



Hydraulic Fracturing Risks

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Overview

1 Operator risks

- ▶ Trying to find and produce hydrocarbons (profitably)
- ▶ Well construction & completion to maximize production
- ▶ Design, materials, subcontractors and consultants, compliance, finance

2 What are risks for non-operator?

Heterogeneous group (mineral owner, surface owner, neighboring owner, more distant)

- ▶ Subsurface impacts
- ▶ Surface impacts

Environmental, not trespass



ND Rig



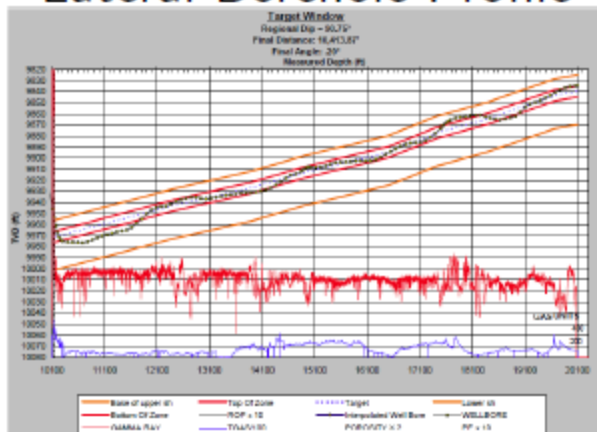
Wells in Jonah field, WY

“Learning by doing”

Fracturing has been widely adopted

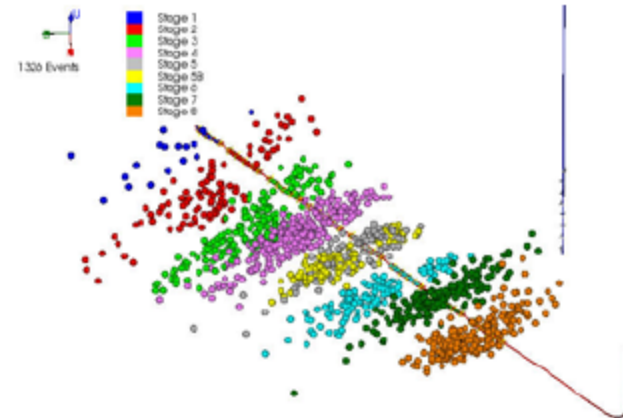
- Implemented w/ and w/o horizontal/directional drilling
- Fractures are cheapest way to touch rocks
- Fracturing is the “least optimized” part of well construction

Lateral Borehole Profile



Graphic courtesy Geo-Link Geological

Microseismic Profile



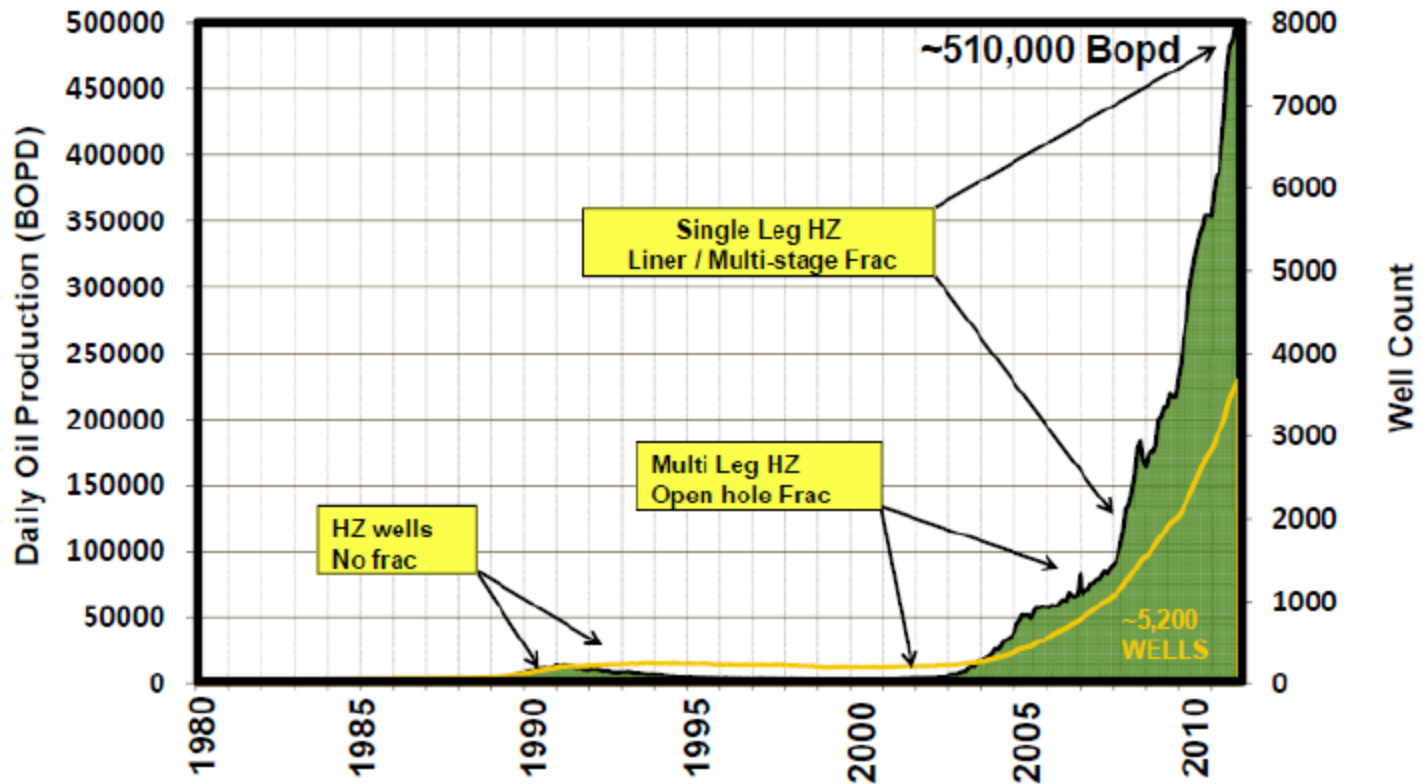
Graphic courtesy Weatherford

The way fracturing is implemented differs:

- *between* formations with different geology
- *within* formations over time

Bakken: One of Most Important Unconventional Plays

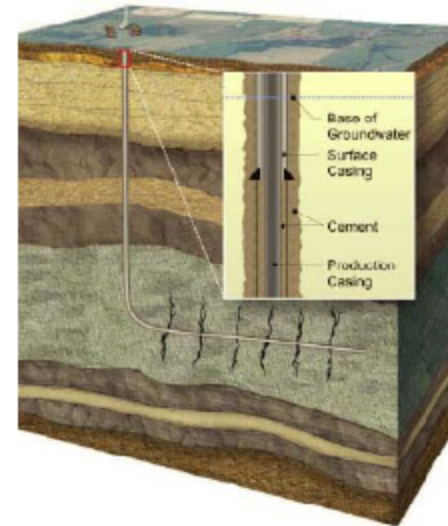
Bakken Production History (MT & ND)



Completions have changed over time:

- Initially open-hole
- Multi-stage completions: increasing number of stages (up to 40)
- Recent trend has been to reduce number of stages (15-20): less cost up front

Operators Make Decisions About Risk Every Day



Operators have many subcontractors: drillers, service crews, wellsite geologists

- Construction

- ▶ best management practices for surface casing: avoid third party impacts
- ▶ how much testing of well integrity?

- Completion

- ▶ designs evolving: fluid, proppant, staging
- ▶ constantly marketing new formulas: competitive marketplace

- Production

- ▶ produced water management trending towards recycling in all basins
- ▶ risk mitigation requires investment in infrastructure

Non-Operator Risks

Aside: Mineral Owners, Surface Owners

The single most important factor in explaining attitudes towards risks is ownership of mineral interest

- Technological change brings development to unfamiliar communities
- Ownership of minerals determines who benefits from development



McKenzie County ND, Feb 2013

Subsurface Environmental Risks

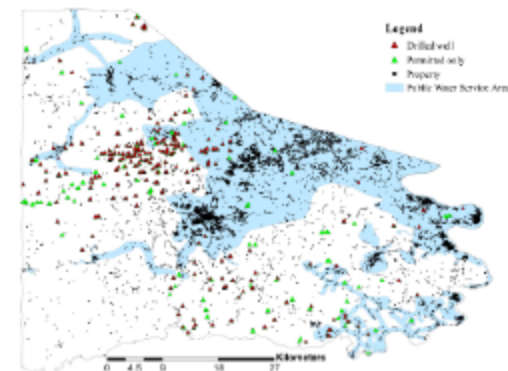
Two primary concerns:

- Will toxic fluid additives contaminate groundwater?**
- Will hydrocarbons contaminate groundwater?**

Evidence that these risks are recognized in the market:

Muehlenbachs, Spiller, Timmins (2013)

- Washington County, PA housing market 2004–2009
- Some houses have municipal water while others rely on private wells
- Homes near gas wells sell for more than those far away (+10.1%): local benefit from development
- Homes with private wells actually sell for less: by about -26.6% than other like houses with municipal water



Washington County Property Sales,
2004–2009

Three Questions about Subsurface Risks

- Nature of Risks

What is in groundwater?

- ▶ Hydrocarbons from target formations (Osborn et al. PNAS 2011)
- ▶ No definitive evidence of fracturing fluid (despite Pavillion, Wyo.)

Is this just because we don't know what to look for?

- Spatial Extent

How far do underground externalities extend in space?

- ▶ Hydrocarbons in water wells within 1.5 km (Osborn et al. PNAS 2011)
- ▶ This could be on-lease or off

- Verifiability

What standard of proof required?

- ▶ Methane in wells: was it there before?
- ▶ Baseline data is sparse, effects are often complex, leases can be extremely long-lived
- ▶ Ownership of groundwater varies

Surface Risks

Developing oil or gas resources impacts the surface: what additional risks does a surface owner face when wells are completed by fracturing?

- More produced water: possible spills, larger footprint, may require add'l infrastructure
 - Rozell & Reaven (2012) identify wastewater (flowback + produced) disposal as primary risk factor
 - ▶ Olmstead et al. PNAS 2013: surface water quality in PA 2000–2011
 - ▶ More upstream wastewater plants treating produced water → increased chloride
 - ▶ More upstream well pads → increased TSS
- Additional process that could have surface spill: less volume
 - ▶ Alternative is additional infrastructure to reduce truck traffic
 - ▶ Pad drilling
 - ▶ Water recycling: local water demand

There are other impacts from development that are not *unique* to fractured wells.