Mapping of Mineralized Groundwater Discharge into Lakes and Rivers

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Ontario Geological Survey
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Aquapath
CANADA ltd
How do we map?

12V Winch

Sled
Instrumentation

In-situ Mapping Parameters-
- pH, conductivity, dissolved oxygen, Eh, temperature, depth, chloride, turbidity

Sled ➔

Hydrolab Datasonde
Why do we map?

- Detect groundwater springs entering lakes and rivers

**Groundwater Emergence Sites**

- **Structural Control**
  - Faults *
  - Joints
  - Igneous contacts (dikes)
  - Stratigraphic boundaries
- **Glaciofluvial Conduits**

- Relate groundwater chemistry to the bedrock and mineralization with which it has been in contact

- Identify geochemical processes, such as precipitation of sulfides from the groundwater upwelling into surface water
Study Area
Ramsey Lake
Sudbury, Ontario
July 2002
Dissolved Oxygen
Sponsored by:
CEM, Laurentian University
Where (and when) do we map?

Epilimnion
Characterized by turbulent flow

Hypolimnion
Characterized by laminar flow

Ramsey Lake, Sudbury, Ontario – July 2002
Working Definitions

- **Oxic** = $\text{DO} \geq 15\%$ saturation
- **Anoxic** = $\text{DO} < 15\%$ saturation  $\text{ORP} > 0 \text{ mV}$
- **Anaerobic** = $\text{DO} < 10\%$ saturation  $\text{ORP} < 0 \text{ mV}$

Redox potential controlled by anaerobic bacteria producing hydrogen sulfide and/or ammonia

Groundwater Characteristics

- Zero % dissolved oxygen
- Higher concentration of TDS than lake / river water (usually)
- Silica concentration $\geq$ quartz saturation
- Higher alkalinity (usually)
Alkalinity (mg/L as CaCO3) and Depth (10ft contours)

Alkalinity (mg/L as CaCO3)
Where (and when) do we map?

Ramsey Lake, Sudbury, Ontario – July & October 2002

July – East Bay

October – East Bay

Depth 28ft

Temperature signature from October groundwater

DO = 90% sat.
Ramsey Lake
Sudbury, Ontario
July 2002
Dissolved Oxygen

Sponsored by:
CEM, Laurentian University
RAMSEY LAKE

Copper (ppb) and Depth (10ft contours)

Copper (ppb)

Degrees North

46.48
46.47
46.46

Degrees West

-80.99
-80.98
-80.97
-80.96
-80.95
-80.94
-80.93
-80.92
-80.91

0 1 2 km

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Temagami Island, Lake Temagami, Ontario

- **Dissolved oxygen (%) saturation**
  - Scale: 0 to 100

- **Zinc**
  - Concentration areas
  - Coordinates: 46.98° N, 750m

- **Copper**
  - Concentration areas
  - Coordinates: 46.98° N, 750m

**Legend:**
- **Middle Precambrian**
  - Nipissing diabase
  - Intrusive Contact

- **Lorrain Formation**
  - Sandstone, conglomerate, greywacke, siltstone

- **Goganda Formation**
  - Mudstone, siltstone, arkose, sandstone, fluvioglacial conglomerate, argillite
  - Unconformity

- **Archean**
  - Granitic Plutonic Rocks
    - Intrusive Contact
  - Int. to Ultramafic Intrusives
    - Diabase, quartz diorite, gabbro
    - Intrusive Contact
  - Detrital Metasediments
    - Volcanic rocks, conglomerate
  - IF = Iron Formation
  - Metavolcanics
  - Felsic to intermediate
  - Mafic to intermediate

Map extracted from Map 2361, OGS, 1976.
Mapping from Chloride Contours

Strike 082°
Dip 4° S
Working Definitions

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- **Anoxic** = DO < 15% saturation ORP > 0 mV
- **Anaerobic** = DO < 10% saturation ORP < 0 mV

Redox potential controlled by anaerobic bacteria producing hydrogen sulfide and/or ammonia

Groundwater Characteristics

- Zero % dissolved oxygen
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- Higher alkalinity (usually)
Distribution of metals under varying Eh conditions

Precipitation of trace metal sulfides such as copper, cadmium & zinc, in some cases depleting soluble levels of these metals below ICP-MS detection limits


<table>
<thead>
<tr>
<th>Eh</th>
<th>n</th>
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<tbody>
<tr>
<td>&lt; -50</td>
<td>14</td>
</tr>
<tr>
<td>-50 - 0</td>
<td>14</td>
</tr>
<tr>
<td>0 - 59</td>
<td>14</td>
</tr>
<tr>
<td>60 - 100</td>
<td>24</td>
</tr>
<tr>
<td>101 - 130</td>
<td>35</td>
</tr>
<tr>
<td>131-150</td>
<td>47</td>
</tr>
<tr>
<td>151-170</td>
<td>52</td>
</tr>
<tr>
<td>&gt; 170</td>
<td>36</td>
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</tbody>
</table>

Precipitation of iron and manganese oxides in oxic environments
Ramsey Lake

Dissolved Oxygen (% saturation) and Depth (10ft contours)
RAMSEY LAKE

Copper (ppb) and Depth (10ft contours)

Copper (ppb)

Degrees North

46.48
46.47
46.46

Degrees West

-80.99 -80.98 -80.97 -80.96 -80.95 -80.94 -80.93 -80.92 -80.91

0 1 2 km

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 AUGUST 2002.
Rates of Groundwater Flow into Lower Circulation Cell

Determinations:
• Volumes of lower & upper circulation cells
• Time since homogenization
• Mean concentration of upper & lower cells
• Mean concentration of incoming groundwater

Calculations:
• Mean lake water concentration at the time of homogenization
  (intermediate between present concentration of upper cell and weighted mean of both cells)
• Mass of constituent required to reach concentration in lower cell
• Litres of groundwater/second to reach this concentration
## Estimation of Groundwater Flow Rate

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Groundwater Flow Rate (L/s)</th>
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<tbody>
<tr>
<td>Nitrate</td>
<td>600</td>
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<tr>
<td>Nickel</td>
<td>580</td>
</tr>
<tr>
<td>Fluorine</td>
<td>480</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>385</td>
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<tr>
<td>TOC</td>
<td>270</td>
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</table>
## Removal of Constituents from the Lower Circulation Cell

<table>
<thead>
<tr>
<th>Constituent</th>
<th>% remaining since homogenization</th>
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</thead>
<tbody>
<tr>
<td>Nitrate</td>
<td>100</td>
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<tr>
<td>Nickel</td>
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</tr>
<tr>
<td>Fluorine</td>
<td>80</td>
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<tr>
<td>Phosphorus</td>
<td>64</td>
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<tr>
<td>Manganese</td>
<td>57</td>
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<tr>
<td>Zinc</td>
<td>49</td>
</tr>
<tr>
<td>TOC</td>
<td>45</td>
</tr>
<tr>
<td>Arsenic</td>
<td>14</td>
</tr>
<tr>
<td>Iron</td>
<td>4</td>
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</tbody>
</table>
Inlet Bay – Lake Temagami

Dissolved Oxygen (% sat.)

Conductivity (mS/cm)

Chloride (mg/L)
Summary

1. Aquapath methodology to prepare contour maps of lake and river bottom water in terms of specific sensor variables, such as dissolved oxygen or TDS

2. Detect, measure and sample sites of groundwater emergence

3. Use groundwater geochemistry to point to source rocks or source material

4. Use structural control or glaciofluvial conduit control to point to source material

5. Within a lake, or isolated lake basin below the thermocline, determine groundwater input flow rates and removal rates for specific constituents / contaminants
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• CEM staff – Laurentian University
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