RFF’s Center for Energy Economics and Policy

Cumulative Risks of Shale Gas Development

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### 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>
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<td>Conventional air pollutants and CO₂</td>
<td>Habitat fragmentation</td>
<td>Invasive species</td>
<td>Industrial landscape</td>
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<td>Light pollution, Noise pollution</td>
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<tr>
<td>On-road vehicle activity</td>
<td>Stormwater flows</td>
<td></td>
<td>Conventional air pollutants and CO₂</td>
<td>Other</td>
<td></td>
<td>Noise pollution, Road congestion/accidents</td>
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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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<td>Drilling equipment operation at surface</td>
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<td>Drilling of vertical and lateral wellbore</td>
<td>Methane</td>
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### Activities

- Site development and drilling preparation
  - Vertical drilling
  - Horizontal drilling
  - Fracturing and completion
  - Well production and operation
- Flowback and produced water storage/disposal
- Shutting-in, plugging and abandonment
- Workovers
- Upstream and downstream activities

### Burdens

- Air pollutants
- Drilling fluids and cuttings
- Saline water intrusion
- Fracturing fluids
- Flowback constituents (other than fracturing fluids)
- Produced water constituents
- Condenser and dehydration additives
- Habitat/community disruptions
- Other

### Intermediate Impacts

- Groundwater
- Surface water
- Soil quality
- Air quality
- Habitat disruption
- Community disruption
- Occupational hazard

### Final Impacts

- Human health impacts
- Market impacts
- Ecosystem impacts
- Climate change impacts
- Quality of life impacts
On-road vehicle activity

- Conventional air pollutants and CO\textsubscript{2}
- Noise pollution
- Road congestion

Intermediate Impacts

- Air quality
- Community disruption

Final Impacts

- Morbidity
- Climate change impacts
- Aesthetics
- Time loss
1. Expert survey of shale gas development risks

2. Statistical analysis:
   a) Effects of shale gas activity on surface water quality in Pennsylvania
   b) Analysis of chemical assays of flowback/produced water

3. State-by-state regulatory analysis

4. Citizen Survey

5. Cross cutting observations
Surveying the Experts: Who & What?

215 experts:

- **NGOs** (35): Most national environmental groups, some local
- **Academics** (63): Universities/think tanks
- **Government** (42): Federal agencies; about half the relevant states; river basin commissions
- **Industry** (75): Operating and support companies, trade associations, consulting firms, law firms

Chose high priorities among 264 possible risks
Overlap of each groups’ high priority risks
What is known about the “consensus” risks?

- Olmstead et al. 2013
- Ongoing TNC/RFF work
- Competing estimates
- Nicot and Scanlon 2012
- ??
- Olmstead et al. 2013
- Warner et al. 2013 (wells, not ponds)
- ??
What is known about the “consensus” risks?

Osborn et al. 2011, Warner et al. 2013
Some surprises:
- Surface waters dominate; groundwater risks identified less frequently
- Only two pathways are unique to the shale gas development process
- Habitat fragmentation

Some expected findings:
- On-site pit and pond storage of flowback
- Freshwater withdrawals
- Venting of methane
- Treatment and release of flowback liquids
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 Cl\(^-\) concentrations.
  • A positive result here would have been consistent with systematic contamination problems from spills, etc.

• Release of treated shale gas waste to surface water by permitted wastewater treatment facilities increases downstream Cl\(^-\) concentrations.
  • Effect is more strongly associated with facilities affected by 2011 regulatory attention from PA DEP/EPA.

• Shale gas well pads increase downstream TSS concentrations.
What are Cumulative Risks?

• Defined as risks that accumulate or have synergy
• Scale
  Flow burdens (needs an increase in rate of development to qualify)
  Stock burdens
• Interactions
  Chemical
  Physiological
  Psychological/behavioral
  Regulatory (though we leave these for the next paper)
• Underlying paradigm: the damage function
  Activities ➔ Burdens ➔ Concentration ➔ Exposure ➔ Impact ➔ Social damage ($)
Damage Functions

Effects or $\rightarrow$ Burden(s)

- Physiologic, regulatory, cognitive

Graph showing different damage functions labeled A, B, C, and D.
Cumulative Risks From Scale: Flow vs. Stock

- Flow burden example
  - Water withdrawals for hydraulic fracturing
  - If the pace of well drilling and completion remains the same, risks from water withdrawals for hydraulic fracturing may not accumulate (because only wells in that stage of production require large water inputs).
  - If the pace of development increases, then the total burden associated with water withdrawals will increase.

- Stock burden example
  - Habitat fragmentation from pipelines
  - More shale gas development (regardless of pace) ➔ more pipelines ➔ more fragmentation of habitat
Cumulative Risks From Scale: Water pollution

- Non-linear (threshold) cumulative damages
  - Risk of non-compliance with wastewater effluent standards under the Clean Water Act (wastewater treatment facilities’ NPDES permits)
  - Risk of violating maximum contaminant levels under the Safe Drinking Water Act
  - Risk of exceeding TMDLs in impaired watersheds (303d listed) under the Clean Water Act (sediments, TDS, etc.)
  - Increased salinity from treated waste disposal or accidental releases ➔ losses in agricultural productivity, but only above thresholds for particular crops.

- Linear (?) cumulative damages
  - Impacts of salinity on downstream municipal and industrial users (corrosion, etc.)
Cumulative Risks From Scale: Methane emissions

- More shale gas development ➔ more fugitive methane ➔ increased stock of greenhouse gases in the upper atmosphere ➔ climate change

- Globally, this cumulative risk (and regulation) could be significant.
Cumulative Risks From Scale: Habitat fragmentation

- More shale gas development $\Rightarrow$ more infrastructure $\Rightarrow$ more fragmented habitat $\Rightarrow$ decreased species richness/composition/populations

- Patch shrinkage and edge effects both create non-linearities

- Can create advantages for some species (invasives, predators)
Cumulative Risks From Scale: Methane and salinity in groundwater

- More shale gas development ➞ greater frequency of casing/cementing failures ➞ increased potential for groundwater contamination

- Methane in drinking water wells poses risks from inhalation, potential explosion. Thresholds?

- If brine migrates to groundwater, this represents a stock burden, the damages of which would be nonlinear.
  - As salinity levels increase beyond thresholds for human consumption, irrigation, etc., groundwater is no longer a cost-effective water source for those uses.
Additional Cumulative Risks From Scale

- NORMs in flowback or produced water reaching soils, sediments, solid waste disposal facilities
- Congestion, accidents from truck traffic
Cumulative Risks From Interactions

• Chemical interactions between similar burdens
  • VOCs and NOx emissions → ozone

• Burdens from dissimilar pathways may interact
  • Surface water withdrawals + water pollution
  • Habitat fragmentation + water pollution may intensify species impacts

• Chemical, physiological, behavioral interactions between a shale gas burden and something else in the environment
  • Chloride in surface water from treated flowback/produced water can mobilize metals, phosphates in stream sediments.
Cumulative Risk Reductions

• Simultaneous risk mitigation on multiple pathways from:
  • Regulatory policies (subject of next committee meeting, paper)
  • Voluntary industry approaches
  • Avoidance behavior by exposed populations

• Example of voluntary industry approach: recycling flowback
  • Firms do this in Marcellus because it is cost-effective (constraints on wastewater disposal); rare in other plays.
  • Reduces risks from pathways related to wastewater storage/disposal (impacts on groundwater, surface water, seismicity), water withdrawals, truck traffic.
  • Note that risks from other pathways could increase (e.g., solid waste disposal, spills)
Cumulative Risk Reductions, cont.

• Example of avoidance behavior:
  • Individuals may move away from shale gas development, reducing exposure to burdens (noise, pollution, traffic).

• While avoidance behavior does mitigate risk, it is costly (both out-of-pocket, and in terms of welfare).
Conclusions

• RFF expert survey suggests significant consensus regarding which risks from shale gas development need more attention from industry, regulators.

• We know more about the magnitudes of some of these (e.g., fugitive methane, sending flowback to wastewater treatment plants) than others (e.g., habitat impacts from infrastructure).

• Though research typically considers risk pathways in isolation, many risks from shale gas development are really cumulative:
  • They may increase together with the scale of development
  • They may be amplified by interactions with other risks, environmental burdens, behavior of firms/exposed individuals