Shale Gas Risk Assessment and Evolving Technology

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Health Effects Institute Workshop

December 10, 2014

U.S. DEPARTMENT OF ENERGY | National Energy Technology Laboratory

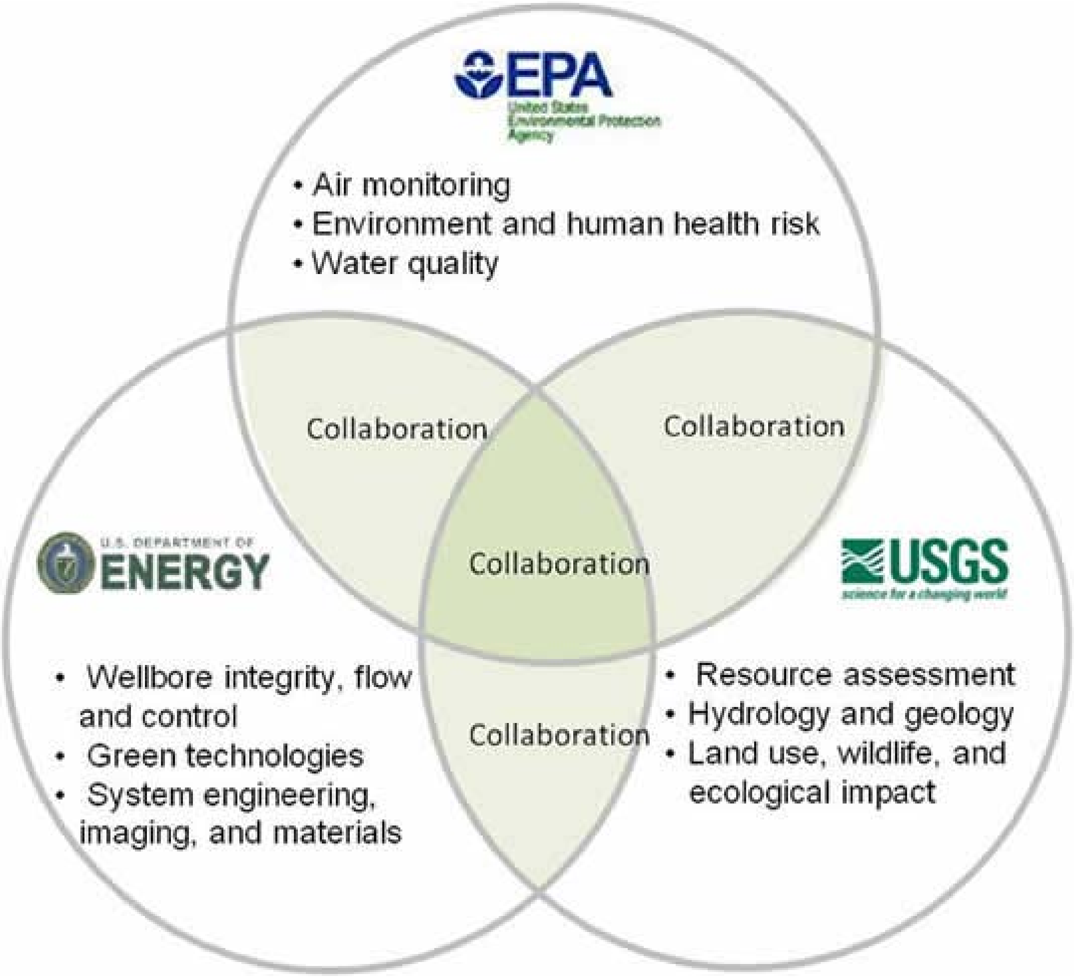
Federal Government Activities

- In 2011, after the BP oil spill on the Macondo well, and in the wake of several contentious EPA stakeholder meetings on hydraulic fracturing, USDOE Secretary Steven Chu ordered DOE oil and gas research to focus on the environmental impacts of deepwater drilling and shale gas development.
- In April 2012, President Obama ordered the EPA, DOE and the U.S. Department of the Interior (mainly the USGS) to cooperate on "fracking" research.
- The three agencies signed an MOU, and assembled a study plan submitted to the White House in November 2012.
- The Administration asked for funding in the FY14 budget.
- DOE and EPA are moving forward using existing funds; USGS is awaiting funding.
- Study plan available at http://unconventional.energy.gov/

Multi-Agency Environmental Assessment

Steering Committee of senior agency executives; chair alternates annually; Technical Committee of experts

- Assess the risks and receptors of hydraulic fracturing
- Unconventional Oil and Gas (UOG) national study plan; built on case studies (Marcellus, Barnett, Bakken)
- Focus on air, water, seismicity, and locations of future impact.
- Incorporates relevant current studies
- HHS and NAS have since been added to the MOU to address health issues and basic science.
- Six flagship projects developed in 2013 to interest Congress.



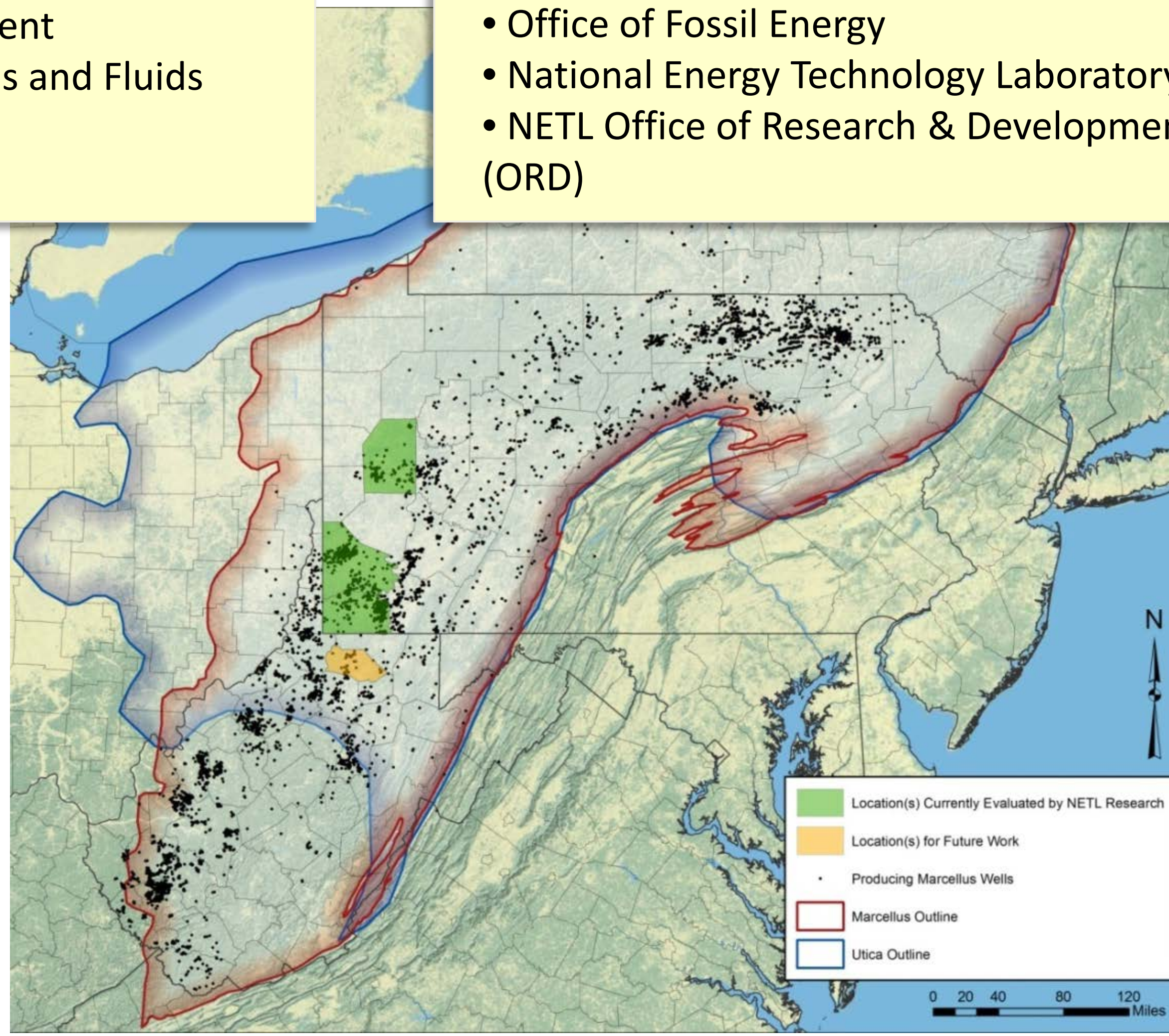
Study Areas: 1) Future resource development, 2) Water availability, 3) Water quality, 4) Air quality, 5) Induced seismicity. Added later: ecosystems and human health.

ORD Approach for Shale Gas Development Risk

Goal: Deliver Risk Assessments for
- Fugitive Air Emissions and GHG
- Produced Water Management
- Subsurface Migration of Gas and Fluids
- Induced Seismicity

Research Plan Organization
- U.S. Department of Energy
- Office of Fossil Energy
- National Energy Technology Laboratory
- NETL Office of Research & Development (ORD)

Approach:
- Field Data to establish baselines and impacts of development
- Laboratory Data for simulations, to understand processes and confirm field data
- Computational Tools to characterize and predict system baselines and behavior

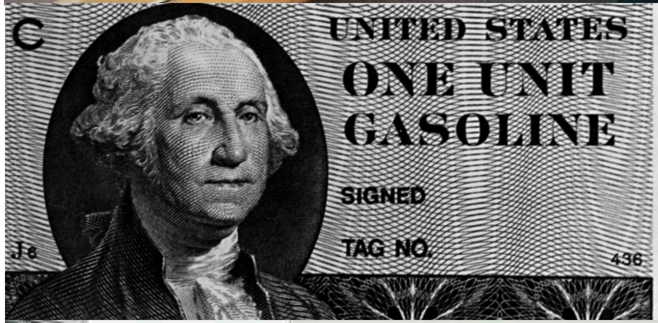


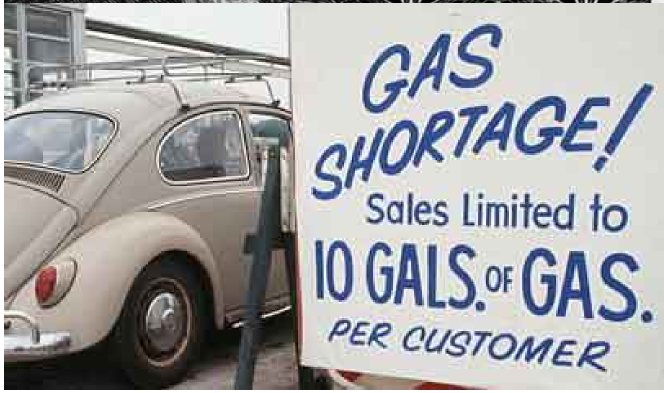
Engineering Risk Assessment

- **Primarily developed for engineered geologic systems**
  - Underground nuclear waste isolation
  - CO_2 geologic storage
  - Oil and gas production: ultra deepwater and unconventional
  - Also known as a site performance assessment
- **Approach is probabilistic, focus is on the release of a hazardous material into the accessible environment.**
  - System divided into components
  - High fidelity, validated models are developed for each
  - Uncertainty reduction by focused data collection
  - Potential impacts of release generally not considered
- **Reduced order models (ROMs) are used to simplify predictions of high fidelity models for computation.**
- **ROMs are integrated into an Integrated Assessment Model (IAM) to predict total system performance and risk.**
- **Model is calibrated using field data and databases.**
- **IAM scenarios are run to test different system interactions.**

Whence Shale Gas?

- **October 20, 1973 to Spring 1974: OPEC oil embargo against United States**
  - Price of gasoline quadrupled ($0.40-$1.60)
  - Gasoline was in short supply
- **U.S. Department of Energy formed by the Carter Administration on August 4, 1977**
- **DOE funded R&D projects to increase domestic energy supplies:**
  - Eastern Gas Shales
  - Western Tight Gas Sands
  - Coal Bed Methane
  - Geopressured Aquifers
- **Later projects (1990s)**
  - Methane hydrates
  - Ultra deep gas
- **Objective: offset imported oil by increasing domestic energy production (in an environmentally-responsible manner).**





Yergin, Daniel, 1991, The Prize: The Epic Quest for Oil, Money, and Power: New York, Simon & Schuster, 912 p. (ISBN: 0671502484)

New Sources of Natural Gas

- **Resources were known and in some cases substantial, but production was typically small.**
  - Dunkirk Shale in NY (1821)
  - Huron Shale in KY (early 1900s)
  - Coal seam gas
  - Tight sands
- **Engineering challenges**
  - Natural fractures = natural gas (not always)
  - Two-phase flow is difficult in low permeability rocks
  - Formation contact limited with vertical wells and single hydraulic fractures
- **Economic challenges**
  - Not enough production to justify the cost of wells

SPE 7628

Potential New Sources of Natural Gas

Leo A. Schrider, SPE, U.S. DOE
Robert L. Wise, U.S. DOE

Introduction

Natural gas continues to be one of the major sources of energy produced and used in the U.S. Declining gas reserves and curtailment of supplies have reemphasized the major influence this energy source has on the U.S. economy. The U.S. DOE is investigating several options for increasing the supply, including a program for unconventional gas recovery (UGR). Four UGR projects currently are being assessed: western tight gas sands, geopressured reservoirs, Devonian shales, and methane from coalbeds.

Both the Devonian shale and methane-from-coalbeds projects are paramount in this assessment, since they underlie a large section of the U.S.

The eastern (Devonian) shales contain a vast, essentially unexplored volume of natural gas. This area could represent new gas recovery from approximately 250,000 sq miles throughout the U.S. Studies by the government and industry have been focused on shale characterization to determine the magnitude of potential gas reserves and technology development needed to improve current state-of-the-art stimulation techniques. The initial R&D results have shown promise and point out the technology needed for successful development.

The goal of the methane-from-coalbeds project is to provide natural gas from coal seams. While coal itself is recognized as a major energy source, it also contains vast quantities of methane gas. This methane source is not new, since coal mine operators have been aware of its presence and release into the atmosphere during mining opertions. Technology studies are being conducted to learn the production potential of this methane and to show how this gas may be put to widespread use.

Devonian Shales

The Devonian shales of the Appalachian, Michigan, and Illinois basins have produced natural gas since the 1800's. These shales in the eastern U.S. (Fig. 1) contain a high volume of gas. Independent estimates of the recoverable gas range from 3 Tcf to several hundred times that amount. To date, the gas produced from these shales has been limited to an estimated 2.5 Tcf[1,2] because of the unpredictable behavior and economics shown by existing Devonian shale wells. Similarly, these uncertainties have restricted private-sector R&D funding and development of technology needed for Devonian shale gas production.

Background

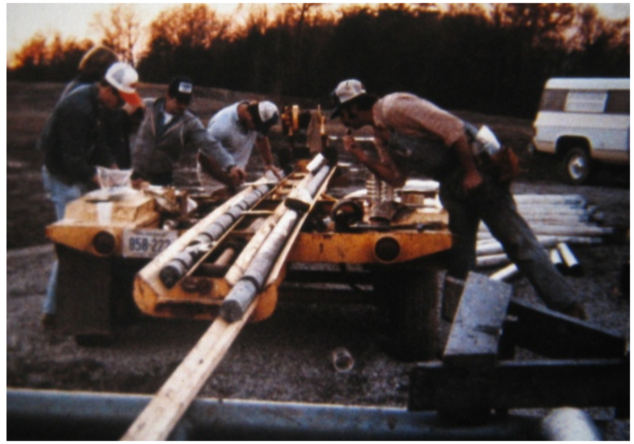
The DOE program for development of Devonian shale natural gas production is the Eastern Gas Shales Project (EGSP), which provides for a DOE-industry partnership to conduct projects that will

0149-2136/80/0004-7628$00.25

The U.S. DOE's gas resource program aims at resolving existing technological barriers to effective recovery of natural gas from Devonian shale and methane from coalbeds. Upon completion of these projects, DOE expects the technology developed jointly with industry to result in wide-scale recovery and use of these new sources of natural gas.

Schrider, L. A. and Wise, R.L., 1980, Potential new sources of natural gas: Journal of Petroleum Technology, April 1980, p. 703-716.

DOE Eastern Gas Shales Project 1976-1992



All photos - DOE

Gas Shale Geology

- Fine-grained, clastic mudrock, composed of clay, quartz, carbonate, organic matter, and other minerals.
- Shale is organic-rich (black), or organic lean (gray), and commonly fissile.

- Shale porosity (φ) ~ 10%
- Shale permeability (k) µd to nd.
- Small grains = small pores; φ can be intergranular, intragranular, and intra-organic.

- Gas occurs in fractures, in pores and adsorbed or dissolved onto organic materials and clays.
- The gas potential of the Marcellus Shale is "surprising" – Soeder, 1988

Soeder, D. J., 1988, Porosity and permeability of eastern Devonian gas shale: SPE Formation Evaluation, v. 3, no. 2, p. 116-124, DOI 10.2118/15213-PA.

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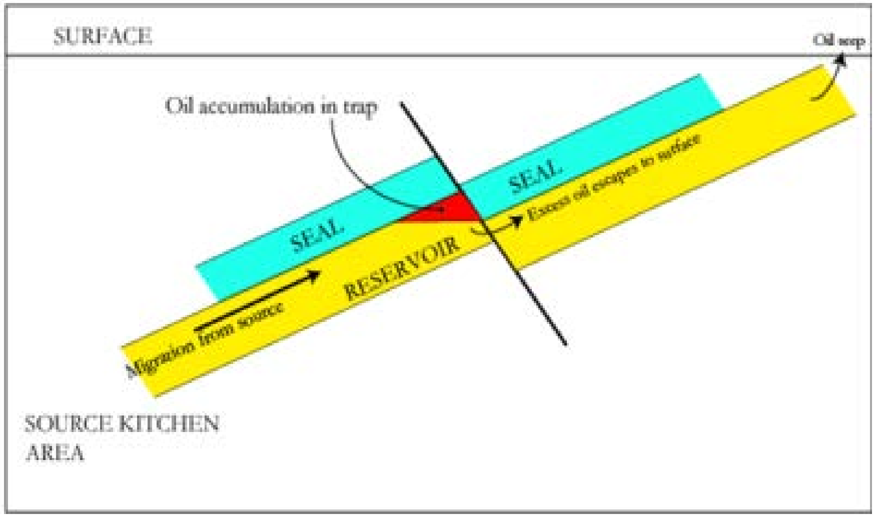
Petroleum Geology

Conventional Reservoir: concentrated deposit of recoverable oil and/or gas.

NEED:

1. Source rock: 1-2% organics (kerogen)
   a. Types I and II kerogen (petroleum + gas)
   b. Type III kerogen (coal + gas)
2. Thermal maturity
3. Reservoir rock
4. Trap and Seal
5. Migration pathway

If any one of these is missing, no production.

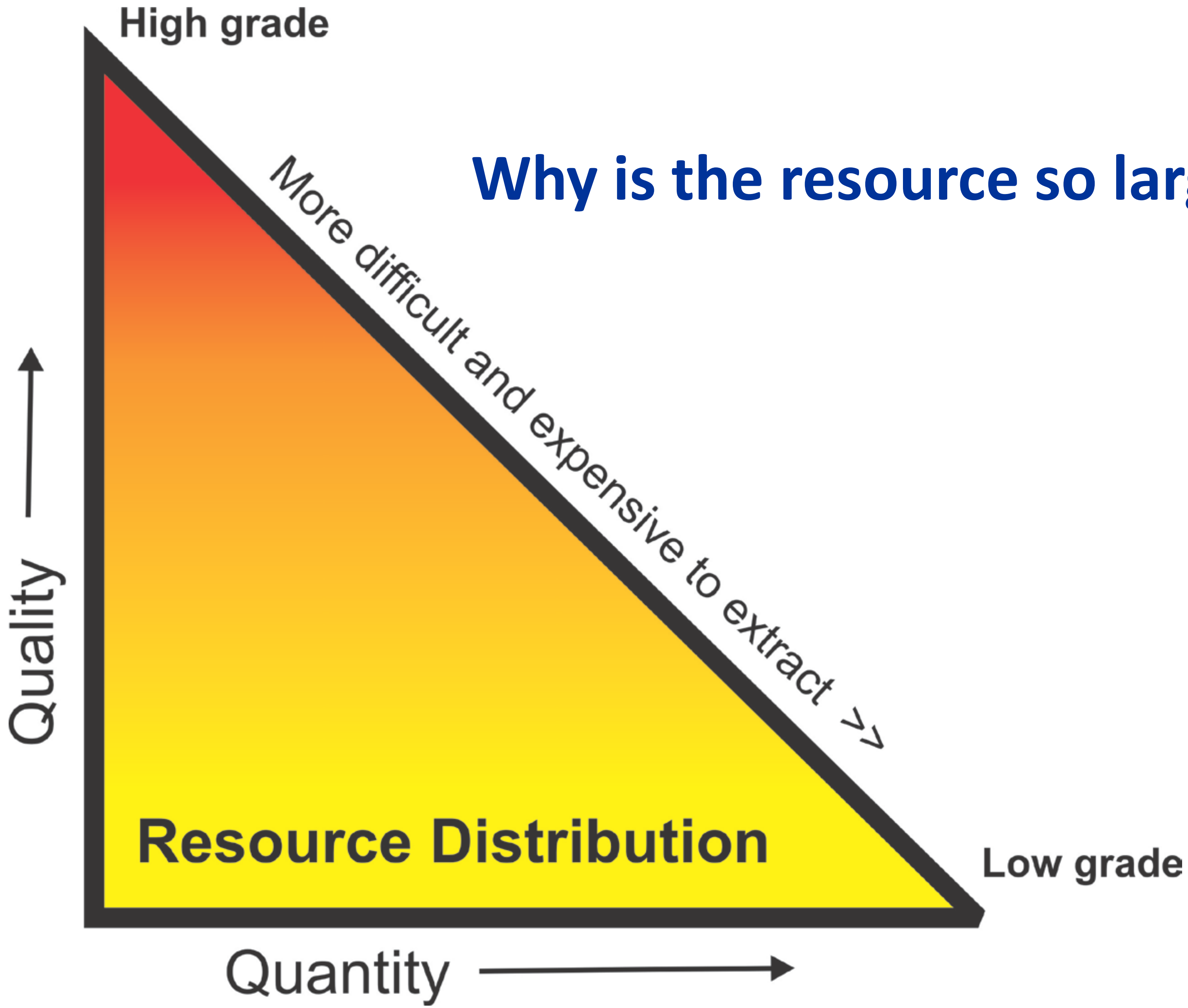


Shale gas is "unconventional": produced directly from thermally-mature high-organic content source rock. No reservoir, trap or seal needed.

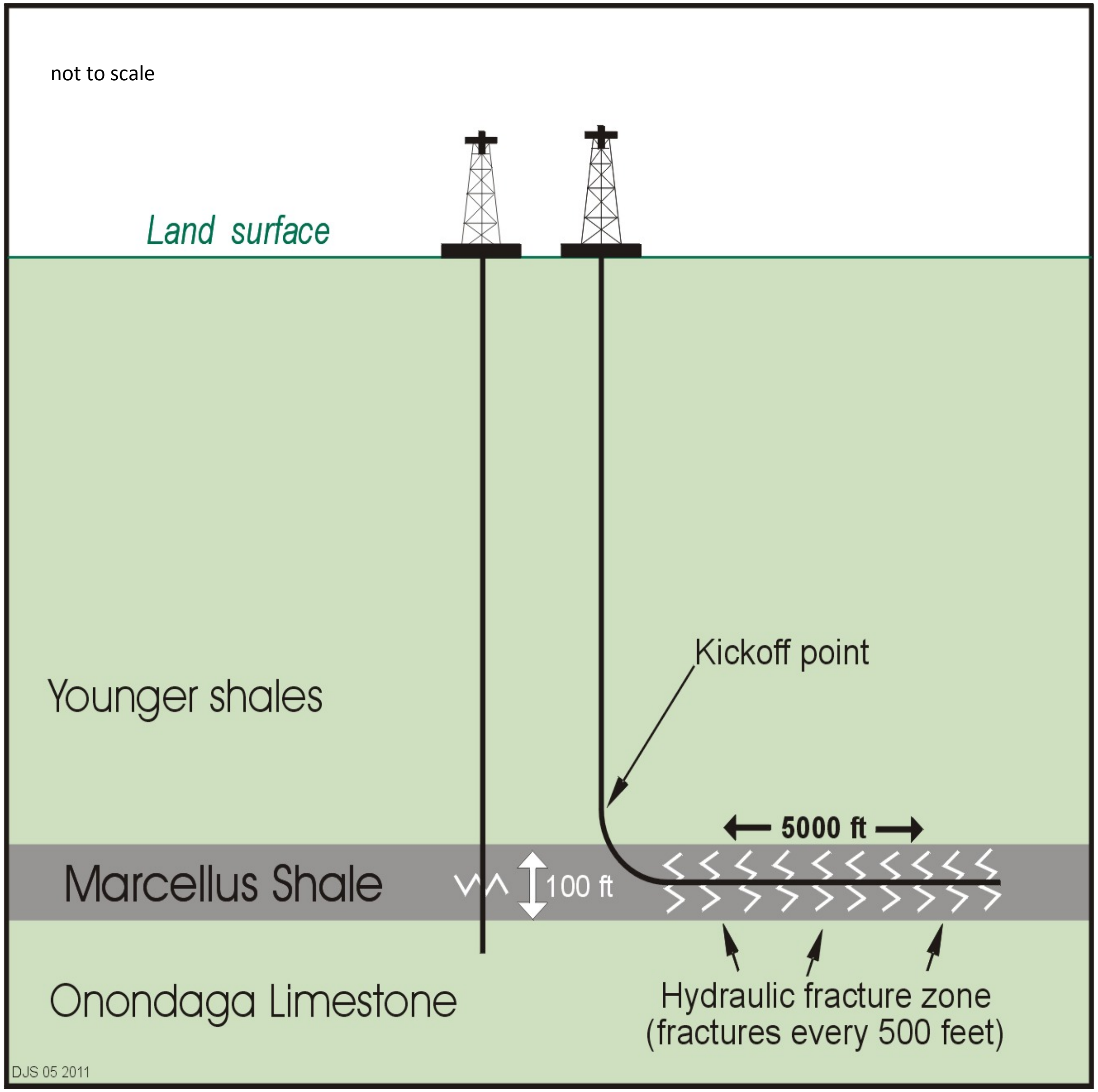
USGS calls this a “continuous resource” producible anywhere

Charpentier, R.R., and Cook, T.A., 2011, USGS Methodology for Assessing Continuous Petroleum Resources: U.S. Geological Survey Open File Report 2011–1167, 75 p.

Why is the resource so large?



New Technology for Natural Gas Production



Developed for deepwater tension leg platforms; applied onshore.

Directional drilling

- Downhole hydraulic motors
- Geosteering:
  - Measurement while drilling
  - Inertial navigation
  - Telemetry: better electronics
- 5,000+ ft laterals

Staged hydraulic fracturing

- Light sand frac
- Slickwater frac
- Fast flowpaths in contact with large volume of rock

Barnett Shale: 1997; Mitchell Energy

Fayetteville Shale: 2004; Southwestern Energy

Haynesville Shale: 2004; Chesapeake Energy

Marcellus Shale: 2007; Range Resources: Gulla #9; IP 4.9 MMCFD

Figure from Soeder, D.J., 2012, Shale gas development in the United States, Chapter 1 in Advances in Natural Gas Technology, Edited by Hamid A. Al-Megren, ISBN 978-953-51-0507-7, InTech Open Access, Rijeka, Croatia, April 11, 2012; DOI: 10.5772/2324, 542 pages.

NETL

New Technology

Large drill rigs are needed to reach depths of gas shales (typically 5,000 to 15,000 ft) and construct long laterals (typically 3,000 to 9,000 ft)

High volume hydraulic fracturing is needed to recover economic amounts of gas.

Large volumes of water, sand and chemicals are needed to support the operation.

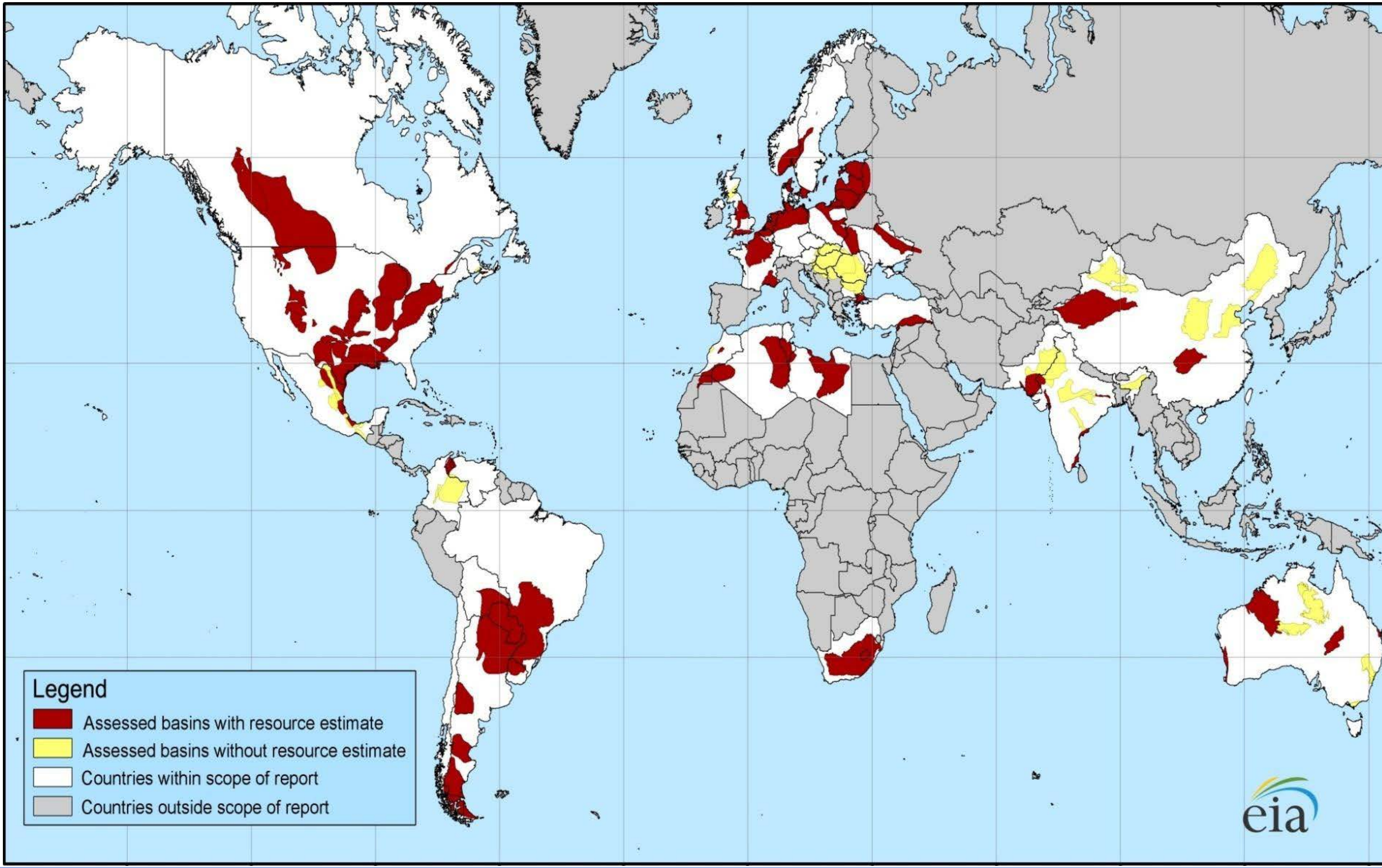
Produced water is recycled; residual waste disposed of down UIC wells.

Triple Flex rig in southwestern Pennsylvania, 2011

Hydraulic fracturing operation near Waynesburg, PA, 2011 (Photo by D. Soeder)

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

Shale Resources Worldwide



Source: U.S. Energy Information Administration

Risks to Groundwater

- **Identified by National Groundwater Association at a workshop in Pittsburgh, November 2014:**
- **Single biggest "contaminant" is methane gas (even though there is no MCL). Explosive limits are 5% to 15%.**
- **Single biggest cause is poor wellbore integrity – bad casing threads, poor cement job, improper curing, etc.**
- **Source and migration pathways of stray gas are notoriously hard to determine.**
- **Surface spills of drilling fluids, frac chemicals, and produced water are second largest concern.**
- **Risks come from human error – when prescribed engineering practices are followed, risks are low.**

https://www.mathesongas.com/pdfs/products/Lower-%28LEL%29-&-Upper-%28UEL%29-Explosive-Limits-.pdf

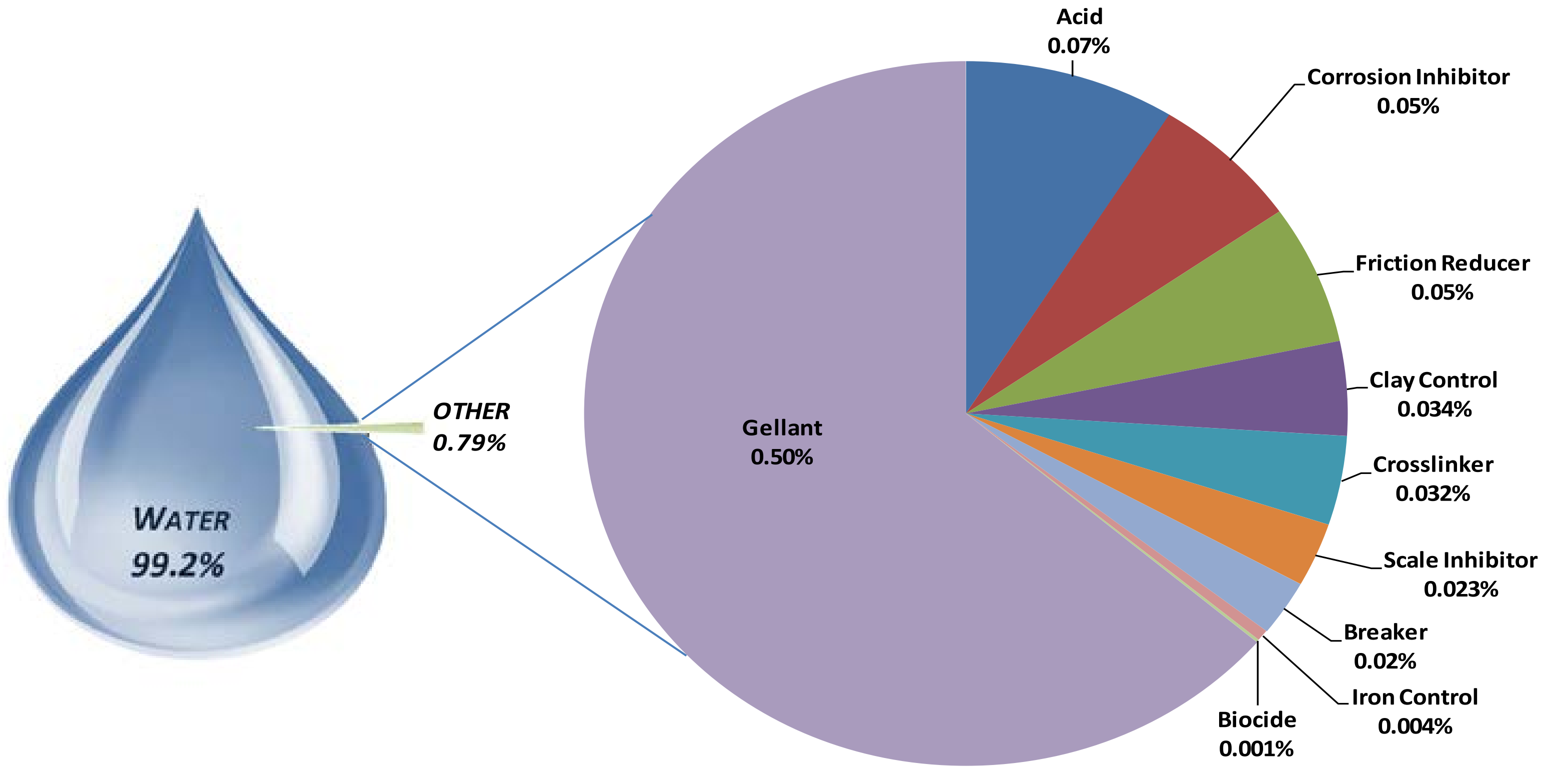
Groundwater Risk per Production Phase

Production Activity	Potential GW Risks
initial spud-in	air/fluid infiltration into aquifer
set surface casing; drill vertical well	well integrity: annular migration of fluids from open hole
set intermediate casing; drill lateral	low risk to groundwater
set production casing; complete well	frac chemicals on site; surface spills, potential leakage
hydraulic fracturing	abandoned wells, faults; frac chemicals on site; P-wave through aquifer
flowback and produced waters	frac chemicals and high TDS waters on site; surface spills, potential leakage
long-term gas production	well integrity: casing/cement deterioration; potential weathering of cuttings

Source: Soeder, D. J., Sharma, S., Pekney, N., Hopkinson, L., Dilmore, R., Kutchko, B., Stewart, B., Carter, K., Hakala, A., and Capo, R., 2014, An approach for assessing engineering risk from shale gas wells in the United States, International Journal of Coal Geology, Vol. 126, p. 4-19

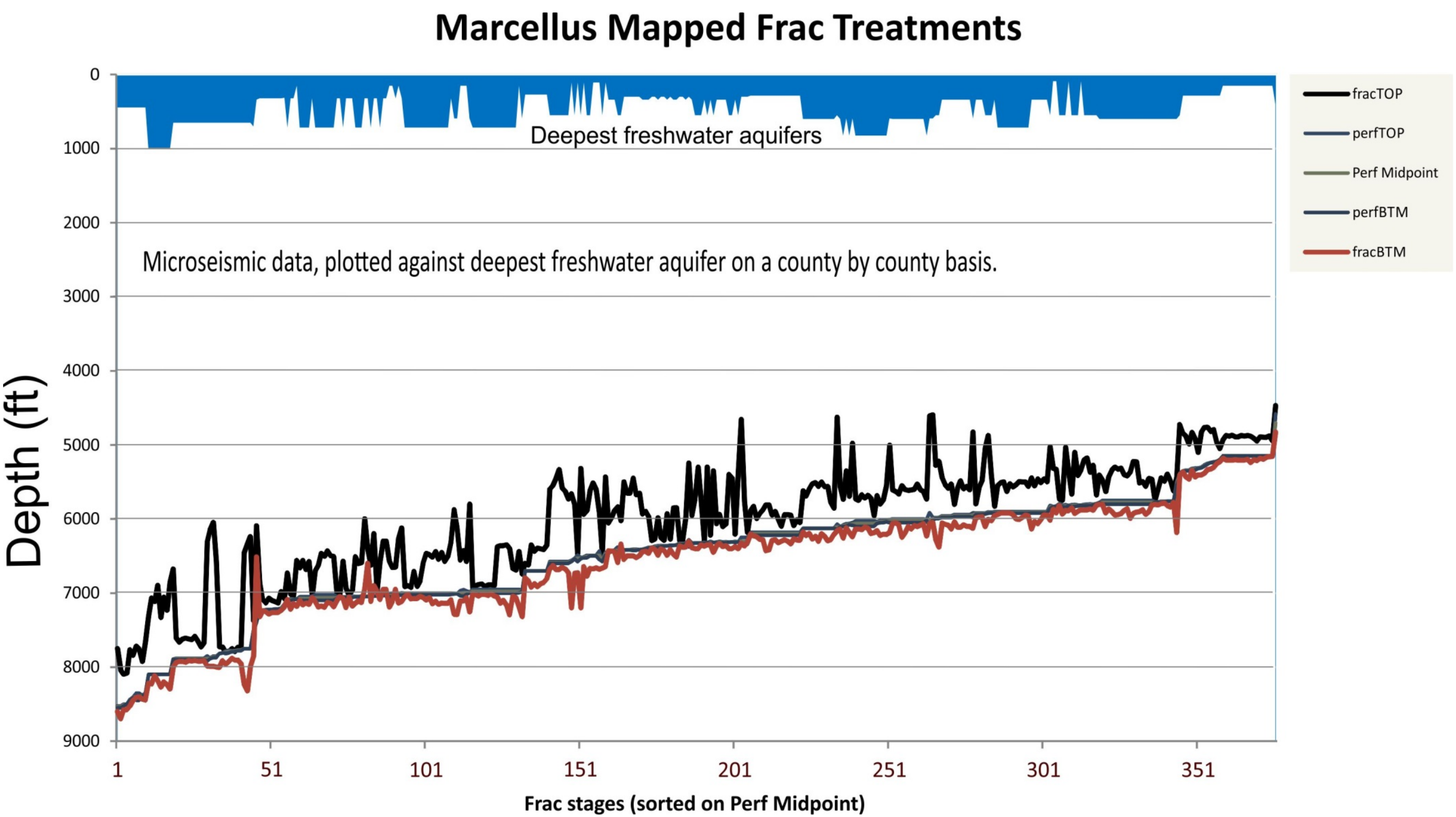
Frac Fluid Chemicals

Average Hydraulic Fracturing Fluid Composition for US Shale Plays



Source: Ground Water Protection Council, 2012, FracFocus well records: January 1, 2011 through February 27, 2012: accessed on-line at http://www.fracfocus.org

Out of Zone Fractures



Environmental Risks to Water Resources

- **Surface spills and leaks**
  - Drilling fluids
  - Frac chemicals
  - Produced water
- **Direct aquifer impacts**
  - Drilling through aquifer
  - Pressure pulse from frac
  - Well integrity problems
  - Reservoir leakage
- **Land use impacts**
  - Headwater streams
  - Small watersheds

Photograph of Indian Run by Doug Mazer, used with permission

Stray gas

Does shale gas development cause stray gas migration in shallow aquifers?

Upward leakage from hydraulically-fractured target formation?

Wellbore integrity/direct leakage?

Mobilization of pre-existing methane in aquifer?

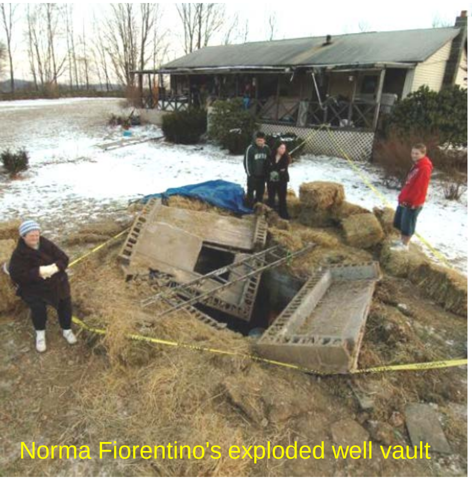
- Drilling through the aquifer
- Vibration caused by surface activity
- Compression from frac p-wave

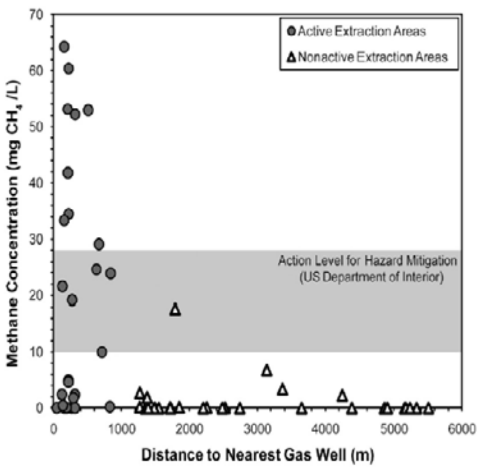
Two questions:

What is the source of the methane?

How is the methane being mobilized?

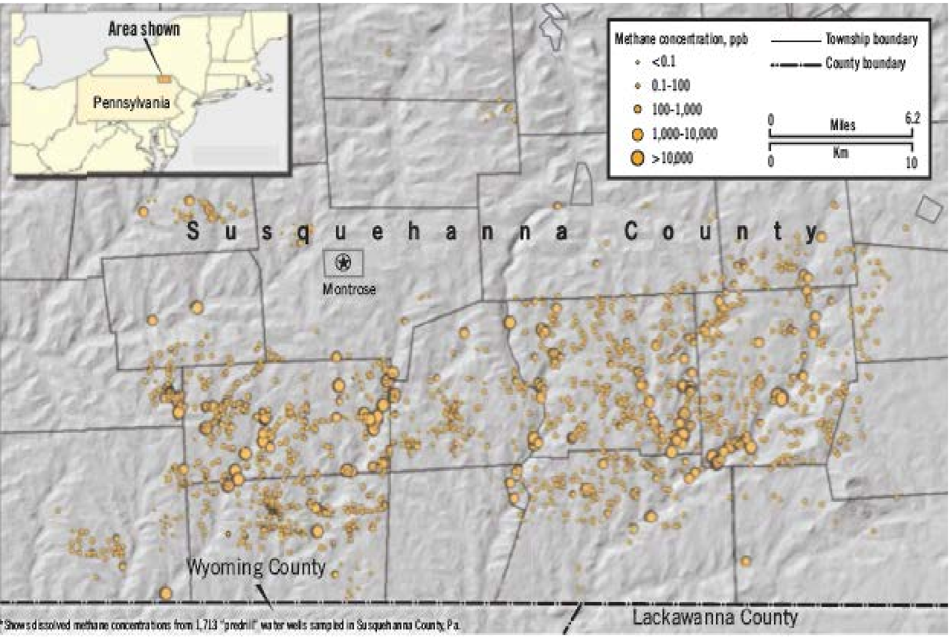
Asking the Right Questions





Duke University study on 68 wells shows methane in groundwater in NE PA occurs in much higher concentrations near gas wells, and concluded it is related to wells.

(Osborn, Stephen G., Avner Vengosh, Nathaniel R. Warner, and Robert B. Jackson, 2011, Methane contamination of drinking water accompanying gas-well drilling and hydraulic fracturing: PNAS Early Edition Direct Submission article, available on-line only; Proceedings of the National Academy of Sciences, 5 p)



Baseline data on 1700 water wells prior to gas drilling shows methane is common in NE PA groundwater, and related to topography (highest in stream valleys).

(Molofsky, L. J., J.A. Connor, S.K. Farhat, A.S. Wylie, Jr., and Tom Wagner, 2011, Methane in Pennsylvania water wells unrelated to Marcellus shale fracturing: Oil & Gas Journal, Vol. 109, no. 49, December 5, 2011, p. 54-67)

The proper question might be: how might drilling affect domestic water wells when methane is present in the aquifer?

Soeder, D.J., 2012, Field test of an alternative hypothesis for stray gas migration from shale gas development (abstract): Stray Gas Incidence and Response Forum: Ground Water Protection Council, July 24-26, 2012, Cleveland, Ohio (http://gwpc.brocodev.com/events/gwpc-proceedings/2012-stray-gas-incidence-response-forum)

Air Infiltration at Sardis, WV

June 6, 2012, Sardis, WV (near Clarksburg)

Drilled to 290 ft using water and air; bit got stuck around 150-170 ft. while withdrawing

The air compressor was left on as crews attempted to dislodge bit

Pressurized groundwater surged out of several old, unused wells nearby

Geng, Xiaolong, Nicholas C. Davatzes, Daniel J. Soeder, Jagadish Torlapati, Rebecca S. Rodriguez, and Michel C. Boufadel, 2013, Migration of high-pressure air during gas well drilling in the Appalachian Basin, Journal of Environmental Engineering; posted ahead of print July 25, 2013. doi:10.1061/(ASCE)EE.1943-7870.0000769, 46 p.

Water Resources Research Trident

- Prong 1: Field Studies
  - Synoptic sampling and continuous monitoring
    - Downgradient wells to monitor contaminant migration
    - Upgradient well for reference and to monitor methane migration
    - Springs for discrete discharge sampling; stream for integrated samples
  - Schedule:
    - Baseline monitoring pre-drilling (monthly)
    - Frequent monitoring during drilling and hydraulic fracturing operations
    - Baseline monitoring for some time after well completion.
- Prong 2: Laboratory Analyses
  - Natural attenuation processes and rates
    - Drilling fluids
    - Frac chemicals
  - Instrumentation response and sensitivity thresholds
- Prong 3: Hydrologic Modeling
  - Gas/water displacement two-phase flow models
  - Reactive transport models

Soeder, D. J., Sharma, S., Pekney, N., Hopkinson, L., Dilmore, R., Kutchko, B., Stewart, B., Carter, K., Hakala, A., and Capo, R., 2014, An approach for assessing engineering risk from shale gas wells in the United States, International Journal of Coal Geology, Vol. 126, p. 4-19

Field Monitoring Research Issues

Problem	Question	Approach
How do we drill a monitoring well? (not a trivial question)	How do we avoid contaminating the aquifer with the very drilling chemicals we want to monitor?	Clean tubulars, no additives in cement, sample and analyze everything that goes into well, document all steps.
Methane in groundwater.	How do CH_4 concentrations vary in "undisturbed" groundwater? How is it mobilized by drilling?	Collect data to improve knowledge of CH_4 in aquifers; investigate potential gas migration mechanisms.
How much "baseline" data are needed to recognize an anomaly?	How do dissolved chemical species vary temporally and spatially in "undisturbed" groundwater?	Collect data to improve knowledge of natural groundwater chemistry variability.
Effective use of geochemical tracers for drilling/frac fluids.	What are "undisturbed" groundwater values for common geochemical tracers?	Collect data to improve knowledge of variation in Sr, Ba, Br, Cl (water), and C, O, H isotopes (dissolved and gas-phase CH_4)
Soluble organic chemicals and polymers.	What are the background levels of these chemicals in groundwater? Do they change with drilling?	Collect data on baseline levels of organic chemicals at site, and monitor for changes.

The Issue of Access

How can the scientific community obtain access to wells, cores, data, produced fluids and groundwater?

Access to sites, samples, and data for independent researchers has been difficult.

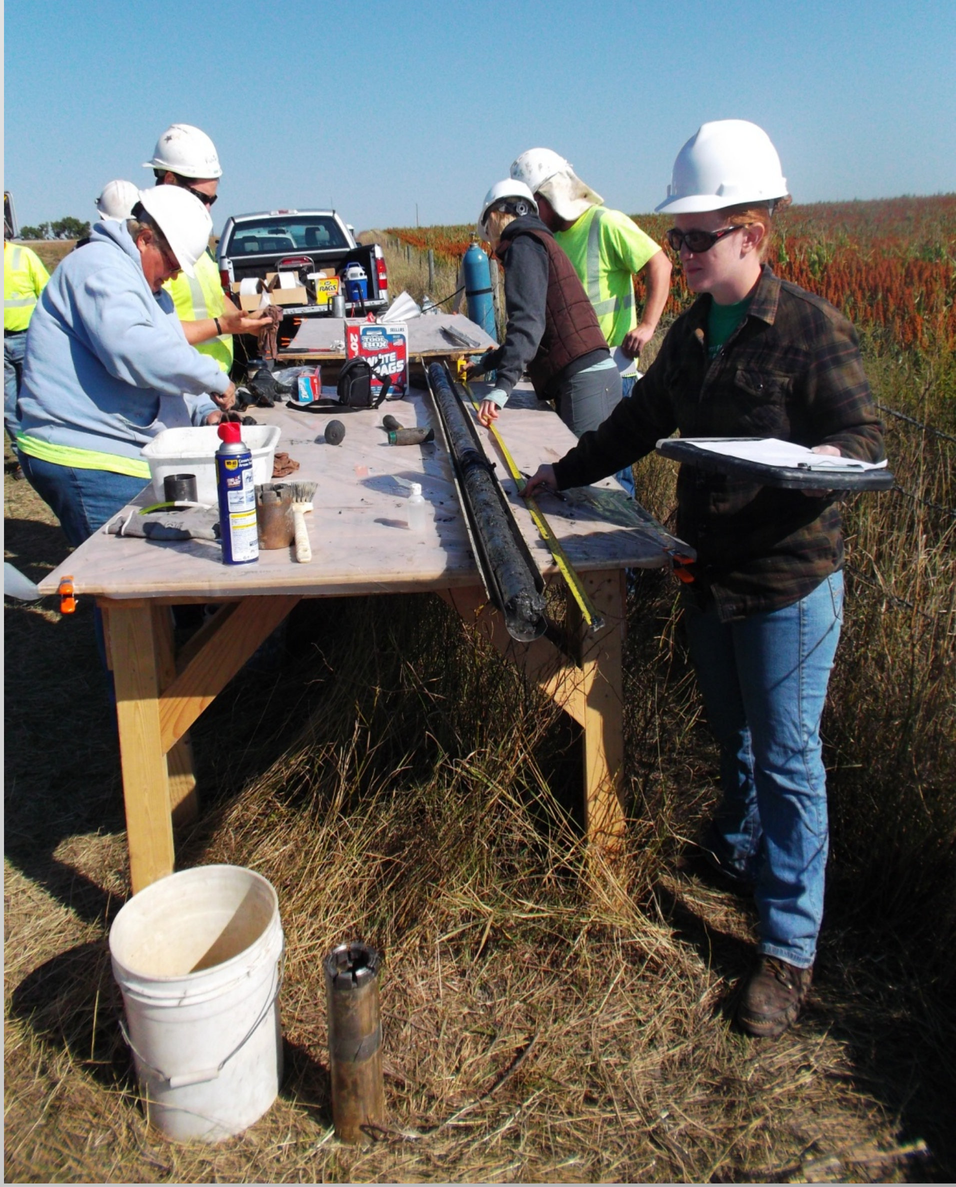
Industry scientists are not usually permitted to investigate issues that are unrelated to hydrocarbon production.

Public shale drill cores are 30 to 40 years old. New core is locked down by consortia and not generally available to outsiders.

Obtaining fluid samples is very hit or miss.

Most shales are deep – drilling is expensive.

Pierre Shale core recovery in 2014 by South Dakota Geological Survey



Types of Accessible Gas Wells

Research Well

Non-commercial well drilled for research purposes.

Driller is paid up-front for cost of well; does not need to produce it for revenue.

Greatest freedom for researchers, but also the most expensive.

Transparent Well

Commercial well drilled on university or government land.

Agency/university owns mineral rights; driller must produce well for revenue.

Lease agreement may require the driller to allow various environmental monitoring programs to take place during well development.

Commercial Well

Investor-owned well drilled on a commercial lease.

Driller must produce well for revenue to cover costs.

Research access is at the discretion of the driller, and the landowner holding the lease.

Other options include piggy-back coring operations, formation water sampling during drilling, additional geophysics and logging, etc., usually for the cost of rig time.

Adventures in Groundwater Monitoring

- **A stand-alone research well has not been funded.**
- **Several transparent wells have been planned:**
  - Ohio State University in the Utica/Point Pleasant Shale.
    - Location: Southeastern Ohio on OSU land
    - Status: Awaiting drilling and land access agreements.
  - University of Tennessee in the Chattanooga Shale
    - Location: Knoxville (possibly in research forest)
    - Status: No industry interest in location, intense local opposition; project abandoned.
  - West Virginia University in the Marcellus Shale
    - Location: WVU Animal Husbandry Farm, Morgantown
    - Status: No pipelines nearby, uneconomical dry gas, project abandoned.
- **Discussions by NETL-ORD with nearly a dozen companies so far have not resulted in access to commercial sites for groundwater studies.**

Reasons Access has been Denied on Commercial Wells

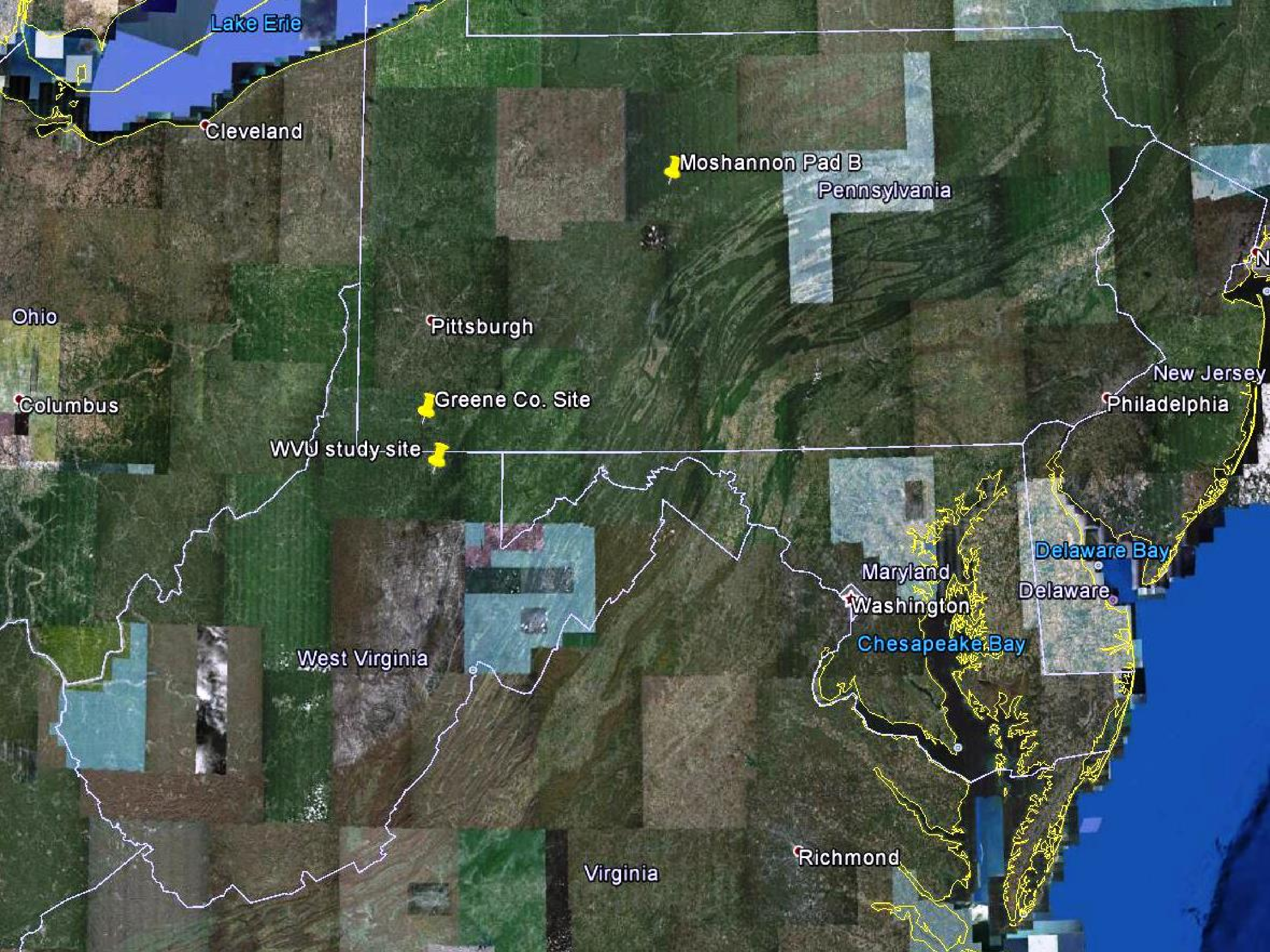
- Potential new regulatory requirements
  - Success could require monitoring wells at every gas well pad.
  - Government agencies subject to FOIA requests may be forced to give up company “secrets.”
  - Research work by DOE is not regulatory, and sensitive information is protected from FOIA release.
- Negative data
  - If industry “does everything right” there will be nothing to measure, and we are wasting our time.
  - Making the measurement, even if nothing is found, reduces the level of uncertainty in the probabilistic risk assessment model.
- Already doing hydrologic monitoring
  - Industry is collecting pre-drilling water quality samples from domestic supply wells within a kilometer or more radius of the pad.
  - These samples are for exposure assessment and liability, not hydrology.
  - Domestic water supply wells are typically open hole completions and mix water from various levels in the aquifer, making them of little use for understanding aquifer behavior and groundwater flow paths.
  - Monitoring wells with multilevel samplers will better define aquifers.

Active and Recent Accessible Well Sites

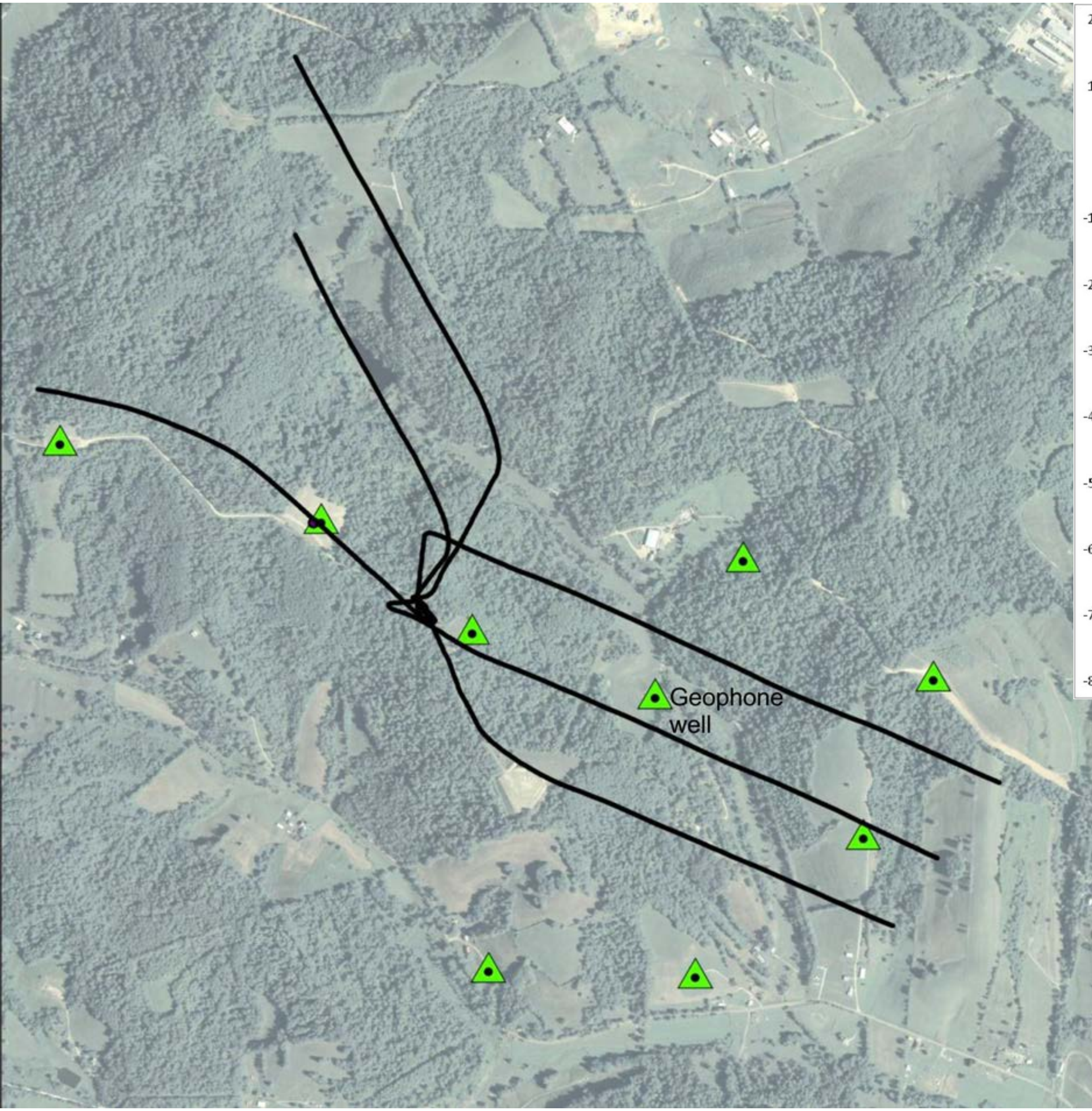
DOE-NETL in the Marcellus Shale.
Location: Commercial field in Greene County, PA.
Status: Microseismic data collected during frac; ongoing collection of produced water and tracer sampling.
Problems: No groundwater component in study.

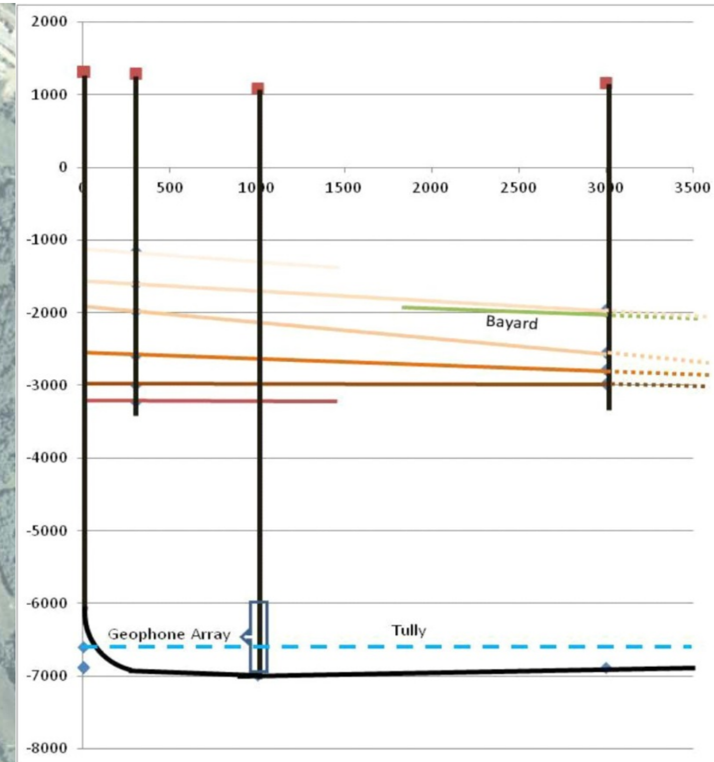
West Virginia University in the Marcellus Shale.
Location: Westover, WV on existing pad in industrial park.
Status: Agreements are in place with driller, university and DOE.
Problems: Hydrogeology is disturbed and very challenging for a groundwater study.

Pennsylvania DCNR in the Marcellus Shale.
Location: Moshannon State Forest adjacent to commercial lease.
Status: NETL moving forward to begin baseline monitoring.
Problems: Dry gas area; may not drill for several years if ever.


Lake Erie
Cleveland
Moshannon Pad B
Pennsylvania
Ohio
Pittsburgh
New Jersey
Columbus
Greene Co. Site
Philadelphia
WVU study site
Delaware Bay
Maryland
Delaware
Washington
Chesapeake Bay
West Virginia
Richmond
Virginia

Greene County Well Site





Marcellus horizontal well drilled below existing Upper Devonian production sands.

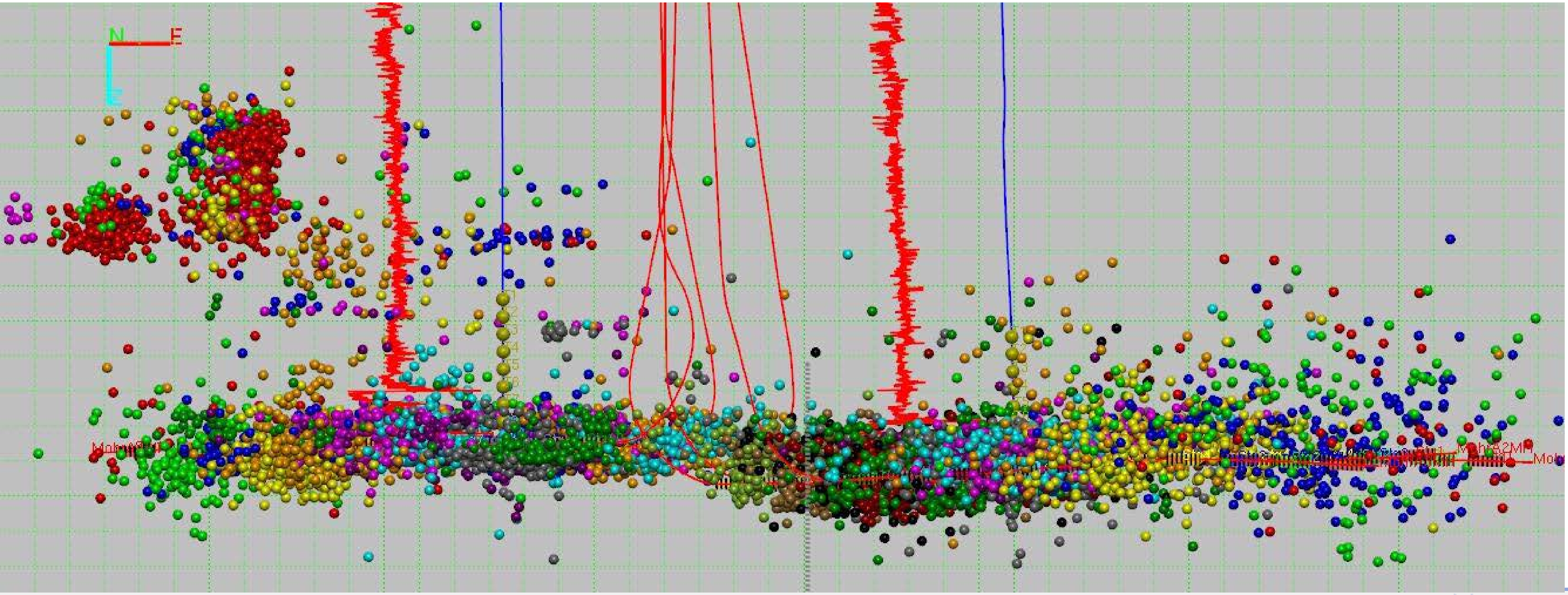
Pre-existing vertical Marcellus well between laterals.

PFC tracers in frac fluid to detect gas migration.

No groundwater component.

Greene County Tracer Study

- **Goal: determine if gas from the Marcellus Shale was migrating upward into the overlying Upper Devonian sandstone after the hydraulic fracture treatment**
- **Used PFC tracer and post-frac pressure and chemical monitoring; modeling suggests 8+ years migration time.**



West Virginia University Study Site

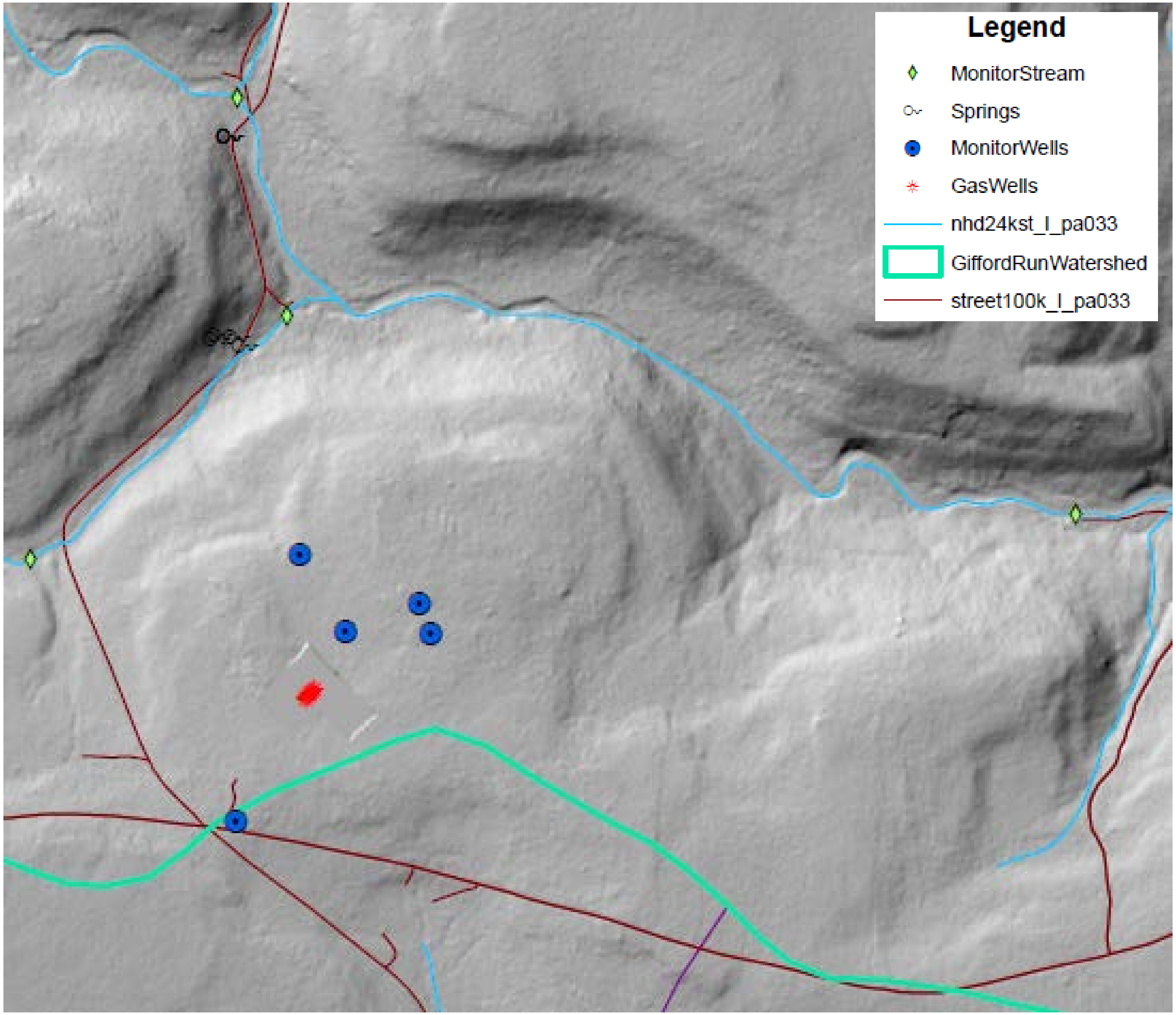
- Marcellus Shale well on existing wellpad in Westover industrial park.

- First two wells on site were drilled and hydraulically fractured in 2012.
- Legacy environmental issues include an ammunition factory from WWII, and an adjacent Superfund site.
- Land access upgradient and downgradient is held by industrial park.
- Pittsburgh Coal was mined from this site sometime in the past.
- New gas wells will be installed in summer 2015, limiting baseline.

Photo: Northeast Natural Energy drillpad with wells in Westover, West Virginia. Photo by Dan Soeder

Moshannon State Forest, Tract 325, Pad B

- Exact location of monitoring wells will be defined by hydrogeology and flowpaths.
- One upgradient; at least 3 downgradient
- Continuous water quality and flow monitoring in stream.
- Samples from springs in area.
- GW wells planned spring 2015; gas wells maybe 2017, maybe never.



Multilevel sampler port with packer system for isolating aquifer flow zones.

Target Analytes for Sampling and Chemistry

Analytes	Method	Location	Team Members
Major cations (Na, K, Mg, Ca)	ICP-OES	Pittsburgh Analytical Laboratory	William Garber, Tracy Bank (URS)
Metals and minor cations (Be, Sr, Ba, Cr, Mn, Fe, Al, As, Se)	ICP-OES	Pittsburgh Analytical Laboratory	William Garber, Tracy Bank (URS)
Anions (NO_3^-, SO_4^{2-}, Cl^-, Br^-)	IC	Pittsburgh Analytical Laboratory	Brian Kail (URS)
Bicarbonate	Alkalinity titration	Pittsburgh Analytical Laboratory	David Blaushild (URS)
Dissolved methane, BTEX, DRO, GRO, HEM	GC-MS	Chromatography Laboratory	Dirk Link (NETL), Brian Kail (URS)
Total Organic Carbon	TOC Analyzer	Environmental Geochemistry Laboratory	Vidhi Mishra (ORISE)
Strontium isotopes	Rapid analysis MC-ICPMS	NETL Multicollector/University of Pittsburgh	Thai Phan (ORISE)
Carbon and Hydrogen isotopes in dissolved and gaseous CH_4	IRMS	External subcontract (Isotech labs in the past)	TBD

Field parameters to be measured: hydraulic head, pH, temperature, dissolved oxygen, specific conductance, oxidation-reduction potential, turbidity.

Moshannon Fieldwork

All photos by Dan Soeder, DOE

Complimentary Laboratory Studies

1. Sensor assessment

– Can current water quality monitoring technology be used to detect hydraulic fracturing chemicals in surface water or groundwater?

2. Natural Attenuation

– If chemicals associated with hydraulic fracturing were to spill or leak, what will be the fate and transport of such contaminants? Are NA processes and rates capable of keeping these chemicals out of the accessible environment?

3. Gas migration/Groundwater quality

– Do drilling operations through aquifers affect shallow groundwater?

Photo: Sand column experiments in NETL Pittsburgh lab. Photo by Dan Soeder

Gas Wells at Moshannon

- NETL-ORD research agreement is with state DCNR, although driller has agreed to collaborate.
- Lease is in place and pad has been designed (on paper) for gas wells.
- Driller needs $5.00/MCF gas price for these wells to be profitable.
- Current price $3.70/MCF; other wells in area are marginal, so company focus is on Greene County (SW PA).
- If they never drill: site will have exceptionally-well characterized groundwater above the Marcellus Shale.
- This could provide a reference for other sites where there might not be baseline or pre-drilling data.
- If operator abandons the lease, site could potentially be used for a research well.
- Other interested researchers could be invited to join in, turning this into a showcase monitoring and sampling site.

Questions?

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Photo by Dan Soeder