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

About the Presenter

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

- B.A.Sc. - Water Resource Engineering, University of Guelph - 2007
  - 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

Outline

Presentation Learning Outcomes

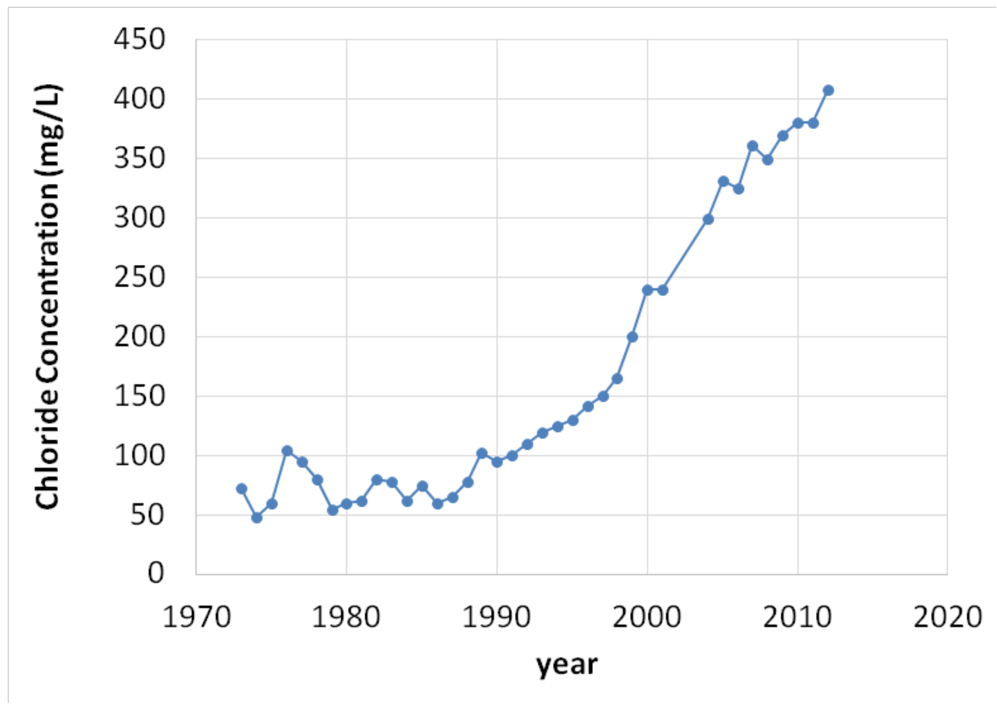
- Introduction to Road Salts
- Salt Management Plans Background
- Identification of Salt Vulnerable Areas
  - Calculation of chloride loading
  - Identifying Surface Water Vulnerable Areas
  - Identifying Groundwater Vulnerable Areas
- Conclusions

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:

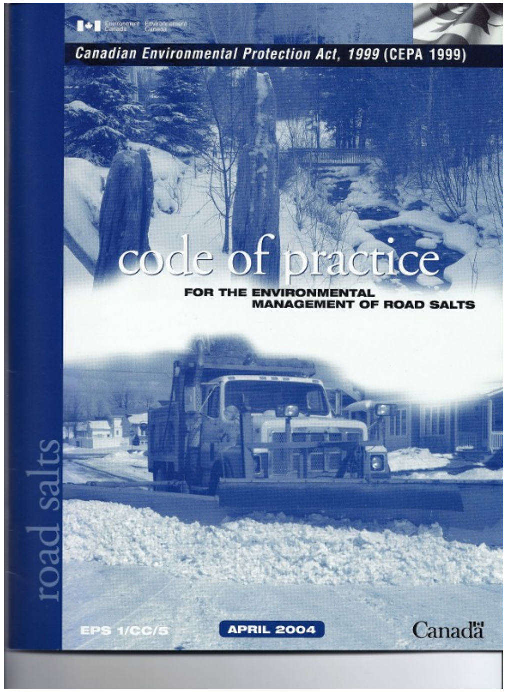
- ➢ Reduction of traffic accidents

Drawbacks

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

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.



Five Year Review of the Code of Practice

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)

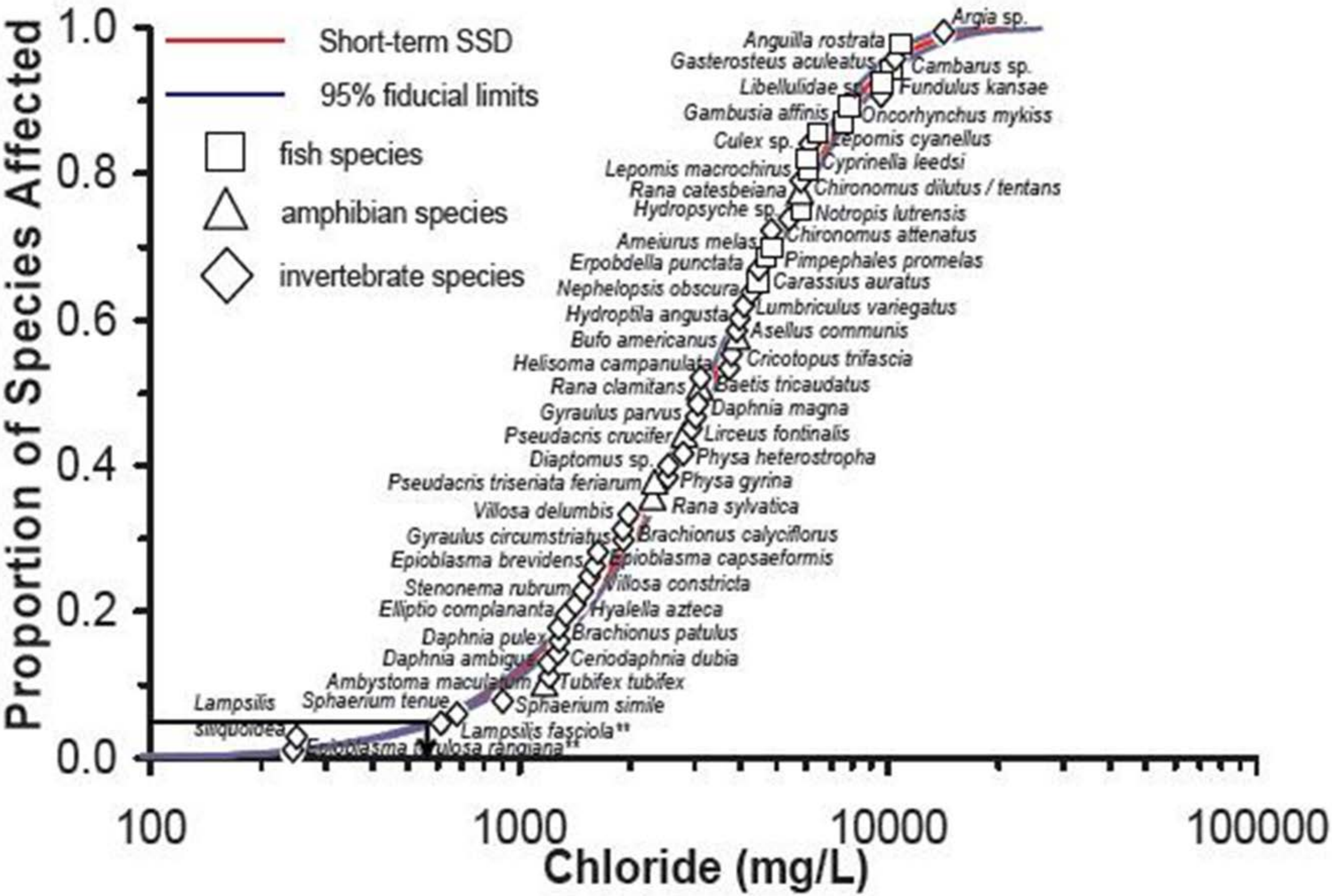
$$SCC = \frac{A * CAD * UAR * (1 - BFI) + BFC * BFI * A * MAF}{A * MAF}$$

Where,

- SCC = Mean Annual Stream Chloride Concentration, (mg/L)
- A = Influence Area, (m^2)
- CAD = Chloride Application Density
- UAR = Unit Chloride Application Rate, (g/m^2 per yr)
- BFI = Base Flow Index
- BFC = Baseflow Chloride Concentration, (mg/L)
- MAF = Mean Annual Flow Depth, (m/yr)

$$SCC = \frac{CAD * UAR * (1 - BFI)}{MAF} + BFI * BFC$$

Impact on Sensitive Species



Probability Distribution

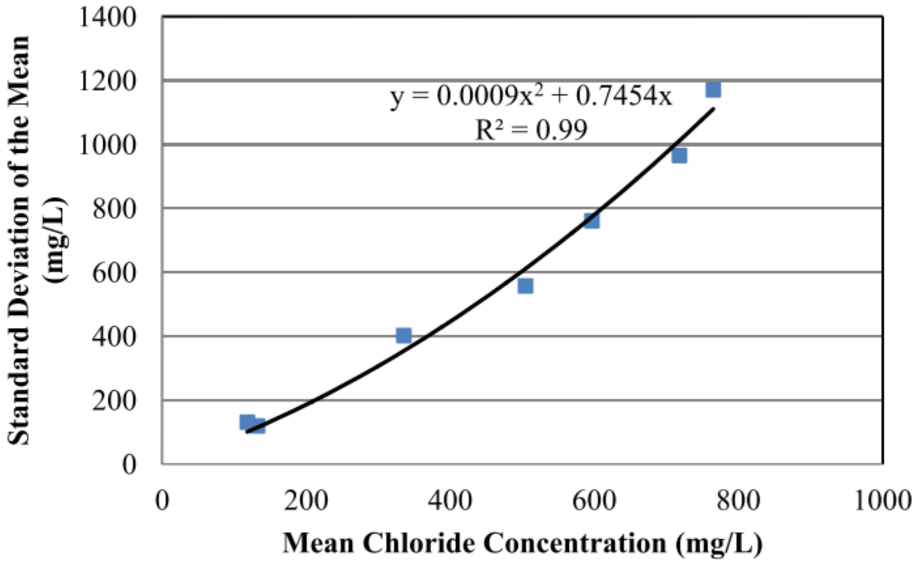
$$\sigma_y = \sqrt{ln\left(1 + \frac{\sigma_x^2}{\mu_x^2}\right)}$$

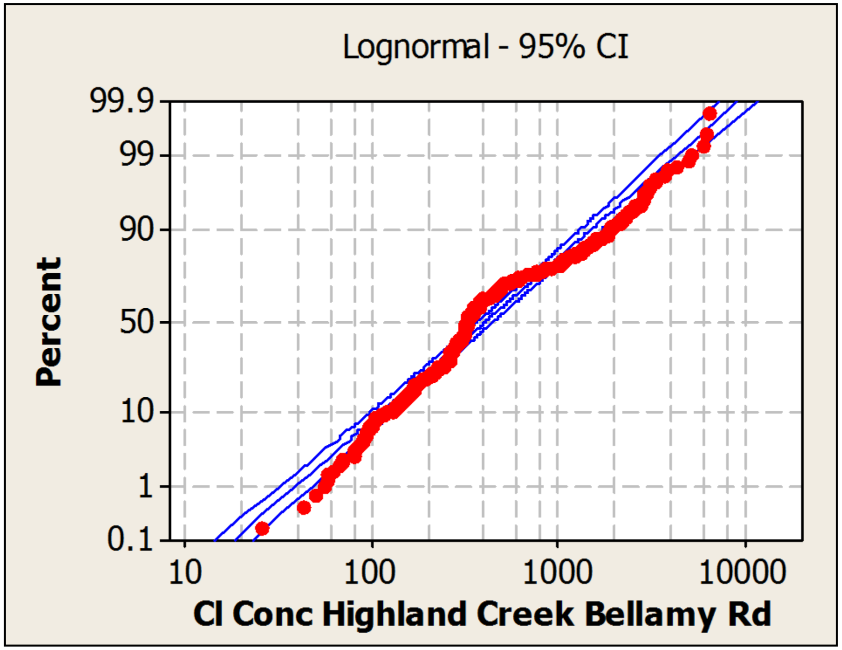
Where,

σ_y= Logarithm Standard Deviation of the Mean

σ_x= Standard Deviation of the Mean (mg/L)

μ_x= SCC (mg/L)





Groundwater Recharge Chloride Concentration (RCC)

$$\mathrm{RCC} = \frac{(1-\varphi)*(1-\theta)*\mathrm{BFI}*\mathrm{CAD}*\mathrm{UAR}*A}{(1-\varphi)*(1-\theta)*\mathrm{BFI}*A*\mathrm{MAF}+\varphi*\mathrm{BFI}*A*\mathrm{MAF}}$$

$\varphi =$ 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

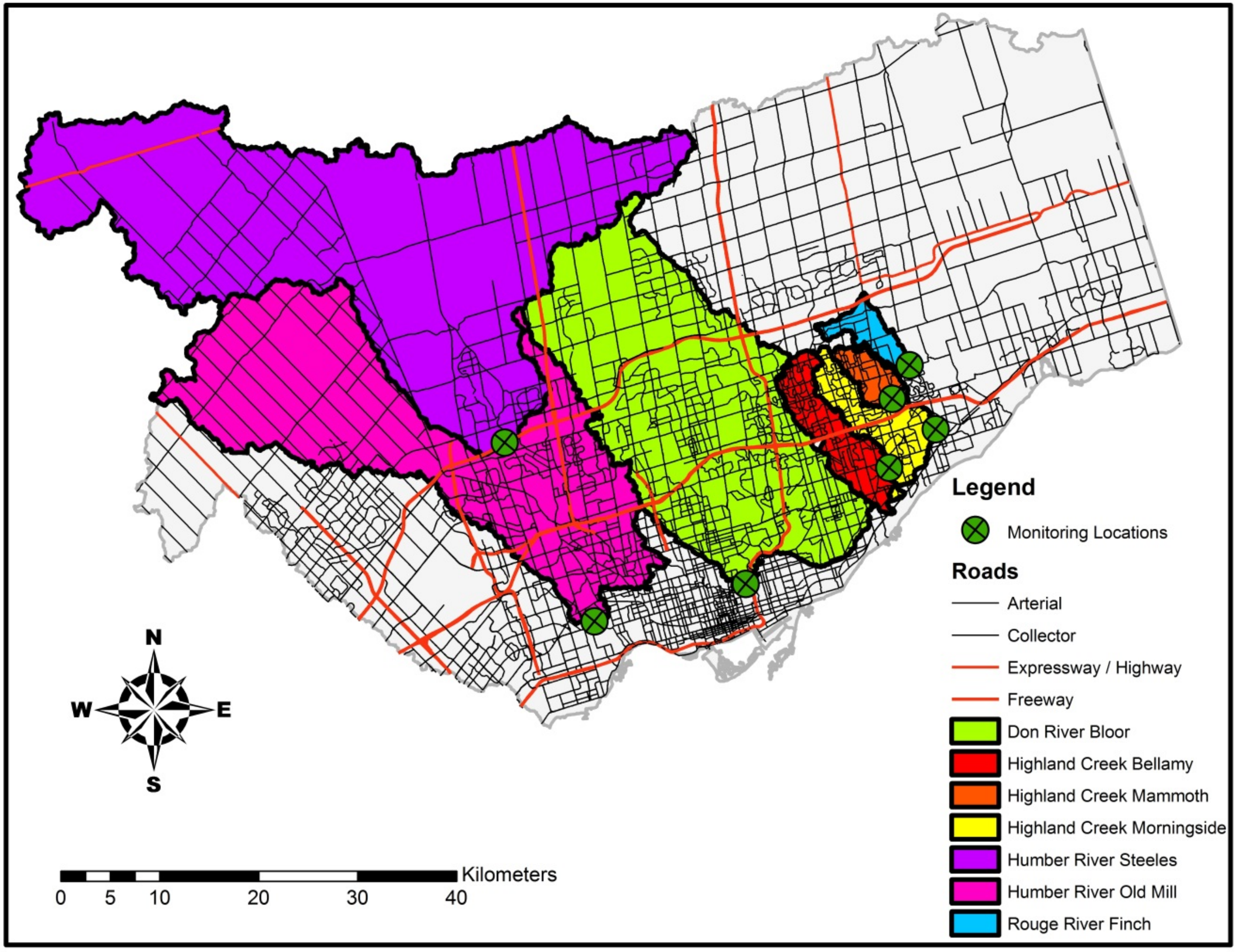
$$\mathrm{RCC} = \frac{\mathrm{CAD}*\mathrm{UAR}}{\mathrm{MAF}} * \frac{(1-\varphi)*(1-\theta)}{(1-\varphi)*(1-\theta)+\varphi}$$

Example Case Study

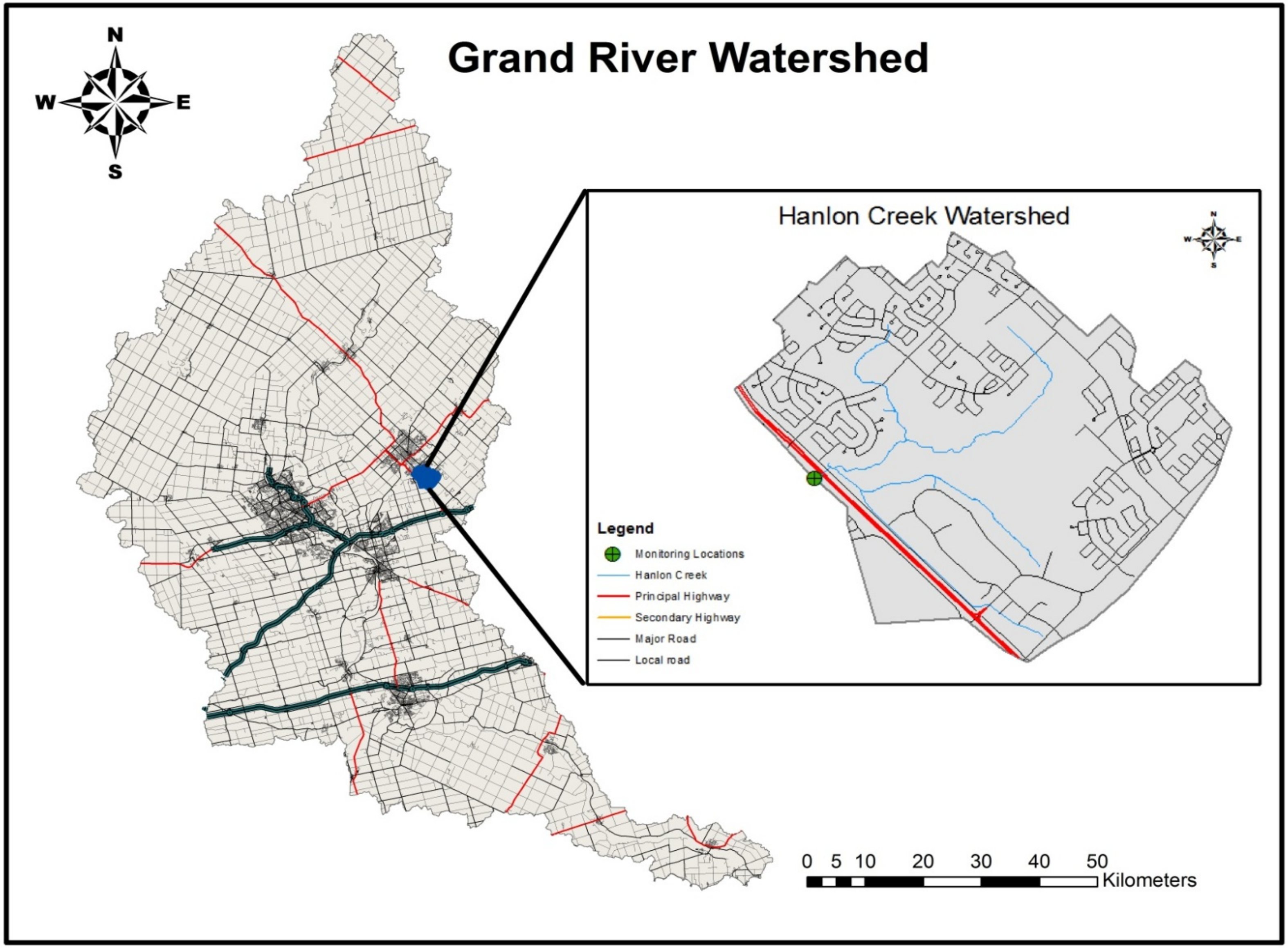
Identification of Surface Water Vulnerable Areas

a. City of Toronto (7 sites)
b. City of Guelph (1 site)

City of Toronto Monitoring Program

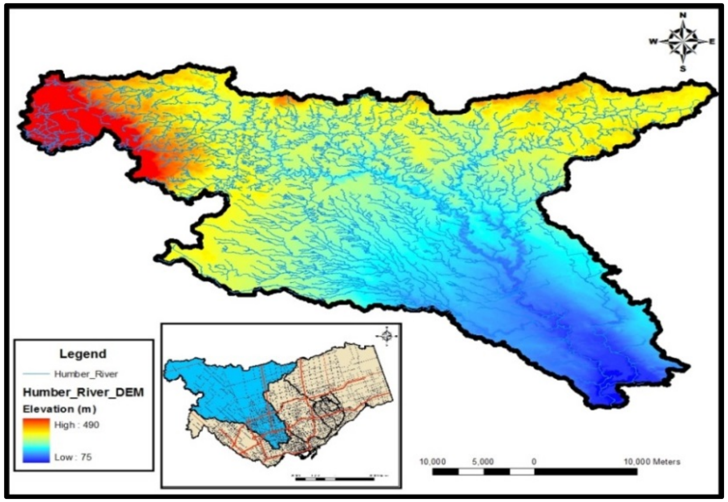


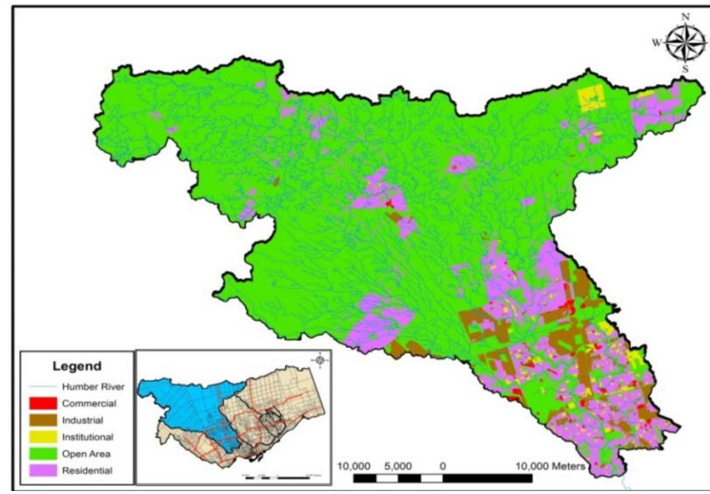
Hanlon Creek Monitoring

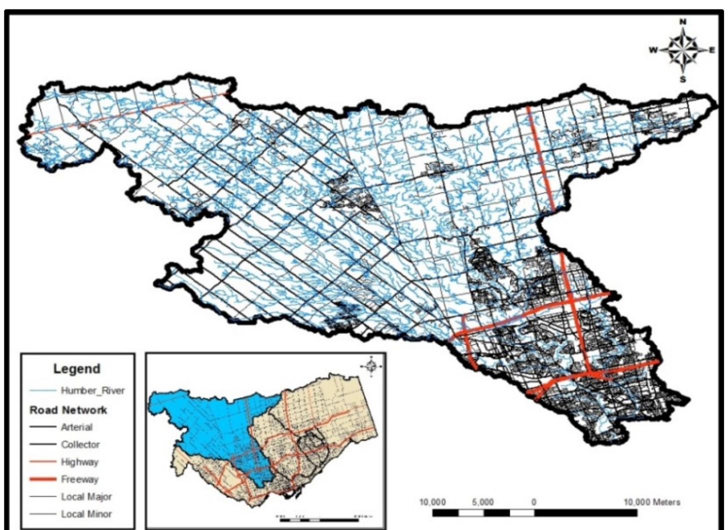


Chloride Application Density (CAD)

$$CAD = \Sigma_i \text{ (Land Use Area Receiving Salt * Weighted Application Rate)}$$



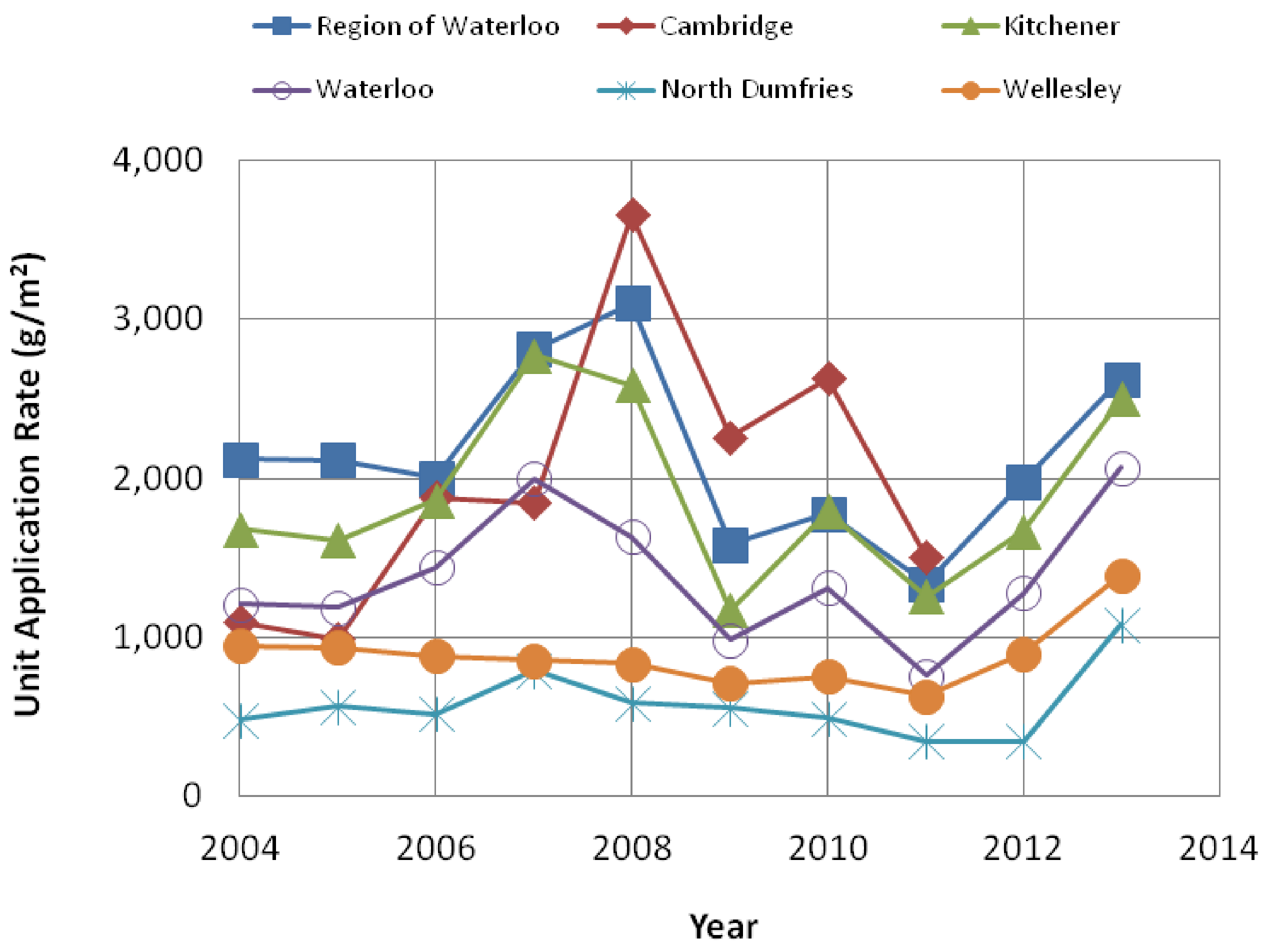




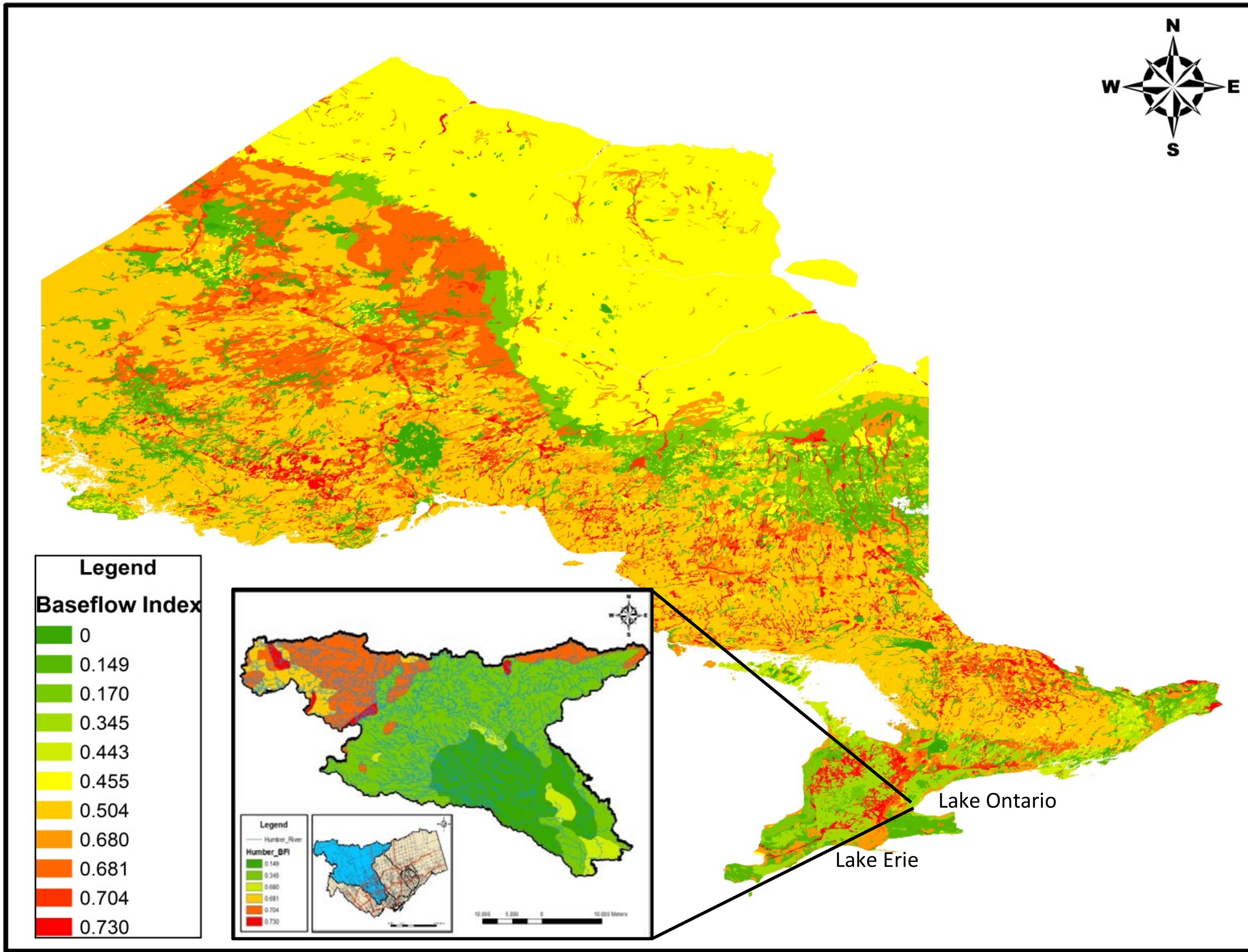
Land Use Type	% of Land Use Area Receiving Road Salt	Salt Application Weighting Factor
Commercial	0.560	2.0
Industrial	0.465	1.0
Institutional	0.154	2.0
City Roads	1.000	1.0
MTO Highway	1.000	1.0
Residential	0.240	0.5
Open	0.000	0.0

Unit Chloride Application Rate (UAR)

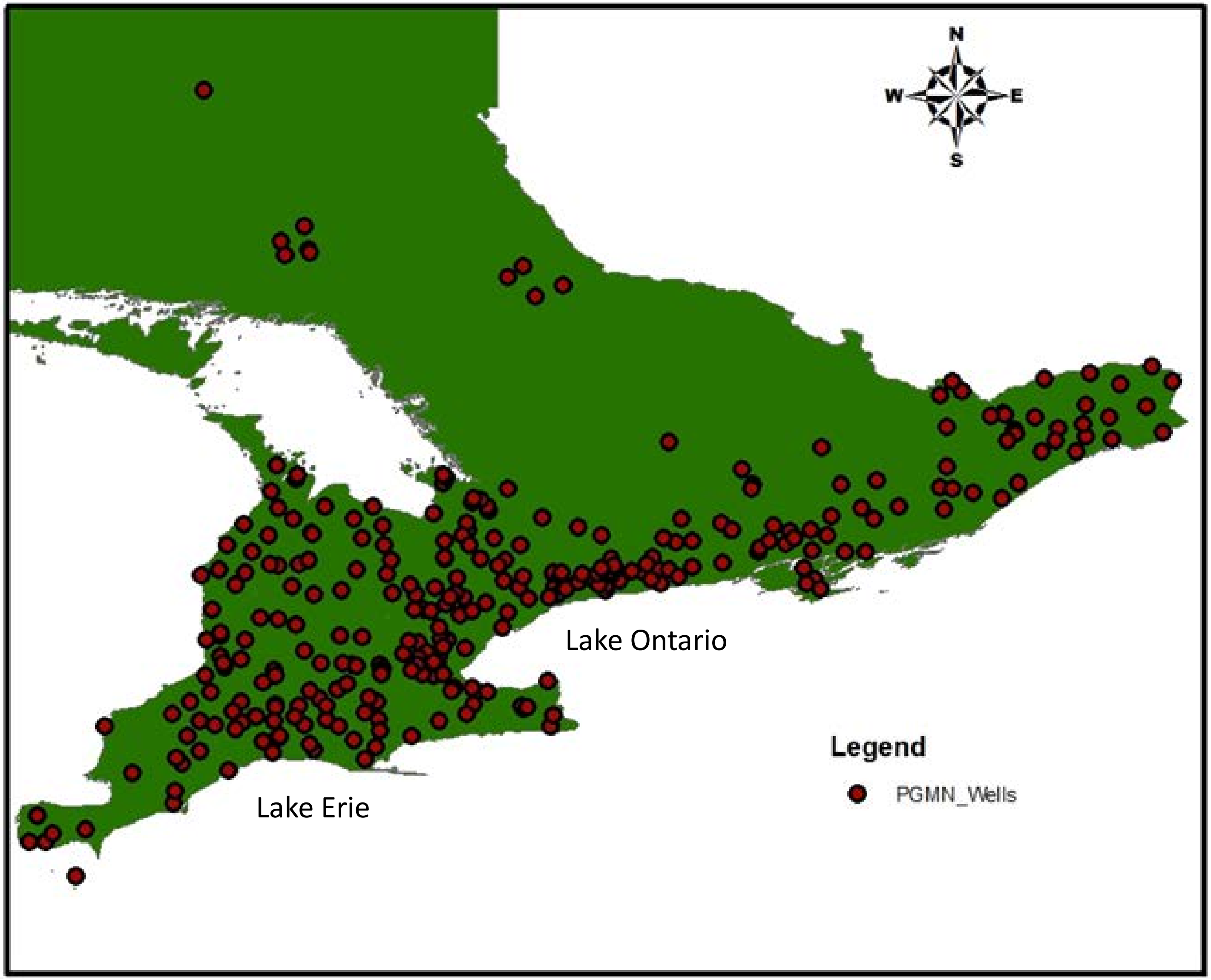
$$UAR\left(\frac{g}{m^2}\right) = \frac{Annual\ Road\ Salt\ Application\ Mass\ (tonnes) * 10^6 \frac{grams}{tonnes}}{Total\ Road\ Length\ (2\text{-}lane\ km) * 1000\frac{m}{km} * 7.0\frac{m}{2\text{-}lane}} * 60.66\% \frac{Cl^-}{NaCl}$$



Ontario BFI Map



Provincial Groundwater Monitoring Network (PGMN)
Groundwater Chloride Concentration

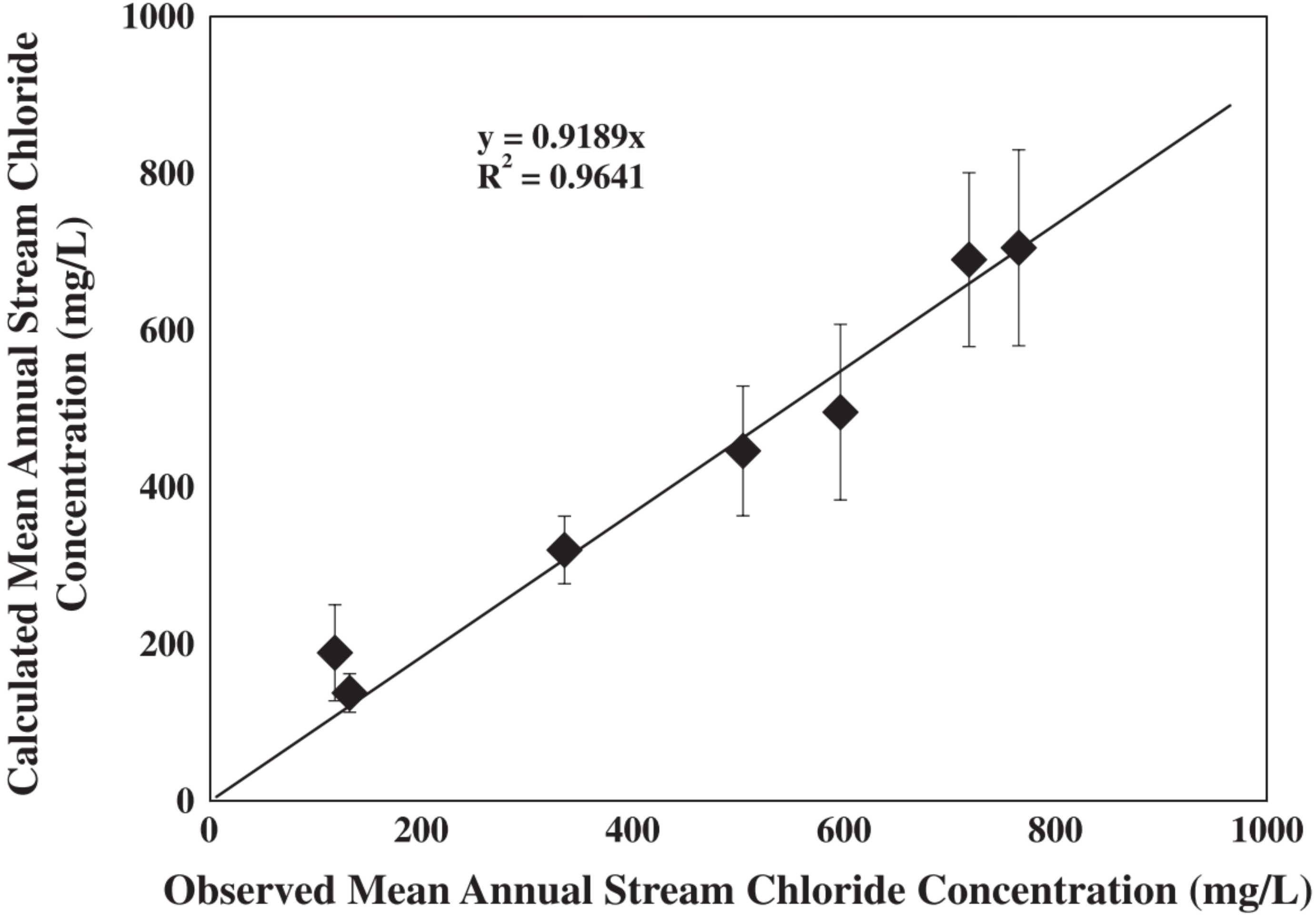


Mean Annual Flow Depth (MAF)

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

Source: Environment Canada, 2010

Calculated SCC Correlation with Measured Chloride Concentration



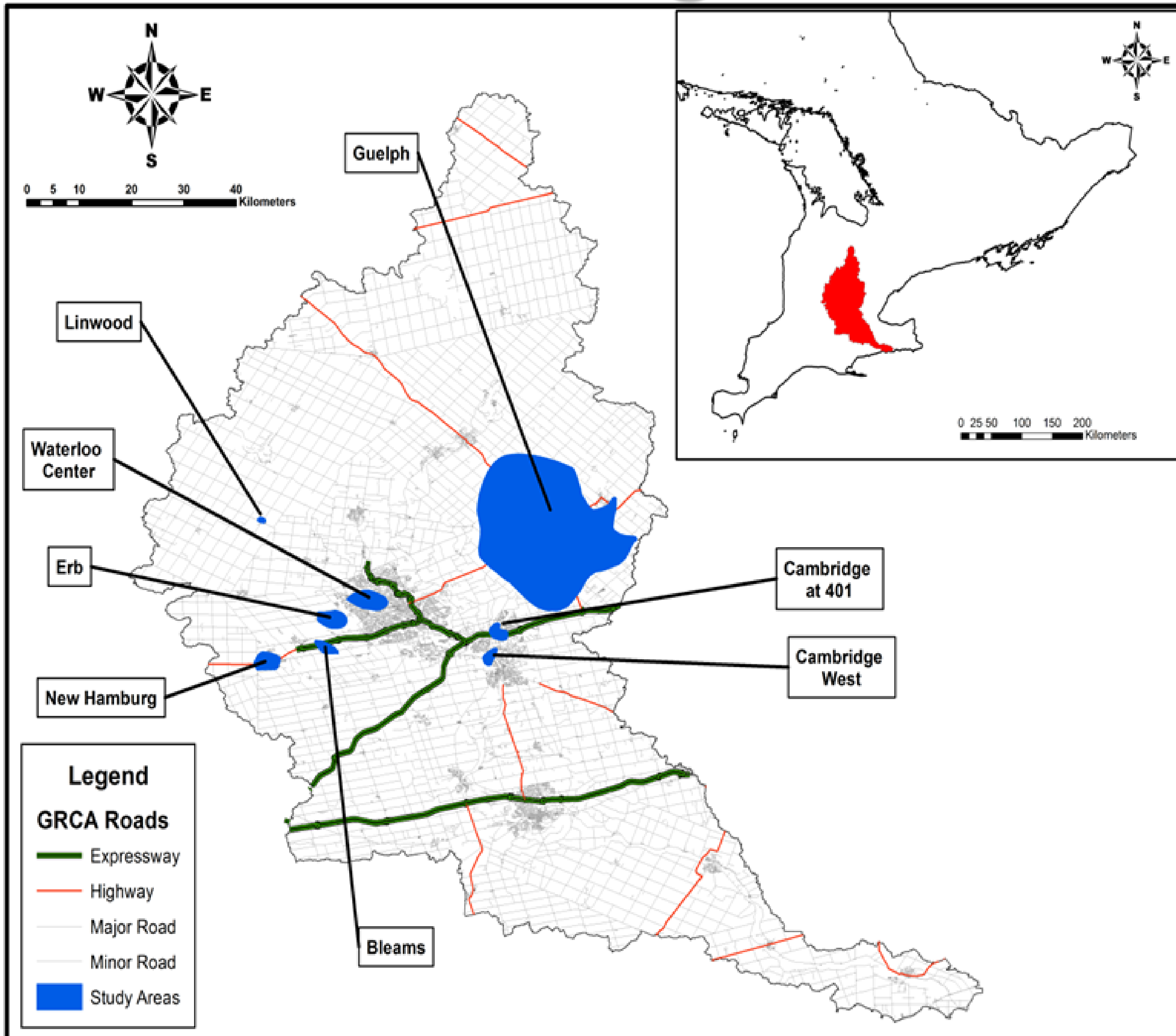
Study Area	Salt Vulnerability Score
Highland Creek at Bellamy Road	43
Highland Creek at Mammoth Hall Trail	43
Don River at Bloor St	37
Highland Creek at Morningside Ave	31
Humber River at Old Mill Rd	20
Rouge River at Finch Ave	4
Humber River at Steeles Ave	3
Hanlon Creek at Highway 6	2

Example Case Study

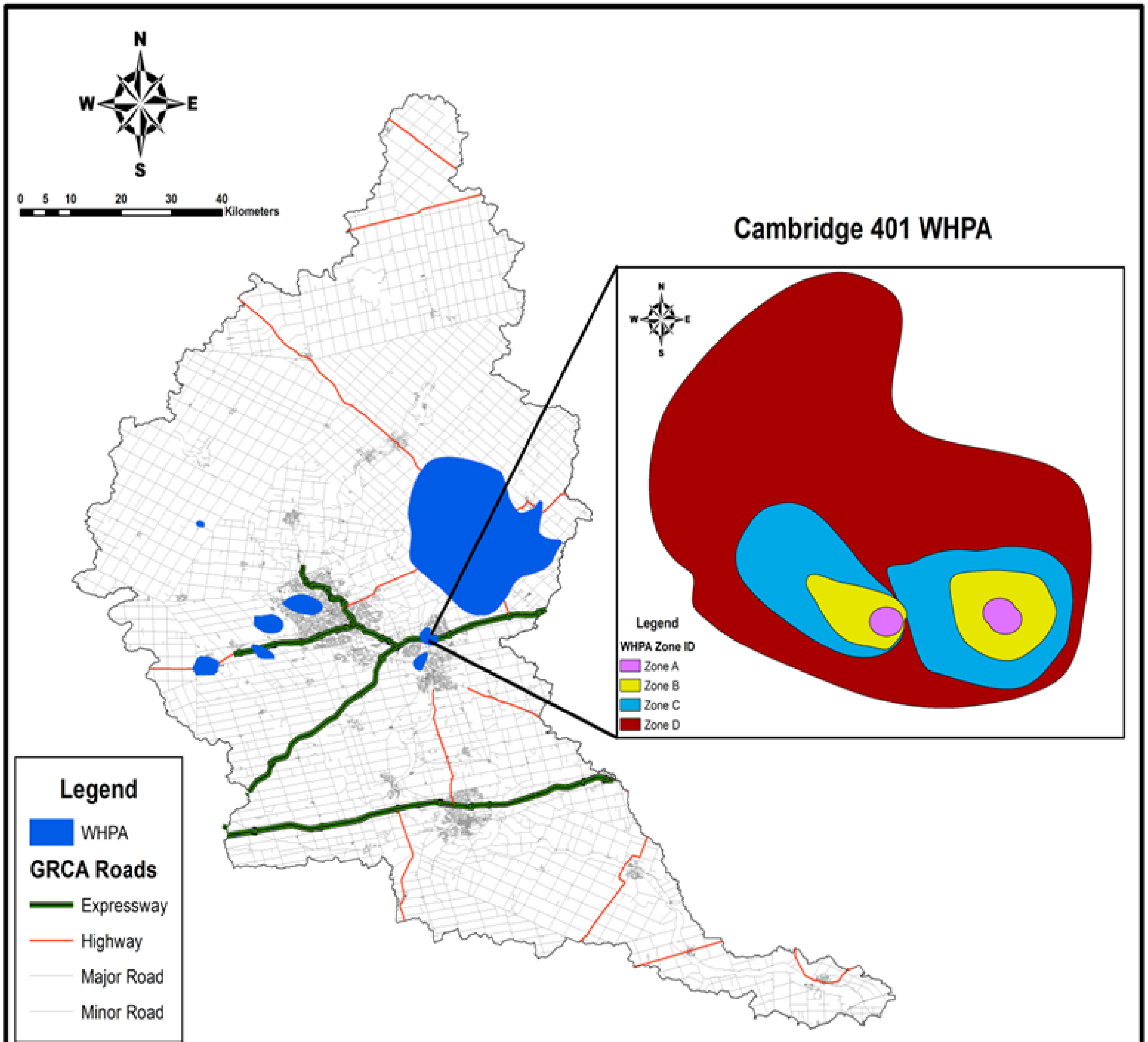
Identification of Groundwater Vulnerable Areas

a. Grand River Conservation Authority (22 sites)

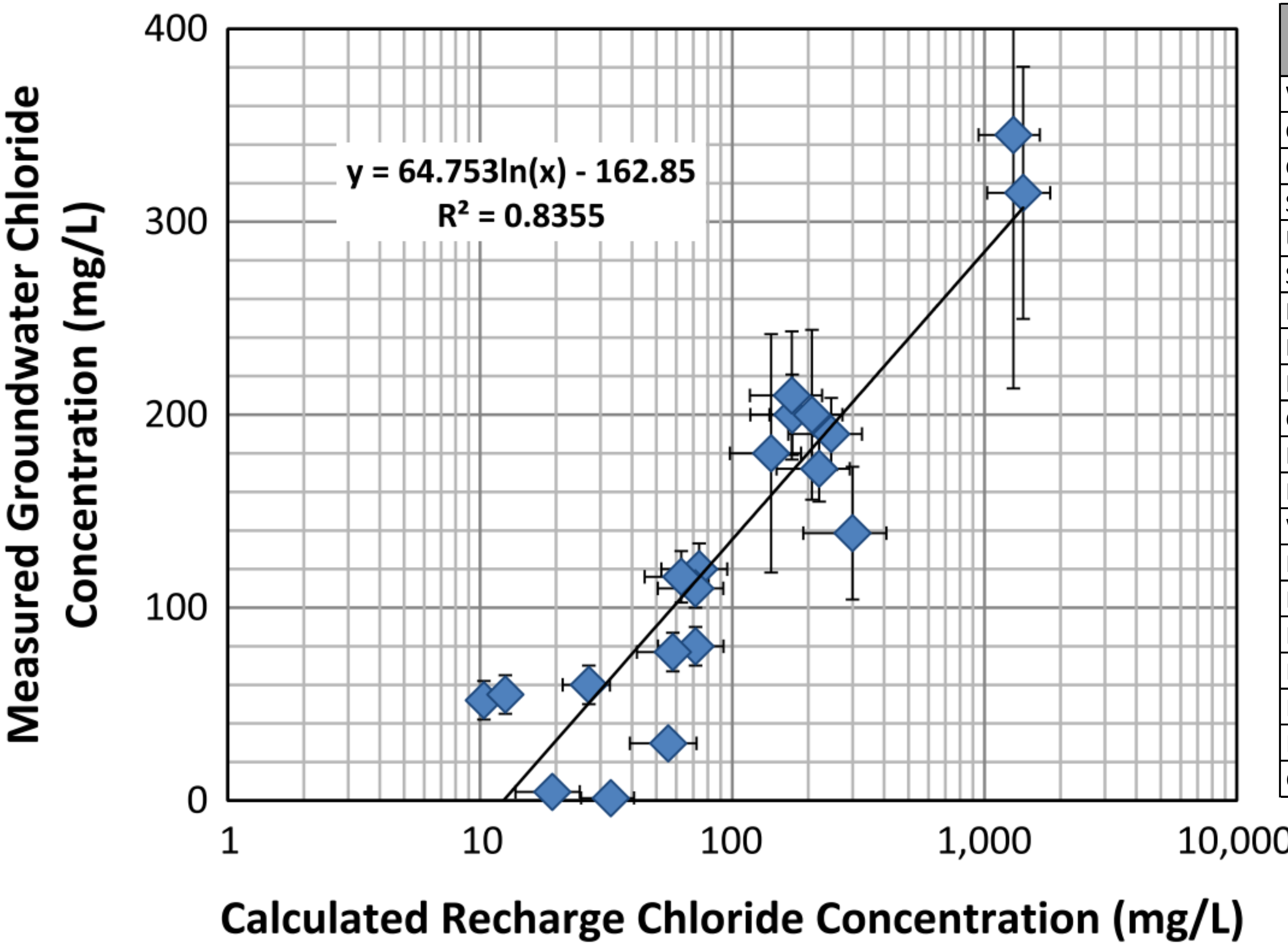
Grand River Conservation Authority Monitoring Sites



Drinking Water Well Protection Area

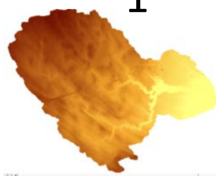


Calculated RCC Correlation with Measured Chloride Concentration



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

Surface Water Vulnerability

1


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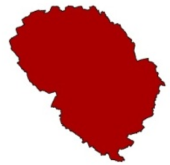

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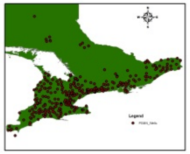

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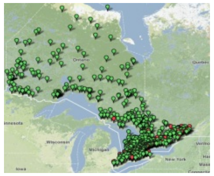

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DEM | BFI | Land Use | Roads | PGMN | WSC | Salt Application Rate

- Area (1)
- Chloride Application Density (1, 3, 4)
- Baseflow Index (2)
- Mean Annual Flow (1, 6)
- Baseflow Concentration (5)
- Salt Application Rate per unit area (1, 4, 7)

Mean Annual Stream Chloride Concentration

$$SCC = \frac{CAD*A*UAR*MAF*(1-BFI)+BFI*BFC*MAF*A}{MAF*A}$$

Calculation of Standard Deviation with linear regression using mean

$$Std\ Dev = 0.1719*\ln(SCC)$$

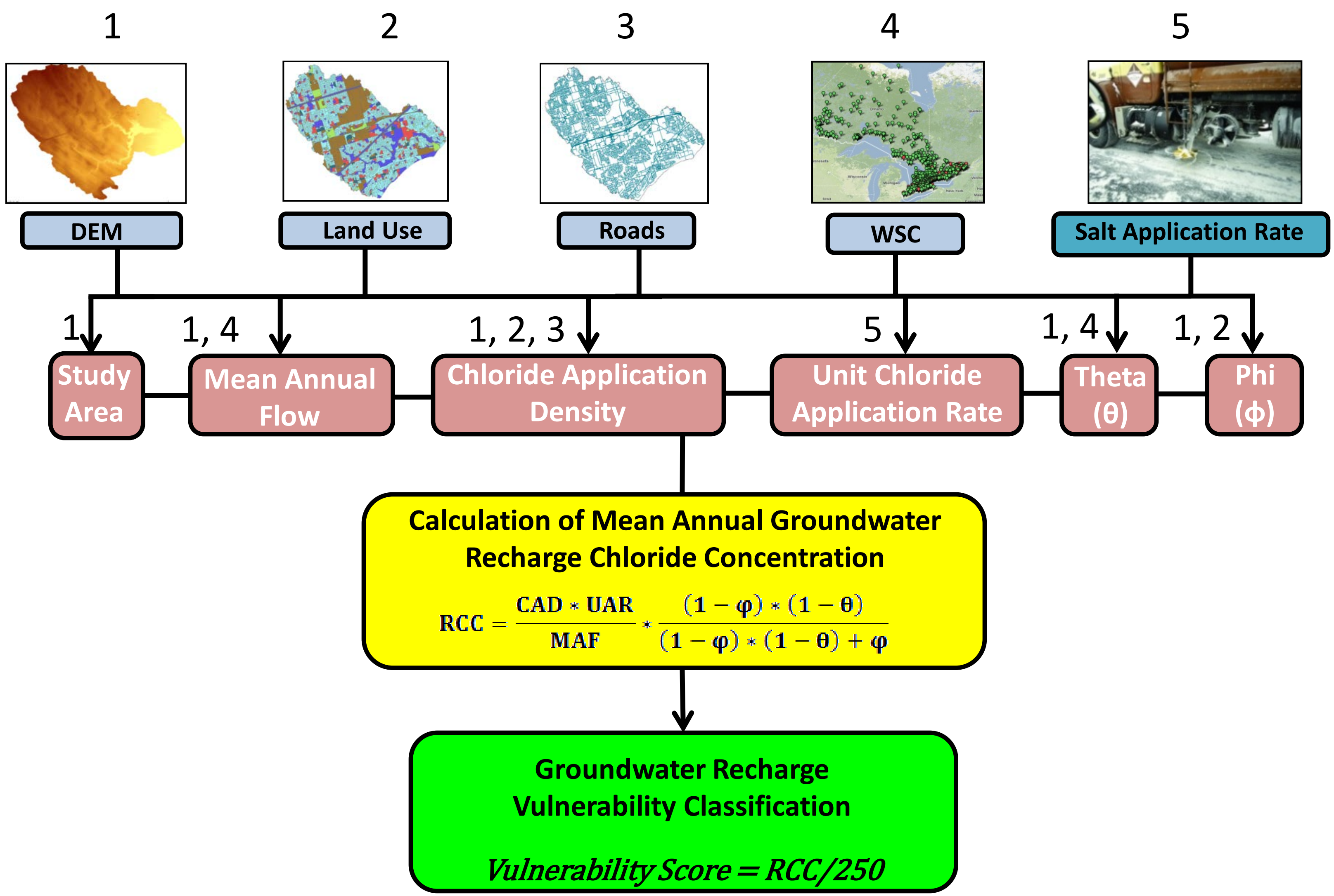
Calculation of Probability of Occurrence using Lognormal Cumulative Distribution Function

$$Probability\ of\ Occurrence = 1 - LogNormalDist\left(\frac{x-\mu}{\theta}\right)$$

Surface Water Vulnerability Classification

$$Vulnerability\ Score = Probability\ of\ Occurrence * Impact$$

Groundwater Recharge Vulnerability



Thank you!

How to contact the presenter

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

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