Groundwater Quality and Fracking: Current Understanding and Science Needs

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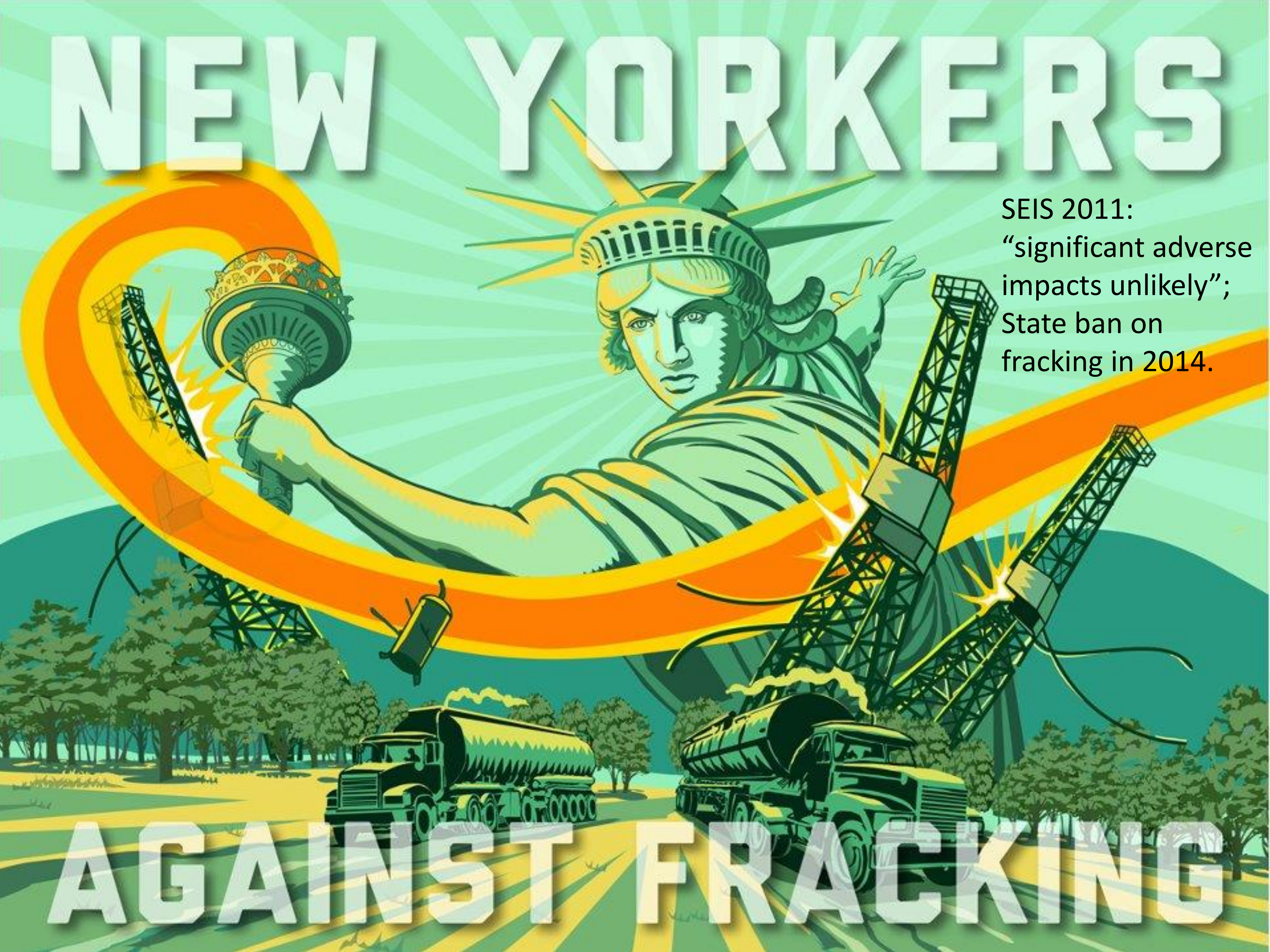
Niobrara Formation drilling, Denver-Julesburg Basin, Colorado, USA, 2015; photo by Dan Soeder

// Is fracking safe?

- This image is often associated with fracking, but is actually coal seam gas.
- Questions about environmental risk have been raised since the beginning.
- Many people expressing opinions on fracking risks are often unaware of what is known and not known.
- Perceived risk is different from actual risk of the O&G production process.
- Lack of data results in contention, monsters in closet, trust us, frac vs frack.

Fracking risk is manageable when prescribed procedures are followed.



SEIS 2011: "significant adverse impacts unlikely"; State ban on fracking in 2014.

//Shale Gas Development

- The first U.S. gas well was hand dug 30 ft into the Dunkirk Shale by William Hart in Fredonia, NY in 1821, to supply gas for street lighting, a tavern and a grist mill.
- The concept that black shales contain oil and gas resources was understood.
- OPEC oil embargo against United States: October 20, 1973 to Spring 1974; U.S. government decided domestic energy resources were needed for security.

// Shale Gas Development

- U.S. Department of Energy was created in 1977; funded Eastern Gas Shales Project (EGSP) from 1977 to 1992.
- Mitchell Energy continued experiments post EGSP on the Barnett Shale in Texas.
- Shales are a million times less permeable than conventional reservoirs.
- Darcy's Law: $Q = kA(\Delta P/\mu L)$; frack increases Q at low k by reducing L, and increasing A and ΔP
- Mitchell achieved success on the Barnett near Ft. Worth in 1997 with horizontal wells and staged hydraulic fracturing. Others soon followed.

Shale formation	Main Developers	Year	Location
Barnett Shale	Mitchell Energy (now Devon)	1997	Texas
Fayetteville Shale	Southwestern Energy	2004	Arkansas
Haynesville Shale	Chesapeake Energy	2006	ArkLaTex
Bakken Formation	EOG Resources & Continental	2006	North Dakota/Montana
Marcellus Shale	Range Resources	2007	Pennsylvania/West Virginia
Eagle Ford Shale	Petrohawk Energy	2008	Texas
Niobrara Chalk	Anadarko and Whiting	2010	Colorado/Wyoming
Utica Shale	Multiple operators	2011	Ohio
Permian Basin–multiple plays	Multiple operators	2014	Texas/New Mexico

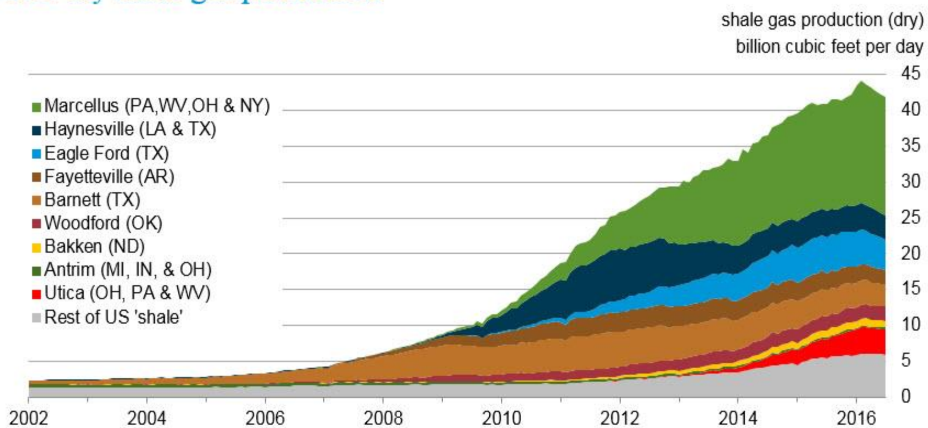
// Shale Resources – North America

2011

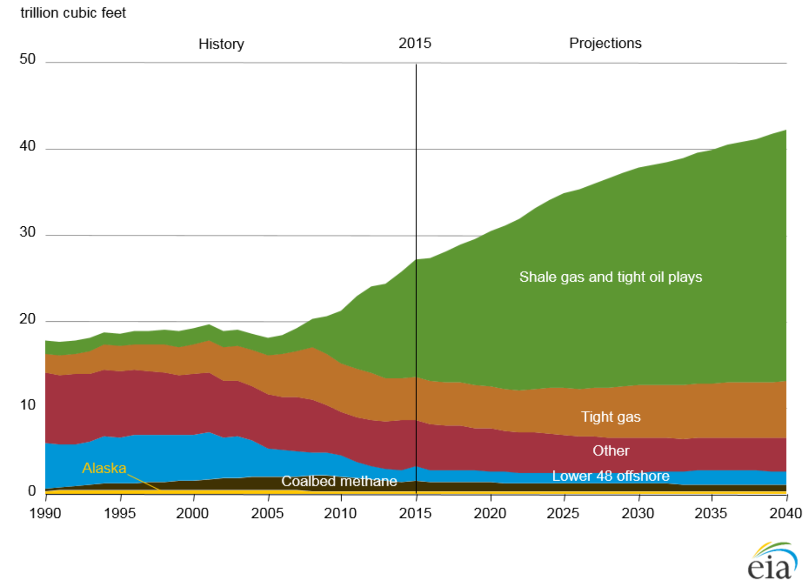
Source: U.S. Energy Information Administration based on data from various published studies. Canada and Mexico plays from ARI.
Updated: May 9, 2011

// The Dominance of Shale

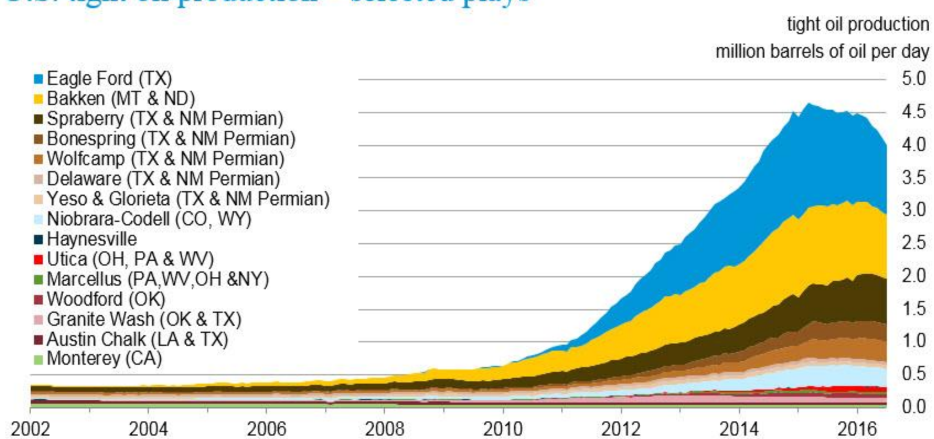
U.S. dry shale gas production



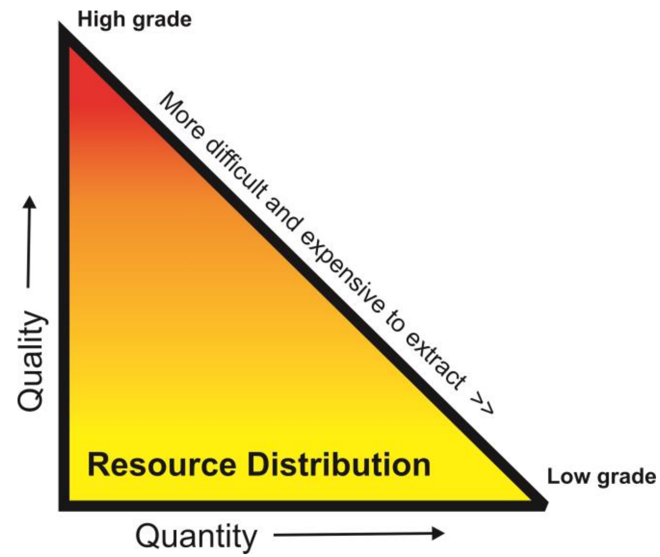
Sources: EIA derived from state administrative data collected by DrillingInfo Inc. Data are through July 2016 and represent EIA's official shale gas estimates, but are not survey data. State abbreviations indicate primary state(s).



U.S. tight oil production – selected plays



Sources: EIA derived from state administrative data collected by DrillingInfo Inc. Data are through July 2016 and represent EIA's official tight oil estimates, but are not survey data. State abbreviations indicate primary state(s).



Source: U.S. Energy Information Administration reports and web pages.

// Shale Gas Development

Requires industrial-scale drilling operations on five-acre pads.

- Large drill rigs are required
- Gas shale depths typically 5,000 to 15,000 ft (1.5 to 4.5 km)
- Lateral lengths typically 3,000 to 9,000 ft (1 to 3 km); 2016 record: 18,544 feet (3.5 miles/5.5 km) in Utica Shale (Ohio).

Environmental impacts:

- Roads and pads on landscapes.
- Impact of heavy equipment and traffic on communities.
- Increased runoff/turbidity in streams.
- Drilling operations: lights, noise, 24/7
- Fate/disposal of drill cuttings and mud.
- Air quality concerns: PM_{25}, PM_{10}
- Restoration of aquatic and terrestrial ecosystems after drilling is completed.

Bakken Shale drill rig, North Dakota, USA 2017; photo by Dan Soeder

//Shale Gas Development

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High-volume hydraulic fracturing.

- Large quantities of water, sand, and chemicals are used.
- Chemicals are transported to wellsites via truck, and blended during the frack.
- Flowback water is often recovered and recycled.
- Residual liquid waste disposed of in UIC wells, solid waste in landfills.

Marcellus Shale hydraulic fracturing operation near Waynesburg, PA, 2011, photo by Dan Soeder

Environmental impacts

- Air quality (PM_{10})
- Chemical spills or leaks
- Exotic/unknown chemicals
- Water source; volume used
- Impact on communities
  - Noise, lights, 24/7
  - Trucks on highways
- High levels of TDS in produced water
- Induced seismicity from liquid waste injection; NORM for solid waste.

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Wellbore integrity

- O&G wells are drilled through drinking water aquifers.
- O&G wells are fracked through drinking water aquifers.
- O&G wells are produced through drinking water aquifers.
- Ingraffea et al. (2014) at Cornell analyzed 75,505 compliance reports for 41,381 wells drilled in Pennsylvania between 2000 and 2012 and reported six-times greater frequency of cement/casing failure in shale gas wells vs. conventional wells
- Shale gas wells are subjected to multiple stages of high-volume hydraulic fracturing, which may affect integrity

Ingraffea, A. R., Wells, M. T., Santora, R. L., and S .B. Shonkoff, 2014. Assessment and risk analysis of casing and cement impairment in oil and gas wells in Pennsylvania, 2000–2012. Proceedings of the National Academy of Sciences 11, 10955-1096.

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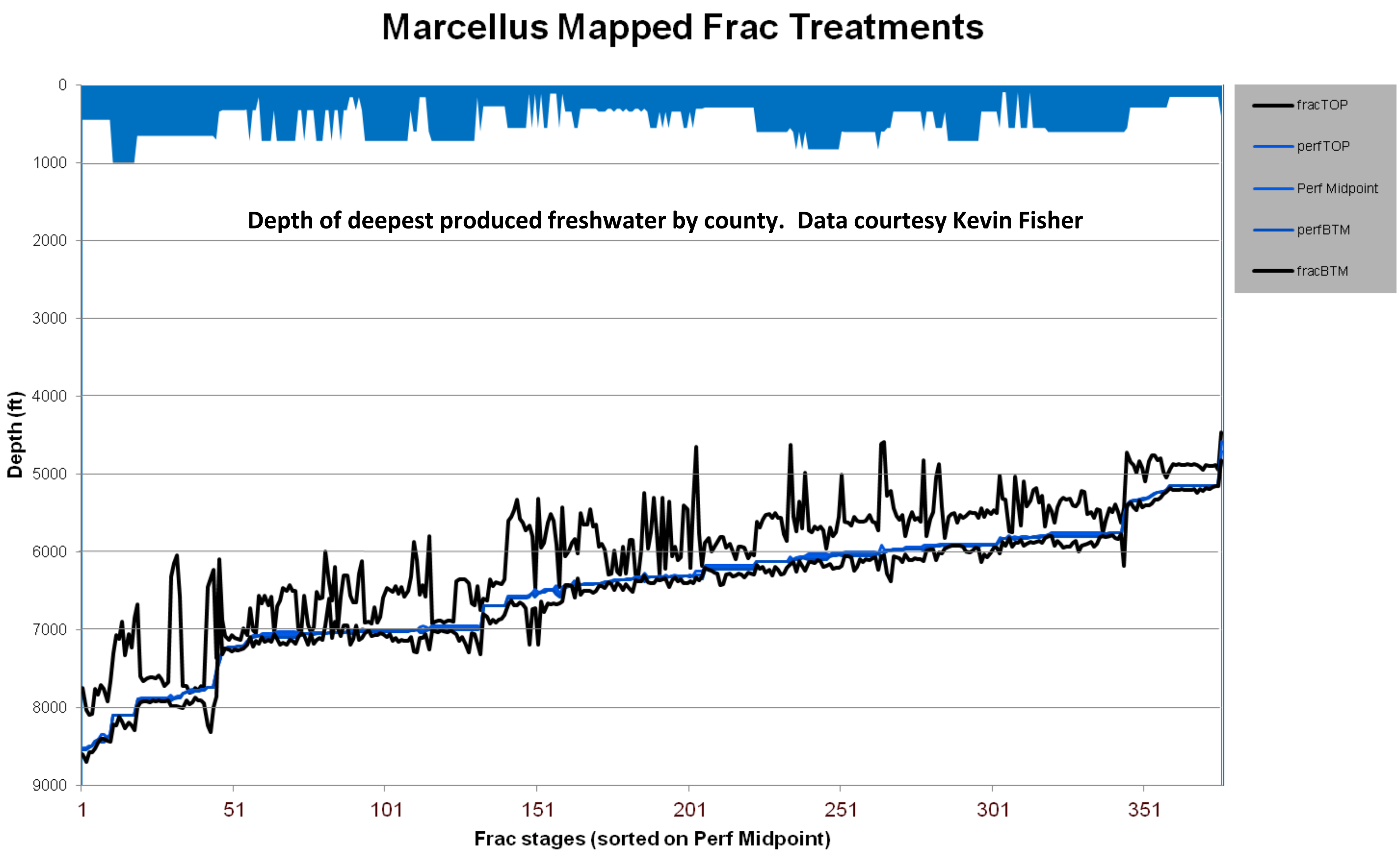
Perceived vs. Actual Risks



Fisher, K., and Warpinski, N., 2012, Hydraulic fracture height growth: real data: SPE Production & Operations, v. 27, no. 1, p. 8-19.

Hammack, R. et al. 2014, An Evaluation of Fracture Growth and Gas/Fluid Migration as Horizontal Marcellus Shale Gas Wells are Hydraulically Fractured in Greene County, Pennsylvania; NETL-TRS-3-2014; EPAct Technical Report Series; U.S. Department of Energy, National Energy Technology Laboratory: Pittsburgh, PA, 76 p.

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Perceived vs. Actual Risks

Leaks and Spills

- Surface spills of drilling fluids, frac chemicals, and produced water can contaminate both surface water and groundwater.
- Metals/organics leaching from black shale cuttings.
- Little is known about fate and transport of these chemicals in groundwater.

Storage of chemicals

- Large volumes of chemicals on well pads.
- Specifics largely unknown to regulators.
- Undetected, long-term seepage

Transport of chemicals

- Transit regulations require drivers to know what they are hauling.
- Accidents more likely, but spills or leaks typically recognized immediately.
- Chemicals can persist for long times.

Photograph of Indian Run WV by Doug Mazer, used with permission

Cozzarelli, I. M., et al., 2017: Environmental Signatures and Effects of a Spill of Untreated Oil and Gas Wastewater in the Williston Basin, North Dakota: *Science of the Total Environment*, v. 579C, p. 1782-1795, DOI: 10.1016/j.scitotenv.2016.11.157.

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Groundwater Risks - Leaks

Natural Attenuation

- What will be the fate and transport of hydraulic fracturing chemicals in groundwater?
- Are NA processes capable of degrading these chemicals before they reach the accessible environment?
- What about new chemicals?

Detection of chemicals

- Can current electronic sensors identify hydraulic fracturing chemicals, drilling fluids, or produced water in groundwater and surface water?
- What are the thresholds and responses?

Haynesville Shale, 2009 Pro-Publica

Kahrilas, G.A., Blotevogel, J., Stewart, P.S., and Borch, T., 2015
Mouser, P.J, Liu, S., Cluff, M.A., McHugh, M, Lenhart, J.J., and MacRae, J.D., 2016
Harris, A. E., Hopkinson, L. and Soeder, D.J., 2016

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Groundwater Risks – Stray Gas

- **Single biggest "contaminant" of concern is stray gas.**
  - Methane is non-toxic, explosive in air at concentrations from 5% to 15%.
  - Migrates through groundwater and accumulates in confined spaces.
- **Empirical relationship between stray gas and unconventional oil and gas wells.**
- **Source and migration pathways of stray gas are notoriously hard to determine.**

Payne home, 2007, Geauga County, Ohio (Photo: Dr. Scott Bair, Ohio State University)

Norma Fiorentino's exploded well vault, Susquehanna County, PA

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NGWA workshop consensus on what we know

- Sources of stray gas: biogenic, shallow geologic, deep thermogenic (Townsend-Small et al., 2016, Geophysical Research Letters, v. 43, p. 2283-2290)
- Occurs in GW as dissolved gas (28 mg/liter at STP) and free gas; mobilized in from drilling process, loss of wellbore integrity, aquifer drawdown, buoyancy.
- GW contaminants result largely from surface spills (Brantley, et al., 2014: Intl. J. Coal Geol., v. 126, p. 140–156)
- No evidence of aquifer contamination from below (Hammack et al., 2014: U.S. DOE report NETL-TRS-3-2014, Pittsburgh, PA, 76 p.)
- Fracking chemicals react with rock downhole to produce new organic compounds and release inorganics in produced water. (Renock et al., 2016: Applied Geochemistry, v. 65, p. 73-86.)
- Characterization of the fate and transport of hydraulic fracturing chemicals has just begun (Kahrilas et al., 2015: ES&T, v. 49, no. 1, p. 16–32.)

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NGWA consensus on what we need to know

- Baseline data are needed to define the changes in groundwater and surface water that may happen as a result of shale gas development.
- Universal environmental indicators for shale gas development need to be identified and established. (Cl, Br, Ba, Sr, Ra, TDS)
- Standardized data collection and analysis methods are needed.
- Faster, cheaper and better monitoring techniques, lab methods, and screening parameters for contaminants are needed.
- Access to field sites, samples, and reliable data from operators on the chemistry of produced water, oil, and gas are hard to obtain.
- Linkages need to be established between groundwater quality and well construction practices.
- Increased public awareness is needed of actual research findings and results for support and funding.

//Environmental Monitoring

Field site access challenges

Drillers

- Environmental monitoring will result in new, burdensome regulations.
- Potential liability if something is "found;" their secrets will be out in the literature.
- Environmental research on shale gas is a waste because nothing will be detected.
- Driller changes schedule or abandons lease because of variable gas prices.

Landowners

- Groundwater monitoring wells will find contaminants requiring costly cleanup.
- Monitoring groundwater will cause delays in gas production and royalty payments.

Soeder, D.J., 2015, Adventures in groundwater monitoring: Why has it been so difficult to obtain groundwater data near shale gas wells? *Environmental Geosciences*, v. 22, no. 4, p. 139–148

// Environmental Monitoring

U.S. Department of Energy field sites

Marcellus Shale Energy & Environmental Laboratory (Morgantown, WV)

- Managed by West Virginia University, focus largely on downhole instrumentation, air and surface water monitoring – no groundwater.

Hydraulic Fracturing Test Site (Permian Basin, TX)

- Managed by Gas Technology Institute, many industry cooperators, focus on improving hydraulic fracturing efficiency for better resource recovery.

Utica Shale Energy & Environmental Laboratory (Greene Co., PA)

- Managed by Ohio State University; project canceled due to site access issues.

Eagle Ford Shale Laboratory (new 2018)

- Managed by Texas A&M Engineering Experiment Station to investigate ways to improve shale oil production using new scientific knowledge and monitoring technology.

Tuscaloosa Marine Shale Laboratory (TMSL) (new 2018)

- Managed by University of Louisiana at Lafayette (Lafayette, LA) to address knowledge gaps for more cost-efficient and environmentally sound hydrocarbon recovery from the Tuscaloosa Marine Shale play.

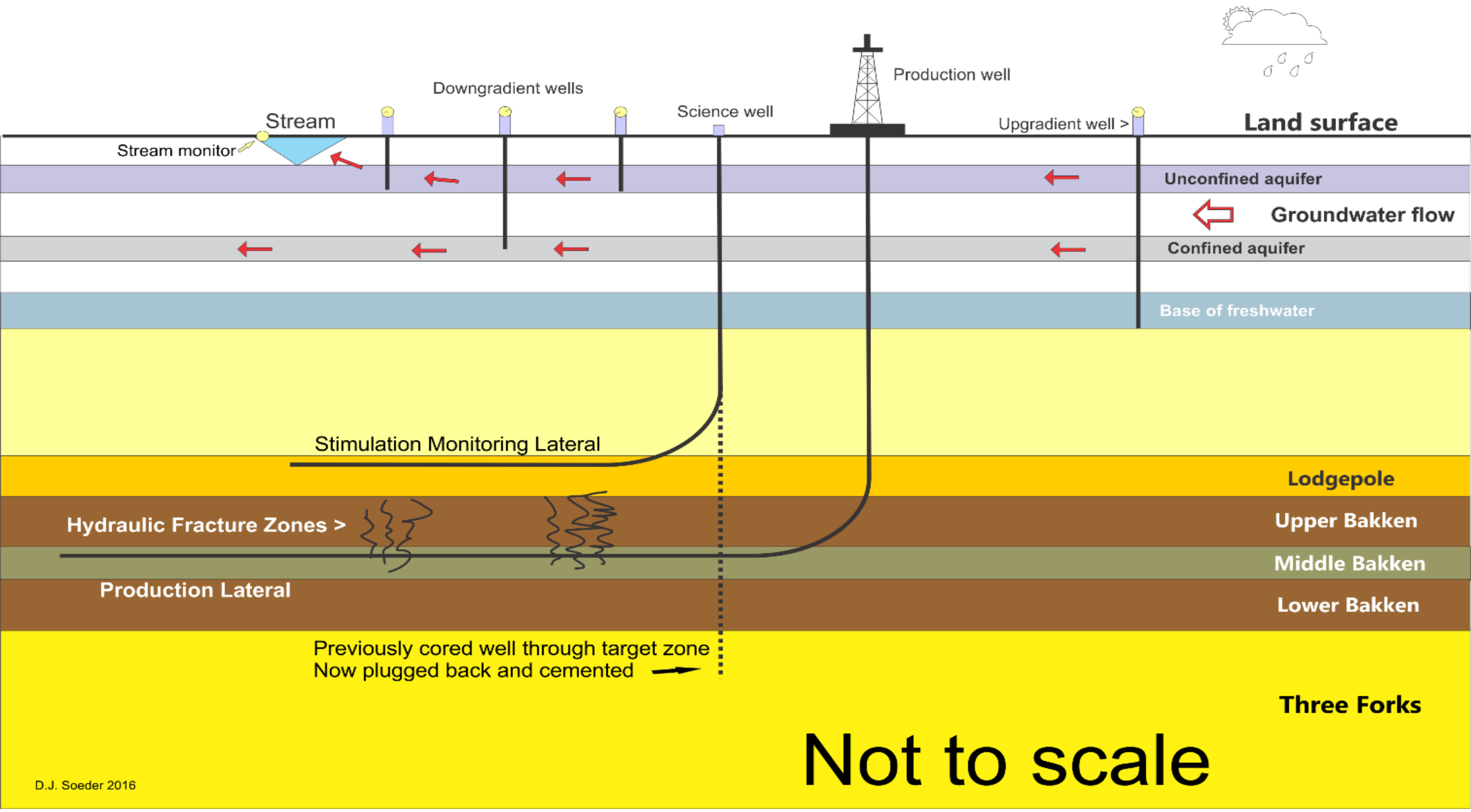
Field Laboratory for Emerging Stacked Unconventional Plays (ESUP) (new 2018)

- Managed by Virginia Tech to investigate the resource potential of emerging multiple unconventional reservoirs in the Nora Gas Field of southwest Virginia.

None are focused on environmental risks, groundwater, or exposure monitoring

// Design for a Field Research Site

Conceptual model



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Summary and Conclusions

1. Successful development of shale gas and tight oil has made the United States energy independent for the first time in decades.
2. The process for extracting these hydrocarbons requires directional drilling and reservoir stimulation, or fracking.
3. Stray gas and chemical spills from fracking are the primary risks to groundwater.
4. Defining contaminant sources and pathways into the environment are critical for risk assessment.
5. Access to field sites and industry data remains problematic.

Actual town in eastern Pennsylvania. Photo by Dan Soeder, 2012

// Questions and Discussion

For more information on shale gas development, please see GSA Special Paper 527.

Available from Geological Society of America Bookstore: http://rock.geosociety.org/store/

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