RFF's Center for Energy Economics and Policy

Cumulative Risks of Shale Gas Development

RESOURCES FOR THE FUTURE

Alan Krupnick, PhD
Director, Center for Energy Economics and Policy
Sheila Olmstead, Senior Fellow
Presentation to the Committee on Shale Gas Risks, NRC
May 31, 2013

Risk Matrix

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.

Activity	Intermediate Impacts					
	Groundwater	Surface Water	Soil Quality	Air Quality	Habitat Disruption	Community Disruption
Clearing of land/construction of roads, well pads, pipelines, other infrastructure		Stormwater flows Invasive species	Stormwater flows	Conventional air pollutants and CO_2	Habitat fragmentation Invasive species	Industrial landscape Light pollution Noise pollution
On-road vehicle activity		Stormwater flows		Conventional air pollutants and CO_2	Other	Noise pollution Road congestion/accidents
Off-road vehicle activity		Stormwater flows		Conventional air pollutants and CO_2	Other	Noise pollution

Return to Top

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.

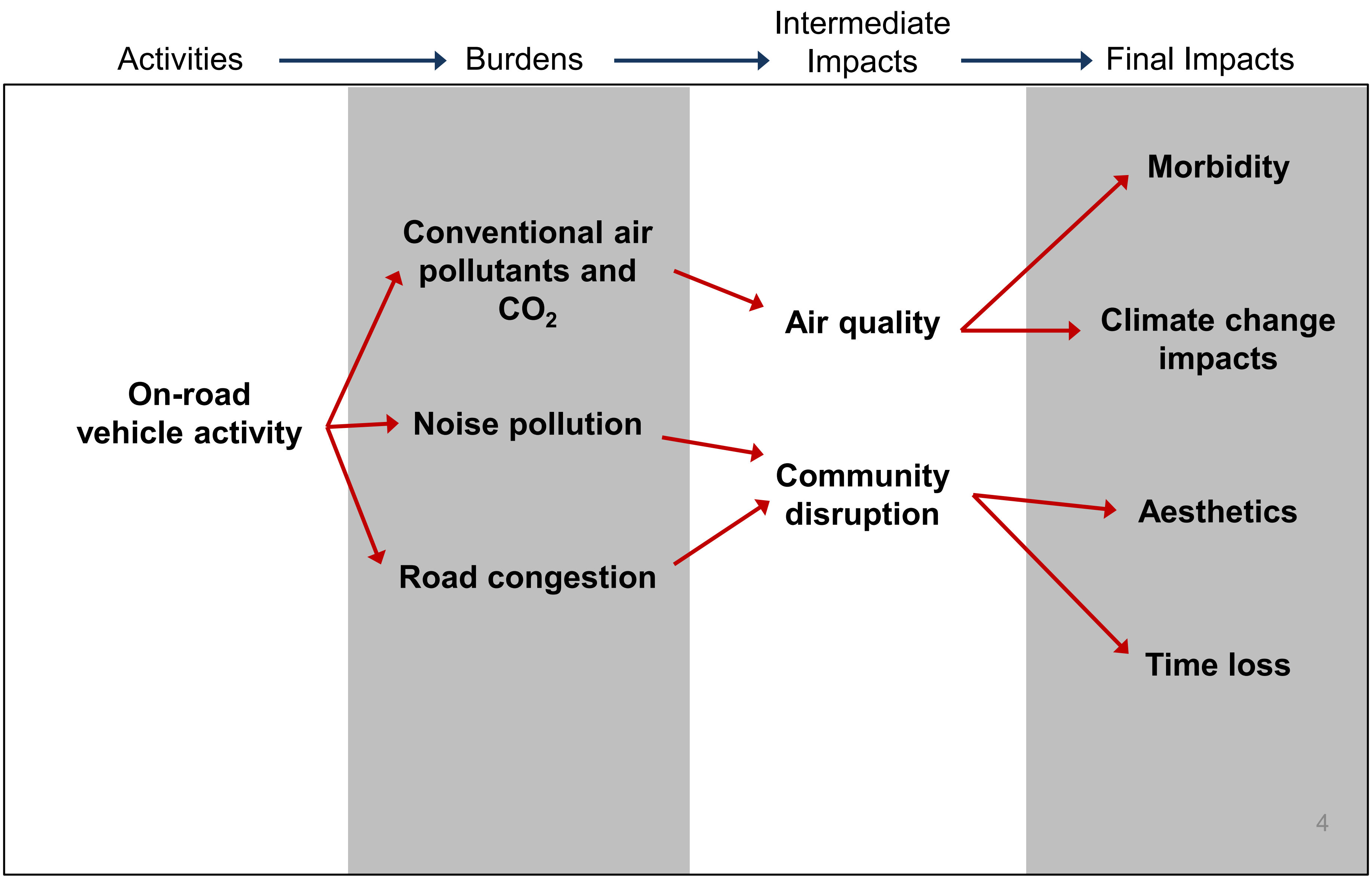
Activity	Intermediate Impacts					
	Groundwater	Surface Water	Soil Quality	Air Quality	Habitat Disruption	Community Disruption
Drilling equipment operation at surface	Drilling fluids/cuttings	Drilling fluids/cuttings	Drilling fluids/cuttings	Conventional air pollutants and CO_2		Industrial landscape Light pollution Noise pollution
Drilling of vertical and lateral wellbore	Methane Drilling fluids/cuttings Intrusion of saline-formation water into fresh groundwater	Drilling fluids/cuttings		Methane		

RFF

Creating Risk Pathways (Risk Matrices on the web)

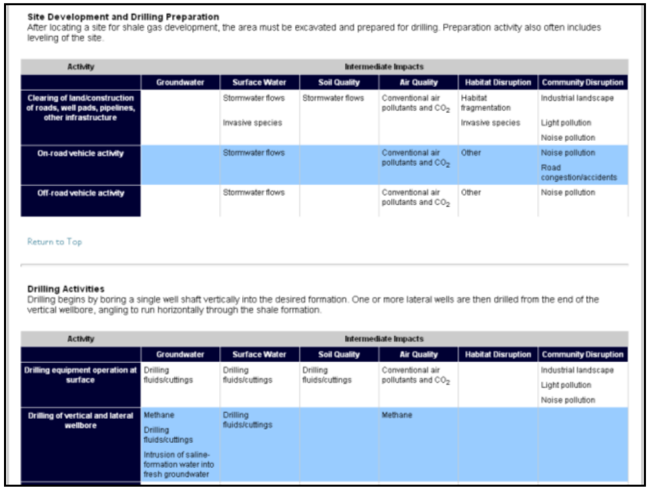
Activities	Burdens	Intermediate Impacts	Final Impacts
Site development and drilling preparation	Air pollutants	Groundwater	Human health impacts
Vertical drilling	Drilling fluids and cuttings	Surface water	Market impacts
Horizontal drilling	Saline water intrusion	Soil quality	Ecosystem impacts
Fracturing and completion	Fracturing fluids	Air quality	Climate change impacts
Well production and operation	Flowback constituents (other than fracturing fluids)	Habitat disruption	Quality of life impacts
Flowback and produced water storage/disposal	Produced water constituents	Community disruption	
Shutting-in, plugging and abandonment	Condenser and dehydration additives	Occupational hazard	
Workovers	Habitat/community disruptions		
Upstream and downstream activities	Other		

Creating Risk Pathways (cont'd)



Sloan Project on Environmental Risks

Risk Matrix



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.

Activity	Intermediate Impacts					
	Groundwater	Surface Water	Soil Quality	Air Quality	Habitat Disruption	Community Disruption
Clearing of land/construction of roads, well pads, pipelines, other infrastructure		Stormwater flows Invasive species	Stormwater flows	Conventional air pollutants and CO_2	Habitat fragmentation Invasive species	Industrial landscape Light pollution Noise pollution
On-road vehicle activity		Stormwater flows		Conventional air pollutants and CO_2	Other	Noise pollution Road congestion/accidents
Off-road vehicle activity		Stormwater flows		Conventional air pollutants and CO_2	Other	Noise pollution

Return to Top

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.

Activity	Intermediate Impacts					
	Groundwater	Surface Water	Soil Quality	Air Quality	Habitat Disruption	Community Disruption
Drilling equipment operation at surface	Drilling fluids/cuttings	Drilling fluids/cuttings	Drilling fluids/cuttings	Conventional air pollutants and CO_2		Industrial landscape Light pollution Noise pollution
Drilling of vertical and lateral wellbore	Methane Drilling fluids/cuttings Intrusion of saline-formation water into fresh groundwater	Drilling fluids/cuttings		Methane		

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

RFF

Surveying the Experts: Who & What?

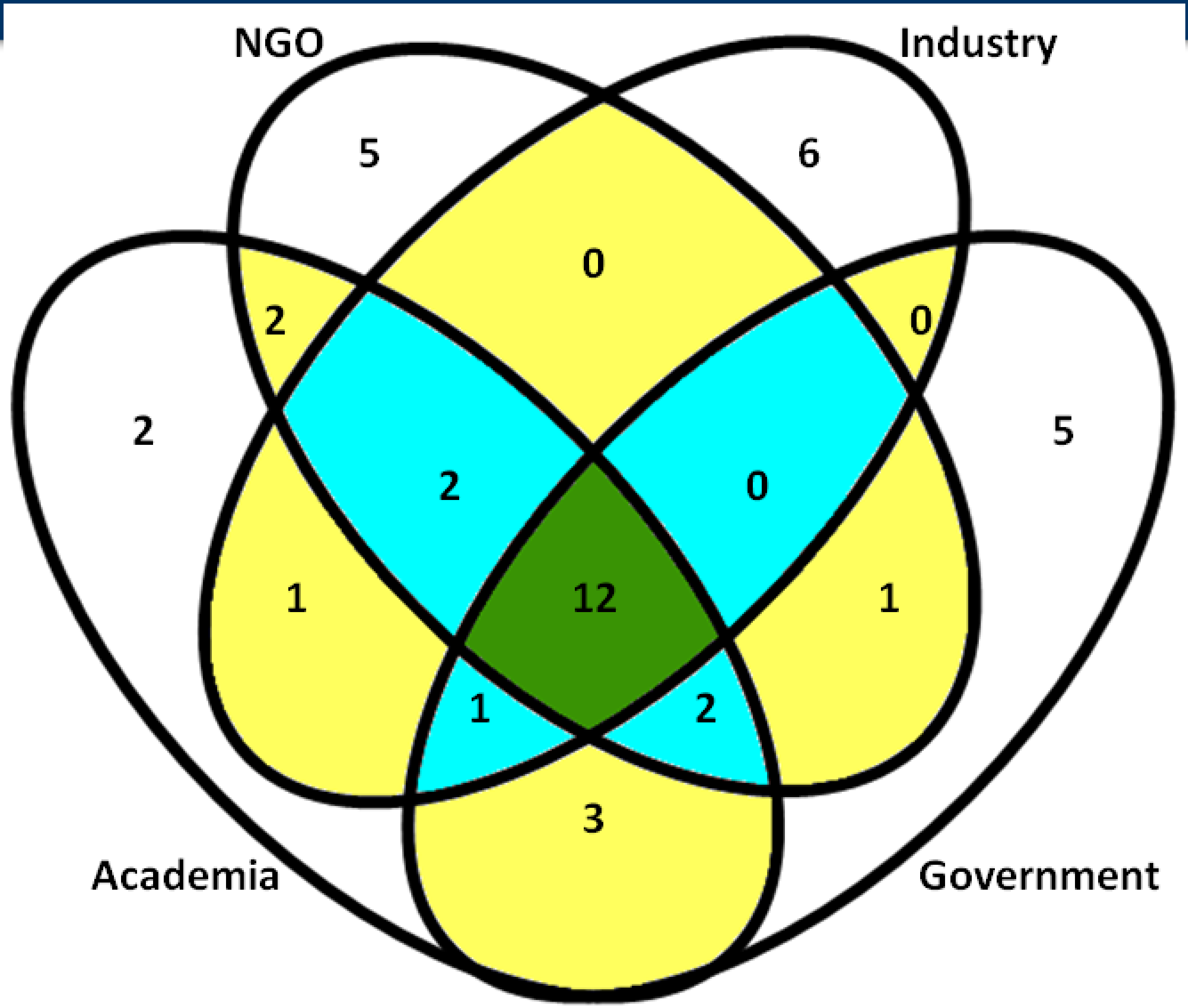
215 experts:

- **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

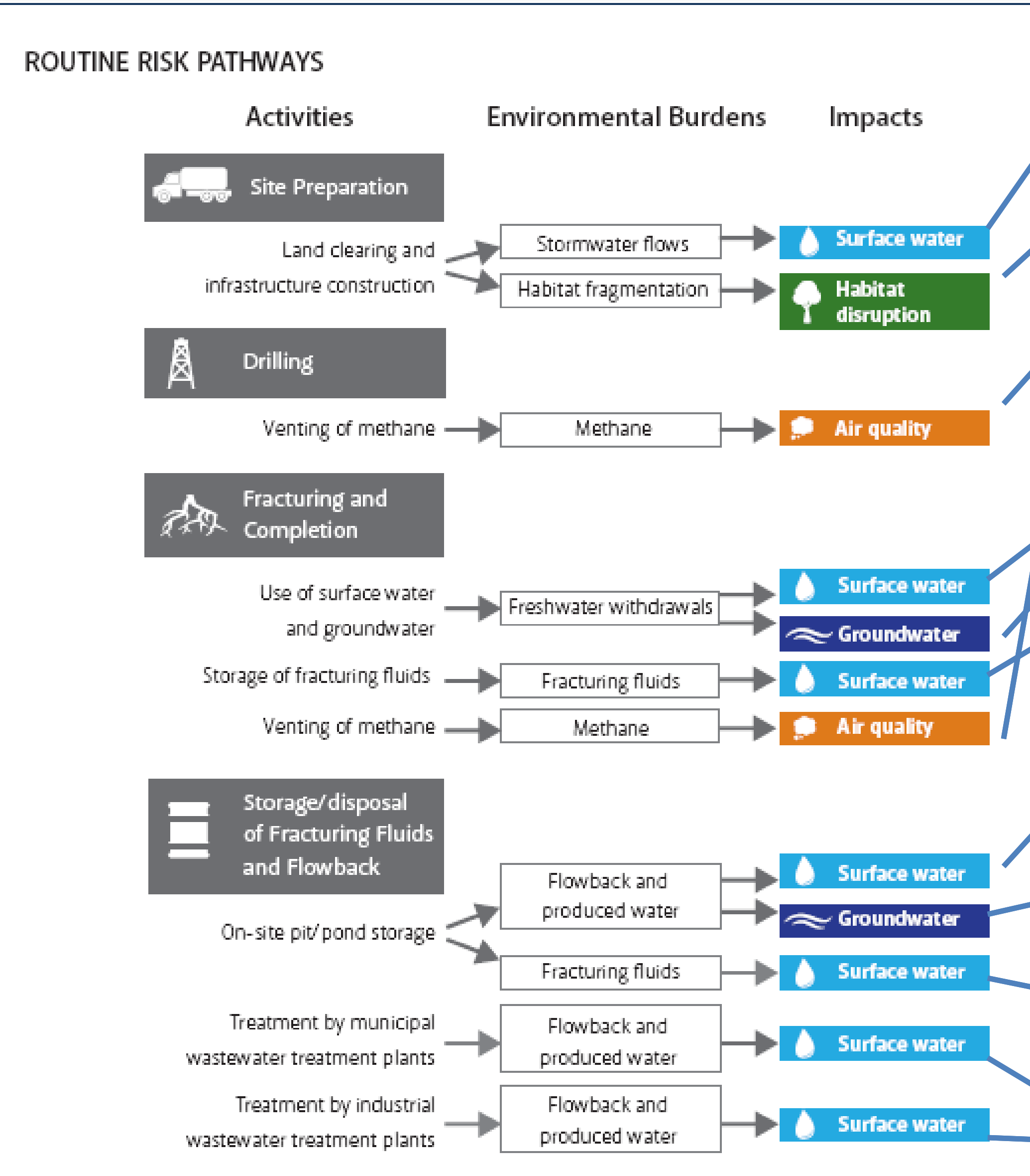
Chose high priorities among 264 possible risks

RFF

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

??

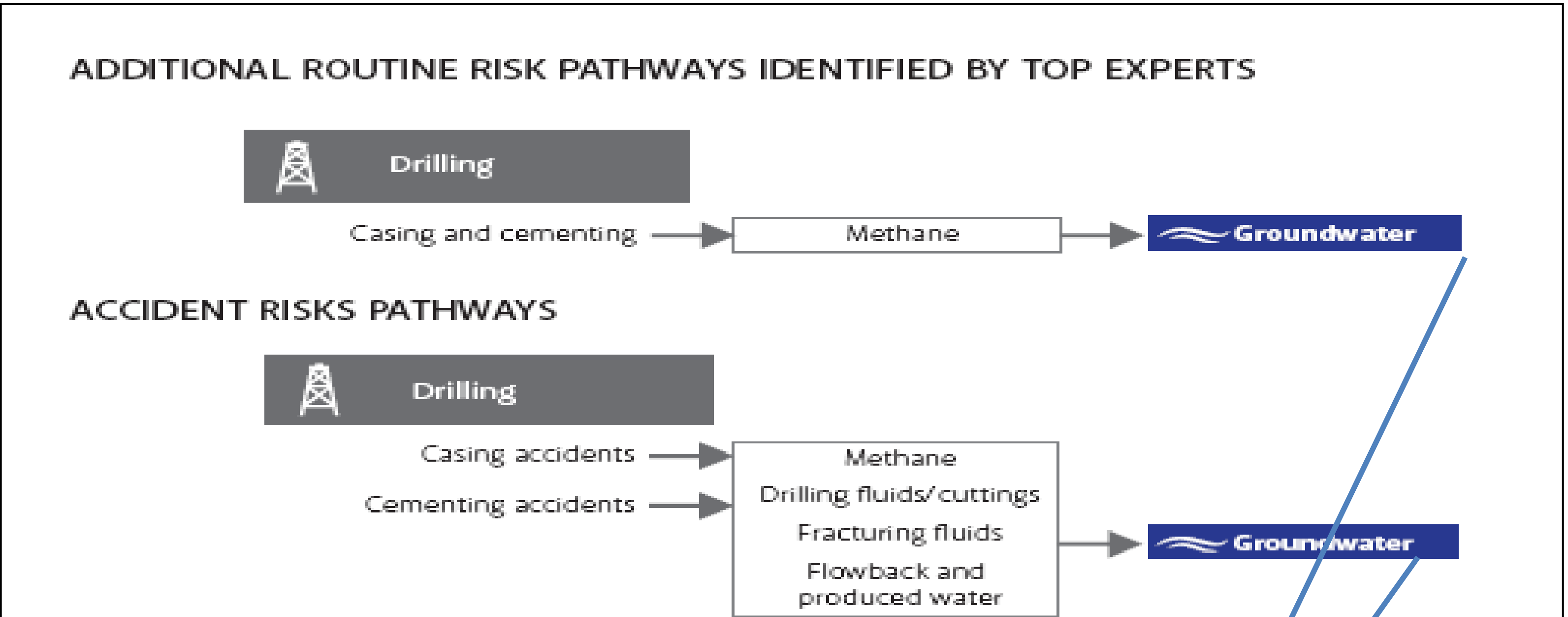
Olmstead et al. 2013

Warner et al. 2013 (wells, not ponds)

??

Wilson and VanBriesen 2012,
Lutz et al. 2013, Olmstead et al. 2013

What is known about the “consensus” risks?



Osborn et al. 2011, Warner et al. 2013

RFF

Surveying the Experts: Findings

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

RFF

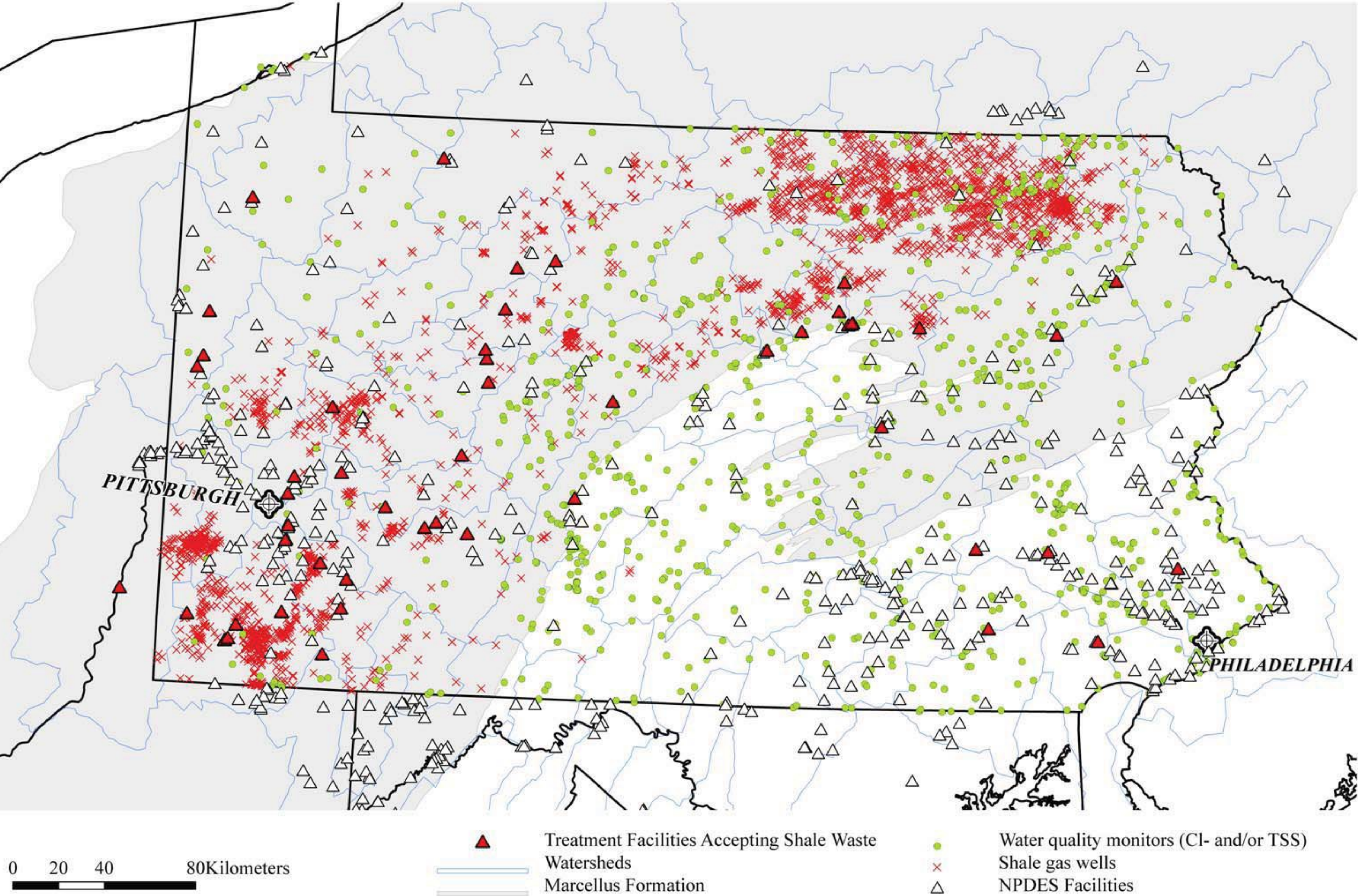
Surface Water Quality Risk Study (PNAS, 2013)

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.

RFF


PITTSBURGH
PHILADELPHIA
0 20 40 80Kilometers
Treatment Facilities Accepting Shale Waste
Watersheds
Marcellus Formation
Water quality monitors (Cl- and/or TSS)
Shale gas wells
NPDES Facilities

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.

RFF

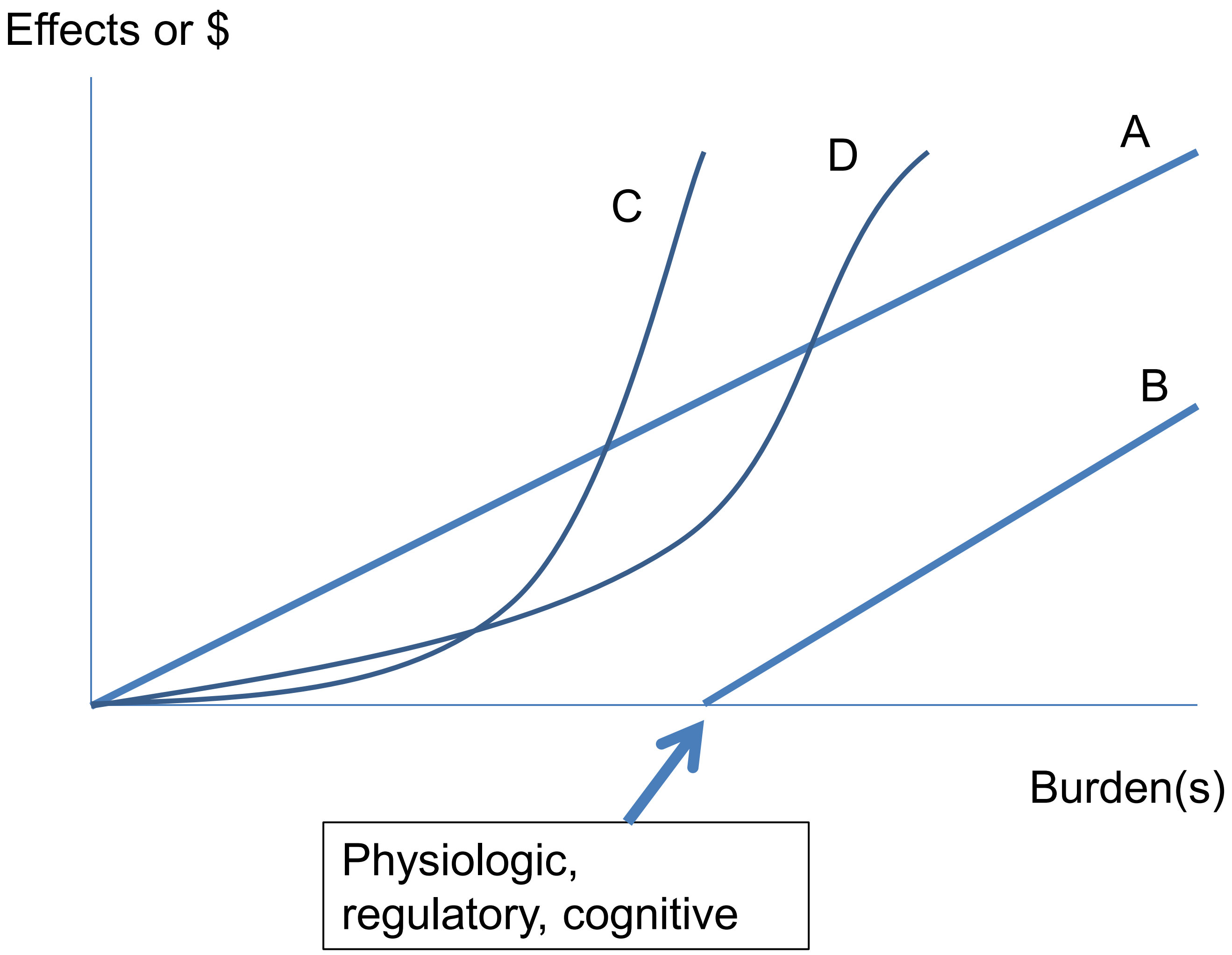
What are Cumulative Risks?

- 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 ($)

RFF

Damage Functions



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

RFF

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.)

RFF

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.

RFF

Cumulative Risks From Scale: Habitat fragmentation

- More shale gas development ➔ more infrastructure ➔ more fragmented habitat ➔ decreased species richness/composition/populations
- Patch shrinkage and edge effects both create non-linearities
- Can create advantages for some species (invasives, predators)

RFF

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.

RFF

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.

RFF

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)

RFF

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).

RFF

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

RFF