Groundwater-Dominated Systems

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Why are lake-groundwater interactions important?

In Trout Lake area:
- Lakes cover 12% of surface area
- About half of the lakes have lake surface water connections
- Lakes only contain about 4% of the water in the whole system. Most is held in groundwater.
Groundwater-dominated systems in contrasting hydrogeologic settings

**NTL LTER**
- Thick glacial deposits (~50m)
- Low topographic relief
- \( P > E \) (0.1 m)
- Low-carbonate till

**Boreal Forest, Alberta**
- Thick glacial deposits (20-200m)
- Low topographic relief
- \( P \approx E \) (\( E \) slightly higher than \( P \))
- High carbonate drift
Focus on *Hydroecology*: Links the groundwater flow system with lake ecosystem

What have we learned?

What are our challenges?
What have we learned?

Interactions with groundwater drive spatial patterns within and among lakes.
Spatial Patterns Within Lakes

- Macrophyte beds in areas of groundwater inflow/outflow
  - (Lodge et al. 1989)
- Benthic algal distributions in areas of groundwater inflow
  - (Hagerthey and Kerfoot 1998)
- Spring diatom blooms fed by groundwater inputs
  - (Hurley et al. 1985)
Spatial patterns among lakes: landscape position concept

- Organize lakes along hydrologic flowpath
- Distinguish connections to local (short) and regional flowpaths
- Groundwater is enriched in cations, silica, ANC
- Increasing concentrations in lakes from high to low
Landscape Position and Species Richness
(Hrabik et al. in prep.)
Lakes were sampled within each of these categories, keeping lake area relatively constant, to test whether landscape position (conductivity) or lake isolation (connectivity from surface connections) determined species richness of a range of aquatic organisms. (Hrabik et al. in prep)
Species richness was correlated with conductivity, an indicator of landscape position.

Stream connectivity was of secondary importance.

(Hrabik et al., in prep)
Landscape patterns in the Utikuma Study area in Northern Alberta (Devito et al. in prep)
Spatial Patterns in pond chemistry: Isolines of TP concentration relative to elevation of 118 ponds surveyed in 1998 and 1999 (Devito et al. in prep)
What have we learned?

- Interactions with groundwater drive spatial patterns within and among lakes
- Lake-groundwater interactions are dynamic
Seasonal Variation: Nearshore groundwater mounds at Crystal Lake

- Mounds form when GW flowpaths reverse
- Seasonally transient
- Did not form in dry years
- Can occur in deep flow systems (heavy arrows) but are more usual in shallow flowpaths

(Anderson and Cheng 1993)
Interannual variation in groundwater inputs

- Groundwater inputs vary widely on an interannual basis
- Switch in hydrology from flow-through to mounded during drought
- Temporal context is important

(Wentz et al. 1995)
Consequences of Groundwater Shifts

- Rapid acidification following reversals in groundwater inflow
- Response depends on lake water residence time relative to time of disturbance

(Webster et al. 1990; Webster unpublished data)
Groundwater fluxes in lakes low and high in the flow system

<table>
<thead>
<tr>
<th>Feature</th>
<th>High</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Importance of GW inputs</td>
<td>Less</td>
<td>More</td>
</tr>
<tr>
<td>Dominant flowpaths</td>
<td>Local</td>
<td>Regional</td>
</tr>
<tr>
<td>Transience in GW inputs</td>
<td>More pronounced</td>
<td>Less pronounced</td>
</tr>
</tbody>
</table>

(Cheng and Anderson 1994)
What have we learned?

Interactions with groundwater drive spatial patterns within and among lakes.

Lake-groundwater interactions are dynamic.

Lake-groundwater interactions are complex!
Persistence of lake water plumes

% of Crystal Lake Water based on isotope analysis

Big Muskellunge Lake

Crystal Lake

10% 30% 50% 70% 90%

lake-water-plume flowpath

silt layer

general direction of ground-water flow

3 m 10 m

(USGS WEBB project: Walker and Bullen 2000)
What are our challenges?

- Improve spatial resolution in models of lake-groundwater interactions
Lake-groundwater models

- At basin scale - dynamic models have greatly improved, but are complicated
  - Need detailed field data to constrain models

- Spatial resolution at smaller scales still problematic
What are our challenges?

- Improve spatial resolution in models of lake-groundwater interactions (water flow)
- Integrate hydrologic models with small-scale biogeochemical studies (solute)
Basin-lake scale hydrologic models

Complex biogeochemical reactions at the sediment-water interface

(USGS WEBB project: Walker and Bullen 2000; Schindler and Krabbenhoft 1998)
Variable Source Area Dynamics

Isolated source areas

Expansion of source areas

Further expansion of source areas that results in:
A. flow reversals;
B. hydrologic connections to the lake

What are our challenges?

- Improve spatial resolution in models of lake-groundwater interactions (water flow)
- Integrate hydrologic models with small-scale biogeochemical studies (solutes)
- Link terrestrial, groundwater and lake ecosystem models
Link terrestrial, groundwater and lake ecosystem models

- Existing, discipline-specific models don't link up at present
  - Different spatial and temporal resolution

- Key to understanding --
  - External drivers like (land use or climate change)

- Biogeochemical cycles (like carbon budgets)
What are our challenges?

- Improve spatial resolution in models of lake-groundwater interactions (water flow)
- Integrate hydrologic models with small-scale biogeochemical studies (solute)
- Link terrestrial, groundwater and lake ecosystem models
- Improve understanding of key drivers influencing groundwater dominated systems
Climate: Interactions with groundwater introduce lags in response

ELA:
Lake 239
Negative Relationship

Wisconsin:
Sparkling Lake
No Relationship

(Webster et al. 2000)
Spatial pattern of land use change relative to hydrology

- GW contributing area changes (and can be transient)
- Groundwater contributing areas not correspond to topographic watershed
- Areas near lakeshore are more important - less probability of GW underflow
What is the nature of the stressor?

- In post-audits of groundwater model predictions, the main reason model prediction failed was because the modeler had made faulty guess as to what the future stresses to the system would be.

- Stochastic or non-linear? What are the lags?
Interacting Drivers

- What is the interplay between regional and local drivers?
- What is the cumulative influence of multiple stresses?
Ultimate goal to link fish ecology and groundwater

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