Hydraulic Fracturing & Well Developments: What are the Factual Risks?

(Focus on Groundwater)

George E. King

13 October 2013
History

• Invented in era of 1943 to 1947 by Standard Oil of Indiana (Pan American => Amoco).
• Fully commercial by 1954.
• First multi-fractured deviated wells in 1975.
• Million pound sand jobs in mid 1970’s
• Million gallon fracs in mid 1980’s.
• Horizontal multi-fractured shale wells in 1988.
• Over 1 million jobs completed by mid 1990’s.
• About 2 million jobs completed by 2012.
Oil and Gas Development – The Stages

1. Assessment – is it worth drilling?
   • Seismic, outcrops, lab work, etc.

2. Exploration - initial drill, well construction, limited fracs
   • Identify what cannot be assessed in laboratory.

3. Development / Construction / Stimulation
   • Main development – drill, construct, fracturing

4. Operations / Production – the work
   • Flow – maintenance, operation styles,

5. Reclamation – Restore surface & seal old well
Exploration to Development – What is the Timing?

• Exploration
  – Few wells, with science, takes longer for D&C
  – Some venting? Better approaches for well evaluation?
  – Scattered locations.

• Development
  – Pads
    • Minimize environmental foot print (pad size, well number, roads, ground disturbance, wildlife disturbance)
    • Minimum venting
    • Normally much easier to permit.
# Definitions

<table>
<thead>
<tr>
<th>Fracturing Operations</th>
<th>Rough Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Transport / Storage water(s)</td>
<td>Truck accidents, spills</td>
</tr>
<tr>
<td>- Transport / Storage of sand</td>
<td>Truck accidents, dust</td>
</tr>
<tr>
<td>- Transport / Storage chemicals</td>
<td>Accidents, spills, toxins?</td>
</tr>
<tr>
<td>- Pumping fracture treatment</td>
<td>Pipe breaks, leaks</td>
</tr>
<tr>
<td>- First two weeks production</td>
<td>Transport, disposal</td>
</tr>
<tr>
<td>- Later production of fluid</td>
<td>Leaks, storage, recycle</td>
</tr>
</tbody>
</table>
Technology Drivers
Barrier Failure or Well Integrity Failure

- **Single Barrier Failure** => No Leak Path? => No Well Integrity Failure
- **Unless All Barriers Fail, A Leak Will Not Happen**

Wells are Designed with Multiple Barriers. Number of Barriers Depends on the Hazard Level.

<table>
<thead>
<tr>
<th>ZONE</th>
<th>Hazard to Ground Water If Well Integrity Is Lost</th>
<th>Typical Number of Barriers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above Surface</td>
<td>Low</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Fresh Water</td>
<td>Low to Moderate</td>
<td>2 to 4</td>
</tr>
<tr>
<td>Mid Depth</td>
<td>Very Low</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Deep</td>
<td>Lowest</td>
<td>1</td>
</tr>
</tbody>
</table>
Fracturing Risk Evaluation

=> Very Small Risks

To Groundwater

Highest Risks are Transport, Some from Well Construction

Full Details in SPE 152596
Frac height growth in four thousand jobs – not even close to water

Microseismic signal from top of fracs in relationship to bottom of fresh water.

>3800 fracs tracked in 4 shales

Table 5 – Fracture Height-Growth Limits in Four Major U.S. Shale Plays (Fisher, 2011)

<table>
<thead>
<tr>
<th>Shale</th>
<th>Number of fracs with microseismic data</th>
<th>Primary Pay Zone Depth Range</th>
<th>Typical Water Depth and (Deepest)</th>
<th>Typical Distance Between Top of Fracture and Deepest Water</th>
<th>Closest Approach of Top of Frac in Shallowest Pay to Deepest Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett (TX)</td>
<td>3000+</td>
<td>4700’ to 8000’</td>
<td>500’ (1200’)</td>
<td>4800’</td>
<td>2800’</td>
</tr>
<tr>
<td>Eagle Ford (TX)</td>
<td>300+</td>
<td>8000’ – 13,000’</td>
<td>200’ (400’)</td>
<td>7000’</td>
<td>6000’</td>
</tr>
<tr>
<td>Marcellus (PA)</td>
<td>300+</td>
<td>5000’ to 8500’</td>
<td>600 (1000)</td>
<td>3800’</td>
<td>3800’</td>
</tr>
<tr>
<td>Woodford (OK)</td>
<td>200+</td>
<td>4400’ – 10,000’</td>
<td>200 (600)</td>
<td>7500’</td>
<td>4000’</td>
</tr>
</tbody>
</table>

- Separation is 1 to 2 km.
- No breach of fresh water.
- The top-most microseismic signals are most likely stress transfer and do not represent fracture growth.
Vertical Fractures – where do they stop?

Fractures are naturally limited:
• Natural formation barriers.
• Stresses in the rock.
• Leakoff limits height growth.
• Natural fracture network.
• Typical effective frac height is 300 ft.

Two inch by 1.5” view from a downhole TV camera run in clear water. Amoco - Circa 1971.
How Much Cement is Needed for Isolation?
Every inch of cement is NOT required to be perfect.

Quality of cement is more important than the volume.

Isolation can only be measured with a pressure test.

Bond logs are not always best tool

- ~10% channels missed.
- Instances of false negatives.

Over 10,000 psi can be held with less than 50 ft of cement, but 200 to 300 ft is routinely used.

Isolation - Pressure Differential vs. Cemented Separation

Source, Amoco, circa 1990's.
The Potential For Pollution is Reduced by Application of Technology.

ERA of Well Construction is More Important Than Age of the Well.

<table>
<thead>
<tr>
<th>Time Era</th>
<th>Operation Norms - Level of Technology</th>
<th>Era Potential For Pollution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1830 to 1916</td>
<td>Cable Tool drilling, no cement, wells vented</td>
<td>High</td>
</tr>
<tr>
<td>1916 to 1970</td>
<td>Cementing isolation steadily improving.</td>
<td>Moderate</td>
</tr>
<tr>
<td>1930’s</td>
<td>Rotary drilling replace cable tool, BOPs</td>
<td>Moderate &amp; Lower</td>
</tr>
<tr>
<td>1952</td>
<td>Fracs reduce # wells. Better pipe &amp; cement</td>
<td>Lower from Frac aspects</td>
</tr>
<tr>
<td>1960</td>
<td>Gas tight couplings and joint make up</td>
<td>Moderate</td>
</tr>
<tr>
<td>1970</td>
<td>Cement improving, Horizontal Wells introduced</td>
<td>Lower</td>
</tr>
<tr>
<td>1988</td>
<td>Multi-frac, horizontal wells, pad drilling reducing environmental land footprint 90%</td>
<td>Lower</td>
</tr>
<tr>
<td>2005</td>
<td>Well integrity assessment, premium couplings, adding barriers &amp; cementing full strings.</td>
<td>Lower after 2008 to 2010 (STRONGER Reg Review)</td>
</tr>
<tr>
<td>2008</td>
<td>Chemical toxicity &amp; endocrine disruptors sharply reduced. Real time well integrity needs studied - early warning &amp; avoidance.</td>
<td>Lowest yet, most states caught up with design and inspection requirements.</td>
</tr>
</tbody>
</table>
Barrier and Integrity Failures: >330,000 US wells
Focus is on groundwater pollution potential

Things That Keep Real Integrity Failures Very Low
1. Pressure inside the wells is lower than outside in hydrostatic of water table.
2. Modern wells are built with multiple barriers.
3. Cement reinforces and protects the casing.
4. Regulations are tighter now than 3 years ago.
5. Multi-Fractured horizontal wells replace 5 to 10 vertical wells in shale. Less pollution potential with fewer water table penetrations.

So – What are Actual Groundwater Pollutants?

- UST – Gas & Diesel
- Septic Systems
- Landfills
- Spills
- Fertilizer
- Large Industrial Facilities
- Hazardous Waste Sites
- Animal Feedlots
- Pesticides
- Surface Impoundments
- Storage Tanks – surface
- Urban Runoff
- Salt Water Intrusion
- Mine Drainage
- Agriculture Chem. Facilities
- Pipelines & Sewer
- Shallow Inj. Wells
- Salt Storage & Road Salting
- Land application of Waste
- Irrigation Practices

**EPA, 2000**

**Oil and Gas Wells Didn’t Make the List.**
What are Groundwater Pollutants Today & Where do Oil & Gas Wells Rank?

Used Texas as a Study Case.

Over a million penetrations through the 29 major & minor aquifers in Texas.

Texas is #2 in total Groundwater withdrawals with ~ 80% going to Agriculture & Municipalities.

If the water was really polluted by O&G wells, we’d see it quickly in Municipal & Ag.
Last 12 years of Pollution Reports in Texas – Top 20 Listed - TCEQ & TGPC Database

SPE 166142, Barrier vs. Well Failure, King
Allocation of Texas TCEQ Pollution Claim Frequency

Legacy issues with surface pads (tanks, compressors, truck terminals, gas plants) !!!

Comparison of Contamination Claims: Underground Petroleum Storage Tanks (Gasoline & Diesel), Surface Facilities, Pipelines, Injectors, Oil Wells and Gas Wells

Source: TGPC Joint Monitoring & Contamination Reports (2000 to 2011)

Producing Wells are less than 1% of total for most years.
Failure Factors Recognized:

- **Type of Well**
- **Maintenance Culture**
- **Era of Construction**
- **Geographical Location**
- **Age of Well**
- **Design & Construction**
- **Usage Change**

Full Details in SPE 166142
<table>
<thead>
<tr>
<th>Area</th>
<th>Number of Wells</th>
<th>Type of Wells</th>
<th>Barrier Failure Freq. Range (w/ containment)</th>
<th>Integrity Failure (leak path – in or out)</th>
</tr>
</thead>
<tbody>
<tr>
<td>US Gulf of Mexico</td>
<td>11,498 (3542 active)</td>
<td>Platform based wells</td>
<td>30% overall for annulus; SCP 50% of cases. 90% of strings w/ SCP have less than 1000 psi. 10% are more serious form of SCP (Wojtanowicz, 2012)</td>
<td>0.00005% to 0.0003% of prod oil spilled 1980 thru 2009.</td>
</tr>
<tr>
<td>US Gulf of Mexico</td>
<td>4,099</td>
<td>Shoe test failures required repair</td>
<td>12% to 18% require cement repair to continue drilling</td>
<td>0 (all repaired before resuming drilling).</td>
</tr>
<tr>
<td>Norway</td>
<td>406</td>
<td>offshore</td>
<td>18%</td>
<td>0</td>
</tr>
<tr>
<td>GOM / Trinidad</td>
<td>2,120</td>
<td>Sand Control</td>
<td>0.5 to 1%</td>
<td>0% subterranean ~0.0001% via surface erosion potential</td>
</tr>
<tr>
<td>Matagorda Island 623</td>
<td>17</td>
<td>Compaction failures; casing shear &amp; sand fail</td>
<td>80% to 100% - the high number is due to high pressure and formation compaction.</td>
<td>Wells routinely shut-in and repaired prior to restart.</td>
</tr>
<tr>
<td>Sumatera</td>
<td>175</td>
<td>without maintenance</td>
<td>43%</td>
<td>1 to 4%</td>
</tr>
</tbody>
</table>

SPE 166142, Barrier vs. Well Failure, King
Gas migration >>200+ yrs. old, highly regional, many causes, 1000’s of seeps.

Problems in methane migration control include lack of water well construction standards and water quality checks when drilled.

Figure 13 Common Factors in Methane Migration

Highest Potential For Methane Migration

Weak/No Regulations on Private Water Well Construction

High Number of Uncharted Well & Mine Locations

Weak Regulations on O&G Well Construction

Mixed Deep and Shallow Fresh Water Wells

Shallow Coal Seams

Land Fills Glacial History

Absence of Natural Seeps

Strong Water Well Regulations

Strong O&G Well Construction Regulation

Lowest Potential for Methane Migration

SPE 166142, Barrier vs. Well Failure, King
Methane Seepage from Soils

Oil & Gas Seeps are indicators of oil & gas beneath the surface

Many natural seep flows diminished as wells were drilled & produced.

Slide Source: NPC Report, 15 Sept 2011
Source: IHS / HPDI

Well Density in US & Canada

Sedimentary Basins in US & Canada

Source: Keen volden 2005, Etiope & Klusman, 2002
Comparing Spills and Seeps

Various sources – data in SPE 166142
## Estimates: Fracture Water Usage, Flow Back Volumes & Chemicals

<table>
<thead>
<tr>
<th>Basin or Area</th>
<th>Typical Frac Volume Used (Gal.)</th>
<th>% Frac Water Recovered</th>
<th>Typical % of Recycled or Salt Water use – Operator dependent</th>
<th>Typical Chemical % in Frac</th>
<th>Chemical % in Flowback (Gross Est.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnett (TX)</td>
<td>4 to 5 mm</td>
<td>30 to 50%</td>
<td></td>
<td>0.2%</td>
<td>&lt;0.05%</td>
</tr>
<tr>
<td>Devonian (PA)</td>
<td>4 to 5 mm</td>
<td>40 to 50%</td>
<td>&lt;40% to 100%</td>
<td>0.2%</td>
<td>&lt;0.1% (polymer)</td>
</tr>
<tr>
<td>Eagle Ford (TX)</td>
<td>4 to 5 mm</td>
<td>5 to 10%</td>
<td>&lt;30% to &gt;50%</td>
<td>0.3 to 0.4% (Hybrid Frac)</td>
<td>&lt;0.2% (polymer)</td>
</tr>
<tr>
<td>Fayetteville (AR)</td>
<td>3 to 4 mm</td>
<td>30 to 60%</td>
<td></td>
<td>0.2%</td>
<td>&lt;0.05%</td>
</tr>
<tr>
<td>Haynesville (LA)</td>
<td>4 to 6 mm</td>
<td>5 to 15%</td>
<td></td>
<td>0.3% (Hybrid Frac)</td>
<td>&lt;0.1% (polymer)</td>
</tr>
<tr>
<td>Woodford (OK)</td>
<td>4 to 5 mm</td>
<td>30 to 50%</td>
<td>~20% to &gt;50%</td>
<td>0.2%</td>
<td>&lt;0.05%</td>
</tr>
<tr>
<td>Permian Basin Oil Shales (TX)</td>
<td>2 to 3 mm</td>
<td>~40%</td>
<td>~40% to 100%</td>
<td>0.4% to 0.5%</td>
<td></td>
</tr>
<tr>
<td>Conventional Well (Not shale)</td>
<td>50,000 to 100,000</td>
<td>60% to 90% +</td>
<td></td>
<td>1%</td>
<td>~0.5%</td>
</tr>
</tbody>
</table>
## Water Usage. BUT – water used or consumed?

<table>
<thead>
<tr>
<th>Energy Source</th>
<th>Liters water used per 1000 kw-hrs</th>
<th>(IEEE data)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td></td>
<td>38</td>
</tr>
<tr>
<td>Coal</td>
<td></td>
<td>530 to 2100</td>
</tr>
<tr>
<td>Fuel Ethanol</td>
<td></td>
<td>32,000+</td>
</tr>
<tr>
<td>Biodiesel</td>
<td></td>
<td>180,000+</td>
</tr>
<tr>
<td>Electric by gas or coal</td>
<td></td>
<td>15,000+</td>
</tr>
<tr>
<td>Hydroelectric</td>
<td></td>
<td>260</td>
</tr>
<tr>
<td>Nuclear</td>
<td></td>
<td>31,000+</td>
</tr>
<tr>
<td>Geothermal</td>
<td></td>
<td>1680+</td>
</tr>
</tbody>
</table>
Waters produced from shales?

• Composition – normally 35,000 to 50,000+ ppm of total dissolved solids. Some suspended solids. Mostly salt water.

• In certain areas of country, NORM (naturally occurring radioactive materials), are found. None known to exceed acceptable limits unless concentrated.

• Water declines rapidly in most shale wells in first 5 to 15 days.
Water Issues:
Produced After a Fracture Treatment

Figure 5  About 40% of the produced water from a well after fracturing comes back as rapid flow in the first one to two weeks of production (0.1% to 0.5% of total well life)
Where does the Produced Water Go?

- Oil field brines – defined as less dangerous waste by EPA compared to toxic waste after 10 year study. Handled as Class II rather than Class I waste.

- Cannot be released at surface (except in very rare cases) and should not be allowed in a POTW facility.

- Best use is to recycle as water flood or frac fluid. Frac Water Cooperatives???

- Disposal is a last and limited option.
Does Fracturing with Fresh Water Remove Water from the Earth’s Hydrological Cycle?

• Average gas shale frac uses 5,000,000 gallons of water (salt water is replacing some fresh water as fracturing fluid).

• When methane is burned as a fuel:
  – \( \text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 = 2\text{H}_2\text{O} \)
  – 100,000 BTU of methane => 9.41 lb of water
  – 100,000 BTU (methane) = 100 scf of methane
  – 1 mmscf of methane produces \([(1,000,000/100 * 9.41)/8.33 \text{ lb/gal}] = 11,300 \text{ gal} \)
  – 1 bcf produces 11,300,000 gallons of fresh water
  – Gas shale wells produce 1 to 10+ bcf over their lifetime.

• Methane may be far from the well when burned, so the water is released in a different area.
Risk = Frequency of Occurrence vs. Impact

Risk exists in every action.

What is operationally safe?

Occurrence & impact create a threat level that we can understand & accept or reject based on what we believe: hopefully on assessment of facts.
Regulations Should Reflect Risk Assessment: Effective Improvement or Development Preventers?

<table>
<thead>
<tr>
<th>Effective Improvers</th>
<th>Development Preventers</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Standards to reduce real risks</td>
<td></td>
</tr>
<tr>
<td>– Consistent operations by all operators</td>
<td></td>
</tr>
<tr>
<td>– Encourages produced water reuse instead of disposal.</td>
<td></td>
</tr>
<tr>
<td>– Addresses chemical concerns</td>
<td></td>
</tr>
<tr>
<td>– Provides a level field for well development.</td>
<td></td>
</tr>
<tr>
<td>– Requires reporting of all fracs to public available site (<a href="http://www.fracfocus.com">www.fracfocus.com</a>)</td>
<td></td>
</tr>
<tr>
<td>• Prevents Any Development</td>
<td></td>
</tr>
<tr>
<td>– Every well a target for environmental impact and endless public challenge.</td>
<td></td>
</tr>
<tr>
<td>– Creates unachievable goals or excessive cost to comply.</td>
<td></td>
</tr>
<tr>
<td>– Continues to make companies prove a negative – regardless of a individual performance record.</td>
<td></td>
</tr>
<tr>
<td>– Slow Down / Delay Approach</td>
<td></td>
</tr>
</tbody>
</table>
Additives – What are the chemicals in fracturing?

<table>
<thead>
<tr>
<th>Most Common Slick Water Frac Additives</th>
<th>Composition</th>
<th>CAS Number</th>
<th>Alternate Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Friction Reducer</td>
<td>Polyacrylamide</td>
<td>9003-05-8</td>
<td>Adsorbent in baby diapers, flocculent in drinking water preparation</td>
</tr>
<tr>
<td>Biocide</td>
<td>Glutaraldehyde</td>
<td>111-30-8</td>
<td>Medical disinfectant</td>
</tr>
<tr>
<td>Alternate Biocide</td>
<td>Ozone, Chlorine dioxide UV,</td>
<td>10028-15-6</td>
<td>Disinfectant in municipal water supplies</td>
</tr>
<tr>
<td></td>
<td>10049-04-4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gellants</td>
<td>Guar and Cellulose</td>
<td>9000-30-0</td>
<td>Thickening ice cream and soup</td>
</tr>
<tr>
<td></td>
<td>9004-62-0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Questions I would ask.

• Does the company have an adequate maintenance culture?

• Will all chemicals, water volumes and water source be listed on the [www.fracfocus.org](http://www.fracfocus.org)? (better search capability now and also see SkyTruth for files)

• Is a minimum distance accepted between designed top of fracture & deepest fresh water?

• Will “green completions” or the regional specific equivalent, or better alternative, be used?

• Can multi-well pads be used in the development phase instead of single well pads?

• Is it possible to limit busy development activity to a certain season, time or remote area?
Questions I would ask.

- Will basic site investigation be done (abandoned wells, seeps, mines or problem area near well site?)
- Methane migration potential? Gas migration is strongly linked to specific geologic regions.
- Will fresh water wells be tested, where permitted, within at least ¼ mile of proposed well prior to drill?
- Will quick lay pipelines with leak-tight connections, be considered to reduce truck traffic?
- Is water supply sustainability a consideration?
- How will recycled water for fracturing be stored?
- Does company have a list of chemicals they will not use?
Problems?

• Transport spills – same frequency as other chemical transport options (rail, barge, truck).
• Technology eras define the leak rates.
  – Well leaks dropped steadily from 1916 to year 2000.
    • Leakage rates of modern wells often less than 0.00005% of volumes produced.
• Safest is horizontal, multi-fractured well.
  – Replaces 5 to 10 vertical wells
  – Can reduce development footprint by >90%.
  – Over 1 million fracs from horizontal wells.
Some Conclusions

1. Risk of GW pollution from producing well is low.
2. Barrier failure rates and well failure rates vary widely.
3. Failure of wells of a specific time era are artifacts of that era; not reflective of wells completed today.
4. Methane gas migration from deep drilling often not connected to O&G production – check the design!
5. Improperly plugged old wells & water wells may be conduits for methane migration.

See SPE 133456, 152596 and 166142 for more information. All available on www.OnePetro.org
Air Emissions – during and after...

• Frac: Do not have to use diesel pumpers!
  – Natural gas bifuel kits cut diesel use 50 to 60%
  – Electric pumpers making their way into the field

• Green Completions – less CH4 gas leakage
  – Target is < 1.0% - we are there now. Can go lower (UT study September 2013)
  – Limit pneumatic equipment venting.
Let’s start with a 50% reduction in diesel exhaust pollutants => Natural Gas as Bifuel

Figure 1  General Schematic of Add-On Natural Gas Equipment to a Diesel Engine
NATURAL GAS DISPLACING ALL OR PART OF DIESEL FUEL

- Reduces CO2 Emissions: 20-30%
- Reduces CO Emissions: 70-90%
- Reduces NOx Emissions: 75-95%
- Reduces Particulate Matter Emissions: 70-80%
- Reduces VOC Emissions: 50-55%

Effect of 50% to 60% substitution of natural gas for diesel

Source: U.S. Dept. of Energy - Argonne National Laboratory Report; TIAx Report; NGV America; AGL