Climate change and potential impact on Coastal aquifers in ATLANTIC CANADA:
Initial Findings

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Introduction

- A significant number of coastal communities in Atlantic Canada rely on groundwater as a source of potable water.

- Climate change can be expected to result changes to the hydrologic cycle

- The implications related to salt water intrusion of coastal have not previously been investigated in this region.

- The issue is
  - Or interest from an academic perspective
  - Has very practical implications for planners, water utilities etc.

- Current study conducted under auspices of Atlantic Climate Adaptation Solution Association (ACASA) with participation by:
  - Governments of NB, NS, NFLD-LAB PEI
  - Academic community (St Fx, UNB)
  - Collaboration with municipal govt.s & First Nations Communities

Sensitivity to Sea Level Rise (NRCan, 2009):

- Relief
- Geology
- Coastal landform
- Sea-level tendency
- Shoreline displacement
- Tidal range
- Tidal height
- SWI potential?
Outline

- The Nature of Salt Water Intrusion
- Selected Case Studies
  - Summerside, PEI
  - Richibucto, NB
- Other work
  - NS (site specific and regional assessment)
  - NFLD-L (regional assessment)
- Conclusions
Salt Water Intrusion

- **The classical view (static conditions):**
  - Salt water is denser than fresh water
  - In coastal regions a "wedge" of salt water may "intrude" inland from the coast
  - Theoretically the position of the saltwater / fresh water interface is determined by the fresh water head (elevation of the water table above sea level)

BUT in reality the extent of saltwater intrusion depends on a variety of **site specific** factors.....
Site Specific Influences on SWI

- Boundary between fresh and saline water
  - Is not sharp (zone of diffusion)
  - Is affected by local geology

- Groundwater Flow Dynamics
  - GW is not static, but discharges to the ocean
  - Sea level determines a “constant head” boundary for the GW flow regime
  - Flux of GW toward ocean influenced by
    - GW recharge
    - GW extraction
Prevalence of SWI in Atlantic Canada (current conditions)

- The occurrence and extent of SWI is highly variable even under conditions of similar geology.

- Knowledge of the extent of SWI highly biased toward those areas of existing GW exploration and development.

- Has not been mapped on a regional scale (perhaps can’t be accurately?)
Approaches to the current investigation

- **Step 1** Characterize extent and dynamics of SWI (locally)

- **Step 2** Develop scenarios for assessment of impacts of CC relative to:
  - Sea level
  - GW recharge
  - GW extraction (not wholly dependant on CC)

- **Step 3** Simulate GW response to CC with respect to SWI

- **Step 4** Draw conclusions regarding adaptive measures to protect coastal GW resources
• **Summerside**
  - located on narrow Isthmus between Northumberland Strait and Gulf of Saint Lawrence
  - 2\textsuperscript{nd} largest city in PEI
  - Historical problems with saltwater intrusion with older municipal wells

• **Lennox Island**
  - Small, low lying Island located off north-west coast of PEI
  - Serviced by municipal water supply
Summerside – site characterization

Total depth and screened intervals for observation wells.

<table>
<thead>
<tr>
<th>Well I.D</th>
<th>Well Depth</th>
<th>Screened Interval (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well #1</td>
<td>82.3 m</td>
<td>79.3-82.3</td>
</tr>
<tr>
<td>Well #2</td>
<td>41.8 m</td>
<td>38.8-41.8</td>
</tr>
<tr>
<td>Well #3</td>
<td>24.4 m</td>
<td>No Screen</td>
</tr>
<tr>
<td>Well #4</td>
<td>83.8 m</td>
<td>80.3-83.8</td>
</tr>
<tr>
<td>Well #5</td>
<td>26.2 m</td>
<td>23.2-26.2</td>
</tr>
<tr>
<td>Well #6</td>
<td>18.3 m</td>
<td>No Screen</td>
</tr>
</tbody>
</table>
Chloride concentrations (ppm) with depth and distance from the coast. Dashed line indicating position of Ghyben-Herzberg interface as calculated from piezometric surface.

Piper diagram depicting relationships between major ions in solution.

<table>
<thead>
<tr>
<th>Ion Ratios</th>
<th>Well 3</th>
<th>Well 2</th>
<th>Well 1</th>
<th>Seawater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl/Br</td>
<td>NA</td>
<td>288</td>
<td>293</td>
<td>297</td>
</tr>
<tr>
<td>Na/Cl</td>
<td>0.84</td>
<td>0.44</td>
<td>0.40</td>
<td>&lt; 0.86</td>
</tr>
<tr>
<td>Ca/(HCO₃+SO₄)</td>
<td>0.23</td>
<td>0.98</td>
<td>1.04</td>
<td>&gt; 1.00</td>
</tr>
</tbody>
</table>
Summerside – SWI Climate Change Scenarios

- Numerical groundwater simulations coupled with various CC scenarios
- Groundwater modeling using 3D variable-density flow and transport model “SEAWAT”
- Simulations run and calibrated to baseline conditions
- Simulations run for various CC scenarios considering:
  - Changes in sea level
  - Changes in groundwater recharge
  - Changes in groundwater extraction rate

<table>
<thead>
<tr>
<th>Simulation</th>
<th>Description</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base-line simulation</td>
<td>Calibrated to represent present conditions</td>
<td>Position of the interface: 0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total fresh SGD: 0.18 m day(^{-1})</td>
</tr>
<tr>
<td>HadCM3 A1B</td>
<td>-139 mm increase in annual recharge</td>
<td>Position of the interface: +20 m</td>
</tr>
<tr>
<td></td>
<td>-0.59 m linear rise in sea-level</td>
<td>Total fresh SGD: 0.24 m day(^{-1})</td>
</tr>
<tr>
<td>HadCM3 A1B</td>
<td>-33 mm increase in annual recharge</td>
<td>Position of the interface: 0</td>
</tr>
<tr>
<td></td>
<td>-0.48 m linear rise in sea-level</td>
<td>Total fresh SGD: 0.19 m day(^{-1})</td>
</tr>
<tr>
<td>HadCM3 A2</td>
<td>-29 mm increase in annual recharge</td>
<td>Position of the interface: 0</td>
</tr>
<tr>
<td></td>
<td>-0.38 m linear rise in sea-level</td>
<td>Total fresh SGD: 0.19 m day(^{-1})</td>
</tr>
<tr>
<td>HadCM3 B1</td>
<td>-31 mm increase in annual recharge</td>
<td>Position of the interface: 0</td>
</tr>
<tr>
<td></td>
<td>-0.48 m linear rise in sea-level</td>
<td>Total fresh SGD: 0.19 m day(^{-1})</td>
</tr>
<tr>
<td>Pumping</td>
<td>- Pumping rate of 70 L/s for 50 years</td>
<td>Position of the interface: -1000 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total fresh SGD: 0</td>
</tr>
<tr>
<td>Multi-ensemble approach</td>
<td>-33 mm increase in annual recharge</td>
<td>Position of the interface: 0</td>
</tr>
<tr>
<td></td>
<td>-1 m linear rise in sea-level</td>
<td>Total fresh SGD: 0.19 m day(^{-1})</td>
</tr>
</tbody>
</table>
Summerside simulation results:

Conclusions:

- Sea level rise is alone is unlikely to have much impact on SWI
- Managing GW withdrawal rates is important
Lennox Island Investigations

- Based on existing hydrogeological data.
- Numerical model simulations for
  - Rising sea level
  - Increased GW extraction rates

Data collection → Numerical modelling → Predictions

Graph showing concentration (mg/L) vs. distance from coast (m)

Legend:
- Pumping (gradual SLR)
- Non-pumping (no SLR)
- Non-pumping (gradual SLR)
Lennox Island

- Sea level rise is predicted to have little impact on the encroachment of the SW / FW interface
- At existing GW extraction rates, water supplies are not at risk
- Substantial increases in GW extraction rates could prove problematic
Selected Case Studies – Richibucto, New Brunswick

- Municipal wells experiencing increased chloride levels over the past decade
- Site characterized by geophysical survey and borehole information to supplement existing hydrogeological information
- Numerical simulations (SEAWAT) examining
  - Sea level change
  - Recharge change
  - GW extraction change
- CC scenarios
  - A1B &A2 emission scenarios
  - Mean deviations in climate indicies by Environmental and Sustainable Development Research Centre

Regional map of the study area bounded by the tidal St. Charles and Richibucto Rivers, showing model boundaries, location of monitoring and pumping wells and location of cross-section
Geophysical characterization of salinity distribution in vicinity of the Richibucto well field

Estimate of the true resistivity structure obtained by inversion with horizontal smoothing constraints.

Figure shows the location of PW1 and suggests presence of four layers with possible upconing through the lower sandstone under the well.
Richibucto Model Domain

Cross-section of model domain showing grid discretization, shale layers (shaded grey and labelled C1-C4), well locations and surface waters (constant head above cells).
Conclusions:

- Declining recharge most significant at shallow to intermediate depths
- Increased pumping most significant near well field
- Sea-level rise least significant, primarily affects deeper portions of the aquifer.

Base line conditions. The source of the shallow zone of elevated TDS is the Richibucto harbour, while the deeper salt water wedge represents intrusion from the Northumberland Strait.

Spatial changes in TDS at yr. 2100 compared to the initial conditions. Dashed concentration contours = absolute TDS for initial conditions, solid concentration contours = absolute TDS at end of the simulation.
Nova Scotia: Regional sensitivity and site specific studies

- Field programs:
  - Pugwash
  - Wolfville

- Regional assessment
  - Geochemical considerations
Newfoundland and Labrador: Reconnaissance of SW Nfld. Potential for Sea-water intrusion – public supply wells

- Baseline survey as a foundation for future work
- Methods
  - Well selection and characterization
  - Geochemical characterization
    - Conductivity profiles
    - Age dating (tritium)
    - Seawater indicators (Br Cl)
- Limited evidence of sea water intursion
Conclusions

- Climate change impacts alone will not cause a significant change in SWI
- Anthropogenic influences regarding GW extraction (related or not to cc) are far more significant
- Extent and severity, as well as the key factors influencing, SWI vary even on a small scale
  - Emphasis should be on
    - better delineation and understanding of SWI
    - sensitivity to management of GW extraction.
THE END

Questions?