NATIONAL ENERGY TECHNOLOGY LABORATORY

Environmental Risk Assessment for Shale Gas Development

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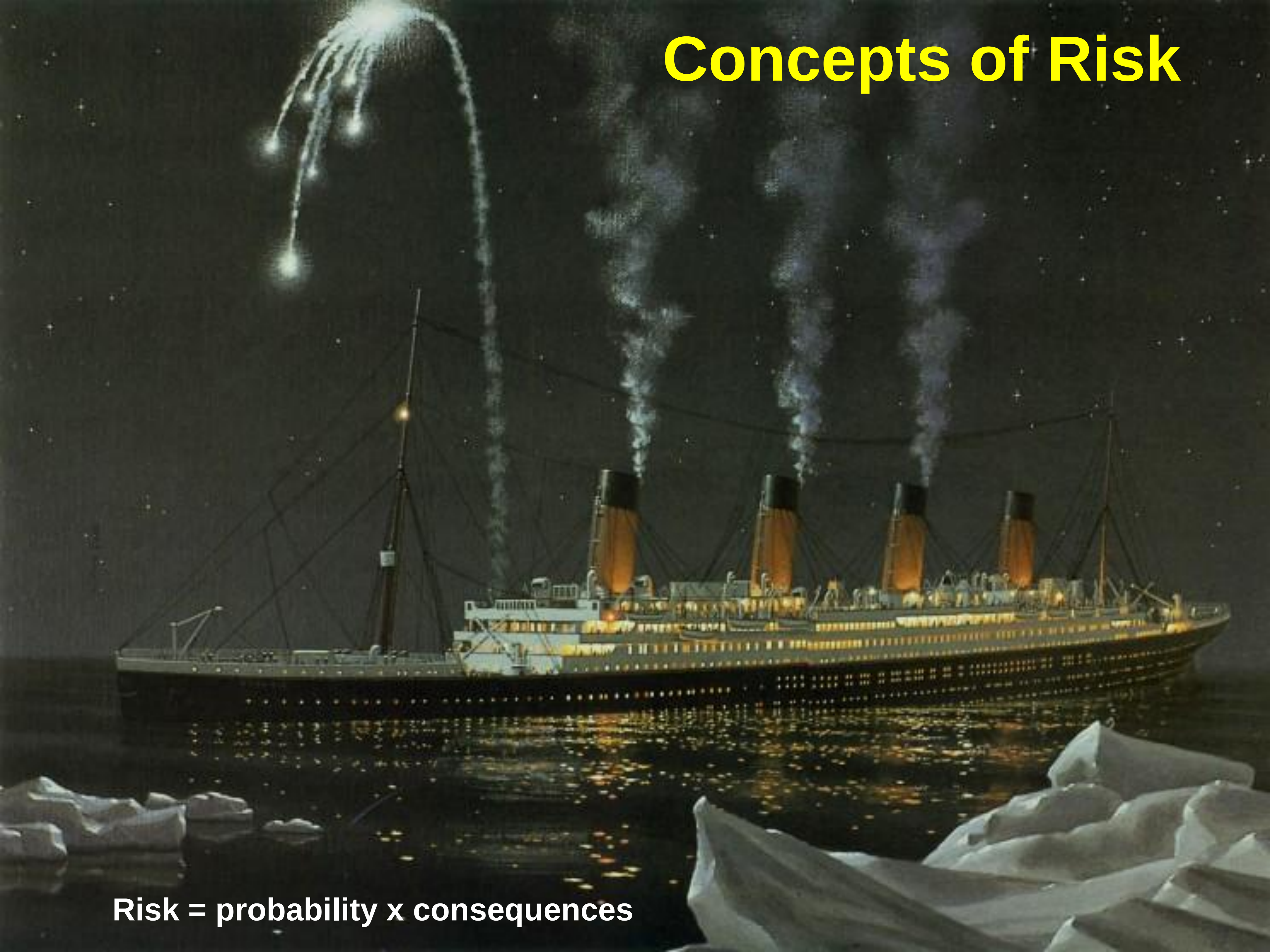
Presentation for Chesapeake Bay Program STAC
State College, PA, April 11, 2012

NETL-RUA Regional University Alliance

U.S. DEPARTMENT OF ENERGY

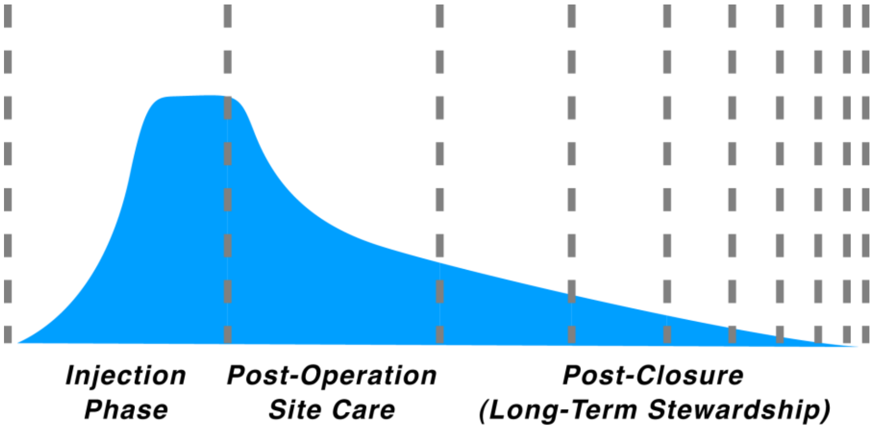
Concepts of Risk



Risk = probability x consequences

Risk in Engineered Geologic Systems

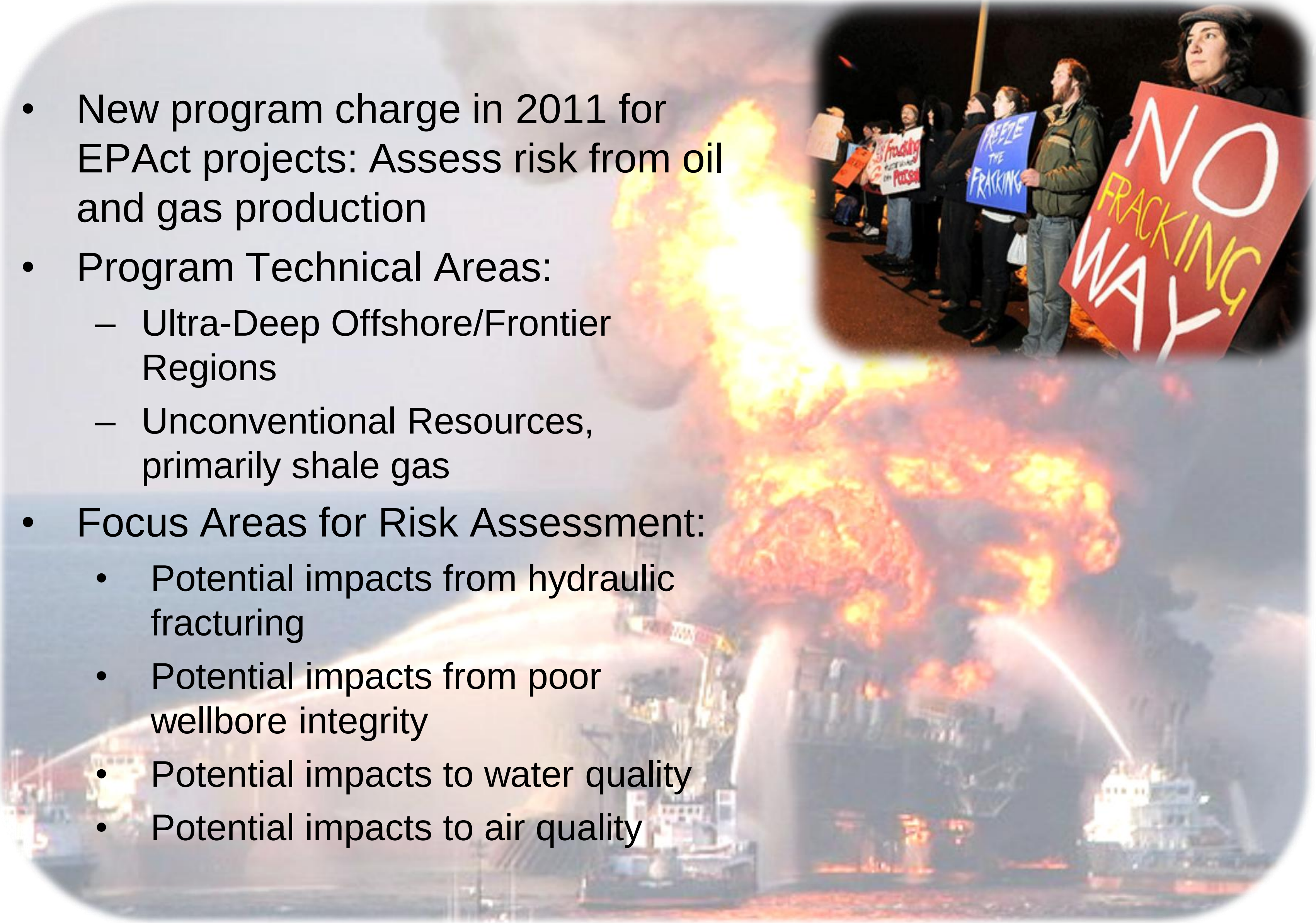
Risk can vary over time >>
(CO2 injection example)



- **Threat: external events that cause risk**
  - Threats can exploit vulnerabilities
  - Threats are assessed in terms of probability (Precautionary Principle)
- **Vulnerability: internal weakness that invites risk**
  - Vulnerability only exists in the face of a threat
  - Vulnerability is assessed in terms of likely threats (Calculated Risk)
- **Both threats and vulnerabilities must be assessed to properly understand risk.**

NETL Office of Research and Development

- New program charge in 2011 for EPAct projects: Assess risk from oil and gas production
- Program Technical Areas:
  - Ultra-Deep Offshore/Frontier Regions
  - Unconventional Resources, primarily shale gas
- Focus Areas for Risk Assessment:
  - Potential impacts from hydraulic fracturing
  - Potential impacts from poor wellbore integrity
  - Potential impacts to water quality
  - Potential impacts to air quality



Potential Shale Gas Risks

- **Engineering Risk Assessment:**
  - What is the probability of a contaminant release?
  - What is the probability of an induced seismic event?
  - What risks are short term versus long term?
- **What are the receptors?**
  - Air, water, landscapes, ecosystems/habitat
- **The major unknown risk is cumulative effects**
  - How will multiple wells make an impact?
  - What is threshold for impacts? (i.e. impervious surfaces)
- **Risk reduction through regulations and enforcement**
  - Not all known environmental impacts are regulated
  - Not all regulations are fully enforced

Risk Assessment in Engineered Systems

- **DOE National Risk Assessment Partnership (NRAP)**
  - Cooperative effort among NETL, LBNL, LLNL, LANL, and PNNL
  - Scenario-based, site modeling for carbon storage in engineered geologic systems
- **Sometimes called site performance assessment**
- **Uses FEP-based scenarios and probabilities**
  - **F**eature: property of a geologic system that may affect risk
  - **E**vent: an action that introduces higher risk conditions into a system
  - **P**rocess: a method or procedure that increases risk
- **Predict performance of components using high fidelity models**
- **Run scenarios to validate models/reduce uncertainty**
- **Provide quantitative basis for geologic storage security**

Integrated Risk Assessment Models

- **Integrated Assessment Models (IAM)**
  - Probabalistic assessment of system risk (multi-site)
  - Interaction of sites can increase or decrease risk
- **Divide system into components, develop detailed, validated models, reduce uncertainty**
- **Develop reduced order models (ROM) to reproduce detailed model predictions of components**
- **Integrate ROMs through IAM to predict total system performance, interactions and risk**
- **Calibrate using field data and databases**
- **Quantify potential long-term liability**

Risk Profile (Quantify) → **Risk Management (Strategy)** → **Validation (Field Data)**

Adapting NRAP to Shale Gas

- **Components:** old wells with potential casing and cement integrity issues, watered-out reservoirs
- **Design Basis:** greatest risk is immediately after injection; when pressure is highest.
- **Model:** seal integrity, well bore leakage, migration through intermediate strata, changes in pressure and saturation
- **Validation:** monitoring, verification and accounting

- **Components:** new wells, with new fractures, tight, dry, overpressured reservoir
- **Design Basis:** greatest risk is after frac during early stages of production under initial high pressure.
- **Model:** fracture heights, fresh groundwater depth, bypass flowpaths, wellbore leakage, pressure/stress changes
- **Validation:** field monitoring and analyses (need defining)

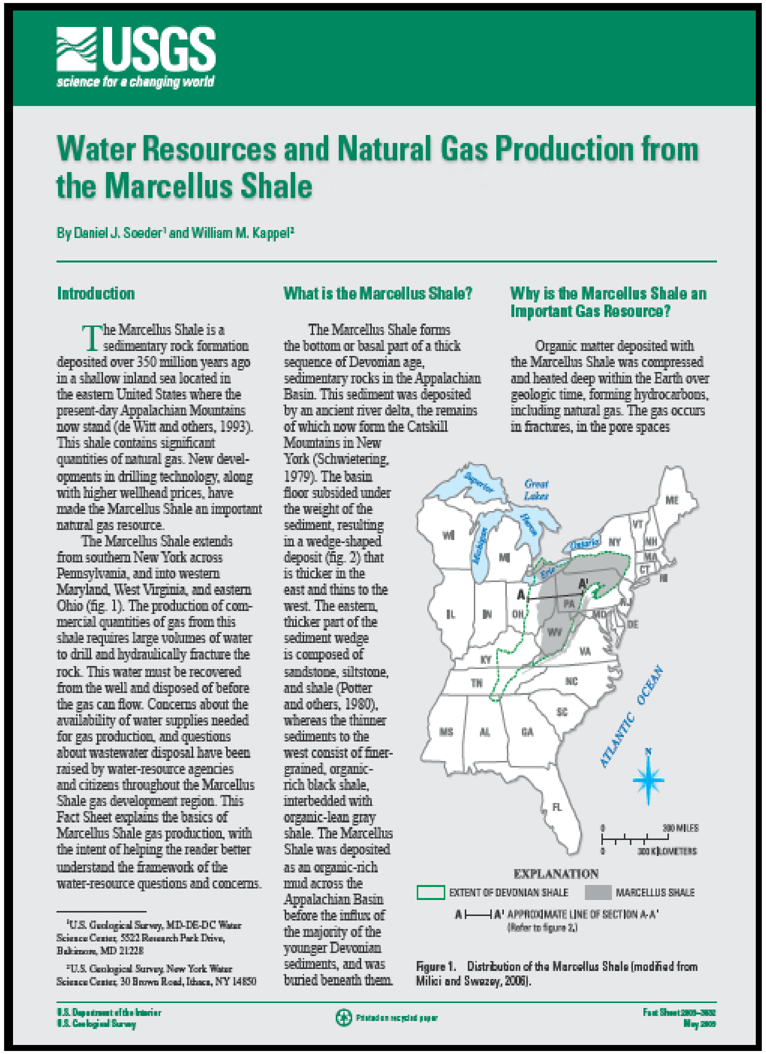
Risk Assessment via Incident Reports

- **One method to help determine the components of an IAM is to review past incident data at oil and gas production sites.**
- **Reporting only the number of incidents is meaningless:** "Discharge of industrial waste" can range from a spilled quart of motor oil to a leak from a ten thousand gallon frac fluid tank.
- **Classification of incidents:**
  - **Administrative:** missing signage, poor record-keeping, incorrect permit application or other missing or wrong "paperwork."
  - **Minor:** small spills or leaks that require clean up, but are contained on site, do not enter the groundwater, and can be remediated by the local rig crew.
  - **Significant:** larger spills or leaks that could potentially leave the site but did not, and required outside assistance (i.e. HAZMAT team) to help clean up.
  - **Serious:** explosion, fire, stream contamination or fish kill, human injury or fatality, significant property damage, contamination of a drinking water supply.
  - **Catastrophic:** destruction of site and serious damage to surrounding area.
- **Frequency, type and seriousness of incidents over time help define risk trends.**
- **State regulatory agencies are the source of most incident reports.**

Water Contamination Incidents

- **Kell, Scott, 2011**, State Oil and Gas Agency Groundwater Investigations and their Role in Advancing Regulatory Reforms: A Two-State Review: Ohio and Texas, Groundwater Protection Council, 165 p., August 2011, Oklahoma City, OK:
  - Incident: "any detected contamination of groundwater or disrupted water supply due to development of oil and gas or management of wastes."
- **Ohio reported 144 incidents in 33,304 wells between 1983 and 2007 (rate = 0.432%); no significant shale gas production at the time.**
  - Most Ohio incidents occurred during drilling/production operations
  - 85 of the 144 incidents (60%) occurred between 1983 and 1988 (boom).
- **Texas reported 211 incidents in 187,788 wells between 1993 and 2008 (rate = 0.112%); Barnett Shale play began in 1997.**
  - Most Texas incidents occurred during waste disposal
  - Texas RR Commission "witnesses" drilling and completion operations on about 1/3 of wellsites
- **Both states reported zero incidents over the time periods studied associated with well stimulation (hydraulic fracturing)**

Water Resource Risks/Questions



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Water Resources and Natural Gas Production from the Marcellus Shale

By Daniel J. Soeder[1] and William M. Kappel[2]

Introduction

The Marcellus Shale is a sedimentary rock formation deposited over 350 million years ago in a shallow inland sea located in the eastern United States where the present-day Appalachian Mountains now stand (de Witt and others, 1993). This shale contains significant quantities of natural gas. New developments in drilling technology, along with higher wellhead prices, have made the Marcellus Shale an important natural gas resource.

The Marcellus Shale extends from southern New York across Pennsylvania, and into western Maryland, West Virginia, and eastern Ohio (fig. 1). The production of commercial quantities of gas from this shale requires large volumes of water to drill and hydraulically fracture the rock. This water must be recovered from the well and disposed of before the gas can flow. Concerns about the availability of water supplies needed for gas production, and questions about wastewater disposal have been raised by water-resource agencies and citizens throughout the Marcellus Shale gas development region. This Fact Sheet explains the basics of Marcellus Shale gas production, with the intent of helping the reader better understand the framework of the water-resource questions and concerns.

What is the Marcellus Shale?

The Marcellus Shale forms the bottom or basal part of a thick sequence of Devonian age, sedimentary rocks in the Appalachian Basin. This sediment was deposited by an ancient river delta, the remains of which now form the Catskill Mountains in New York (Schwietering, 1979). The basin floor subsided under the weight of the sediment, resulting in a wedge-shaped deposit (fig. 2) that is thicker in the east and thins to the west. The eastern, thicker part of the sediment wedge is composed of sandstone, siltstone, and shale (Potter and others, 1980), whereas the thinner sediments to the west consist of finer-grained, organic-rich black shale, interbedded with organic-lean gray shale. The Marcellus Shale was deposited as an organic-rich mud across the Appalachian Basin before the influx of the majority of the younger Devonian sediments, and was buried beneath them.

Why is the Marcellus Shale an Important Gas Resource?

Organic matter deposited with the Marcellus Shale was compressed and heated deep within the Earth over geologic time, forming hydrocarbons, including natural gas. The gas occurs in fractures, in the pore spaces

EXPLANATION

▭ EXTENT OF DEVONIAN SHALE ▨ MARCELLUS SHALE

A ├──┤ A' APPROXIMATE LINE OF SECTION A-A'
(Refer to figure 2.)

Figure 1. Distribution of the Marcellus Shale (modified from Milici and Swezey, 2006).

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U.S. Department of the Interior
U.S. Geological Survey

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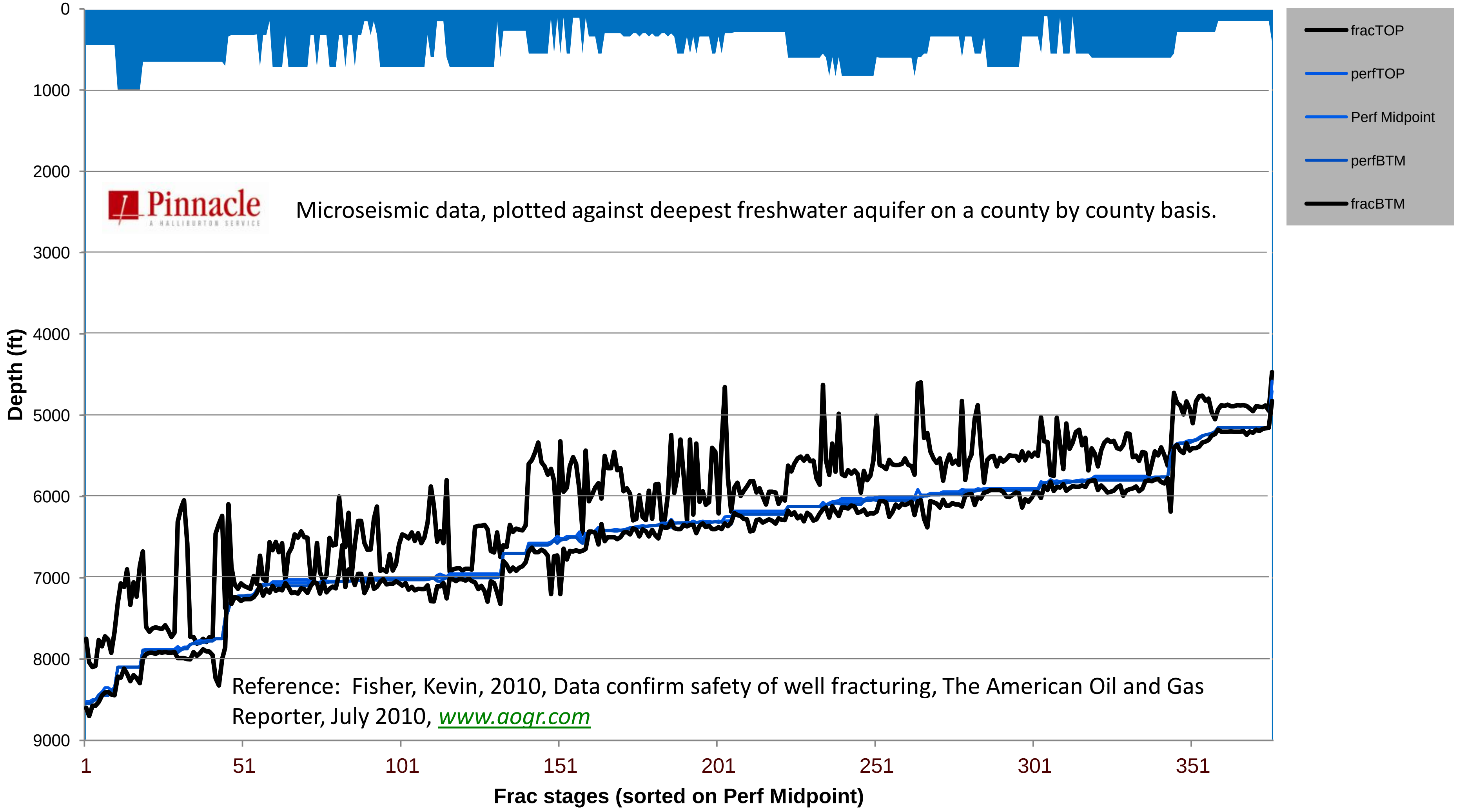
Fact Sheet 2009–3032
May 2009

http://pubs.usgs.gov/fs/2009/3032/

- **Supply**
  - – 3 to 4 million gallons per well
  - – 2/3 to 3/4 consumptive use
  - – Watershed management vs. stress
- **Watershed Impacts**
  - – Stream degradation from roads-pads-operations
  - – Water quality degradation from leaks/spills
- **Groundwater**
  - – Infiltration from above
  - – Frac fluid/formation water from below
  - – Changes in GW flow directions or gradients
  - – Fate of fluids that remain underground
- **Water quality**
  - – Infiltration of chemicals/spills into shallow groundwater
  - – Long-term leaching of drill cuttings
  - – Minerals-sediment-gas contaminating nearby water wells

Hydraulic Fracture Heights and Aquifers

Marcellus Mapped Frac Treatments



Microseismic data, plotted against deepest freshwater aquifer on a county by county basis.

Reference: Fisher, Kevin, 2010, Data confirm safety of well fracturing, The American Oil and Gas Reporter, July 2010, www.aogr.com

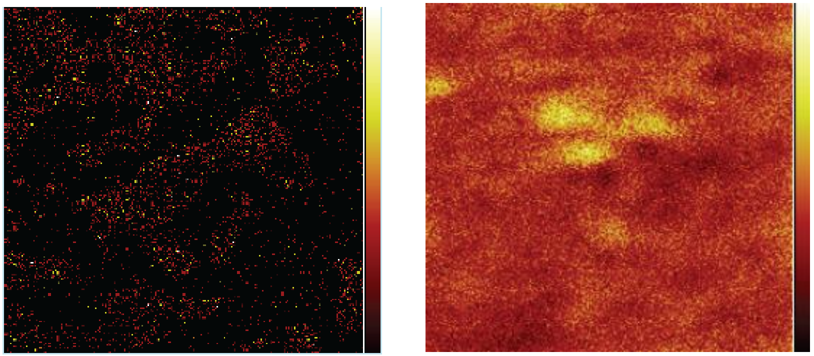
Surface Leaks and Spills

- Higher risk to groundwater and surface water than frac fluid underground (Groat, UT Austin study, 2012)
- Baseline data on existing contaminants are required to assess drilling impacts.
- Studies underway in 2012:
  - Retrospective investigation of impacted streams; large and small watersheds
  - Comparison of stream reaches: affected and unaffected; also compare two similar small watersheds (WVU)
  - Comparison of impacts versus watershed management practices (Pitt)
  - Assessment of impacts, damage, costs
  - Forensics of what caused the leak
  - Better leak detection and warning, including field-deployable instruments to monitor surrogates (pH, conductance, turbidity)
  - Prospective data from Marcellus Test Site

Photo by Doug Mazer, used with permission.

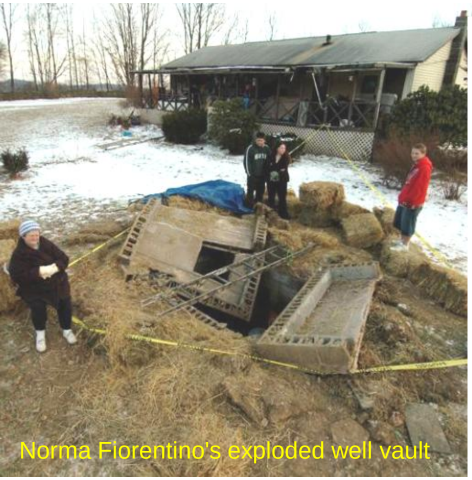
Geochemistry of Shale Drill Cuttings

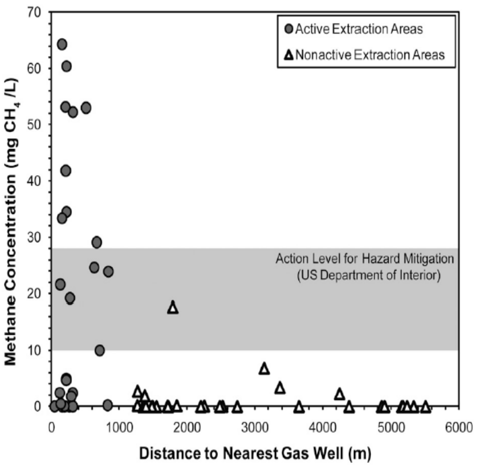
- Vertical: 5 metric tons of cuttings
- Horizontal: 270 metric tons of cuttings
- Anoxic black shales preserved organic material with associated radionuclides.
- Highest gas content is in the organic-rich, radioactive black shale; cuttings at surface are exposed to air and rainwater
- Oxidized forms of these metals are much more soluble and mobile
- Time-of-Flight Secondary Ion Mass Spectrometry (TOF-SIMS) to determine speciation of U and Cr (SUNY@Buffalo)
- Uranium is associated with organics in the shale, especially hydrogen.
- Also investigating how organics in the shale might oxidize and weather



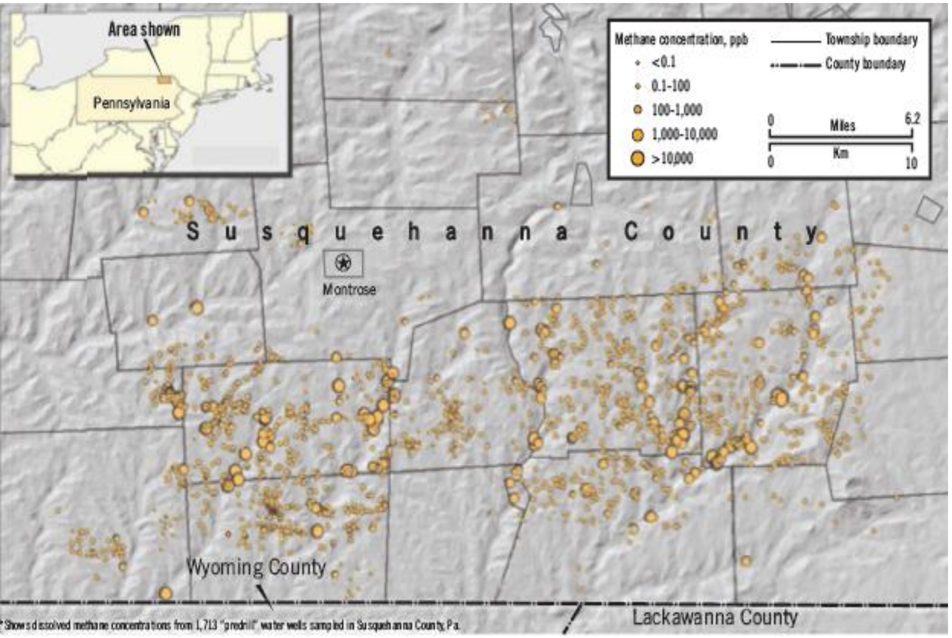
UH+ on left, Hydrocarbons on right
< Native sulfur on weathered Marcellus

NE PA: Methane in Groundwater





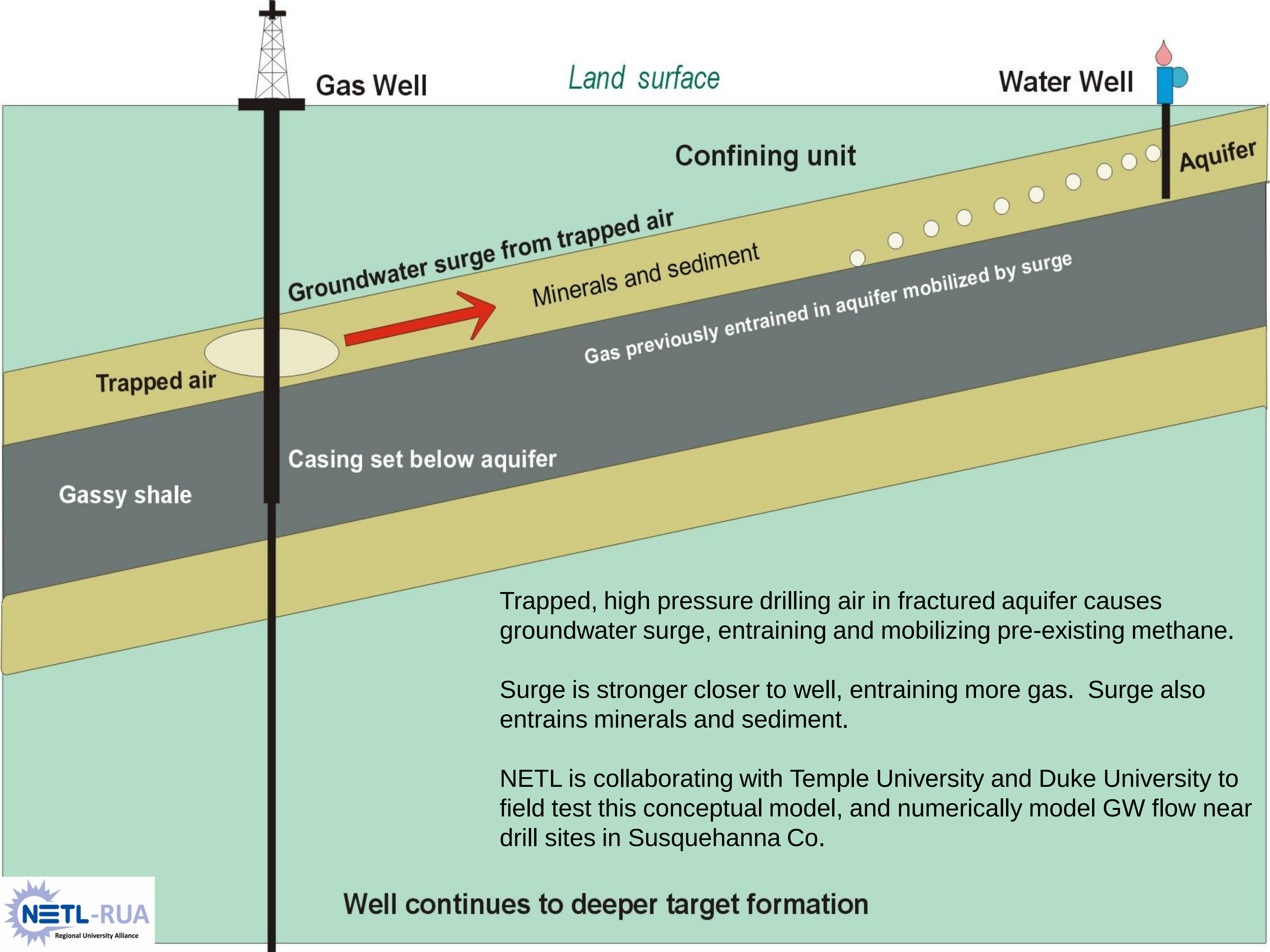
Duke University study on 68 wells shows methane in groundwater in NE PA occurs in much higher concentrations near gas wells, and concludes it is related to wells. (Osborn, Stephen G., Avner Vengosh, Nathaniel R. Warner, and Robert B. Jackson, 2011, Methane contamination of drinking water accompanying 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)



*Shows dissolved methane concentrations from 1,713 "predrill" water wells sampled in Susquehanna County, Pa.

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 does drilling affect domestic water wells when methane is present in the aquifer?

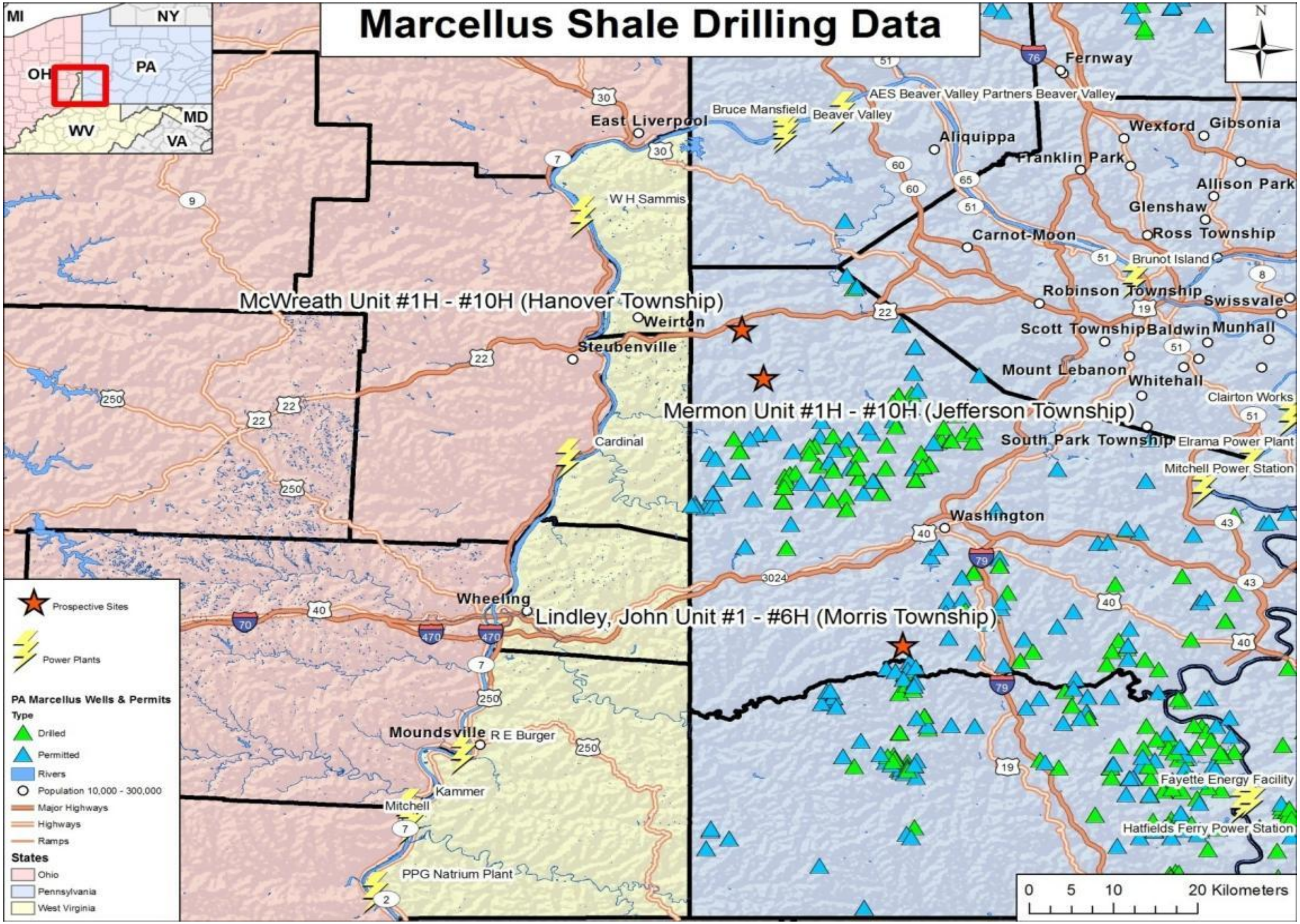


Trapped, high pressure drilling air in fractured aquifer causes groundwater surge, entraining and mobilizing pre-existing methane.

Surge is stronger closer to well, entraining more gas. Surge also entrains minerals and sediment.

NETL is collaborating with Temple University and Duke University to field test this conceptual model, and numerically model GW flow near drill sites in Susquehanna Co.

Range Resources Site for Baseline Monitoring



Marcellus Test Site Monitoring Team

1. **U.S. Dept. of Energy-NETL**: Air emissions, soil gas surveys, electromagnetic surveys for abandoned wells, avian surveys
2. **U.S. Environmental Protection Agency:** prospective site in USDW – hydrofrac investigation (no longer involved in fieldwork)
3. **U.S. Geological Survey**: Groundwater monitoring
4. **U.S. Fish and Wildlife Service:** Rare and endangered species
5. **U.S.D.A. NRCS:** soil surveys, erosion
6. **U.S. Army Corps of Engineers:** Stream water quality, sedimentation
7. **PA DCNR (Geological Survey):** Drill site monitoring and completion
8. **Pennsylvania DEP**: Fish and macroinvertebrate surveys

Second Test Site Study

- Energy Corp. America (ECA) drill site in Greene Co., PA
- Old, vertical Upper Devonian well present on site, located between two, parallel Marcellus laterals.
- Vertical well used for microseismic geophone string
- ECA allowed a volatile tracer to be placed in frac fluid.
- Upper Devonian well will be monitored and sampled to determine if volatile tracer moved into shallower gas sands from Marcellus after the frac.
- Test hypothesis that the greatest risk of upward gas migration occurs when an overpressured reservoir is hydraulically fractured and just starting to be produced
- Once pressure drops to hydrostatic or less, all flow is into the wellbore.

DOE Shale Gas Environmental Risk Assessment

Utica Shale, New York

Goals

Assess short/long term and cumulative environmental impacts.

Define engineering risks.

Data-based, scientific investigations of impacts and processes.

Outcomes

Rigorous study with conclusions supported by well-documented data

Benefits

Information-based regulations and indicators for regulatory monitoring

Improved management practices for shale gas production to mitigate problems

Create a more informed environmental debate