Shale Development – Does Cheap Energy Really Mean Flaming Tap Water?

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Presentation Outline

• Introduction
• Why is US shale development important?
• Aquifer protection
• Wattenberg study
• San Juan Basin Results
• Summary
• Questions and answers
Introduction

• Shale development:
  – Controversial
  – Leakage estimates disputed

• This presentation provides a fact based estimate of leakage
Why is US Shale Development Important?

Weekly U.S. Field Production of Crude Oil

Source: U.S. Energy Information Administration

US EIA
Shale Plays Around the World
Historical Well Construction

• The first recorded salt well in China
  – 2,250 years ago
• Persian oil development
  – 8 centuries ago
• Baku hand-dug holes to 35 meters
  – 4 centuries ago
More “Modern” Drillers

- To access the subsurface you need a hole.
- To drill a hole, typically an aquifer is encountered.
- Early drillers recognized the need to case aquifers but:
  - How deep?
  - Good cement job?
  - Legacy wells?

http://drakewell.org
Aquifer Protection

• Aquifer protection:
  – Drill through the aquifer to an impermeable formation
  – Run surface casing and cement

Simple?

Exhibit 10: Vertical Migration of Fluids

Does Methane Exist in Fresh Water Aquifers?

Biogenic gas is naturally occurring in aquifers (swamp gas).

Thermogenic gas is associated with deeper oil and gas development.
Aquifer Protection

Wellbores should have at least three barriers in place

1. Cemented surface casing
2. Cemented prod. casing
3. Annular hydrostatic head
Contamination Probability Hypothesis

Multiplication rule for independent events can be used to estimate aquifer contamination. This requires multiple barrier failures for a catastrophic failure:

$$P = \prod_{i=1}^{N} P(A_i)$$

What if a barrier failure probability is 5% or 1/20?
Contamination Probability Hypothesis
5% of an individual barrier failure

During production:
three independent failures

1. Cemented surface casing
2. Cemented production casing
3. Annular hydrostatic head

During fracturing: two more:

4. Frac string pressure monitoring
5. Annular pressure monitoring
Contamination Probability Hypothesis - Production

Probability of hydrocarbon migration:

\[ P = \prod_{i=1}^{N} P(A_i) \]

\[ P = 0.05^3 \]

1 per 8,000 wells.
Contamination Probability Hypothesis - Fracturing

- Probability of frac fluid migration:

\[ P = \prod_{i=1}^{N} P(A_i) \]

\[ P = 0.05^5 \]

- 1 per 3,200,000 wells.
Aquifer Protection Case Study

- The Wattenberg Field near Denver, CO.
- Data from 17,948 oil wells (1970 – 2013).
- Wells were classified by construction types.
- Possible barrier failures were identified by:
  - Remedial cementing below the surface casing
  - Possible presence of Sustained Annular Pressure
- Catastrophic barrier failures:
  - Thermogenic gas detected in offset water wells combined with barrier failure in an adjacent well.
Aquifer Methane Study

Li and Carlson 2014
Wattenberg Pressure Profile

Weimer, 1995
1970’s shallow surface casing depths were designed for the purpose of well control during drilling operations and not for aquifer isolation.
The Niobrara and Codell formations, at an average depth of 6,950 – 7,400 ft TVD, were thought to be unproductive until their “discovery” in the early 1980’s.
<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SHALLOW SURFACE CASING + TOP OF PRODUCTION CASING CEMENT BELOW OVER PRESSURED HYDROCARBON RESERVOIR</td>
</tr>
<tr>
<td>2</td>
<td>SHALLOW SURFACE CASING + TOP OF PRODUCTION CASING CEMENT BELOW UNDER PRESSURED HYDROCARBON RESERVOIR</td>
</tr>
<tr>
<td>3</td>
<td>SHALLOW SURFACE CASING + TOP OF PRODUCTION CASING CEMENT ABOVE TOP OF GAS</td>
</tr>
<tr>
<td>4</td>
<td>SHALLOW SURFACE CASING + TOP OF PRODUCTION CASING CEMENT ABOVE SURFACE CASING SHOE</td>
</tr>
<tr>
<td>5</td>
<td>DEEP SURFACE CASING + TOP OF PRODUCTION CASING CEMENT BELOW UNDER PRESSURED HYDROCARBON RESERVOIR</td>
</tr>
<tr>
<td>6</td>
<td>DEEP SURFACE CASING + TOP OF PRODUCTION CASING CEMENT ABOVE TOP OF GAS</td>
</tr>
<tr>
<td>7</td>
<td>DEEP SURFACE CASING + TOP OF PRODUCTION CASING CEMENT ABOVE SURFACE CASING SHOE</td>
</tr>
</tbody>
</table>
Wellbore Design Impacts

SPE-175401-MS • An Assessment of Risk of Migration to Fresh Water Aquifers: Fleckenstein
Well Designs in Use
Well Barrier Possible Failures
### Potential and Catastrophic Barrier Failures

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>ORIGINAL WELL COUNT</th>
<th>POTENTIAL BARRIER FAILURES</th>
<th>POTENTIAL BARRIER FAILURE %</th>
<th>CATASTROPHIC BARRIER FAILURES</th>
<th>CATASTROPHIC BARRIER FAILURE %</th>
<th>AVG COMPLETION DATE</th>
<th>P&amp;A WELL COUNT</th>
<th>CURRENT WELL COUNT</th>
<th>ORIGINAL AVG SURFACE CASING DEPTH (FT)</th>
<th>ORIGINAL AVG TOP OF PRODUCTION CEMENT (FT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATEGORY 1</td>
<td>166</td>
<td>100</td>
<td>60.24%</td>
<td>3</td>
<td>1.81%</td>
<td>1979</td>
<td>57</td>
<td>15</td>
<td>253</td>
<td>7,334</td>
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<tr>
<td>CATEGORY 2</td>
<td>621</td>
<td>219</td>
<td>35.27%</td>
<td>5</td>
<td>0.81%</td>
<td>1983</td>
<td>138</td>
<td>301</td>
<td>306</td>
<td>6,566</td>
</tr>
<tr>
<td>CATEGORY 3</td>
<td>46</td>
<td>16</td>
<td>34.78%</td>
<td>1</td>
<td>2.17%</td>
<td>1987</td>
<td>14</td>
<td>31</td>
<td>321</td>
<td>4,008</td>
</tr>
<tr>
<td>CATEGORY 4</td>
<td>7</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
<td>1982</td>
<td>1</td>
<td>15</td>
<td>222</td>
<td>125</td>
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<tr>
<td>CATEGORY 5</td>
<td>8,789</td>
<td>77</td>
<td>0.88%</td>
<td>1</td>
<td>0.01%</td>
<td>1995</td>
<td>782</td>
<td>6,140</td>
<td>559</td>
<td>6,111</td>
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<tr>
<td>CATEGORY 6</td>
<td>5,433</td>
<td>6</td>
<td>0.11%</td>
<td>0</td>
<td>0.00%</td>
<td>2007</td>
<td>105</td>
<td>7,181</td>
<td>712</td>
<td>2,816</td>
</tr>
<tr>
<td>CATEGORY 7</td>
<td>1,766</td>
<td>0</td>
<td>0.00%</td>
<td>0</td>
<td>0.00%</td>
<td>2009</td>
<td>8</td>
<td>2,040</td>
<td>719</td>
<td>534</td>
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<tr>
<td>TOTAL</td>
<td>16,828</td>
<td>418</td>
<td>2.48%</td>
<td>10</td>
<td>0.06%</td>
<td></td>
<td>1,105</td>
<td>15,723</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D&amp;A</td>
<td>147</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

SPE-175401-MS  An Assessment of Risk of Migration to Fresh Water Aquifers: Fleckenstein

973 horizontal wells (Categories 6 and 7) have had neither potential or catastrophic barrier failures
Contamination Probability Hypothesis – Did it work?

Probability of hydrocarbon migration

\[ P = 0.05^3 \quad P_{\text{act}} = 0.024^3 \]

1 per 8,000 wells – original hypothesis
10 per 17,950 wells (1 per 1,795)
– actual (4 times larger) – Why??

9 per 833 poorly constructed wells
1 per 15,995 well constructed wells
A Continued Assessment of the Risk of Migration of Hydrocarbons or Fracturing Fluids into Fresh Water Aquifers in the Piceance, Raton, and San Juan Basins of Colorado
San Juan Basin, Colorado (only)
Well Barrier Possible Failures
San Juan Basin Catastrophic Barrier Failures

<table>
<thead>
<tr>
<th>SAN JUAN BASIN WELLS</th>
<th>ORIGINAL WELL COUNT</th>
<th>CATASTROPHIC BARRIER FAILURES</th>
<th>CATASTROPHIC BARRIER FAILURE %</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATEGORY 1</td>
<td>0</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>CATEGORY 2</td>
<td>12</td>
<td>1</td>
<td>8.33%</td>
</tr>
<tr>
<td>CATEGORY 3</td>
<td>13</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>CATEGORY 4</td>
<td>71</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>CATEGORY 5</td>
<td>54</td>
<td>1</td>
<td>1.85%</td>
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<tr>
<td>CATEGORY 6</td>
<td>348</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>CATEGORY 7</td>
<td>2,677</td>
<td>0</td>
<td>0.00%</td>
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<tr>
<td>CATEGORY 8</td>
<td>64</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>CATEGORY 9</td>
<td>17</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>CATEGORY 10</td>
<td>148</td>
<td>0</td>
<td>0.00%</td>
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<tr>
<td>CATEGORY 11</td>
<td>427</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>CATEGORY 12</td>
<td>0</td>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>3,831</strong></td>
<td><strong>2</strong></td>
<td><strong>0.05%</strong></td>
</tr>
<tr>
<td>D&amp;A</td>
<td>358</td>
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<tr>
<td>TOTAL WELLS</td>
<td>4,189</td>
<td></td>
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</tr>
</tbody>
</table>
1. Aquifers can be protected against “fracking”. No evidence of subsurface aquifer contamination by stimulation operations through wellbores was discovered in the Wattenberg Field. No undisputed cases of subsurface contamination have been reported in the US from hydraulic fracturing in shale development.

2. Migration of natural occurs, but infrequently. Nine undisputed cases of methane migration to aquifers were discovered in the Wattenberg field. A single possible case of surface contamination from wellbore migration was discovered. All but one of these cases occurred in legacy wells with poor well construction methods.
3. Probability of potential failure of one or more barriers in all vertical wells without hydrocarbon migration was determined to be 2.4%.

4. Probability of failure of one or more barriers in all vertical wells resulting in catastrophic failure and hydrocarbon migration to a freshwater aquifer or surface was determined to be 0.06%.

5. Eighty percent of the potential barrier failures occurred on wells with shallow surface casing set above the base of the Fox-Hills aquifer.

6. No evidence of failures of one or more barriers was detected in horizontal wells for shale development.
Acknowledgments

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Thank you!

Questions?