Identification of Salt Vulnerable Areas: A Critical Step in Road Salt Management

Andrew Betts, M.A.Sc., P.Eng.
GHD Ltd.

Bahram Gharabaghi, PhD, P.Eng.
University of Guelph

Edward McBean, PhD, P.Eng., P.E.
University of Guelph

Jana Levinson, PhD, P.Eng.
University of Guelph
Presenter: Andrew Betts, M.A.Sc., P.Eng.

  - Focus on Hydrology and Hydraulic
- M.A.Sc. – Water Resource Engineering, University of Guelph - 2013
  - Research focus on Environmental Management of Road Salts, particularly in Identification of Salt Vulnerable Areas
- Water Resource Engineer, GHD Ltd, 2007-present
Presentation Learning Outcomes

- Introduction to Road Salts
- Salt Management Plans Background
- Identification of Salt Vulnerable Areas
  - Calculation of chloride loading
  - Identifying Surface Water Vulnerable Areas
  - Identifying Groundwater Vulnerable Areas
- Conclusions
Introduction

Snow and ice on roads cause impacts to:
- Public safety
- Roadway capacity
- Travel time

Solution: De-Icing Agents (Road Salts)

Benefits of road salts:
- Reduction of traffic accidents

Drawbacks
- Adverse impact on groundwater resources and aquatic and terrestrial ecosystem

Chloride Concentration (mg/L)

<table>
<thead>
<tr>
<th>Year</th>
<th>Chloride Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>50</td>
</tr>
<tr>
<td>1980</td>
<td>100</td>
</tr>
<tr>
<td>1990</td>
<td>200</td>
</tr>
<tr>
<td>2000</td>
<td>300</td>
</tr>
<tr>
<td>2010</td>
<td>400</td>
</tr>
<tr>
<td>2020</td>
<td>450</td>
</tr>
</tbody>
</table>
Salt Management Plans

- The use of road salts is critical to winter safety but causes damage to drinking water sources and local ecosystems.

- Canadian Transportation sector worked with Environment Canada to develop a Canadian strategy to manage road salts.

- The strategy was published as Environment Canada’s Code of Practice for the Environmental Management of Road Salts (2004).

- GOAL - To maintain safe winter travel while reducing the negative environmental effects of road salt.
Conclusion:

- The percentage of provincial and municipal road agencies, using over 500 tonnes of salt annually, that have developed salt management plans grew from **82%** in 2005 to **96%** by 2009.

- The percentage of provincial and municipal road organizations that have inventoried SVAs has increased from **2005** to **2009** but still remains below **30%**.
Identification of Salt Vulnerable Areas

- To develop a GIS-based methodology to identify if an area is vulnerable to road salt application

- Quantify the vulnerability to the area in order to prioritize implementation of best management practices to those that are the most vulnerable

- The proposed methodology for assigning a vulnerability score to a given area has been divided into the two receiving receptors:
  - surface water (Aquatic Species)
  - groundwater recharge (Drinking Water Source)
Stream Chloride Concentration (SCC)

\[ SCC = \frac{A \times CAD \times UAR \times (1 - BFI) + BFC \times BFI \times A \times MAF}{A \times MAF} \]

Where,

- SCC = Mean Annual Stream Chloride Concentration, (mg/L)
- A = Influence Area, (m²)
- CAD = Chloride Application Density
- UAR = Unit Chloride Application Rate, (g/m² per yr)
- BFI = Base Flow Index
- BFC = Baseflow Chloride Concentration, (mg/L)
- MAF = Mean Annual Flow Depth, (m/yr)
Impact on Sensitive Species

Proportion of Species Affected

- Fish species
- Amphibian species
- Invertebrate species

Chloride (mg/L)

Short-term SSD
95% fiducial limits

Species:
- Anguilla rostrata
- Gasterosteus aculeatus
- Cambarus sp.
- Libellulidae sp.
- Fundulus kansae
- Gambusia affinis
- Oncorhynchus mykiss
- Culex sp.
- Leptomis cyaneellus
- Cyprinella leedsi
- Argia sp.
- Lepomis macrochirus
- Rana catesbeiana
- Chironomus dilutus / tentans
- Hydropsyche sp.
- Notropis lutrensis
- Chironomus attenuatus
- Ameius melas
- Erpobdella punctata
- Pimephales promelas
- Nephelepsis obscura
- Carassius auratus
- Hydroptila angusta
- Lumbricus variegatus
- Bufo americanus
- Helisoma campanulata
- Cricotopus trifascia
- Rana clamitans
- Baetis tricaudatus
- Gyraulus parvus
- Daphnia magna
- Pseuacris crucifera
- Lirceus fontinalis
- Diaptomus sp.
- Physa heterostropha
- Pseuacris trisenaferiarum
- Physa gyirina
- Villosa delumbis
- Rana sylvatica
- Gyraulus circumstriatus
- Brachionus calyciflorus
- Epioblasma brevidens
- Epioblasma capsaeformis
- Stenonema rubrum
- Villosa consticta
- Elliptio complanata
- Hyalella azteca
- Daphnia pulex
- Brachionus patulus
- Daphnia ambigua
- Ceriodaphnia dubia
- Lampsilis
- Ambystoma maculatum
- Tubifex tubifex
- Sphaerium tenuis
- Sphaerium simile
- Lampsilis fasciola
- Epioblasma tulea reiliana
\[ \sigma_y = \sqrt{ln \left(1 + \frac{\sigma_x^2}{\mu_x^2}\right)} \]

Where,

\( \sigma_y \) = Logarithm Standard Deviation of the Mean

\( \sigma_x \) = Standard Deviation of the Mean (mg/L)

\( \mu_x \) = SCC (mg/L)

\[ y = 0.0009x^2 + 0.7454x \]

\[ R^2 = 0.99 \]
Groundwater Recharge Chloride Concentration (RCC)

\[ RCC = \frac{(1 - \varphi) \times (1 - \theta) \times BFI \times CAD \times UAR \times A}{(1 - \varphi) \times (1 - \theta) \times BFI \times A \times MAF + \varphi \times BFI \times A \times MAF} \]

\( \varphi = \) Is a dilution factor, that accounts for the clean non-salted groundwater recharge

\( \theta = \) Is the fraction of groundwater recharge that discharges, in a relatively short period of time, back into surface waters through interflow

\[ RCC = \frac{CAD \times UAR}{MAF} \times \frac{(1 - \varphi) \times (1 - \theta)}{(1 - \varphi) \times (1 - \theta) + \varphi} \]
Example Case Study

Identification of Surface Water Vulnerable Areas

a. City of Toronto (7 sites)
b. City of Guelph (1 site)
City of Toronto Monitoring Program
Hanlon Creek Monitoring

Grand River Watershed

Legend
- Monitoring Locations
- Hanlon Creek
- Principal Highway
- Secondary Highway
- Major Road
- Local road

Hanlon Creek Watershed

0 5 10 20 30 40 50 Kilometers
Chloride Application Density (CAD)

\[ CAD = \Sigma_i \left( \text{Land Use Area Receiving Salt} \times \text{Weighted Application Rate} \right) \]

<table>
<thead>
<tr>
<th>Land Use Type</th>
<th>% of Land Use Area Receiving Road Salt</th>
<th>Salt Application Weighting Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial</td>
<td>0.560</td>
<td>2.0</td>
</tr>
<tr>
<td>Industrial</td>
<td>0.465</td>
<td>1.0</td>
</tr>
<tr>
<td>Institutional</td>
<td>0.154</td>
<td>2.0</td>
</tr>
<tr>
<td>City Roads</td>
<td>1.000</td>
<td>1.0</td>
</tr>
<tr>
<td>MTO Highway</td>
<td>1.000</td>
<td>1.0</td>
</tr>
<tr>
<td>Residential</td>
<td>0.240</td>
<td>0.5</td>
</tr>
<tr>
<td>Open</td>
<td>0.000</td>
<td>0.0</td>
</tr>
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</table>
Unit Chloride Application Rate (UAR)

\[
UAR \left( \frac{g}{m^2} \right) = \frac{\text{Annual Road Salt Application Mass (tonnes)} \times 10^6 \text{grams/tonnes}}{\text{Total Road Length (2-lane km)} \times 1000 \frac{m}{km} \times 7.0 \frac{m}{2\text{-lane}}} \times 60.66\% \frac{Cl^-}{NaCl}
\]

Graph showing the Unit Application Rate (g/m²) from 2004 to 2014 for Region of Waterloo, Cambridge, Kitchener, Waterloo, North Dumfries, and Wellesley.
Ontario BFI Map

Legend
Baseflow Index
- 0
- 0.149
- 0.170
- 0.345
- 0.443
- 0.455
- 0.504
- 0.680
- 0.681
- 0.704
- 0.730

Lake Ontario
Lake Erie
Provincial Groundwater Monitoring Network (PGMN)
Groundwater Chloride Concentration
Mean Annual Flow Depth (MAF)

\[
MAF \left( \frac{m^3}{s} \right) \times 31,557,600 \frac{s}{yr}
\]

\[
MAF \text{ Depth (m/yr)} = \frac{MAF \left( \frac{m^3}{s} \right) \times 31,557,600 \frac{s}{yr}}{\text{Area km}^2 \times \frac{10^6 \text{ km}^2}{m^2}}
\]

Source: Environment Canada, 2010
Calculated SCC Correlation with Measured Chloride Concentration

\[ y = 0.9189x \]
\[ R^2 = 0.9641 \]

<table>
<thead>
<tr>
<th>Study Area</th>
<th>Salt Vulnerability Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highland Creek at Bellamy Road</td>
<td>43</td>
</tr>
<tr>
<td>Highland Creek at Mammoth Hall Trail</td>
<td>43</td>
</tr>
<tr>
<td>Don River at Bloor St</td>
<td>37</td>
</tr>
<tr>
<td>Highland Creek at Morningside Ave</td>
<td>31</td>
</tr>
<tr>
<td>Humber River at Old Mill Rd</td>
<td>20</td>
</tr>
<tr>
<td>Rouge River at Finch Ave</td>
<td>4</td>
</tr>
<tr>
<td>Humber River at Steeles Ave</td>
<td>3</td>
</tr>
<tr>
<td>Hanlon Creek at Highway 6</td>
<td>2</td>
</tr>
</tbody>
</table>
Example Case Study

Identification of Groundwater Vulnerable Areas

a. Grand River Conservation Authority (22 sites)
Drinking Water Well Protection Area
Calculated RCC Correlation with Measured Chloride Concentration

\[ y = 64.753 \ln(x) - 162.85 \]

\[ R^2 = 0.8355 \]

<table>
<thead>
<tr>
<th>Study Area</th>
<th>RCC (mg/L)</th>
<th>Risk Ranking Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waterloo Center</td>
<td>1423</td>
<td>5.69</td>
</tr>
<tr>
<td>Cambridge at 401</td>
<td>1302</td>
<td>5.21</td>
</tr>
<tr>
<td>Cambridge West</td>
<td>300</td>
<td>1.2</td>
</tr>
<tr>
<td>Sacco</td>
<td>247</td>
<td>0.99</td>
</tr>
<tr>
<td>University</td>
<td>221</td>
<td>0.88</td>
</tr>
<tr>
<td>Smallfield</td>
<td>207</td>
<td>0.83</td>
</tr>
<tr>
<td>Dean</td>
<td>173</td>
<td>0.69</td>
</tr>
<tr>
<td>Edinburgh</td>
<td>172</td>
<td>0.69</td>
</tr>
<tr>
<td>Membro</td>
<td>143</td>
<td>0.57</td>
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<tr>
<td>Clythe</td>
<td>74</td>
<td>0.3</td>
</tr>
<tr>
<td>Downey</td>
<td>71</td>
<td>0.29</td>
</tr>
<tr>
<td>Emma</td>
<td>71</td>
<td>0.29</td>
</tr>
<tr>
<td>Waterloo Center</td>
<td>63</td>
<td>0.25</td>
</tr>
<tr>
<td>Paisley</td>
<td>58</td>
<td>0.23</td>
</tr>
<tr>
<td>Bleams Road</td>
<td>56</td>
<td>0.22</td>
</tr>
<tr>
<td>Linwood</td>
<td>33</td>
<td>0.13</td>
</tr>
<tr>
<td>Burke</td>
<td>27</td>
<td>0.11</td>
</tr>
<tr>
<td>New Hamburg</td>
<td>19</td>
<td>0.08</td>
</tr>
<tr>
<td>Helmar</td>
<td>13</td>
<td>0.05</td>
</tr>
<tr>
<td>Calico</td>
<td>10</td>
<td>0.04</td>
</tr>
</tbody>
</table>
Surface Water Vulnerability Classification

\[ \text{Vulnerability Score} = \text{Probability of Occurrence} \times \text{Impact} \]

Mean Annual Stream Chloride Concentration

\[ SCC = \frac{CAD \cdot A \cdot UAR \cdot MAF \cdot (1 - BFI) + BFI \cdot BFC \cdot MAF \cdot A}{MAF \cdot A} \]

Calculation of Standard Deviation with linear regression using mean

\[ \text{Std Dev} = 0.1719 \times \ln(SCC) \]

Calculation of Probability of Occurrence using Lognormal Cumulative Distribution Function

\[ \text{Probability of Occurrence} = 1 - \text{LogNormalDist} \left( \frac{x - \mu}{\theta} \right) \]
Groundwater Recharge Vulnerability

\[
RCC = \frac{CAD \times UAR}{MAF} \times \frac{(1 - \phi) \times (1 - \theta)}{(1 - \phi) \times (1 - \theta) + \phi}
\]

Groundwater Recharge Vulnerability Classification

\[
Vulnerability Score = RCC/250
\]
Thank you!

How to contact the presenter

Andrew Betts, M.A.Sc., P.Eng.

Email: andrew.betts@ghd.com
Phone: 519-884-0510