The health and environmental impacts of shale gas development:
What we know and don’t

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Damage function chain

Activity ➔ burden ➔ toxicity ➔ probability in environment ➔ probability of exposure ➔ impact ➔ value
This talk

Comprehensive risk matrix
Risks from liquid wastes: produced water, ponds and tanks, surface water, seismic
Ecological
Health (truck accidents, low birth weight)
Quality of life (property values)
Valuation
Research priorities

Activity ➔ burden ➔ toxicity ➔ probability in environment ➔ probability of exposure ➔ impact ➔ value
### Site Development and Drilling Preparation

After locating a site for shale gas development, the area must be excavated and prepared for drilling. Preparation activity also often includes leveling of the site.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Groundwater</th>
<th>Surface Water</th>
<th>Soil Quality</th>
<th>Air Quality</th>
<th>Habitat Disruption</th>
<th>Community Disruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearing of land/construction of roads, well pads, pipelines, other infrastructure</td>
<td>Stormwater flows</td>
<td>Stormwater flows</td>
<td>Conventional air pollutants and CO₂</td>
<td>Habitat fragmentation</td>
<td>Invasive species</td>
<td>Industrial landscape</td>
</tr>
<tr>
<td></td>
<td>Invasive species</td>
<td></td>
<td></td>
<td></td>
<td>Light pollution</td>
<td>Noise pollution</td>
</tr>
<tr>
<td>On-road vehicle activity</td>
<td>Stormwater flows</td>
<td></td>
<td></td>
<td>Conventional air pollutants and CO₂</td>
<td>Other</td>
<td>Noise pollution</td>
</tr>
<tr>
<td>Off-road vehicle activity</td>
<td>Stormwater flows</td>
<td></td>
<td></td>
<td>Conventional air pollutants and CO₂</td>
<td>Other</td>
<td>Noise pollution</td>
</tr>
</tbody>
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### Drilling Activities

Drilling begins by boring a single well shaft vertically into the desired formation. One or more lateral wells are then drilled from the end of the vertical wellbore, angling to run horizontally through the shale formation.

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<th>Community Disruption</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling equipment operation at surface</td>
<td>Drilling fluids/cuttings</td>
<td>Drilling fluids/cuttings</td>
<td>Drilling fluids/cuttings</td>
<td>Conventional air pollutants and CO₂</td>
<td>Industrial landscape</td>
<td>Light pollution Noise pollution</td>
</tr>
<tr>
<td>Drilling of vertical and lateral wellbore</td>
<td>Methane</td>
<td>Drilling fluids/cuttings</td>
<td>Methane</td>
<td></td>
<td>Light pollution</td>
<td>Noise pollution</td>
</tr>
</tbody>
</table>
Wastewater characteristics from Marcellus shale gas development in PA

- Researchers: J. Shih, S. Olmstead (UT Austin), J. Chu, L. Muehlenbachs (U. Calgary), J. Saiers (Yale), S. Anisfeld (Yale).
- Statistically analyzes characteristics of flowback, produced water, and drilling fluid waste sent to wastewater treatment facilities in PA, 2008-2011.
- Data Source: Form 26R, submitted to PADEP by “residual waste” generators.
- 432 different analytes were identified in the data, in the following categories:
  1. General chemicals
  2. Organics
  3. Pesticides
  4. Metals
  5. Radioactive Materials
Comparison of **General Chemicals** in Produced Water and Fracking Fluid Waste

* Number at the bottom of the boxplot is the sample size
Comparison of **Metals** in Produced Water and Fracking Fluid Waste
Comparison of Organics in Produced Water and Fracking Fluid Waste

- **Oil & Grease**: MCL = 0.005 mg/L
- **Benzene**: MCL = 0.005 mg/L
- **Toluene**: MCL = 1 mg/L

Flowback (804) □ Produced Water (802)
Comparison of Naturally Occurring Radioactive Materials inProduced Water and Fracking Fluid Waste

![Comparison of Naturally Occurring Radioactive Materials in Produced Water and Fracking Fluid Waste](chart)

- **RFF project** focuses on environmental risks from shale development.

**Comparison of Naturally Occurring Radioactive Materials in Produced Water and Fracking Fluid Waste**

- **Max**
- **75%**
- **50%**
- **25%**
- **Min**

**Concentration (pCi/L)**

- **Max**
- **75%**
- **50%**
- **25%**
- **Min**

- **MCL = 5 pCi/L**

**Legend:**
- **Flowback (804)**
- **Produced Water (802)**
Analysis of state databases of spills and releases

- New Mexico, Colorado, and Oklahoma (not comparable)
- Only reported spills/releases
- Materials spilled: Produced water, fracturing fluid, brine, drilling mud/fluid, HCl, KCl, crude oil, fresh water

Figure: Spills from pits and frac tanks as reported to New Mexico OCD.
## Analysis of state databases of spills and releases

### Number of spills in New Mexico by category (2000 – 2013)

#### Panel A: Pits

<table>
<thead>
<tr>
<th>Cause of spill</th>
<th># spills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overflow</td>
<td>33</td>
</tr>
<tr>
<td>Liner malfunction</td>
<td>31</td>
</tr>
<tr>
<td>Unidentified or undocumented</td>
<td>19</td>
</tr>
<tr>
<td>Discovery of historical spill</td>
<td>8</td>
</tr>
<tr>
<td>Blowover</td>
<td>7</td>
</tr>
<tr>
<td>Improper closure or reclamation</td>
<td>3</td>
</tr>
<tr>
<td>Sinkhole</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>105</strong></td>
</tr>
</tbody>
</table>

#### Panel B: Frac Tanks

<table>
<thead>
<tr>
<th>Cause of spill</th>
<th># spills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leak</td>
<td>21</td>
</tr>
<tr>
<td>Unidentified or undocumented</td>
<td>13</td>
</tr>
<tr>
<td>Overflow</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
</tr>
<tr>
<td>Collapse</td>
<td>2</td>
</tr>
<tr>
<td>Vandalism</td>
<td>2</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>50</strong></td>
</tr>
</tbody>
</table>
Surface Water Quality Risk Study (PNAS, 2013)

We exploit spatial and temporal variation in the proximity of shale gas wells, waste treatment facilities, and surface water quality monitors in Pennsylvania to estimate:

1. the impact of *shale gas wells* on downstream chloride and TSS concentrations; and

2. the impact of *shale gas waste treatment* and release to surface water on downstream chloride and TSS concentrations.
Conclusions

• No statistically significant impact of shale gas wells on downstream chloride concentrations.
  • A positive result here would have been consistent with contamination problems from spills, dumping, etc.

• Release of treated shale gas waste to surface water by permitted waste facilities appears to increase downstream chloride concentrations.
  • Effect is significant only for POTWs, not CWTs.

• Shale gas wells appear to increase downstream TSS concentrations.
Induced Seismicity

• Seismicity from fracking NOT a problem
• Deep well injection
  • #3 in anthropogenic earthquakes):
  • 40,000 wells taking oil and gas liquid wastes.
  • Growth in earthquakes > 3.0 since 2009, “coincident with” oil and gas waste injections.”
  • In CO, TX, OH, ARK, OK. a few “caused by.”
Cumulative number of earthquakes with a magnitude of 3.0 or larger in the central and eastern United States, 1970–2013. The dashed line corresponds to the long-term rate of 20.2 earthquakes per year, with an increase in the rate of earthquakes starting around 2009.
Induced Seismicity, cont.

• DWI better than pits, which leak; better than CWTs which can’t treat some elements of produced water

• Can it be managed?
  • Industry cutting water flows through reuse/recycling, using less liquids
Figure 3. Satellite image of Mesa in 1999 (left) compared to 2009 (right).

Figure 6. Predicted level of mule deer habitat use during Year 10 (winter of 2009-10) of natural gas development on the Mesa.
Truck Traffic Accidents in Pennsylvania by Well Activity

Accidents in counties with more than 20 wells
Accidents in counties with less than 20 wells
Well pads drilled
Property Values

• Great aggregator of local perceived risks – with **real** effects
• Effects of proximity and intensity
• Proximity Matters
  • Within 1.5 km and on groundwater: $33,000 decrease versus homes further away and on public water
• Intensity Matters a little
Figure 2. Estimated WTP ($ household\(^{-1}\) year\(^{-1}\)), on average, for the reduction of risks associated with shale gas development
Research priorities for the future

• Remainder of the water cycle
• **Net** benefits to communities of SGD
• Approaches for internalizing externalities and compensating locals.
  • Act 13. Turned down by PA Supreme Court.
• Mental health effects of SGD? Low Birth Weight effect?
• Legacy
Thank you!

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