Hydrogeologic assessment in support of the development of the Peace River Oil Sands

a case study concerning a pilot-scale in-situ SAGD operation

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Objective

• Create a preliminary hydrogeological characterization in an area where there is limited hydrogeological data

• Use this characterization to identify potential source and disposal aquifers to test for SAGD development
Make-up dependent on RR, process efficiency, upgrading, ZLD, etc…

SAGD produces wastewater ≈ make-up water demand

Need to test and secure aquifers
Criteria for Selecting Aquifers to Test

- **Salinity**
  - Disposal (>4,000 mg/L Total Dissolved Solids)
  - Source (4,000 mg/L < TDS < 10,000 mg/L)

- **Productivity**
  - Aquifer extent/thickness
  - Aquifer permeability
  - Acceptable pressure change

- **Responsible Use**
  - Conflicts with other groundwater users
  - Potential environmental impacts
Athabasca Oil Sands (SAGD Alley)

- 13 SAGD projects
  - 800,000 bpd bitumen
  - 70,000 m³/d water
- >900 chemistry samples
- >16,500 industry wells
- >60 pumping tests
- >1,650 DSTs
- EIAs and regional reports

Map showing Athabasca River and Fort McMurray with marked SAGD projects and industry wells.
Peace River Oil Sands

- 143 industry wells
- 68 not cased
- 2 DSTs
- 3 chemistry samples
- 8 core
- 0 pumping tests
- 0 SAGD operators
- Regional geology reports

Hydrogeology Assessment Focus

50 km
The Issue

- Drilling and testing deep aquifers is expensive!

- How do we identify these target aquifers with limited data?
Petrophysical Type Log Bluesky Aquifer

Gamma (API) Porosity (%) Resistivity (ohm-m)

<table>
<thead>
<tr>
<th>Material</th>
<th>Gamma</th>
<th>Porosity (%)</th>
<th>Resistivity (ohm-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>63330</td>
<td>30</td>
<td>80</td>
</tr>
<tr>
<td>Bitumen</td>
<td>1500</td>
<td>100</td>
<td>1000</td>
</tr>
<tr>
<td>Water</td>
<td>45</td>
<td>-15</td>
<td>1</td>
</tr>
</tbody>
</table>

Bluesky Aquifer (~17m)
Petrophysical Type Log
Paddy/Cadotte Aquifer

Gamma (API)  Porosity (%)  Resistivity (ohm-m)

sand  water

Gas

Paddy/Cadotte Aquifer (~27 m)
Aquifer Salinity Methodology

- Only 3 chemistry samples (Bluesky)
- 68 uncased well logs with deep resistivity measurements
- These resistivity measurements can provide estimate of salinity

**Equation 1 - calculate resistivity of the brine (Archie, 1959)**

\[ R_t = a \phi^{-m} S_w^{-n} R_w \]

Where:
- \( \phi \): Porosity
- \( R_t \): Resistivity of the fluid saturated rock (deep resistivity from logs)
- \( R_w \): Resistivity of the brine (Aquifer)
- \( S_w \): Brine saturation (1)
- \( m \): Cementation exponent of the rock (usually in the range 1.8–2.0)
- \( n \): Saturation exponent (usually close to 2)
- \( a \): Constant (1)

**Equation 2 - calculate TDS (Rakhit, 1997)**

\[ R_w = TDS^{-0.854387} \times 4.51686 \]
Aquifer Salinity Estimate
Will Productivity be Sufficient?

• Productivity is constrained by 3 parameters
  - Aquifer extent/thickness
  - Aquifer permeability
  - Acceptable pressure change
Aquifer Productivity Methodology

• Aquifer extent/thickness
  ➢ Map aquifers using 143 well logs

• Aquifer permeability
  ➢ No pumping tests, therefore, estimate permeability of both aquifers referencing 8 Bluesky cores analysis

• Acceptable pressure change
  ➢ Only 2 Bluesky DSTs to estimate aquifer pressure in both aquifers
Bluesky Aquifer Isopach (mapping results)
Paddy/Cadotte Aquifer Isopach (mapping Results)
Aquifer Permeability Estimate

- **Bluesky**
  - Core analysis (4 to 10 D)
  - Gamma <45 API, Porosity >30%
  - Very clean sand

- **Paddy/Cadotte**
  - Gamma <45 API, Porosity >30%
  - Very clean sand
  - Assumption – Paddy/Cadotte ≈ Bluesky

- **Best Guess**
  - Bluesky 5D and Paddy/Cadotte 2D
  - Conservative 1D (used for calculations)
Available Head Estimate

Conservative estimate for available head is 100 m and 200 m for the Paddy/Cadotte and Bluesky aquifers, respectively.
Paddy/Cadotte Aquifer Productivity

• Given;
  - Aquifer thickness \((b)\) \(\approx 25\) m
  - Hydraulic conductivity \((K)\) \(\approx 1 \times 10^{-5}\) m/s (1D)
  - Available Head \((AH)\) \(\approx 100\) m

[Equation 3 – calculate yield of well Farvolden (1959) Method]

\[
Q_{20} = (0.68)(Kb)(AH)(0.7)
\]

\(Q_{20} \approx 1,000\) m\(^3\)/day
Bluesky Aquifer Productivity

- We know the Bluesky Aquifer is permeable
- Acceptable pressure change is constrained by fracture pressure
- ERCB Directive 051 suggests a pressure head build-up of 800 m (8,000 kPa) is acceptable in this aquifer
Responsible Use of Aquifers?

- Both aquifers are deep and saline
- Very thick aquitards mitigate vertical pressure propagation
- No other users of aquifers in area (no conflicts)
- Using Theis (1935) we can estimate drawdown at Paddy/Cadotte subcrop

\[
dd = \frac{Q}{4\pi Kb} W(u)
\]

Where:
- \(dd\): drawdown (m)
- \(Q\): pumping rate (1,000 m\(^3\)/day)
- \(W\): well function
- \(W(u)\): well function
- \(b\): aquifer thickness (25 m)
- \(r\): radius (40 km)
- \(Q\): pumping rate (1,000 m\(^3\)/day)
- \(Ss\): specific storage (1x10\(^{-6}\) m\(^{-1}\))
- \(K\): conductivity (0.9 m/day)
- \(t\): time (5 years)

- Negligible (<1 mm) drawdown at Paddy/Cadotte Aquifer subcrop
Conclusion

Absence of traditional hydrogeological data

Industry data
- Petrophysical logs
- Core samples
- Drill stem tests

Conceptual understanding of hydrogeological system

Recommendation for SAGD project
- Testing the Bluesky as a wastewater disposal aquifer
- Testing the Paddy/Cadotte as a source aquifer