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

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RESOURCES FOR THE FUTURE

Environmental, Health and Safety Issues
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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

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

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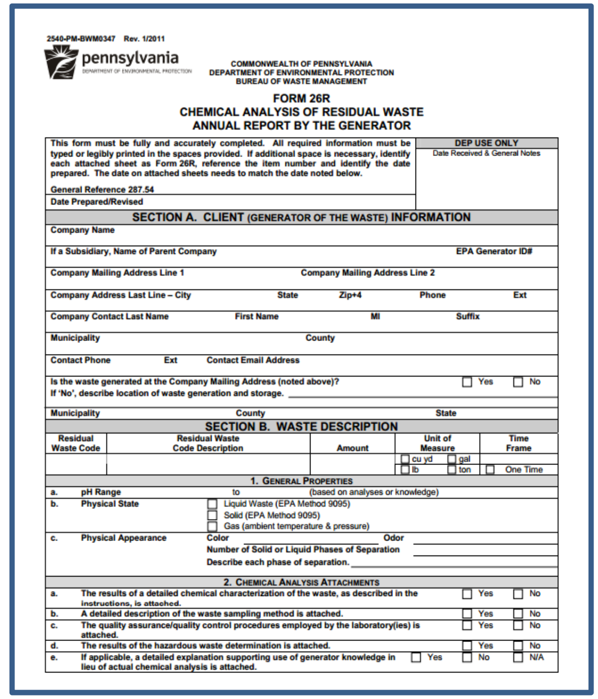
Drilling Activities
Drilling begins by boring a single well shaft vertically into the desired formation. One or more lateral wells are then drilled from the end of the vertical wellbore, angling to run horizontally through the shale formation.

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		

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



2540-PM-BWM0347 Rev. 1/2011

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL PROTECTION
BUREAU OF WASTE MANAGEMENT

FORM 26R
CHEMICAL ANALYSIS OF RESIDUAL WASTE
ANNUAL REPORT BY THE GENERATOR

This form must be fully and accurately completed. All required information must be typed or legibly printed in the spaces provided. If additional space is necessary, identify each attached sheet as Form 26R, reference the item number and identify the date prepared. The date on attached sheets needs to match the date noted below.

General Reference 287.54

Date Prepared/Revised

DEP USE ONLY
Date Received & General Notes

SECTION A. CLIENT (GENERATOR OF THE WASTE) INFORMATION

Company Name

If a Subsidiary, Name of Parent Company — EPA Generator ID#

Company Mailing Address Line 1 — Company Mailing Address Line 2

Company Address Last Line – City — State — Zip+4 — Phone — Ext

Company Contact Last Name — First Name — MI — Suffix

Municipality — County

Contact Phone — Ext — Contact Email Address

Is the waste generated at the Company Mailing Address (noted above)? ☐ Yes ☐ No
If 'No', describe location of waste generation and storage. ______

Municipality — County — State

SECTION B. WASTE DESCRIPTION

Residual Waste Code	Residual Waste Code Description	Amount	Unit of Measure	Time Frame
			☐ cu yd ☐ gal	
			☐ lb ☐ ton	☐ One Time

1. General Properties

a. pH Range ______ to ______ (based on analyses or knowledge)

b. Physical State ☐ Liquid Waste (EPA Method 9095) ☐ Solid (EPA Method 9095) ☐ Gas (ambient temperature & pressure)

c. Physical Appearance Color ______ Odor ______
Number of Solid or Liquid Phases of Separation ______
Describe each phase of separation. ______

2. Chemical Analysis Attachments

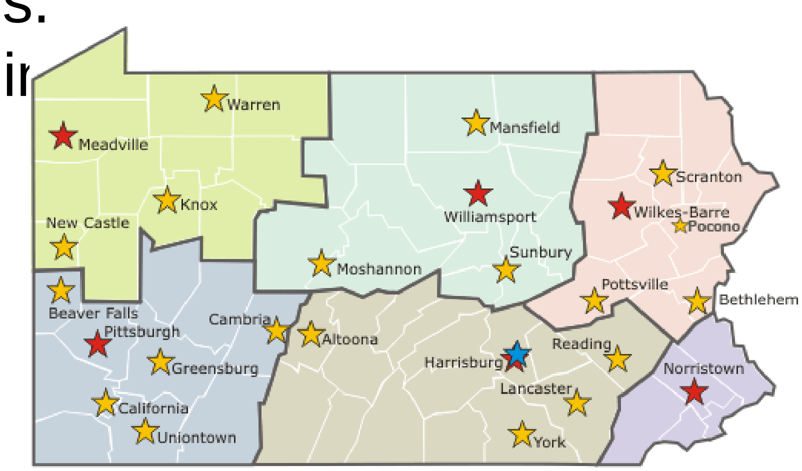
a. The results of a detailed chemical characterization of the waste, as described in the instructions, is attached. ☐ Yes ☐ No

b. A detailed description of the waste sampling method is attached. ☐ Yes ☐ No

c. The quality assurance/quality control procedures employed by the laboratory(ies) is attached. ☐ Yes ☐ No

d. The results of the hazardous waste determination is attached. ☐ Yes ☐ No

e. If applicable, a detailed explanation supporting use of generator knowledge in lieu of actual chemical analysis is attached. ☐ Yes ☐ No ☐ N/A



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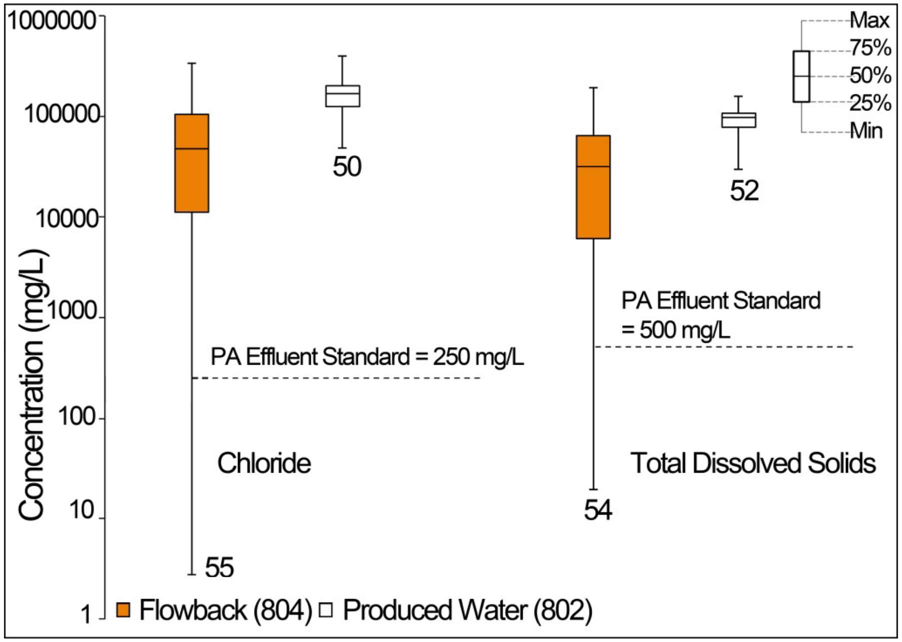
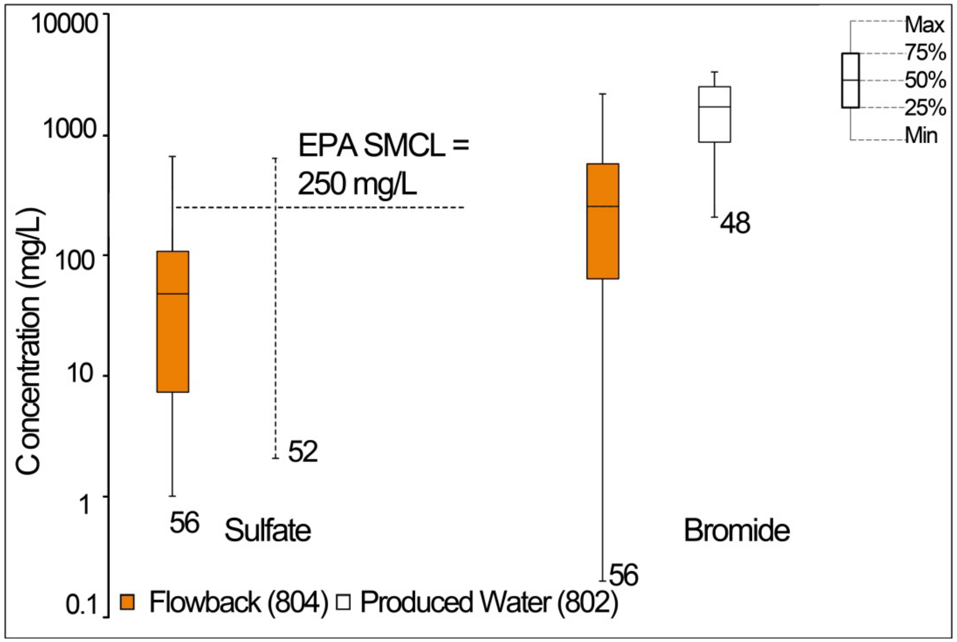
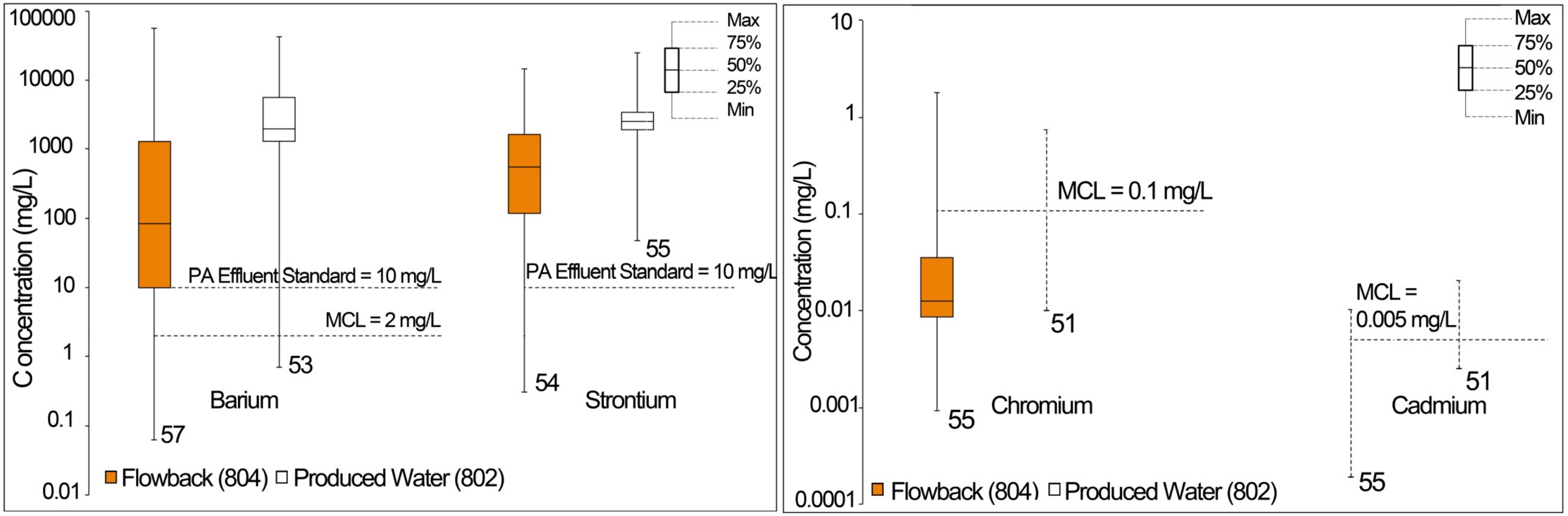
Comparison of General Chemicals in Produced Water and Fracking Fluid Waste





* Number at the bottom of the boxplot is the sample size

Comparison of Metals in Produced Water and Fracking Fluid Waste



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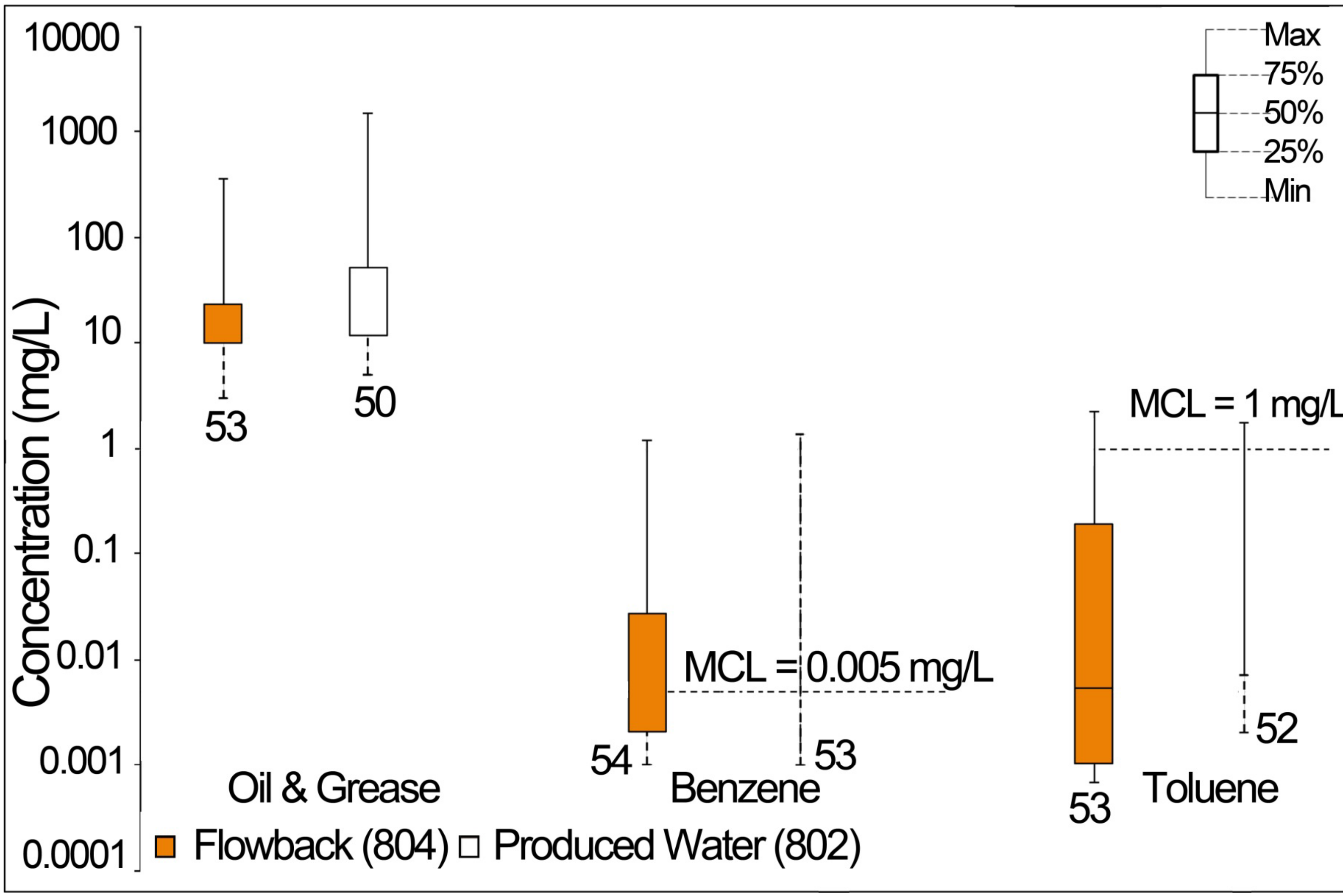
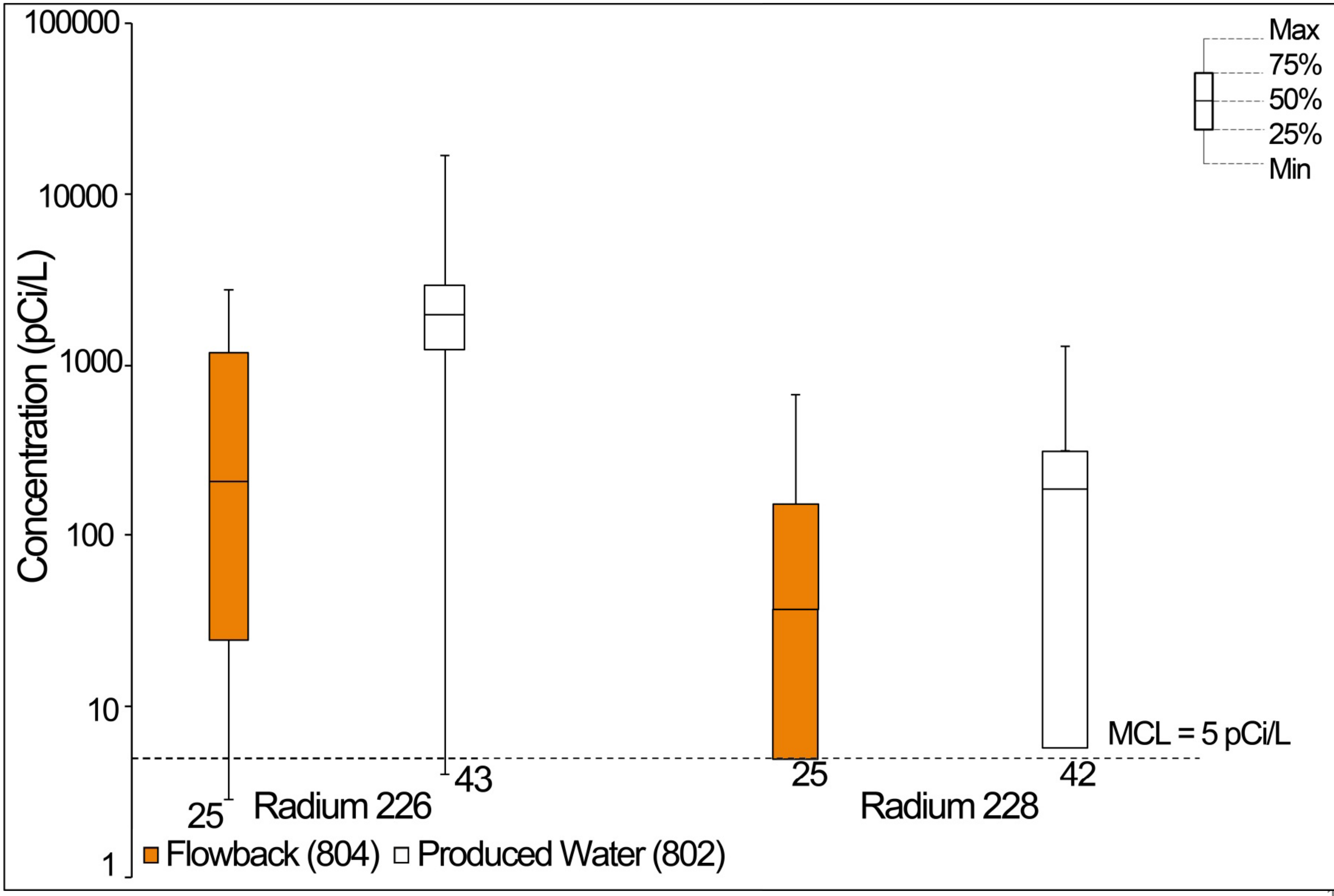
Comparison of Organics in Produced Water and Fracking Fluid Waste



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



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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

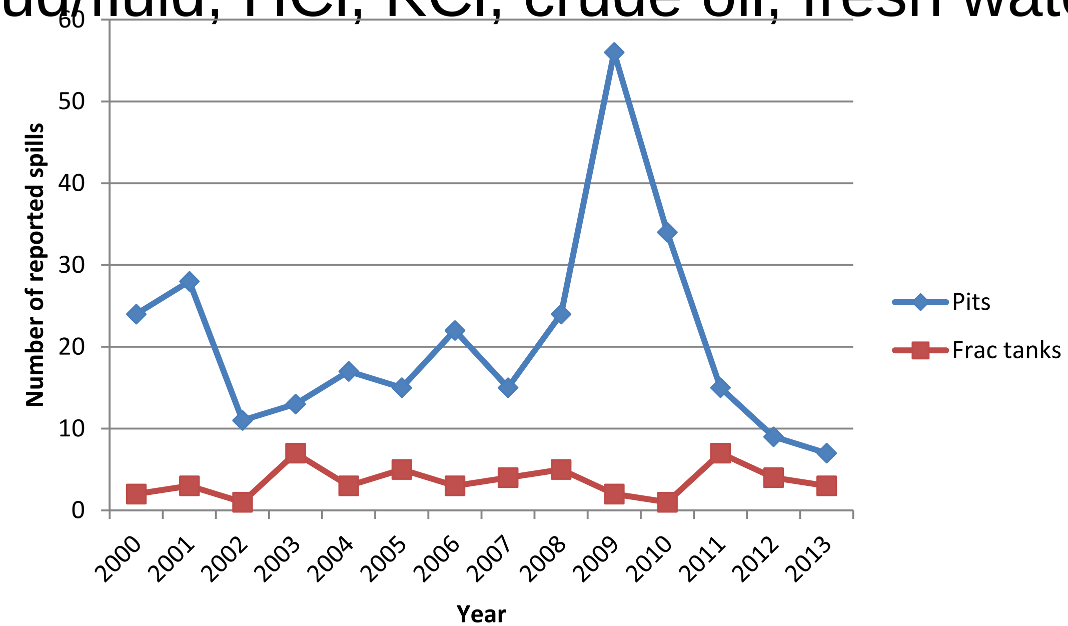

Figure: Spills from pits and frac tanks as reported to New Mexico OCD.

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Analysis of state databases of spills and releases

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

Panel A: Pits

Cause of spill	# spills
Overflow	33
Liner malfunction	31
Unidentified or undocumented	19
Discovery of historical spill	8
Blowover	7
Improper closure or reclamation	3
Sinkhole	2
Other	2
TOTAL	**105**

Panel B: Frac Tanks

Cause of spill	# spills
Leak	21
Unidentified or undocumented	13
Overflow	9
Other	3
Collapse	2
Vandalism	2
TOTAL	**50**

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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.

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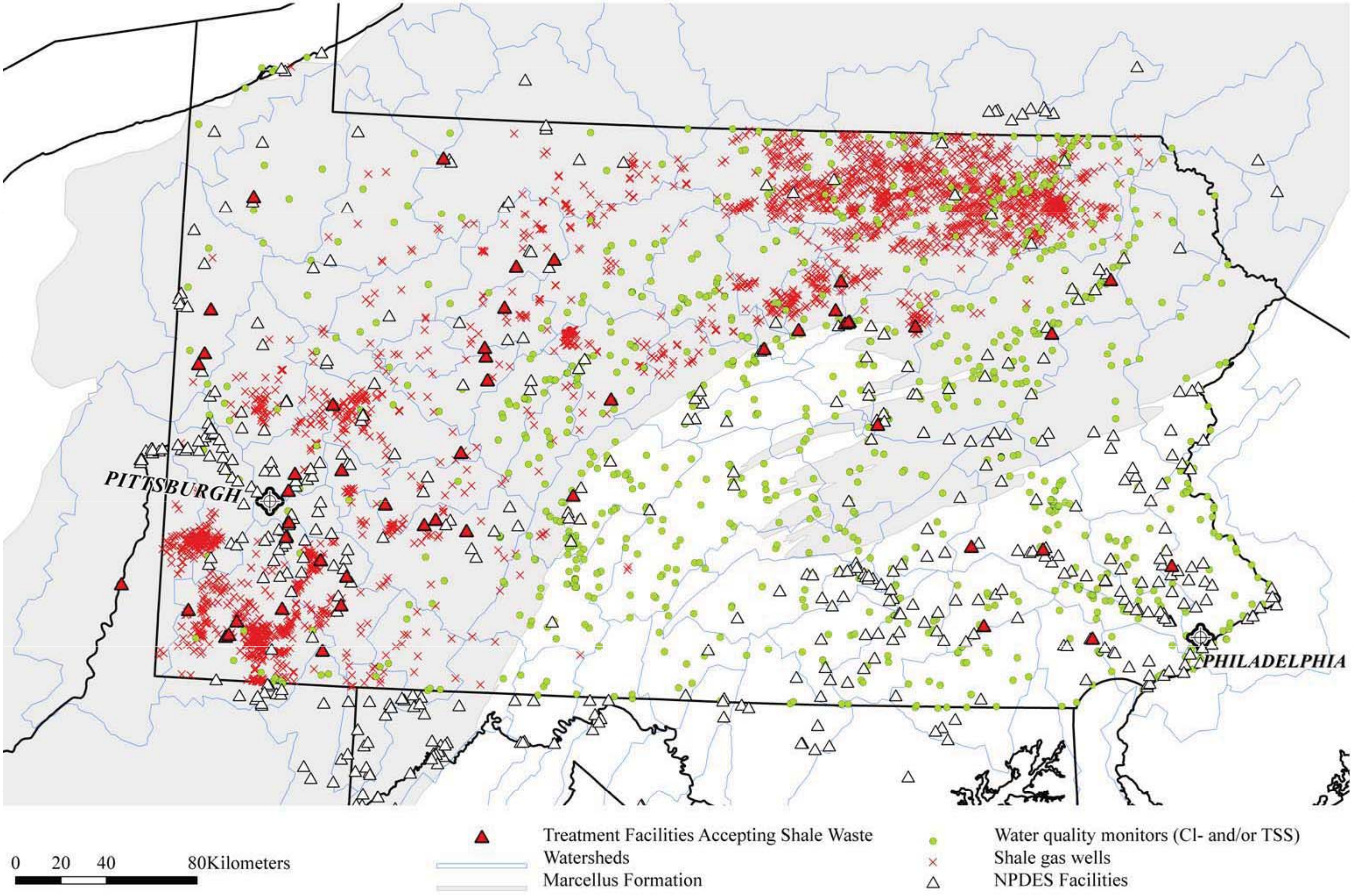
PITTSBURGH
PHILADELPHIA
Treatment Facilities Accepting Shale Waste
Watersheds
Marcellus Formation
Water quality monitors (Cl- and/or TSS)
Shale gas wells
NPDES Facilities
0 20 40 80Kilometers

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.

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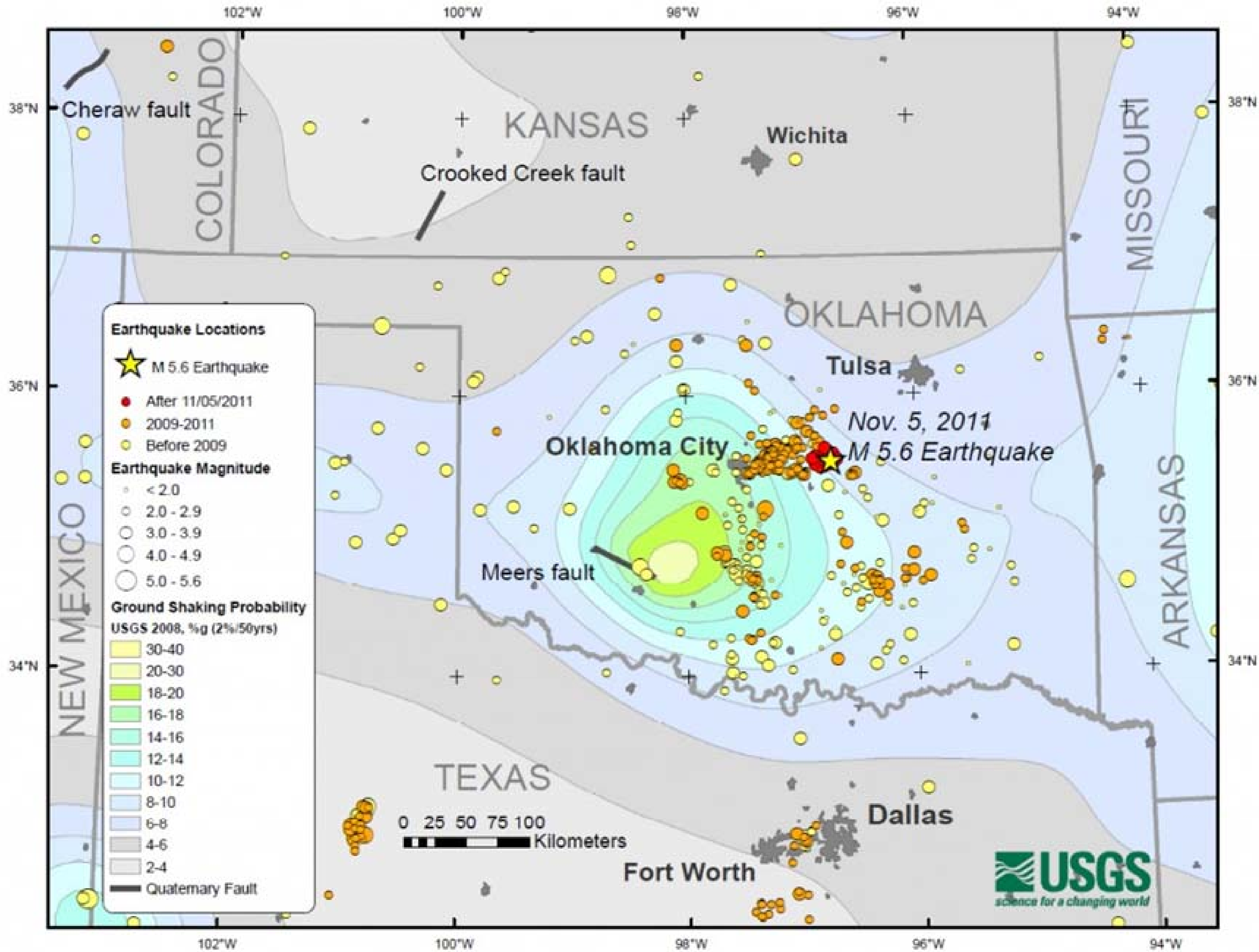
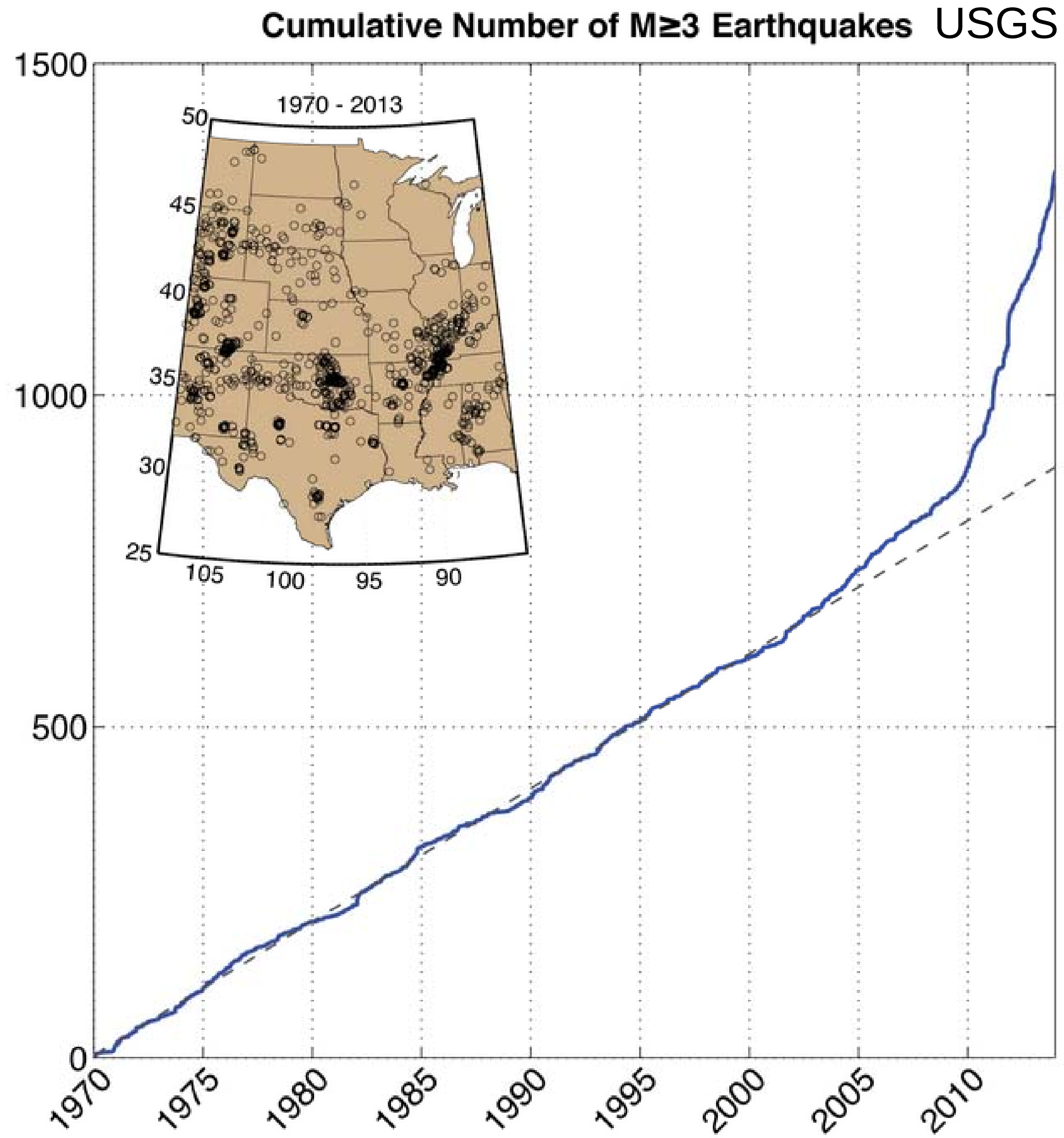
Induced Seismicity

- 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.”



102°W
100°W
98°W
96°W
94°W
38°N
36°N
34°N
Cheraw fault
COLORADO
KANSAS
Wichita
Crooked Creek fault
MISSOURI
OKLAHOMA
Tulsa
Nov. 5, 2011
M 5.6 Earthquake
Oklahoma City
Meers fault
ARKANSAS
NEW MEXICO
TEXAS
Dallas
Fort Worth
0 25 50 75 100
Kilometers
Earthquake Locations
M 5.6 Earthquake
After 11/05/2011
2009-2011
Before 2009
Earthquake Magnitude
< 2.0
2.0 - 2.9
3.0 - 3.9
4.0 - 4.9
5.0 - 5.6
Ground Shaking Probability
USGS 2008, %g (2%/50yrs)
30-40
20-30
18-20
16-18
14-16
12-14
10-12
8-10
6-8
4-6
2-4
Quaternary Fault
USGS
science for a changing world



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.

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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

Sawyer, Hall, and Ryan Nielson. 2010. Mule Deer Monitoring in the Pinedale Anticline Project Area: 2010 Report. Cheyenne, WY: Western Ecosystems Technology.

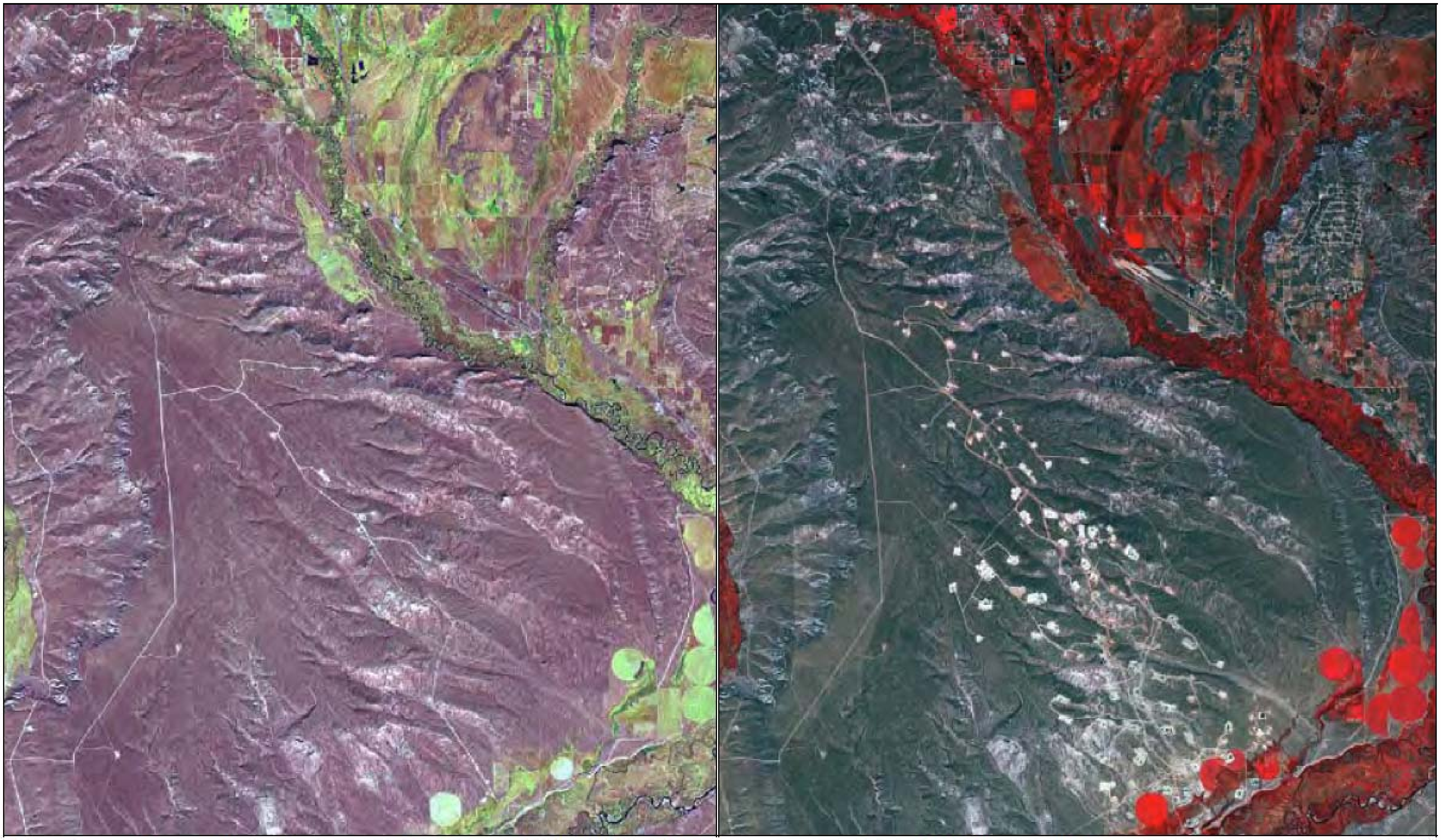
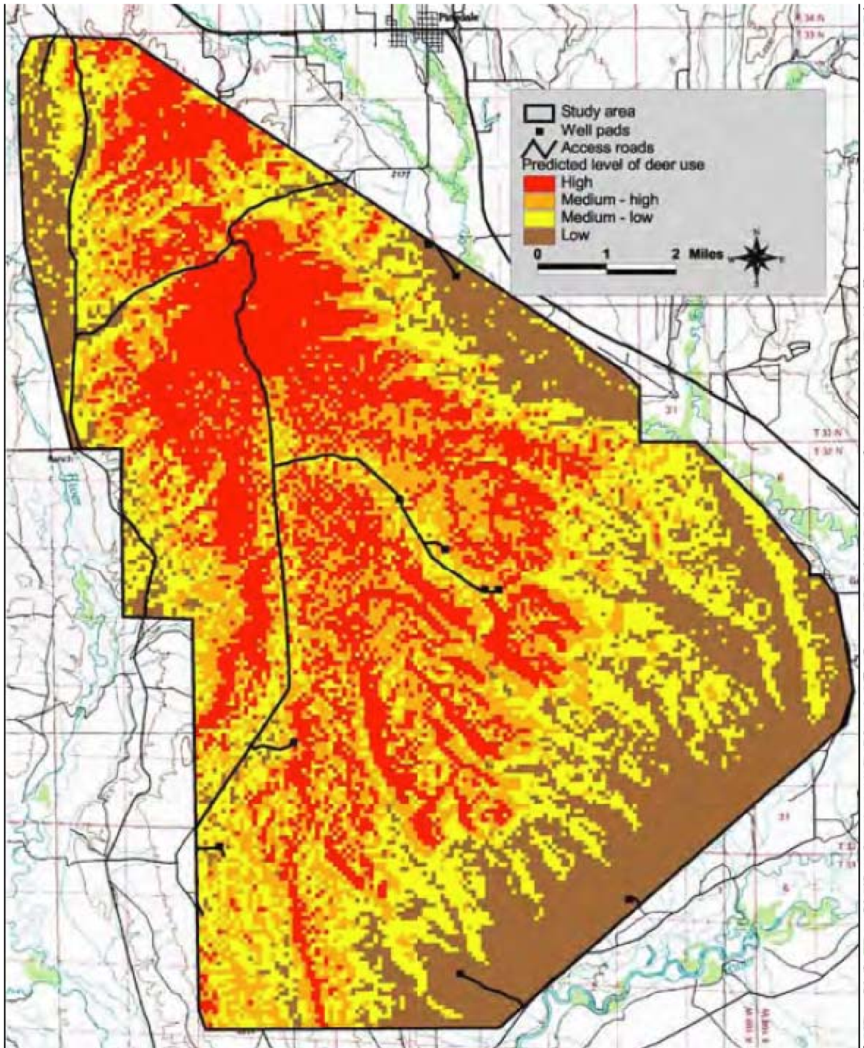


Figure 3. Satellite image of Mesa in 1999 (left) compared to 2009 (right).

Sawyer, Hall, and Ryan Nielson. 2010. [Mule Deer Monitoring in the Pinedale Anticline Project Area: 2010 Report]. Cheyenne, WY: Western Ecosystems Technology.



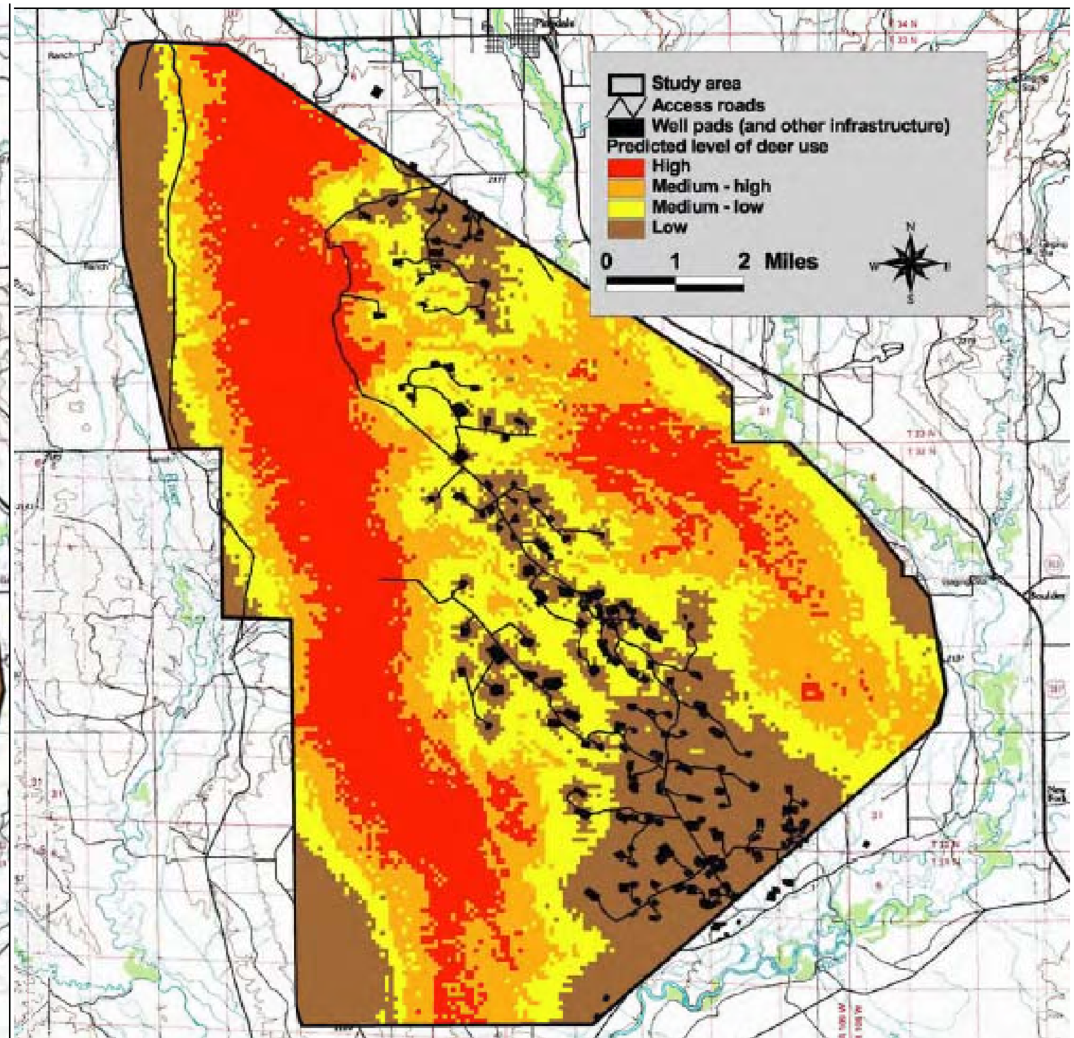


Figure 6. Predicted level of mule deer habitat use during Year 10 (winter of 2009-10) of natural gas development on the Mesa.

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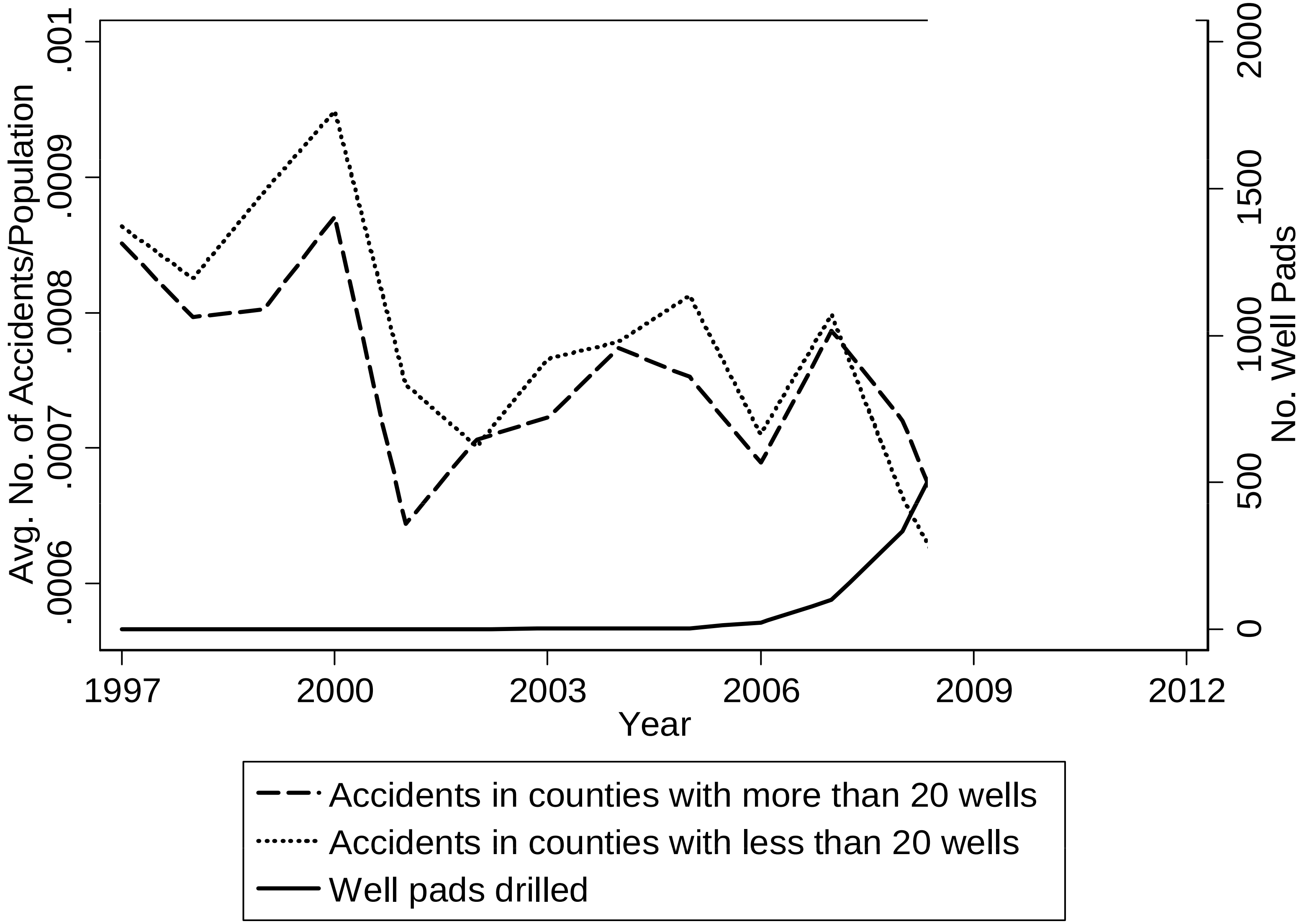
Truck Traffic Accidents in Pennsylvania by Well Activity



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

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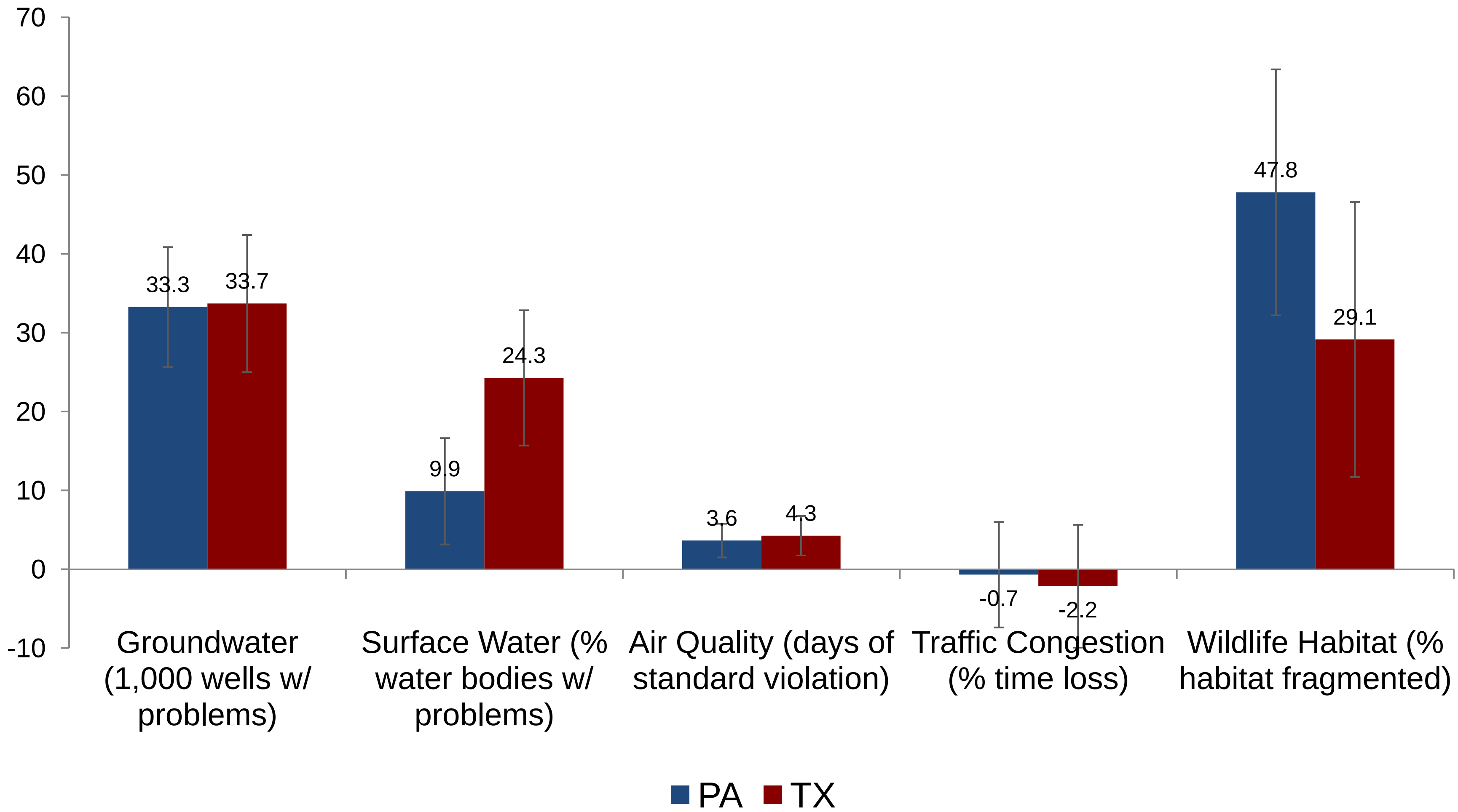

Figure 2. Estimated WTP ($ household^{-1} year^{-1}), on average, for the reduction of risks associated with shale gas development

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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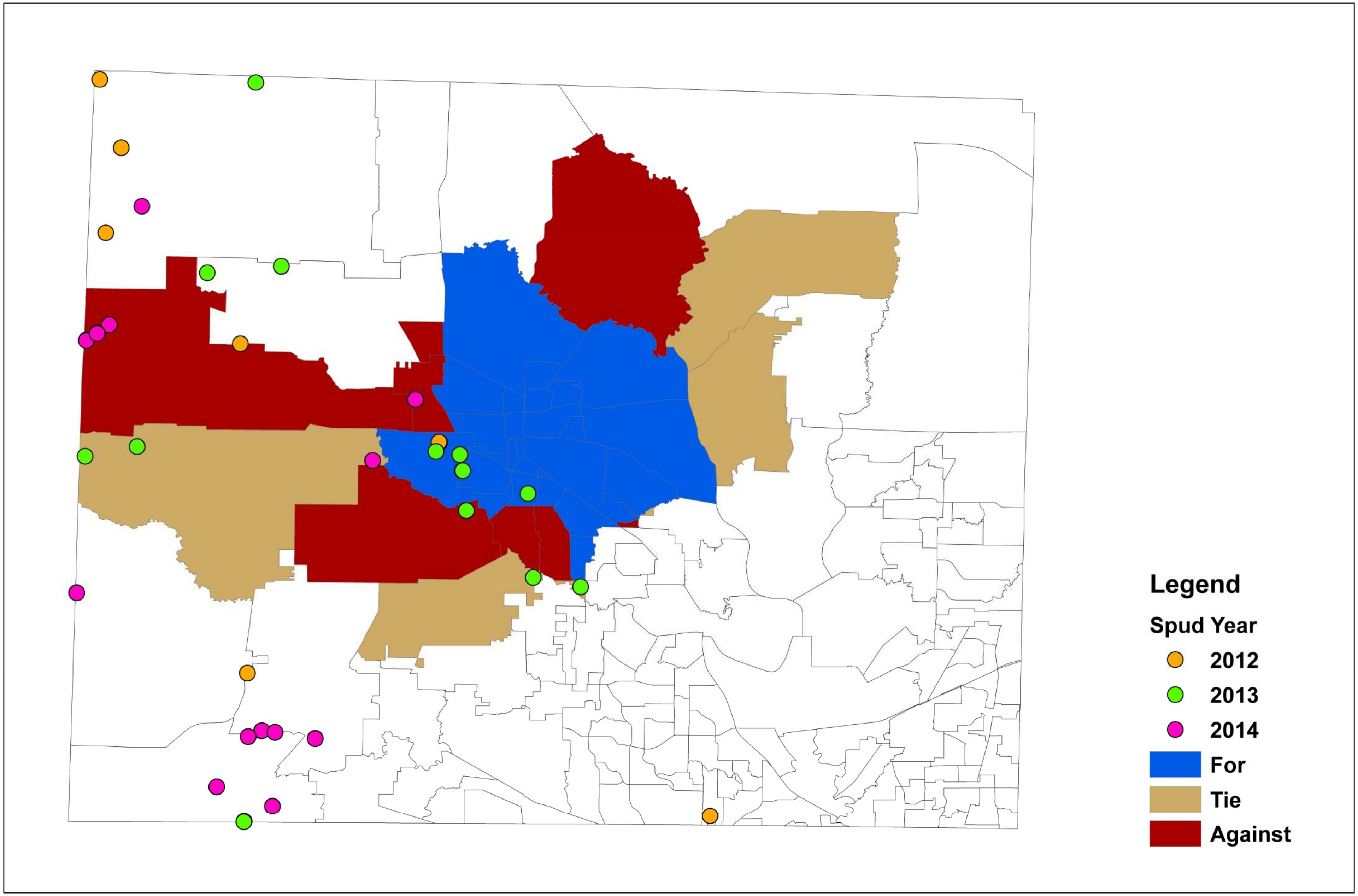

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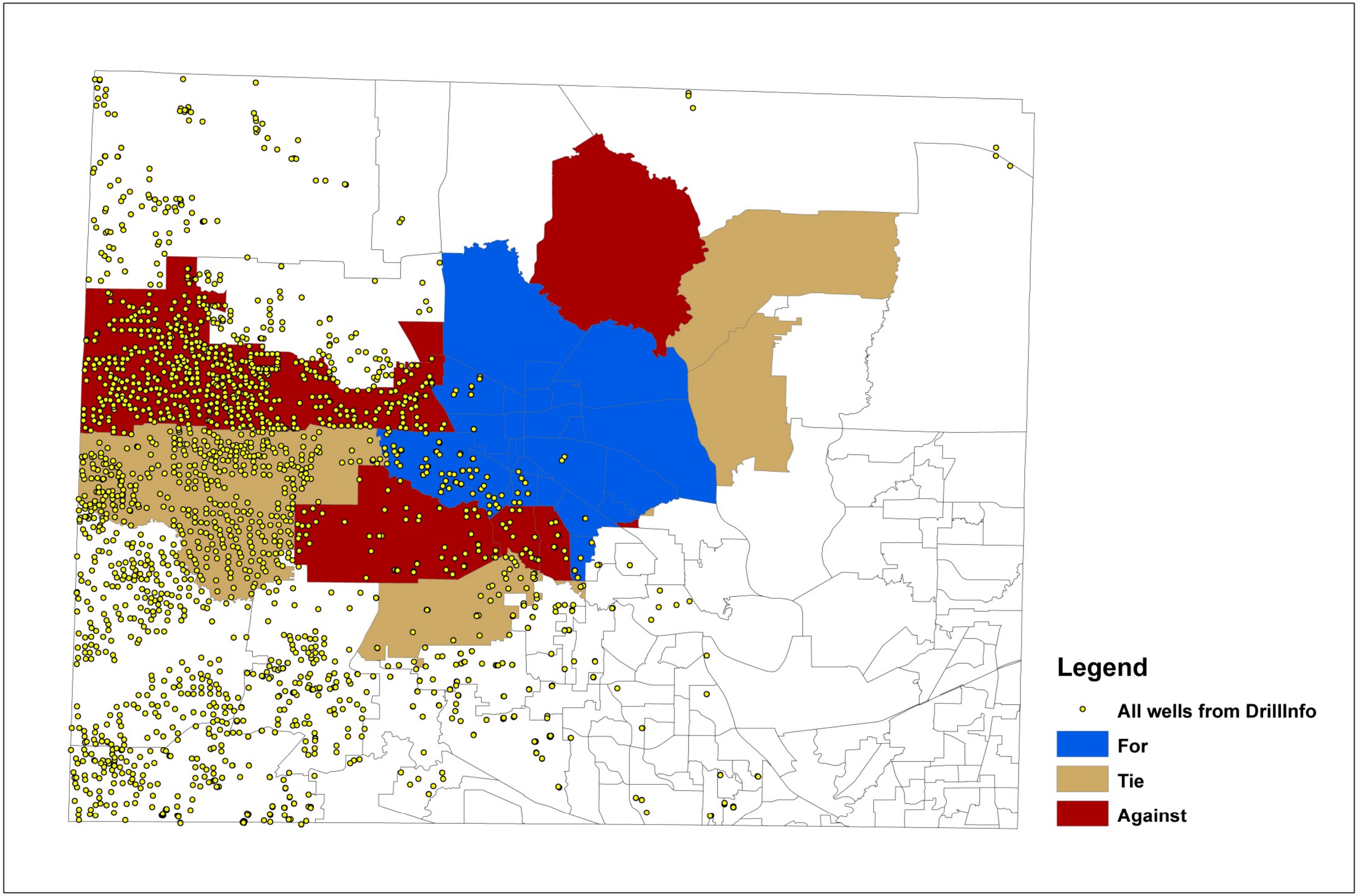

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