Water concerns in hydraulic fracturing in western Alberta

Daniel S. Alessi
Assistant Professor and Encana Chair in Water Resources

Hydraulic fracturing

- Process – Inject water and chemicals (fracturing fluid) with a proppant (sand, ceramics) to fracture formation rock and release tightly-held oil and gas
- Opens up oil and gas deposits not previously accessible using conventional oil and gas wells
- Modern hydraulic fracturing, is the combination of horizontal drilling with hydraulic fracturing. These two technologies have existed independently for many decades.

Reserves in and near Alberta

- Primary fields include Duvernay and Montney in AB, and the Horn River in BC
- >9000 wells in AB
- Tens of thousands of m³ of freshwater per well, on average
Fluids involved in hydraulic fracturing

• Fracturing fluid – a mixture of water (typically fresh surface water in AB) with hundreds of organic chemicals (to improve well performance) that is injected into the subsurface to fracture the formation
• Flowback water – a mixture of the fracturing fluid, deep saline brines and potential reactions between these fluids and the formation rocks
• Produced waters – later fraction of waters that return up the well, that typically represent the chemistry of the deep saline brine

Report to Canadian Water Network

Plays: Marcellus (NE US), Barnett (TX), Duvernay (AB), Montney (BC, AB)

1. Regulatory and policy regimes across jurisdictions (Allen, SFU)
2. Stakeholder concerns, public perception, and social license to operate (Gehman, U Alberta)
3. Wastewater handling, treatment, and reuse (Alessi, U Alberta)

1. Regulatory framework

• Wastewater disposal rules:
  – Only in deep injection wells in Canada
  – Beneficial reuse allowed in the United States (road de-icing and dust control, formerly treatment and discharge)
• Canada lacks more stringent injection well regulations of United States (EPA – UIC Injection Program, 2013):
  – Hydroconnectivity
  – Micro-seismicity
  – Monitoring within a 2-mile radius for contamination and seismicity
• No consistent regulatory framework on hydraulic fracturing-induced seismicity
2. Stakeholder concerns

<table>
<thead>
<tr>
<th>State/Province</th>
<th>General concerns (health, contamination, chemical, water)</th>
<th>Wastewater concerns (wastewater, flowback water, produced water)</th>
<th>Political concerns (tax, moratorium)</th>
</tr>
</thead>
<tbody>
<tr>
<td>New York</td>
<td>155</td>
<td>185</td>
<td>436</td>
</tr>
<tr>
<td>Ohio</td>
<td>19</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>2745</td>
<td>409</td>
<td>496</td>
</tr>
<tr>
<td>West Virginia</td>
<td>558</td>
<td>58</td>
<td>126</td>
</tr>
<tr>
<td>Texas</td>
<td>100</td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Alberta</td>
<td>858</td>
<td>29</td>
<td>177</td>
</tr>
<tr>
<td>British Columbia</td>
<td>892</td>
<td>56</td>
<td>177</td>
</tr>
</tbody>
</table>

Conducted a survey of keyword frequencies in major newspapers in PA, NY, WV, OH, TX, AB, and BC from 2008 – 2014.

Gehman et al., 2016, Sustainability

3. Wastewater handling, treatment, and reuse

- **Research approach:** use oil and gas databases (GeoScout, AccuMap, FracFocus) and, insofar as possible, cross-reference data to identify information gaps
- **Pilot regions:** Duvernay Formation (Alberta), Montney Formation (Alberta, BC)
Location and **water use** of hydraulic fracturing (Nov 2011 – Mar 2014)

4078 wells in Alberta
837 wells in British Columbia

25+ Olympic swimming pools of water

**Volumes of water in m³**


---

Information we can extract from databases

- **Number of wells**
- **Number of fracturing stages per well**
- **Cumulative injected water (10⁶ m³)**


---

Database search gaps to address

- No guarantee any one database is complete
- Wastewater disposal data not readily available in databases used (may require further sources such as provincial / state databases)
- Source of water not well-known (difficult to differentiate between fresh, saline, and recycled water)
- Holistic overview of trends in wastewater geochemistry would be difficult at best:
  - Partial organic chemistry of fracturing fluids in FracFocus
  - In some cases detailed inorganic chemistry of flowback and produced waters in AccuMap, but many heterogeneities (type of frac, sampling times, shut ins, ...)
Flowback and produced water concerns

- Complex:
  - Inorganics (200,000 ppm+ salinity)
  - Organics
  - Microorganisms
  - Suspended solids
  - Toxicity (sources?, mechanisms?)

- Biofouling of wells and produced fluids (surface versus deep biota)

- Overall, current state of chemical and microbiological characterization for flowback water is underdeveloped
Access to fluids from partner Encana

Agilent 8800 ICP-MS/MS

- Advantages
  - High TDS front end means flowback brines require less dilution
  - Extra quadrupole in front of reaction cell, key for eliminating interferences in complex fluids

Inorganic analyses

<table>
<thead>
<tr>
<th>Element</th>
<th>Isotope</th>
<th>Method</th>
<th>Mean Concentration (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
<td>C</td>
<td>ICP-QQQ</td>
<td>136,000</td>
</tr>
<tr>
<td>Na</td>
<td>23</td>
<td>ICP-QQQ</td>
<td>70,000</td>
</tr>
<tr>
<td>Ca</td>
<td>44</td>
<td>ICP-QQQ</td>
<td>13,800</td>
</tr>
<tr>
<td>K</td>
<td>39</td>
<td>ICP-QQQ</td>
<td>2,570</td>
</tr>
<tr>
<td>Sr</td>
<td>88</td>
<td>ICP-QQQ</td>
<td>1,470</td>
</tr>
<tr>
<td>Mg</td>
<td>24, 25</td>
<td>ICP-QQQ</td>
<td>1,110</td>
</tr>
<tr>
<td>Total N</td>
<td></td>
<td>TN</td>
<td>498</td>
</tr>
<tr>
<td>Br</td>
<td>79</td>
<td>C and ICP-DQQ</td>
<td>276</td>
</tr>
<tr>
<td>TOC</td>
<td></td>
<td>TOC/BN</td>
<td>211</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>ICP-QQQ</td>
<td>73.6</td>
</tr>
<tr>
<td>U</td>
<td>7</td>
<td>ICP-QQQ</td>
<td>54.6</td>
</tr>
<tr>
<td>Fe</td>
<td>56</td>
<td>ICP-QQQ</td>
<td>43.1</td>
</tr>
<tr>
<td>SO4</td>
<td></td>
<td>IC</td>
<td>8.1</td>
</tr>
<tr>
<td>Zn</td>
<td>64, 65, 68</td>
<td>ICP-QQQ</td>
<td>4.4</td>
</tr>
<tr>
<td>As</td>
<td>75</td>
<td>ICP-QQQ</td>
<td>&lt; 0.004</td>
</tr>
<tr>
<td>P2O5</td>
<td>206, 207, 208</td>
<td>ICP-QQQ</td>
<td>0.05</td>
</tr>
</tbody>
</table>

- 242,600 mg/L total dissolved solids (TDS).
- 93% of TDS has been accounted for.
- Solution charge balance within 0.3%. 
Untargeted Organics Analyses

- Separate a broad range of organic compounds
  - Orbitrap: ESI, positive mode, 5 kV, 350°C, RP = 120,000
- Use software to look for similarities/differences among samples
- Follow-up by characterizing unknown peaks

Orbitrap MS fingerprint

Polycyclic Aromatic Compounds (GC-MS)

Canadian Council of Ministers of the Environment (CCME) guidelines for protection of aquatic life:
- 15 ng/L BAP
- 3000 ng/L Fluorene
Aquatic species toxicity assays

- **Zebrafish** breeding
  - Fertilized embryo collection

- Exposure to fluids
  - Morphological changes
  - LC_{50} calculation
  - Ethoxyresorufin-O-deethylase (EROD) activity measurement (PAH response)

Morphological observations on zebrafish larvae

Exposed to 2.5% solution of flowback fluid for 72 h

- Malformed spine
- Pericardial edema
- Aggregated material on body surface

Suspended solids fraction increases toxicity

- **Mortality of Zebrafish Embryo Exposed to HFFWs (0 to 90 hpf)**

<table>
<thead>
<tr>
<th>Dilutions of HFFWs (%)</th>
<th>HFFW-SF</th>
<th>HFFW-SF</th>
<th>LC_{50} (HFFW-SF) = 0.9%</th>
<th>LC_{50} (HFFW-S) = 0.5%</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Flowback solids characterization

- Orange colour – rust appearance
- Contains high concentrations of iron and silicon

He et al., in revision, Water Research

Electron microscopy

Solids toxicity pathway

Fe(II) → Fe(III)
SiO₂(aq) → SiO₂(s)
Solution cooling
Si-doped Ferrihydrite (small particles)

O₂ oxidation

PAHs sorption

Particle sorption and delivery to organism (shift in PZC of Si-Fh)
Toxicity vector in waterways?
Filtration / removal a treatment technology?
Ongoing goals

• Ascertain role of flowback sediments in heavy metals transport and potential aquatic toxicity
• Better understand the role of microbes in the hydraulic fracturing water cycle
• Build up a temporal and spatial database of hydraulic fracturing flowback chemistry, toxicity and microbiology (next 3-4 years)
• Engage with stakeholders to both discuss our findings and learn about emerging concerns (stay tuned for on-campus University of Alberta fracturing forum in 2018)
• Continue to publish our findings in peer-reviewed scientific journals
Funding acknowledgements

Fracturing fluid components

Called "proppant"; can be sand or ceramic beads; used to hold open fractures so that gas can migrate from formation to the surface

EROD induction (exposure to PAH) is greater in sediment-containing fluid

Control

Sample with sediment

He et al., in revision, Water Research