# Charting the future: Saltwater intrusion vulnerability along island and continental coastlines

IWRA Congress

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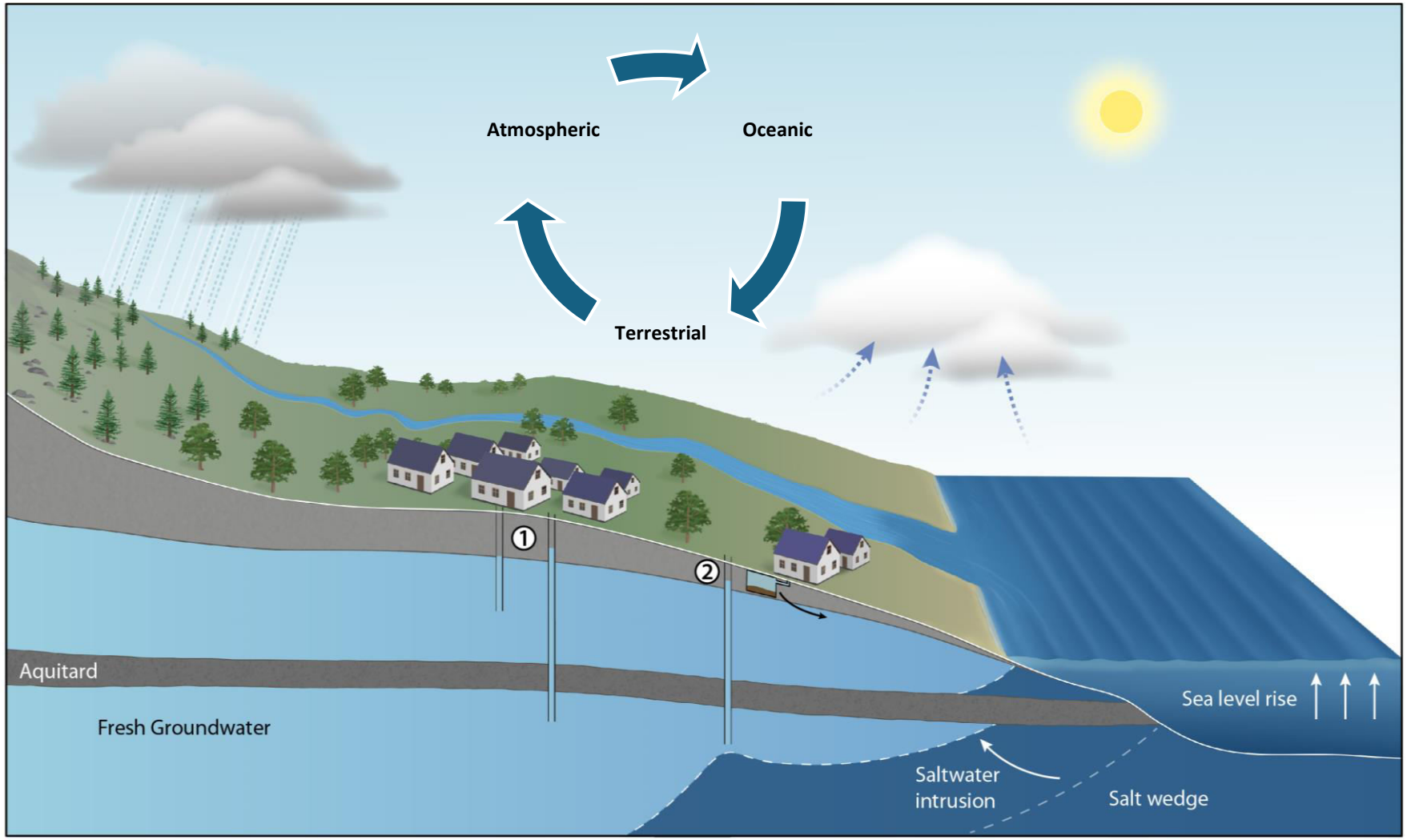
COASTAL HYDROLOGY LAB · DALHOUSIE UNIVERSITY ·

IWRA International Water Resources Association

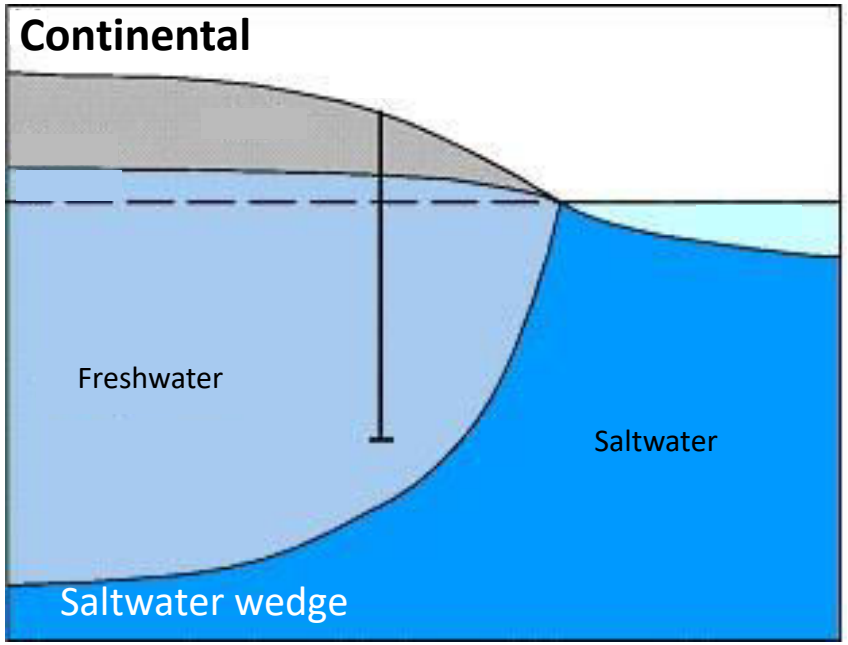
# Coastal zones and converging forces

- Approximately 40% of the global population lives within 100 km of the coastline
- Coastal zones experience converging terrestrial, oceanic, and atmospheric pressures
- Coastal groundwater processes are influenced by both land and sea domains

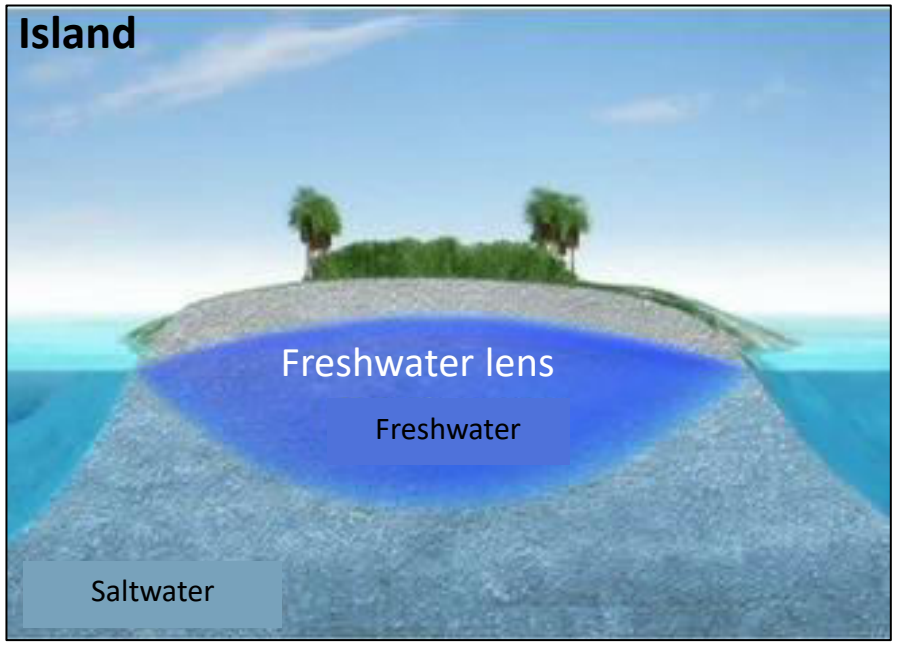


# Coastal aquifers and saltwater intrusion

- Saltwater-freshwater interfaces form along marine coastlines
- Salt wedge vs. freshwater lens
- Lateral vs. vertical saltwater intrusion
- Various methods exist to estimate salt wedge location and freshwater lens volume




Modified from OzCoasts Geoscience Australia

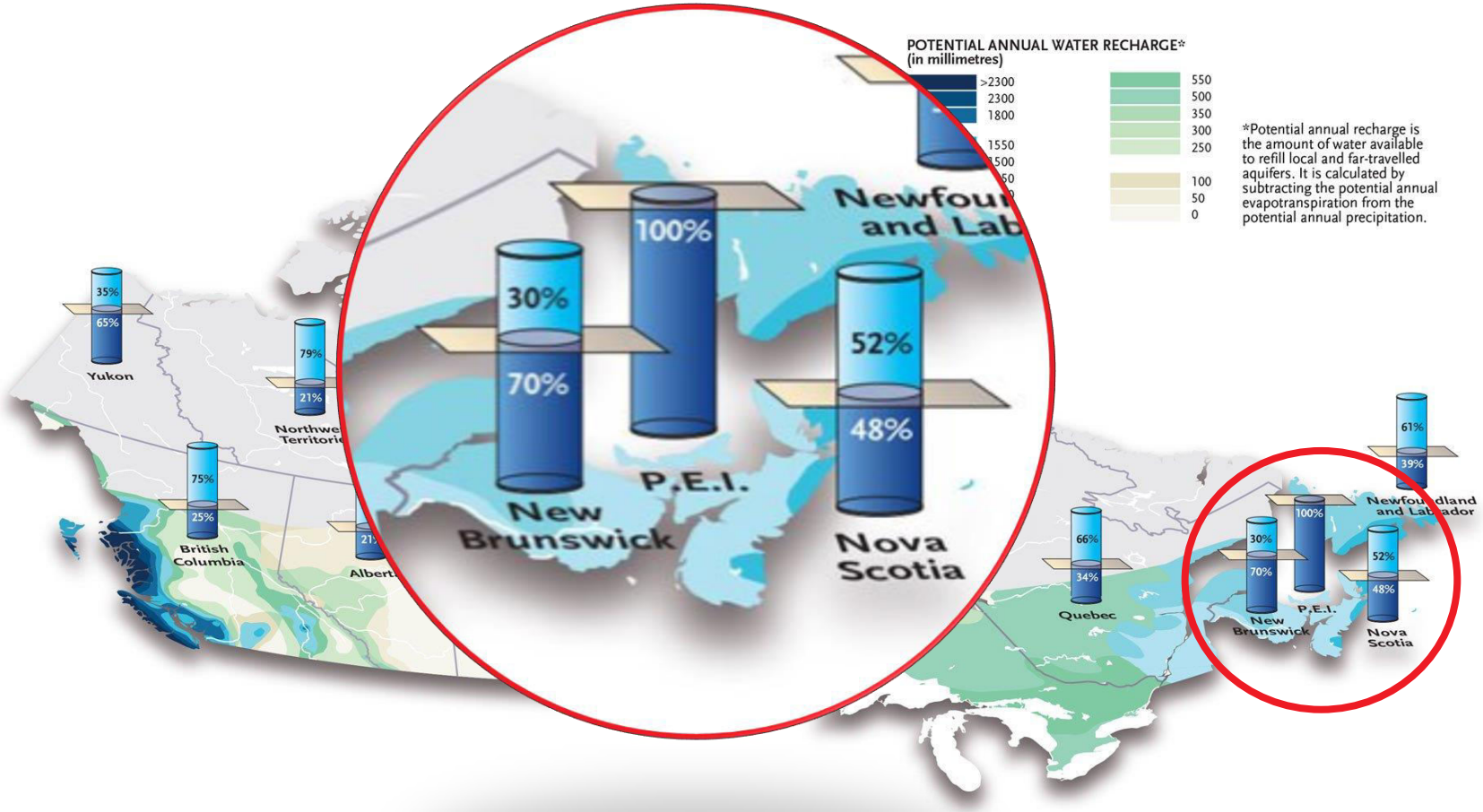



Modified from Masuoka & Nakaya (2021)

# Study purpose

- Monitoring and management of our coastal freshwater resources is of paramount importance
- Process-based approach to map saltwater intrusion vulnerability using an analytical solution
- **Goal:** *identify coastal regions most vulnerable to saltwater intrusion using a grounded and robust analytical solution*

# Canada's groundwater resources

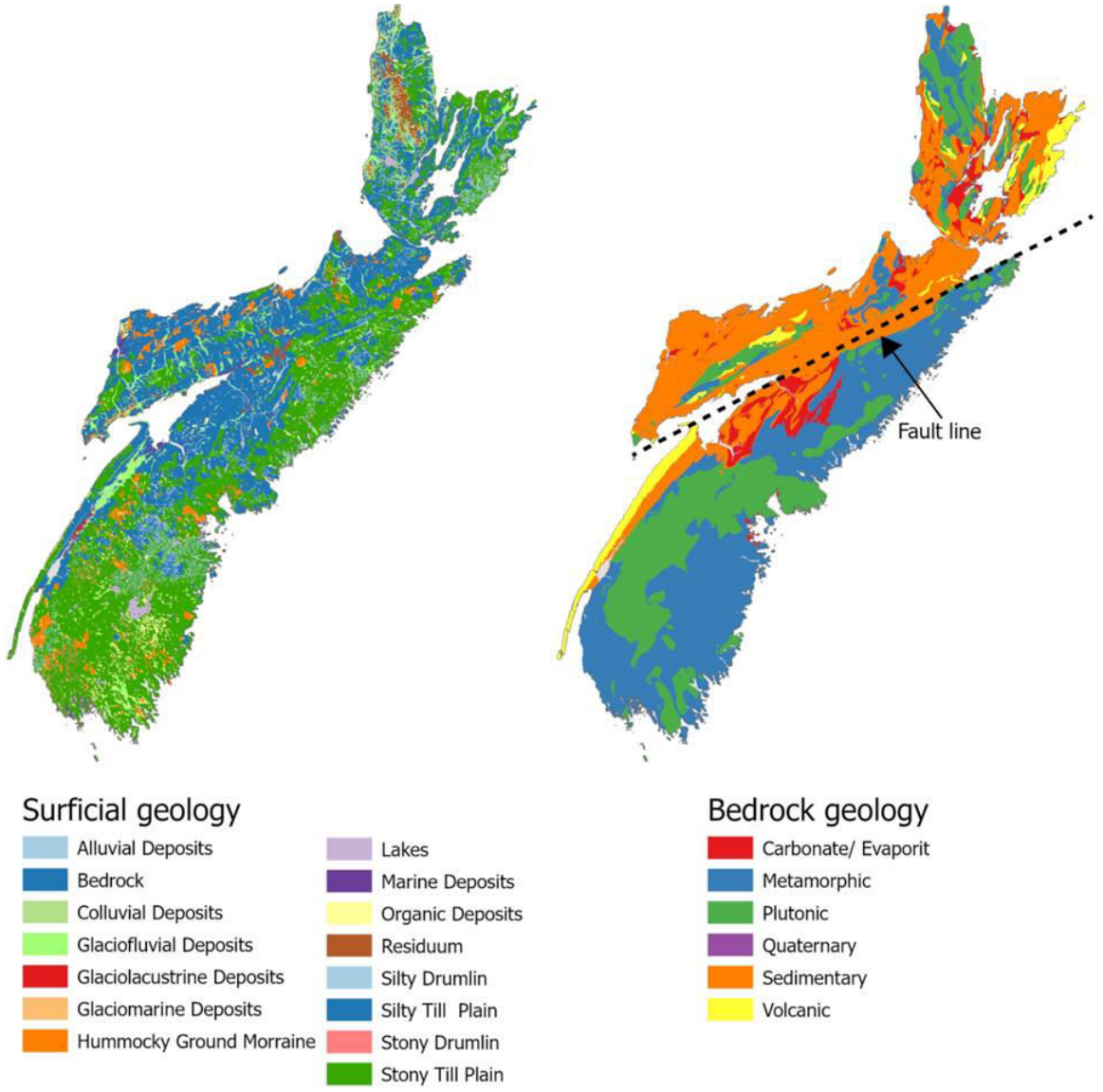



POTENTIAL GROUNDWATER RECHARGE AND GROUNDWATER USE

MAP: CHRIS BRACKLEY/CAN GEO

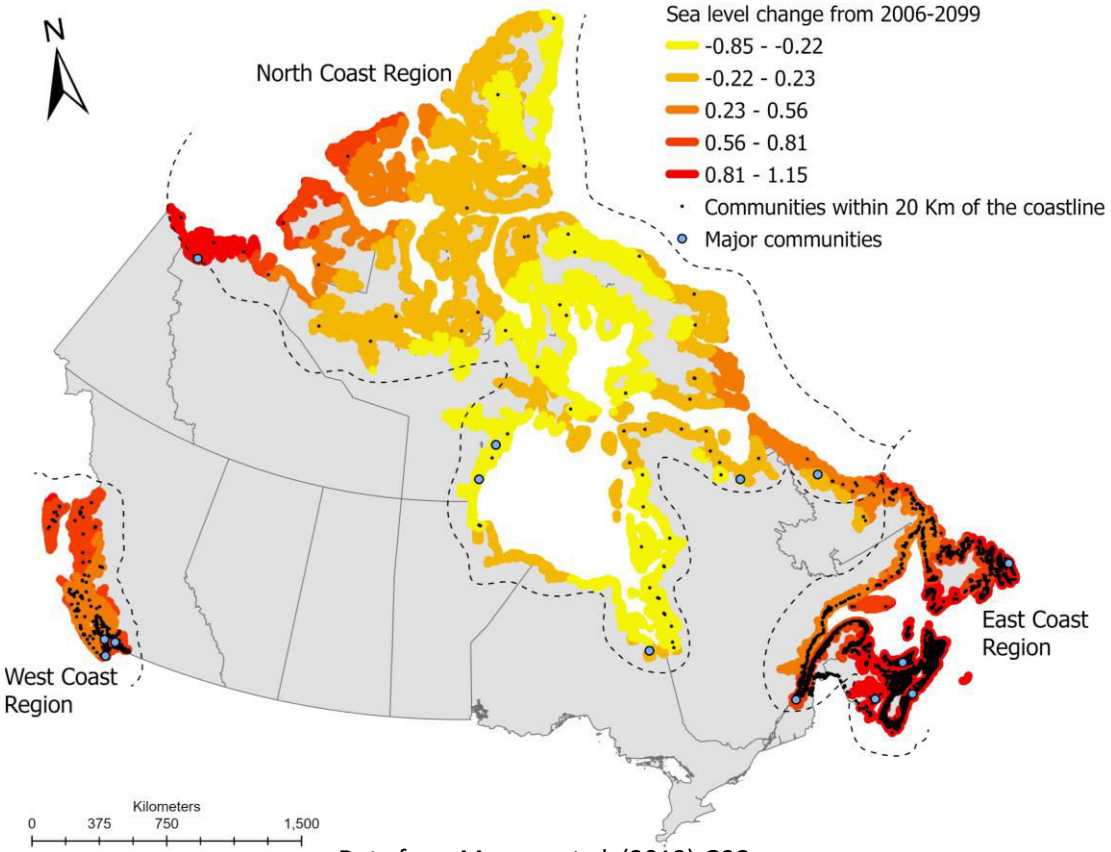
# Nova Scotia's groundwater resources

- Complex and variable geology across Nova Scotia
- Surficial geology units provide drinking water resource to rural homeowners
- Sharp geologic discontinuity divides the province
- Cape Breton Island (~90,000 residents) uses both surface and groundwater resources

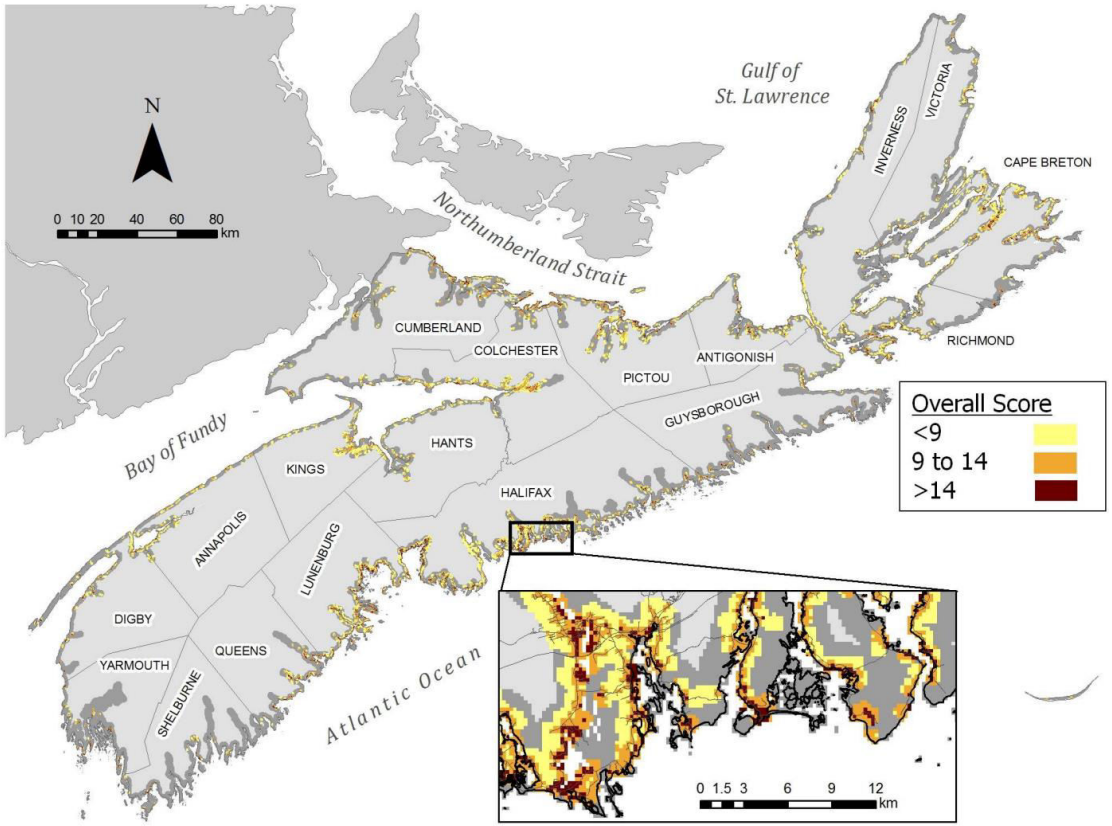


# Nova Scotia's groundwater resources

- NS has over 10,000 km of coastline and ~70% of residents live within 20 km of the coast
- Population of ~1M where ~50% rely on fresh groundwater resources
- Highest projected sea-level rise across Canada
- Preliminary work identified areas of saltwater intrusion vulnerability



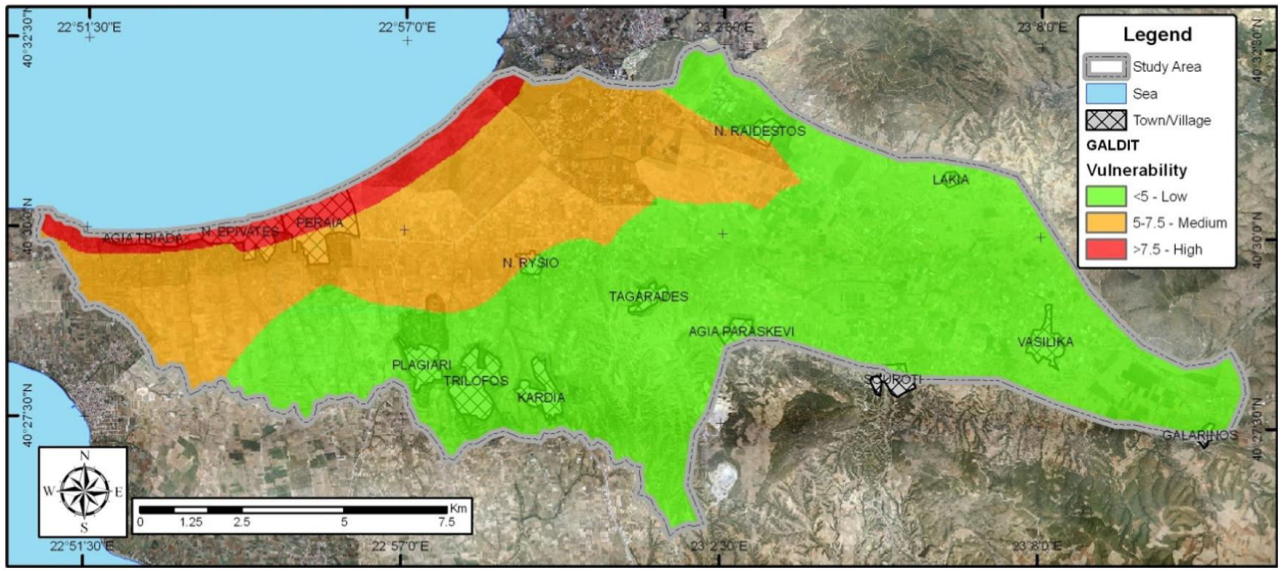

Data from Manson et al. (2019) *GSC*




Kennedy (2012) *IAH conference paper*

# Vulnerability mapping: indexing approaches

- Saltwater intrusion is inherently difficult to monitor and investigate
- Large scale detailed analyses are often not possible
- Vulnerability indexing methods are commonly applied for rapid assessments
- Simple indicators of the propensity for saltwater intrusion to occur
- **GALDIT**: **G**roundwater occurrence, **A**quifer hydraulic conductivity, groundwater **L**evel, **D**istance from the sea, **I**mpact of previous saltwater intrusion, and aquifer **T**hickness



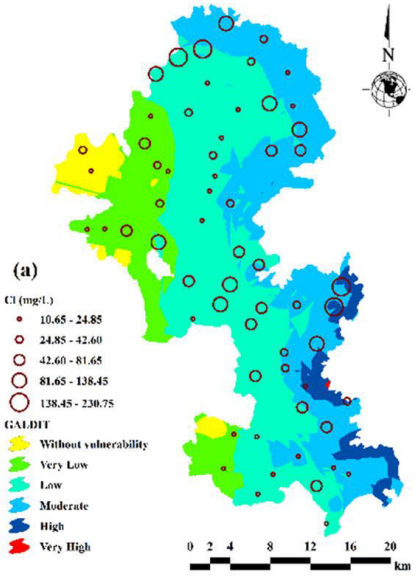

Kazaki et al. 2018 *STOTEN*

# More on GALDIT

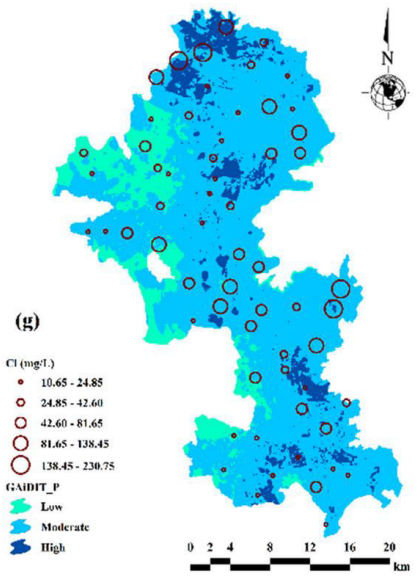
- Arbitrary weighting
- Several variations exist, such as incorporating hydraulic gradient and pumping rate
- Results vary depending on parameters included and weighting assigned

$$GALDIT\ Index = \sum_{i=1}^{6}(W_i \times R_i) \Big/ \sum_{i=1}^{6}(W_i)$$

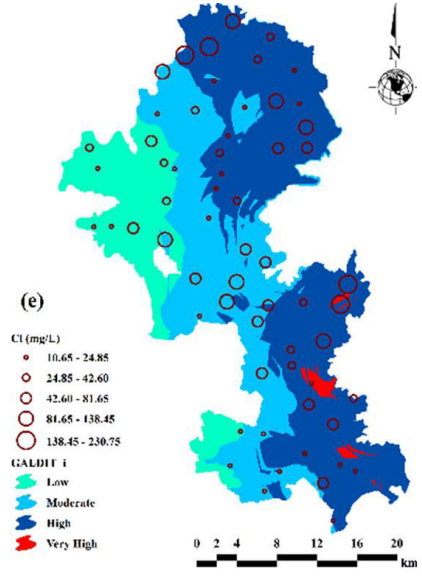
GALDIT




GALDIT-P



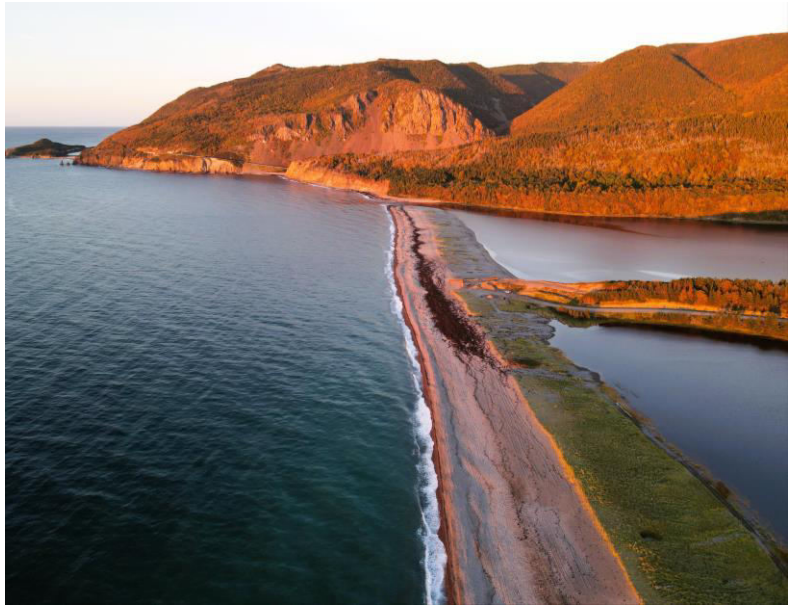

GALDIT-I

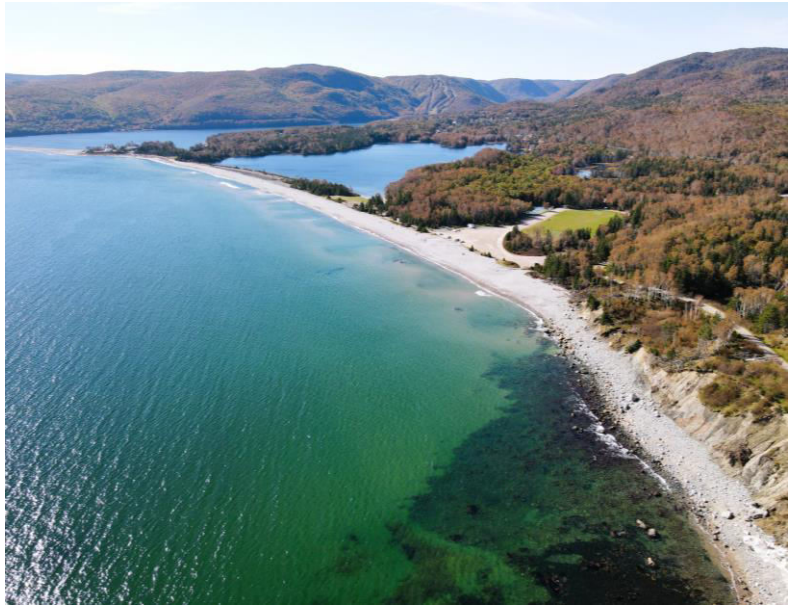



Modified from Fakhri et al. (2024), *Environmental Science and Pollution Research*

# Vulnerability mapping: analytical approaches

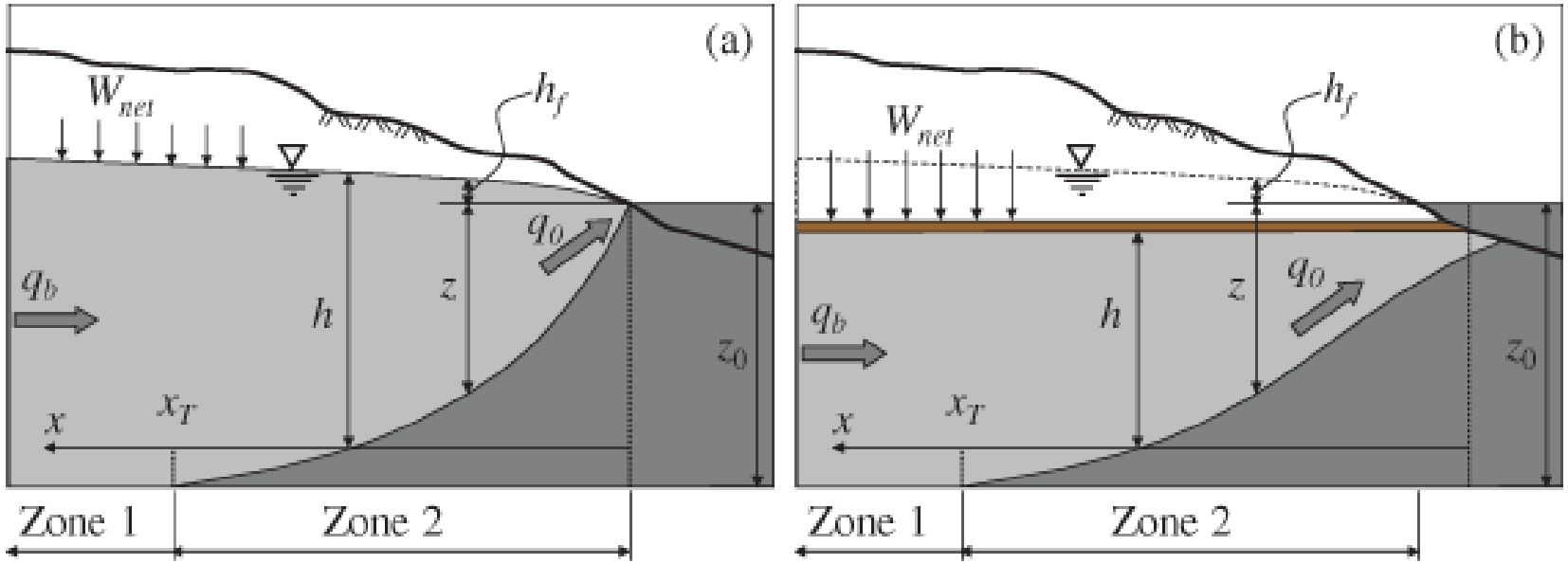
- Limit subjectiveness by relying on theoretical hydrogeological characteristics
- Indicators of saltwater intrusion vulnerability are more robust but still relatively simple to apply to achieve a first-order assessment
- Strack (1976) analytical solution
  - Accounts for various conditions (unconfined/confined, pumping/recharge)
  - Can be used for both continental and island aquifers





# Vulnerability mapping: analytical approaches

- Strack (1976) uses similar inputs as GALDIT but is based on physics
- Partial derivatives used to describe rates-of-change in saltwater intrusion indicators
- Novel approach: has not been used at a regional scale



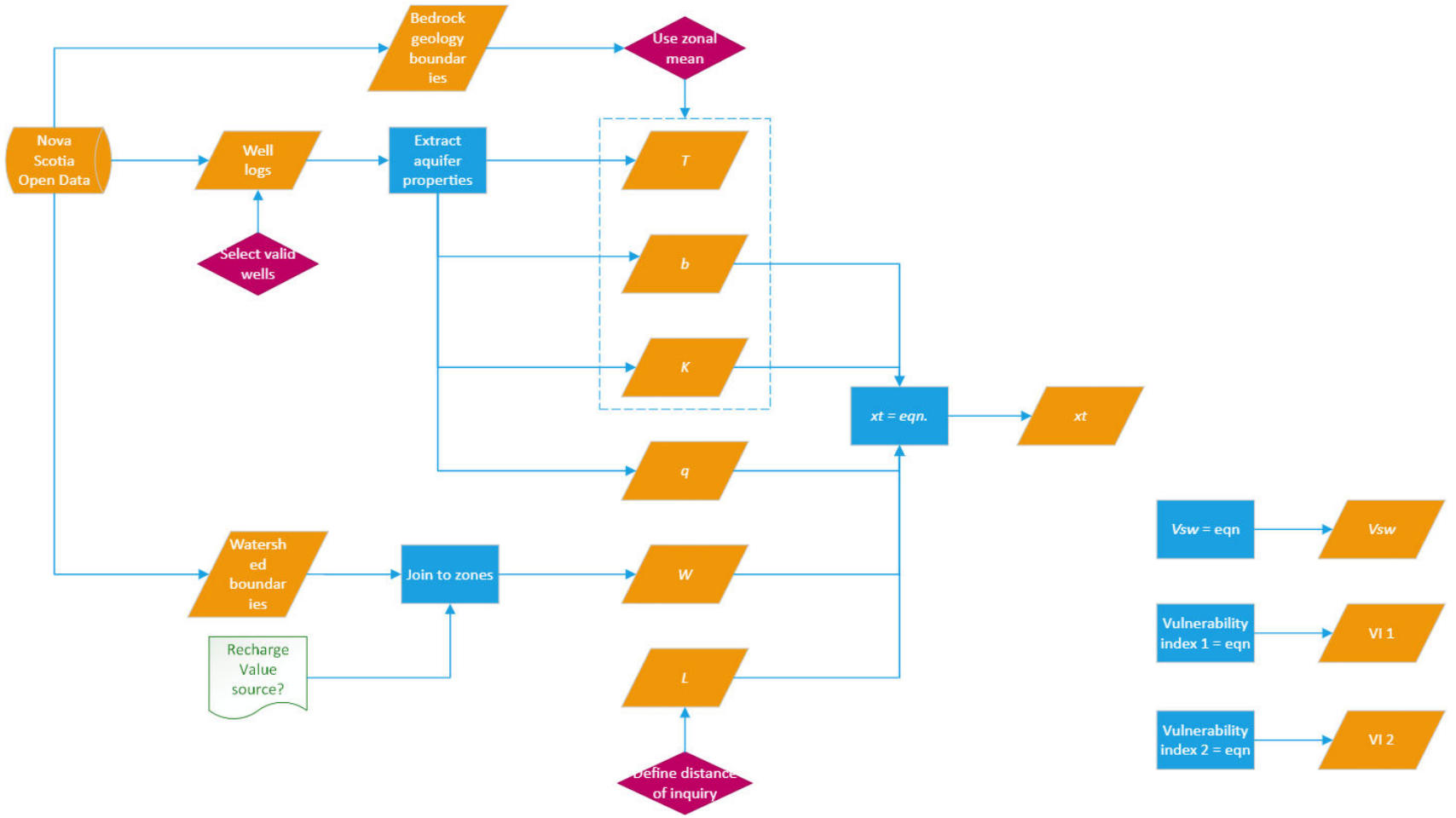

Werner et al. (2011) *Groundwater*

$$h_f = \sqrt{(2q_o x - W_{net}x^2)\frac{\delta}{K} + \delta Z_o - \delta h_o} \qquad V_{SW} = \frac{\emptyset \delta K {h_o}^3}{6q_o} \qquad x_T = \frac{q_o}{W_{net}} + \sqrt{\left(\frac{q_o}{W_{net}}\right)^2 - \frac{\delta K {h_o}^2}{W_{net}}}$$

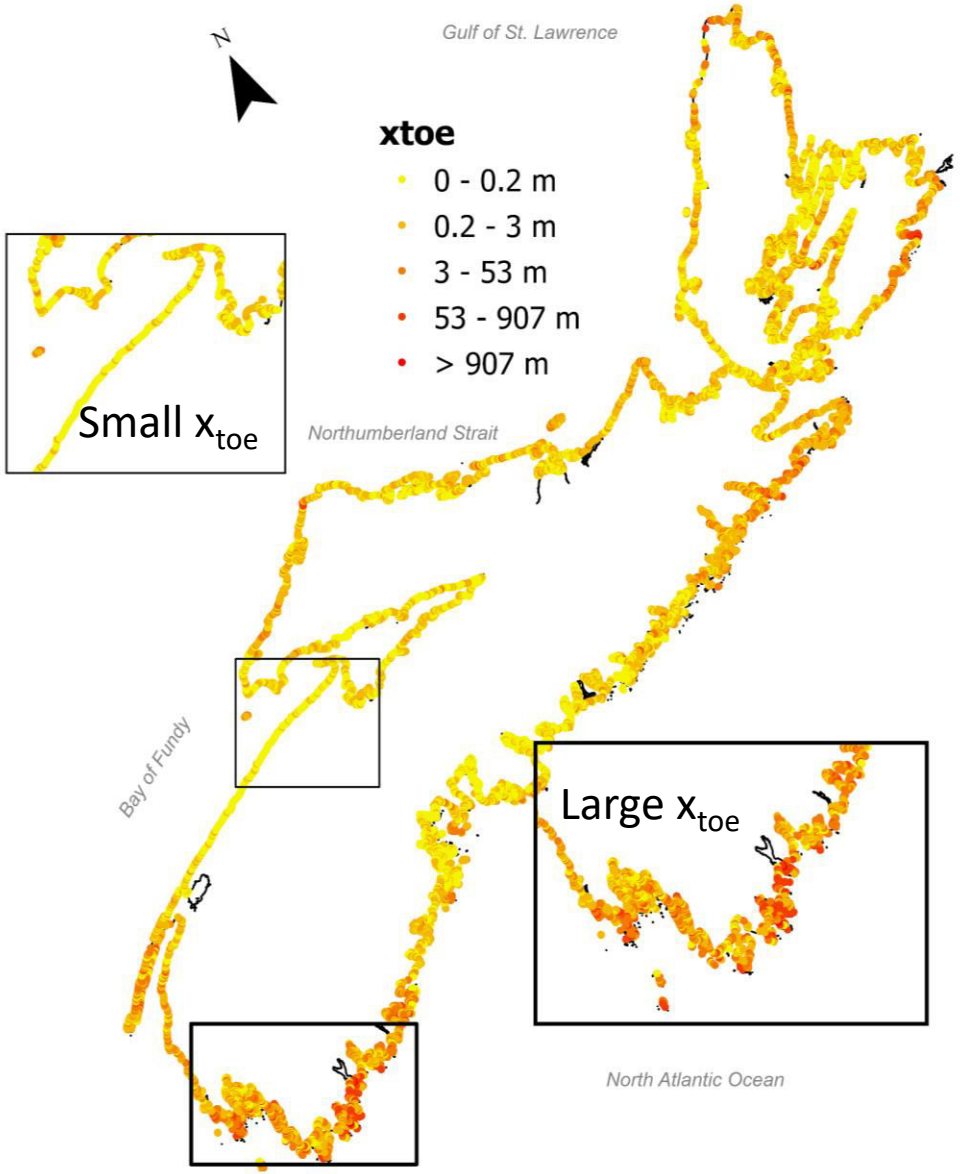
# ArcGIS model

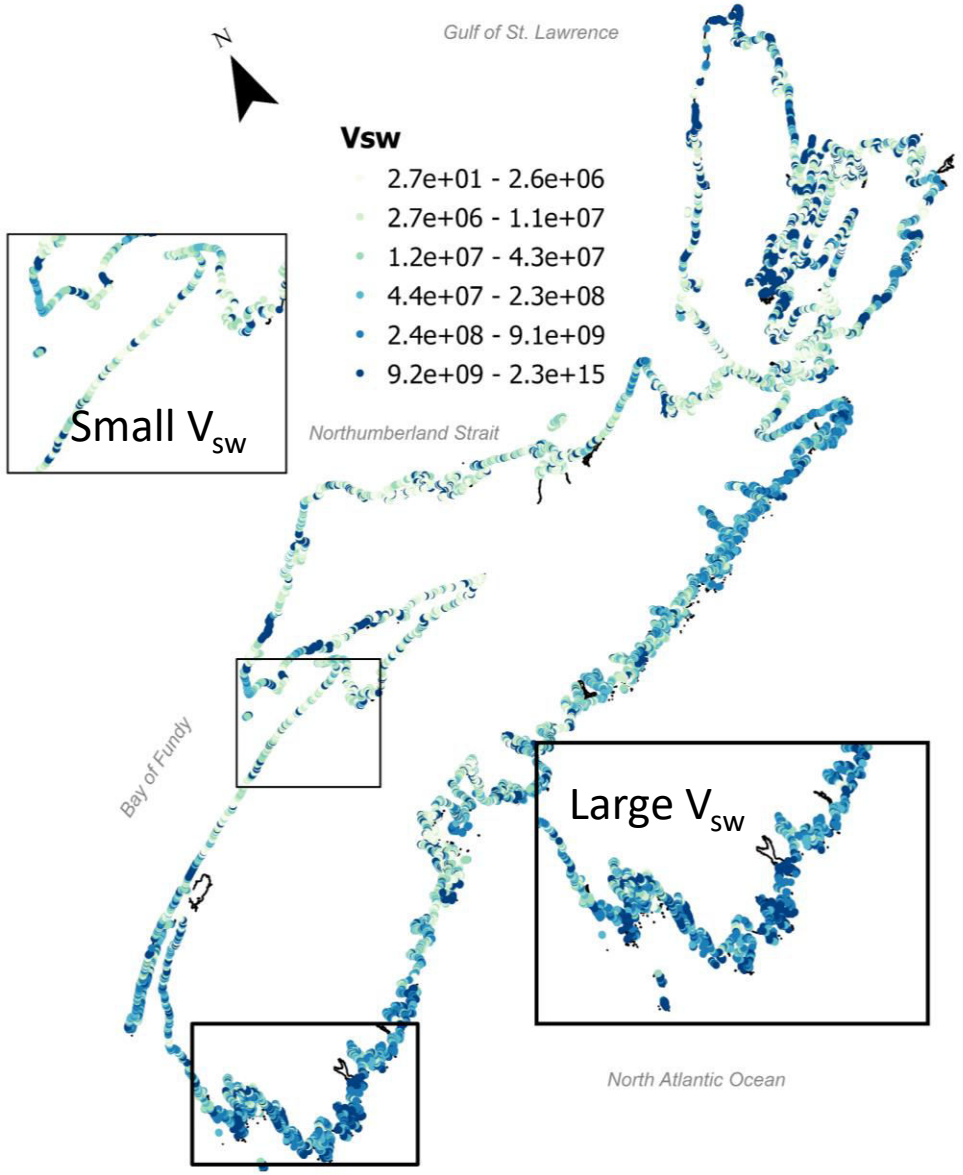
- Data sourced from publicly available provincial database
- Transects extended 250 m inland
- Static water level surface created
- K and B calculated from well log database
- $x_{toe}$ and $V_{sw}$ were calculated and then their functions were differentiated with respect to different variables

$$x_T = \frac{q_o}{W_{net}} + \sqrt{\left(\frac{q_o}{W_{net}}\right)^2 - \frac{\delta K {h_o}^2}{W_{net}}} \qquad V_{SW} = \frac{\emptyset \delta K {h_o}^3}{6 q_o}$$



# Preliminary results – current conditions

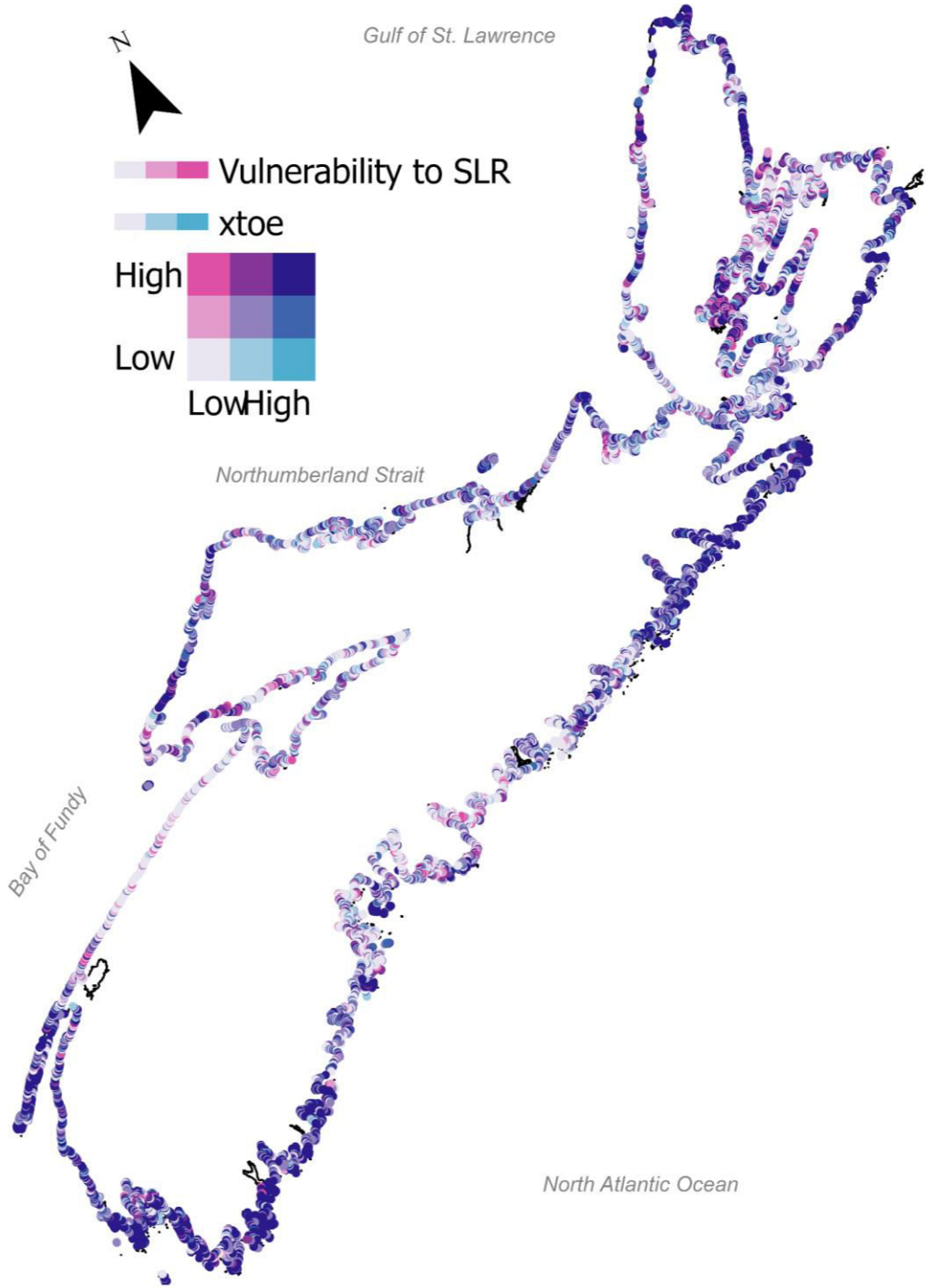


# Preliminary results

$$\frac{\partial x_{toe}}{\partial z_0} = \frac{0.026K^2B^3}{2q^2L}$$

- Vulnerability to sea-level rise was estimated
- Confined conditions limit saltwater intrusion
- Strong relationships between large $x_{toe}$ values and vulnerability to sea-level rise
- Limitations: assumed confined conditions, data averaging



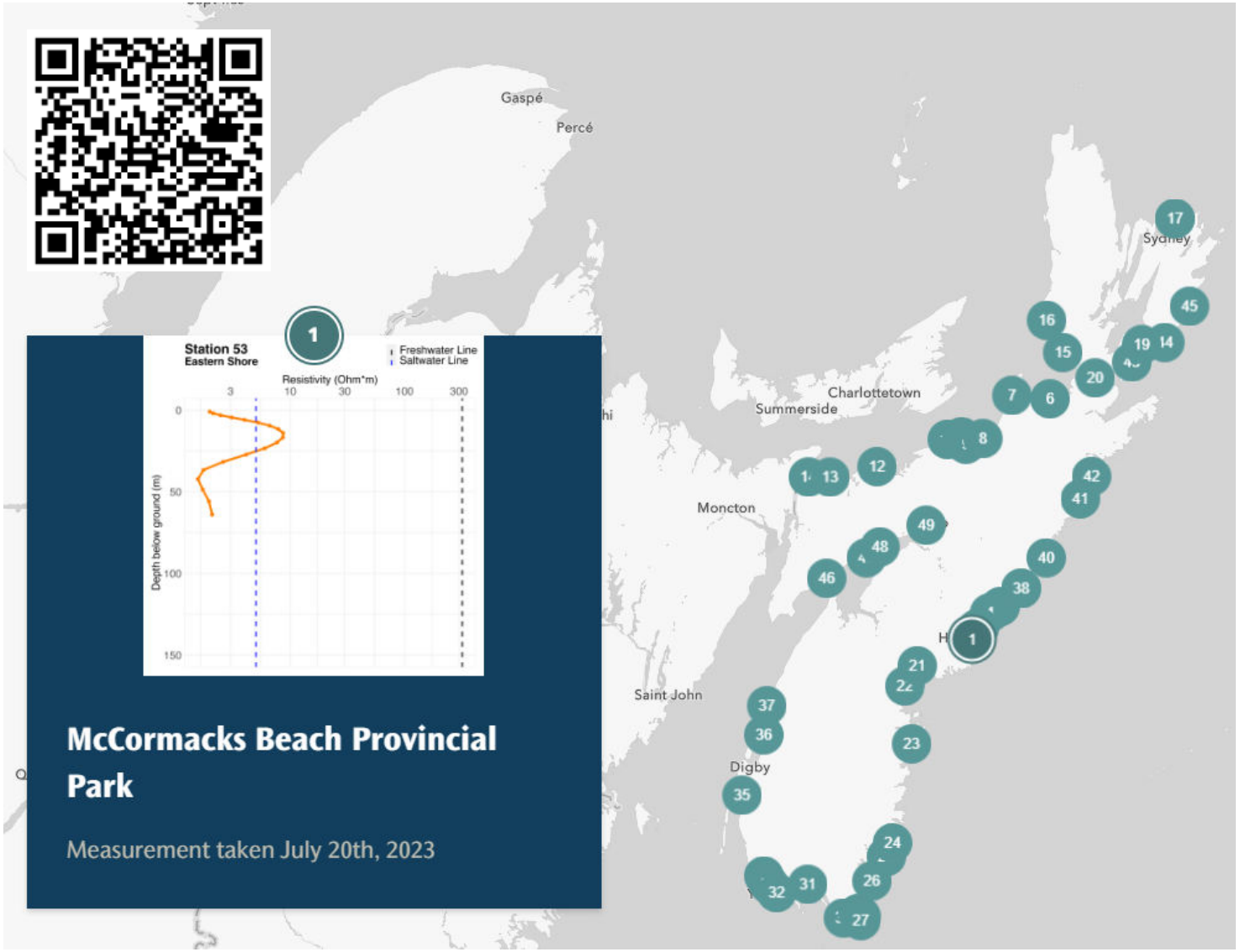
# Challenges and next steps

**Challenges:**

- Data sparsity
- Limited ground truthing

**What's next?**

- ArcGIS story map
- Comparing results with geophysical data collected



# Final thoughts

- Confined conditions limit lateral saltwater intrusion, but further refinement and sensitivity analyses are needed
- Data collection is critical in a data-limited province
- If GALDIT is possible, analytical approach is possible
- Identifying coastal regions most vulnerable to saltwater intrusion is the first step towards effective adaptation practices

# Acknowledgements

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