Water concerns in hydraulic fracturing in western Alberta

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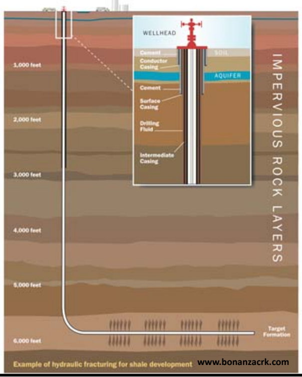
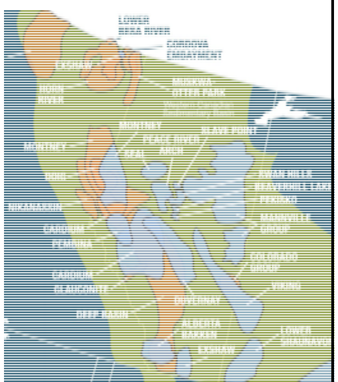
Hydraulic fracturing

- 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 m^3 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

TABLE 4—TOTAL COST OF ONE WELL IN MONTNEY SHALE USING ONLY FRESH WATER

	$/bbl	Volume, bbl	Total Cost, $
Trucking + fresh water cost	3.35	339,606	1,137,680
Flowback disposal cost	8.00	169,803	1,358,424
Cost to recycle/ reuse flowback + transfers	2.75	0	0
Total cost/well			2,496,104

Source: Paktinat et al 2011.

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)

CWN Report
Goss et al., 2015

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WATER INITIATIVE

UNCONVENTIONAL WASTEWATER MANAGEMENT: A COMPARATIVE REVIEW AND ANALYSIS OF HYDRAULIC FRACTURING WASTEWATER MANAGEMENT PRACTICES ACROSS FOUR NORTH AMERICAN BASINS

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

Fox Creek, AB, January 22, 2015
Magnitude 4.4

Fort St. John, BC, August 17, 2015
Magnitude 4.6

Canada May Have Just Set A Fracking Earthquake World Record

cbc.ca

Notte et al., 2017, Can. Water Resour. J.

2. Stakeholder concerns

State/Province	General concerns (health, contaminate, chemical, waste)	Wastewater concerns (wastewater, flowback water, produced water)	Political concerns (ban, moratorium)
New York	1253	143	436
Ohio	89	32	32
Pennsylvania	2745	489	698
West Virginia	538	58	128
Texas	100	21	21
Alberta	858	29	177
British Columbia	892	56	177

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

Concern versus accountability

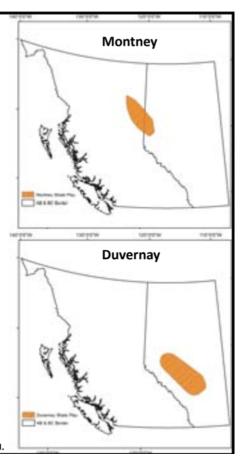
Region	Total concern mentions	Total accountability mentions	Concern to accountability ratio
New York	1278	12	107
Ohio	88	3	29
Pennsylvania	2822	30	94
West Virginia	496	10	50
Texas	94	2	47
Alberta	692	126	5
British Columbia	715	112	6

Accountability terms: *social license, sustainability, corporate responsibility, corporate social responsibility, sustainable development, cumulative effects stakeholder management*

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)



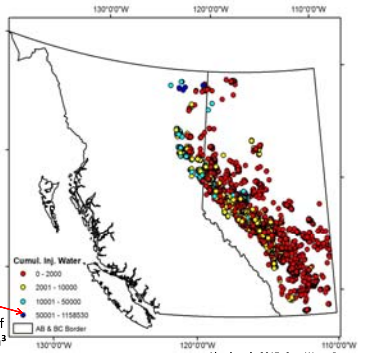
Alessi et al., 2017, Can. Water Resour. J.

Location and **water use** of hydraulic fracturing (Nov 2011 – Mar 2014)

4078 wells in Alberta
837 wells in British Columbia

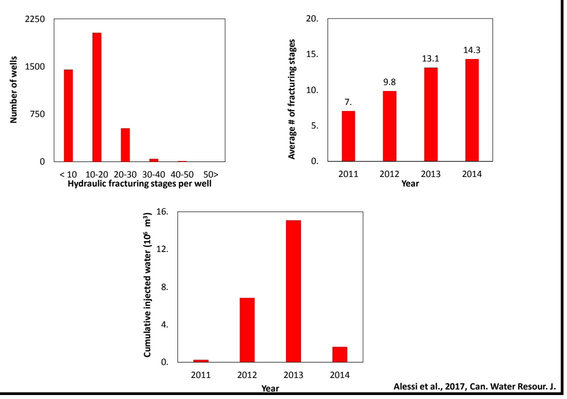
25+ Olympic swimming pools of water

Volumes of water in **m³**



Alessi et al., 2017, Can. Water Resour. J.

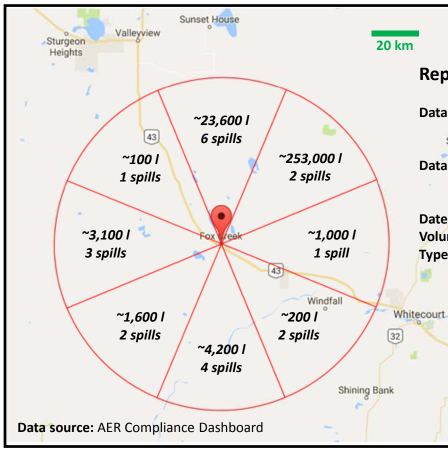
Information we can extract from databases



Alessi et al., 2017, Can. Water Resour. J.

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, …)



Reported Fluid Spills

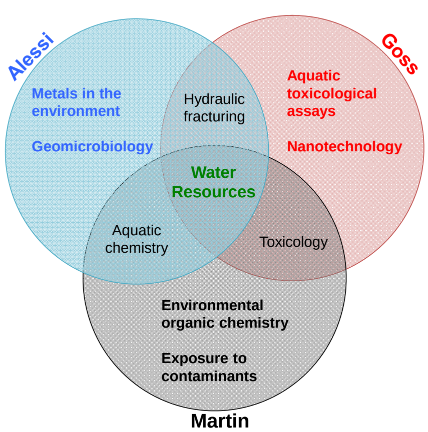
Data source:
AB Energy Regulator Compliance Dashboard
Data used:
Only spills referenced to Fox Creek, AB
Dates: July 2014 – present
Volume: ~286,000 liters
Types of releases reported:
Emulsion
Produced water
Crude oil
Hydraulic fluid
Methanol
Condensate
Oily sludge

Data source: AER Compliance Dashboard

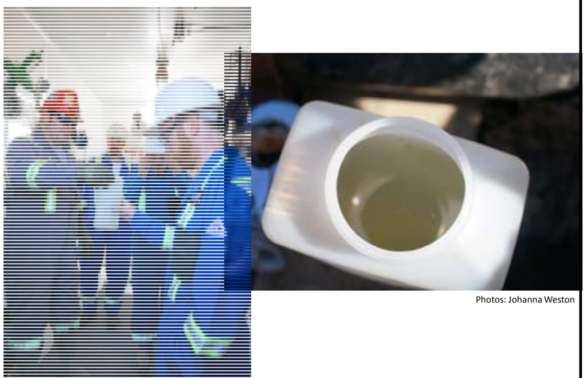
Flowback and produced water concerns

- 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**


Day 7 flowback, Duvernay Fm., AB



Access to fluids from partner Encana



Photos: Johanna Weston

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

Photos: Agilent Technologies

Inorganic analyses

Element	Isotope	Method	Mean Concentration (mg/L)
Cl		IC	136,000
Na	23	ICP-QQQ	70,000
Ca	44	ICP-QQQ	11,800
K	39	ICP-QQQ	2,570
Sr	88	ICP-QQQ	1,470
Mg	24, 25	ICP-QQQ	1,110
Total N		TOC/TN	498
Br	79	IC and ICP-QQQ	276
TOC		TOC/TN	211
B	10	ICP-QQQ	71.6
Li	7	ICP-QQQ	54.6
Fe	56	ICP-QQQ	43.1
SO4		IC	4.81
Zn	64, 66, 68	ICP-QQQ	4.4
As	75	ICP-QQQ	< 0.004
Pb	206, 207, 208	ICP-QQQ	0.05

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

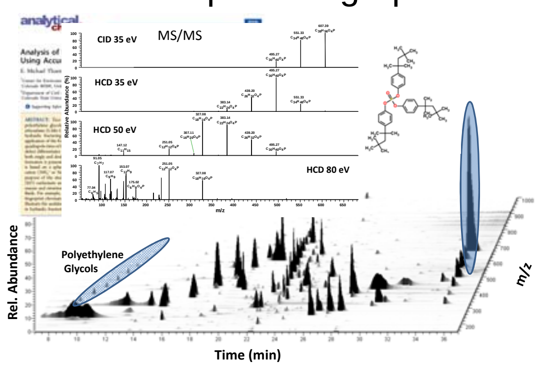
Untargeted Organics Analyses

HPLC-Orbitrap Elite

Photo: Dr. Alberto Pereira, U. Alberta

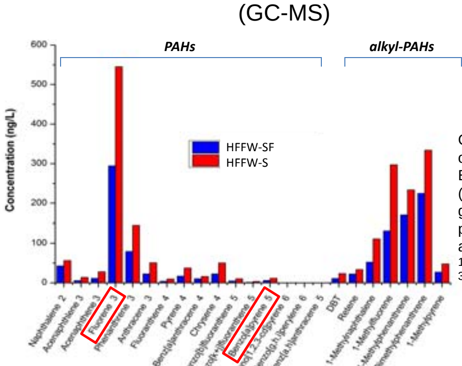
- Separate a broad range of organic compounds
  - Orbitrap: ESI, positive mode, 5 kV, 350°C, RP = 120,000
- Use software to look for similarities/differences among samples
- Follow-up by characterizing unknown peaks

Orbitrap MS fingerprint



He et al., in revision, Water Research

Polycyclic Aromatic Compounds
(GC-MS)



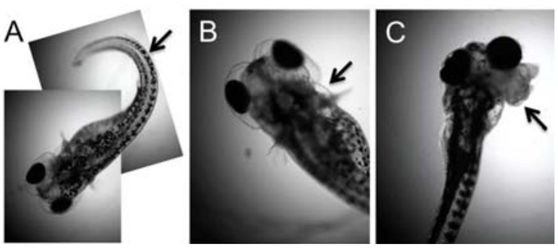
Canadian Council of Ministers of the Environment (CCME) guidelines for protection of aquatic life:
15 ng/L *BAP*
3000 ng/L *Fluorene*

He et al., in revision, Water Research

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

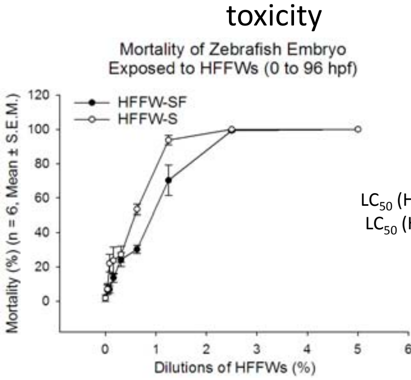


Malformed spine | **Pericardial edema** | **Aggregated material on body surface**

Exposed to 2.5% solution of flowback fluid for 72 h

He et al., in revision, Water Research

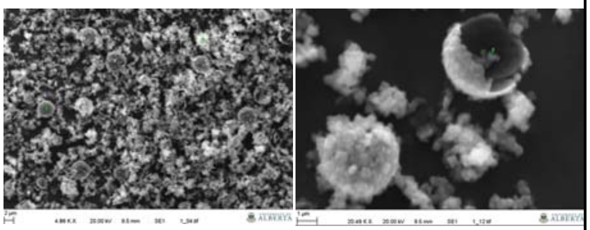
Suspended solids fraction increases toxicity



LC_{50} (HFFW-SF) = 0.9%
LC_{50} (HFFW-S) = 0.5%

He et al., in revision, Water Research

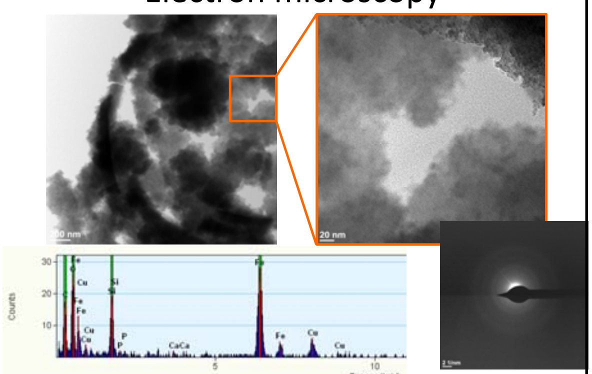
Flowback solids characterization



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

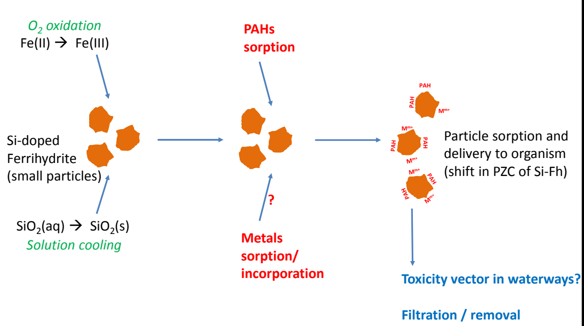
He et al., in revision, Water Research

Electron microscopy



Flynn et al., in preparation

Solids toxicity pathway



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


Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 2016
http://dx.doi.org/10.1080/07011784.2016.1238782

Comparative analysis of hydraulic fracturing wastewater practices in unconventional shale development: Water sourcing, treatment and disposal practices

Daniel S. Alessi, Ashkan Zolfaghari, Stefanie Kletke, Joel Gehman, Diana M. Allen and Greg G. Goss

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Environmental Science & Technology

Effects on Biotransformation, Oxidative Stress, and Endocrine Disruption in Rainbow Trout (*Oncorhynchus mykiss*) Exposed to Hydraulic Fracturing Flowback and Produced Water

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sustainability

Article

Comparative Analysis of Hydraulic Fracturing Wastewater Practices in Unconventional Shale Development: Newspaper Coverage of Stakeholder Concerns and Social License to Operate

Joel Gehman, Dara Y. Thompson, Daniel S. Alessi, Diana M. Allen and Greg G. Goss

Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 2016
http://dx.doi.org/10.1080/07011784.2016.1218795

Comparative analysis of hydraulic fracturing wastewater practices in unconventional shale developments: Regulatory regimes

Chelsea Notte, Diana M. Allen, Joel Gehman, Daniel S. Alessi and Greg G. Goss

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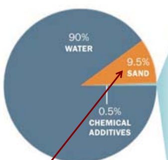
Fracturing fluid components

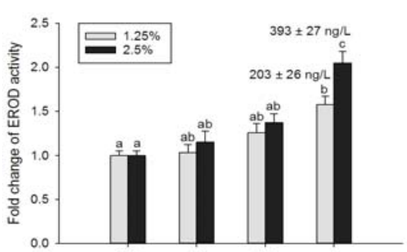


Called "proppant"; can be sand or ceramic beads; used to hold open fractures so that gas can migrate from formation to the surface

Compound	Purpose	Common application
Acids	Helps dissolve minerals and initiate fissure in rock (pre-fracture)	Swimming pool cleaner
Sodium Chloride	Allows a delayed breakdown of the gel polymer chains	Table salt
Polyacrylamide	Minimizes the friction between fluid and pipe	Water treatment, soil conditioner
Ethylene Glycol	Prevents scale deposits in the pipe	Automotive anti-freeze, deicing agent, household cleaners
Borate Salts	Maintains fluid viscosity as temperature increases	Laundry detergent, hand soap, cosmetics
Sodium/Potassium Carbonate	Maintains effectiveness of other components, such as crosslinkers	Washing soda, detergent, soap, water softener, glass, ceramics
Glutaraldehyde	Eliminates bacteria in the water	Disinfectant, sterilization of medical and dental equipment
Guar Gum	Thickens the water to suspend the sand	Thickener in cosmetics, baked goods, ice cream, toothpaste, sauces
Citric Acid	Prevents precipitation of metal oxides	Food additive; food and beverages; lemon juice
Isopropanol	Used to increase the viscosity of the fracture fluid	Glass cleaner, antiperspirant, hair coloring

Source: DOE, GWPC: Modern Gas Shale Development in the United States: A Primer (2009).

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



Salinity

Salinity + Organics

Salinity + Organics + Sediment

Control

Sample with sediment

He et al., in revision, Water Research