and prewetting, which aids in keeping salt crystals from refracting off the pavement and onto pervious areas. Two subscenarios were considered, the first representing a gradual linear decrease beginning in 2002 and ending in 2007, and the second an immediate 25% reduction in 2002.

Both scenarios show a somewhat similar integrated response pattern at the wells, comprising a relatively small drop, followed by a more gradual rise to concentrations ~20% to 25% less than in the base case by 2041 (Figure 11). In the gradual reduction case, a temporary minimum concentration is reached after ~7 years, whereas with an immediate reduction, the minimum occurs after ~4 to 5 years. The gradual increase after the minima are reached indicates that with a 25% reduction of mass input, the system approaches but does not reach steady state by 2041.

Scenarios 3 and 4: 100% Reduction within 5- and 10-Year Capture Zones

Scenarios 3 and 4 present the option of eliminating NaCl within the 5- and 10-year ground surface zones, respectively (capture zones are shown in Figure 4). This option could be achieved, for example, by replacing the salt with a deicing agent that is less harmful to the environment, such as potassium formate (Hellstén and Nystén 2003).

The breakthrough curves for these scenarios show an initially rapid decline followed by a more moderate rise.

In scenario 3, for example, fresh water infiltrating within the first 5 years after reduction dilutes the chloride, and a minimum concentration of ~120 mg/L is reached after ~8 years (Figure 11). Well K4b responds the strongest due to a higher pumping rate than its neighboring production wells. At 5 years, however, chloride from outside the 5-year capture zone begins to arrive at the wells, and mixing with fresh water from recharge within the capture zone is not sufficient to keep the chloride levels from rising again.

The response in scenario 4 is similar (Figure 11), but shows a greater initial drop to ~100 mg/L because chloride has been removed from a larger area. A minimum concentration is reached after ~18 years (2020); however, concentrations begin to rise again as the plumes from outside the 10-year capture zone reach the wellfield. At 2041, the vertical profile (Figure 12b) shows a salt-free zone in aquifer 1, but not in aquifer 2, where higher concentrations have arrived from outside the capture zone.

The initial response of the wells to the salt reduction in scenarios 3 and 4 is fairly rapid because of the proximity of the contaminant source and relatively short travel times to the wells. This response should not be generalized for other wellfields, where response times will likely differ depending on the degree of confinement and protection. An indication of these factors is given by the ground water age (Molson and Frind 2005), which generally increases in the moraine with depth and degree of protection. Thus, for deeper and less vulnerable wells, the impact of road salt contamination may be delayed (but not prevented), while for shallower wells, the response may be even more rapid.

Scenario 5: Elimination of Salt from Secondary Roads

When road salt is eliminated from secondary roads and applied only to arterial roads throughout the area, concentrations dramatically decrease in the wells and continue to decrease until 2041 (Figure 11). With the secondary road input removed, more fresh water enters the system, and the chloride reaching the wells from the other road types is therefore more diluted. Although relatively less salt is applied per 2–lane kilometer of secondary roads, these roads constitute a significant fraction of the total road length; hence, their contribution is important.

The impact is best seen in the vertical profile at 2041, which shows an extensive chloride-free zone between Highland Road and Greenbrook (Figure 12c). In particular, the two windows within aquitard 2 just upgradient from the wellfield are now relatively chloride-free and serve to bring in clean water from aquifer 1. Still, a significant amount of salt remains in the deeper units and continues to impact the wellfield.

Scenario 6: 100% Reduction within Study Area

In this scenario, the entire chloride source loading is eliminated in 2002. The results show that most high levels of chloride are flushed out of the system by 2041, except for some that remains trapped in low-conductivity material, primarily within the aquitards (Figure 12d). Within ~15 years after source removal, chloride concentrations at the wells have dropped by one-half, and by 2041, chloride contamination is no longer a threat (Figure 11).

Conclusions

This study provides insight into the impact of road salt on a complex ground water system in an urban setting. The simulations show that a very large chloride mass can be stored in the subsurface before a well is impacted, thus delaying the emergence of the inevitable source contamination problems. When the impact finally becomes apparent, it may foretell a serious long-term quality issue since even with complete elimination of salt input, flushing the residual chloride can take many years or decades. The simulation results suggest that some wells in the Greenbrook wellfield may not yet have reached their maximum chloride concentrations even after 57 years (1945 to 2002) of road salt application. Under conditions of continuous salt input, attainment of equilibrium concentrations in the system may require on the order of 100 years.

Although a water supply aquifer can be somewhat protected from road salt by overlying aquitards, the simulations show that aquitard windows, common in glacial moraine settings, can serve as short-circuit pathways for downward salt migration. On the other hand, when the source loading is reduced or removed, these same pathways can serve as conduits for cleaner recharge into the deeper aquifers.

Aquifer heterogeneity, for example in the form of windows that control flow and transport, can lead to a very heterogeneous chloride distribution in the aquifer system, even at depth. This inherent heterogeneity is an important fact to consider when designing monitoring systems or locating new water supply wells in this or any similarly stressed aquifer system.

Concentrations in the aquifer can be substantially higher than concentrations observed in the well water, which benefits by dilution with clean water. Thus, the quality of the well water is not necessarily a good indicator of water quality in the aquifer. This characteristic could be a factor in assessing aquifer vulnerability.

The most important result of the study is that the impact of road salting on ground water can be severe and therefore every effort should be made to reduce or eliminate salting where possible. The first step is to carefully control and monitor any salting to avoid overapplication. The elimination of salting on secondary roads can also be a very effective mitigation measure. Another good option would be to completely eliminate road salt from designated sensitive areas and to use an alternative deicer instead. A further option would be to reduce dependence on salting by introducing lower speed limits during the snow season. A combination of these options might offer the best hope for averting the progressive and practically irreversible contamination of our precious ground water resources by road salt chloride.

Acknowledgments

The authors wish to thank Eric Hodgins, Tammy Middleton, and Jim Robinson of the RMOW for their cooperation and for supplying important data for the model. We also thank Craig Johnston of Stantec Consulting Ltd., Kitchener, and Paul Martin of AquaResource

Inc., Waterloo, for their helpful advice. The manuscript was improved through helpful comments by reviewers K. Howard (University of Toronto), T. Nystén (Finnish Environment Institute), and E. Mehnert and S. Panno (Illinois State Geological Survey), and through critical reading by Michael Frind. Financial support was provided by an Industrial Scholarship to the first author from the Natural Sciences and Engineering Research Council of Canada, in partnership with the RMOW, and an NSERC Research Grant held by the second author.

References

Beckers, J., and E.O. Frind. 2001. Simulating groundwater flow and runoff for the Oro Moraine aquifer system: 2. Automated calibration and mass balance calculations. *Journal of Hydrology* 243 no. 1–2: 73–90.

Béland, A. 1977. Management of the Greenbrook well field. M.Sc. thesis, Department of Earth Sciences, University of Waterloo.

Bester, M.L. 2002. Numerical simulation of road salt impact at the Greenbrook well field, Kitchener, Ontario. M.Sc. thesis, Department of Earth Sciences, University of Waterloo.

Canada Gazette. 2004. Part 1. Ottawa. April 3, 2004. 138, no. 14.

Canada Gazette. 2001. Part 1. Ottawa. December 1, 2001. 135, no. 48.

Canadian Environmental Protection Act. 1999. *Environment Canada (CEPA 1999)*. http://www.ec.gc.ca/CEPARegistry/the_act/. Access date: Aug 21, 2005.

Coster, A.D., K. Grandlund, and J. Soveri. 1994. The effect of road salting on a glaciofluvial aquifer in Finland—A model approach. Proceedings of the Helsinki Conference on Future Groundwater Resources at Risk. Ed by J. Soveri and T. Suokko. International Association of Hydrological Sciences Publication no. 222.

Engesgaard, P., K.H. Jensen, J.W. Molson, and E.O. Frind. 1996. Large scale dispersion in a sandy aquifer: Simulation of subsurface transport of environmental tritium. *Water Resources Research* 32, no. 11: 3253–3266.

Envirocast Newsletter. 2003. Snow, Road Salt and the Chesapeake Bay. Vol. 1, no. 3, January. Published by the National Environmental Education and Training Foundation (NEETF) and the Center for Watershed Protection (CWP).

Environment Canada. 2001. Priority Substances List Assessment Report: Road salts. Technical Report by Environment Canada and Health Canada. http://www.ec.gc.ca/nopp/roadsalt/reports/en/socio.cfm. Access date: Aug 21, 2005.

Farvolden, R., and M. Weitzman. 1980. Technical Report: Greenbrook well field study. Department of Earth Sciences, University of Waterloo. Waterloo, Ontario.

Frind, E.O., D.S. Muhammad, and J.W. Molson. 2002. Delineation of three-dimensional capture zones in complex multi-aquifer systems. *Ground Water* 40, no. 6: 586–589.

Fritz, S.J., R.J. Drimmie, and P. Fritz. 1991. Characterizing shallow aquifers using tritium and 14C: Periodic sampling based on tritium half-life. *Applied Geochemistry* 6, no. 1: 17–33.

Gelhar, L.W., C. Welty, and K.R. Rechfeld. 1992. A critical review of data on field-scale dispersion in aquifers. *Water Resources Research* 28, no. 7: 1955–1974.

Gustafsson, J., and T. Nystén. 2000. Trends of chloride concentration in groundwater and results of risk assessment of road salting in Finland. In *Ground Water 2000: Proceedings of the International Conference on Ground Water Research, Copenhagen, Denmark*, ed. P. Bjerg, P. Engesgaard, and T. Krom, 249–251. Rotterdam, Netherlands: A.A. Balkema.

Gutiw, P., and Y.C. Jin. 1998. Roadside salinity changes generated by pavement deicing practices on a Saskatchewan highway. In *Deicing and Dustbinding—Risk to Aquifers*, ed. T. Nystén and T. Suokko, 23–30. Helsinki, Finland: Finnish Environment Institute.

Hellstén, P., and T. Nystén. 2003. Migration of alternative de-icers in the unsaturated zone of aquifers—In vitro study. *Water Science and Technology* 48, no. 9: 45–50.

Hellstén, P., T. Nystén, J. Salminen, K. Granlund, T. Huotari, and V.-M. Vallinkoski. 2004. Biodegradation of potassium formate in soil and groundwater: Final report of studies on alternative de-icing chemicals: MIDAS Project (in Finnish). Helsinki, Finland: Finnish Environment Institute (SYKE).

Howard, K.W.F., and P.J. Beck. 1992. Hydrogeochemical implications of groundwater contamination by road de-icing chemicals. *Journal of Contaminant Hydrology* 12, no. 3: 245–268.

Howard, K.W.F., J.I. Boyce, S.J. Livingston, and S.L. Salvatori. 1993. Road salt impacts on ground water quality—The worst is still to come! *GSA Today* 3, no. 301: 319–321.

Howard, K.W.F., and J. Haynes. 1993. Urban geology 3. Groundwater contamination due to road de-icing chemicals—Salt balance implications. *Geoscience Canada* 20, no. 1: 1–8.

Huling, E., and T. Hollocher. 1972. Groundwater contamination by road salt: Steady-state concentrations in East Central Massachusetts. *Science* 176, 288–290.

Johnston, C. 1994. Geochemistry, isotopic composition and age of groundwater from the Waterloo Moraine: Implication for groundwater protection and management. M.Sc. thesis, Department of Earth Sciences, University of Waterloo.

Jones, P.H., B.A. Jeffrey, P.K. Watler, and H. Hutchon. 1986. Environmental impact of road salting—State of the art. Downsview, Ontario, Canada: Ministry of Transportation and Communications.

Karrow, P.F. 1993. Quaternary geology, Stratford-Conestoga area, Ontario Geological Survey. Report 283. Toronto, Ontario.

Locat, J., and P. Gélinas. 1989. Infiltration of de-icing road salts in aquifers: The Trois-Rivières-Ouest Case, Quebec, Canada. *Canadian Journal of Earth Science* 26, no. 11: 2186–2193.

Martin, P.J., and E.O. Frind. 1998. Modeling a complex multi-aquifer system: The Waterloo Moraine. *Ground Water* 36, no. 4: 679–690.

McConnell, H., and J. Lewis. 1972. Add salt to taste. *Environment* 14, no. 9: 38.

Molson, J.W., J. Beckers, P.J. Martin, and E.O. Frind. 2002. WATFLOW/3D version 2.0. A three-dimensional groundwater flow model with modules for automated calibration and parameter sensitivity analysis. Department of Earth Sciences, University of Waterloo. Waterloo, Ontario.

Molson, J.W., and E.O. Frind. 2005. How old is the water? Simulating groundwater age at the watershed scale. In *Proceedings: 2004 IAH Conference on Groundwater Quality, International Association of Hydrogeologists, Waterloo, Canada*. IAHS Publ. 297 p. 482–488.

Molson, J.W., and E.O. Frind. 2003. WTC Transport Model User Guide. Department of Earth Sciences, University of Waterloo. Waterloo, Ontario.

Muhammad, D. S 2000. Methodologies for capture zone delineation for the Waterloo Moraine well fields. M.Sc. thesis, Department of Earth Sciences, University of Waterloo.

Niemi, A. 1998. Modeling of chloride transport in aquifers due to salt from highway de-icing—Representative example condition in Finnish aquifers. In *Proceedings: International Symposium on Deicing and Dustbinding—Risk to Aquifers, Helsinki, Finland, October 14–16*. Nystén, T. and Suokko, T. Eds. Nordic Hydrological Programme, NHP Report No. 43, Helsinki, Finland, p 31–40.

Novotny, V., D.W. Smith, D.A. Kuemmel, J. Mastriano, and A. Bartošová. 1999. Urban and highways snowmelt: Minimizing the impact of receiving water. Technical Report Project 94-IRM-2. Water Environment Research Foundation.

Nystén, T. 1998. Transport processes of road salt in quaternary formations. *Proceedings: International Symposium on De-*

icing and Dustbinding—Risk to Aquifers, Helsinki, Finland. October 14–16, 31–40. Nystén, T. and Suokko, T. Eds. Nordic Hydrological Programme, NHP Report No. 43, Helsinki, Finland, p 31–40.

Nystén, T., and J. Gustafsson. 2000. Migration of road salt in ground water. *Finncontact* 8, no. 4: 7–8. Quarterly Newsletter of the Finnish Highway Transportation Technology Transfer Center, Finnish National Road Administration.

Paine, L. 1979. Chlorides in the Don River watershed resulting from road de-icing salt. Technical Report Working Paper Publication no. SIC-3. University of Toronto, Institute of Environmental Studies Snow and Ice Working Group. Toronto, Ontario.

Pilon, P., and K. Howard. 1987. Contamination of subsurface waters by road de-icing chemicals. *Water Pollution* 22, 157–171.

Pollock, S. 1992. Remediating highway de-icing salt contamination of public and private water supplies in Massachusetts. *Resources, Conservation and Recycling* 7, no. 1–3: 7–24.

RMOW. 2000. Regional Official Policies Plan, Amendment #12, Water Resources Protection Strategy. Future urban point source and background documentation. Kitchener, Ontario, Canada: RMOW.

Sarwar, G., D.L. Rudolph, J.D. Campbell, and C. Johnston. 2002. Field characterization of road salt impacts on ground water resources in an urban setting: Kitchener, Ontario. In *Proceedings, 55th Canadian Geotechnical and 3rd Joint IAH-CNC CGS Groundwater Speciality Conferences*. D. Stolle, A.R. Piggott and J.J. Crowder, Eds. Canadian Geotechnical Society, Niagara Falls, Ontario, Canada, p. 457–463.

Stantec. 2003. Road salt management and chloride reduction study. Phase 2: Evaluation of chloride reduction options. Technical Report. Kitchener, Ontario, Canada: Stantec Consulting Ltd.

Stantec. 2001. Road salt management and chloride reduction study. Phase 1: Road salt management study. Technical Report. Kitchener, Ontario, Canada: Stantec Consulting Ltd.

Woeller, R.M., and R.N. Farvolden. 1989. The past, present and future of ground water development in the tri-cities of Kitchener, Waterloo and Cambridge, Ontario, Canada. In *Proceedings of the NWWA FOCUS Conference on the Regional Ground Water Issues, Kitchener, Ontario.*

Attachment

City of Barrie, 2017
Infiltration Low Impact Development Screening Process

The City of BARRIE

DRINKING WATER SOURCE PROTECTION
DE L'EAU POTABLE À LA SOURCE

CITY OF BARRIE

Infiltration Low Impact Development Screening Process

Note to Reader: This document has been provided to outline a decision making framework for determining the suitability of an infiltration LID feature in relation to Drinking Water Source Protection considerations. Other factors that determine the suitability of an infiltration LID project including but not limited to cost estimates, life-cycle planning, property acquisition, and other policies and standards are beyond the scope of this document. The document will serve as an excellent starting point for undertaking your project. However, pre-consultation with the LID working group is strongly recommended to determine scope constraints in relation to Source Water Protection. Professional judgement will need to be used to determine overall project feasibility.

Table of Contents

List of Appendices

List of Figures

List of Tables

1.0 Introduction

Stormwater management is a highly evolving field. In the 1970's urban stormwater management was practiced to capture increasing runoff and for flood management. In the 1990's it became standard to use stormwater management as a means to help improve water quality. At this time, large centralized detention facilities dedicated to help improve water quality of stormwater returning to lakes and streams, also referred to as end-of-pipe control, became predominant and are still largely used today.

However, these conventional methods do not address the changes to the hydrologic cycle experienced in an urbanized watershed. It fails to address the increase in stormwater volume and runoff rates which leads to erosion and stream degradation, and does little to treat certain contaminants of concern. Low-impact development (LID) practices have received increasing attention as these strategies attempt to capture the runoff and mimic the natural hydrologic cycle.

There are two primary categories of LIDs. The first promotes the infiltration of stormwater close to the source. These infiltration type LIDs are preferred when hydrogeological and physical conditions are optimal and allow for their emplacement. The second capture and slowly release the water to the surface water system through the process of storage and filtration. Filtration and storage type LIDs are to be considered when conditions do not permit infiltration LIDs to be implemented. Therefore many municipalities in Ontario are now looking to make greater use of LIDs, including the City of Barrie, as a need for better solutions to stormwater management are increasingly required.

The Lake Simcoe Protection Plan (LSPP) has established policies for stormwater management that encourages municipalities within the Lake Simcoe watershed to implement a hierarchy of source, lot-level, conveyance and end-of-pipe controls to meet adequate stormwater treatment. The Lake Simcoe Region Conservation Authority (LSRCA) has also published guidelines for stormwater management that require a significant portion of runoff from an event be captured and infiltrated, retained, treated on-site.

However, there is concern that implementing infiltration LIDs, especially along road right of ways, will lead to contamination of groundwater resources. Of particular concern is the risk of sodium and chloride contamination, as a result of winter maintenance practices. When road salt is applied to roads, parking lots, sidewalks and other surfaces it dissolves easily in water and the resulting ions remain in solution and can enter the groundwater system. Currently there is no viable option to remove these ions from solution. As the City has Issues Contributing Areas relating to drinking water sources for sodium and chloride, a forward thinking approach on how and where infiltration type LIDs should be permitted is necessary to adequately manage some of the associated potential risks.

This document will focus on offering guidance for the implementation of infiltration type LIDs within the City with a focus on Source Water Protection vulnerable areas. It will be updated from time to time as the science and understanding of LIDs evolves.

2.0 Proposed Approach

The proposed approach for implementing infiltration LID features follows a three step approach.

The first step is a location suitability screening that considers drinking water vulnerable areas and the general water quality characteristics of the stormwater to be infiltrated. If based on these two factors the infiltration facility is deemed permitted the project can immediately proceed to the third step of the process. However, if it has been deemed permitted with conditions it will require to go through the second step of the screening process. During the second screening the application or project must meet additional requirements set by the Infiltration LID Working Group. Finally the third step of the process ensures that all other legislative requirement, including federal and provincial requirements as well as City of Barrie policies and standards are met. In all cases where infiltration LIDs are not appropriate given conditions, consideration should be given to filtration and storage type LIDs.

The following section of the report will go over the three step approach. Figure 1 shows a process map of the approach.

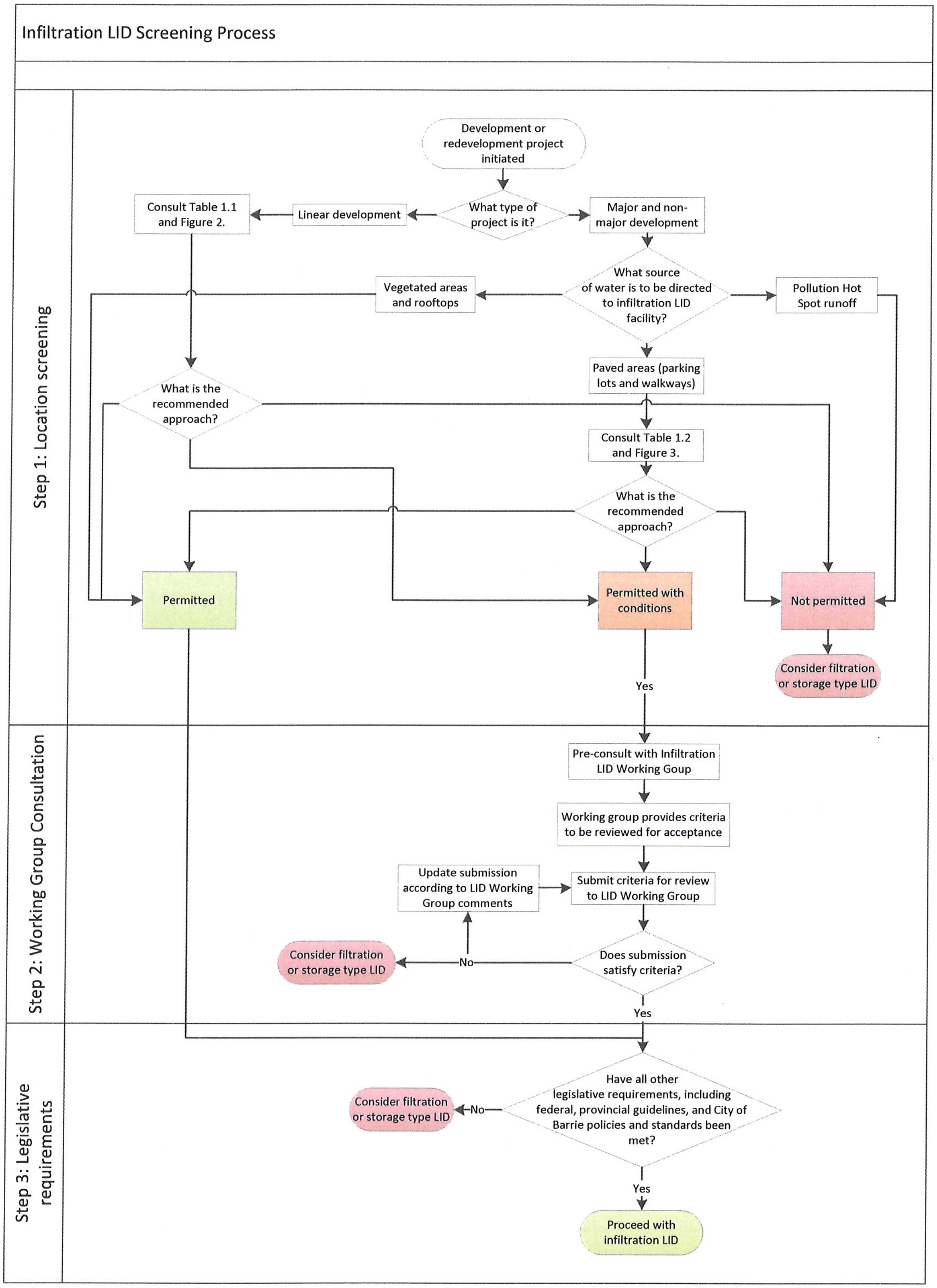


Figure 1. Process map for the screening of infiltration LID features to be implemented based on location suitability.

Step 1: Location Screening

The current screening document is to be used when a development or redevelopment project is initiated and infiltration LIDs are being considered for stormwater management. The first step of the screening process is designed to screen areas where infiltration LIDs would be suitable based on Source Water Protection vulnerable area, and the general water quality characteristics of the stormwater to be infiltrated in the LID facility.

To complete this task we must first determine what type of project is being proposed: a linear development or a major or non-major development. The type of project going forward will affect the first step of the process and the recommendation for implementing infiltration type LIDs.

Requirements from the first step of the screening process will fall within one of the following categories. Stormwater is:

1. Infiltration based practices are **permitted**
2. Infiltration based practices are **permitted with conditions**
3. Infiltration based practices are **not permitted**

The practices that are deemed permitted with conditions will continue to the second step of the screening process, where the Infiltration LID Working Group will outline additional criteria to be satisfied. When stormwater is not permitted to be conveyed or treated using infiltration based practices, filtration or storage type features should be considered.

2.1.1 Recommendations for Linear Development

Given the nature of stormwater originating from roadways, the viability of implementing infiltration type LIDs in road right of ways for linear developments are considered separately from other projects. Recommendations for linear developments have been made according to the road classification of the existing or proposed roadway.

The road classifications that are being considered for the purposes of this document are either arterial and collector roadways or local roadways:

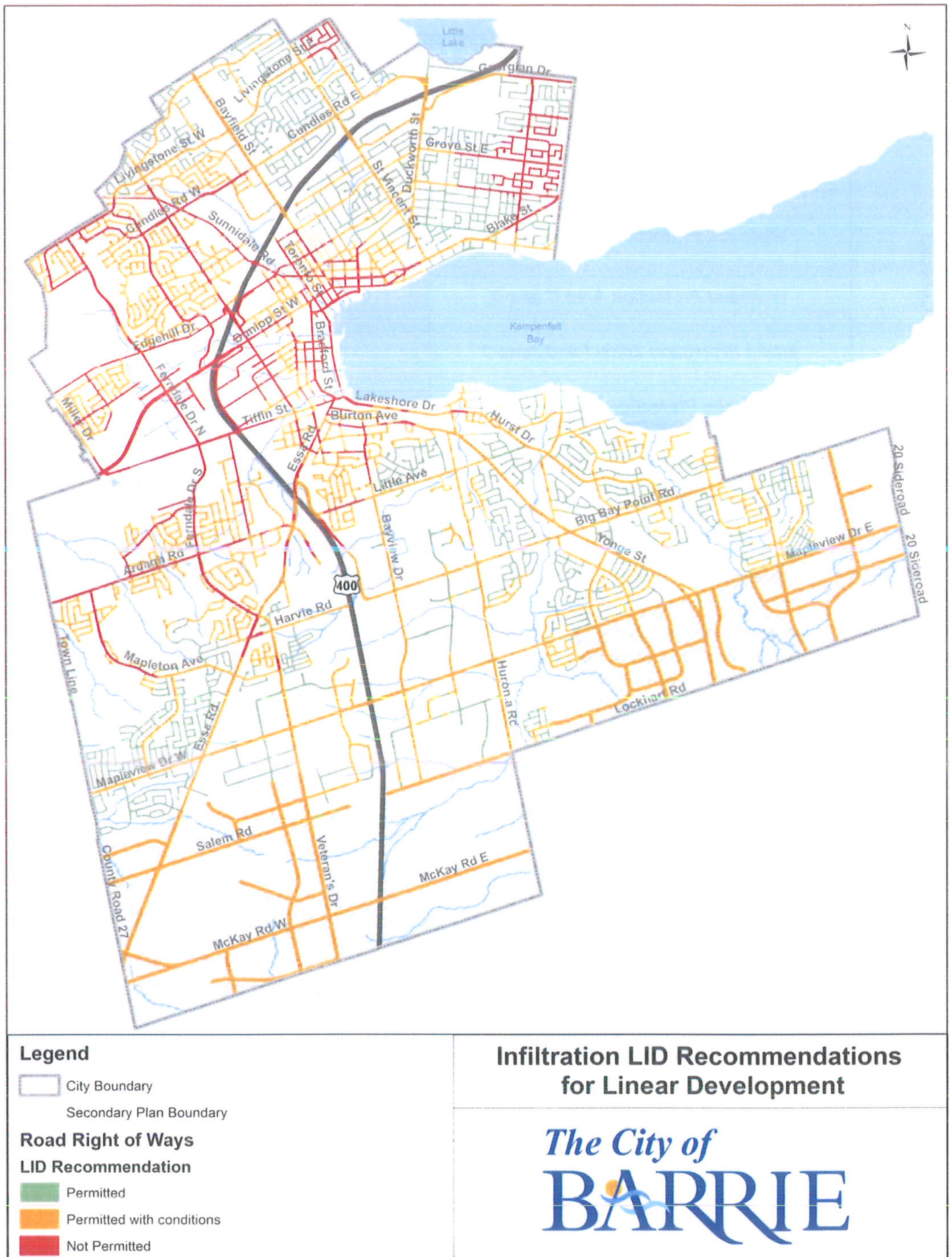
Arterial or Collector Roadways: Arterial and collector roadways are the most heavily used roadways and receive a priority level of service in terms of winter maintenance. As such they receive the highest load of road salt. The requirements for arterial and collector roadways, which can be consulted in Table 1.1, are conservative given the general water quality characteristics of runoff from these roadways.

Local Roadways: Local roadways are those that have lower volumes of traffic and for the most part have a lower level of service than arterial and collector roadways. Lesser amounts of road salt are used as de-icing material along local roads and as a result, the requirements for LIDs along local roads (see Table 1.1) are less restrictive than those for arterial and collector roadways.

Table 1.1 outlines the detailed requirements for implementing infiltration type LIDs according to road classification. To help visualize the recommended approach for implementing infiltration type LIDs along linear developments, Figure 2 was created by overlaying vulnerable areas and Official Plan roadway classification. When determining what the recommendation is for the implementation of an infiltration type LID the table and map should be consulted simultaneously.

Table 1.1 City of Barrie requirements for the implementation of infiltration type LIDs for linear developments based on Source Water Protection Vulnerable Area and road classification

Road Classification	Vulnerable Area	Requirement
Arterial & Collector	*Issues Contributing Area*	Infiltration based practices not permitted
	Wellhead Protection Area A and B	
	Wellhead Protection Area C and D	
	Intake Protection Zone-1 and Zone-2	Infiltration based practices are permitted with conditions
	Lake Simcoe Protection Plan Significant Groundwater Recharge Areas	
	Highly Vulnerable Aquifers	
	Not Vulnerable	
Local	*Issues Contributing Area*	Infiltration based practices are permitted with conditions
	Wellhead Protection Area A and B	Infiltration based practices are not permitted
	Wellhead Protection Area C and D	Infiltration based practices are permitted
	Intake Protection Zone-1 and Zone-2	
	Lake Simcoe Protection Plan Significant Groundwater Recharge Areas	Infiltration based practices are permitted with conditions
	Highly Vulnerable Aquifers	Infiltration based practices are permitted
	Not Vulnerable	



Note: Roads in the Secondary Plan boundary are conceptual and subject to change as development is propsosed. Please use table concurrently during screening.

Source:
-City of Barrie, 2014, The City of Barrie Official Plan.
-South Georgian Bay-Lake Simcoe Source Protection Region, 2015, Approved Assessment Report: Lakes Simcoe and Couchiching-Black River Source Protection Area.

Figure 2. Screening map showing infiltration LID requirements for linear development

2.1.2 Recommendations for Major and Non-Major Development

The recommended approach for the implementation of infiltration type LIDs for major and non-major developments are to be based firstly on the source of the stormwater to be directed into the infiltration LID facility. The four sources of runoff considered in this document include vegetated areas, rooftop runoff, paved areas, including parking lots and walkways, and pollution hot spot runoff (e.g. a gas station). Secondly, considerations are given to the proposed land use activities of the project property for certain sources of runoff (paved areas).

Vegetated and rooftop runoff: As vegetated and rooftop runoff are a relatively clean source of runoff, these sources are permitted to be conveyed or treated using infiltration based practices regardless of the land use activities proposed for the project site.

Pollution hot spot runoff: Pollution hot spot runoff is never permitted to be conveyed or treated using infiltration based practices given the high potential for soil and groundwater contamination.

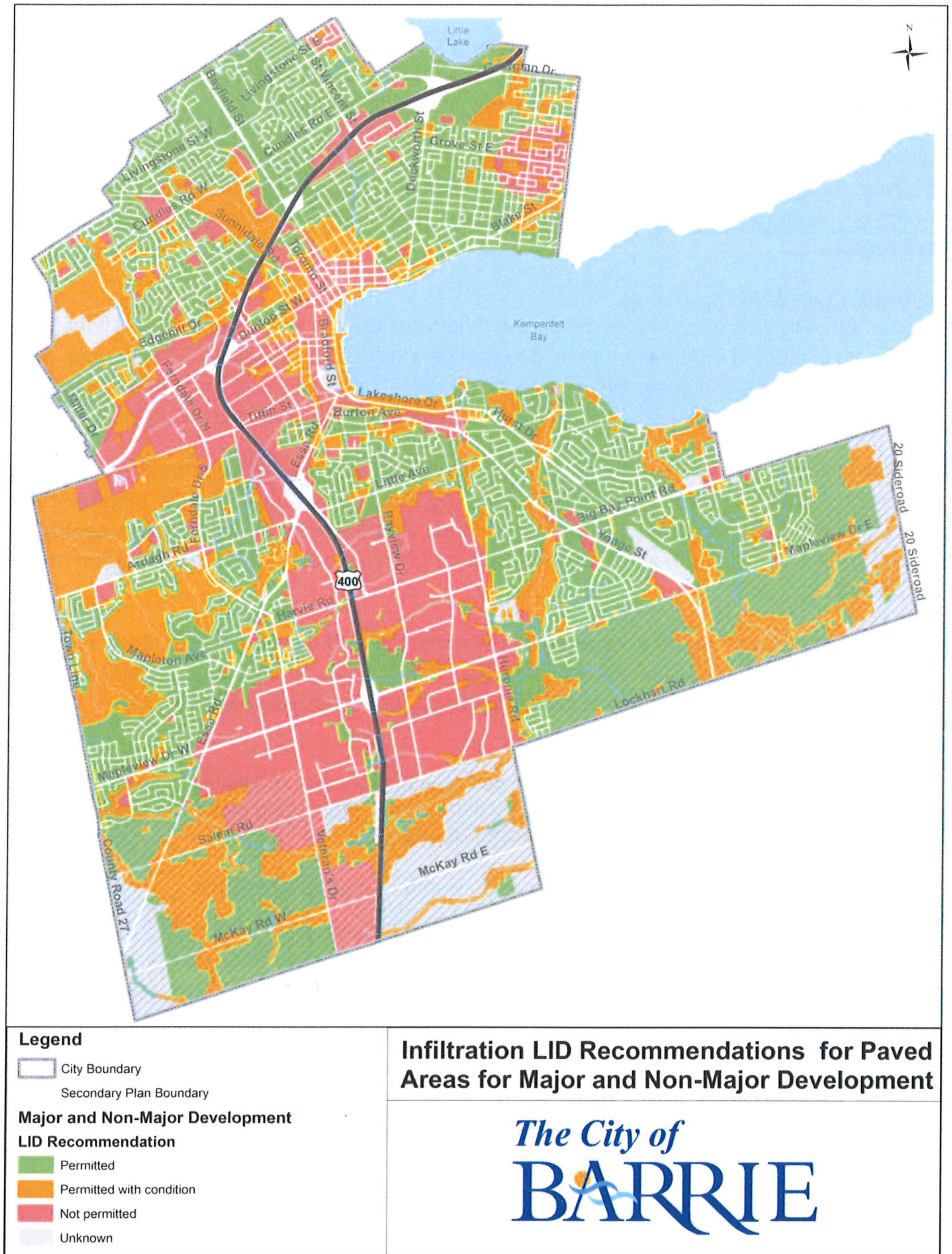
Paved area runoff: The water quality characteristics of runoff from paved areas, including parking lots and walkways, ranges widely depending on the land use activities of the project site. Of particular concern to Source Water Protection is the fact that land-use will have a significant influence on the amount of road salt that is applied on these paved surfaces. As such runoff from paved areas, given its location within a Source Water Protection vulnerable area, will be assigned a recommendation similar to those for linear projects. To consult the requirements based on land-use activities see Table 1.2. Figure 3 can be used to help visualize the requirements for implementing infiltration type LIDs that are receiving paved area runoff within major and non-major developments. Figure 3 was created by overlaying vulnerable areas and Official Plan zoning designations.

Figure 3 should be consulted with caution noting that if the proposed end land use of the site is not the current land use as it exists in the Official Plan, Table 1.2 must be consulted to determine the appropriate recommendation.

Table 1.2 Infiltration LID requirements for **paved area** runoff for major and non-major development

Note: This table outlines requirements for paved area runoff only. Runoff from vegetated areas and rooftop are always permitted to be infiltrated, while runoff from pollution hot spot is never permitted.

Land Use	Vulnerable Area	Requirement
Low Density Residential	*Wellhead Protection Area A and B*	Infiltration based practices are not permitted
	Issues Contributing Area	Infiltration based practices are permitted
	Wellhead Protection Area C and D	
	Intake Protection Zone-1 and Zone-2	
	Lake Simcoe Protection Plan Significant Groundwater Recharge Areas	
	Highly Vulnerable Aquifers	
	Not Vulnerable	
Commercial & Institutional	*Wellhead Protection Area A and B*	Infiltration based practices are not permitted
	Issues Contributing Area	
	Wellhead Protection Area C and D	Infiltration based practices are permitted with conditions
	Intake Protection Zone-1 and Zone-2	Infiltration based practices are permitted
	Lake Simcoe Protection Plan Significant Groundwater Recharge Areas	Infiltration based practices are not permitted
	Highly Vulnerable Aquifers	
	Not Vulnerable	Infiltration based practices are permitted
Industrial	*Wellhead Protection Area A and B*	Infiltration based practices are not permitted
	Issues Contributing Area	
	Wellhead Protection Area C and D	
	Intake Protection Zone-1 and Zone-2	
	Lake Simcoe Protection Plan Significant Groundwater Recharge Areas	
	Highly Vulnerable Aquifers	
	Not Vulnerable	
Mixed Use and High Density Residential	*Wellhead Protection Area A and B*	Infiltration based practices are not permitted
	Issues Contributing Area	Infiltration based practices are permitted with conditions
	Wellhead Protection Area C and D	
	Intake Protection Zone-1 and Zone-2	Infiltration based practices are permitted
	Lake Simcoe Protection Plan Significant Groundwater Recharge Areas	Infiltration based practices are permitted with conditions
	Highly Vulnerable Aquifers	
	Not Vulnerable	Infiltration based practices are permitted
Open Spaces and Environmental Protection Areas	*Wellhead Protection Area A and B*	Infiltration based practices are permitted with conditions
	Issues Contributing Area	
	Wellhead Protection Area C and D	
	Intake Protection Zone-1 and Zone-2	
	Lake Simcoe Protection Plan Significant Groundwater Recharge Areas	
	Highly Vulnerable Aquifers	
	Not Vulnerable	Infiltration based practices are permitted



Note: Land use determined for the Secondary Plan boundary is conceptual and subject to change as development is propsosed. Please use table concurrently during screening. If the proposed end land use of the site is not the current land use as it exists in the Official Plan, Table 1.2 must be consulted to determine the appropriate recommendation.

Source:

-City of Barrie, 2014, The City of Barrie Official Plan.

-South Georgian Bay-Lake Simcoe Source Protection Region, 2015, Approved Assessment Report: Lakes Simcoe and Couchiching-Black River Source Protection Area.

Figure 3. Screening map showing infiltration LID recommendations for paved area runoff for major and non-major development

2.2 Step 2: Additional Considerations

The second step of the screening process only applies to those areas where the source of stormwater has been recommended as permitted to be conveyed or treated using infiltration based practices provided additional requirements are met (permitted with conditions).

A proposal to implement infiltration based LIDs in these areas will be reviewed by the Infiltration LID Working Group. They are only to be considered if it has been demonstrated that the LSRCA stormwater quantity control criteria for peak flow control cannot be met through the infiltration of clean sources only (permitted sources).

2.2.1 Infiltration LID Working Group

The Infiltration LID Working Group is the proposed group that will review and outline additional criteria for going ahead with infiltration LIDs within areas deemed permitted with conditions. The purpose of the group is to review projects and applications to test the process internally until the group is comfortable with some of the associated risks of such features and a clear list of conditions is established.

The LID Working Group should be formed by members from many different departments (ex. Source Water Protection, Infrastructure Planning, Parks Planning, Policy and Standards, Development Services, Design & Construction, Environmental Operations, Roads Operations and Planning Services) to bring a wide range of knowledge to the table. A proposed Terms of Reference for the working group can be found in Appendix A.

Two types of considerations will be addressed by the Infiltration LID Working Group. These include on-going review of site specific conditions on an individual project basis, and working towards establishing overall corporate objectives to deal with associated risks of infiltration features.

2.2.1.1 Corporate Objectives

The Infiltration LID Working Group will work towards some key corporate initiatives aimed at establishing a level of comfort in implementing infiltration LID projects. They include big picture objectives intended to reduce the risk of contamination for all project proposals regardless of location.

1. Establish a **spill response process** for spills within or near LID features
2. Develop a **maintenance and monitoring plan** for LID features
3. Analyze feasibility of having centralized infiltration facilities with **by-pass valve capacity**
4. Implementation of **road salt reduction measures**
   a. Salt Optimization Strategy
   b. Parking Lot Design Guidelines
   c. Risk Management Plans and outreach to local businesses
   d. Smart About Salt
5. Develop Engineering **policy and standards for LIDs**
6. Continued consideration of **new and emerging science and policy directions**

New corporate objectives may be determined and added to this list as new information becomes available. Some of the above mentioned corporate initiatives will be required to be in place for site specific projects to go forward.

2.2.1.2 Site Specific Information

Site specific information will need to be reviewed by the Infiltration LID Working Group prior to allowing infiltration LIDs to be implemented in areas permitted with conditions. This review should be done on an individual project basis until such time the Infiltration LID Working Group determines otherwise. Below is a potential list of information needed to be reviewed by the working group; however this list will continue to be updated as the process is tested.

1. An understanding of the **background water quality** conditions; it is recommended that quarterly water quality sampling occur for a period of 1-2 years prior to implementation
2. An understanding of the **local hydrogeological system**
3. Submission of a site specific **monitoring recommendations** prior to implementation
4. Submission of a **contingency plan** prior to implementation
    a. What happens in case of failure,
    b. Contaminants of concern are found at unacceptable concentrations
5. For paved surfaces and road segments: **design guidelines for effective winter maintenance** are to be employed on-site (as to minimize the amount of road salt needed)
6. Development of a Risk Management Plan relating to winter maintenance for the site (note this is not a Risk Management Plan as required under PartIV of the Clean Water Act, but is to be developed using a similar template and be incorporated as a condition through the site plan agreement)

The Infiltration LID Working Group may request to view additional information that is not included in this list based on the individual project. If the project is working through the EA process, the working group may also request to complete a secondary review at time of detailed design.

2.2.2 Future Guidance

Listed below are a series of documents/initiatives that are currently being completed. The outcome of these will hopefully help address some of the concerns of groundwater contamination (mainly salt loading) through infiltration LID features. Additional considerations for the implementation of LIDs in areas deemed permitted with conditions may be reassessed upon the results from these initiatives.

2.2.2.1 Provincial Stormwater Guidance Document

The Ministry of Environment and Climate Change is currently working on an LID stormwater management guidance document that is expected to specify the ministry's expectation on water balance, outline monitoring and maintenance of LID facilities and provide further guidance on suitability. Currently the document is expected to be released in 2017. Until the release of this document a conservative approach to LID implementation is recommended.

2.2.2.2 LSRCA Parking Lot Design Guidelines

Lake Simcoe Region Conservation Authority (LSRCA) recently initiated a project to develop guidelines for the design of commercial/institutional parking lots for salt reduction. The project is expected to focus on a minimum of three key design features that promote the greatest reduction of road salt application and are most likely to be implemented in the design of future parking lots or the retrofit of existing parking lots. The guidelines are anticipated to be released in February 2017.

2.2.2.3 Research Results from Current LID Practices
Many municipalities have started implementing LID features as pilot projects (ex. permeable pavers in a Bradford West Gwillimbury municipal parking lot, LSRCA parking lot, CVC numerous pilot projects). Analysis and research of long term datasets on the effectiveness of these LID practices would be beneficial in understanding the ability of LIDs in controlling water quantity and effectively treating for water quality.

2.2.2.4 Salt Optimization Strategy
As a requirement under the Clean Water Act (2006), an evaluation of drinking water issues was completed for the City of Barrie drinking water supply system. It was found that concentrations of sodium and chloride for certain municipal supply wells within the central portion of the City are trending to exceed Ontario Drinking Water Quality Standards within the next 50 years. This prompted the outlining of an Issues Contributing Area and as a consequence the development of a Salt Optimization Strategy. The Strategy outlines a series of recommendation that are designed to optimize the use of road salt to help minimize the impacts of application. The outcomes of this Strategy implementation will be analyzed following the each winter maintenance season to measure its success in reducing salt application on municipal roadways.

2.2.2.5 Smart About Salt
It is the intention of the City of Barrie to have the Smart About Salt training sessions brought to Barrie for City staff as well as private contractors. Smart About Salt offers innovative training programs that teach how to effectively balance winter safety and environmental protection.

2.3 Step 3: Legislative Requirements
Whether a proposed infiltration LID facility is permitted or permitted with conditions, based on the location screening completed in step 1, it must meet additional legislative requirements that are beyond the scope of this document.

A project proposing infiltration LIDs must adhere to all federal and provincial requirements as well as requirements set out in the City of Barrie's Storm Drainage and Stormwater Management Policies and Design Guidelines. LID specific policies and standards for the City are currently being developed and reviewed. For those projects deemed permitted with conditions it is recommended to complete steps 2 and 3 concurrently.

3.0 Definitions

High Density Residential: High density residential is a land use category that generally includes three or more unit dwellings, townhouse dwellings and apartment dwellings and is designated by the following zoning codes (RM2, RM2-TH, RA1, RA2) as outlined in the City of Barrie Comprehensive Zoning By-law.

Linear Development: Linear development is defined as a road or highway project that results in full road reconstruction and/or increases in total impervious area. Mill and overlay and other resurfacing activities are not considered linear developments. (Lake Simcoe Region Conservation Authority, 2016)

Low Density Residential: Low density residential is a land use category that generally includes single detached dwellings and two unit dwellings and is designated by the following zoning codes (RH, R1, R2, R3, R4, RM1, RM1-SS) as outlined in the City of Barrie Comprehensive Zoning By-law.

Major Development: Major development means the construction of a building or buildings on a lot with the ground floor area cumulatively equal or greater than 500 m^2, and any other impervious surface. Note single detached residential properties are exempt from the definition. (Ministry of the Environment, 2009)

Non-Major Development: Non-major development is considered to be anything not captured in the definition of major development.

Pollution Hot Spot: Pollution hot spots are areas where certain land uses or activities have the potential to generate highly contaminated runoff (e.g., vehicle fueling, service or demolition areas, outdoor storage and handling areas for hazardous materials and some heavy industry sites).

4.0 References

City of Barrie, 2014, The City of Barrie Official Plan.

City of Barrie, 2015, Comprehensive Zoning By-law.

Credit Valley Conservation & Toronto Region Conservation Authority (CVC & TRCA), 2010, Low Impact Development Stormwater Management Planning and Design Guide.

Lake Simcoe Region Conservation Authority, 2014, Guidance for the Protection and Restoration of Significant Groundwater Recharge Areas (SGRAs) in the Lake Simcoe Watershed.

Lake Simcoe Region Conservation Authority, 2016, LSRCA Technical Guidelines for Stormwater Management Submissions.

Ministry of the Environment, 2009, Lake Simcoe Protection Plan.

South Georgian Bay-Lake Simcoe Source Protection Region, 2015, Approved Assessment Report: Lake Simcoe and Couchiching-Black River Source Protection Area

Appendix A Proposed Terms of Reference- Infiltration LID Working Group

Proposed Terms of Reference- Infiltration LID Working Group

Purpose of Infiltration LID Working Group Terms of Reference

This document outlines the role of the Infiltration LID Working Group in providing recommendations and decisions on proposed infiltration Low Impact Development (LID) projects regarding drinking water sources. It also presents how the working group will operate, including how and when meetings will take place. Any amendments to these Terms of Reference (TOR) will be done in consultation with the Manager of Infrastructure Planning and working group members.

Working Group Overview

The City of Barrie is looking to make greater use of LIDs, as the need for better solutions to stormwater management are increasingly required. However, there is concern that implementing infiltration LIDs, especially along road right of ways, will lead to contamination of groundwater resources. Of particular concern is the risk of sodium and chloride contamination, as a result of winter maintenance practices.

The Infiltration LID Working Group will focus on offering guidance, working through case studies and participating in corporate initiatives that address drinking water source protection concerns.

Mandate

The Infiltration LID Working Group is an internal working group guided by these Terms of Reference. It provides an opportunity for key stakeholders to discuss and require the implementation of actions to support the successful implementation of infiltration LID projects in the City of Barrie.

The mandate of the working is to provide on-going review of certain infiltration LID projects as outlined in the Infiltration LID Screening Process, and advance the implementation of key corporate initiatives required to establish a level of comfort in implementing infiltration LID projects.

The role of working group membership includes:

- Coming prepared to meetings by reviewing any reports prior to meetings and having comments, questions and concerns previously identified;
- Actively participating and sharing knowledge during discussions on Infiltration LID projects
- Identifying potential Issues and Concerns and how these might be addressed
- Attending all working group meetings whenever possible; and
- Working collaboratively with others on advancing and implementing corporate initiatives aimed at establishing a level of comfort in implementing infiltration LID projects.

Work Plan

It is proposed that the working group will meet in person on a quarterly basis over the life of the working group. Additional meetings may be scheduled to review proposed projects upon request.

Membership

Working group membership will consist of the following groups:

Development Services	Planning Services
Design and Construction	Policy and Standards
Environmental Operations	Road Operations
Infrastructure Planning	Source Water Protection
Parks Planning	Field Coordinator

Term of Membership
Membership in the Infiltration LID Working Group is anticipated to be for a minimum of three years, starting in 2017 and continuing until a level of comfort has been established for implementing Infiltration LID projects in the City of Barrie. After, three years the purpose and role of the working group will be reassessed.

Decision Making
It is envisioned that a consensus-based approach-where members seek general agreement on advice, recommendations and project specific conditions- will be the operating model for the working group. If consensus is not achieved, differing perspectives and viewpoints will be recorded and noted in the working group minutes.

If consensus is not achieved, a vote will occur. Quorum will be required for decision making to occur. To have quorum 2/3rds of the working group members will need to be present.

Meeting Management, Agendas and Reporting
The following procedures will be used in convening meetings of the Infiltration LID Working Group:

- Meetings will be scheduled on a quarterly basis by the chair, and subject to confirmation of working group member availability.
- Meetings will be held on weekdays (mornings or afternoons) for up to two hours. When more discussion time is required, members may consider holding an extended or additional meeting.
- Meeting agendas and any materials will be distributed to working group members one week in advance of each meeting.
- Working group members will be consulted on agenda items for future meetings at the conclusion of each meeting.
- Action items and key points from each working group meeting will be recorded. Meeting highlights will be prepared within 10 business days of each meeting.

Advisors and Experts
The working group may wish to invite or request additional advisors or experts to attend at various points during the term of working group existence. Considerations will be given to each request by the Chair and will be subject to timing, availability and budget considerations.