Update on Moshannon Groundwater Monitoring Project

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**DOE National Energy Technology Laboratory**

- GOGO National lab for fossil energy; 5 sites with ~1200 employees
- Fundamental science to technology demonstration
- Onsite research (ORD), and extramural R&D (Strategic Centers)

**Regional University Alliance for Energy Technology Innovation**

**Energy Technology Solutions**
- Energy System Dynamics
- Geological and Environmental Systems
- Computational and Basic Sciences
- Material Science and Engineering

**Map showing locations:**
- Pittsburgh, PA
- Morgantown, WV
- Sugar Land, TX
- Albany, OR
- Fairbanks, AK

**Images showing: Oregon, Pennsylvania, West Virginia**
DOE Risk Assessment for Shale Gas Development

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

Research Plan Organization
- Science Base to Support Assessments
- Tool for Data Management and Model Baselines
- Development of Integrated Assessments

Field Data to establish baselines and impacts of processes
Laboratory Data for simulations and confirmation of field data
Computational Tools to characterize and predict system baselines and behavior
Shale gas drilling, Greene Co., PA, 2011
(Photos by Dan Soeder)
Hydraulic fracturing operation near Waynesburg, PA, 2011  

(Photo by D. Soeder)
Out of Zone Fractures
Marcellus Mapped Frac Treatments

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

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

• Land use impacts
  – Headwater streams
  – Small watersheds
Average Hydraulic Fracturing Fluid Composition for US Shale Plays

Acid 0.07%
Corrosion Inhibitor 0.05%
Friction Reducer 0.05%
Clay Control 0.034%
Crosslinker 0.032%
Scale Inhibitor 0.023%
Breaker 0.02%
Iron Control 0.004%
Biocide 0.001%
Gellant 0.50%
OTHER 0.79%

## Groundwater Risk per Production Phase

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

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

Water Resources Research

• Field Studies
  – Groundwater observation wells near a shale gas well
    • Downgradient wells to monitor contaminant migration
    • Upgradient well for reference and to monitor methane migration
    • Springs for discrete discharge sampling; stream for integrated samples
  – Synoptic sampling of groundwater wells, springs and streams
  – Monitoring plan and schedule:
    • Baseline monitoring pre-drilling
    • Frequent monitoring during drilling and hydraulic fracturing operations
    • Baseline monitoring for some time after well completion.

• Laboratory Analyses
  – Natural attenuation processes and rates
    • Drilling fluids
    • Frac chemicals
  – Instrumentation response and sensitivity thresholds
  – Gas mobilization during fracture flow

• Hydrologic Modeling
  – Gas/water displacement two-phase flow models
  – Reactive transport models
## Research issues for groundwater monitoring field program

<table>
<thead>
<tr>
<th>Problem</th>
<th>Question</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do we drill a monitoring well? (or, lessons from Pavillion)</td>
<td>How do we avoid contaminating the aquifer with the very drilling chemicals we want to monitor?</td>
<td>Clean tubulars, no additives in cement, sample and analyze everything that goes into well, document all steps.</td>
</tr>
<tr>
<td>Methane in groundwater; source and mobilization</td>
<td>How do CH$_4$ concentrations vary in “undisturbed” groundwater?</td>
<td>Collect data to improve knowledge of natural CH$_4$ variability in groundwater</td>
</tr>
<tr>
<td>Groundwater contamination by high-TDS fluids</td>
<td>How do dissolved chemical species vary in “undisturbed” groundwater?</td>
<td>Collect data to improve knowledge of natural groundwater chemistry variability</td>
</tr>
<tr>
<td>Ability to effectively use geochemical tracers due to natural complexity</td>
<td>What are “undisturbed” groundwater values for geochemical tracers?</td>
<td>Collect data to improve knowledge of variation in Sr (water), and C, O, H isotopes (dissolved and gas-phase CH$_4$)</td>
</tr>
</tbody>
</table>
Objective: To monitor baseline groundwater composition prior to unconventional shale gas pad development

What is the natural variability and mobility of methane and dissolved chemical species in groundwater aquifers in active gas-producing regions?
Hypothesis: Variability in background levels of shallow methane and dissolved chemical species in the groundwater monitoring wells will be correlated with groundwater flow pathways and seasons. Two questions: 1) source? 2) mobilization mechanisms?

Is a one-year pre-drill monitoring timeframe necessary, or can similar information about background groundwater variability be obtained from an upgradient monitoring well as a site undergoes development?
Hypothesis: Monitoring an upgradient groundwater well should reflect the same variability in groundwater constituents as monitored baseline groundwater wells downgradient from the proposed drill pad site over a one-year timeframe prior to drilling.

What is the potential vulnerability of groundwater to adverse effects from drilling fluid or hydraulic fracture chemical infiltration?
Hypothesis: Water quality effects from contamination will depend on aquifer storativity and groundwater flowpaths. GWTT and reactive transport scenarios will be modeled using MODFLOW, TOUGH2, and other appropriate models with aquifer characteristics from the site.
In this schematic, monitor wells are placed in a triangle 400 ft N30°E and 750 ft North and N60°E from the center of the Marcellus well site with a deep well 800 ft S30°W of the site.

The ground-water gradient is assumed to be to the northeast, toward Gifford Run. The actual positions will be adjusted based on the size, location, and configuration of the Marcellus drill pad, topography, and consideration of minimal impact on vegetation. Subject to change based on the actual groundwater gradients. See plan map for details.
Moshannon State Forest site groundwater wells located to capture groundwater flow pathways relative to future well pad location

- Exact location of groundwater monitoring wells determined by hydraulic gradient and groundwater flowpaths.
- Hydrogeology to define flow paths prior to well placement is in progress (complicated)

Legend
- MonitorStream
- Springs
- MonitorWells
- GasWells
- nhd24kst_l_pa033
- GiffordRunWatershed
- street100k_l_pa033

Map prepared by Rebecca Rodriguez
Sampling of springs and streams to provide information on conditions prior to drilling groundwater wells

- Integrated values for the baseline groundwater study
- Continuous water quality measurement of surface water that receives runoff from the drilling operations, as well as springs from aquifers surrounding the impacted area.
- Field test of instrumentation to monitor small watersheds for spills.
Marcellus Activity in Pennsylvania

PENNSYLVANIA MARCELLUS WELLS
permits issued as of March 9, 2012

Total Marcellus Permits Issued - 11772
- Vertical Well Permits - 2152
- Horizontal Well Permits - 9620

Data source: Active Permits, Pennsylvania Department of Environmental Protection;
March 9, 2012

Source: Pennsylvania DCNR
Groundwater Monitoring

• **Research Objectives:**
  – At least one year of baseline monitoring of groundwater and surface water surrounding a gas lease, including methane gas, pressure changes, major ions, metals, organics, TDS.
  – Baseline will determine flow pathways. Multi-level samplers will enable the measurement of discrete flow paths and provide a greater understanding of the site hydrogeology.
  – Continuous groundwater monitoring during top-hole drilling through aquifer, and during hydraulic fracturing.
  – Post-drilling water quality monitoring for acute or chronic water quality changes due to drilling.

• **Configuration:**
  – Up-gradient reference well, initially 300 ft deep, open hole completion, equipped with a highly precise methane detector to measure headspace gases. Eventual completion to 1500 ft reaching depth of deepest freshwater.
  – Three down-gradient monitoring wells; nominal depth 300 ft; open hole completions, two equipped with multilevel samplers, the other equipped with continuous electronic monitoring.

Figure illustrates a packer-and-port multilevel sampler system (source: Schlumberger).
Downhole port with packer system for isolating aquifer flow zones.
## Proposed Project Schedule

<table>
<thead>
<tr>
<th>Activity</th>
<th>Planned Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site pre-drill survey</td>
<td>September 2014</td>
</tr>
<tr>
<td>Initial bid from groundwater well drilling company to URS</td>
<td>October 2014</td>
</tr>
<tr>
<td>URS re-bids drilling for shallow wells only</td>
<td>November 2014</td>
</tr>
<tr>
<td>Completion of site hydrogeology and final placement of wells</td>
<td>January 2015</td>
</tr>
<tr>
<td>Approval of site development plan by PA State Forester</td>
<td>February 2015</td>
</tr>
<tr>
<td>Installation of groundwater wells</td>
<td>March 2014</td>
</tr>
<tr>
<td>Completion of multilevel sampler design and installation plan</td>
<td>April 2015</td>
</tr>
<tr>
<td>Installation of two multilevel sampler units in shallow monitoring wells</td>
<td>May 2015</td>
</tr>
<tr>
<td>Final date for any URS activity on contract</td>
<td>May 15, 2015</td>
</tr>
<tr>
<td>Begin monthly synoptic sampling of wells, springs and stream</td>
<td>June 2015</td>
</tr>
<tr>
<td>Complete baseline data phase of investigation</td>
<td>June 2016</td>
</tr>
</tbody>
</table>
### Target analytes for sampling and chemical analysis

<table>
<thead>
<tr>
<th>Analytes</th>
<th>Method</th>
<th>Location</th>
<th>Team Members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major cations (Na, K, Mg, Ca)</td>
<td>ICP-OES</td>
<td>Pittsburgh Analytical Laboratory</td>
<td>William Garber, Tracy Bank (URS)</td>
</tr>
<tr>
<td>Metals and minor cations (Be, Sr, Ba, Cr, Mn, Fe, Al, As, Se)</td>
<td>ICP-OES</td>
<td>Pittsburgh Analytical Laboratory</td>
<td>William Garber, Tracy Bank (URS)</td>
</tr>
<tr>
<td>Anions (NO$_3^-$, SO$_4^{2-}$, Cl$^-$, Br$^-$)</td>
<td>IC</td>
<td>Pittsburgh Analytical Laboratory</td>
<td>Brian Kail (URS)</td>
</tr>
<tr>
<td>Bicarbonate</td>
<td>Alkalinity titration</td>
<td>Pittsburgh Analytical Laboratory</td>
<td>David Blaushild (URS)</td>
</tr>
<tr>
<td>Dissolved methane, BTEX, DRO, GRO, HEM</td>
<td>GC-MS</td>
<td>Chromatography Laboratory</td>
<td>Dirk Link (NETL), Brian Kail (URS)</td>
</tr>
<tr>
<td>Total Organic Carbon</td>
<td>TOC Analyzer</td>
<td>Environmental Geochemistry Laboratory</td>
<td>Vidhi Mishra (ORISE)</td>
</tr>
<tr>
<td>Strontium isotopes</td>
<td>Rapid analysis MC-ICPMS</td>
<td>NETL Multicollector/University of Pittsburgh</td>
<td>Thai Phan (ORISE)</td>
</tr>
<tr>
<td>Carbon and Hydrogen isotopes in dissolved and gaseous CH$_4$</td>
<td>IRMS</td>
<td>External subcontract (Isotech labs in the past)</td>
<td>TBD</td>
</tr>
</tbody>
</table>

Field parameters to be measured: Hydraulic head, pH, temperature, dissolved oxygen, specific conductance, oxidation-reduction potential, turbidity
### Schedule – Sampling and Analysis

<table>
<thead>
<tr>
<th>Activity</th>
<th>Planned Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Analysis of site survey spring samples for cations, anions, metals, and</td>
<td>October 2014</td>
</tr>
<tr>
<td>dissolved organic carbon using standard laboratory techniques through</td>
<td></td>
</tr>
<tr>
<td>the Pittsburgh Analytical Laboratory</td>
<td></td>
</tr>
<tr>
<td>Collection of “baseline to baseline” samples (spring and stream) for</td>
<td>October 2014</td>
</tr>
<tr>
<td>analysis of inorganic and organic compounds</td>
<td></td>
</tr>
<tr>
<td>Analysis of “baseline to baseline” samples (spring and stream) by the</td>
<td>November 2014</td>
</tr>
<tr>
<td>Pittsburgh Analytical Laboratory, team members with experience in</td>
<td></td>
</tr>
<tr>
<td>organics and isotope measurements, and external lab (C, H, O isotopes</td>
<td></td>
</tr>
<tr>
<td>only)</td>
<td></td>
</tr>
<tr>
<td>Complete discussion with EPA and USGS colleagues regarding field</td>
<td>November 2014</td>
</tr>
<tr>
<td>sampling methods and analytical protocols for remainder of study</td>
<td></td>
</tr>
<tr>
<td>Collection of samples during groundwater well drilling and chemical</td>
<td>March 2015</td>
</tr>
<tr>
<td>analysis</td>
<td></td>
</tr>
<tr>
<td>Collection of samples from groundwater wells (pre-multilevel sampler</td>
<td>Synoptic in April 2015</td>
</tr>
<tr>
<td>installation) and chemical analysis</td>
<td></td>
</tr>
<tr>
<td>Collection of samples from groundwater wells (“bulk” sample for wells</td>
<td>Monthly from June 2015 to June</td>
</tr>
<tr>
<td>without multilevel samplers; “zone-specific” samples for wells with</td>
<td>2016</td>
</tr>
<tr>
<td>multilevel samplers)</td>
<td></td>
</tr>
</tbody>
</table>
Other Potential Sites of Interest to NETL

• West Virginia University: Marcellus Shale well on existing wellpad in Westover industrial park.

• Ohio State University: Utica Shale well on university-owned land between Columbus and Cambridge.

• Gas Technology Institute: cooperative well with industry; target formation and location unknown.
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?
Hydrologic Modeling Research

• Reasons for Research
  – Reactive transport model to determine minimum groundwater travel times for contaminants to reach the accessible environment.
  – Two phase flow model on compressed air entering aquifers and causing groundwater flow surges.

• Input Data
  – NA breakdown pathways and rates under various geochemical and microbial conditions.
  – Field data from monitoring site, plus any other available data on groundwater flow surges.
Water saturation versus time (non-fractured aquifer)

Leaking point

50 s

1000 s

$1 \times 10^5$ s

$5 \times 10^5$ s

$5 \times 10^6$ s

$6.8 \times 10^6$ s

10.4 days
Water saturation versus time (fractured aquifer)

About 2 hours
Current plans and status of external partnerships for field site

• USEPA: Contribute to sampling methods discussion, research with multilevel sampler, data interpretation. Status: preliminary discussions/Westbay field visit

• USGS: Potentially assist with sampling, streamflow measurements, data downloads/maintenance of field instrumentation. Status: preliminary discussions.

• University of Guelph/360 Group: Assess aquifers and design multilevel samplers, help characterize hydrology and methane migration paths through aquifers, design/run aquifer tests. Status: proposal in preparation.

• Penn State: Assist with field sampling and analysis. Status: They have expressed interest/will follow-up in November

• PA DCNR: Assist with field logistics and scheduling, help with geology and core collection. Status: work is ongoing.
Anticipated outcomes

• In any case: Improved understanding of shallow aquifer chemistry above an active shale gas play.

• If 300-ft up- and downgradient wells are drilled: Experimental investigation of methane sources, migration pathways, lateral and temporal variations in shallow groundwater chemistry.

• If 1500-ft upgradient well is drilled: Knowledge of depth of deepest freshwater, aquifer petrophysics and geochemistry from core, and data on groundwater chemistry variations with depth.

• If gas wells are drilled: Understanding via field evidence of the impacts of shale gas development on extremely well-characterized aquifers above a shale play.