Isotopes and Geochemistry: Improving our Understanding of Groundwater Resources through Canada’s Oil Sand Innovation Alliance (COSIA)

Jon Fennell, Integrated Sustainability
Jean Birks, InnoTech Alberta
Mike Brewster, COSIA Project Lead
Canada’s Oil Sand Innovation Alliance

Our Vision

To enable responsible and sustainable growth of Canada’s oil sands while delivering accelerated improvement in environmental performance through collaborative action and innovation.
Aspirations

We take pride in what we do and will strive to…

- Produce oil with lower *greenhouse gas* emissions than other sources of oil.
- Be world leaders in *land* management, restoring the land and preserving biodiversity of plants and animals.
- Be world leaders in *water* management, producing Canadian energy with no adverse impact on water.
- Transform *tailings* from waste into a resource that speeds land and water reclamation.
COSIA EPA members will strive to be world leaders in water management, producing Canadian energy with no adverse impact on water.
Outline

- Project Background
- Methods
- Results
  - Sources of water, sources of solutes, ages
- Summary
Project Background
Objective

Compile COSIA and public geochemical and isotope data for Southern Athabasca Oil Sands (SAOS) region and interpret regional dataset to refine knowledge on:

- Evolutionary history and age of groundwater within key aquifers
- Connectivity between key aquifers and surface environment
Challenge

- Variety of conceptual models exist for the regional groundwater evolution and aquifer connectivity.
- Detailed understanding exists on the site scale, but regional interpretation has been constrained by fragmented datasets.
Opportunity

- Geochemical and isotopic tracers provide additional information not available from conventional monitoring.
- COSIA members have comprehensive geochemical datasets that can be combined to improve understanding of regional groundwater flow and aquifer connectivity.
Physical setting

- Approx. 35,000 km$^2$
- Dominated by boreal forest
- Upland areas to west and south; lowlands to north and south
- Wetlands and peat deposits common
Prevailing Conceptual Models

- Topographically-driven recharge in shallow formations (Barson et al. 2002); mixing with deeper formation waters
- Migrating basin fluids in Paleozoic Formations (Grasby and Chen 2005)
- Ancient origin suggested by variable groundwater salinity in Grand Rapids, Clearwater, and McMurray Formations
How does one explain the presence of high salinity water with a glacial water signature discharging at the end of a regional flow system?
Pleistocene glaciation reversed gradient leading to subglacial recharge and infiltration of meteoric water. Removal of ice, reversed gradient, leading to discharge of glacial meltwater that has acquired high salinity. Topography driven basin-scale fluid flux. 

Historical Conceptual Flow Model

After Grasby and Chen, 2005
Methods
This Study: Use variations in geochemistry and isotopes to identify where aquifers may be connected

Regional flow system includes very high salinity in Devonian aquifers with glaciogenic \( \delta^{18}O \) and \( \delta^2H \) signatures (Grasby and Chen, 2005)

Topographically-driven recharge in shallow formations (Barson et al. 2002)

McMurray Formation saline where Prairie Evaporite has been dissolved (Cowie et al., 2016)
Geochemical Tracer Toolkit

<table>
<thead>
<tr>
<th>Questions Answered:</th>
<th>Useful Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of water and solutes</td>
<td>• $^{14}$C (~&lt; 40,000 years),</td>
</tr>
<tr>
<td></td>
<td>• $^{3}$H (post-1950 recharge),</td>
</tr>
<tr>
<td></td>
<td>• $^{36}$Cl, $^{129}$I</td>
</tr>
<tr>
<td>Indicators of the sources of water, GW/SW</td>
<td>• $\delta^{18}$O, $\delta^{2}$H</td>
</tr>
<tr>
<td>Indicators of sources of salinity, geochemical processes</td>
<td>• Major ion chemistry, TDS (calculated and gravimetric), Routine parameters,</td>
</tr>
<tr>
<td></td>
<td>• Metals and trace elements,</td>
</tr>
<tr>
<td></td>
<td>• Selected ion ratios (e.g. Cl:Br, Cl:SO$_4$)</td>
</tr>
<tr>
<td></td>
<td>• $\delta^{13}$C$_{DIC}$, $\delta^{34}$SO$<em>4$, $\delta^{18}$O$</em>{SO_4}$, $^{87}$Sr/$^{86}$Sr, $\delta^{81}$Br, $\delta^{37}$Cl, $\delta^{11}$B</td>
</tr>
<tr>
<td>Indicators of sources of organics</td>
<td>$\delta^{13}$C$_{DOC}$</td>
</tr>
</tbody>
</table>
Data Sources: COSIA + Public

Groundwater Geochemistry Data

Groundwater Isotope Data

- Greater density of geochemistry data (surficial aquifers)
- SAOS isotope dataset is extensive
Grand Rapids Subdivision

- Grand Rapids Formation is the key aquifer in the region
- Subdivided based on geology

Colorado Group: fully present
Grand Rapids Subdivision

- Grand Rapids Formation is the key aquifer in the region
- Subdivided based on geology

- Colorado Group: partially eroded
Grand Rapids Subdivision

- Grand Rapids Formation is the key aquifer in the region
- Subdivided based on geology

- Colorado Group: incised
Grand Rapids Subdivision

- Grand Rapids Formation is the key aquifer in the region
- Subdivided based on geology

Colorado Group: absent or nearly absent
Results
Sources of Water: $\delta^{18}$O and $\delta^{2}$H

- Recent precipitation ($\text{Edm.}$) -19‰
- Devonian Brines -10 to +10 ‰ (Simpson, 1999; Connolly, 1990)
- Cretaceous Paleo-waters (Lemay, 2002)
- Glaciogenic <-22 ‰
Sources of Water: $\delta^{18}O$ and $\delta^2H$

- Mixing with glaciogenic water
- Mixing with paleo-water
- Mixing with evaporated paleo-water

Legend:
- Surficial Deposits
- Buried Channel
- Colorado Group
- Grand Rapids
- Clearwater
- McMurray
- Devonian

- Grand Rapids
  - CG absent
  - CG incised
  - CG partially eroded
  - CG fully present

Surficial Deposits
Buried Channel
Colorado Group
Grand Rapids
Clearwater
McMurray
Devonian

CG absent
CG incised
CG partially eroded
CG fully present
Sources of Water: $\delta^{18}O$

- More negative $\delta^{18}O$ values adjacent to Christina River
- Isolated areas of more positive $\delta^{18}O$ values in south and southwest
Sources of Water – Total Dissolved Solids (TDS)

Two main mixing trends identified for high TDS water:

- Mixing with glaciogenic waters
- Mixing with paleo-waters water
Sources of Solutes

- Hydrochemical typology = information regarding groundwater evolution and distribution

- HCO$_3$ type waters dominate

- Na-Cl type waters dominate

- Isolated Na-Cl waters

- Shallow groundwater

- Na-Cl type waters dominate

- Shallow groundwater

- Shallow groundwater

- Shallow groundwater
Sources of Solutes

Mineralization provides information regarding residence time (i.e., degree of water:rock interaction)

- TDS (mg/L)
  - <500
  - 501 to 3000
  - 3001 to 5000
  - 5001 to 10000
  - 10001 to 20000
  - 20001 to 40000
  - 40001 to 100000
  - >100000

- Low TDS waters dominate
- Isolated high TDS wells
- TDS increases
- Pockets of higher TDS water
- Variable TDS, Dissolution scarp
- TDS increases
- Pockets of higher TDS water
Groundwater Ages

- Older ages near limit of $^{14}$C dating
- Areas of geologically younger (<20,000 years BP) water adjacent older water noted (>30,000 years BP)

Modelled $^{14}$C Age

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>25001-30000</th>
<th>30001-35000</th>
<th>35001-40000</th>
<th>40001-45000</th>
<th>&gt;45000</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10001-15000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15001-20000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20001-25000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Younger modeled ages

Oldest water? Or dead carbon?
Summary
The geochemical and isotopic data identified three main mixing patterns:

- Mixing with shallow aquifers
- Mixing with glaciogenic water
- Mixing with paleo-waters

**Salinity**

**Charateristics:**
- Low TDS, HCO$_3$ type water, young ages

**Interpretation:**
- Connectivity to local shallow flow system

**Characteristics:**
- Glaciogenic $\delta^{18}$O and $\delta^2$H

**Interpretation:**
- Areas at end of regional flow system where discharge of glacial meltwater, vertical connectivity

**Characteristics:**
- High TDS, enriched $\delta^{18}$O and $\delta^2$H

**Interpretation:**
- Areas of limited aquifer connectivity.
- Thick Colorado cover? Hydraulic isolation?
Conclusions

Areas of mixing with shallow aquifers during geological history:
- Lack of Colorado Group cover and proximity to incised buried channels and rivers

Areas of mixing with deep aquifers during geological history:
- Lack of Colorado Group cover and proximity to incised buried channels and rivers
- Vertical connectivity features such as dissolution scarp
Conclusions

Areas of limited aquifer connectivity (sparse data) during geological history could be related to:

– Thick Colorado Group Cover

– Local groundwater flow fields (e.g. stagnation zones, identified by high TDS and less negative $\delta^{18}O$ and $\delta^2H$ values)

– Has implications for potential waste disposal beyond existing McMurray Formation and more difficult to find Devonian intervals
Benefits

- Holistic approach providing enhanced understanding of conceptual models of groundwater flow in the SAOS.

- Novel use of geochemical and isotopic tracers to identify sources of salinity and presence of more connected, or isolated, areas of major bedrock aquifers in the SAOS.
Benefits

- Collaboration through COSIA allowed compilation of an unprecedented large regional groundwater isotope dataset that otherwise would not have been realized.

- The interpretation of this data set provides a foundational piece for the development of a world class regional groundwater monitoring program.
Thank you

Jon Fennell, Integrated Sustainability

Jean Birks, InnoTech Alberta

Mike Brewster, COSIA Project Lead, Devon Canada