Changes in the Quantity and Quality of Produced Water from Appalachian Shale Energy Development and their Implications for Water Reuse

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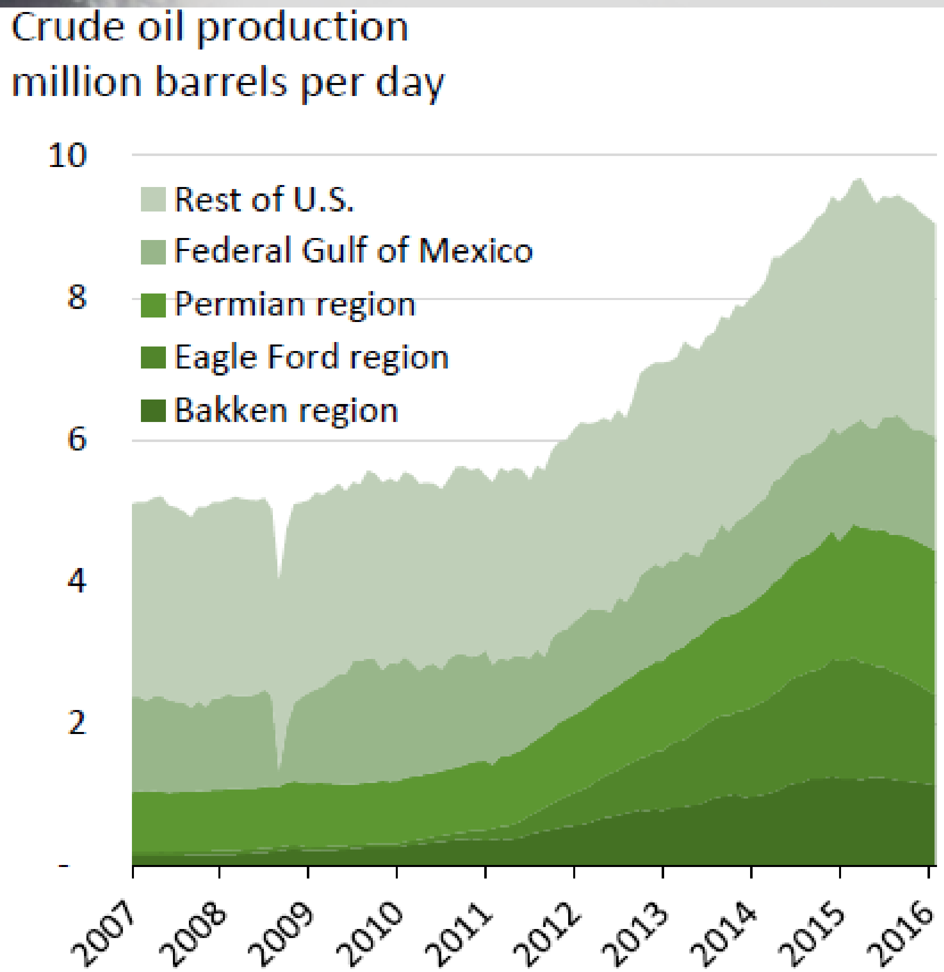
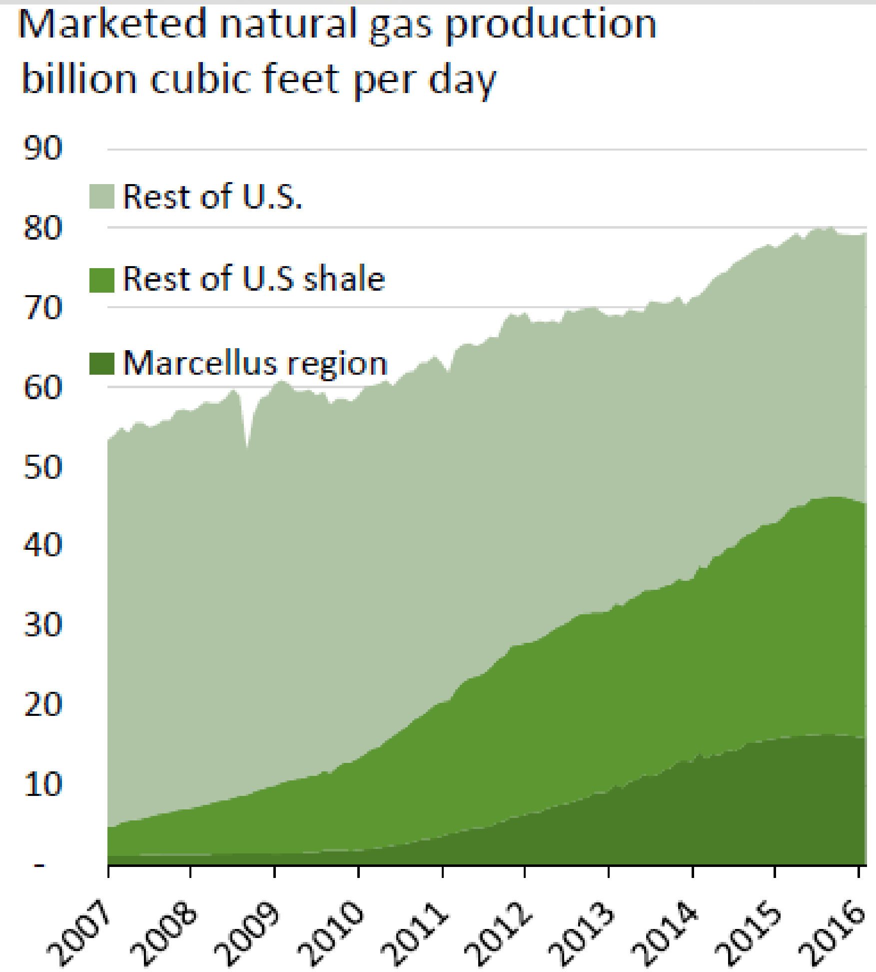
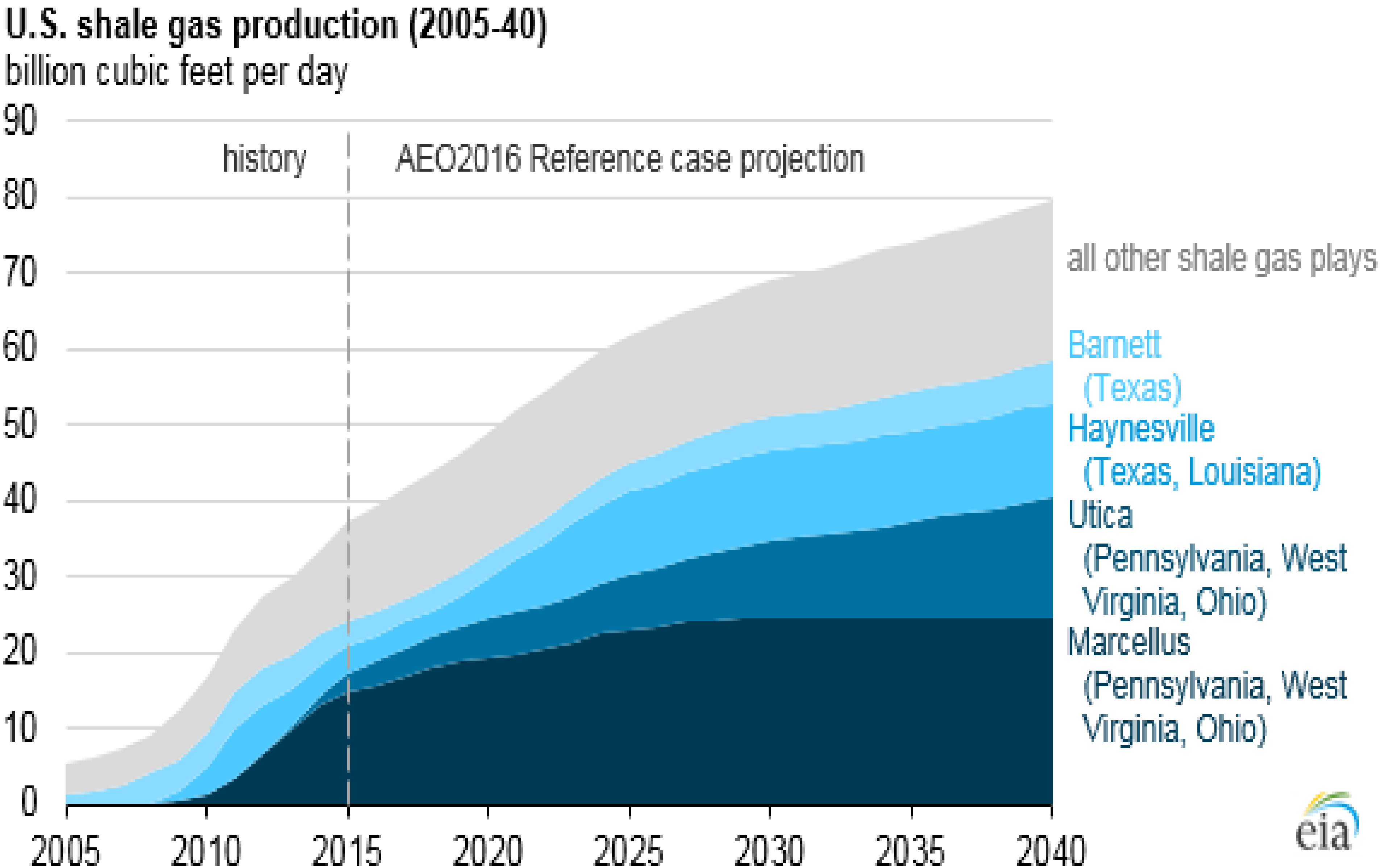
Unconventional Energy Driving US Oil and Gas Production Growth





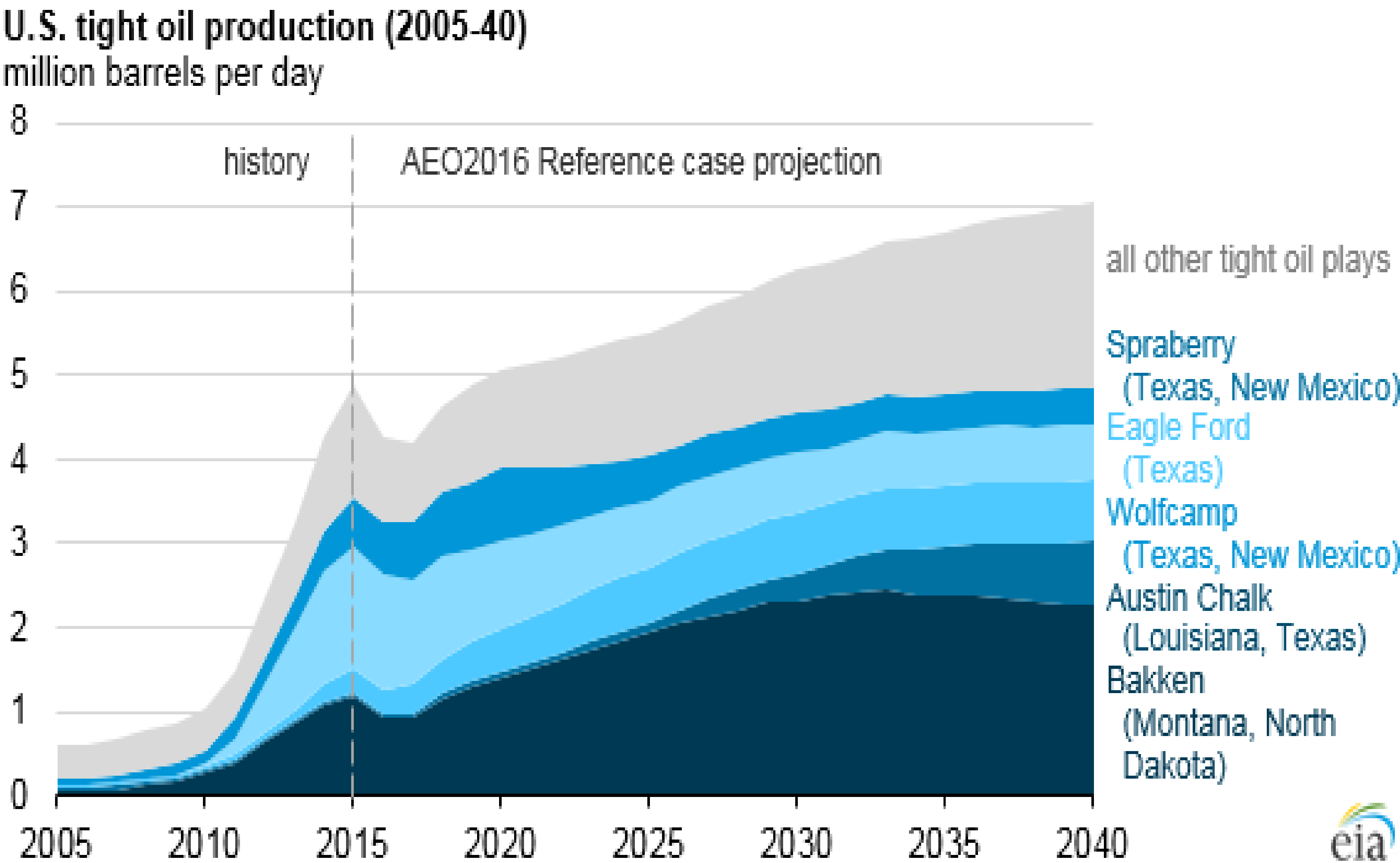
Source: EIA

U.S. Shale Gas Production



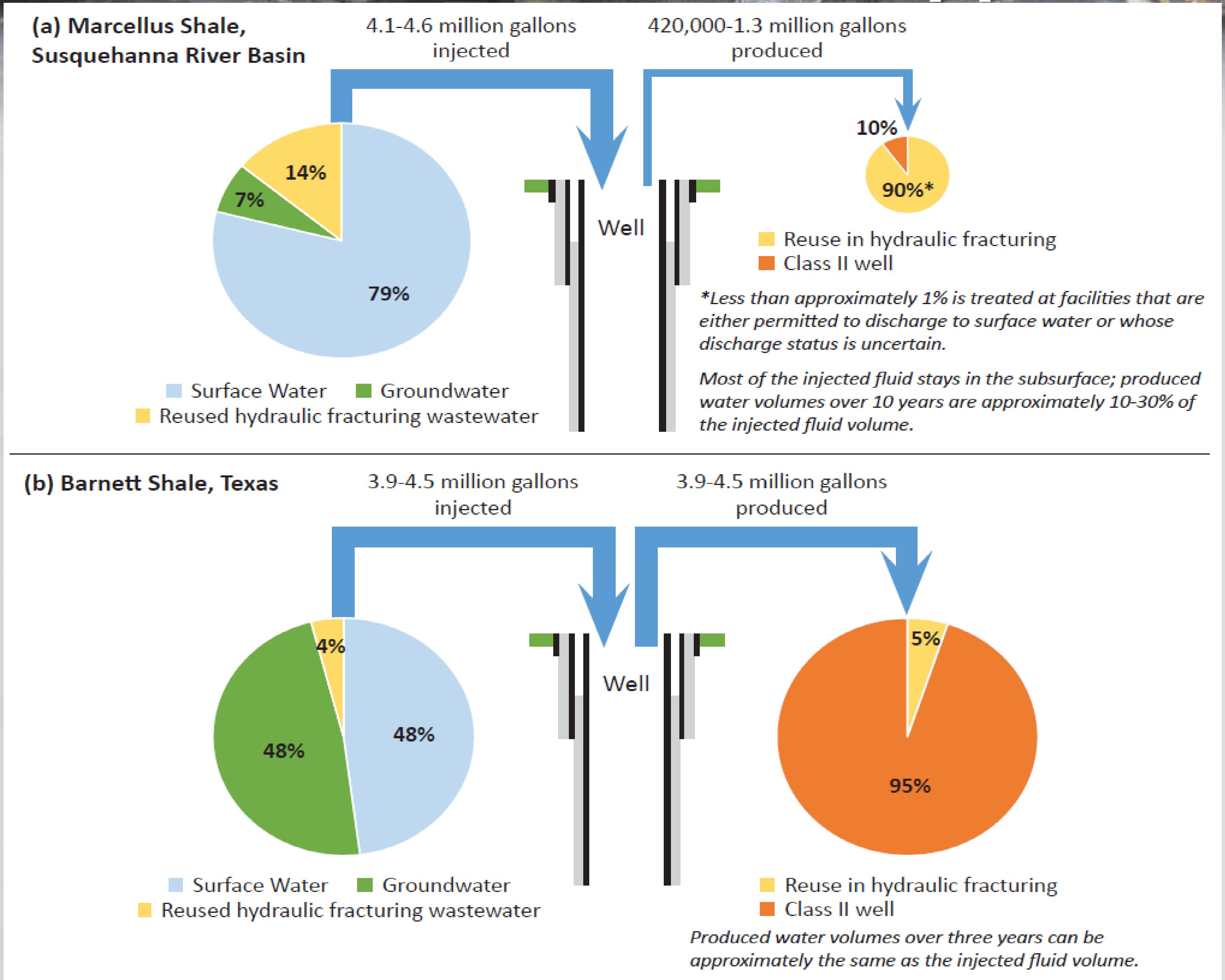
Source: EIA (2016)

U.S. Tight Oil Production



Source: EIA (2016)

Different Basins Different Approaches



Source USEPA, 2016

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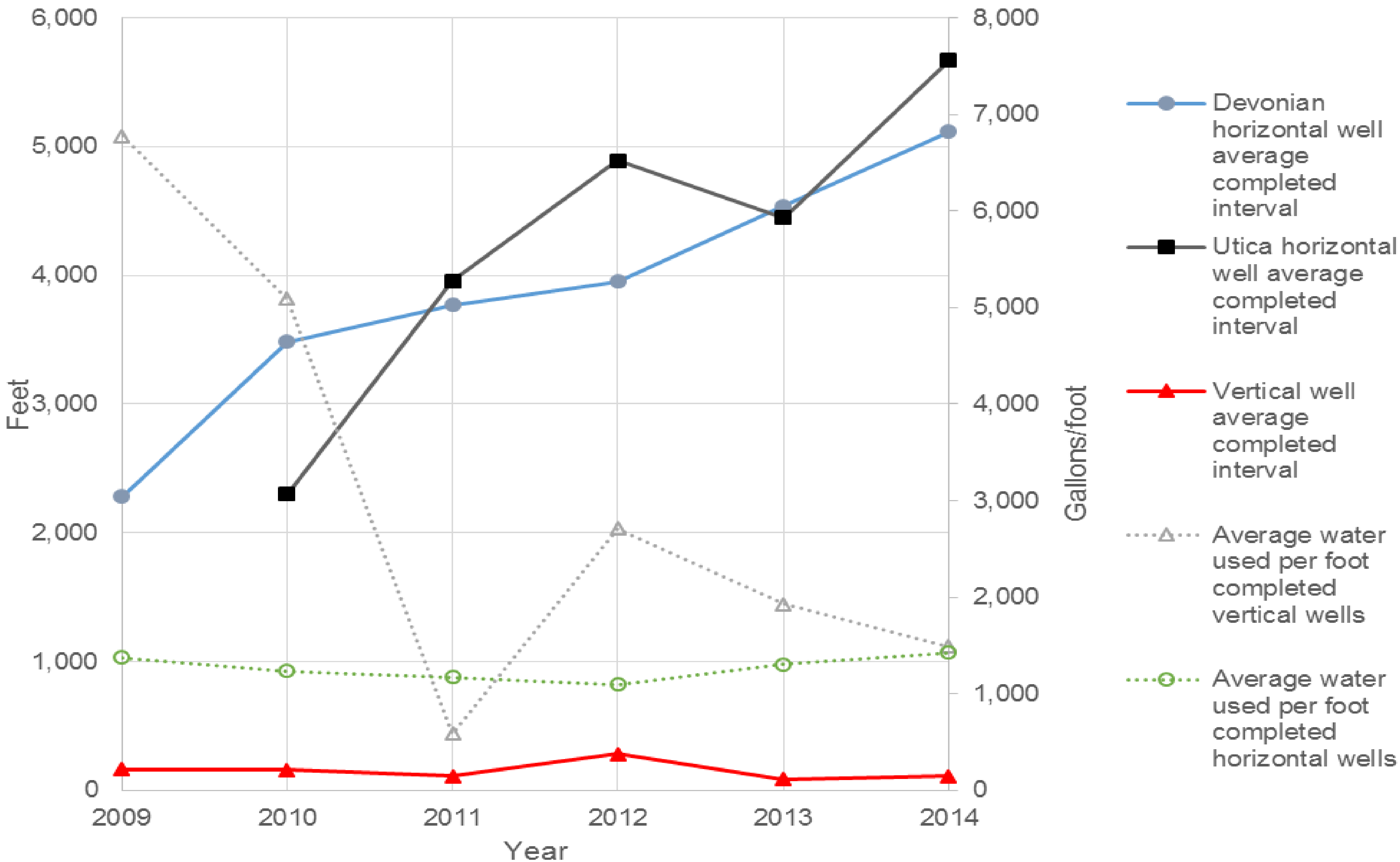
Well length vs Water use per foot in PA



Schmid and Yoxtheimer, 2015

Flowback and Produced Fluids Management

~5% of injected fluids return initially as flowback depending on formation

5 BBLs of fluids produced with every 1 MMCF of gas during the productive life of a well

Recycling/reuse rate of 92% in PA in 2016

Fluids management options

- Direct reuse (blending)
- On-site treatment w/reuse
- Off-site treatment w/reuse
- Treatment with discharge
- Class II UIC well disposal

Treatment technologies

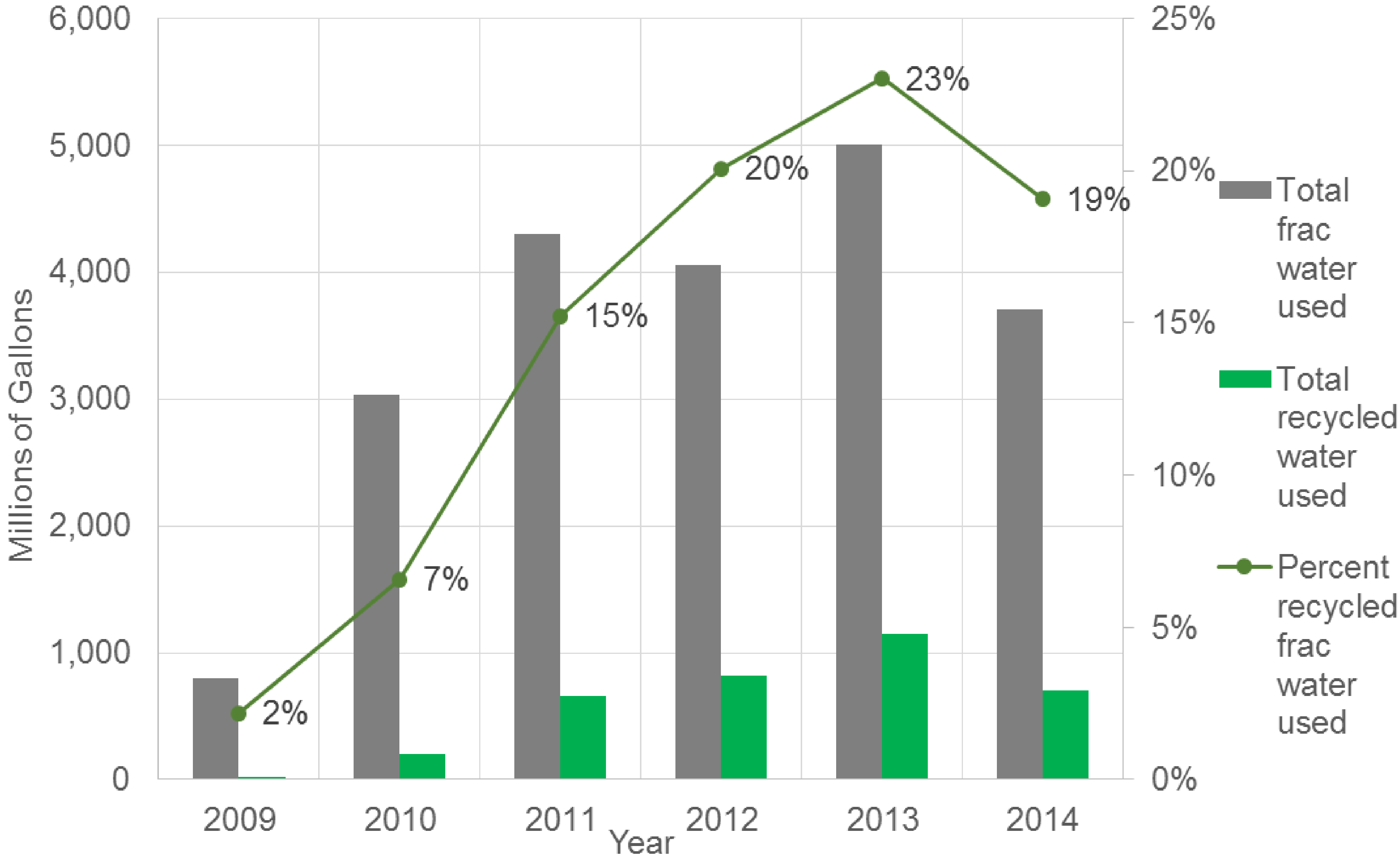
- Filtration (sock filters)
- Chemical precipitation
- Evaporation (eg MVR)
- Crystallization

Field Treatment Technologies

Field treatment for recycling benefits:

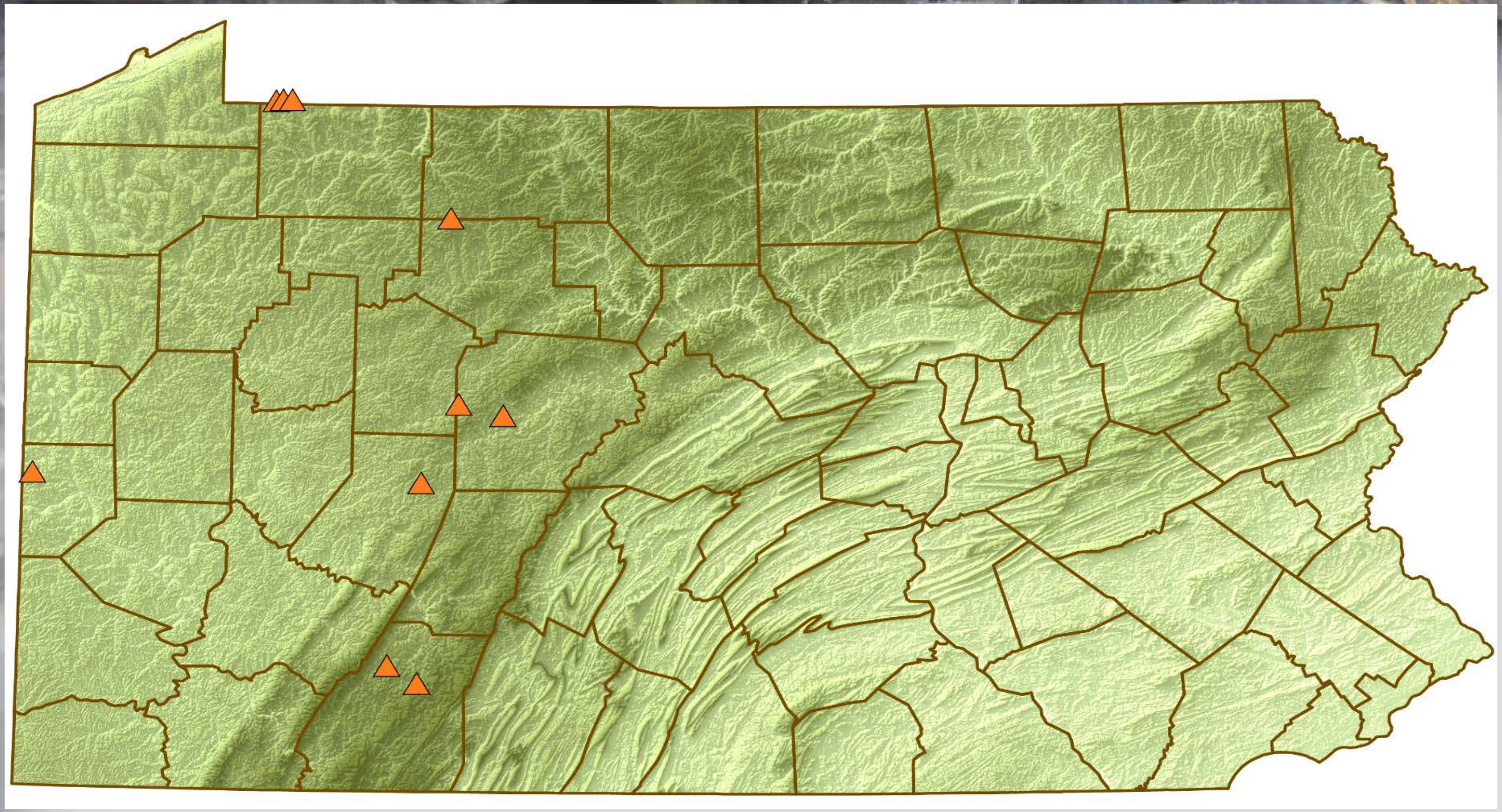
- Cost effective
- Improving technology and efficiency
- Less trucking transport
- Lower visibility
- Minimize fresh water use
- Less overall environmental impact
- In PA in 2016 about 60% of fluids that were recycled were managed in the field

Relative Volumes of Frac Water Used in PA



Schmid and Yoxtheimer, 2015

PA Class IID UIC Well Locations



-6 operational Class IID UIC wells in PA w/ 3 permitted but offline and ~5 permits in review

-60,000 BPM of commercial capacity via two Class IID wells in PA

-Most wells targeting depleted sandstone gas reservoirs (Oriskany, Medina, Elk Sands)

-Nearly 95% of PA unconventional brine disposed of via OH wells

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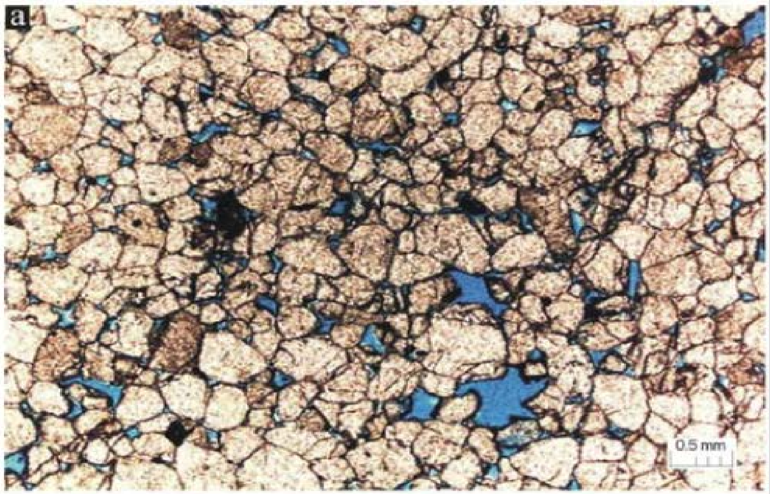
Example of Injection Capacity-Oriskany Sandstone

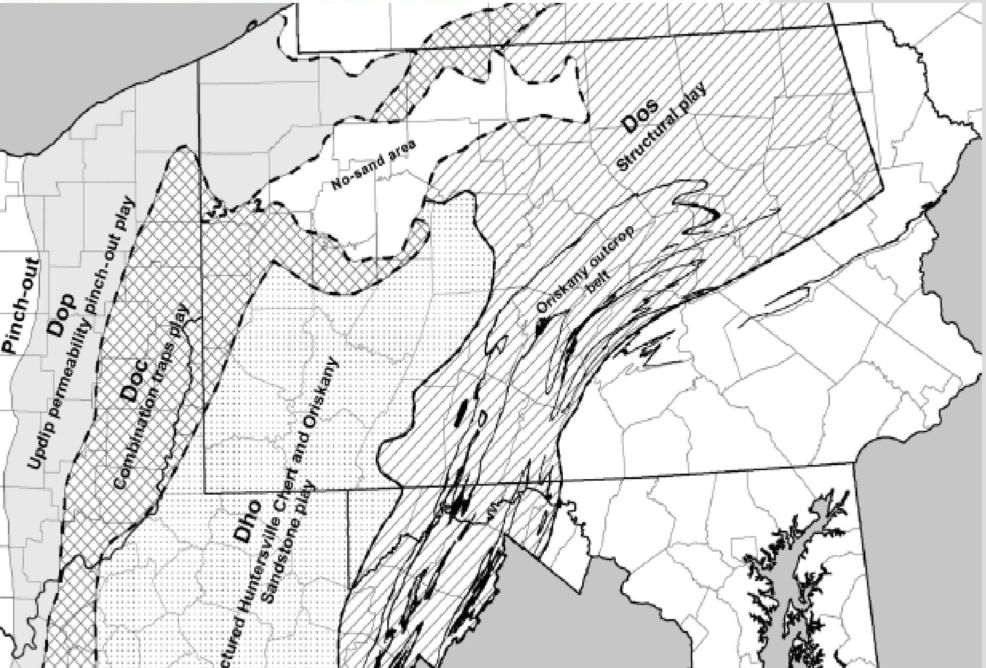


Oriskany sandstone

-calcite-cemented quartzite to chert with variable primary and fracture porosity

-depleted conventional gas reservoir

-used for brine injection and gas storage



Source: Kostelnik and Carter, 2009

Estimated Brine Injection Capacity (Volumetric)

-Using effective porosity of 4%, 50 feet of pay, and 40-ac injection zone area

-A typical injection well in the depleted Oriskany sandstone could ultimately accommodate an estimated 620,000 BBLs (~26 million gallons) of brine before filling available porosity

-Need to determine reservoir frac pressure to determine actual upper limit of injection

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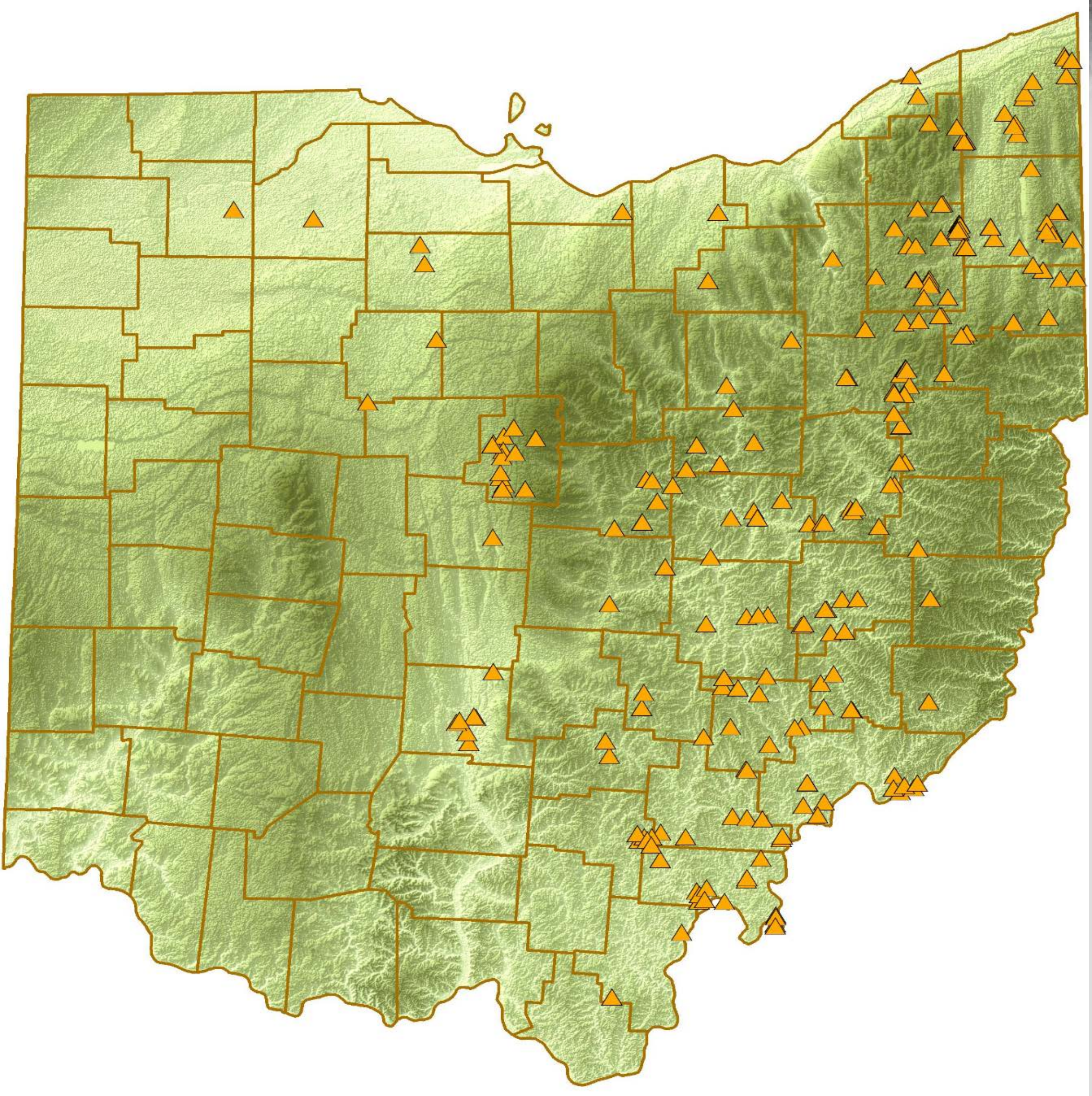
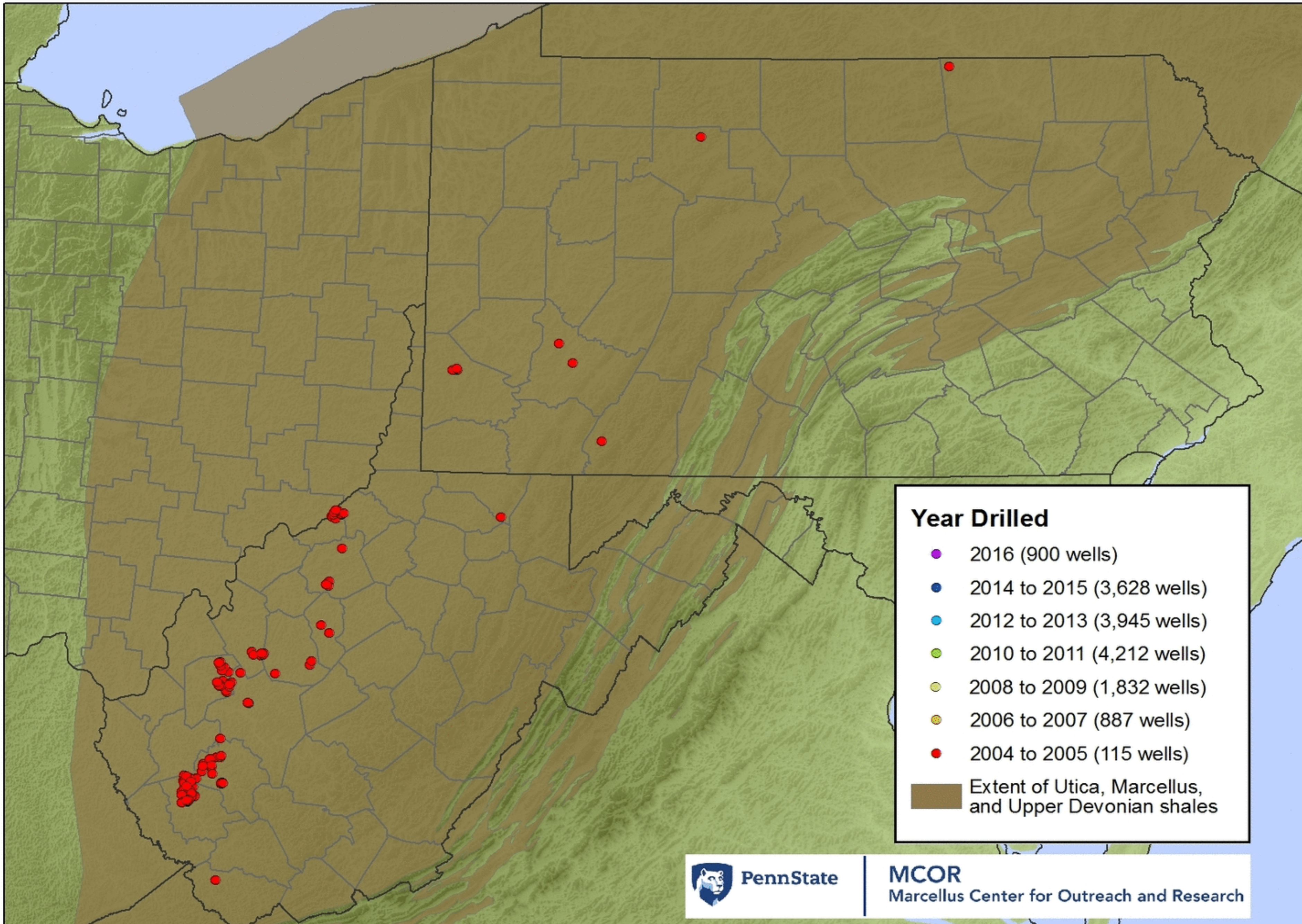
Class IID UIC Wells in Ohio

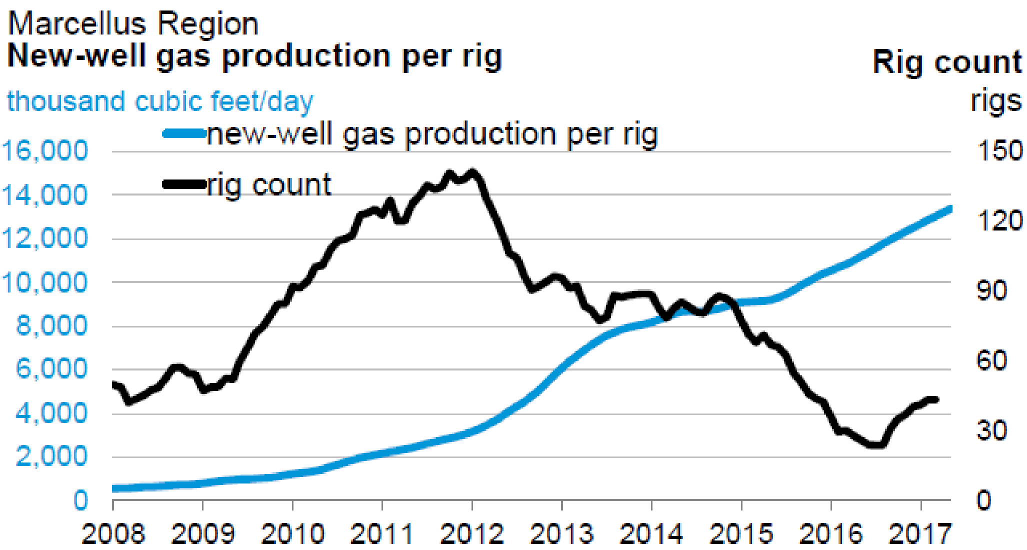


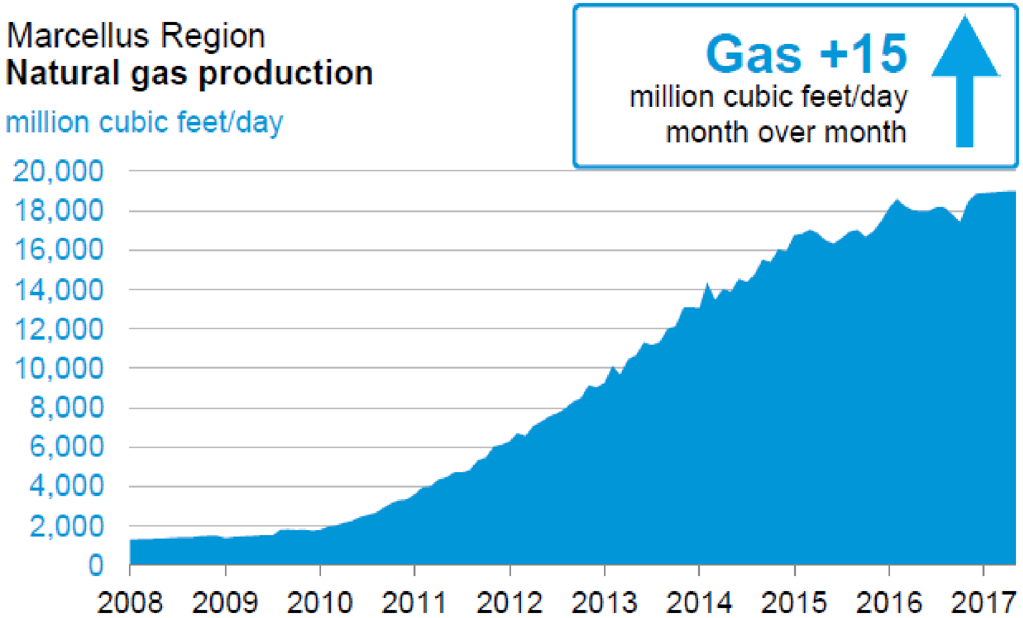
- 217 operational Class IID wells in OH
- Estimated 30 MMBBLs injected in 2016
- Approximately 43% of injected fluids from out of state
- Average injection rate of 400 BPD/well

Unconventional Wells Drilled by Year



Marcellus Shale Energy and Brine Production





Current Production

- 19 BCF/D of gas
- 3800 BBLs/D of oil
- 5 BBLs of brine/MMCF gas
- Current estimate of 95,000 BBLs/D of produced fluids
- 24.2 MMBBLS of fluids in PA in 2016
  - 3.5 MMBBLs of flowback
  - 20.7 MMBBLs of produced fluids
- In PA 92% recycled and <1% treated for discharge, with 8% disposal via Class IID wells (2016)

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Source: EIA

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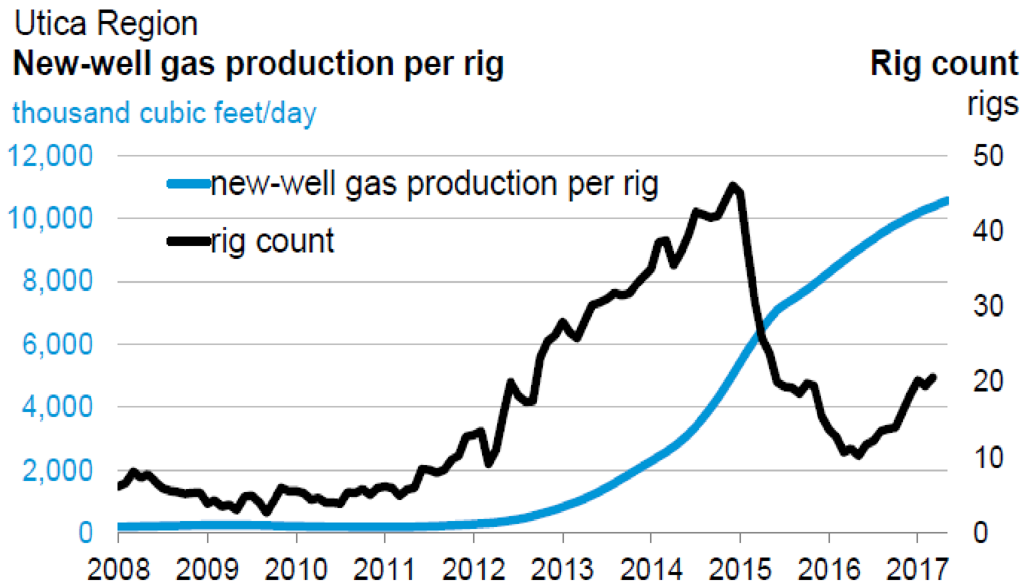
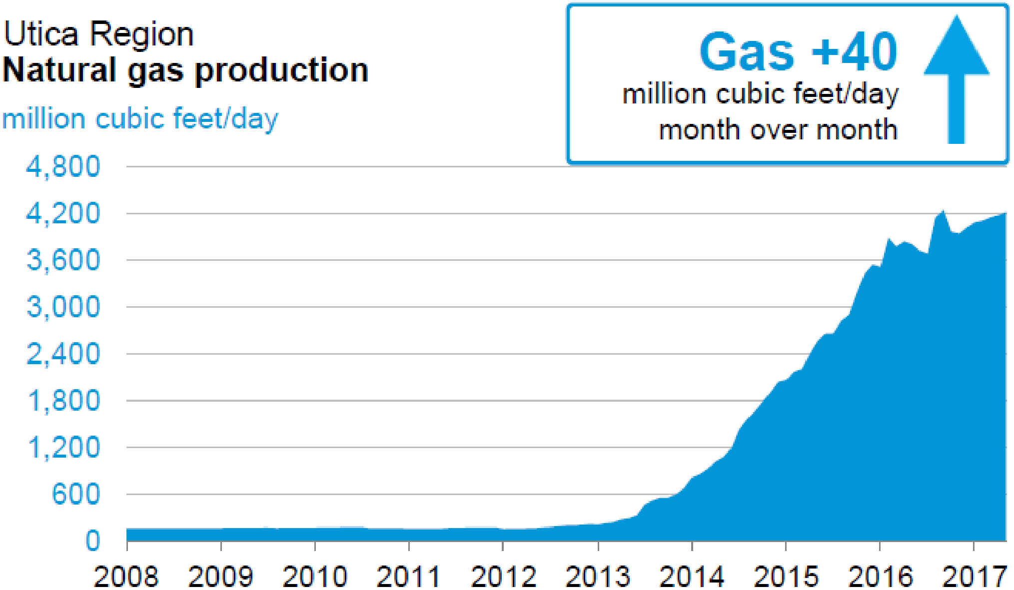
Utica/Pt. Pleasant Shale Energy and Brine Production



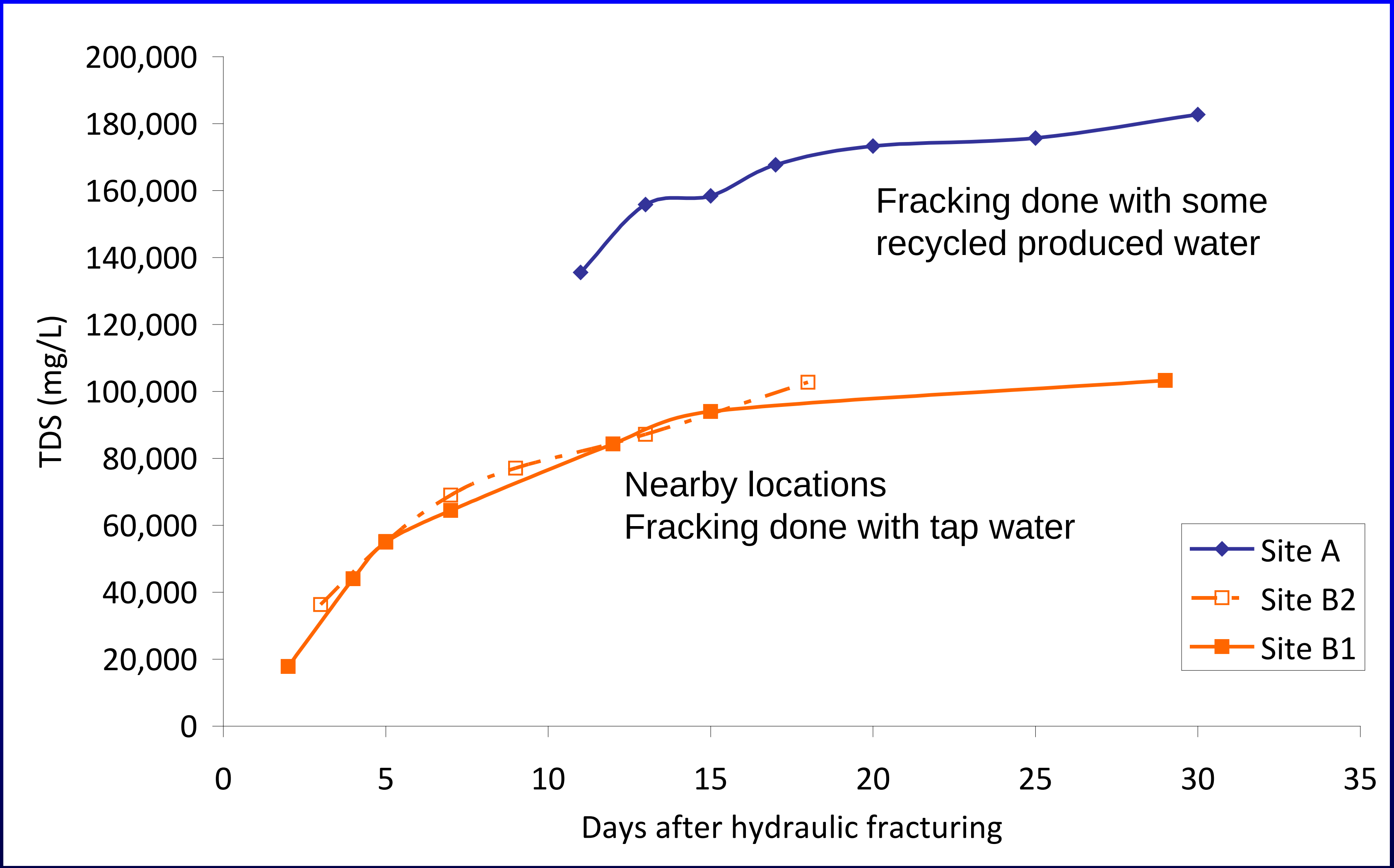


Current Production

- 4.2 BCF/D of gas
- 39 MBBLs/D of oil
- Current estimate of 50,000 BBLs/D of produced fluids (assuming 12.5 BBLs brine per MMCF gas)

Source: EIA

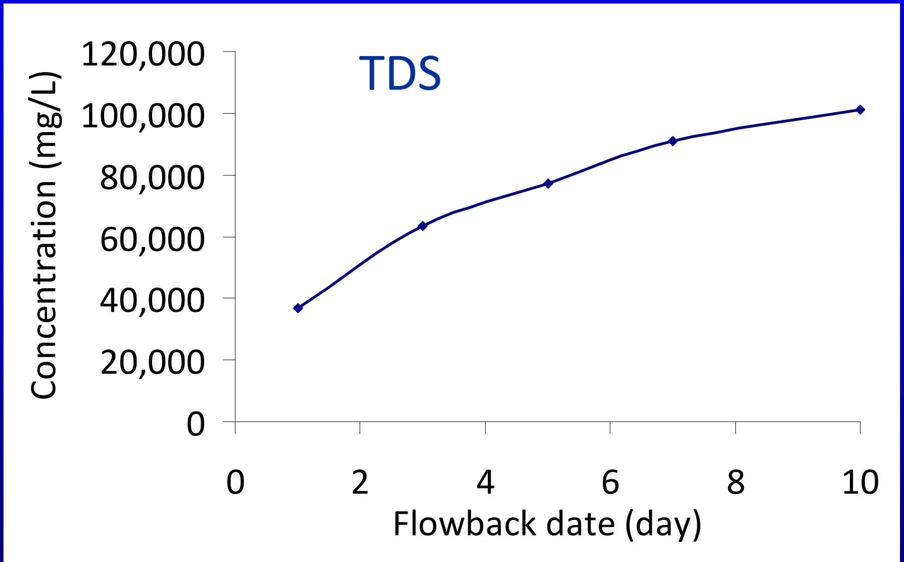
Flowback Water Quality evolves with Time

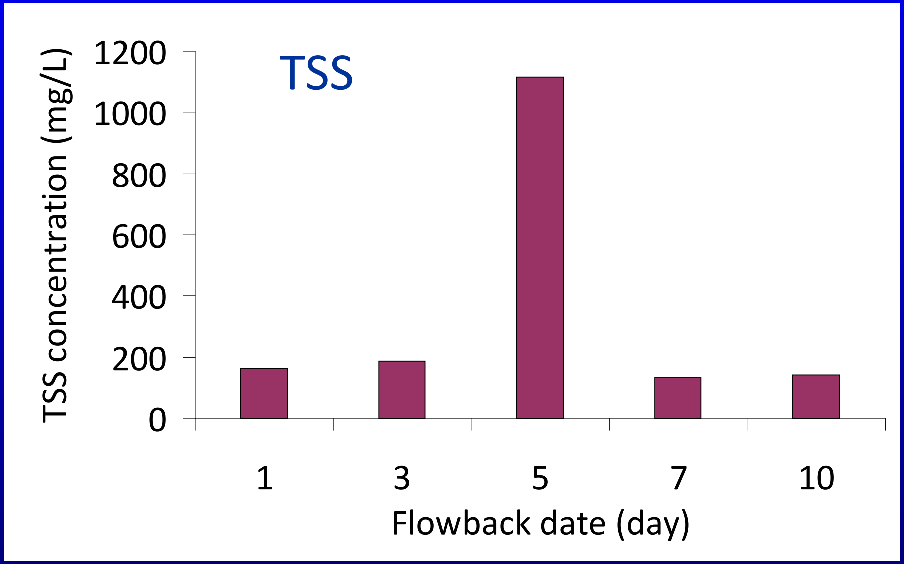


Barbot, et al., ES&T, 47, 2562-2569, 2013

Flowback Water Quality evolves with Time

Samples collected from one well

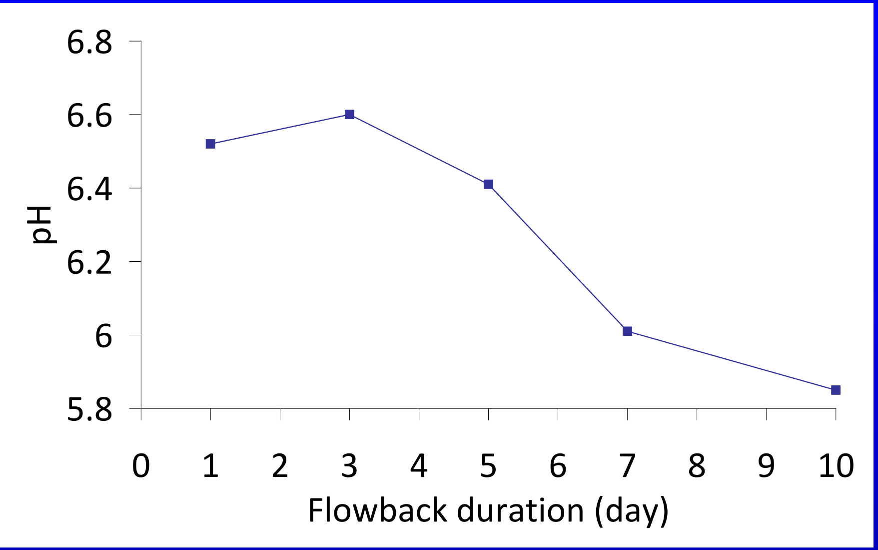


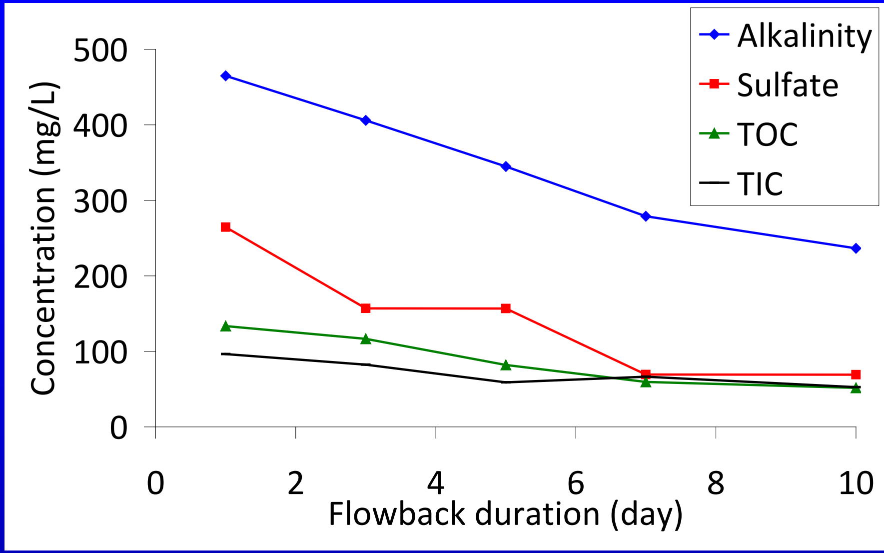


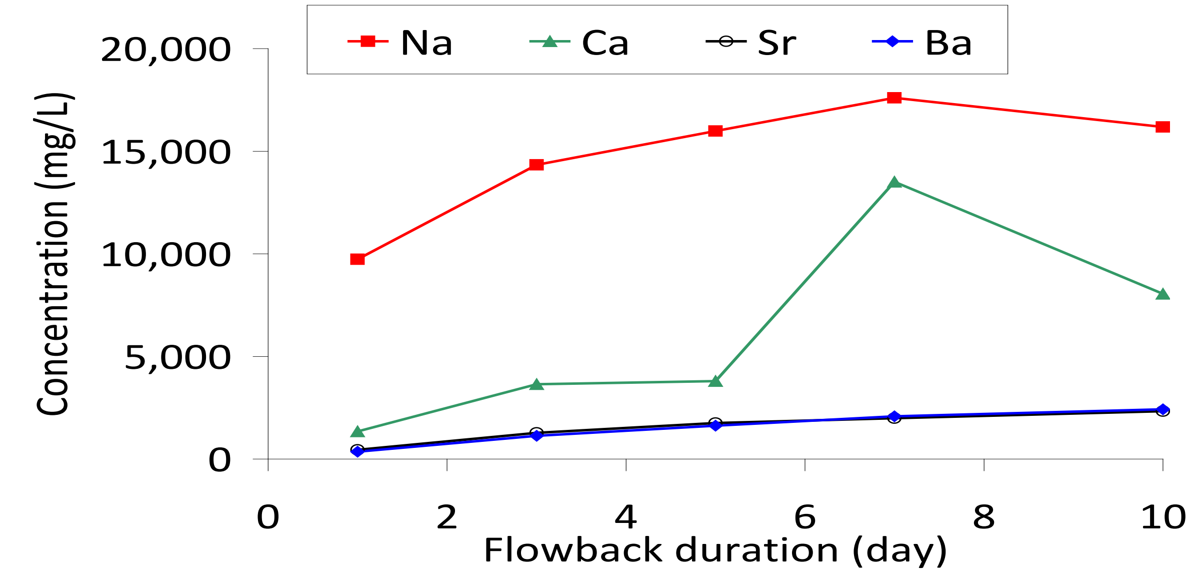
Regular TDS increase

Irregular TSS variations

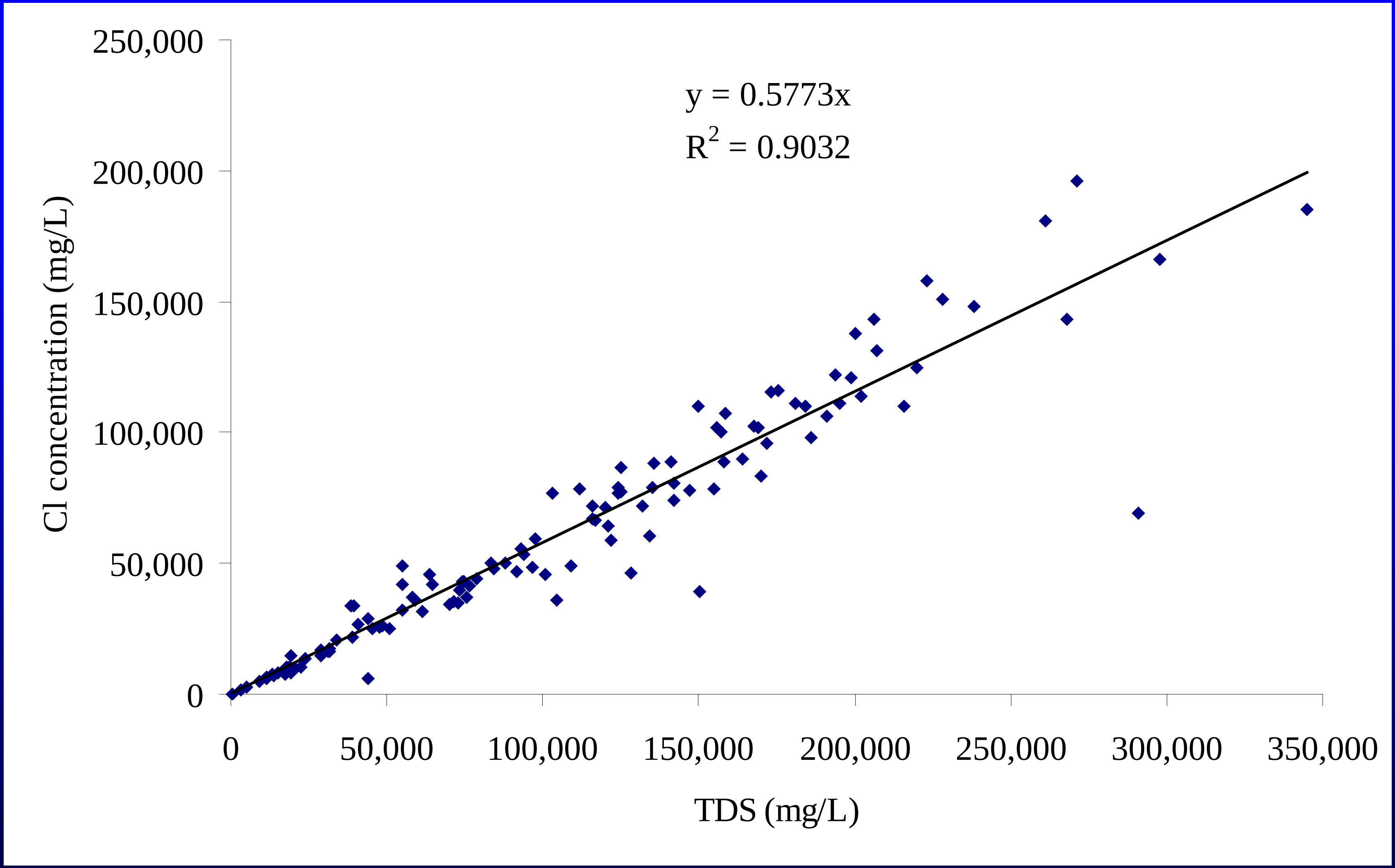
Flowback Water Quality vs. Time







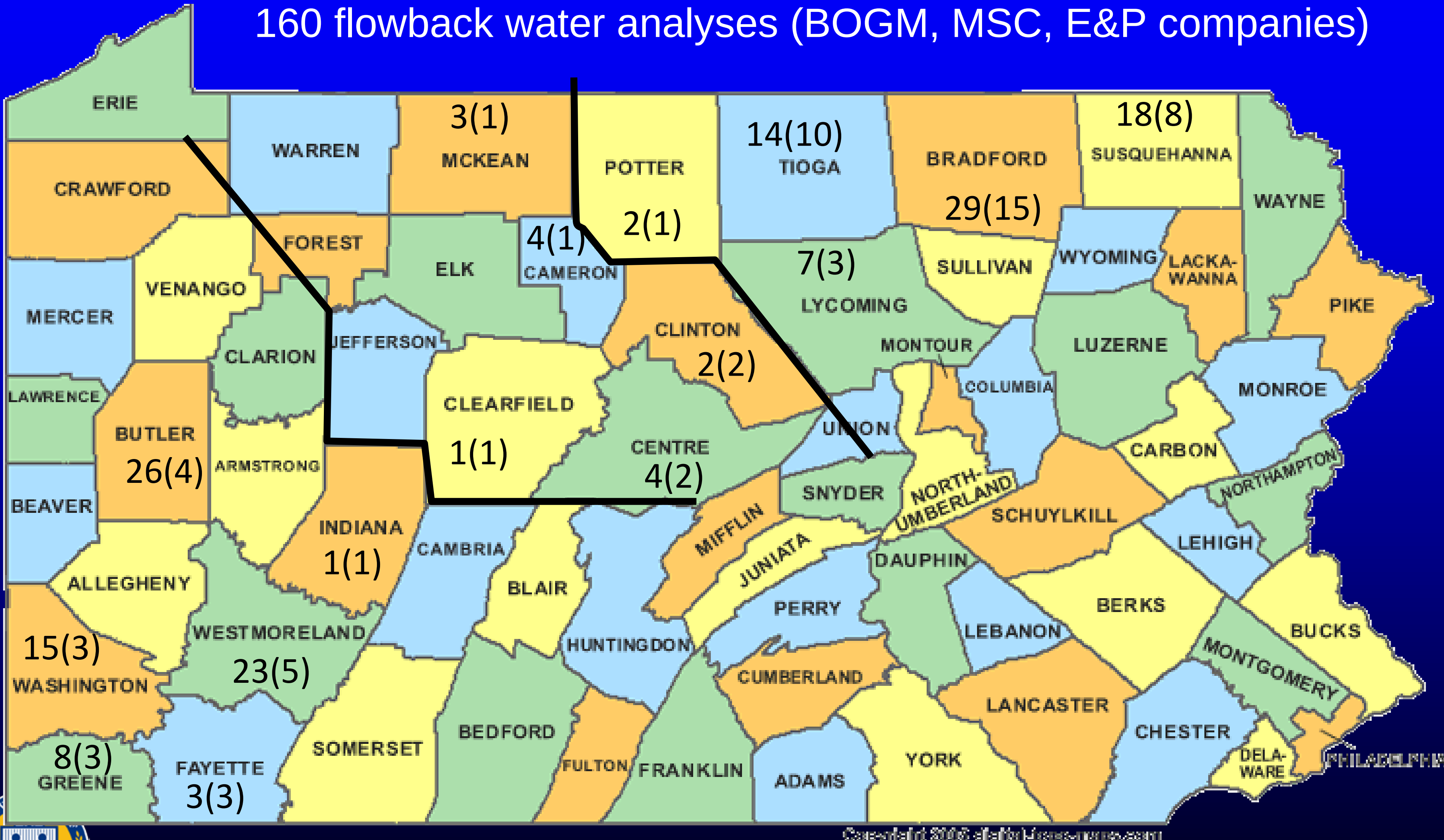
Flowback Quality



Barbot, et al., ES&T, 47, 2562-2569, 2013

Flowback Water Characterization

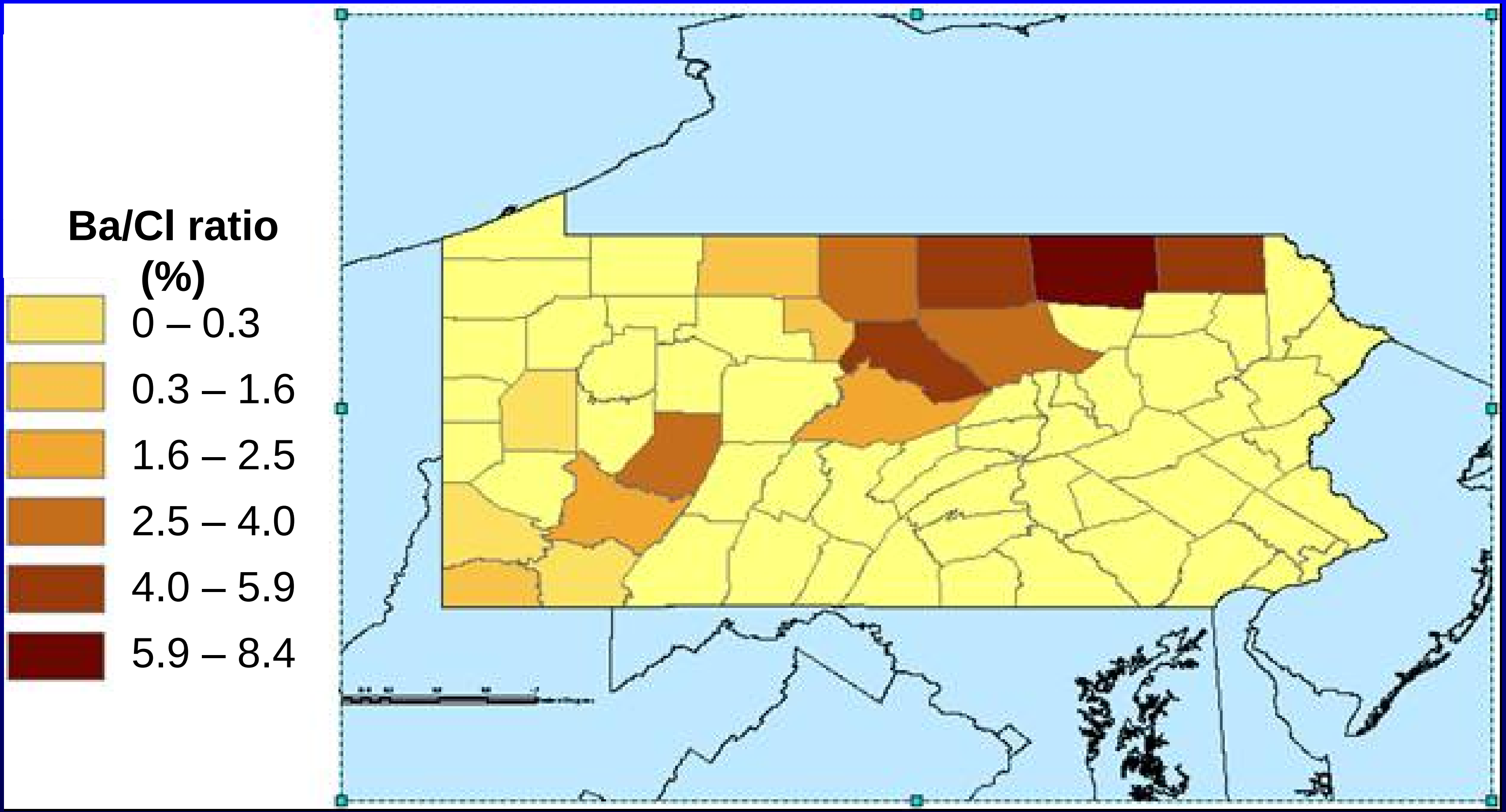
160 flowback water analyses (BOGM, MSC, E&P companies)



Flowback Water Quality

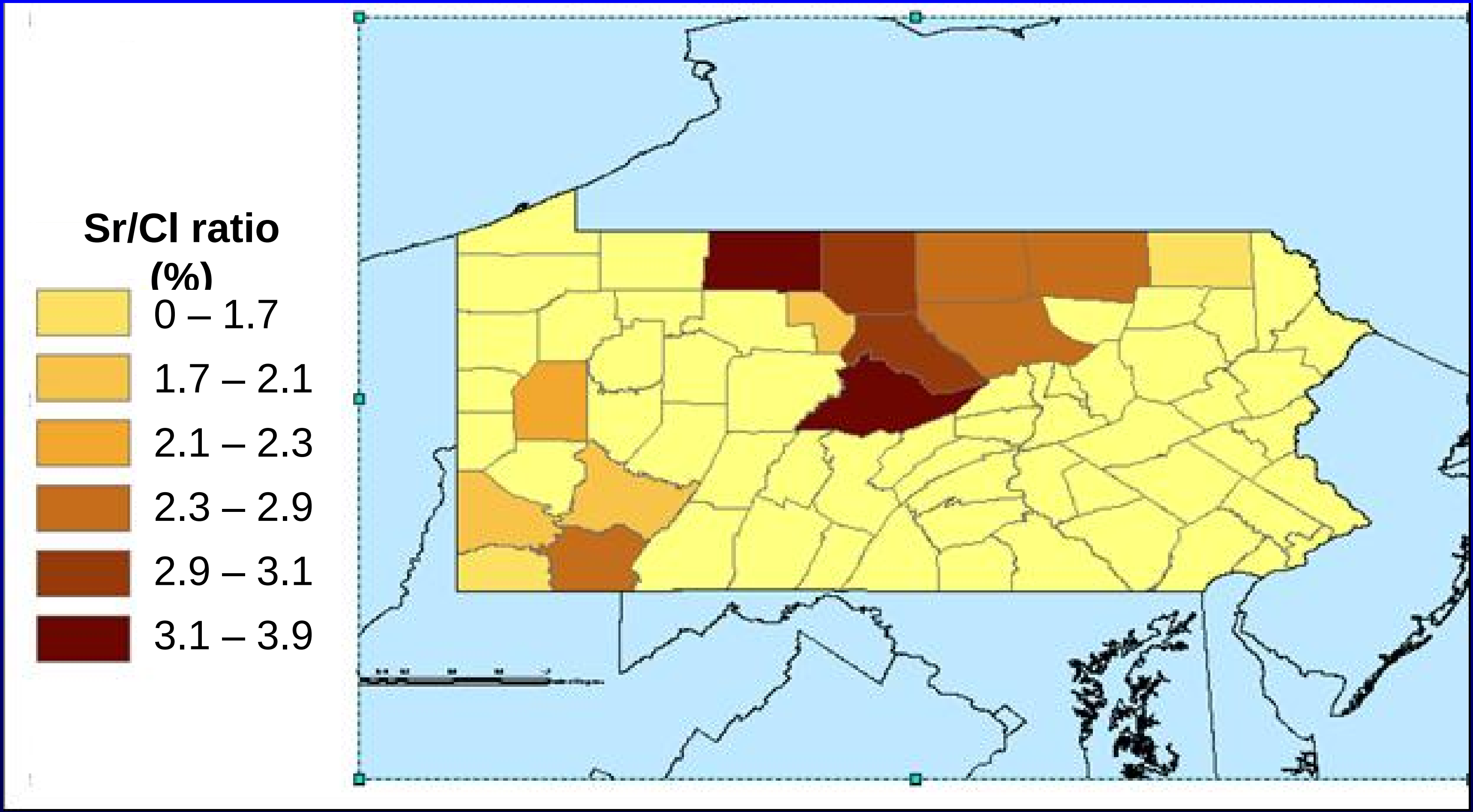
Constituent	Low	Medium	High
Ba (mg/L)	2,300	3,310	13,500
Sr (mg/L)	1,390	2,100	8,460
Ca (mg/L)	5,140	14,100	41,000
Mg (mg/L)	438	938	2,550
Hardness (mg /L as $CaCO_3$)	17,900	49,400	90,337
TDS (mg/L)	69,400	175,600	345,000
Gross Beta (pCi/L)	ND	43,415	597,000
Ra^{226} (pCi/L)	ND	623	9,280
COD (mg/L)	850	12,550	36,600

Flowback Water Quality: Ba trends

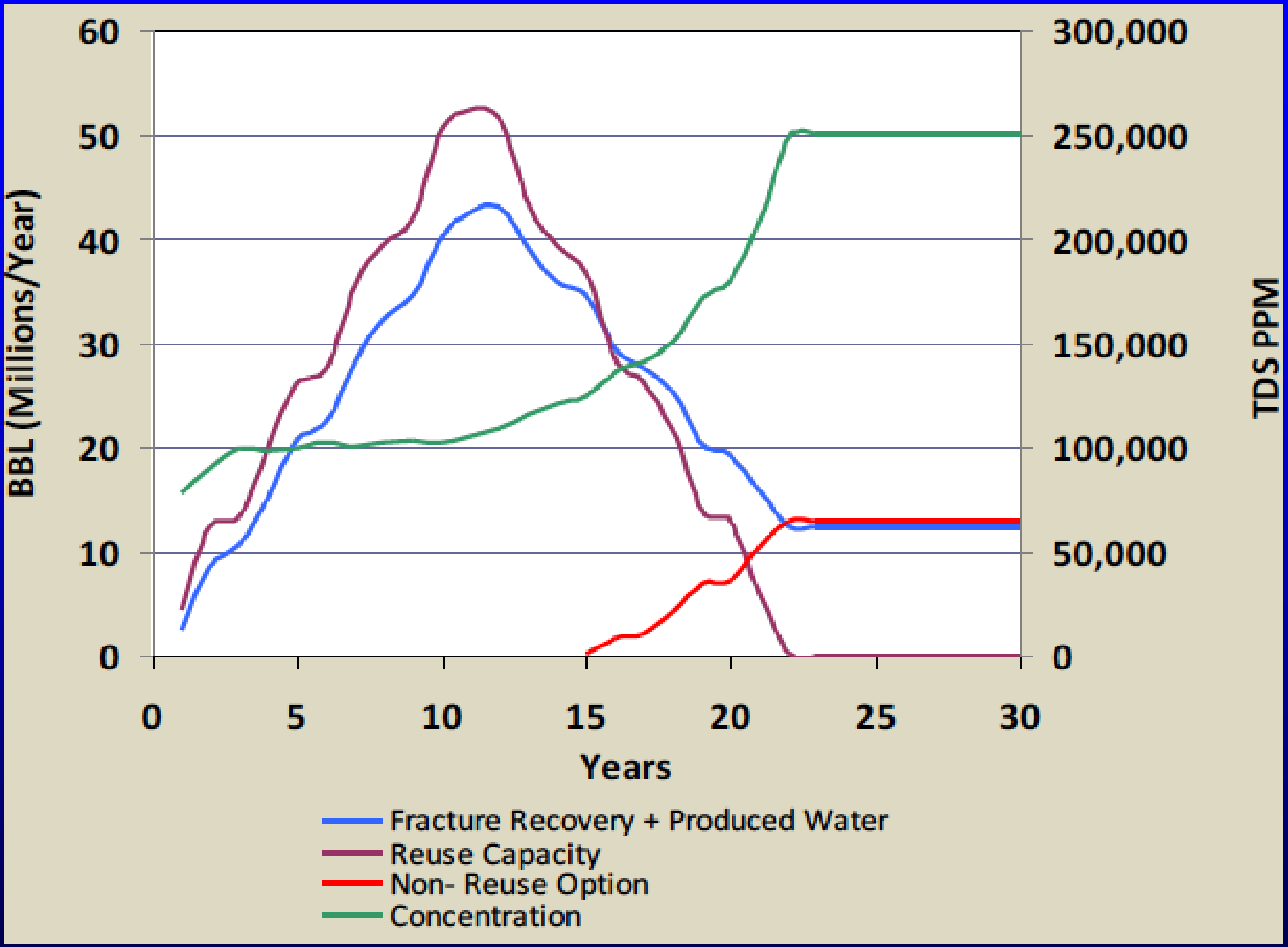


Barbot, et al., ES&T, 47, 2562-2569, 2013

Flowback Water Quality: Sr trends



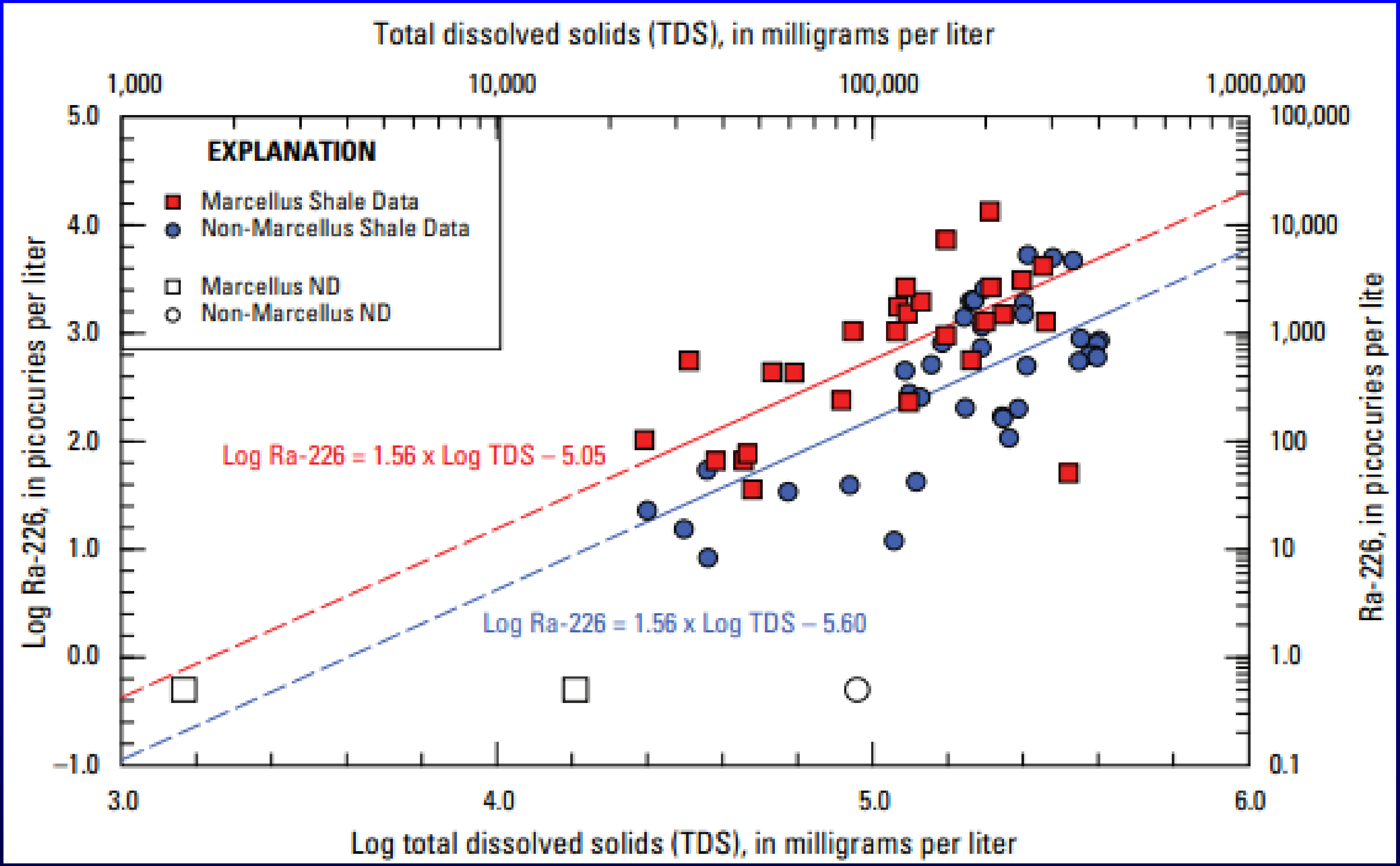
Recycling/Reuse



- 4800 wells on 625 mi^2
- 3 refractures/well
- 33% water reuse

- Recycling works for 12-15 yr with a continuous increase in salinity
- Eventually net water production in a filed

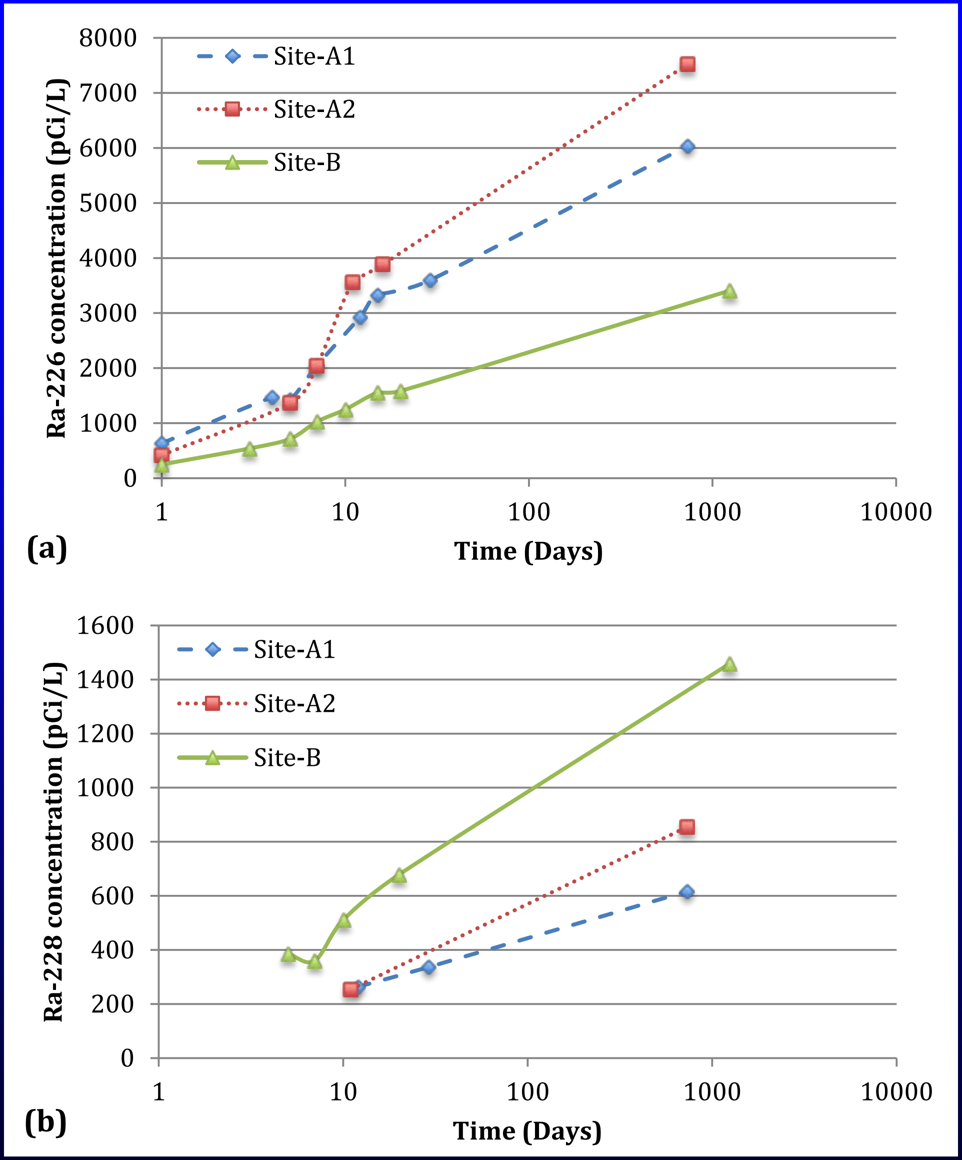
Radium in Flowback Water



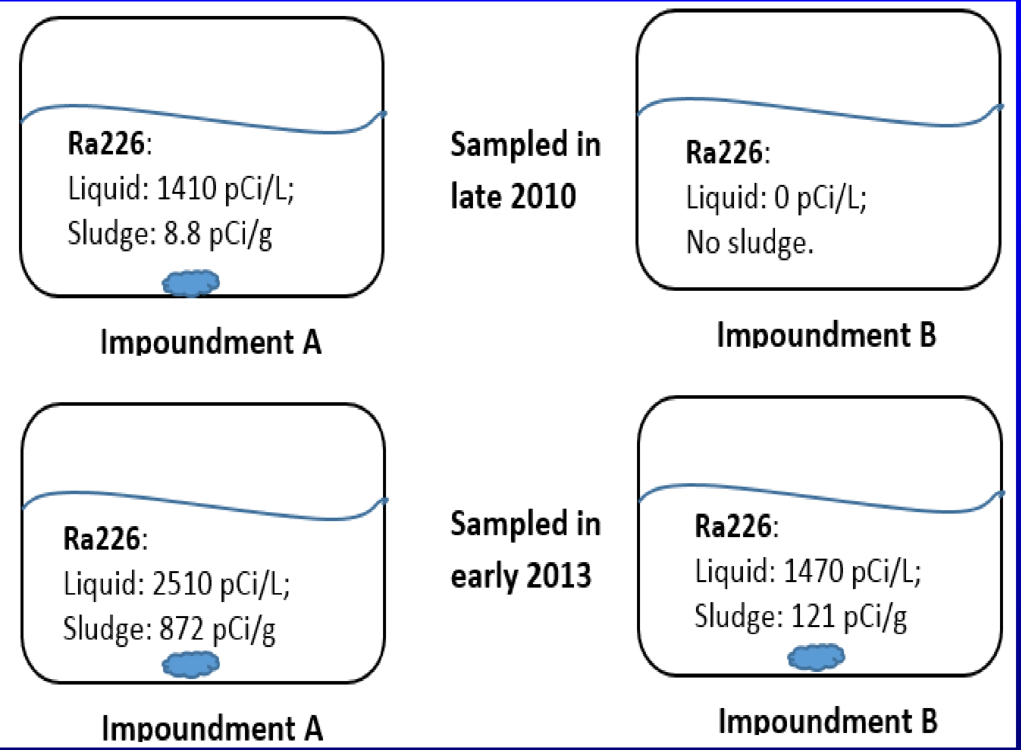
USGS, 2011.

Fate of Radium in Marcellus flowback water

- Ra-226/228 keeps increasing after the hydraulic-fracturing is completed;
- Ra concentration is highly depend on the local lithology of the shale;
- Ra-226 concentration ranges from several hundred to several thousand pCi/L.



Radioactive solid waste accumulation in storage impoundments



- Ra keeps accumulating in the bottom sludge of storage impoundments
- Ra concentration ranges from <10 to several hundred pCi/g, which exceeds regulatory limit for landfill disposal (25 pCi/g).

Zhang et al. ES&T, 49, 9347-9354, 2015.

Summary

- Chemical reactions influence the quality of the early flowback water but the salinity of produced water continues to increase (~ 300,000 mg/L)
- Produced water quality depends on local lithology (NE vs. SW)
- Recycling of produced water is not limited by its quality but it leads to an overall increase in the salinity of water in a well field
- NORM concentration in produced water increases with time and NORM accumulates in storage reservoirs

Thank You for Your Attention

Questions?