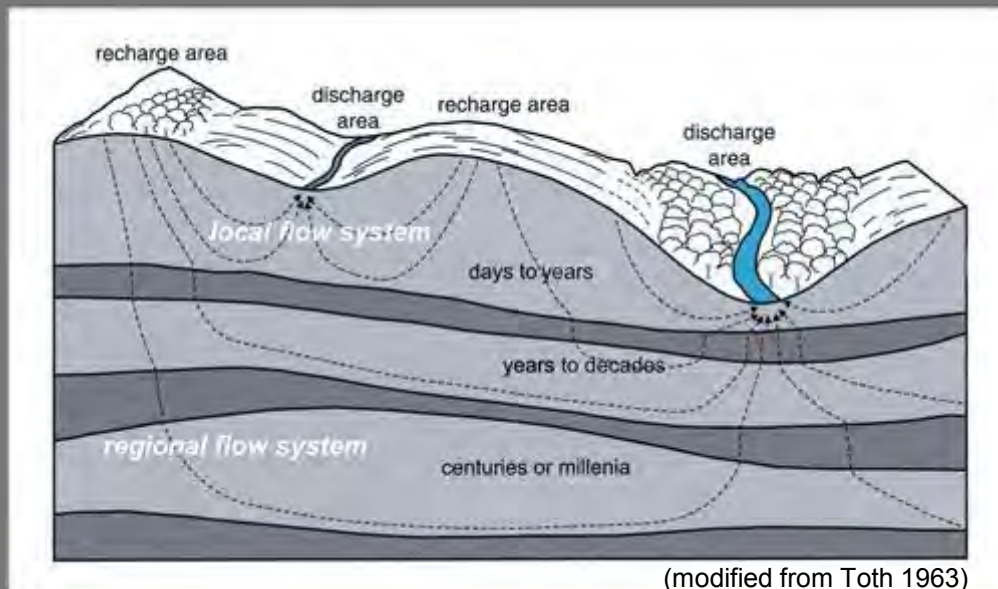


Groundwater systems and sustainability at new scales



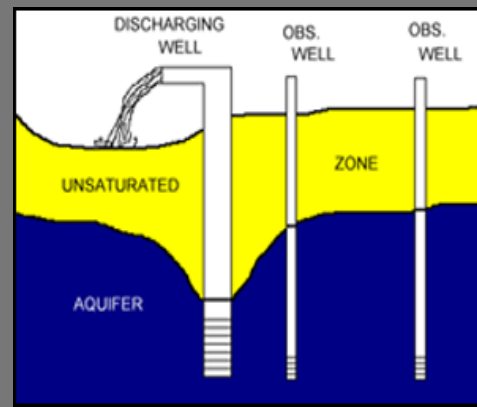
(modified from Toth 1963)

Tom Gleeson
Civil Engineering,
McGill University



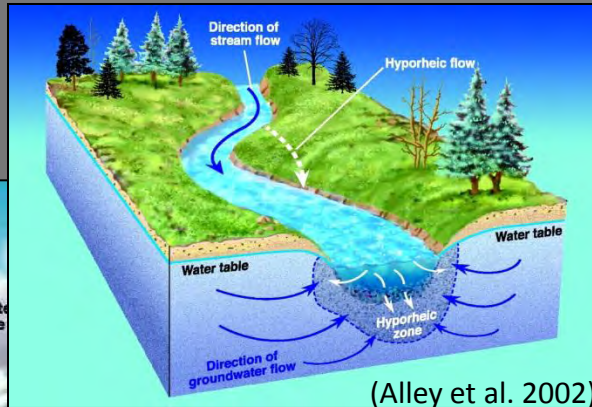
December 1, 2011

Multi-scale hydrogeology



Groundwater supply

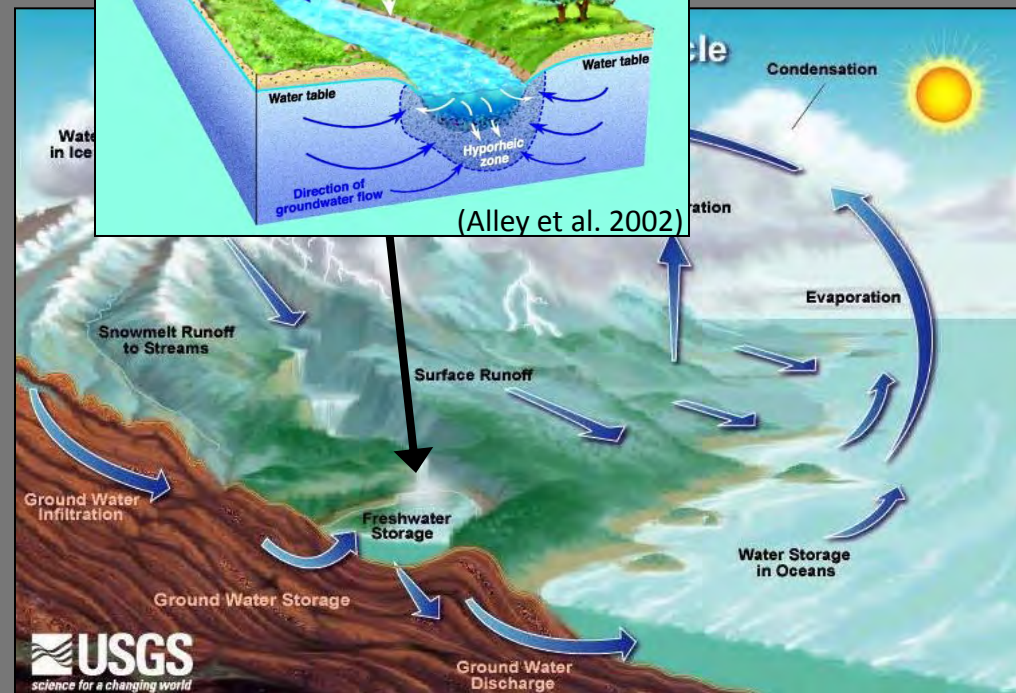
Groundwater contamination



(Alley et al. 2002)

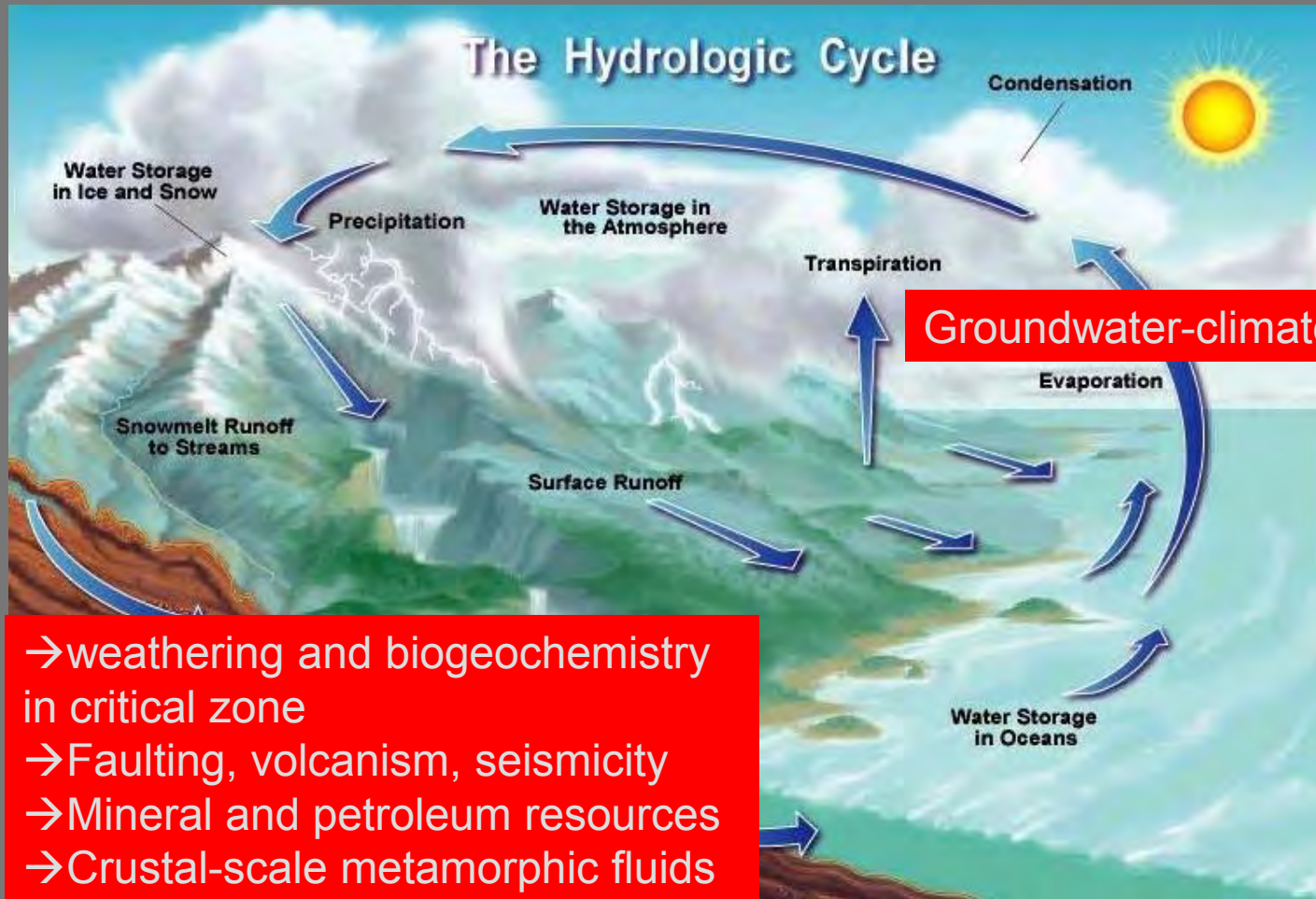
- Local-scale systems
- Short-term planning
- Groundwater separate from surface water

- Regional-scale systems
- Multigenerational planning
- Groundwater and surface water a single resource



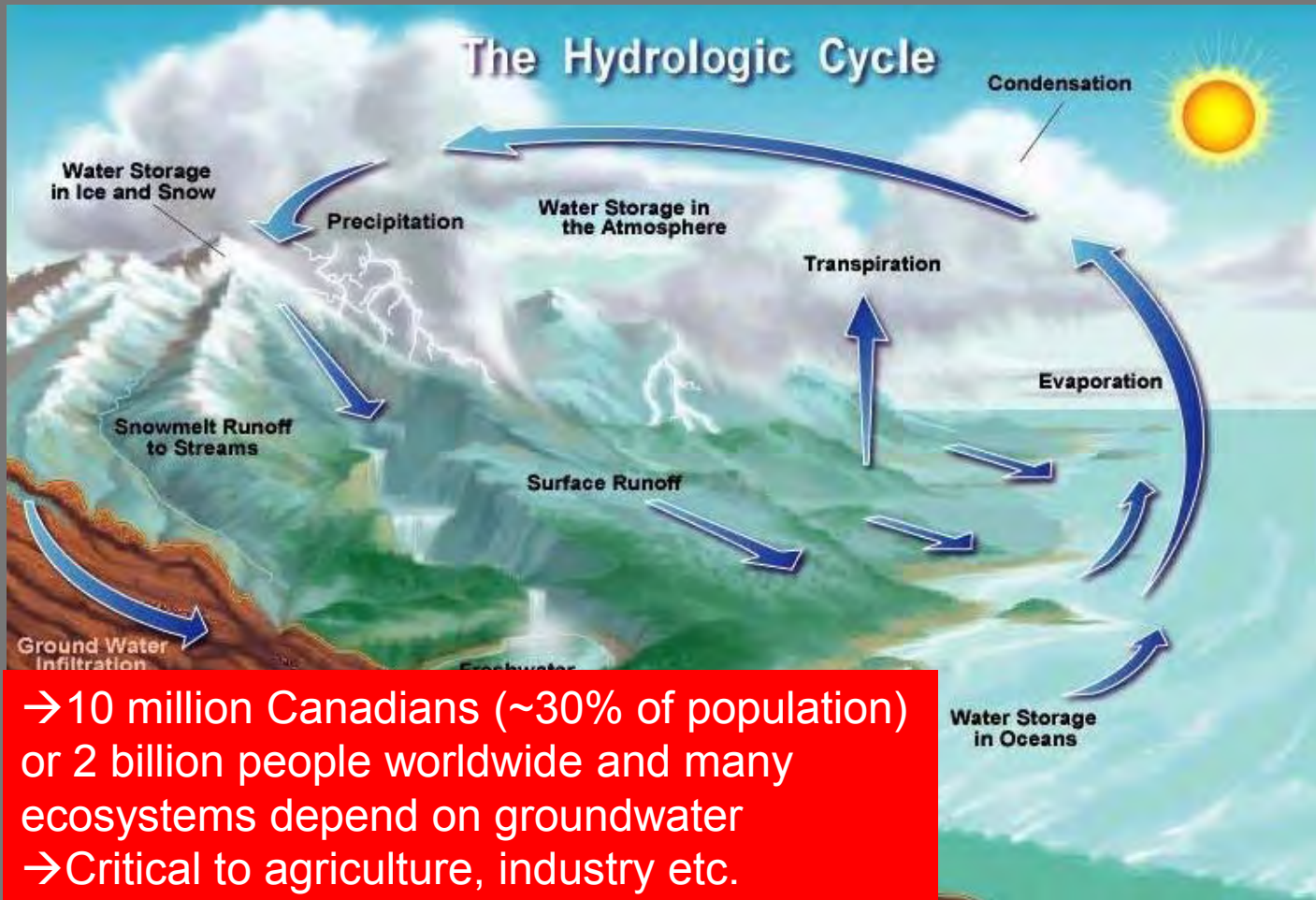
Multi-scale hydrogeology

→ Groundwater connects various parts of the earth system



Multi-scale hydrogeology

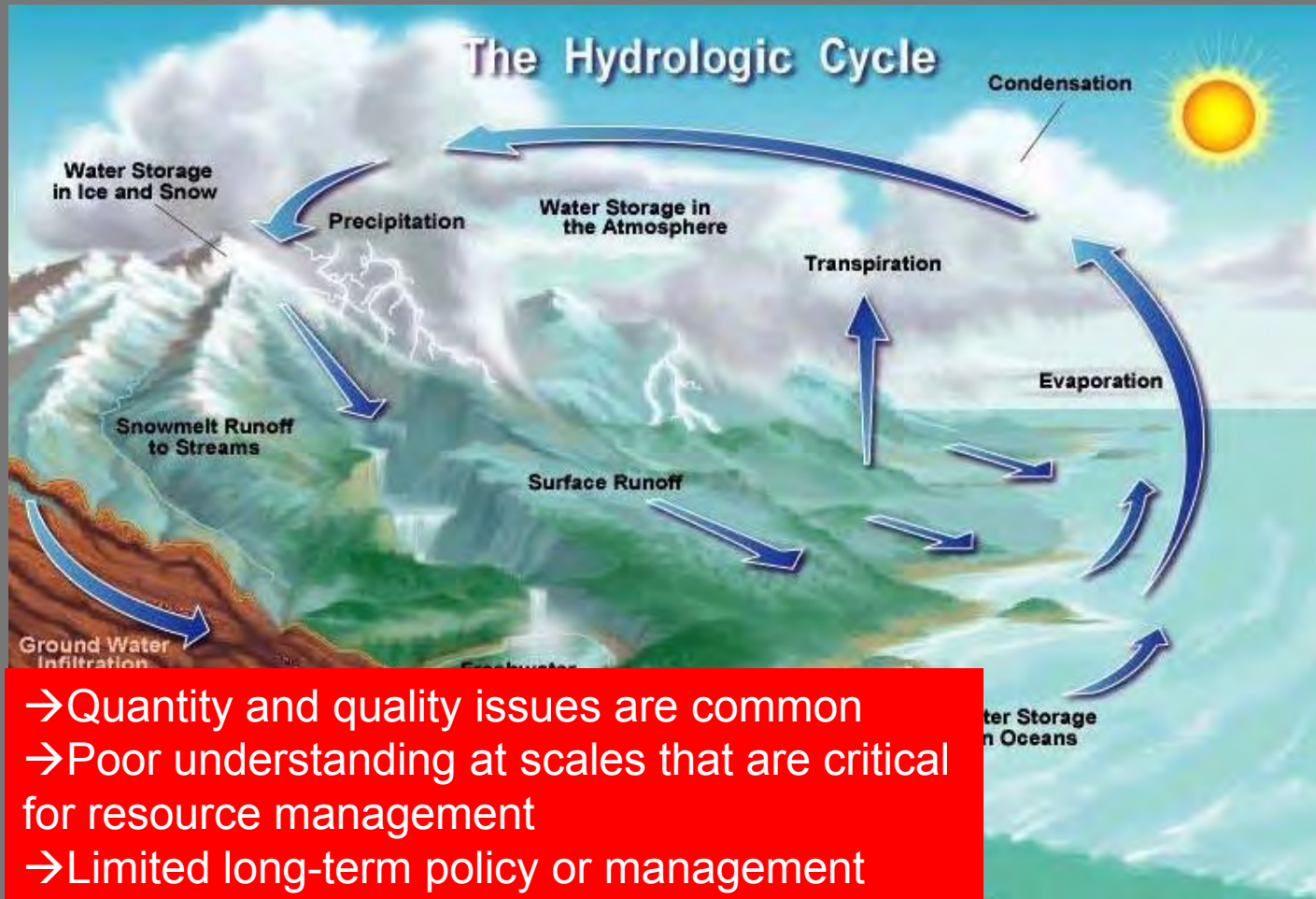
- Groundwater connects various parts of the earth system
- Groundwater is a critical resource



→ 10 million Canadians (~30% of population) or 2 billion people worldwide and many ecosystems depend on groundwater
→ Critical to agriculture, industry etc.

Multi-scale hydrogeology

- Groundwater connects various parts of the earth system
- Groundwater is a critical resource
- Groundwater sustainability is threatened



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The Gazette

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HOME

Shale gas: The stance has changed significantly Development; Report on industry about to be submitted

BY MONIQUE BEAUDIN, THE GAZETTE FEBRUARY 26, 2011 COMMENTS (2)

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PHOTOS (1)

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BY MARIA

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lawsuit o
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in the da



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Groundwater
discharge

Mega-scale
hydrogeology

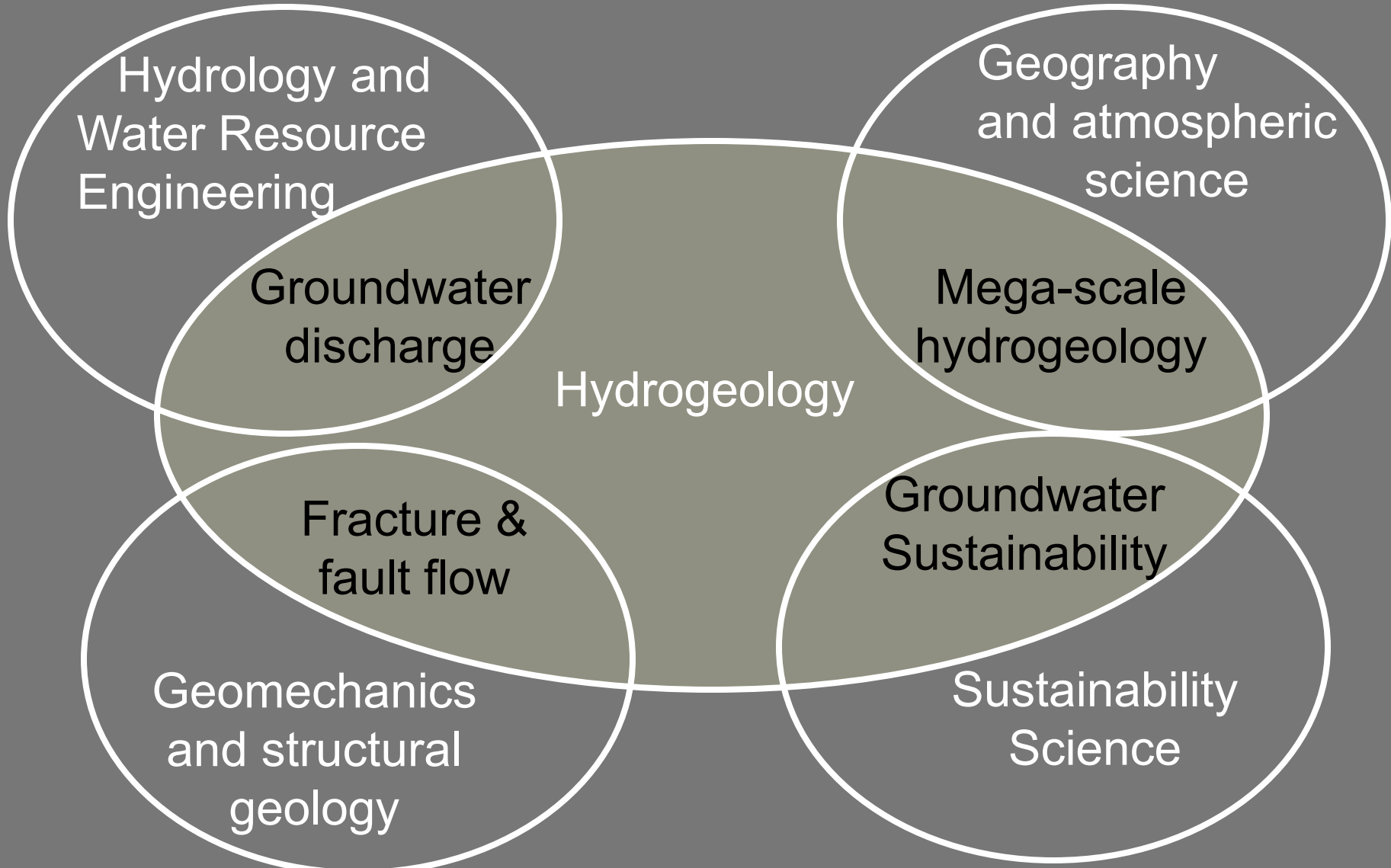
Hydrogeology

Fracture &
fault flow

Groundwater
Sustainability

Geomechanics
and structural
geology

Sustainability
Science



Research program

Hydrology and
Water Resource
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Hydrogeology

Fracture &
fault flow

Groundwater
Sustainability

Geomechanics
and structural
geology

Sustainability
Science

1. Regional-scale (lineaments in the Canadian Shield)



Research program

2. Continental-scale
(permeability map)



Hydrology and
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hydrogeology

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fault flow

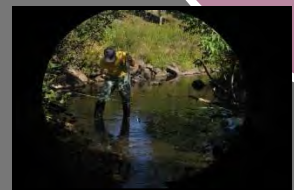
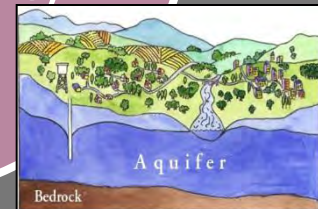
Geomechanics
and structural
geology

Groundwater
Sustainability

Sustainability
Science

1. Regional-scale

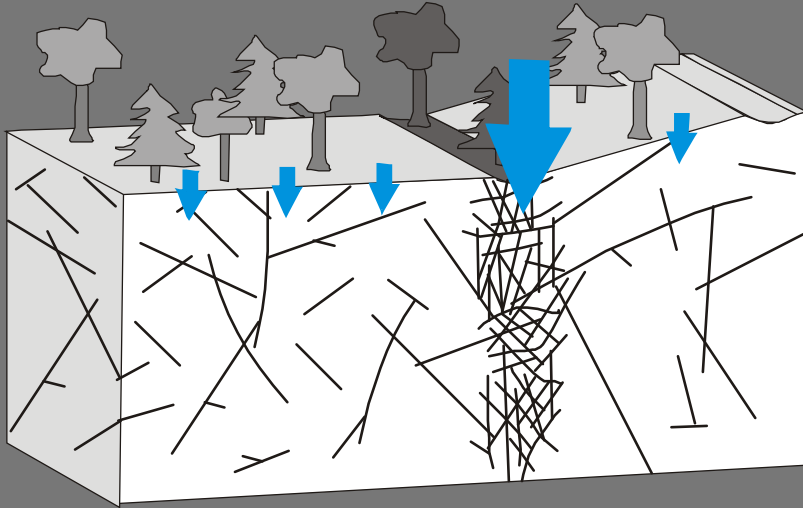
3. Multi-generational scale



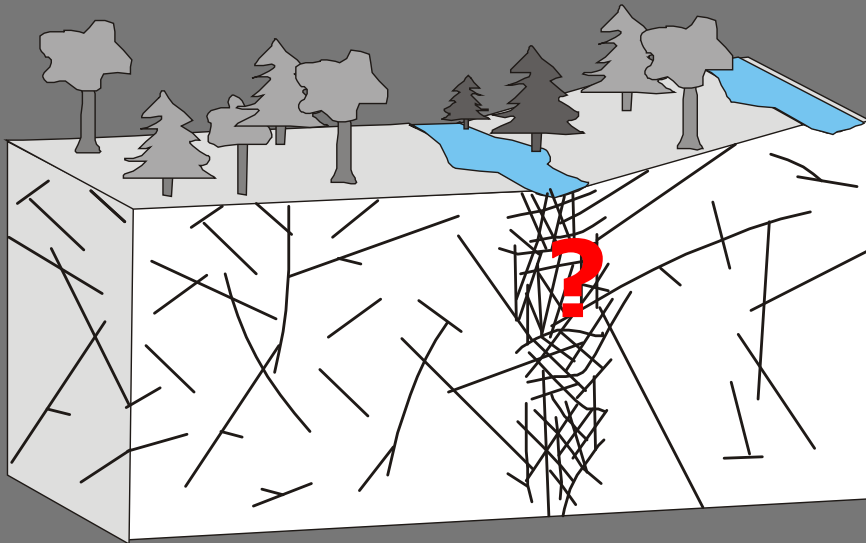
Lineaments in the Canadian Shield



Previous conceptual model



- **Dense fracture zones and/or faults**
- **Flow conduits with higher groundwater potential**



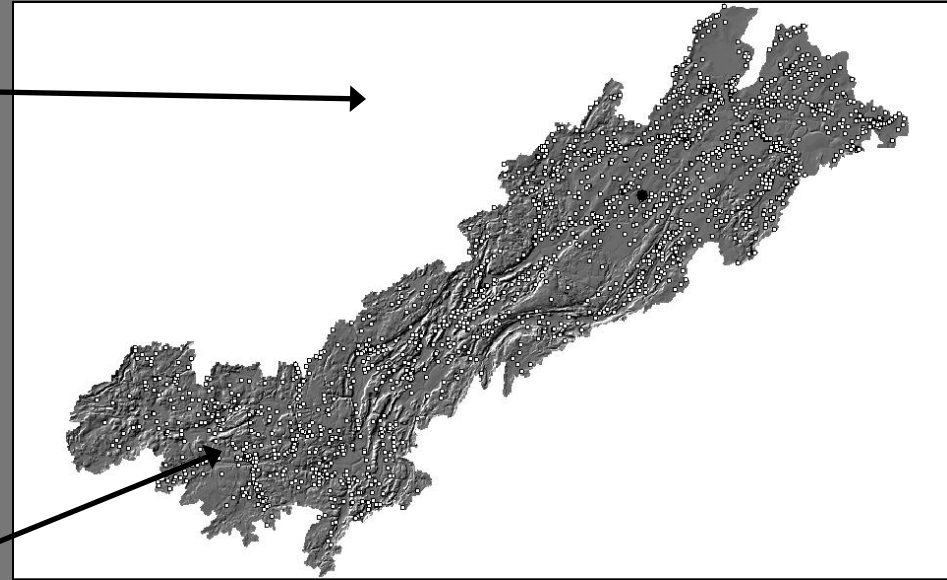
Objectives

- **Are lineaments structurally controlled?**
- **Are lineaments hydraulic conduits or barriers?**

Methods

- **Geomatics**

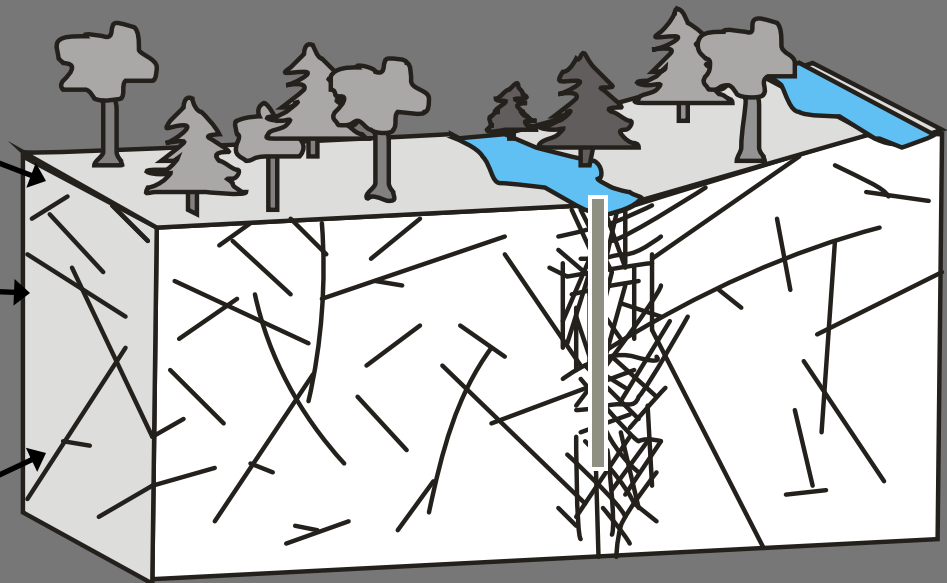
- **Lineament identification**
- **Well database**
- **Surface water gradient**



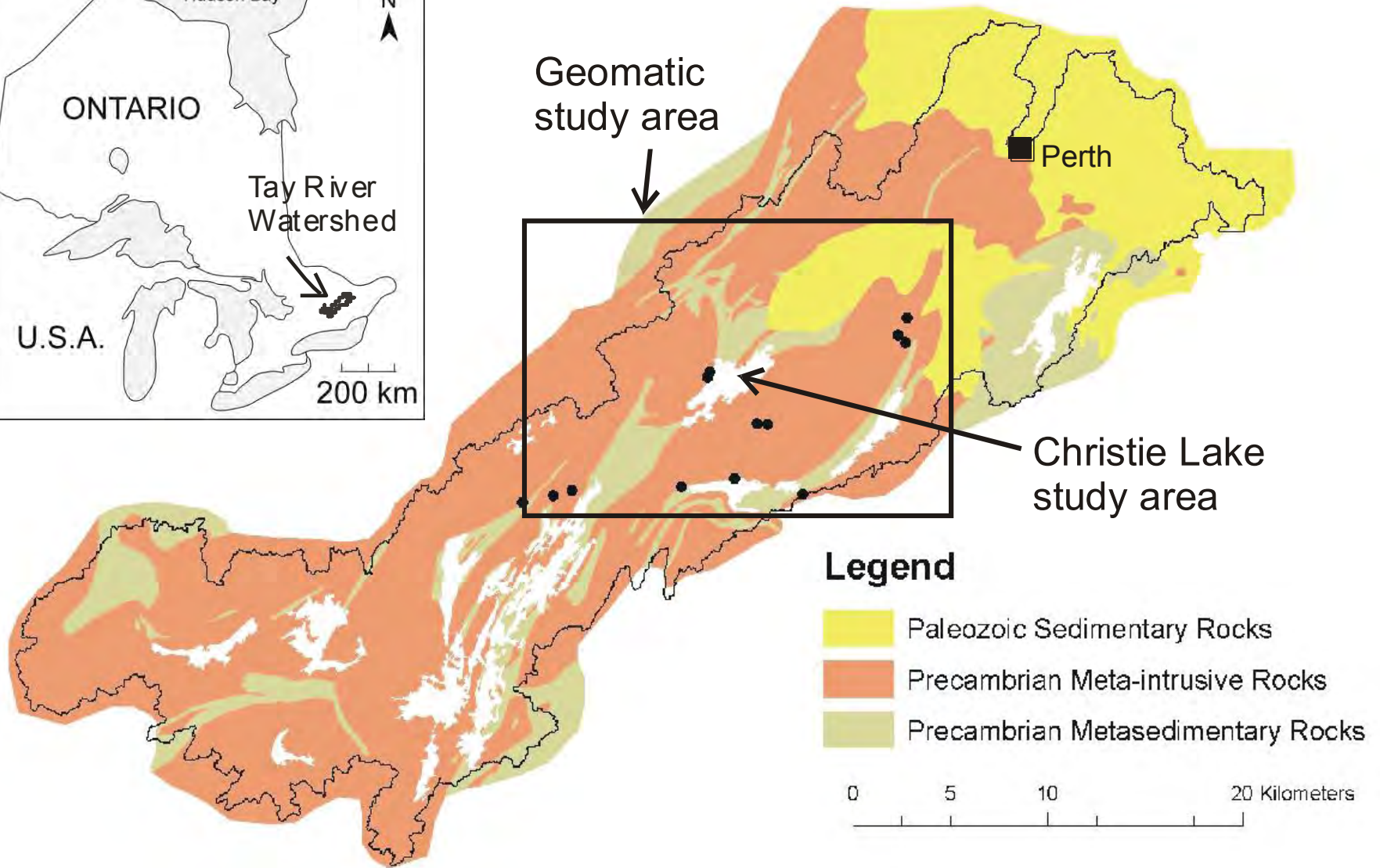
- **Fracture mapping**

- **Hydrogeological characterization**

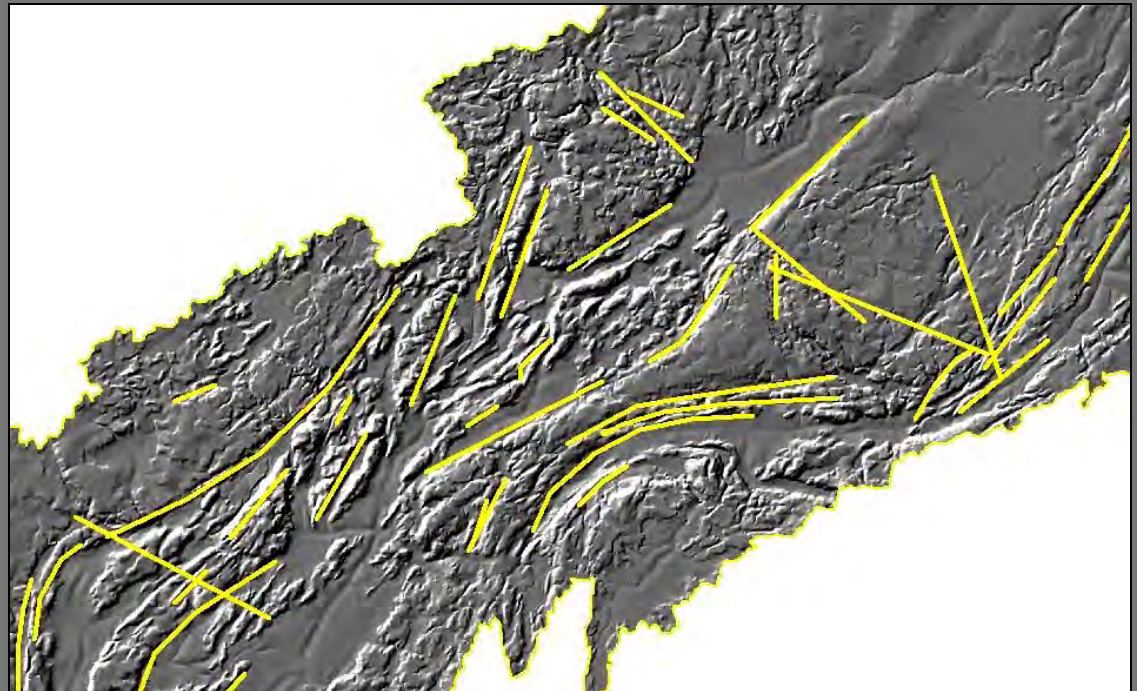
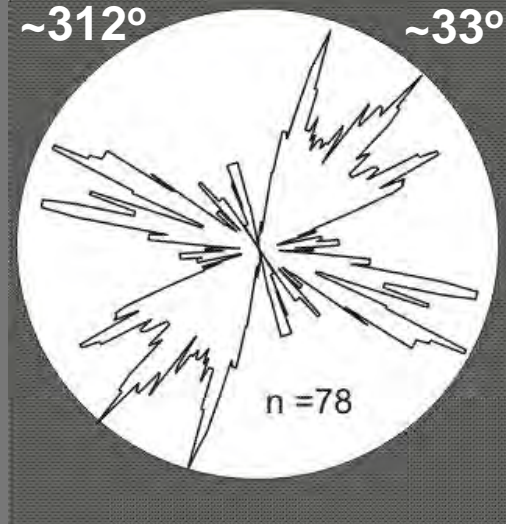
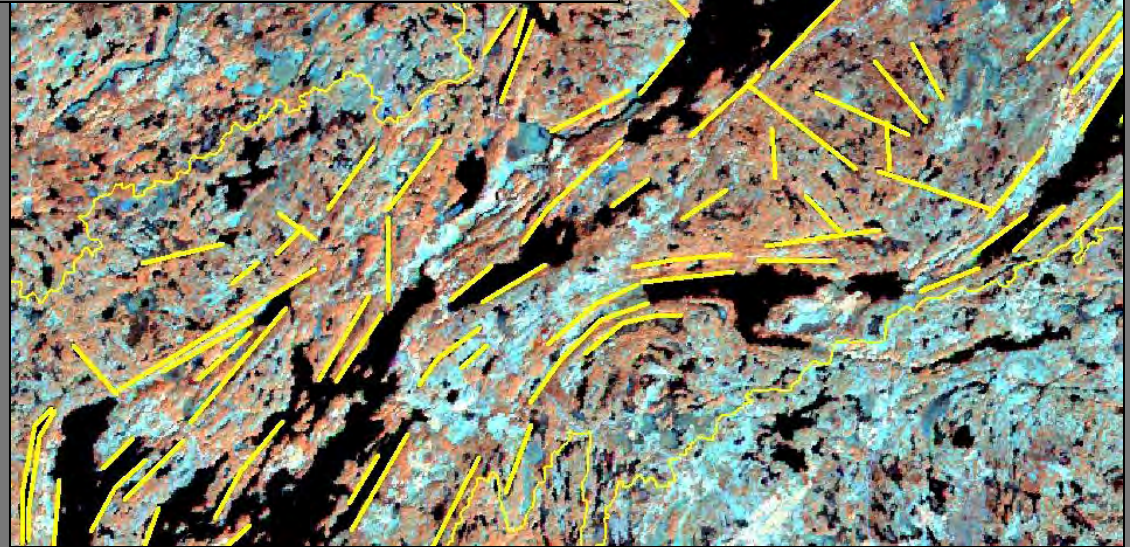
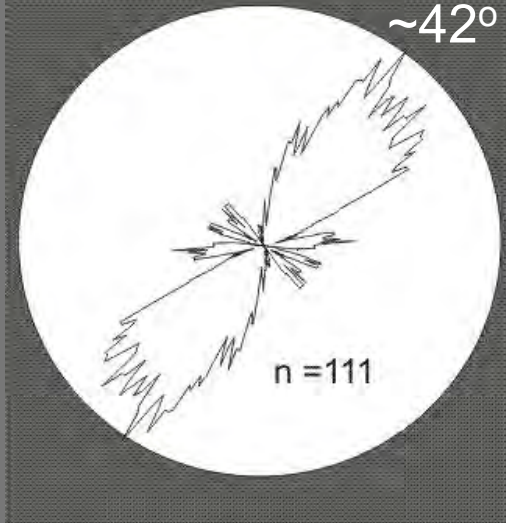
- **Numerical modeling**



Study Area



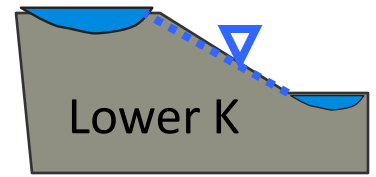
Lineament Orientations



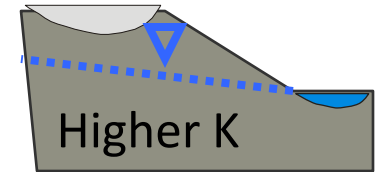
(Landsat False Color Composite 754
from DongMei Chen, Queen's University
Geography Department)

(DEM, vertically exaggerated)

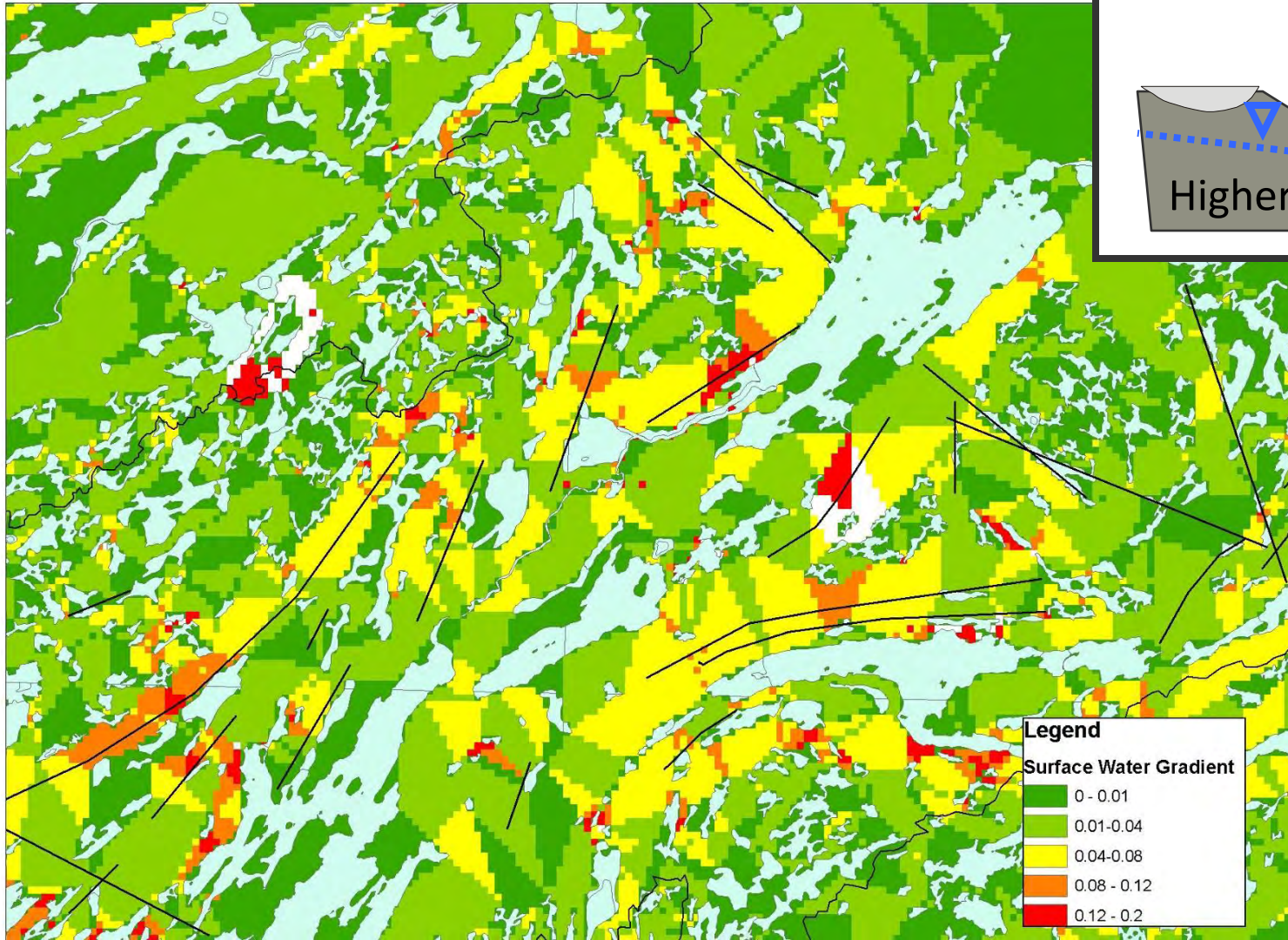
Surface water gradients



Lower K



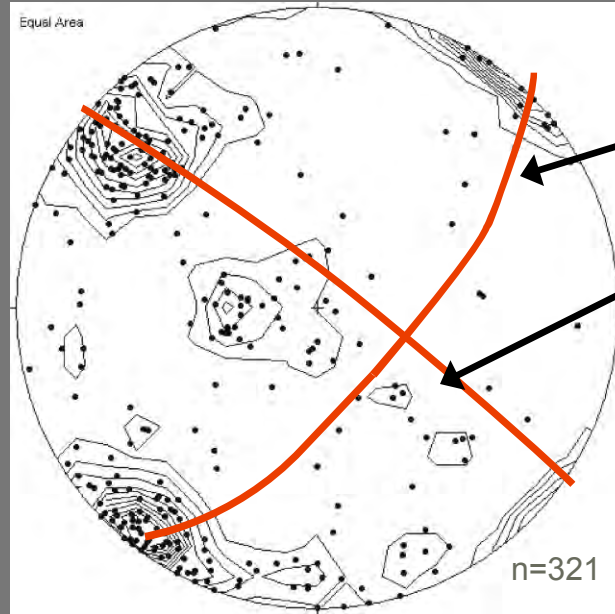
Higher K



0 1,250 2,500 5,000 Meters

Fracture Orientations

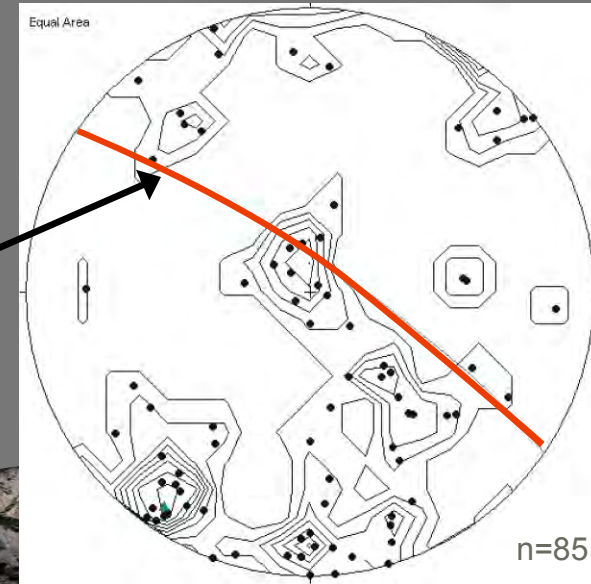
Regional patterns



Steep NE-SW set

Vertical NW-SE set

Vertical NW-SE set



Christie Lake outcrop

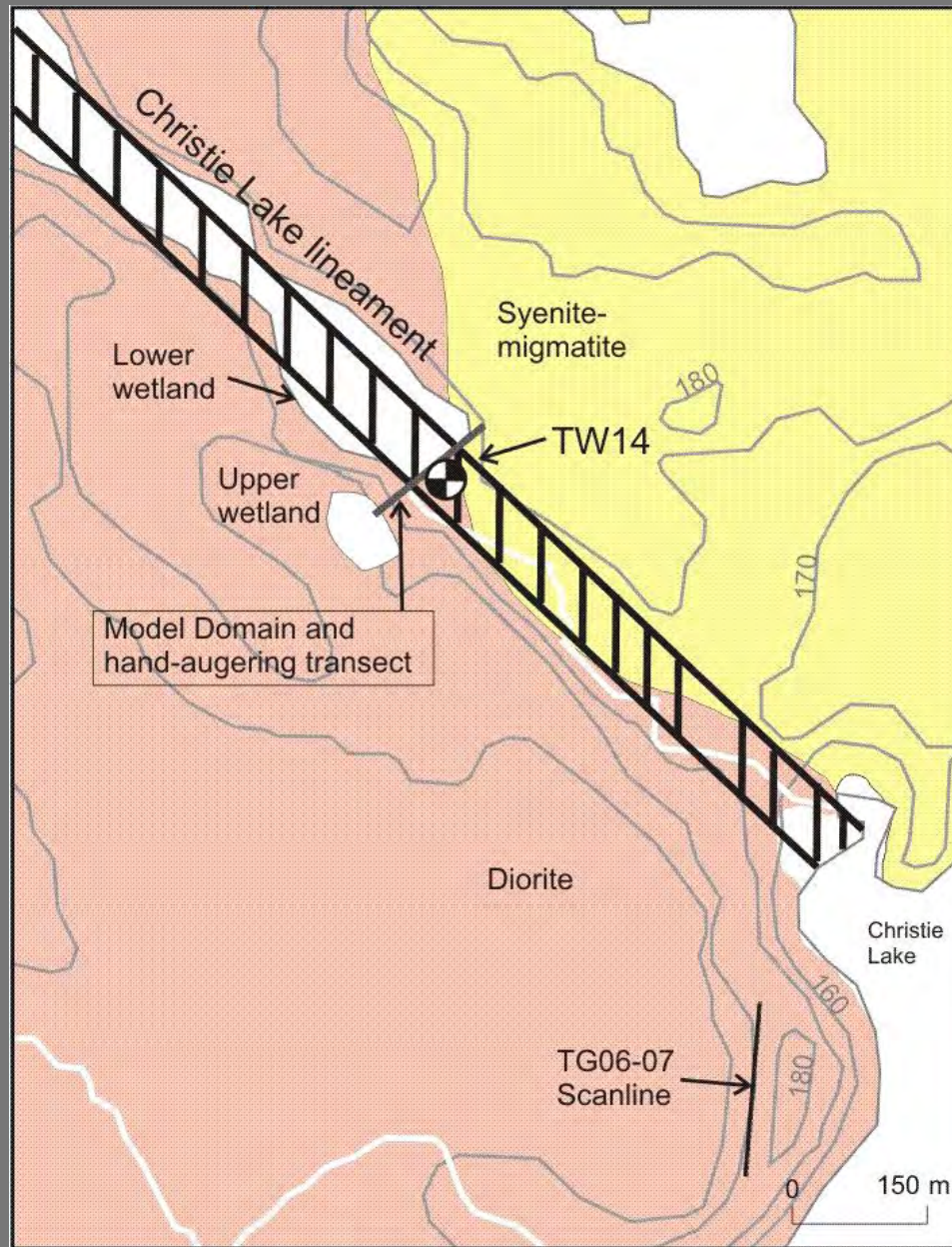


Hydrogeological characterization

Christie Lake site

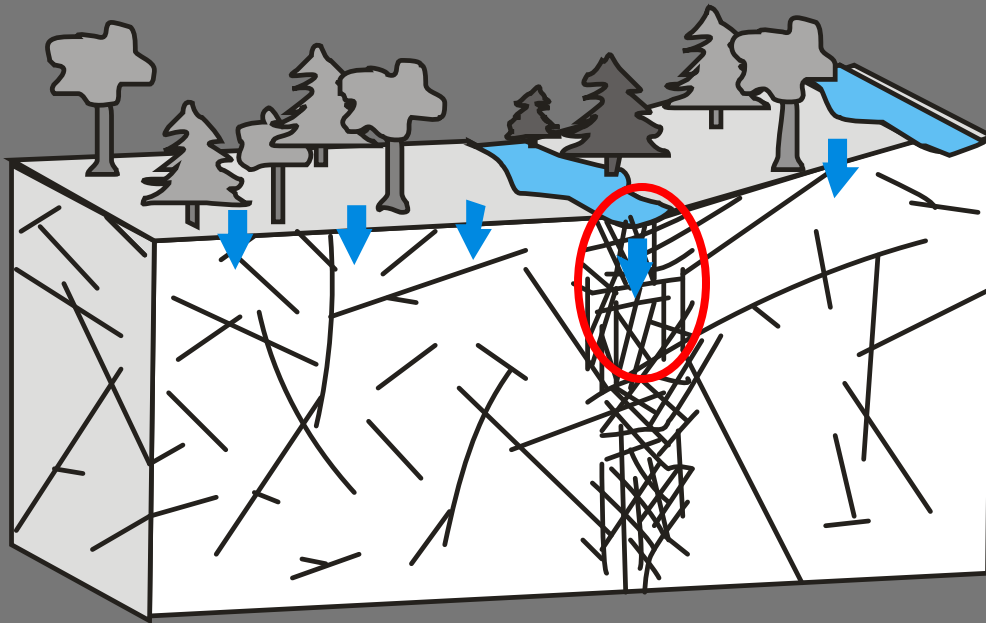


Downhole camera



(Geology from Dugas, 1961)

Conclusions: new conceptual model

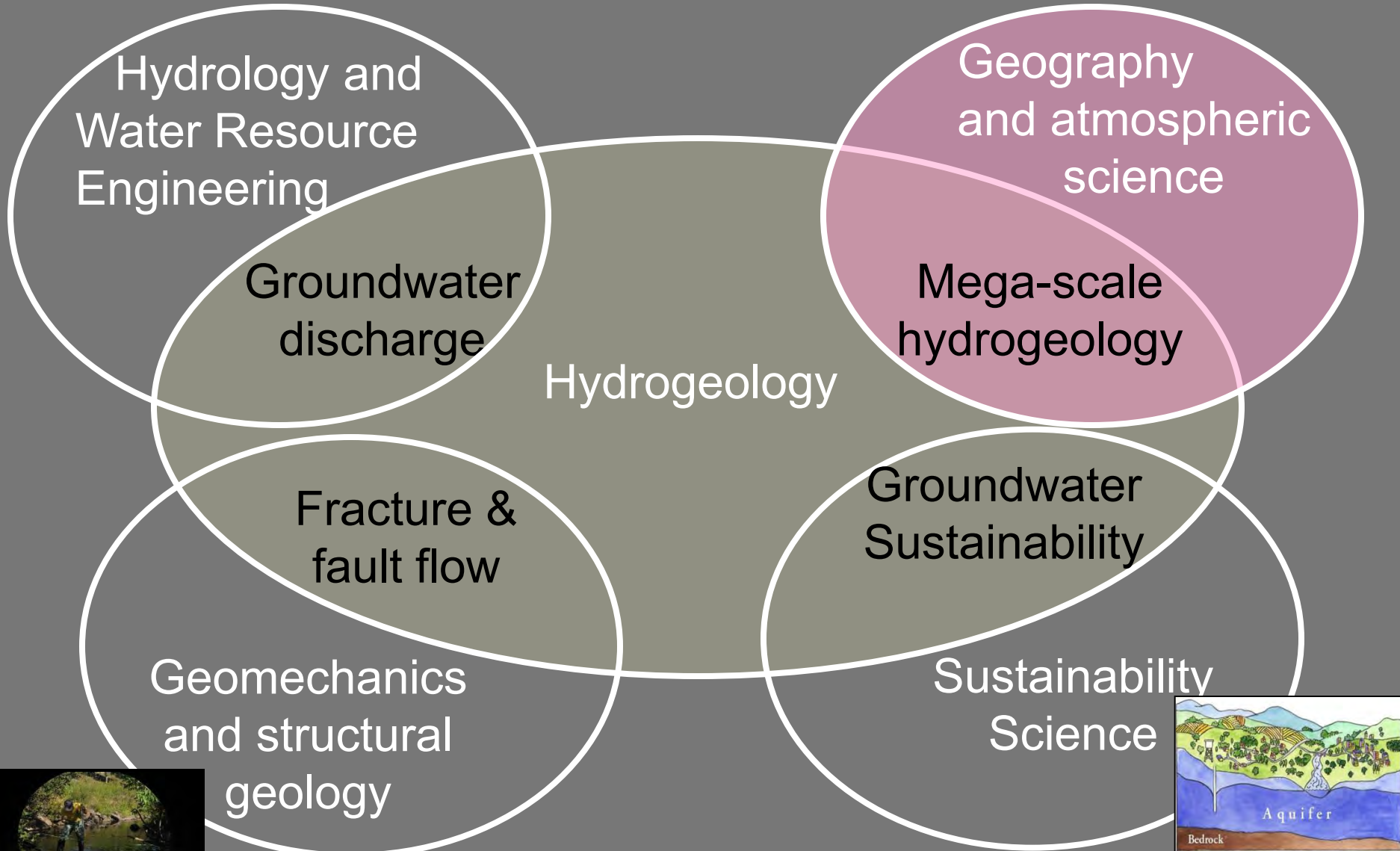


- Lineaments are structurally controlled, some are faults
- Zones of low to moderate permeability and well productivity
- Discrete shallow and steep fractures

Lineaments can be structural barriers to flow

Research program

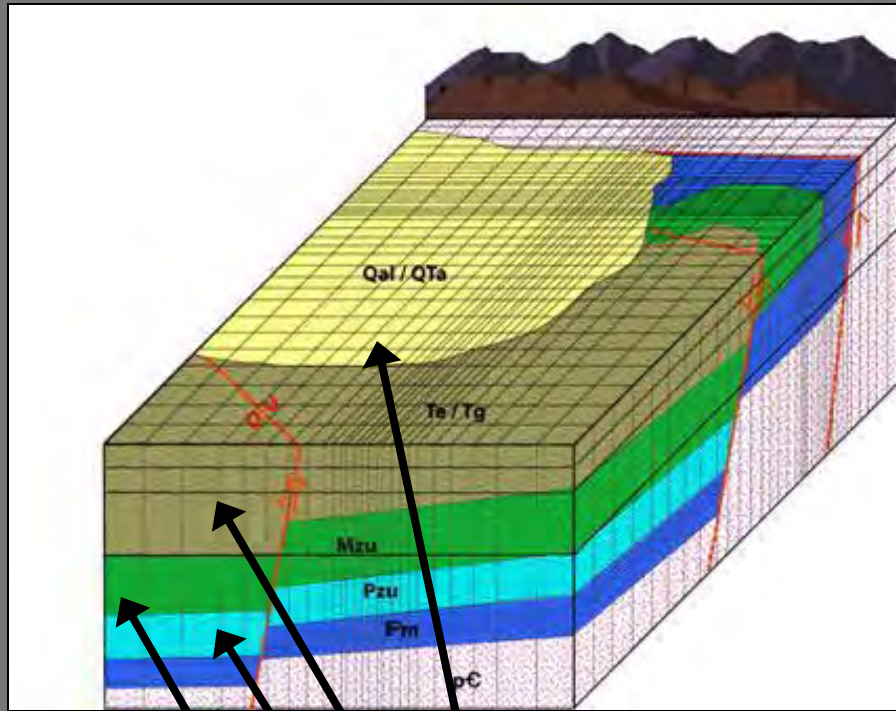
2. Continental-scale
(permeability map)



1. Regional-scale

3. Multi-generational scale

Permeability compilation



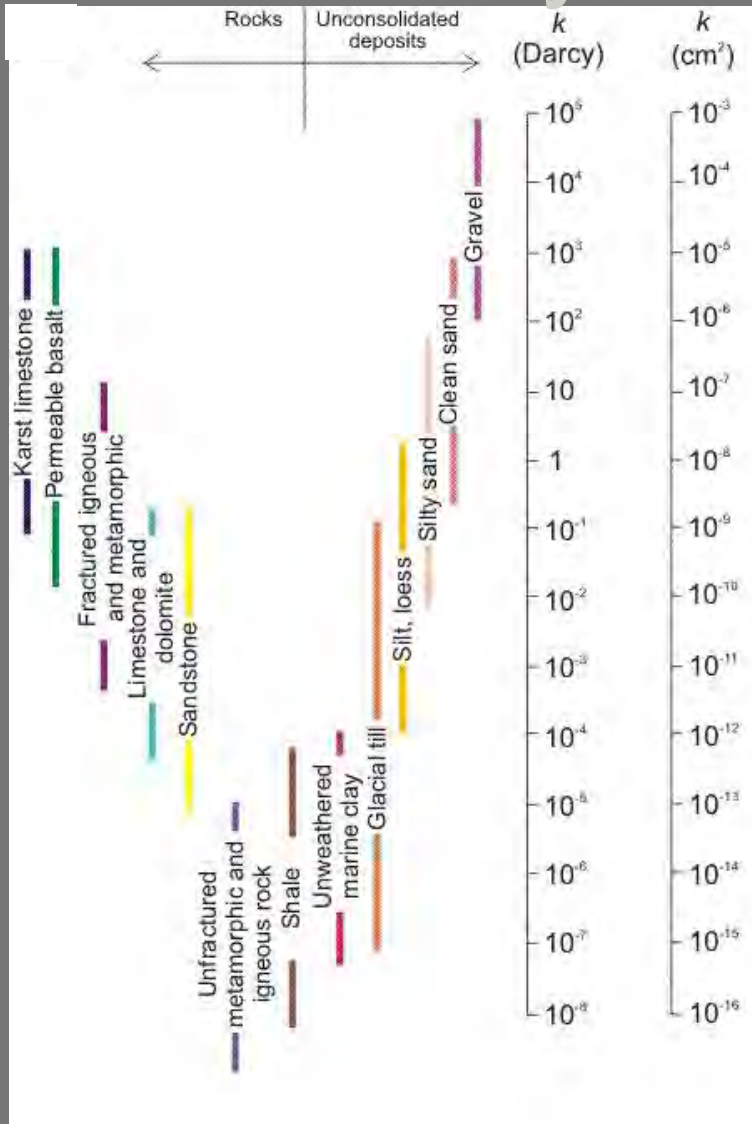
Regional scale groundwater models calibrated to:

- hydraulic heads (water levels)
- fluxes (baseflow)
- transport (contaminants, groundwater age)
- heat (groundwater temperature)

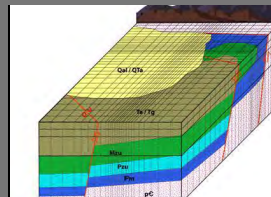
Hydrolithology

- Unconsolidated (fine and coarse-grained)
- siliciclastic sedimentary (fine and coarse-grained)
- carbonate
- crystalline
- volcanic

Permeability compilation

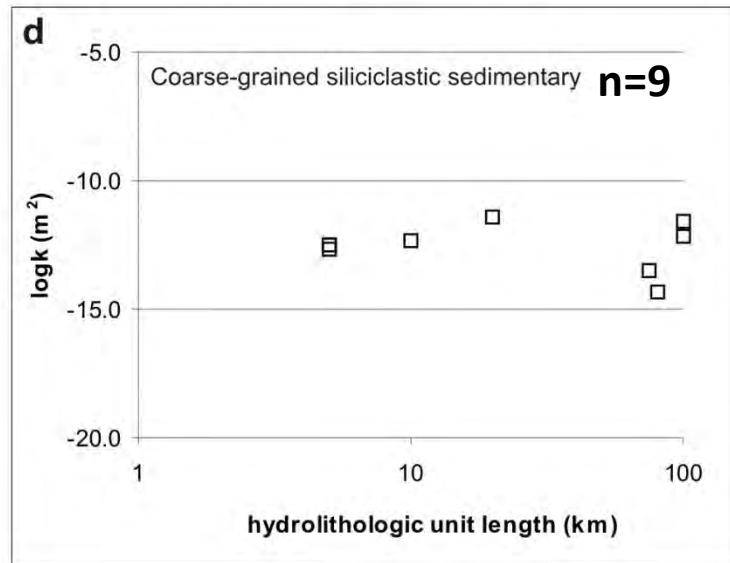
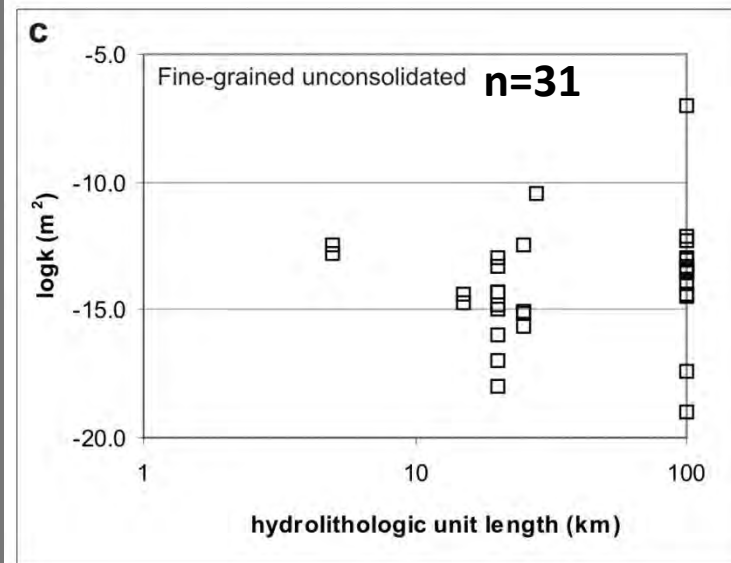
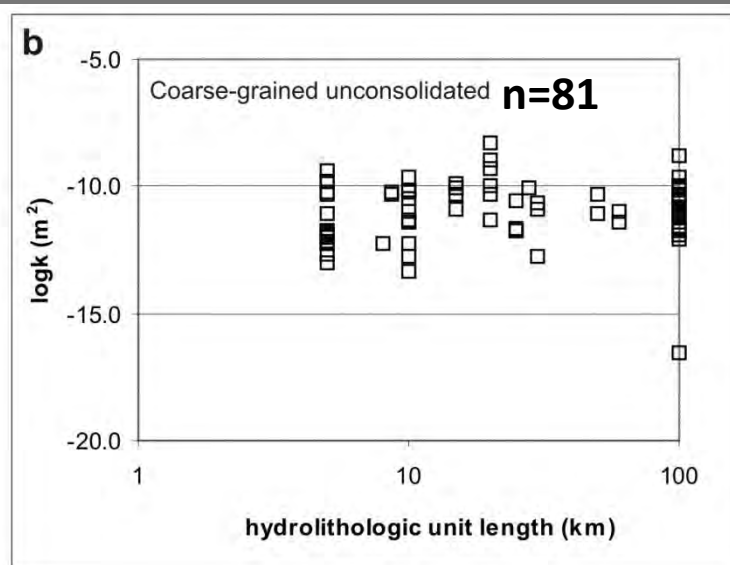
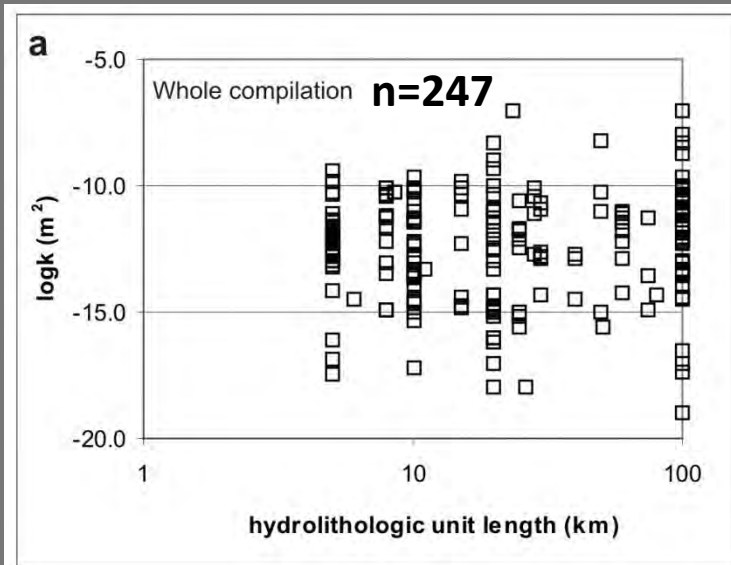


Freeze and Cherry (1979)

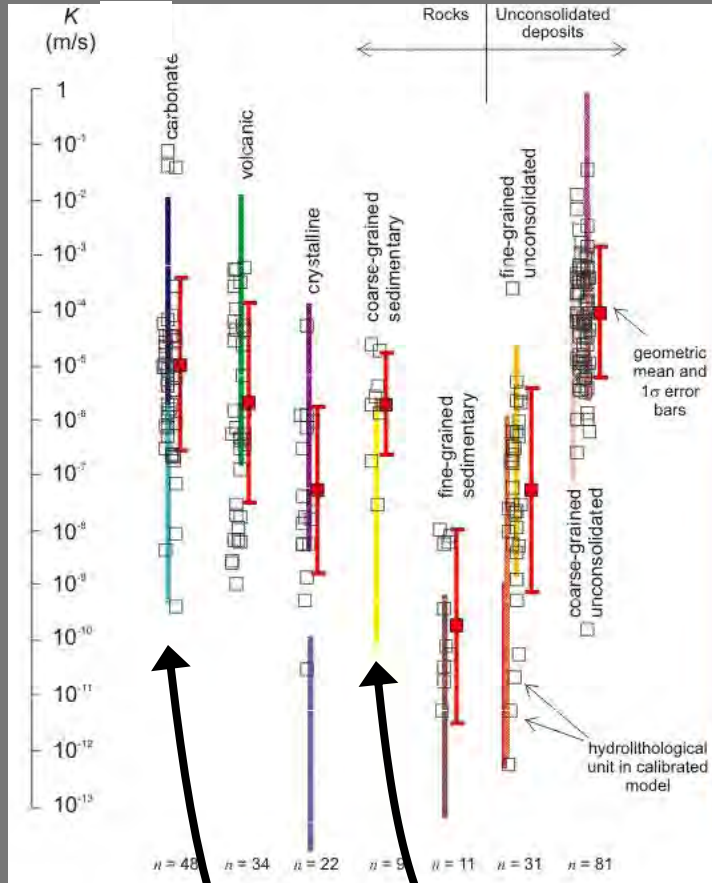


Calibrated, regional-scale groundwater models

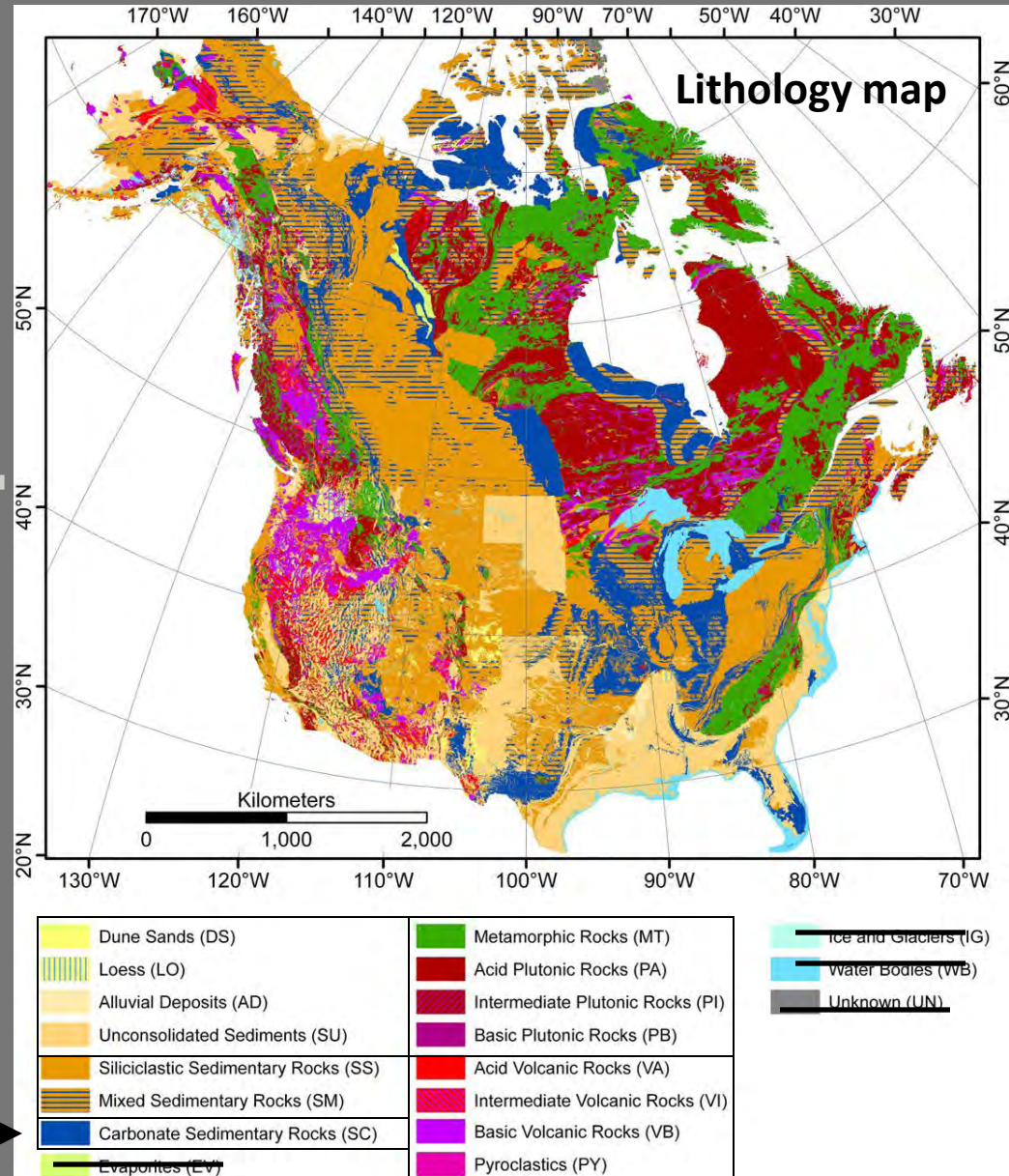
Permeability and scale



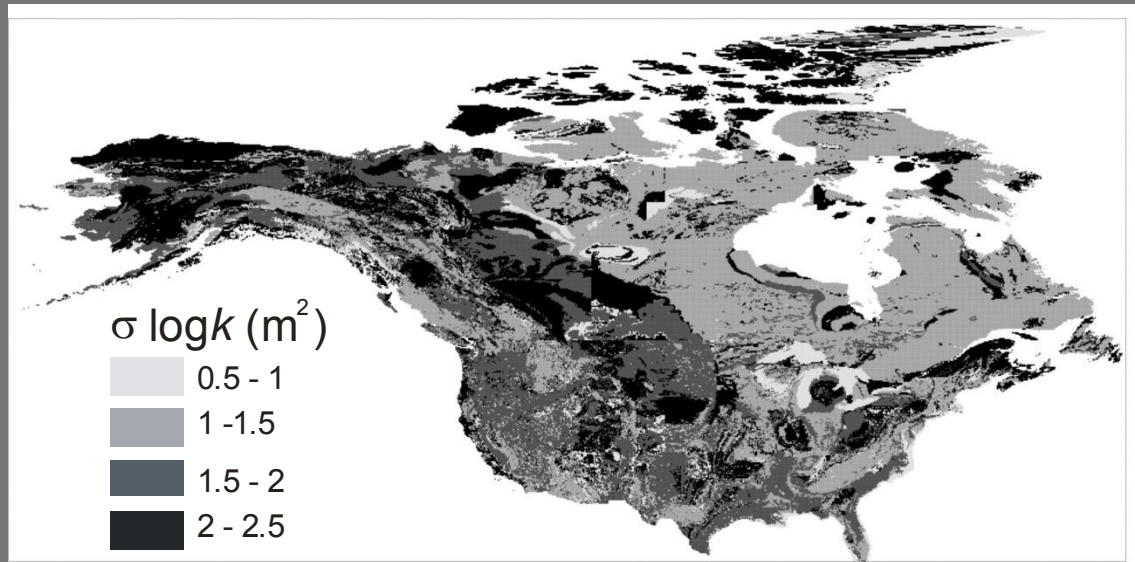
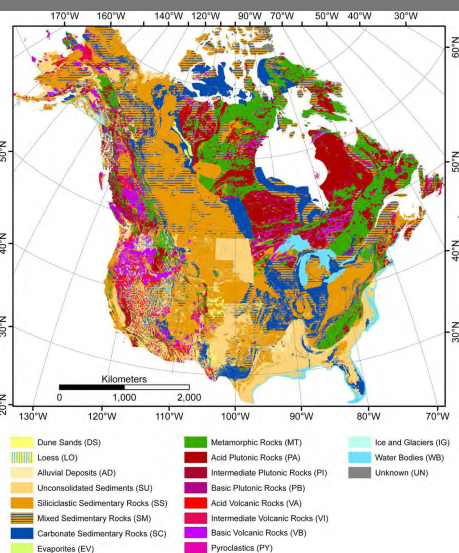
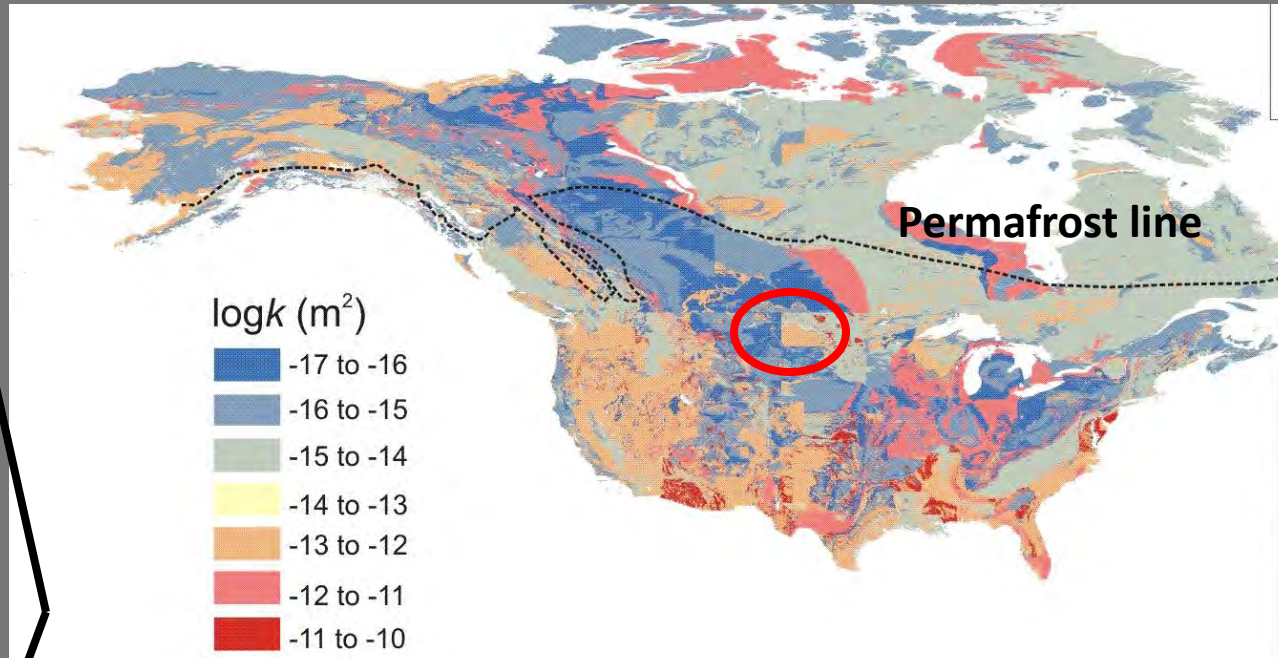
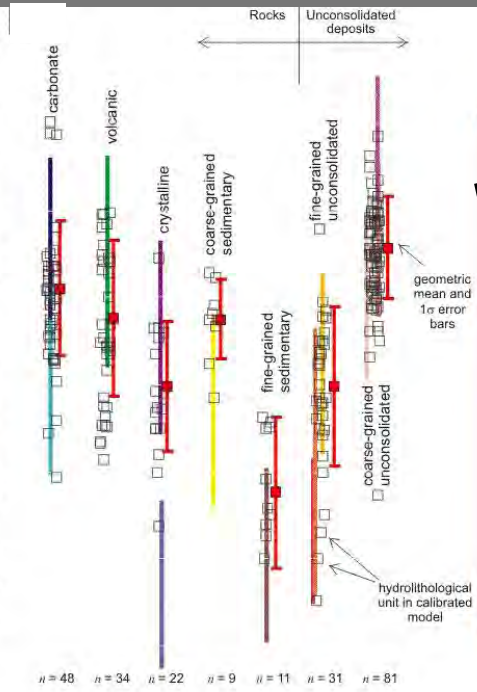
Permeability mapping



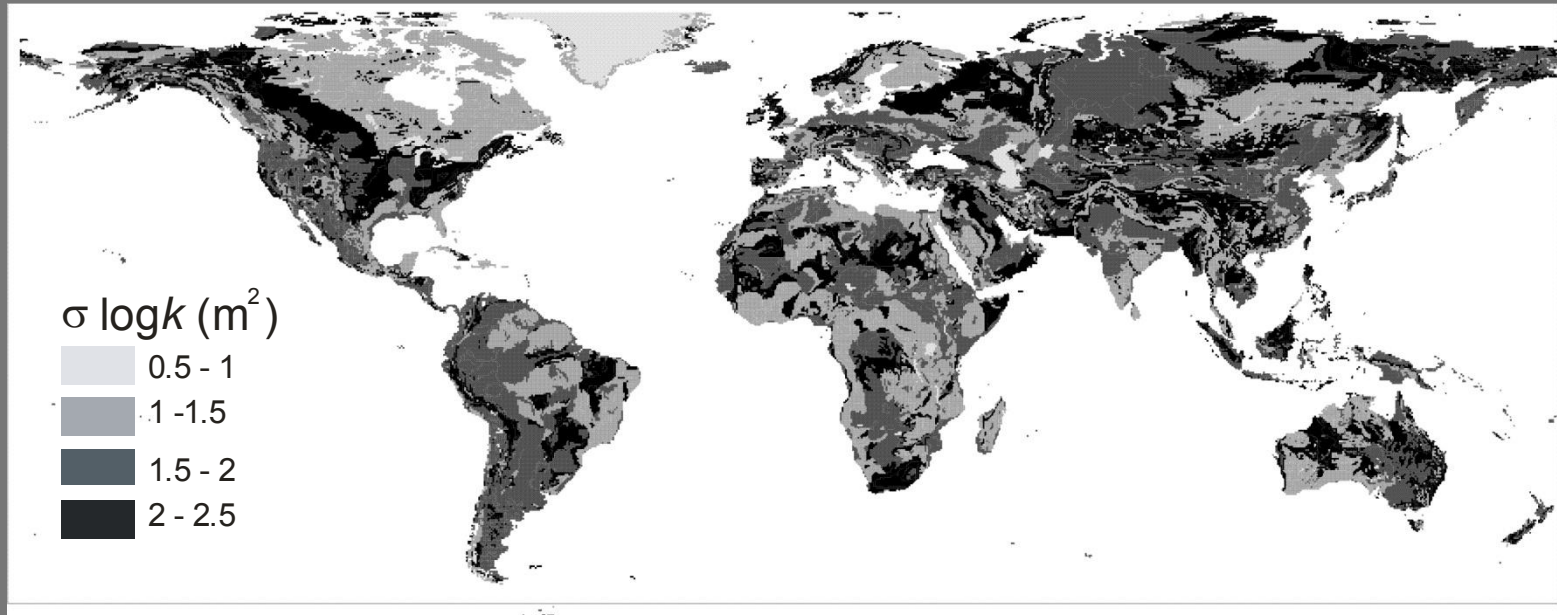
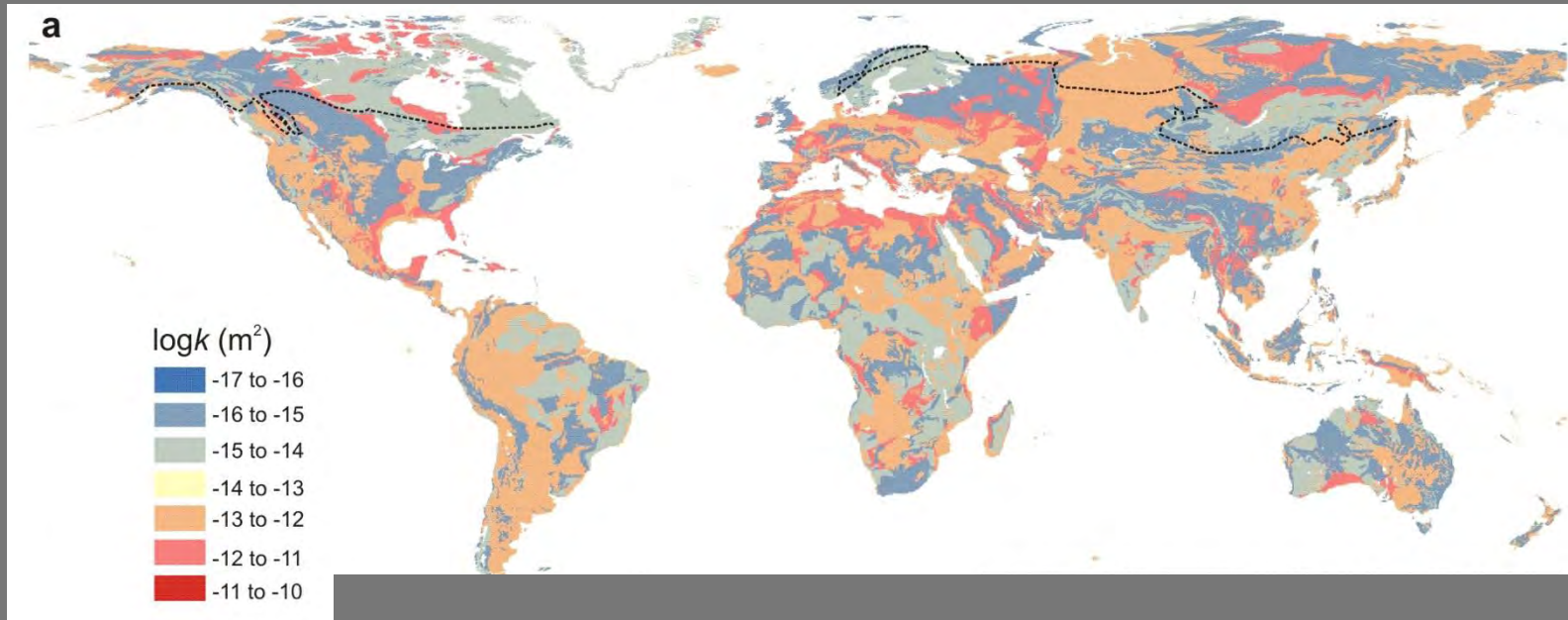
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Permeability mapping

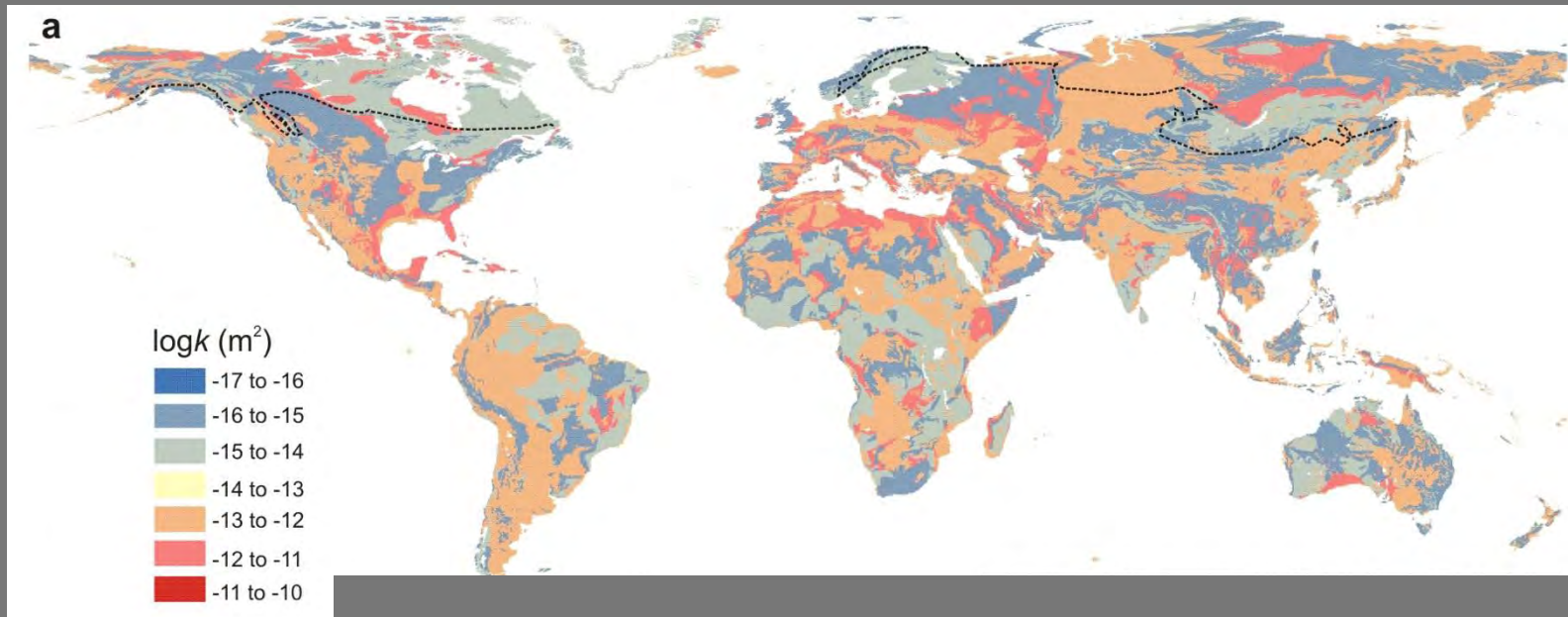


Permeability mapping



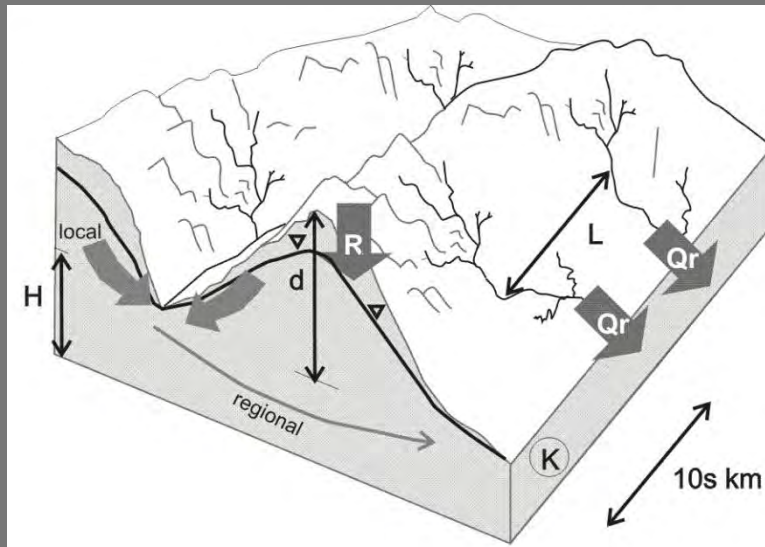
Permeability mapping – applications

- characteristics of regional water tables
- groundwater and climate
- global sustainable groundwater resources
- role of permeability in weathering

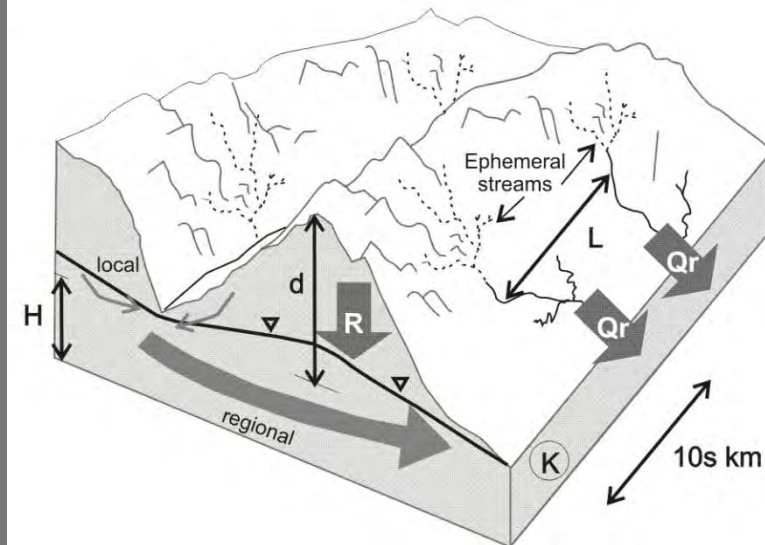


Water table type

(Hajema and Mitchell-Bruker 2005)



Topography- controlled
 $\log(\text{WTR}) > 0$

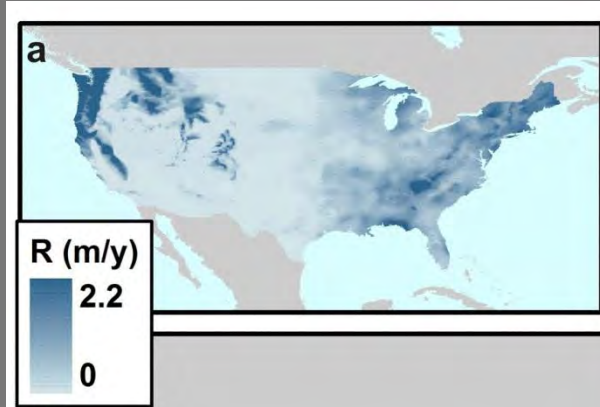
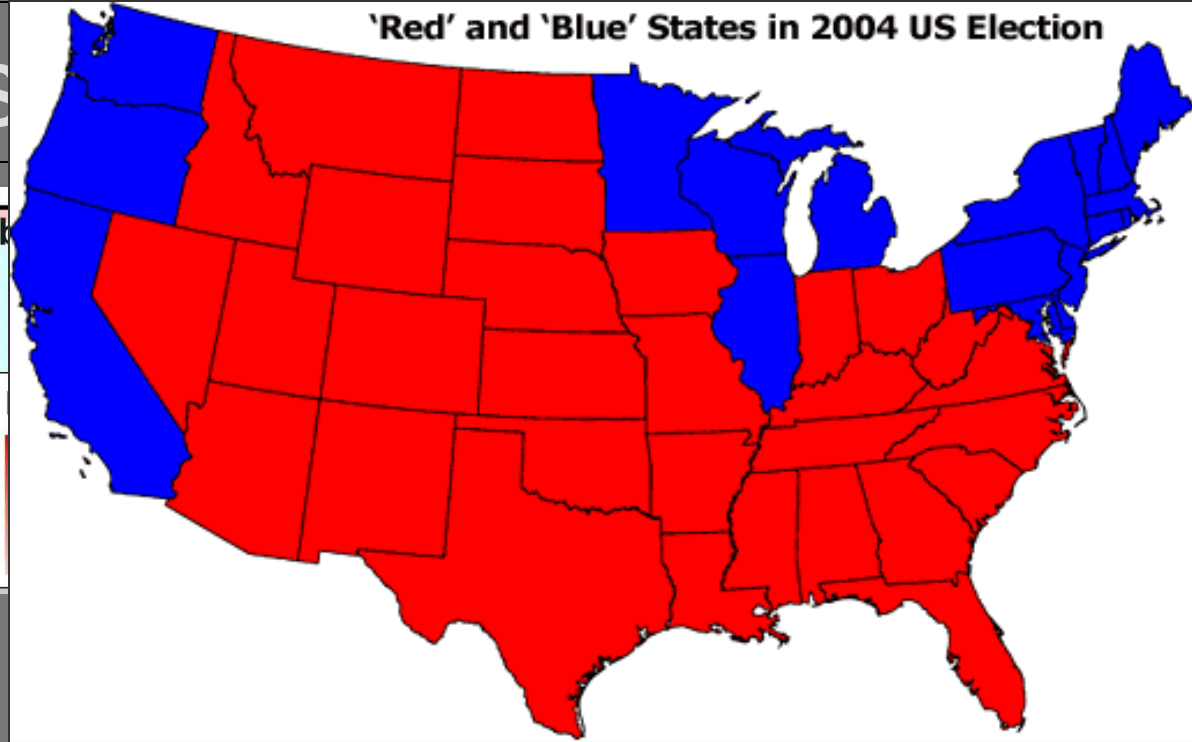


Recharge- controlled
 $\log(\text{WTR}) < 0$

Water Table Ratio (WTR) =

$$\frac{\text{Recharge}}{mkHd} \leftarrow \begin{array}{l} \text{Watershed size} \\ \text{Elevation} \\ \text{difference} \\ \text{Aquifer} \\ \text{thickness} \end{array}$$

Continental s



Research program

2. Continental-scale



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Water Resource
Engineering

Geography
and atmospheric
science

Groundwater
discharge

Mega-scale
hydrogeology

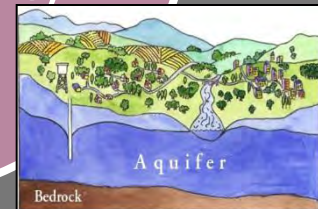
Hydrogeology

Fracture &
fault flow

Groundwater
Sustainability

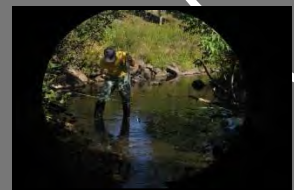
Geomechanics
and structural
geology

Sustainability
Science

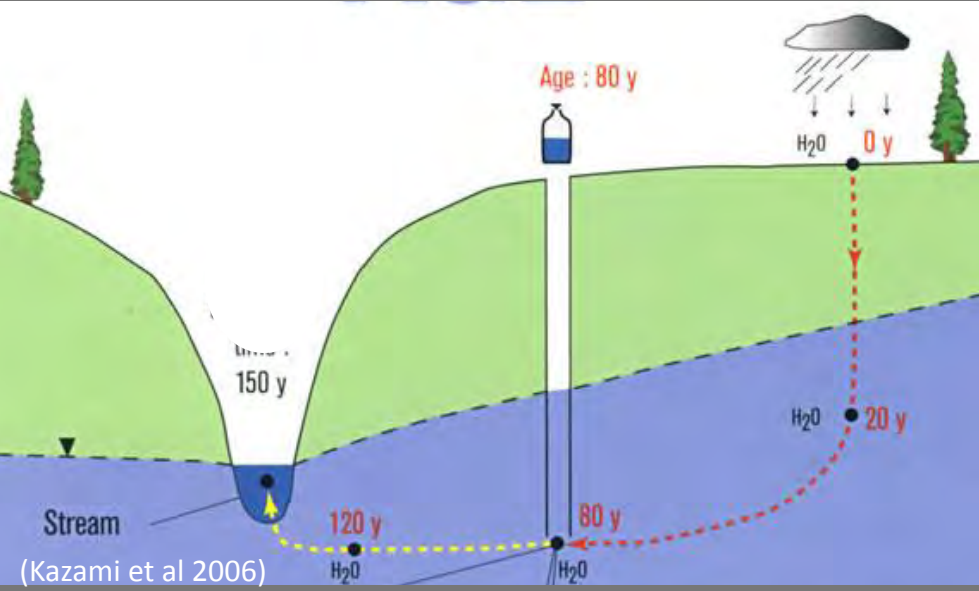


1. Regional-scale

3. Multi-generational scale



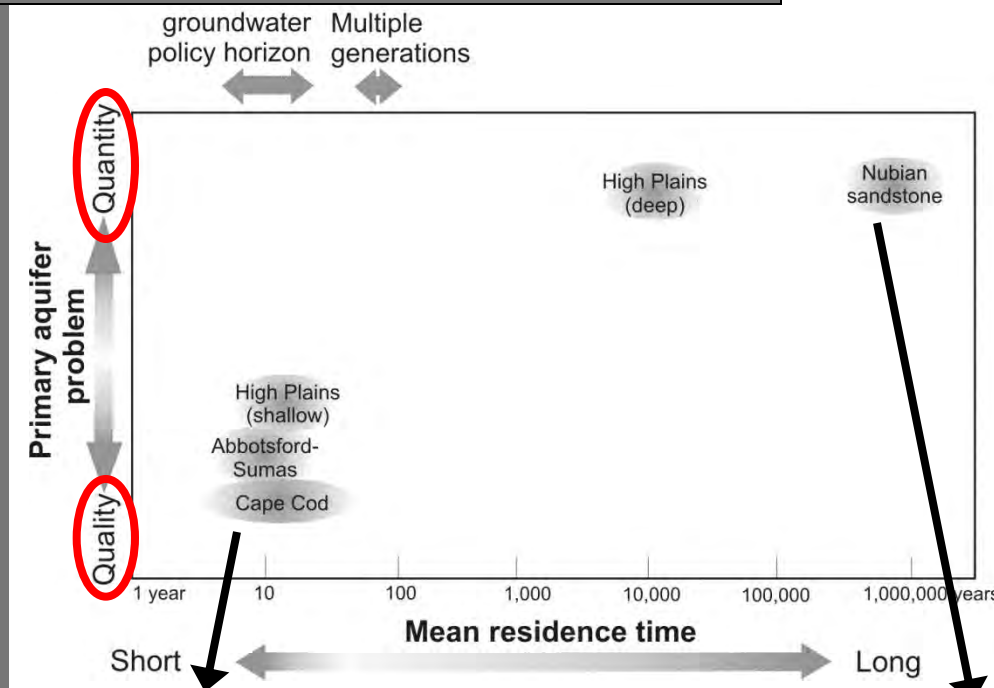
Sustainability tools



- residence time is the average time it takes for groundwater to flow from recharge to discharge areas
- Approximates the aquifer renewal time
- Quantified through groundwater ages or numerical modeling



Sustainability tools



Gleeson et al. 2010 Nature Geoscience
Gleeson et al. Ground Water in press

Abbotsford-Sumas aquifer
(~10 year mean age)



High Plains aquifer
(3000-15,000 year ages)



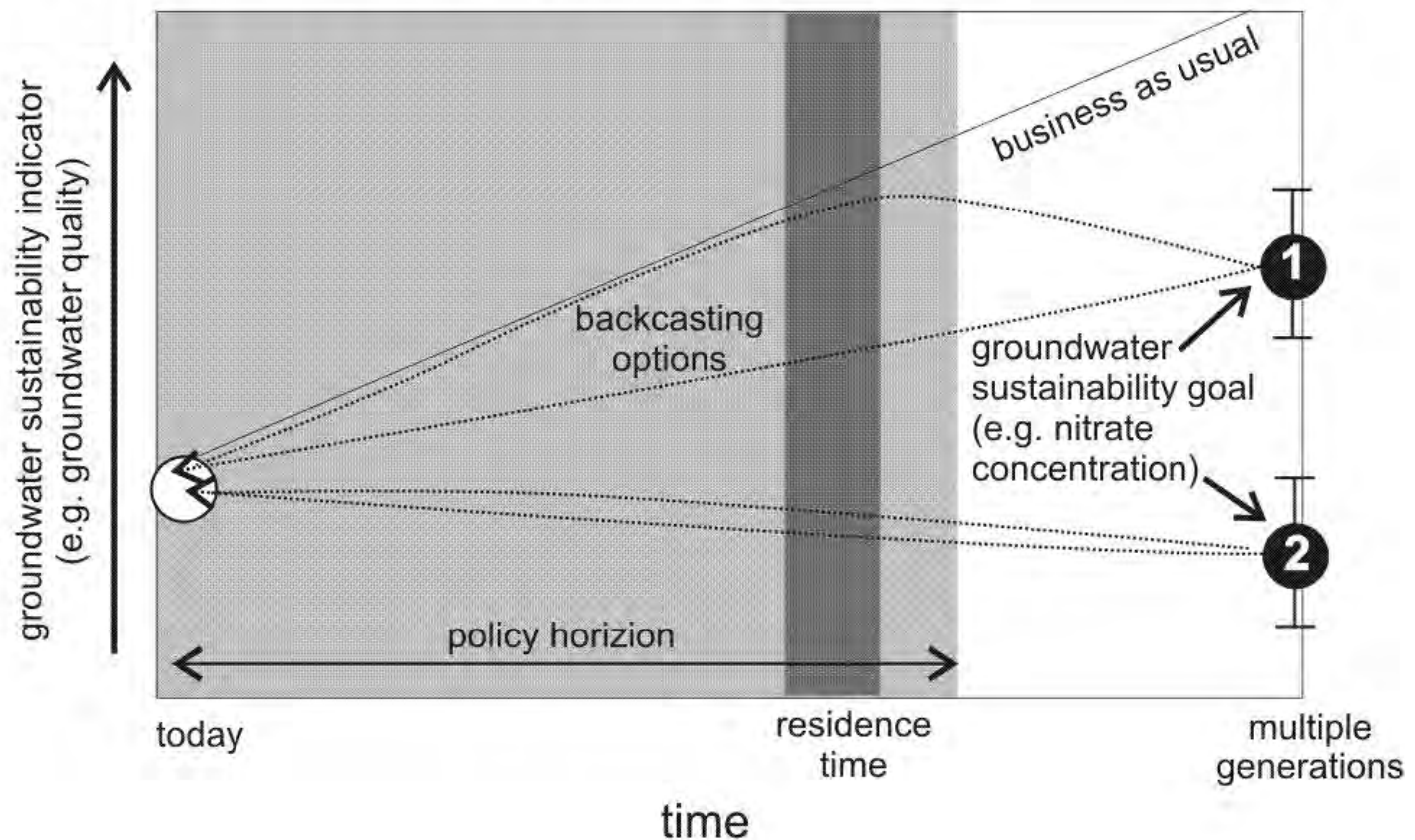
→ Both aquifers have significant long-term issues

Sustainability tools



Set multi-generational sustainability goals and backcast

Aquifers with short mean residence time (e.g. Abbotsford-Sumas)

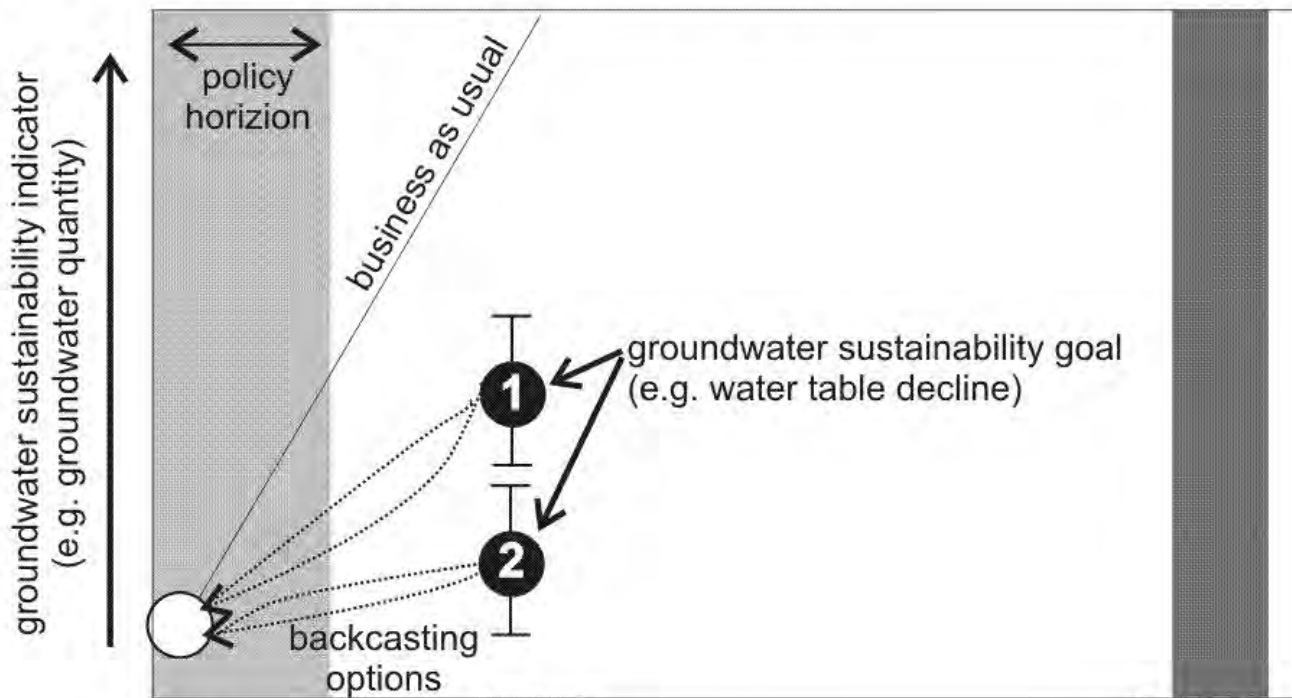


Sustainability tools



Set multi-generational sustainability goals and backcast

Aquifers with long mean residence time (e.g. High Plains)



→ Hydrologic tools can enable groundwater sustainability

Summary

Email me if you are interested in summer or graduate work

Regional Scale

→ lineaments can be barriers to regional groundwater flow

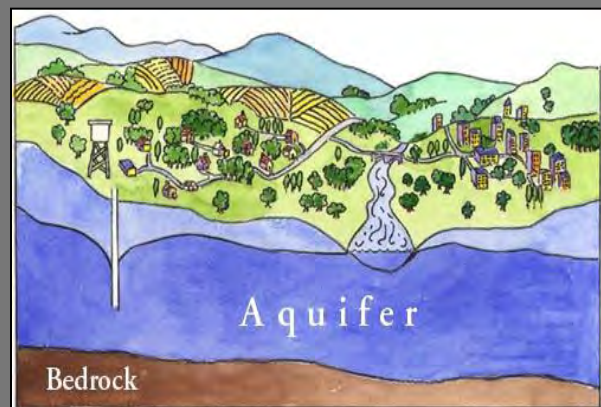
Continental-scale

→ Permeability can be mapped over continents

→ Water table type is contiguous over regions

Multi-generational time scale

→ Hydrologic tools (residence times, numerical modeling) can be integrated with policy framework



Acknowledgements

- Natural Sciences and Engineering Research Council
- Ontario Research and Development Challenge Fund
- Leslie Smith, Roger Beckie, Mark Johnson and the hydrogeology graduate students at UBC
- Kent Novakowski, Kurt Kyser, Bernie Kueper, Rob Harrap, Kerry Klassen, Matt Herod & Richard Zavitz and the hydrogeology grad students at Queen's
- Peter Cook (CSIRO, Australia)
- Andrew Manning, Jonathan Caine and Bill Alley (USGS, Denver and Reston)
- Rob McLaren and Young-Jin Park (University of Waterloo)
- Nick Utting & Ian Clark (University of Ottawa)
- Nils Moosdorf and Jens Hartmann (University of Hamburg, Germany)
- Hans Durr and Rens van Beek (Utrecht University, Netherlands)
- Marios Sophocleous (Kansas Geological Survey)
- Diana Allen (Simon Fraser University)
- Makoto Taniguchi (Research Institute for Nature and Humanity, Japan)
- Yangxiao Zhou (UNESCO-IHE Institute for Water Education, Netherlands)
- Jonathan Vandersteen (University of Guelph)