Using CUAHSI HIS in the Shale Network to Assess Water Quality and Quantity Data in Regions of Hydraulic Fracturing

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...and many involved with Shale Network at Penn State (Dave Yoxtheimer, Paul Grieve, Maggie Peacock, Irena Gorski); Dickinson University (Candie Wilderman, Julie Vastine); University of Pittsburgh (Jorge Abad, Radisav Vidic, Cesar Simon, Sina Arjmand, Yue Han); CUAHSI (Rick Hooper, Jon Pollak, Jennifer Arrigo, many others) ; Bucknell University (Carl Kirby)
Many other participants have contributed ideas, help, time, and data

Teen Shale Network includes high school students from State College High School PA (Teacher Nell Herrmann) and Mountain Ridge High School WV (Teacher Tom Kozikowski)

Photo from the annual Shale Network workshop April 2012 (shalenetwork.org). Next workshop: May 19-20, 2013
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 m³ 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).
Unconventional gas wells are drilled vertically, then horizontally, and then the horizontal leg is hydraulically fractured.

The technique was pioneered in the Barnett shale in OK and TX in the 1990s and then first used in Marcellus shale in PA in 2003.
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)
Hydraulic Fracturing Fluids

- Each PA well uses about 3 to 7 million gallons of water.

- Approximately 10-20% of the fluids return as flowback water.

Source: Chesapeake Energy
Locations of Shale Wells – 10,000 well pads by 2030?
Report issued by researchers out of University of Buffalo summarized the Notices of Violations (NOVs) to PA DEP from Jan 2008 to Aug 2011.

- More than ½ wells in 2008 had some level of NOV (most minor), declining to 1/5 in 2011.
- 25 major environmental events: 9 major spills on land; 8 spills into water supplies; 4 well blowouts/venting; 2 site restoration impacts; 2 gas migration incidents.
- 85/3500 (2%) wells had casing problems.
- 0.11% probability of well blowout.
Incidents that have happened have created public push-back

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

http://www.lhup.edu/rmyers3/marcellus.htm

Univ of Buffalo report (Lead, Tim Considine, released May 15 2012) said that it examined 3000 violations from 4000 gas wells since 2008 in PA. 62% were administrative and 38% were environmental, stemming from 845 events – 25 classified as major, like site restoration failures, serious contamination of water supplies, major land spills, blowouts, and venting and gas migration. Total violations tripled from 99 in 2008 to 331 in the first eight months of 2011 as number of wells rose from 170 to 1200. But % dropped from 58.2 to 30.5 (2008 to 2010).
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.
Two Intertwined Goals of This Talk

• Discuss an effort by the Shale Network Research Coordination Network (RCN) funded by the National Science Foundation to publish water quality and quantity data online as part of CUAHSI HIS for areas of hydraulic fracturing in the northeast

• Discuss what has been learned about water quality issues with respect to development of unconventional gas in the Marcellus region
We are building the ShaleNetwork database as a HydroServer in the CUAHSI Hydrological Information System (NSF facility). CUAHSI’s tool, HydroDesktop, allows people to find the data along with data such as USGS NWIS and EPA STORET. Below: all locations for which Shale Network uploaded data from 10/11 – 12/12

By putting Shale Network data (shalenetwork.org) into the CUAHSI Hydrologic Information System (cuahsi.org), it can be easily accessed with all the other data that are available, using HydroDesktop.
What is the Hydrologic Information System?

HydroServers are computers around the world that post online data.

HydroDesktop is the computer program that helps you pull the metadata and data onto your home computer.

HIS Central is the computer that houses the metadata for online datasets.

First you grab metadata.

Then you grab data.

CUAHSI
universities allied for water research
What we are doing

- Finding data, working with data providers to get metadata
- Organizing the data into the format required by the Observations Data Model (ODM) and the CUAHSI-HIS data/metadata standards (Horsburgh et al., 2008). For GIS coverages and spatial data we follow FGDC Federal Metadata Standard
- We use the ODM Data Loader for data uploads for sample-based data (non-streaming) data
- We use ODM Tools to query and look at the data
- We publish the data in WaterML with WaterOne Flow webservice
- We register the web service with HIS
- We work with the data by accessing it using HydroDesktop
Partial list of analytes included (all sites do not include all analytes)

• **Common water quality measurements**: pH, Na, K, Mg, Ca, sulfate, chloride, bromide, ammonia, nitrate, nitrite, total N, acidity, alkalinity, BOD, COD, hardness, TDS, specific conductance, TSS

• **Trace elements**: Ag, Al, As, Ba, Be, B, Cd, Cr, Co, Cu, Fe, Pb, Li, Mg, Mn, Hg, Mo, Ni, Pb, Se, Sr, Th, U, Zn

• **NORMs**: Gross alpha, Gross beta, Ra-226, Ra-228

• **Organics**: acetophenone, benzene, bis(2-ethylhexyl) phthalate, ethylbenzene, ethylene glycol, methane, methanol, methylene blue active substances, napthalene, oil and grease, phenolics, toluene, xylenes

• **Stable isotopes**: delta 13C, delta 18O, delta D
We only input data from volunteer groups which have some sort of data quality control. In this effort, we work with ALLARM (Candie Wilderman, Julie Vastine)

- ShaleNetwork database now includes data for water quality in stream waters, spring waters, ground waters, injection, flowback, and production waters in the area of Devonian shale gas development in northeast.
- The database is accessed through HydroDesktop (download from www.cuahsi.org), and www.shalenetwork.org
- We have uploaded data from published literature, unpublished literature, industry, government agencies, volunteer groups, university scientists

Screen shot from HydroDesktop showing ShaleNetwork data with EPA data for Ba, Sr, pH: Highlighted data provided from Wysox Creek Watershed Association, analyses by Chemical Solutions in Mechanicsburg (through ALLARM)
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Screen shot from HydroDesktop showing ShaleNetwork data with EPA data for Ba, Sr, pH: Highlighted data provided from Wysox Creek Watershed Association, analyses by Chemical Solutions in Mechanicsburg (through ALLARM)
Data are plentiful (shown here, all Shale Network sites for all analytes as of Nov 2012 (black)) ...but...

...in Pennsylvania, the density of sampling (black) is low compared to well density (green).
Data for individual analytes (such as methane, shown here) can be particularly scarce.

Methane data input to ShaleNetwork database by Paul Grieve (Penn State) March 2013 for all published data in PA, WV, NY to that point.


(4) Appalachian Hydrogeologic and Environmental Consulting, Sampling Results from Salt Springs State Park.
Potential Contaminants to Waters

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

Drilling and hydraulic fracturing lasts only about 2 months, then the equipment and activity is gone.
What are the impacts of injection and fracturing process itself?

1. Muds during drilling
2. Fracking constituents
3. Gas
Truck traffic, pipeline construction, etc. can all cause natural sediment inputs to waterways

“50-70% of pads occur on slopes at risk to...local erosion.”
(Drohan and Brittingham, 2012)
Mud Release also due to drilling accidents: e.g. Larry’s Creek

- The week of 10/19/2011, drilling was occurring beneath Larry’s Creek. The creek was running rich with clay but the settling process was working very well. Then drilling “fracked out” and released drilling mud to creek.
- 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
Data from Susquehanna River Basin Commission (SRBC): ShaleNetwork database data shown here in a screen shot on HydroDesktop

SRBC's automated Remote Water Quality Monitoring Network (RWQMN)

Increase of the turbidity as a result of the spill

Day of the Spill
Interpreting the sensor data is difficult due to problems of fouling. Sensors also do not reveal the cumulative impact.
Will transport through porous media or fractures bring fracking constituents into near-surface drinking water resources?

(HydroDesktop will not return any data relevant to incidents summarized on next slides)
Only two cases of alleged contamination of water resources due to hydrofrack fluid injection. Case 1: W Va

- 1987 EPA report on incident in Ripley, Jackson County, W Va, based on a 3 month study, but the incident is controversial as an example of frack fluids getting into a well
- Gel, allegedly from fracturing fluid from a shale gas well >4000 ft deep, contaminated well water only 400 feet from the land surface
- Investigation was hampered by confidentiality agreements between industry and homeowners
- API called the EPA report “inaccurate” and “careless”
- There were four abandoned natural gas wells within 1700 feet of the newly drilled gas well and the water well ... may have acted as conduits
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. We are building a customized version of hydroDesktop that will have all Marcellus wells and other wells on it as an optional layer.
Only two cases of alleged contamination of water resources due to hydrofrack fluid injection..2) Pavillion WY

- Pavillion WY, EPA investigation began in 2008..169 gas wells plus fluid storage pits
- EPA’s deep monitoring wells detected glycols and alcohols; also benzene above Safe Drinking Water Act standards and high methane
- Fracking was as shallow as 372 m (in Wind River Formation sandstone) and occurring in or near aquifers (as deep as 244 m)
- Interpretation of re-sampling by USGS has not been published yet, data may be consistent with first sampling at one of the wells...ongoing
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
• Only one well showed before/after change in water quality but we cant include data in database because of confidentiality (common problem)
  – ~40% of wells failed at least one drinking water standard; background methane found in ~24% of the wells.
Can fracking constituents enter near-surface drinking water resources through spills?
Other than the alleged 1987 case in W Va, no cases of hydrofrack constituents in northeast entering drinking water supplies directly in the subsurface.
Hydrofrack constituents do come back in flowback

Screen Shot from HydroDesktop with ShaleNetwork Data Sites with benzene reported in injection and/or flowback water (data from Hayes)
Flowback chemistry versus time from ShaleNetwork in HydroDesktop
(data from Hayes (2009))

Benzene

According to the Univ of Buffalo report, from Jan 2008 to Aug 2011, there were 9 major spills on land and 8 spills into water resources due to hydrofracturing itself.
Flowback and brine chemistry in the database or being entered

- Industry data from Hayes 2009
- Data collected for a few wells from the PA DEP by Carl Kirby and students (26R forms)
- From Haluszczak et al. 2012, Applied Geochemistry
- Working on data from Barbot et al., 2013 EST
- Working on data from PA DEP 26R forms for Southwest region
Does development of shale gas cause natural gas to enter drinking water?
Many pathways for methane to enter drinking water aquifers

- 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)

Vidic, Brantley, Vandenbossche, Yoxtheimer, Abad, in review:

Review of PADEP violations for 6466 unconventional wells through 3/23/1013:
- 202 had a casing or cementing issue (3.1%)
- 47 had an inadequate groundwater protection string of casing (0.73%)
- 18 noted to specifically have inadequate cement (0.27%)
- 16 noted specifically to have had methane migration into groundwater (0.25%)
Methane concentrations in drinking water from wells (Osborn et al., 2011, PNAS)

[Methane] plotted versus distance from drilling, not taking into account underground horizontal activity.

Methane saturation at atm pressure = 26 mg CH$_4$/L (20°C) and 42 mg/L (10°C).
Methane concentrations in ~500 ground water wells in NY, PA, and W Va

Nonactive area is > 1 km from active gas drilling; active is < 1 km from drilling

Average for 34 wells in nonactive areas  
= 1.1 mg CH\(_4\) / L

Average for 26 wells in active areas  
= 19.2 mg CH\(_4\) / L

More than 340 wells < 5 mg/L


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Data for individual analytes (such as methane, shown here) can be particularly scarce.

Methane data input to ShaleNetwork database by Paul Grieve (Penn State) March 2013 for all published data in PA, WV, NY to that point.


PA Regulations

• PA drilling companies test DW supplies within 1000 ft before drilling
• Osborn et al. suggest a better distance would be 1000 m
• Companies do not have to give data to PA DEP, although many give it for legal reasons but it is held by DEP only in paper form
• We are in process of setting up an MOU with PA DEP for them to give us some of the data
What is in the flowback and production waters and what happens to it?
Dissolved concentrations in flowback increase with time

(screen print from ShaleNetwork in HydroDesktop)

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)
Basin Stratigraphy

- Salina Gp.

Net salt thickness of the Salina Group in Pennsylvania (www.dcnr.state.pa.us/info/carbon/mastercstareport2.pdf).
Discharges of Marcellus flowback were legal in PA before 2011; spills also occurred

- 2008...high TDS in Monongahela river with high Br, Cl, sulfate...contamination from water treatment plant receiving Marcellus flowback and coal mine water
- Fish kill in Dunkard Creek, a trib of Monongahela in 2009
- A number of spills of fracture fluid, brine, and flowback water in Susquehanna county, elsewhere
- Br in Allegheny river (next slide)
In early 2011, several noticed that Br in intake for PWSA was high enough to be problematic...at that time it was legal to send flowback waters to municipal water treatment plants for river discharge.
Br in Allegheny River water at Pittsburgh Water and Sewer Authority intake

Screen shot from Shale Network data in HydroDesktop

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**Multiple TimeSeries**

- **Bromide, dissolved - parts per billion**
- **Discharge, cubic feet per second (10^3)**

**Date and Time**

- **PWSA INTAKE (Allegheny River), Bromide, dissolved, ID: 4**
- **Allegheny River at Natrona, PA, Discharge, cubic feet per second, ID: ...**
Bromide in surface water versus time for all 40 PA counties with Marcellus drilling

High concentrations since 2003 were generally in areas with permitted brine discharge or for Salt Springs. Line = 3σ above mean from 1960-2003 for USGS data (early data not shown). Detection limit = 10 – 200 ug/L. EPA is considering an MCL for Br = 6000 ug/L

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

Vidic, Brantley, Vandenbossche, Yoxtheimer, Abad, in review
New treatment regulations in place in 2011 except for a few CWTs that were grandfathered in for discharge of fluids from conventional oil/gas wells

- Discharged water must have TDS < 500 mg/L
- Cl < 250 mg/L
- Ba, Sr < 10 mg/L
Approximate location of former municipal treatment facilities that were discharging waste in April/May 2011.

8 light blue dots are POTWs and industrial treatment facilities that stopped taking waste in April/May 2011.

8 dark blue stars are centralized treatment plants for flowback from conventional wells

We are putting the locations of the treatment plants into the customized version of HydroDesktop for researchers as well so that all relevant information is available.

Approximate location of permitted recycling facilities (with no discharge)
PA Water Management Trends

- Use of alternative water sources
  - Groundwater supply wells closer to drilling
  - Municipal wastewater use
  - Acid mine drainage

- Use of above ground temporary storage

- Flowback water reuse is increasing
  - ~90% industry-wide in PA, was ~10% just a couple years ago.

- Closed loop drilling and fluids storage
- Lined well pads to minimize releases
- Additional centralized treatment facilities in various stages of permitting/construction

- UIC disposal well use in OH
  - Was ~5% a few years ago

- UIC well sites being pursued in PA
What about the long – term or cumulative effects: are we seeing levels rise above background (Sr, Ba, Br-- the three most likely “fingerprints” of Marcellus brines)?
Coal mines in PA
(data from PA DEP upload 2012)
Pennsylvania rivers retain an imprint of coal extraction...

The northeast needs to use proper care to avoid similar cumulative impact from shale gas exploitation.
Barium in surface water versus time for all 40 PA counties with Marcellus drilling

High concentrations since 2003 were generally in areas with permitted brine discharge or for Salt Springs. Line = 3σ above mean from 1960-2003 for USGS data. Detection limit = 10ug/L. EPA MCL = 2000 ug/L

High concentrations since 2003 were generally in areas with permitted brine discharge or for Salt Springs. Line $= 3\sigma$ above mean from 1960-2003 for USGS data. Detection limit $= 10 – 100 \mu g/L$. EPA one-day health advisory level $= 4000 \mu g/L$

Includes data from EPA Storet, USGS NWIS, SRBC, Appal., Hydrogeo. and Enviro Consulting, ALLARM, PA DEP.
Bromide in surface water versus time for all 40 PA counties with Marcellus drilling

High concentrations since 2003 were generally in areas with permitted brine discharge or for Salt Springs. Line = $3\sigma$ above mean from 1960-2003 for USGS data (early data not shown). Detection limit = $10 - 200 \, \mu g/L$. EPA is considering an MCL for Br = $6000 \, \mu g/L$

Includes data from EPA Storet, USGS NWIS, SRBC, Appal. Hydrogeo. and Enviro. Consulting, ALLARM, PA DEP

Vidic, Brantley, Vandenbossche, Yoxtheimer, Abad, in review
Summary

• The Marcellus play is huge, and is located near big population centers; development is generating public push-back.
• Only two documented but controversial cases where frack fluid components have entered ground water due to injection, despite a million wells fracked. Analysis for organic compounds is difficult however, and data are scarce.
• Water quality issues to be considered include problems during drilling, problems with casings (3% problem rate), problems with radioactivity and salts in fluids when spilled or disposed, problems related to mobilization of methane, problems related to older oil/gas wells and coal mines, and other 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 (especially government data, industry data, and confidential homeowner well data) – and site locations are not always appropriate or analyses for certain components are missing. Release of data related to incidents is often restricted.
• We are building a ShaleNetwork database that is described at shalenetwork.org to enable sharing and investigation of data. This would not have been possible without CUAHSI HIS.
• The database does not document many examples of environmental impact irrefutably related to unconventional shale gas development but: 1) the densities of sample or sensor sites are low compared to the well density; 2) it is often difficult to determine true background; 3) in many areas of drilling some of the waters already have contaminants.
• More sampling and chemical analysis is required that targets the outstanding research questions (PA DEP has instituted one such sampling effort using SAC046 analysis). Industry has more money to drill than researchers have money to study.
• Want to contribute to Shale Network database? Help us find data, format data, and look for issues in the dataset.

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