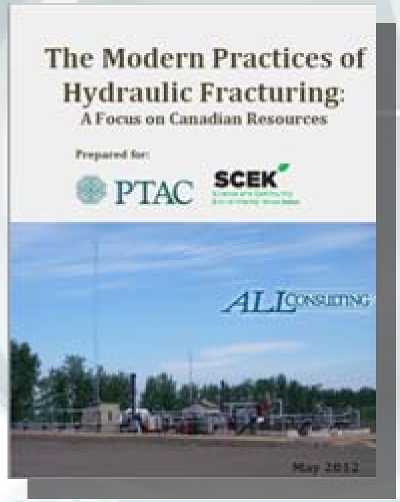
THE MODERN PRACTICE OF HYDRAULIC FRACTURING FOR CANADIAN RESOURCES



The Modern Practices of Hydraulic Fracturing:
A Focus on Canadian Resources

Prepared for:

PTAC SCEK

ALL CONSULTING

May 2012

Prepared by
ALL Consulting

Presented at
Interstate Oil & Gas Compact Commission
October 28-31, 2012

ALL CONSULTING

Agenda

- Introduction
- Research Overview
- Hydraulic Fracturing
- North American Shale Geology
- Fluid Composition
- Best Management Practices
- Hydraulic Fracturing Regulation (Canada)
- Major Pathways of Fluid Migration
- Alleged Past Incident Analysis
- Summary

PROJECT PREMISE

- Tremendous natural gas resource potential has been identified in shale basins in Canada.
- Hydraulic fracturing of shale formations in combination with horizontal wellbore drilling over the last decade has raised questions about potential environmental and human health risks.
- This project assesses potential risks <u>during the process of injection</u>, quantifies those risks where possible, and identifies practices that could be used to minimize the risks.
- The research was performed by ALL Consulting while funded and managed by the Petroleum Technical Alliance Canada (PTAC) and Science and Community Environmental Knowledge (SCEK) Fund.

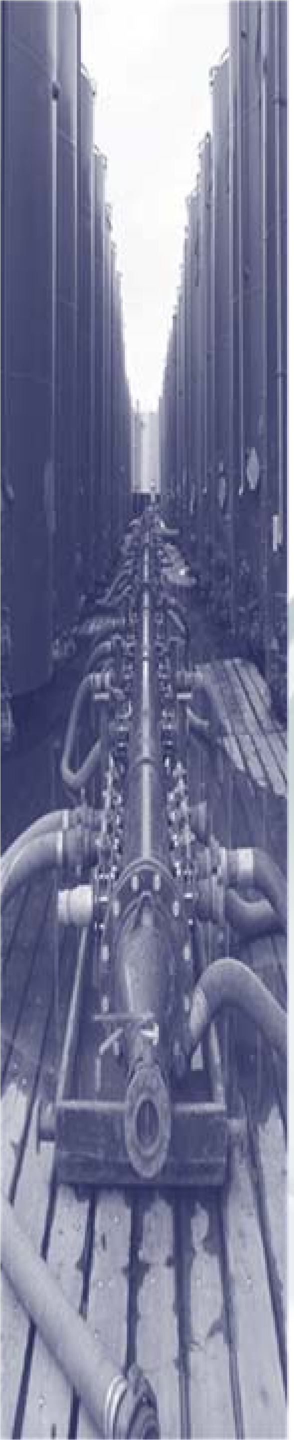
PTAC

(Reference #09-9171-50)

SCEK

Science and Community Environmental Knowledge

(RA 2011-03)



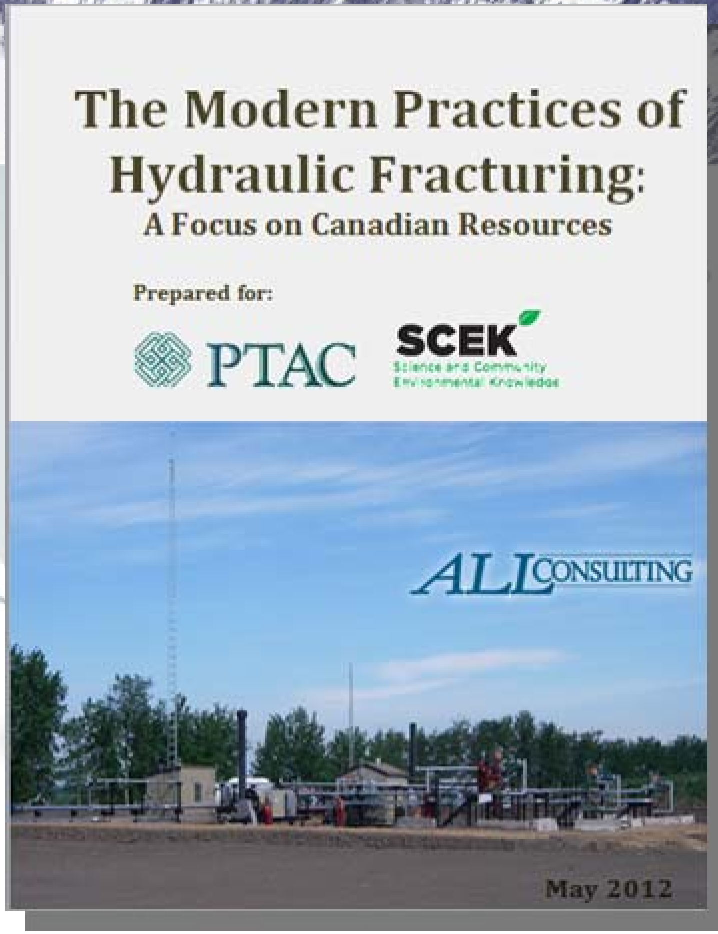
Research Coordination

CAPP
CANADIAN ASSOCIATION OF PETROLEUM PRODUCERS

- The Principal Researcher for the effort was Dan Arthur.
- Coordination of the research effort was led by a CAPP representative with support from other CAPP members, PTAC, and SCEK.
- Technical Review was conducted by a broader group, primarily inclusive of CAPP members.
- Peer Review included an even broader review circle beyond CAPP members.

September 8, 2011*: Canadian natural gas producers today announced new guiding principles for hydraulic fracturing that guide water management and improved water and fluids reporting practices for shale gas development in Canada. The principles were created by members of the Canadian Association of Petroleum Producers (CAPP) and apply to all CAPP natural gas producing members, large and small, operating in Canada.*

RESEARCH OVERVIEW


The Modern Practices of Hydraulic Fracturing:
A Focus on Canadian Resources

Prepared for:

PTAC

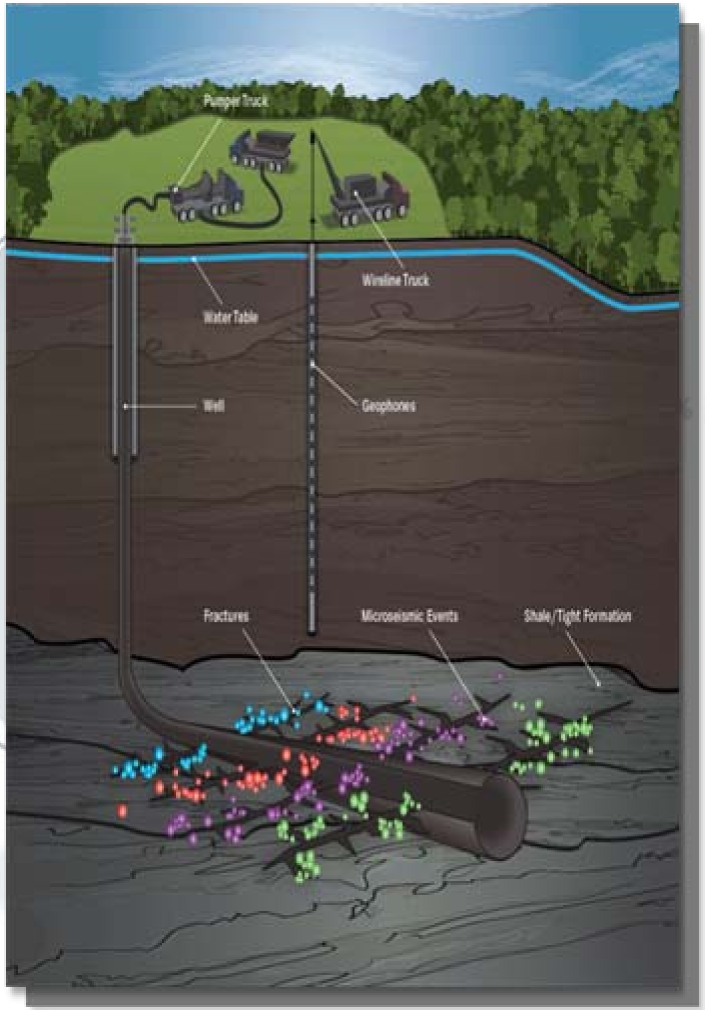
SCEK
Science and Community Environmental Knowledge

ALL CONSULTING

May 2012

Injection-Focused Research

- Flow paths available to hydraulic fracturing fluids during injection and the risk that occurs relative to these flow paths;
- Geologic Review of Canadian Shale Basins;
- Chemical use during hydraulic fracturing;
- Regulatory review of national and provincial regulations;
- Current and best management practices of hydraulic fracturing;
- Past and current hydraulic fracturing events.



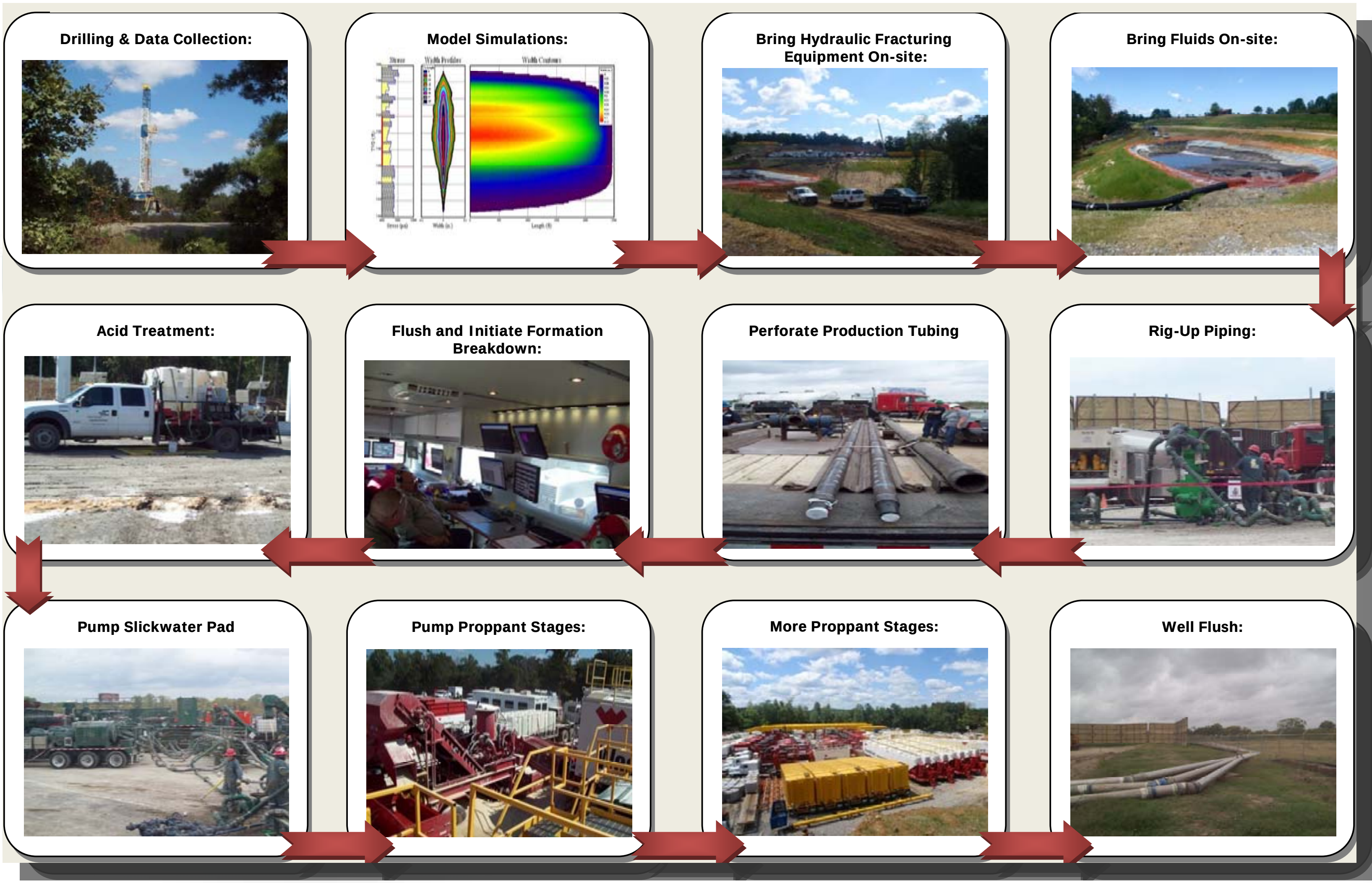
The Role of Technology

- Obvious Technologies
  - Deep horizontal drilling
  - High volume hydraulic fracturing
- Other Technologies
  - 3-D Seismic Analysis
  - Multi-well drilling pads
  - Water sourcing and transport
  - Impact mitigation

FRACTURING OVERVIEW

HF Process

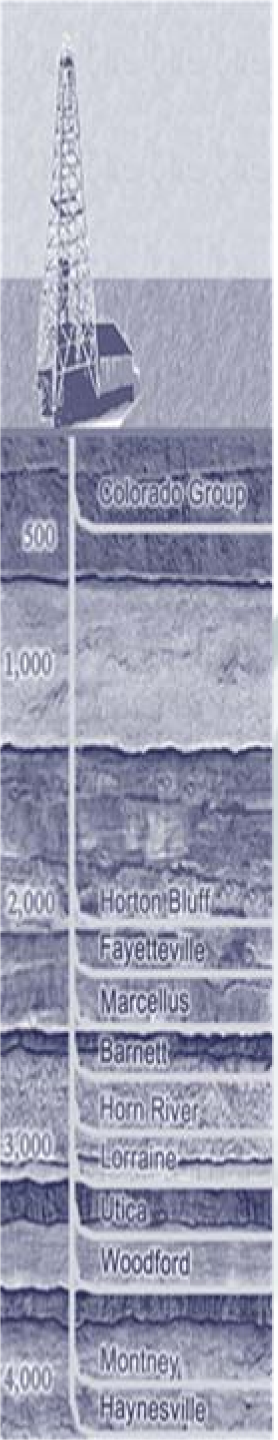
Surface Casing & Cement
Intermediate Casing & Cement
Production Casing & Cement
Tubing
Packer Set above Perforations
Perfs
Bottom of Production Casing



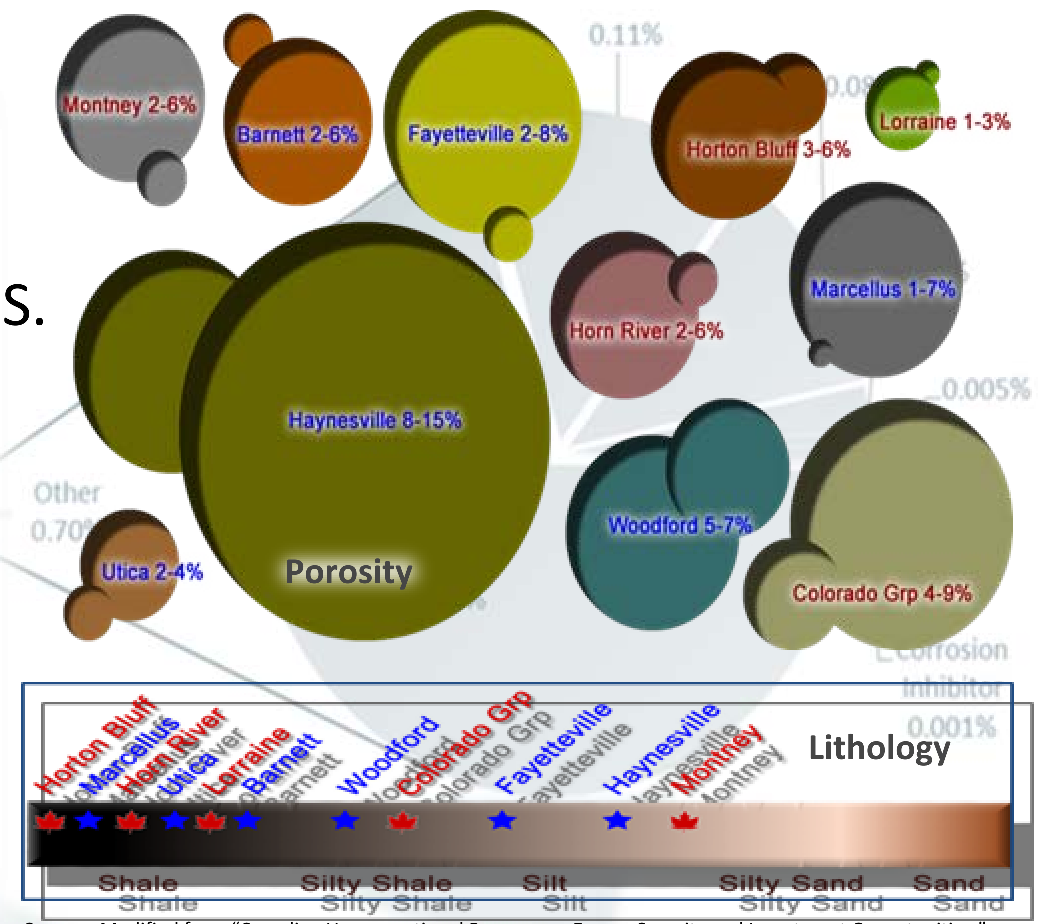
Drilling & Data Collection:
Model Simulations:
Bring Hydraulic Fracturing Equipment On-site:
Bring Fluids On-site:
Rig-Up Piping:
Perforate Production Tubing
Flush and Initiate Formation Breakdown:
Acid Treatment:
Pump Slickwater Pad
Pump Proppant Stages:
More Proppant Stages:
Well Flush:

NORTH AMERICAN SHALE GEOLOGY

GEOLOGIC FINDINGS



- No two shales are alike.
- Analogies can be drawn between U.S. and Canadian shales.
- Development techniques similar but shale and location specific.



Source: Modified from "Canadian Unconventional Resources: Energy Security and Investment Opportunities," presentation given by Mike Dawson, President ,Canadian Society for Unconventional Resources at NAPE International Forum, Houston, Texas February 16, 2011.

FLUID COMPOSITION

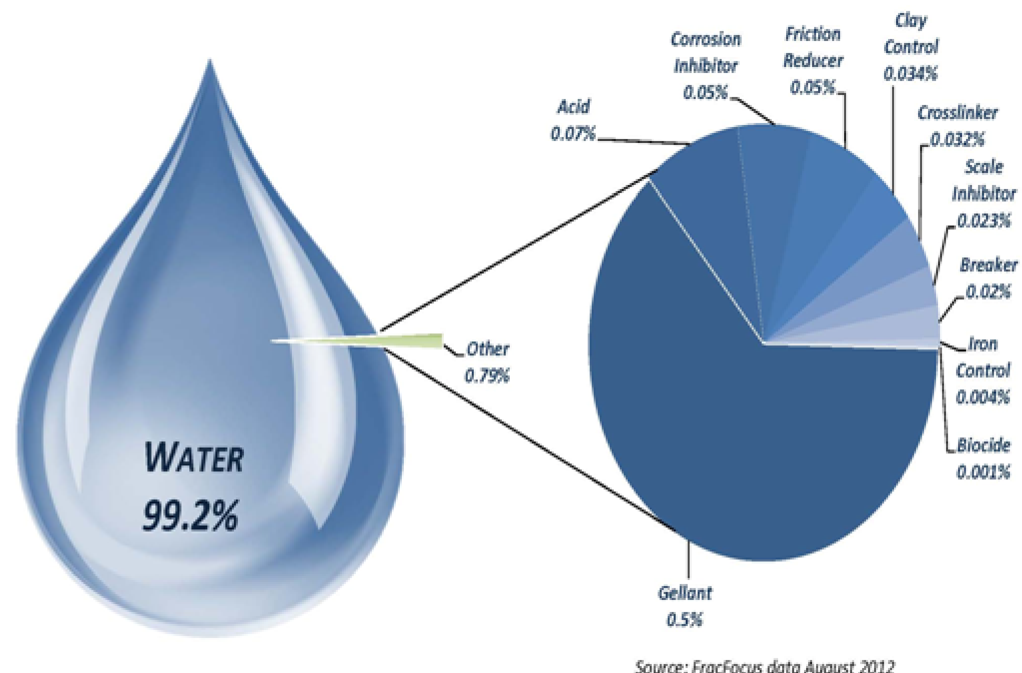
HF FLUID ADDITIVES

- Data has been collected on hydraulic fracturing chemicals used in active shale basins in the US.
- Compiled to provide "common" or "typical" chemical and their function in hydraulic fracturing job profiles used in those basins.
- This was performed through a review of voluntarily submitted chemical disclosures to the FracFocus.org website and industry interviews.
- A review of current chemical use trends is presented.
- Only those chemicals listed as hazardous on material safety data sheets (MSDS) are included.
- Alberta should also have a HF fluid disclosure requirement in-place by the end of 2012.

Frac Focus
Chemical Disclosure Registry

Average HF Fluid Composition

- Fluid composition varies
  - By play
  - Within a play
  - Between operators
  - By service company
  - Over time
- Average compositions for a single play can be calculated from public disclosure submittals (e.g., FracFocus, Completion Reports, etc.)
- Average compositions for multiple plays can be calculated by averaging play specific compositional data



NOTE: Limited to US Major Plays

Water composition overall is less than ALL has previously reported for shale gas plays because development efforts like the Niobrara and Eagle Ford use higher ratios of gel, which increases the gel composition compared to water composition. Overall, water composition as a percentage has increased since 2008 and the number of additives used has decreased within individual plays (ALL Consulting, 2012).

FLUID COMPOSITION

- 18 common additives.
- Fluids comprised of 5 to 14 additives.
- Water volumes/well increase with number of fracturing stages and length of horizontal wellbore.
- Trend toward less additives and increased use of "**green**" chemicals.

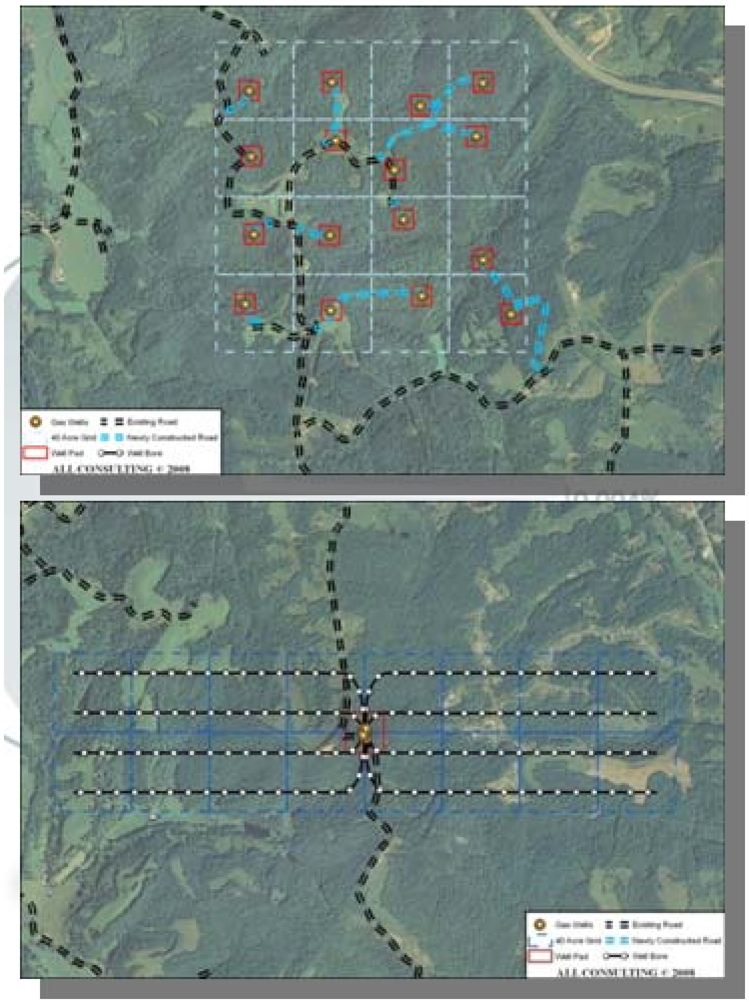
Table 10: Range of Water Volumes per Well Observed by Play and Number of Fracturing Job Disclosures Reviewed

U.S. Shale Play	Disclosures Reviewed	Upper Water Volume (m^3)	Lower Water Volume (m^3)
Bakken (Oil)	69	11,356	2,271
Barnett (Gas)	318	37,854	3,785
Barnett (Oil)	73	35,961	5,300
Barnett-Woodford (Gas)	45	16,277	378
Eagle Ford (Gas)	102	51,860	7,722
Eagle Ford (Oil)	112	32,176	5,300
Fayetteville (Gas)	455	36,340	5,678
Haynesville (Gas)	187	31,419	13,249
Horn River (Gas)[1]	**133**	**81,000**	**34,700**
Marcellus/Utica (Gas)	366	35,204	1,514
Montney (Gas)[1]	**312**	**7,800**	**2,100**
Woodford (Gas)	51	37,854	1,893
Woodford (Oil)	83	61,702	1,136
Woodford-Caney (Gas)	28	59,810	13,249
Total	1889		

BEST MANAGEMENT PRACTICES

What are BMPs?

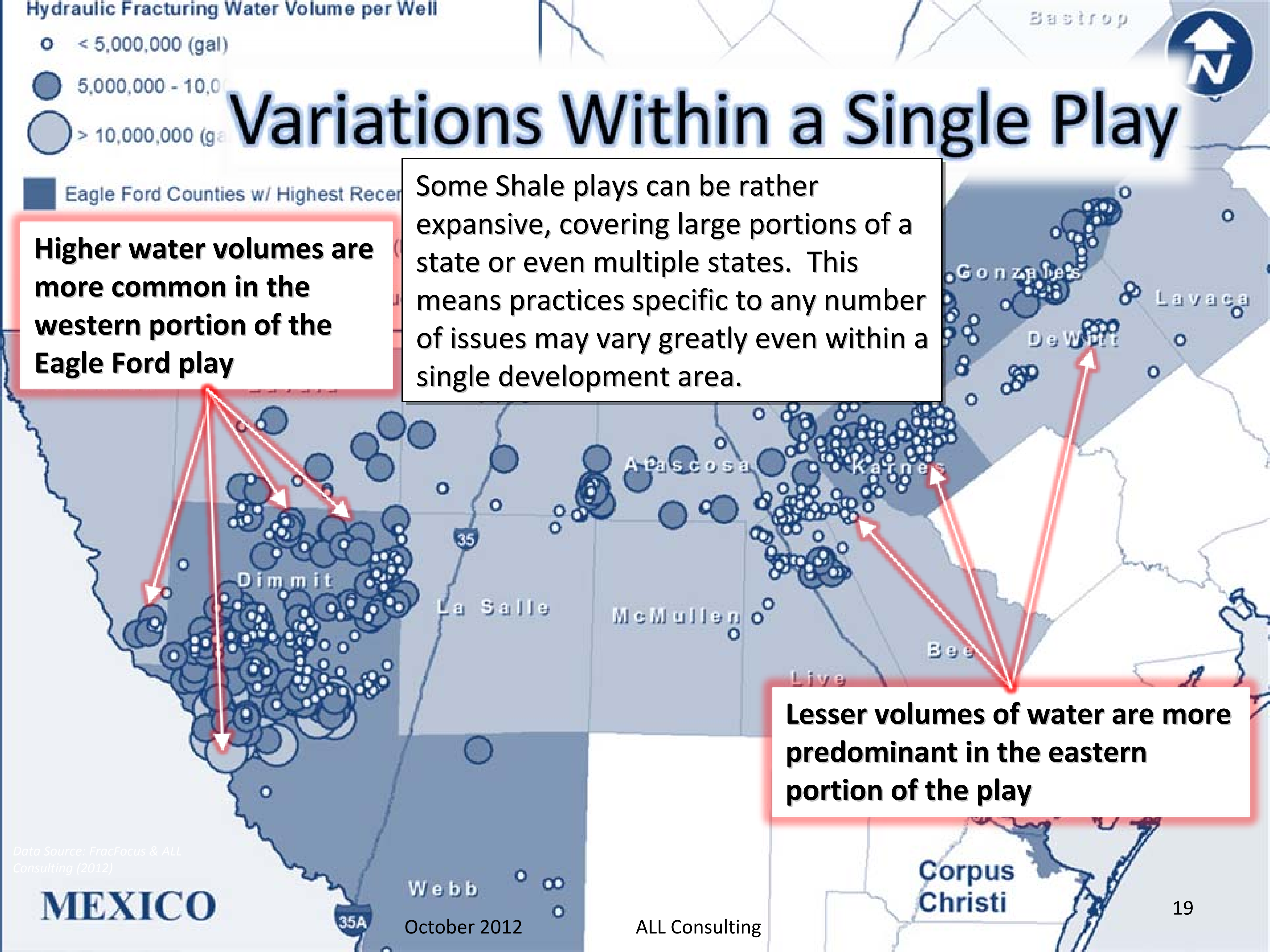
- Technologies, methods, and procedures that avoid, reduce, or mitigate environmental and community impacts associated with oil and gas activities
- BMPs are proactive and can also be reactive:
  - Often best incorporated early in a project
  - Site specific
  - Economically feasible
- BMPs are not required, but often allow an operator to meet a regulatory requirement



BMP Words of Caution…

- *Not – An assurance of 100% impact avoidance*
  - Some degree of impact is unavoidable if the gas resource is to be produced
- *Not – Universally applicable*
  - Depending on the situation, what works in Texas may be totally inappropriate for New York. Further, applicability may vary from one part of a play to another!
- *Not – One-size-fits-all*
  - Multiple BMP options may address the same basic concern from different approaches or under different circumstances

Variations Within a Single Play



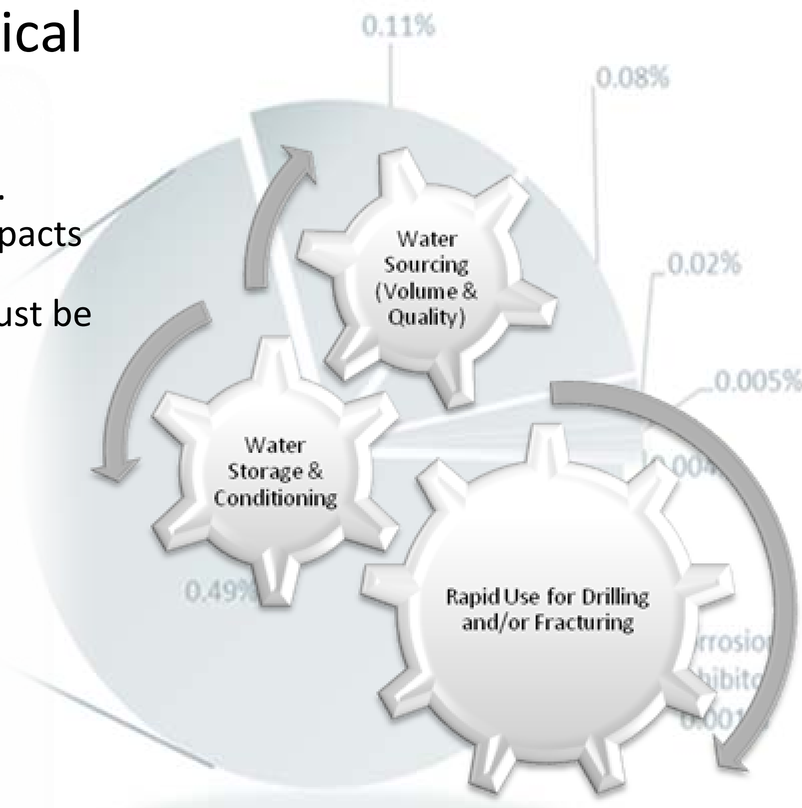
Some Shale plays can be rather expansive, covering large portions of a state or even multiple states. This means practices specific to any number of issues may vary greatly even within a single development area.

Higher water volumes are more common in the western portion of the Eagle Ford play

Lesser volumes of water are more predominant in the eastern portion of the play

BMP Application & Objectives

- Apply BMPs using a hierarchical approach
  - Avoid environmental impacts.
  - Minimize environmental impacts.
  - Mitigate those environmental impacts that are unavoidable.
  - Technical and logistical details must be considered in the process.
- Objectives of BMPs
  - Environmental
    - Meet or exceed regulatory requirements
    - Environmental stewardship/ responsibility
    - Achieve site-specific priorities
  - Health and safety
    - On-site workers
    - General public
  - Community
    - Quality of life



Example BMPs for Fracturing

- Review of Baseline Conditions
- Appropriate Wellbore Construction
- Use of Green Fracturing Chemicals
- Reduction of Chemical Usage
- Cement Integrity Logging
- Well Integrity Testing
- Fracturing Treatment Design
- Pre-Fracturing Treatment and Analysis
- Monitoring During Hydraulic Fracturing
- Post-Fracture Modeling
- Information Exchange

Note: The above are examples and not intended as an "all inclusive listing of considerations.

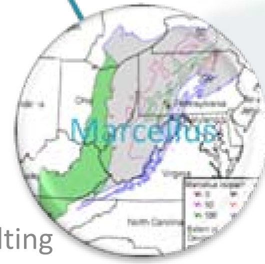
Using BMPs/Lessons Learned

Shublik Shale
Alaska's North Slope

- Traffic and Routing
- HF Chemical Screening
- Water Sourcing
- Disposal Well Planning

- Wetlands Management
- Siting in Sensitive Areas
- Wildlife BMPs

- Multi-Well Pads
- Sustainable Water Mgmt
- Seasonal Logistics
- Siting and Transport
- First Nations Concerns



- Minimizing Footprint
- Well Integrity Analysis
- Managing Releases
- Erosion/Stormwater
- Watershed Mgmt

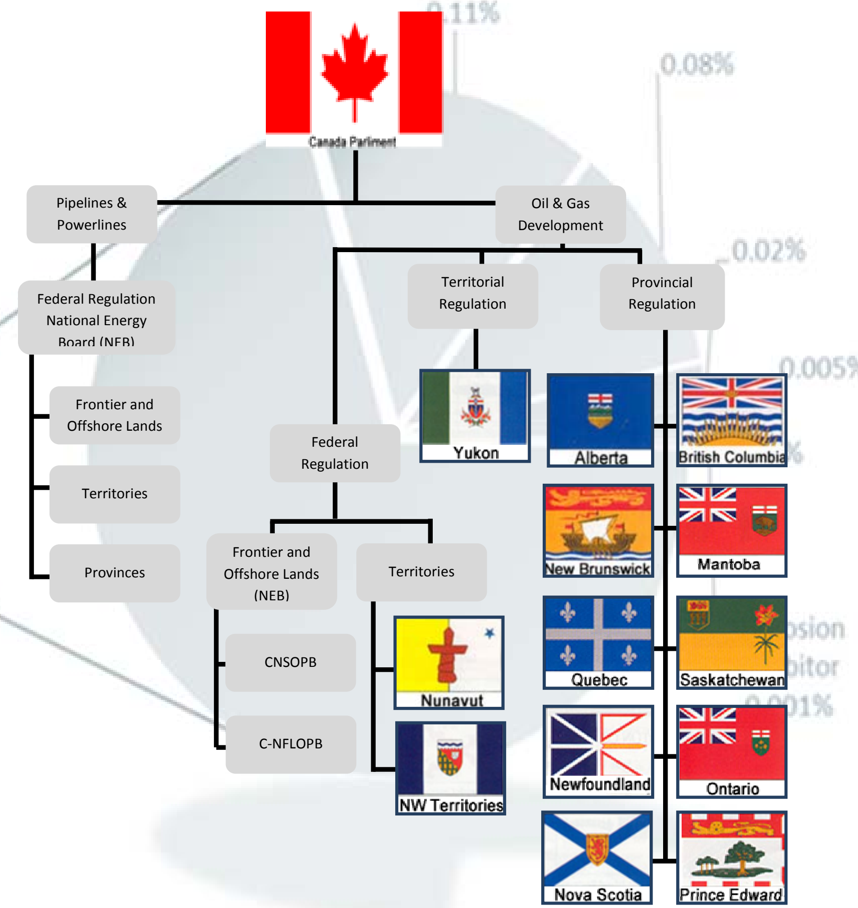
HYDRAULIC FRACTURING REGULATIONS (CANADA)

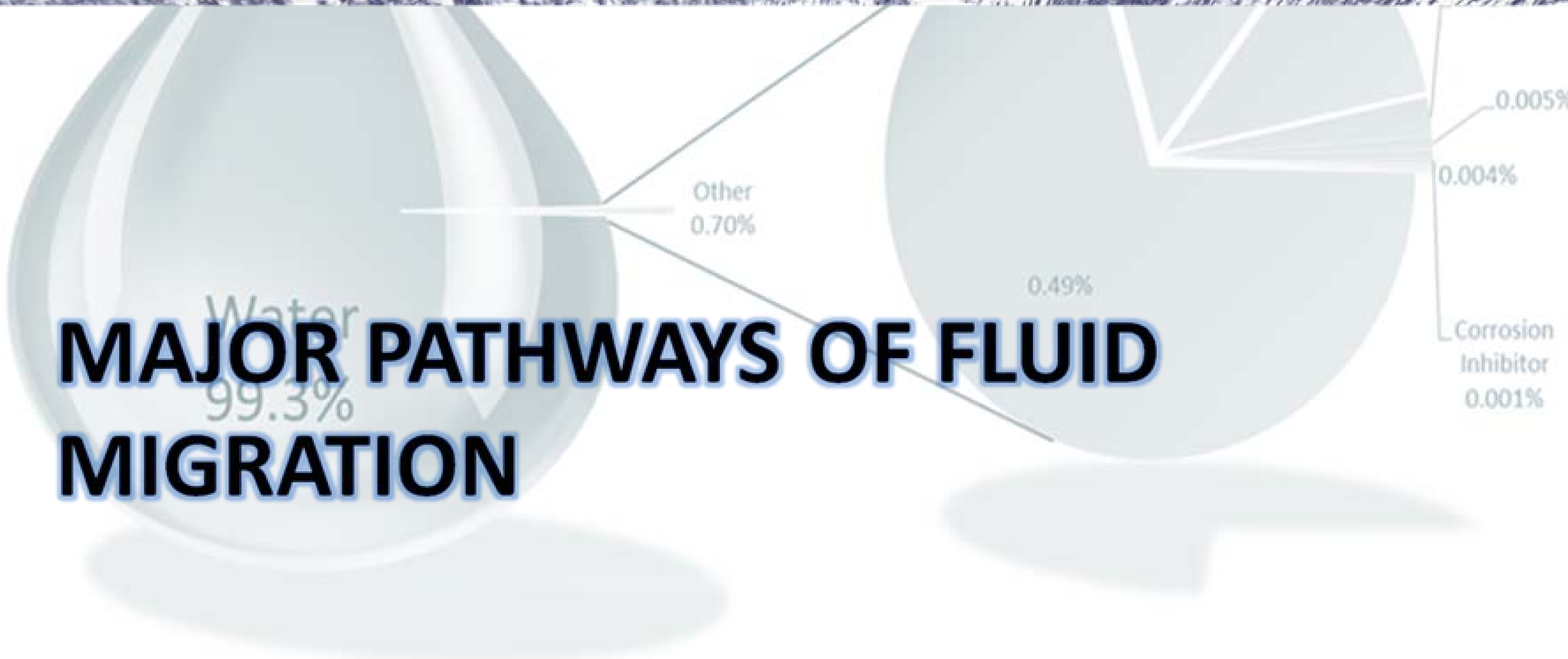
Regulatory Review

- Evaluate the existing regulations to determine their effectiveness of mitigating the potential impacts to water resources.
- National, provincial and territorial regulations within Canada relative to hydraulic fracturing have been compiled and reviewed.
- Regulations are in place to protect groundwater and the environment, in every Province and Territory.

REGULATORY FINDINGS

- Some Provinces have more specific requirements than others.
- None are without groundwater protection regulations.
- No regulatory program gaps were identified.
- Regulatory programs focus on well construction.





MAJOR PATHWAYS OF FLUID MIGRATION

INJECTION FLOWPATHS

- Vertical fractures created by the HF process.
- Communication with existing conduits (vertical fractures or abandoned wellbores) during the HF process.
- Poor well construction of the well being fractured.
- Operating practices performed during well injection that could cause risk to existing fresh water.
- Migration in connection with other producing wells in the area.

FLOWPATH RESULTS

- Understanding and designing a fracture requires specific data that must be collected
  - existing faults
  - abandoned wellbores
- Analysis of each of the pathways demonstrates that it is highly improbable that fracture fluids or reservoir fluids would migrate from a production zone to a fresh water source as a result of hydraulic fracturing.

$$\textit{Pressure} = \textit{Head} \times \textit{Water Gradient} \times \textit{Specific Gravity of Fluid}$$

[illegible]

[illegible]

[illegible]

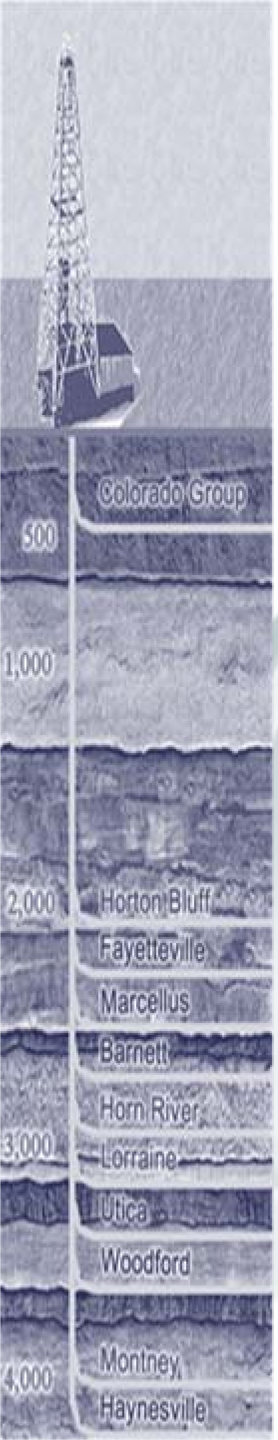
< 1 in 200,000,000

Michie, T.W., and C.A. Koch. Evaluation Of Injection-Well Risk Management In The Williston Basin, June, 1991.

ALLEGED PAST INCIDENT ANALYSIS

PAST & CURRENT HF EVENTS

- Assess situations where water impacts occurred to determine the pathway and the cause of the impact.
- Numerous instances of environmental contamination across North America have been attributed in the popular media to hydraulic fracturing.
- None of the incidents have been documented to be caused by the process of hydraulic fracturing.
- **No evidence of chemicals from hydraulic fracturing fluid has been found in aquifers as a result of fracturing operations.**



Did You Know?

Well Construction (in British Columbia - Horn River Basin Shale):

Example Well:

Total depth of 14,100 ft with a 5,750 ft horizontal section.

Includes:

682,675 lbs of steel or 341.34 tons of cement, which weighs 860,461 lbs.

The combined total weight of the steel and cement is: 1,543,136 lbs./771.6 tons.

Production Casing has a min. tensile strength of 125,000 psi and a burst pressure of 12,635 psi.

Groundwater protection:

Nine barriers comprised of alternating cement and steel, separate the well from groundwater with a combined thickness of 10.5 inches, 5 layers of steel equal to 1.89 inches and 4 layers of cement equal to 8.61 inches.

Typical well casing has yield strength of over 80,000 psi and tensile strength of over 95,000 psi.

Projected Annual Average:

HRB on average (last 2 years) has construction that increased over 200% per year, thus assuming 300 new shale gas wells per year:

Every year, 46,448.4 tons of steel and 129,000 tons of cement are used to construct the average 300 HRB wells.

For Consideration:

- On average, one car contains 1,800 lbs of steel
- CN Tower, 117,910 metric tonnes or 130,000 tons
- One mile of four lane interstate highway contains 155.65 tons of steel and 1,245 tons cement
- Blast resistant structures used in bank vaults and military operations often have walls about 6 inches thick with compression strength exceeding 14,500 psi.
- To reduce Gamma ray intensity in half (halving thickness) one needs 2.4 inches of concrete or 0.99 inches of steel.

COMPARISONS

- The steel in one well equals 379.3 cars
- The steel in 21.4 wells equals one Eiffel Tower
- The combined steel and cement (by weight) in 168.5 wells equals one CN tower
- It would take the cement (m^3) in 194.6 wells to equal the cement in the CN tower
- One well has enough steel for 2.19 miles of interstate, and enough cement for 0.34 miles.
- Annually the steel in 300 HRB wells is equal to 298.4 miles of interstate highway and the cement equals 103 miles of interstate.
- The tensile strength of the well casing is capable of suspending one fully loaded semi-truck and trailer or three city buses.

ALL CONSULTING

Special Thanks to:
Mark Layne, Ph.D., P.E.
Brian Bohm, P.G.
David Alleman
Bill Hochheiser
Jon Seekins
Dave Cornue, P.G.
Bobbi Coughlin, EIT
Greg Casey, P.E.
Dave Bockelmann, P.G.
Jason Veale
Leon McNally

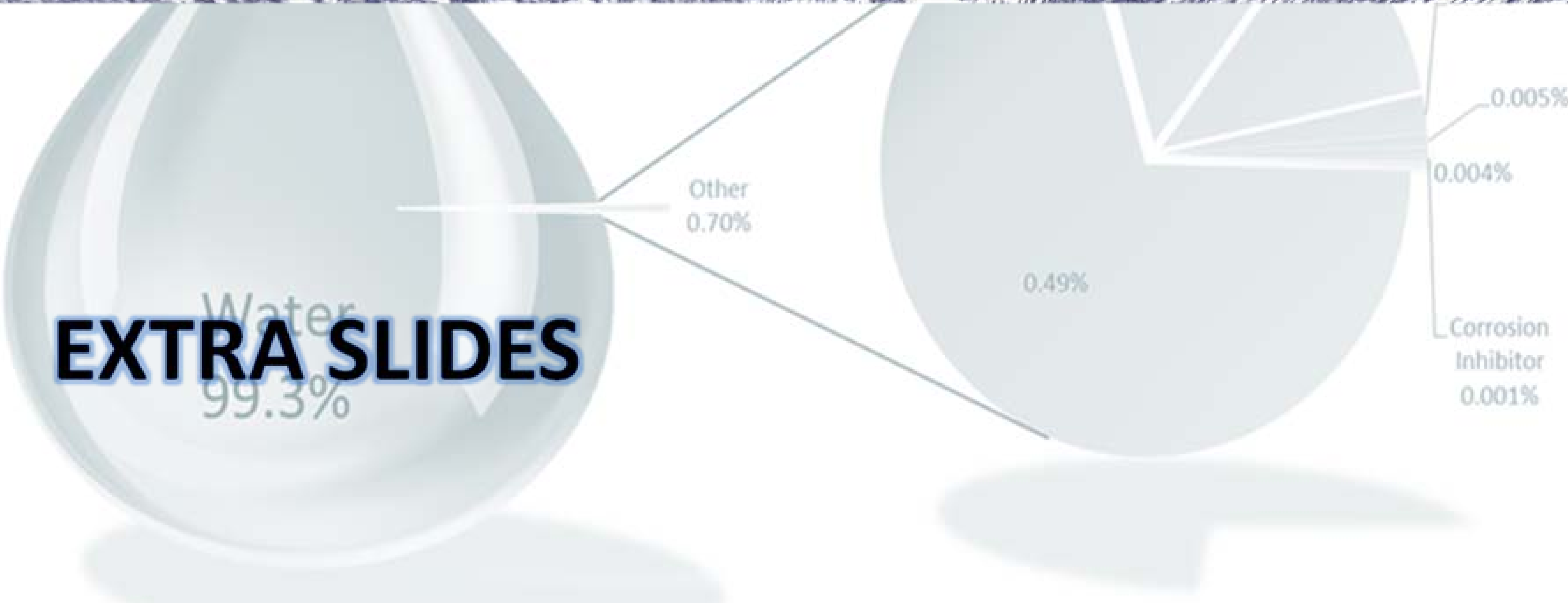
Principal Researcher

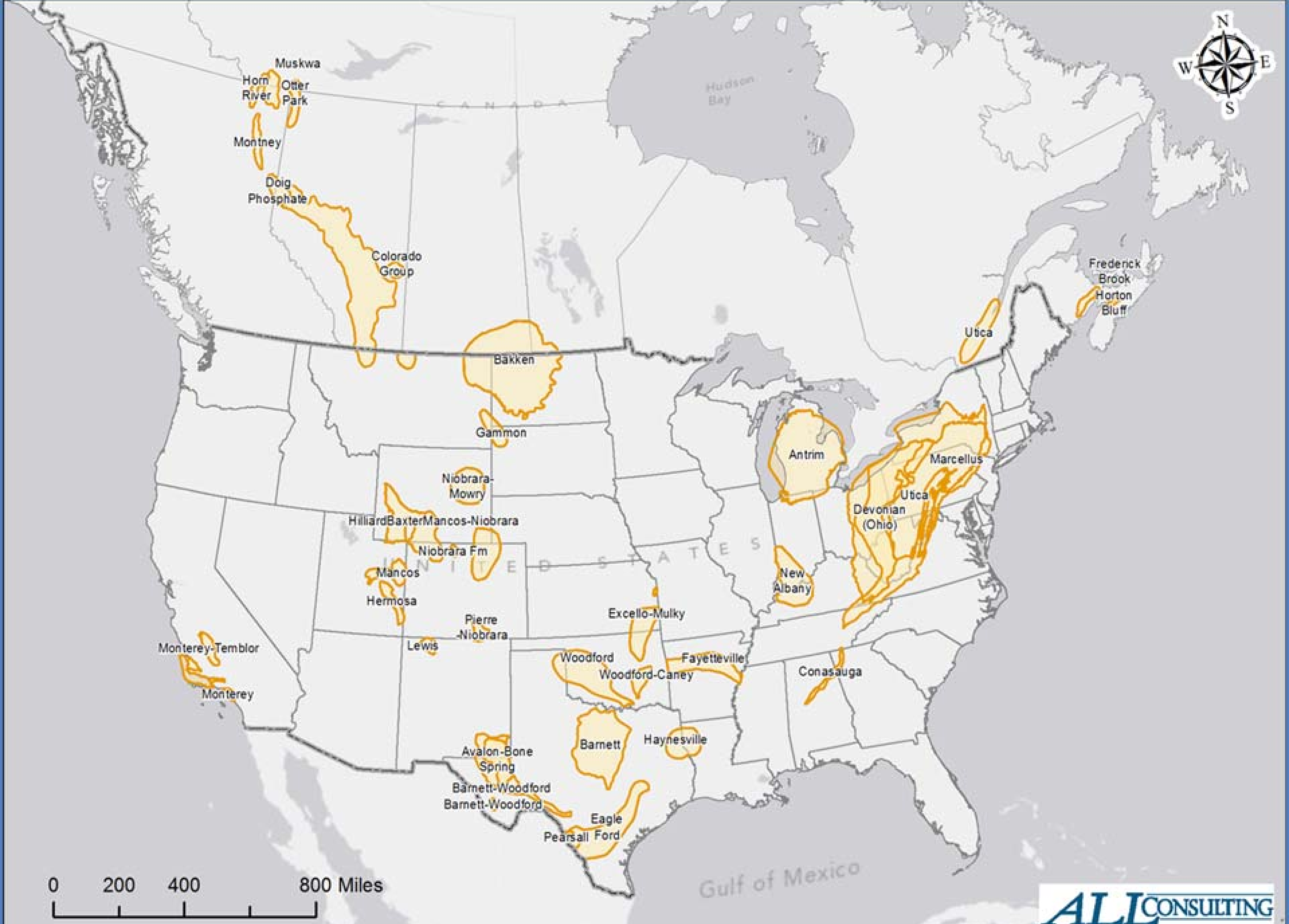
J. Daniel Arthur, P.E., SPEC
Project Manager
darthur@all-llc.com
ALL Consulting
1718 S. Cheyenne Ave.
Tulsa, OK 74119
www.all-llc.com

Citation Information:

ALL Consulting. "The Modern Practice of Hydraulic Fracturing For Canadian Resources". Presented at the Interstate Oil & Gas Compact Commission, October 28-31, 2012.

EXTRA SLIDES




Muskwa
Horn River
Otter Park
Montney
Doig Phosphate
Colorado Group
Hudson Bay
CANADA
Bakken
Gammon
Niobrara-Mowry
HilliardBaxterMancos-Niobrara
Niobrara Fm
Mancos
Hermosa
Lewis
Pierre -Niobrara
UNITED STATES
Monterey-Temblor
Monterey
Antrim
Marcellus
Utica
Devonian (Ohio)
Utica
New Albany
Frederick Brook
Horton Bluff
Excello-Mulky
Woodford
Woodford-Caney
Fayetteville
Conasauga
Barnett
Haynesville
Avalon-Bone Spring
Barnett-Woodford
Barnett-Woodford
Eagle Ford
Pearsall
Gulf of Mexico
MEXICO
0 200 400 800 Miles
N E S W

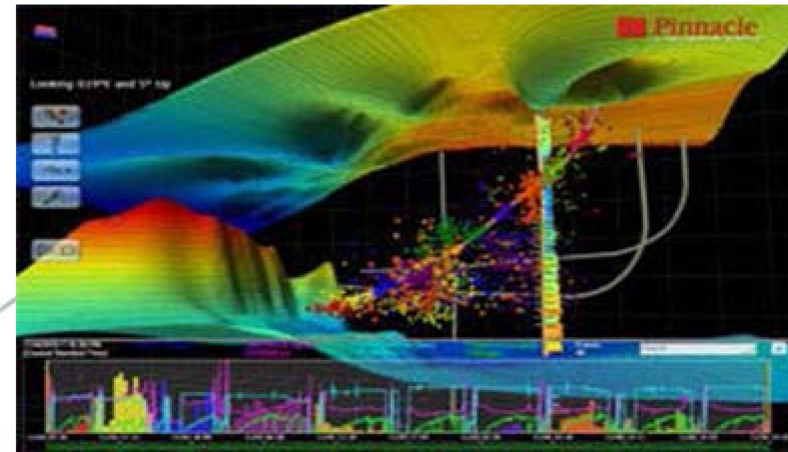
CAPP Guiding Principles for Hydraulic Fracturing

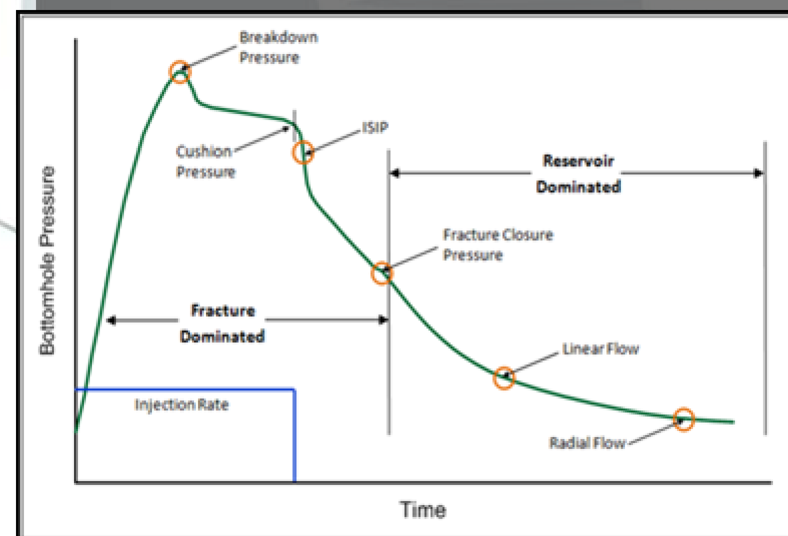
1. We will safeguard the quality and quantity of regional surface and groundwater resources, through sound wellbore construction practices, sourcing fresh water alternatives where appropriate, and recycling water for reuse as much as practical.
2. We will measure and disclose our water use with the goal of continuing to reduce our effect on the environment.
3. We will support the development of fracturing fluid additives with the least environmental risks.
4. We will support the disclosure of fracturing fluid additives.
5. We will continue to advance, collaborate on and communicate technologies and best practices that reduce the potential environmental risks of hydraulic fracturing.

CAPP Hydraulic Fracturing Operating Practices

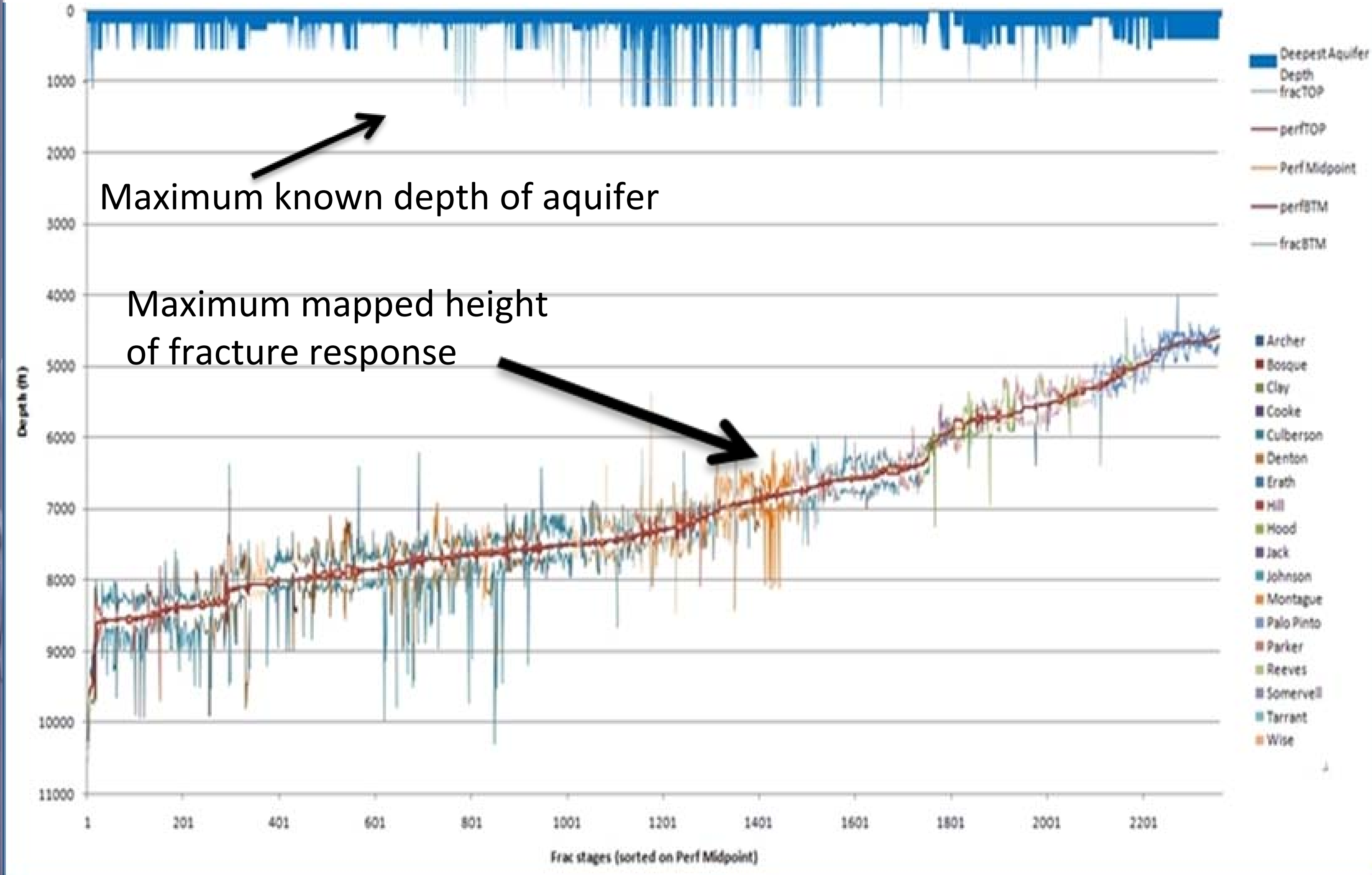
Fracturing BMPs

- For any given situation there may be multiple BMPs available.
- Most of the commonly used BMPs identified for hydraulic fracturing and oilfield operations address issues at the surface.
- Their use will depend on many factors that are specific to the location, geology, hydrology, climate, surface conditions, and demographic features.
- Several BMPs that have been adopted by industry are also being integrated into regulatory practices.





Barnett Shale Mapped Fracs



Hydraulic Fracturing Additives

Additive Type	Main Compound	Use in Hydraulic Fracturing Fluids	Common Use of Main Compound
Acid	Hydrochloric acid or muriatic acid	Acids are used to clean cement from casing perforations and drilling mud clogging natural formation porosity (dilute acids are typically about 15% acid).	Swimming pool chemical and cleaner
Biocide	Glutaraldehyde	Biocides are added to the mixing tanks with the gelling agents to kill bacteria.	Cold sterilant in health care industry
Breaker	Sodium Chloride	Chemicals that are typically introduced toward the later sequences of a fracturing job to “break down” the viscosity of the gelling agent.	Food Preservative
Corrosion inhibitor	N,n-dimethyl formamide	Used in fracture fluids that contain acids; inhibits the corrosion of steel tubing, well casings, tools, and tanks.	Crystallization medium in Pharmaceuticals
Crosslinker	Borate Salts	There are two basic types of gels used in fracturing fluids; linear and cross-linked. Cross-linked gels have the advantage of higher viscosities that do not break down quickly.	Non-CCA wood preservatives and fungicides
Friction Reducer	Petroleum distillate or Mineral oil	Minimizes friction allowing fracture fluids to be injected at optimum rates and pressures.	Cosmetics, nail and skin products
Gel	Guar gum or hydroxyethyl cellulose	Gels are used in fracturing fluids to increase fluid viscosity allowing it to carry more proppant than a straight water solution. In general, gelling agents are biodegradable.	Food-grade product used to increase viscosity and elasticity of ice cream, sauces and dressings.
Iron Control	Citric acid	Sequestering agent that prevents precipitation of metal oxides.	Used to remove lime deposits. Lemon Juice is ~ 7% Citric Acid
KCl	Potassium Chloride	Added to water to create a brine carrier fluid.	Table salt substitute
Oxygen scavenger	Ammonium bisulfate	Oxygen present in fracturing fluids through dissolution of air causes the premature degradation of the fracturing fluid, oxygen scavengers are commonly used bind the oxygen.	Used in cosmetics
Proppant	Silica, quartz sand	Proppants consist of granular material, such as sand, mixed with the fracture fluid. It is used to hold open the hydraulic fractures allowing the gas or oil to flow to the production well.	Play box sand, concrete or mortar sand
Scale inhibitor	Ethylene glycol	Additive to prevent precipitation of scale (calcium carbonate precipitate).	Antifreeze and de-icing agent
Surfactant	Naphthalene	Used to increase the viscosity of the fracture fluid.	Household fumigant

Source: GWPC and ALL Consulting, Modern Shale Gas Development in the United States: A Primer, prepared for the U.S. Department of Energy Office of Fossil Energy and National Energy Technology Laboratory (April 2009).

Evaluating Trade-Offs

- BMPs may entail trade-offs:
  - Centralized water reservoirs may reduce water withdrawal issues but may result in additional surface disturbance and concentrated truck traffic
- Watch for unintended consequences:
  - CBM impoundments in the Powder River Basin were seen as benefit for wildlife – but increases in mosquito populations have been implicated as a cause of increasing West Nile virus in sage grouse