How Fracking Impacts Our Water: the Pennsylvania Experience

S L Brantley

Pennsylvania State University

With thanks to Paul Grieve, Sina Arjmand, Dave Yoxtheimer, Terry Engelder, Radisav Vidic, Art Rose, Carl Kirby, Rick Hooper, Jon Pollak, Mike Arthur, Xin Gu, Candie Wilderman, Julie Vastine, Jorge Abad, Cesar Simon

April 9, 2014
Univ of CA, Riverside
Natural gas: 90% methane

- U.S. Energy Information Administration (US EIA) estimates the USA has 2119 trillion cubic feet of *recoverable* natural gas

- 60% of this is “unconventional gas” found in low permeability formations (shale, coalbeds, tight sands). “Conventional” gas wells are drilled into more permeable formations, not the source rocks

- Shale gas development is fast (EIA data): in 2009, in the USA 63 billion m$^3$ of gas were produced from deep shale; in 2010 -- 137.8 billion; 2035 projection -- 340 billion
Gas shale plays in the U.S.A.

There are a total of 29 gas shales across 20 states with enough recoverable gas to last the United States 110 years (Entrekin et al., 2011).

In 2000, shale gas provided 1% of U.S. natural gas production: in 2010 it provided 20%
Locations of Shale Wells – 10,000 well pads by 2030?
Incidents that have happened have created public push-back
Oil and gas wells in PA
(data from PA DEP upload 2012)

Pennsylvania DEP estimates that 350,000 oil and gas wells have been drilled in PA. The location of maybe 100,000 of them are unknown. **Red** = active, **Blue** = inactive, **Black** = abandoned.

Interstate Oil and Gas Compact Commission (IOGCC) estimates that hydrofracking is used to stimulate 90% of domestic oil and gas wells (unconventional shales use higher volume). Technique used since 1940s.
Percent of wells drilled each year since 2005 that received at least one Notice of Violation (NOV) in PA has stayed roughly constant at 20%.

http://www.portal.state.pa.us/portal/server.pt/community/oil_and_gas_compliance_report/20299

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Brantley et al., 2014, Int. J. Coal Geology
Map showing locations of all wells with at least one violation recorded by PA DEP (wells with only permitting or recording violations are not shown).

Brantley et al., 2014, Int. J. Coal Geology
What is unconventional gas shale?

A shale of low permeability that has significant gas within it: permeability must be increased to extract the gas economically.
Depth to Marcellus

*Generalized Geologic Cross Section Showing Marcellus Shale in Western Pennsylvania*
Basin Stratigraphy

- Salina Gp.

Net salt thickness of the Salina Group in Pennsylvania
(www.dcnr.state.pa.us/info/carbon/mastercstareport2.pdf).
Unconventional gas wells use horizontal drilling + hydraulic fracturing.

Average total water use per well in PA equals 4 million gallons ..and only about 10-20% usually returns to the surface.
Micro-seismic data are consistent with a radius of influence of these fractures reaching beyond 300 m from the borehole; after 6 months the frac half-length < 150 m, Edwards et al. 2011; SPE 140463). At most, the increase in volume is << 1%.

“A lot of us in the field have different mental pictures of... fractures.” (Schlumberger engineer, 2012)
Well Site in Operation
Now they drill 5-20 laterals per pad. Distance between laterals in TX is about 300 m (Nicot and Scanlan, 2012), and is similar in Marcellus (Edwards et al., 2011)
Photo from Terry Engelder, Chesapeake well pad in Them Farm

Separators  Heaters  Production Water
<table>
<thead>
<tr>
<th>Additive type</th>
<th>Example compounds</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid</td>
<td>Hydrochloric acid</td>
<td>Clean out the wellbore, dissolve minerals, and initiate cracks in rock</td>
</tr>
<tr>
<td>Friction reducer</td>
<td>Polyacrylamide, petroleum distillate</td>
<td>Minimize friction between the fluid and the pipe</td>
</tr>
<tr>
<td>Corrosion inhibitor</td>
<td>Isopropanol, acetaldehyde</td>
<td>Prevent corrosion of pipe by diluted acid</td>
</tr>
<tr>
<td>Iron control</td>
<td>Citric acid, thioglycolic acid</td>
<td>Prevent precipitation of metal oxides</td>
</tr>
<tr>
<td>Biocide</td>
<td>Glutaraldehyde, 2,2-dibromo-3-nitropropionamide (DBNPA)</td>
<td>Bacterial control</td>
</tr>
<tr>
<td>Gelling agent</td>
<td>Guar/xanthan gum or hydroxyethyl cellulose</td>
<td>Thicken water to suspend the sand</td>
</tr>
<tr>
<td>Crosslinker</td>
<td>Borate salts</td>
<td>Maximize fluid viscosity at high temperatures</td>
</tr>
<tr>
<td>Breaker</td>
<td>Ammonium persulfate, magnesium peroxide</td>
<td>Promote breakdown of gel polymers</td>
</tr>
<tr>
<td>Oxygen scavenger</td>
<td>Ammonium bisulfite</td>
<td>Remove oxygen from fluid to reduce pipe corrosion</td>
</tr>
<tr>
<td>pH adjustment</td>
<td>Potassium or sodium hydroxide or carbonate</td>
<td>Maintain effectiveness of other compounds (such as crosslinker)</td>
</tr>
<tr>
<td>Proppant</td>
<td>Silica quartz sand</td>
<td>Keep fractures open</td>
</tr>
<tr>
<td>Scale inhibitor</td>
<td>Ethylene glycol</td>
<td>Reduce deposition on pipes</td>
</tr>
<tr>
<td>Surfactant</td>
<td>Ethanol, isopropyl alcohol, 2-butoxyethanol</td>
<td>Decrease surface tension to allow water recovery</td>
</tr>
</tbody>
</table>
In Feb 2011, PA required disclosure of chemicals in fluids (No federal law requiring disclosure; CO requires limited disclosure; WY requires public disclosure with some exemptions)

Information available online at FracFocus.org
Some of the components used in the hydraulic fracturing products were common and generally harmless, such as salt and citric acid. Some were unexpected, such as instant coffee and walnut hulls. And some were extremely toxic, such as benzene and lead. Appendix A lists each of the 750 chemicals and other components used in hydraulic fracturing products between 2005 and 2009.

The most widely used chemical in hydraulic fracturing during this time period, as measured by the number of compounds containing the chemical, was methanol. Methanol, which was used in 342 hydraulic fracturing products, is a hazardous air pollutant and is on the candidate list for potential regulation under the Safe Drinking Water Act. Some of the other most widely used chemicals were isopropyl alcohol (used in 274 products), 2-butoxyethanol (used in 126 products), and ethylene glycol (used in 119 products).

Between 2005 and 2009, the oil and gas service companies used hydraulic fracturing products containing 29 chemicals that are (1) known or possible human carcinogens, (2) regulated under the Safe Drinking Water Act for their risks to human health, or (3) listed as hazardous air pollutants under the Clean Air Act. These 29 chemicals were components of more than 650 different products used in hydraulic fracturing.
<table>
<thead>
<tr>
<th>Chemical Component</th>
<th>Chemical Category</th>
<th>No. of Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol (Methyl alcohol)</td>
<td>HAP</td>
<td>342</td>
</tr>
<tr>
<td>Ethylene glycol (1,2-ethanediol)</td>
<td>HAP</td>
<td>119</td>
</tr>
<tr>
<td>Diesel(^{19})</td>
<td>Carcinogen, SDWA, HAP</td>
<td>51</td>
</tr>
<tr>
<td>Naphthalene</td>
<td>Carcinogen, HAP</td>
<td>44</td>
</tr>
<tr>
<td>Xylene</td>
<td>SDWA, HAP</td>
<td>44</td>
</tr>
<tr>
<td>Hydrogen chloride (Hydrochloric acid)</td>
<td>HAP</td>
<td>42</td>
</tr>
<tr>
<td>Toluene</td>
<td>SDWA, HAP</td>
<td>29</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>SDWA, HAP</td>
<td>28</td>
</tr>
<tr>
<td>Diethanolamine (2,2-iminodiethanol)</td>
<td>HAP</td>
<td>14</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>Carcinogen, HAP</td>
<td>12</td>
</tr>
<tr>
<td>Sulfuric acid</td>
<td>Carcinogen</td>
<td>9</td>
</tr>
<tr>
<td>Thiourea</td>
<td>Carcinogen</td>
<td>9</td>
</tr>
<tr>
<td>Benzyl chloride</td>
<td>Carcinogen, HAP</td>
<td>8</td>
</tr>
<tr>
<td>Cumene</td>
<td>HAP</td>
<td>6</td>
</tr>
<tr>
<td>Nitrilotriacetic acid</td>
<td>Carcinogen</td>
<td>6</td>
</tr>
<tr>
<td>Dimethyl formamide</td>
<td>HAP</td>
<td>5</td>
</tr>
<tr>
<td>Phenol</td>
<td>HAP</td>
<td>5</td>
</tr>
<tr>
<td>Benzene</td>
<td>Carcinogen, SDWA, HAP</td>
<td>3</td>
</tr>
<tr>
<td>Di (2-ethylhexyl) phthalate</td>
<td>Carcinogen, SDWA, HAP</td>
<td>3</td>
</tr>
<tr>
<td>Acrylamide</td>
<td>Carcinogen, SDWA, HAP</td>
<td>2</td>
</tr>
<tr>
<td>Hydrogen fluoride (Hydrofluoric acid)</td>
<td>HAP</td>
<td>2</td>
</tr>
<tr>
<td>Phthalic anhydride</td>
<td>HAP</td>
<td>2</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>Carcinogen, HAP</td>
<td>1</td>
</tr>
<tr>
<td>Acetophenone</td>
<td>HAP</td>
<td>1</td>
</tr>
<tr>
<td>Copper</td>
<td>SDWA</td>
<td>1</td>
</tr>
<tr>
<td>Ethylene oxide</td>
<td>Carcinogen, HAP</td>
<td>1</td>
</tr>
<tr>
<td>Lead</td>
<td>Carcinogen, SDWA, HAP</td>
<td>1</td>
</tr>
<tr>
<td>Propylene oxide</td>
<td>Carcinogen, HAP</td>
<td>1</td>
</tr>
<tr>
<td>p-Xylene</td>
<td>HAP</td>
<td>1</td>
</tr>
<tr>
<td><strong>Number of Products Containing a Component of Concern</strong></td>
<td></td>
<td><strong>652</strong></td>
</tr>
</tbody>
</table>
Hydrofrack constituents do come back up in the water that returns: **flowback and production water**

Screen Shot from HydroDesktop with ShaleNetwork Data Sites with benzene reported in injection and/or flowback water (data from Hayes)

No known cases of hydrofrack fluids contaminating drinking water from movement at depth in PA (only 2 alleged cases nationwide, very controversial)

Graph from Carl Kirby, Bucknell Univ
Flowback chemistry versus time from Hayes (2009) recovered from ShaleNetwork online database

Cl, Br, Na, K, Ca, Mg, Sr, Ba, Fe, Mn, TDS all usually increasing with time. pH, alkalinity, sulfate decrease with time.

TDS often above 200,000 ppm: Na, Ca, Cl brine (relatively low in Mg, Sulfate)
Naturally Occurring Radioactive Materials (NORMs) also increase with time in flowback (Rowan et al. 2011)
What the EPA is thinking about

• **1. Water Volume**: Will large withdrawals of water impact drinking water resources?
• **2. Hydrofracturing itself**: What are the possible impacts of the injection and fracturing process on drinking water resources?
• **3. Fracking fluids**: If hydraulic fracturing fluids are spilled, how will this impact drinking water resources?
• **4. Flowback and Produced Waters**: If flowback and produced waters are spilled, how will this impact drinking water resources?
• **5. Wastewater Treatment and Disposal**: What are the possible impacts of inadequately treated hydraulic fracturing wastewaters on drinking water resources?
Approved public water withdrawal points (SRBC, 2013)

- SW/GW Sources for Oil & Gas Companies in Susquehanna River Basin
- SW/GW Sources for non Oil & Gas Companies in Susquehanna River Basin
- SRBC Water Trails
- SRBC Basin Boundary
PA Water Withdrawals by Water Use*

- **Domestic Water Supply**: 152 million gallons per day
- **Public Water Supply**: 1.42 billion gallons per day
- **Irrigation**: 24.3 million gallons per day
- **Livestock**: 61.8 million gallons per day
- **Aquaculture**: 524 million gallons per day
- **Industrial**: 770 million gallons per day
- **Marcellus Shale Development**: 95.7 million gallons per day
- **Thermoelectric Power**: 6.43 billion gallons per day
- **5-6 mgd*”

*Source: Pa Fish and Boat Commission

*Estimated based on recent SRBC/DEP data


Marcellus Shale Gas Development Water Use: June 1, 2008 - May 21, 2010 Susquehanna River Basin Commission basin-wide reported daily use of 0.99 MGD expanded to statewide estimate. Water sources: 29% Public water supplies/71% Surface water withdrawals

1 MGD daily use in Susq, Basin + wells drilled in Susq, Basin/wells drilled statewide=1 MGD ÷ (765/1428)
Potential Contaminants

• Drilling muds, cuttings
• Frack fluids
• Emissions from diesel motors/electric generators into air, some impact on water
• Natural sediments
• Methane
• Natural contaminants from flowback and production fluids

Drilling and hydraulic fracturing lasts only about 2 months, then the equipment and activity is gone.
Potential Water Quality Impact Pathways

- **Direct spill** of fluids to ground surface via leaking pipes or impoundments
- **Trucking spills** (i.e. accidents)
- **Methane migration** into groundwater/surface water due to faulty well construction
- **Effluent from treatment facility** (largely a non-issue with new treatment standards in PA)
- **Erosion and sediment transport** from pads and roads
THE SHALE NETWORK

The ShaleNetwork is creating a central and accessible repository for geochemistry and hydrology data collected by watershed groups, government agencies, industry stakeholders, and universities working together to document natural variability and potential environmental impacts of shale gas extraction activities.
We are building a ShaleNetwork database of water quality in stream waters, ground waters, injection, flowback, and production waters in the area of Devonian shale gas development. The database is described at shalenetwork.org and accessible through HydroDesktop (online program that will allow access to database (download from www.cuahsi.org))
Impacts of drilling, injection and hydrofracturing

1. Drilling muds or constituents (i.e., Airfoam)
2. Fracking constituents
3. Gas
10 out of 31 identified spill incidents in the NOVs since 2009.
Example Mud Release: Larry’s Creek 10/19/11

• The week of 10/19/2011, Larry’s Creek, near a drilling site, was running rich with clay but the settling process was working very well. Then a mud release occurred.

• SRBC saw an increase in conductivity/turbidity in the creek

Larry’s Creek is near Salladsburg, PA, located in Mifflin Twp., Lycoming Co., PA. Off route 287, north of Jersey Shore, above the junction of Routes 220 and 287
Detail of the days after the incident on 10/19/2011
(Shale Network database, HydroDesktop graph)

Susquehanna River Basin Commission sensor data

Increase in turbidity caused by the spill

Day of the Spill
Comparison of turbidity to precipitation in Larrys Creek
Will transport of contaminants through porous rock or fractures bring fracking constituents or subsurface brines into near-surface drinking water resources?
• “To our knowledge, there have been a million wells fracked, and no documented cases of contamination of groundwater from hydraulic fracturing.” Exxon CEO Rex Tillerson told House Energy and Commerce Committee in January 2010
Myers 2012 concludes that transport to the surface could require 10 to 10s of thousands of years. He simulated pressure of fluids after injection into a well.

The data and his model (MODFLOW-2000) show return to pre-injection levels within 300 days.

The model shows new pressure equilibrium reached within 3-6 y, which he concludes could cause advection upward to aquifers within as little as 10 y.
Does hydrofracturing cause natural gas to enter drinking water?

- About 44 million people in USA use private water supplies for house and farm

- (Hutson, S. et al., 2000; Estimated Use of Water in the United States in 2000; US Geol Survey Circular 1268)
• Locations of sampling in active sites (within 1 km of drilling) and nonactive sites reported by Osborn et al.

Methane concentrations in drinking water from wells (Osborn et al., 2011)

Methane saturation at atm pressure = 26 mg CH₄/L (20°C) and 42 mg/L (10°C).
Osborn et al.

- δ13C in the methane becomes more like the thermogenic signature as gas concentration increases.
- Methane concentrations and δ 13C increase regardless of formation.
- Grey areas are typical δ 13C values for biogenic and thermogenic (Osborn and McIntosh (2010)).

Isotope standard = VDPB (Vienna Pee Dee Belemnite)
Study of Groundwater Quality Before and After Drilling in PA Marcellus drilling area

• PSU Researchers including Beth Boyer and Bryan Swistock received funding from The Center for Rural PA to collect pre- and post-drilling water sample from private wells
• Collected and analyzed nearly 230 samples within 1,000 feet and within 1 mile of Marcellus wells
• No significant before/after changes in water quality
  — ~40% of wells fail at least one drinking water standard..about 25% had measurable methane
More than 340 wells < 5 mg/L

Average for 34 wells in nonactive areas
= 1.1 mg CH₄/L

Average for 26 wells in active areas
= 19.2 mg CH₄/L
PA Regulations

• In PA, unconventional gas companies are presumed responsible for water contamination within 2500 ft within 12 months of well completion if they have no pre-drill data that shows the water quality did not change. Most (all?) companies therefore test water supplies within 2500 ft before drilling so that they can determine if WQ did or did not change after drilling.

• Companies do not have to give data to PA DEP, although to protect themselves legally, they generally give it to DEP. PA DEP cannot readily share the data because it must be redacted to remove confidential info. PA DEP has shared some of this data with ShaleNetwork under an MOU between the state and Penn State and we are working to get the data online.
Methane concentration data in PA groundwaters are sparse

Most data are in ShaleNetwork online database; figure made by PSU grad student Paul Grieve. Red points: PA DEP attributed methane to oil/gas activity

Data from

Brantley et al., 2014, Int. J. Coal Geology
Map documenting the % of spudded wells in each county that have received NOVs from the PA DEP from 5/2005 to 3/2013 for casing, cementing or well construction issues

There is an indication that methane migration problems are worse in northern, glaciated part of state

Brantley et al., 2014, subm. Int. J. Coal Geology
Issues related to flowback and production waters

Can briny flowback or production waters get into ground or surface waters? (9 spills of flowback/production/brine waters, 6 spills of frack components since 2009 in PA)
Currently about 90% of the brines are reinjected for hydrofracturing.
Before 2011 in PA, it was permitted to send flowback/production waters to municipal water treatment plants for discharge into rivers. In early 2011, several noticed that Br in intake for Pittsburgh Water Sewer Authority was high enough to be problematic...
Br in Allegheny River water at Pittsburgh Water and Sewer Authority intake

Screen shot from Shale Network data in HydroDesktop
Bromide in surface water versus time for all available data in Shale Network database for 40 PA counties with Marcellus drilling

High concentrations since 2003 were generally in areas with permitted brine discharge or natural spring discharge (e.g. Salt Springs). Line = 3σ above mean from 1960-2003 for USGS data (early data not shown).

Detection limit = 10 – 200 µg/L. EPA is considering an MCL for Br = 6000 µg/L

Includes data from EPA STORET, USGS NWIS, SRBC, Appal. Geo. Consulting, ALLARM, PA DEP

Vidic, Brantley, Vandenbossche, Yoxtheimer, Abad, Science 2013
In contrast to low concentration constituents such as hydrofracking compounds, salts are present in flowback/production waters at much higher concentrations. A spill or leakage would therefore most likely be identified by analyzing salts. Here are all locations where PA DEP determined that shale gas development could be presumed responsible for contamination of drinking water supplies with dissolved salts.
But, is this contamination due to leakage of flowback in subsurface, due to spills, or due to shale gas development-related movement of shallow, natural brines?

Depth to the Salina formation in PA, graph by Paul Grieve, PSU graduate assistant
Spills on the ridgetops where the drill sites are now usually located can allow movement in unexpected directions.

This study was completed by Garth Llewellyn of Appalachia Hydrogeologic and Environmental Consulting, LLC to investigate quarry contamination into surface waters.
Incidents versus time in PA
Spills

31 Spills:
- Diesel (1)
- Discharge (1)
- Airfoam (1)
- Hydrot. test water (2)
- Sediment (3)
- Frack fluids or components (6)
- Drilling muds or fluids (9)
- Flowback, prod. water or brine (9)

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Fig. 3. Number of unconventional shale-gas wells spudded in PA per year (black squares, plotted after division by 100) and number of major spills (>400 gal, see Table 5) reported for PA associated with these shale gas activities (red circles). Blue triangles indicate the number of cases reported by PA DEP per year where either unconventional or conventional oil or gas activity was implicated in the impact of one or more water supplies (see text). Black triangles document the number of new producing wells (divided by 100) per year, i.e., the number of wells completed by hydraulic fracturing and brought into production per year. Data derive from PA DEP, U.S. EPA, and media reports as described in the text. The number of new producing wells in 2010 was assessed by doubling the number of new producing wells in the second half of 2010 (375) because data for the first half of the year were not available.
## Table 5
Major spills to water bodies in Pennsylvania as of Sept 2013.

<table>
<thead>
<tr>
<th>Date</th>
<th>County</th>
<th>Receiving water body</th>
<th>Spilled material</th>
<th>Volume (gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008 to 2013 (&gt;400 gal)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nov 23, 2009¹</td>
<td>Bradford</td>
<td>Webier Creek</td>
<td>Fracking and flowback</td>
<td>4200 to 6300</td>
</tr>
<tr>
<td>Mar 19, 2011¹</td>
<td>Bradford</td>
<td>Towanda Creek</td>
<td>Produced water</td>
<td>4700</td>
</tr>
<tr>
<td>Dec 13, 2012</td>
<td>Butler</td>
<td>Thorn Creek</td>
<td>Drilling fluids</td>
<td>Unknown</td>
</tr>
<tr>
<td>May 24, 2010⁴</td>
<td>Blair</td>
<td>Bobs Creek</td>
<td>Rowback</td>
<td>Unknown</td>
</tr>
<tr>
<td>Jul 30, 2010⁴</td>
<td>Cameron</td>
<td>Unknown</td>
<td>Drilling mud</td>
<td>1500</td>
</tr>
<tr>
<td>Oct 12, 2009⁶</td>
<td>Clearfield</td>
<td>Little Laurel Creek</td>
<td>Rowback</td>
<td>7980</td>
</tr>
<tr>
<td>Mar 26, 2010⁷</td>
<td>Clinton</td>
<td>Queens Run</td>
<td>Drilling mud</td>
<td>8000 to 12,000</td>
</tr>
<tr>
<td>Jan 29, 2011⁸</td>
<td>Clinton</td>
<td>headwaters of the South Renovo water supply</td>
<td>Fracking</td>
<td>3400</td>
</tr>
<tr>
<td>Sep 10, 2012³</td>
<td>Sullivan</td>
<td>Mill Creek</td>
<td>Sediment</td>
<td>Unknown</td>
</tr>
<tr>
<td>Oct 15, 2012</td>
<td>Lycoming</td>
<td>Blacklick Creek</td>
<td>Bentonite</td>
<td>Unknown</td>
</tr>
<tr>
<td>Mar 13 &amp; 14, 2010¹</td>
<td>Lycoming</td>
<td>Pine Creek</td>
<td>Airfoam</td>
<td>180 gal/min</td>
</tr>
<tr>
<td>Aug 12, 2010⁶</td>
<td>Lycoming</td>
<td>Big Run</td>
<td>Hydrostatic testing water</td>
<td>25,200</td>
</tr>
<tr>
<td>Nov 16, 2010⁷</td>
<td>Lycoming</td>
<td>Trib to Sugar Run</td>
<td>Fracking and produced</td>
<td>6300 to 57,373</td>
</tr>
<tr>
<td>Before Nov 22, 2010⁸</td>
<td>Lycoming</td>
<td>Trib to Sugar Run</td>
<td>Fracking</td>
<td>-13,000</td>
</tr>
<tr>
<td>Jan 6 &amp; 15, 2012²</td>
<td>Lycoming</td>
<td>Pine Creek</td>
<td>Brine</td>
<td>8200</td>
</tr>
<tr>
<td>Oct 9, 2012³</td>
<td>Lycoming</td>
<td>Trib to Slack Run</td>
<td>Sediment</td>
<td>Unknown</td>
</tr>
<tr>
<td>Dec 27, 2012²</td>
<td>Lycoming</td>
<td>Brion Creek</td>
<td>Hydrostatic test (water, sediment)</td>
<td>232,604</td>
</tr>
<tr>
<td>Nov 21, 2012⁶</td>
<td>Lycoming</td>
<td>Muncy Creek</td>
<td>Fracking</td>
<td>4275</td>
</tr>
<tr>
<td>Aug 20, 2012⁹</td>
<td>Sullivan</td>
<td>Harts Run</td>
<td>Bentonite</td>
<td>-10,000</td>
</tr>
<tr>
<td>Sep 4, 2012²</td>
<td>Sullivan</td>
<td>Black Water Run</td>
<td>Turbid discharge</td>
<td>Unknown</td>
</tr>
<tr>
<td>Dec 19, 2012³</td>
<td>Sullivan</td>
<td>Wellman’s Creek, Salt Lick Creek</td>
<td>Discharge</td>
<td>Unknown</td>
</tr>
<tr>
<td>Jan 1, 2013³</td>
<td>Sullivan</td>
<td>Big Bottom Run</td>
<td>Sediment</td>
<td>Unknown</td>
</tr>
<tr>
<td>Sep 16 &amp; 22, 2009⁴</td>
<td>Susquehanna</td>
<td>Stevens Creek</td>
<td>Water/liquid gel mixture</td>
<td>8000</td>
</tr>
<tr>
<td>Jul 29, Aug 2 &amp; 10, 2011⁷</td>
<td>Susquehanna</td>
<td>Laurel Lake Creek</td>
<td>Drilling mud</td>
<td>1500</td>
</tr>
<tr>
<td>May 26, 2009⁶</td>
<td>Washington</td>
<td>Cross Creek</td>
<td>Rowback and brine</td>
<td>4200</td>
</tr>
<tr>
<td>Oct 6, 2009¹</td>
<td>Washington</td>
<td>Brush Run</td>
<td>Rowback</td>
<td>10,500</td>
</tr>
<tr>
<td>Dec 4 &amp; 5, 2009⁹</td>
<td>Washington</td>
<td>Dunklee Run</td>
<td>Fracking fluid</td>
<td>Unknown</td>
</tr>
<tr>
<td>Jul 5, 2011³</td>
<td>Washington</td>
<td>Ten Mile Creek</td>
<td>Drilling mud</td>
<td>2400</td>
</tr>
<tr>
<td>Oct 31, 2011¹</td>
<td>Washington</td>
<td>Hopewell Township</td>
<td>Rowback</td>
<td>16,800</td>
</tr>
<tr>
<td>Oct 30, 2009⁶</td>
<td>Westmoreland</td>
<td>Unknown</td>
<td>Diesel</td>
<td>790</td>
</tr>
<tr>
<td>Mar 13, 2013⁸</td>
<td>Wyoming</td>
<td>Washington Township</td>
<td>Fracking</td>
<td>227,000 (at rate of 800 gal/min)</td>
</tr>
<tr>
<td>April 30, 2013⁸</td>
<td>Wyoming</td>
<td>Washington Township</td>
<td>Rowback</td>
<td>-9000</td>
</tr>
</tbody>
</table>
Cases of GW contamination

From 2008 to 2012, PA DEP received about 1000 complaints about contamination in drinking water wells. 17% of the incidents were deemed by DEP to have been caused by oil/gas activities. Half were due to conventional half due to unconventional oil/gas activity. They were classified by PA DEP into 83 “cases” and each case could implicate 1 or more gas wells and one or more drinking water well. According to DEP, one problematic conventional oil/gas well before 2008 generally impacted only “a few” water wells. In contrast, one problematic unconventional oil/gas well may have impacted 18 water wells in Dimock PA. From these data we estimate that between 7 and 64 unconventional gas wells contaminated 85 drinking water well sites: i.e. between 0.1 and 1% of the 6061 spudded wells. This is consistent with 0.24% of wells receiving NOVs for methane migration into GW.
Very few incidents have been documented in publicly available water quality data
We can find data showing very few contamination incidents in the Shale Network database due to shale gas industry. Example: SRBC RWQMN at Bob’s Creek (http://mdw.srbc.net/remotewaterquality/data_viewer.aspx)

A leak in a liner allowed flowback water to run off a well pad site (leak discovered 5/24/2010 but was presumed to have started earlier) and PA DEP thought that some contaminant got into Bob’s creek, a Class A trout stream in Juniata Township, Blair County.
Bob’s Creek: May 24 2010 spill of flowback. Data from USGS, SRBC, PA DEP available in Shale Network database.
Incidence of significant water quality impacts in PA due to shale gas activities have occurred at relatively low frequency. Contaminants have been quickly diluted. But firm conclusions are impossible because:

• We often lack specific information about location and timing of incidents
• A lot of WQ data are not released due to liability or confidentiality issues
• Sample and sensor data for analytes of interest are sparse spatially and temporally
• Pre-existing water quality impairments (e.g. acid mine drainage, road salt) make it difficult to discern shale gas impact
• Even when sensors are deployed, they can malfunction or drift
Summary

• The Shale Network team has not identified any incidents where *frack fluid components* have been identified in ground water from subsurface transport after or during fracking.

• Geology matters: glaciated part of state may have more issues

• The frequency of significant problems appears small but data about water quality impacts are too sparse to make firm conclusions about the impact of shale gas activity

• Sharing of data must be encouraged by all people in industry, government, academia, and in the general public.

• The water quality issues we need to be concerned about include methane migration, brine disposal issues, spills, naturally occurring radioactive materials, and short circuiting by old wells.

Acknowledgements: This work was funded by National Science Foundation OCE SEES funding to S. Brantley (Shale Network Database).
Relevant Federal Regulations

- Safe Drinking Water Act (SDWA) Underground Injection Control Program requires EPA or EPA-authorized states to prevent underground injection of fluids that could endanger drinking water; however, EPA has never regulated hydraulic fracturing under SDWA
- 2005 Energy Policy Act excluded underground injection of fluids or proppants other than diesel fuels that are related to oil, gas, geothermal from regulation as “underground injection”
- FRAC Act 2009: bills granting EPA authority over fracking under SDWA were introduced in House and Senate (Fracturing Responsibility and Awareness of Chemicals Act)....neither bill was reported out of committee
- FRAC Act reintroduced in 2011 to both houses
- Natural gas companies are not required to disclose identity of chemical constituents in fracturing fluids under federal law; EPA issued a voluntary request to 9 providers in 2010 and indicated they had legal authority to compel disclosure
- DOI Secretary Ken Salazar has indicated DOE will require disclosure of chemicals used on public lands
- EPA has an ongoing study of drinking water impacts from hydraulic fracturing, expected in preliminary form in 2012 and completed in 2014

Greenhouse gas controversy

• 1-3% of total gas production per well is lost to atmosphere (Kirchgessner et al. 1997, Chemosphere 35: 1365-1390)

• Cornell Univ: 3.6-7.9% of methane from shale-gas production lost to atmosphere (Howarth, Santoro, Ingraffea, 2011, Climatic Change doi: 10.1007/s10584-011-0061-5)
Greenhouse gas emissions:
Unpublished from Paula Jaramillo, Carnegie
From NAS workshop at Univ of WV, Sept 2012

Different studies have resulted in different values

![Graph showing life cycle GHG emissions](image)

- Stephenson et al. 2011
- Howarth et al. 2011
- Conventional
- Unconventional

Carnegie Mellon University
Private Well TDS Pre- and Post-Drilling

The Impact of Marcellus Gas Drilling on Rural Drinking Water Supplies, Center for Rural PA, October 2011
Summary

• The Shale Network team has not identified any incidents where *frack fluid components* have been identified in ground water from subsurface transport after or during fracking.
• Water quality and quantity issues include potential problems during drilling, problems with casings (3.5% problem rate but problem wells are fixed), problems with salts in fluids when spilled or disposed, problems related to mobilization of methane, and other potential problems.
• Many improvements have been instituted in PA to deal with these issues.
• A lot of water quality data are already available – but data are hard to access – and site locations are not always appropriate or analyses for certain components are missing. Also, releases of data around incidents are restricted. We are building a ShaleNetwork database that is described at shalenetwork.org and accessible through CUAHSI.org to enable sharing and investigation of data.
• The publicly accessible data do not show a high incidence of problems. Why? Probably because the density of monitoring stations that record appropriate analytes in appropriate places is low compared to the number of well pads; the actual rate of problems that are large enough to impact waters is relatively low; it is still hard to get data and information about spills and incidents; often data are not released; analysis of baseline data is lacking.
• Sharing data should be encouraged by all people in industry, government, academia, and in the general public.

Acknowledgements: This work was funded by National Science Foundation OCE SEES funding to S. Brantley (Shale Network Database).
Burning the creek...how the natural gas industry began

"The first attempt which has ever been made to apply natural gas to so extensive and useful a purpose”

quoted from the Fredonia Censor newspaper November 25th, 1825
The first gas well preceded the first well drilled for the sole purpose of oil (1859): in Pennsylvania

The first successful oil well drilled for the sole purpose of finding oil was the Drake Well drilled in Titusville PA in 1859.

www.historycentral.com
Marcellus shale deposition

315 m years ago: collision, slid for 15 my

389 million years ago: clay + organic matter + quartz + Fe oxides deposited

300 million years ago: entered the oil window

260 million years ago: seals formed that trapped in the gas

Schematic of Laurentia/Gondwana at time of deposition of Marcellus shale

(Engelder and Lash, American Oil and Gas Reporter, May 2008; after Blakey, R.C. www2.nau.edu/rcb7/nam.html; Right figure from Ettsonohn, 1994)
Hydrofrack constituents do come back up in the water that returns: **flowback and production water**

Screen Shot from HydroDesktop with ShaleNetwork Data Sites with benzene reported in injection and/or flowback water (data from Hayes)