Environmental Issues of Shale Gas – the Pennsylvania Experience

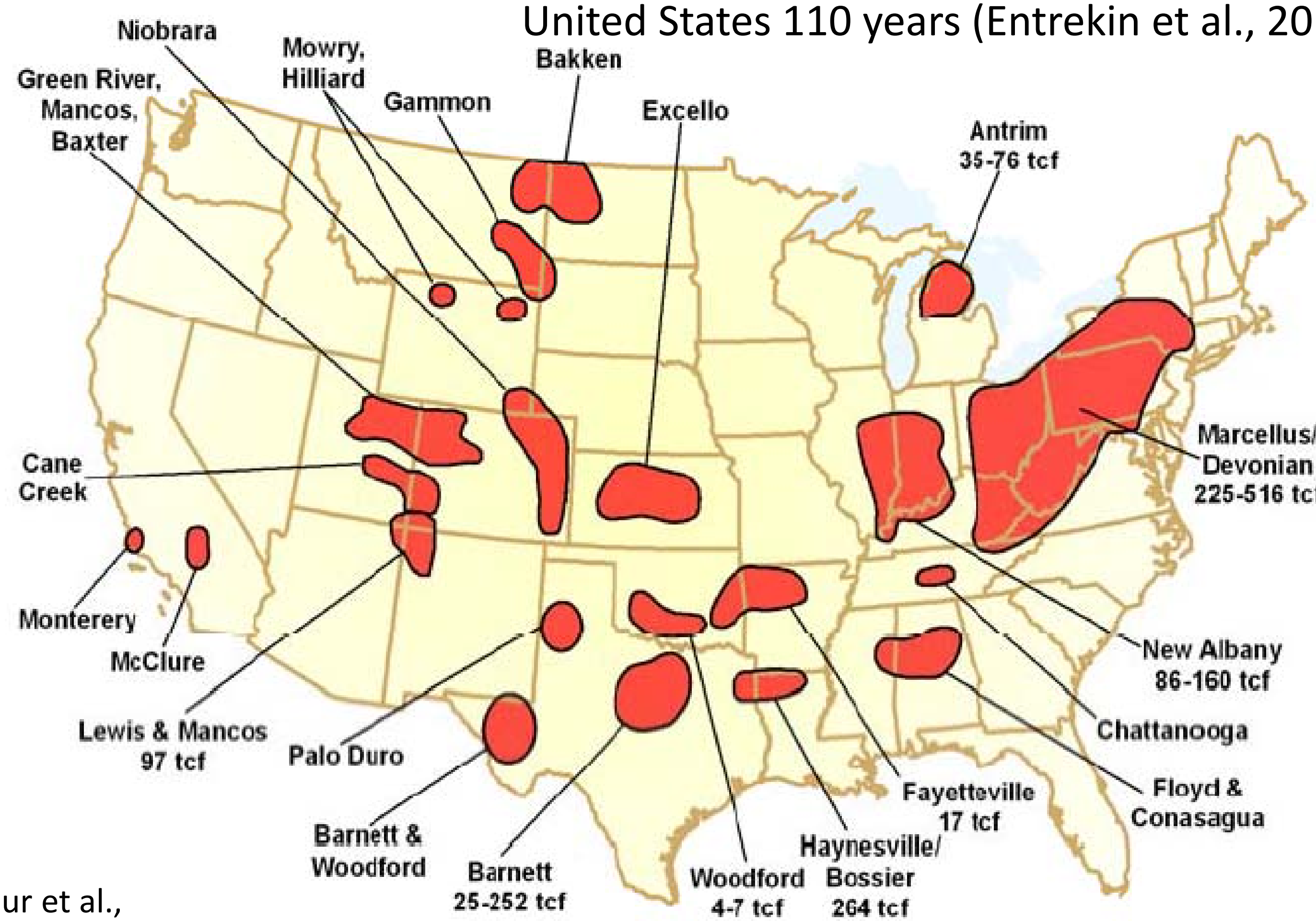
Susan L. Brantley

Pennsylvania State University

With thanks to Dave Yoxtheimer, Terry Engelder, Radisav Vidic, Art Rose, Carl Kirby, Lixin Jin, Rick Hooper, Mike Arthur, Paul Grieve, Xin Guin, Candie Wilderman, Julie Vastine, Jorge Abad, others

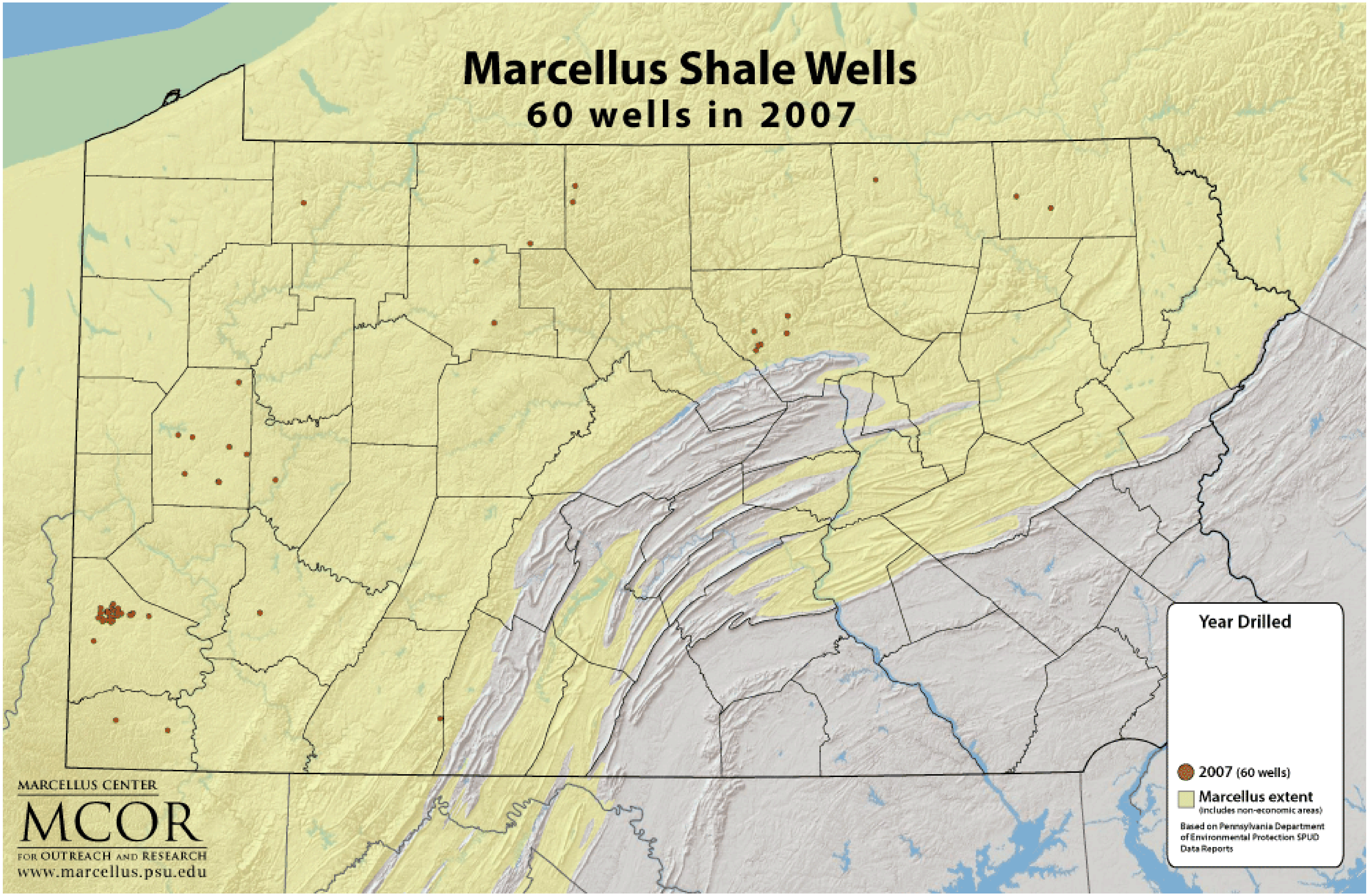
Gas shale plays in the U.S.A.

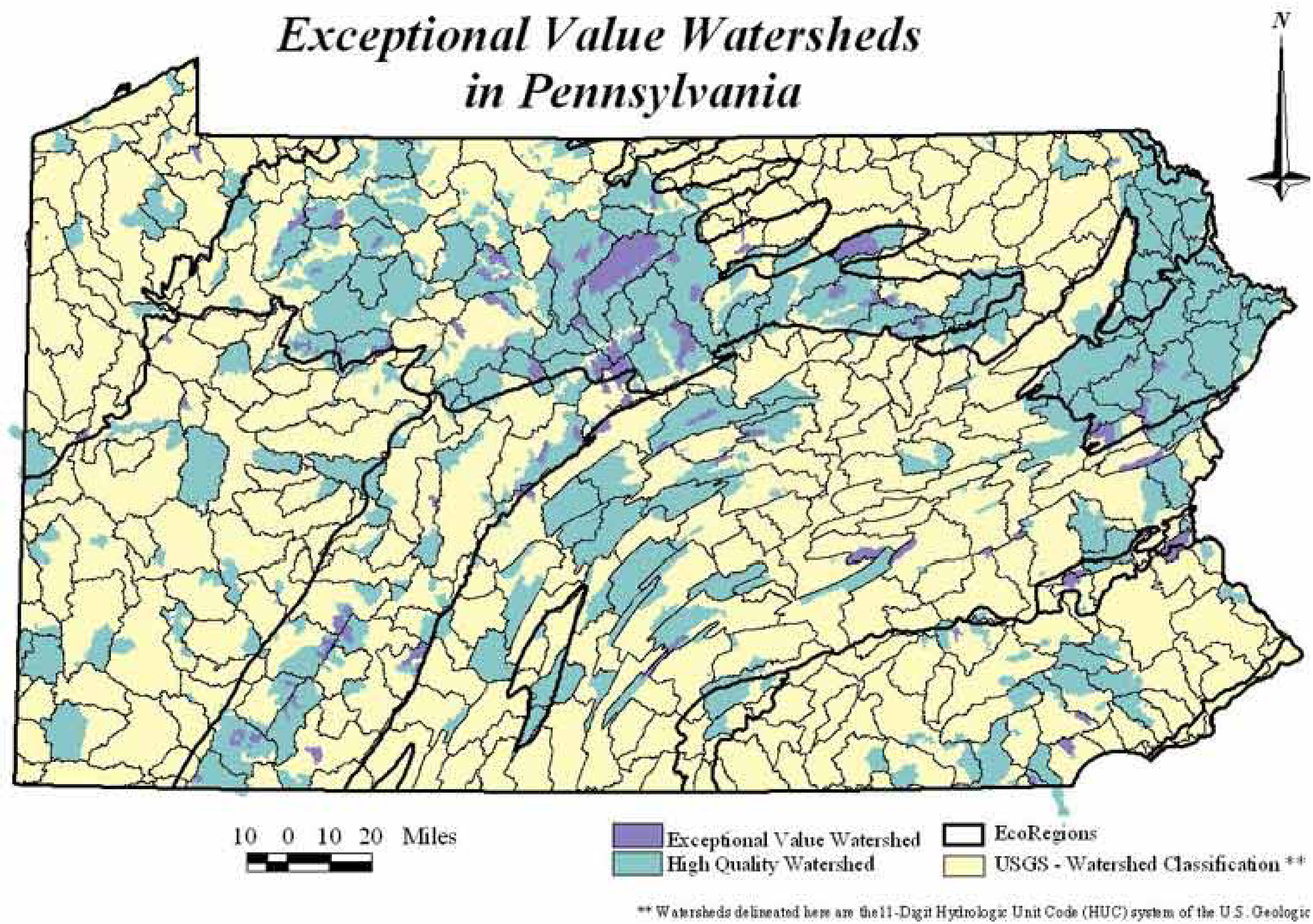
There are a total of 29 gas shales across 20 states with enough recoverable gas to last the United States 110 years (Entrekin et al., 2011).



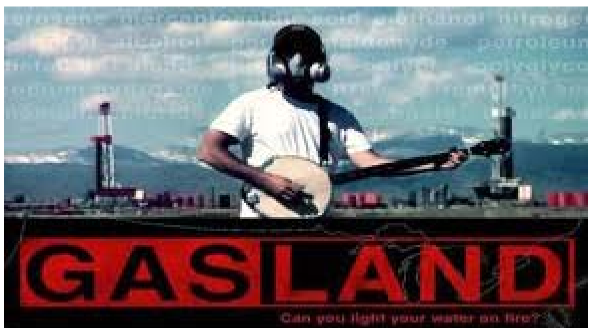
Map from Arthur et al., 2008

Locations of Shale Wells – 10,000 well pads by 2030?




Exceptional Value Watersheds
in Pennsylvania
N
10 0 10 20 Miles
Exceptional Value Watershed
High Quality Watershed
EcoRegions
USGS - Watershed Classification **
** Watersheds delineated here are the11-Digit Hydrologic Unit Code (HUC) system of the U.S. Geologic

Incidents that have happened have created public push-back



http://www.fredonia.edu/shaleinstitute/history.asp

Burning the creek…how the natural gas industry began

Photo of first Hartwell
Courtesy of the Barker-Darwin Historical Museum

McLaren photo from 1850 showing a cistern-like hole where gas was allowed to accumulate before flowing into the gasometer.

"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

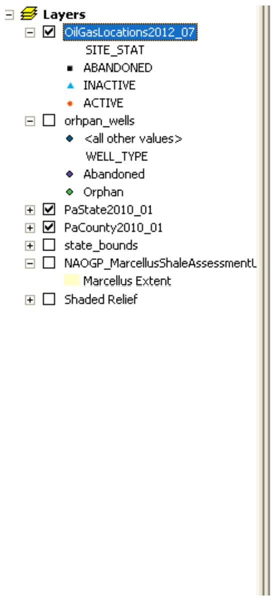
The first gas well preceded the first well drilled for the sole purpose of oil (1859): in Pennsylvania

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

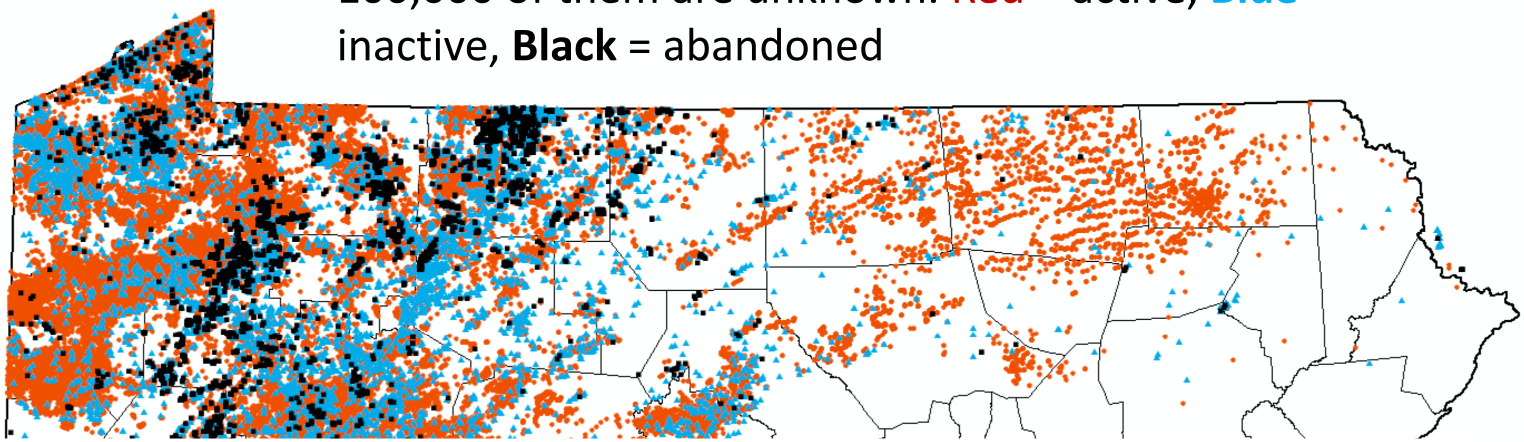
Now, Pennsylvania alone has 300,000 oil and gas wells – and the location of maybe 100,000 of them are unknown.

www.historycentral.com

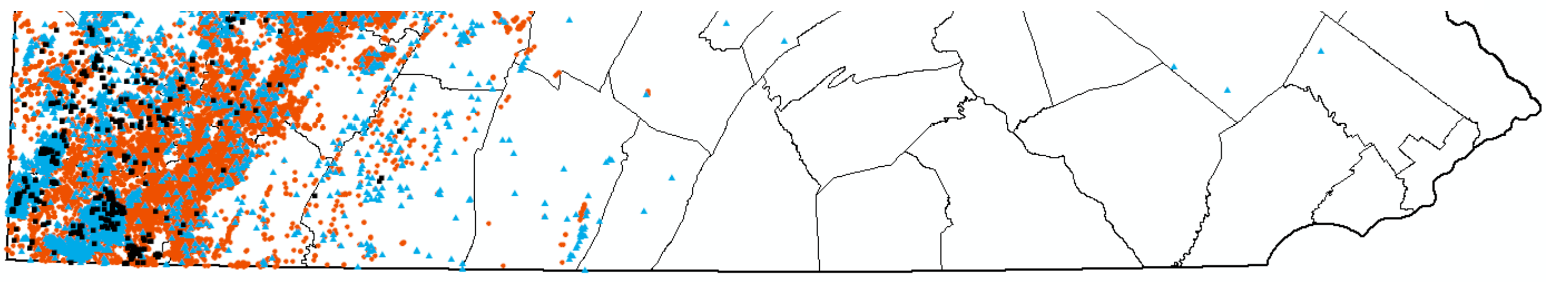
Oil and gas wells in PA (data from PA DEP upload 2012)



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



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

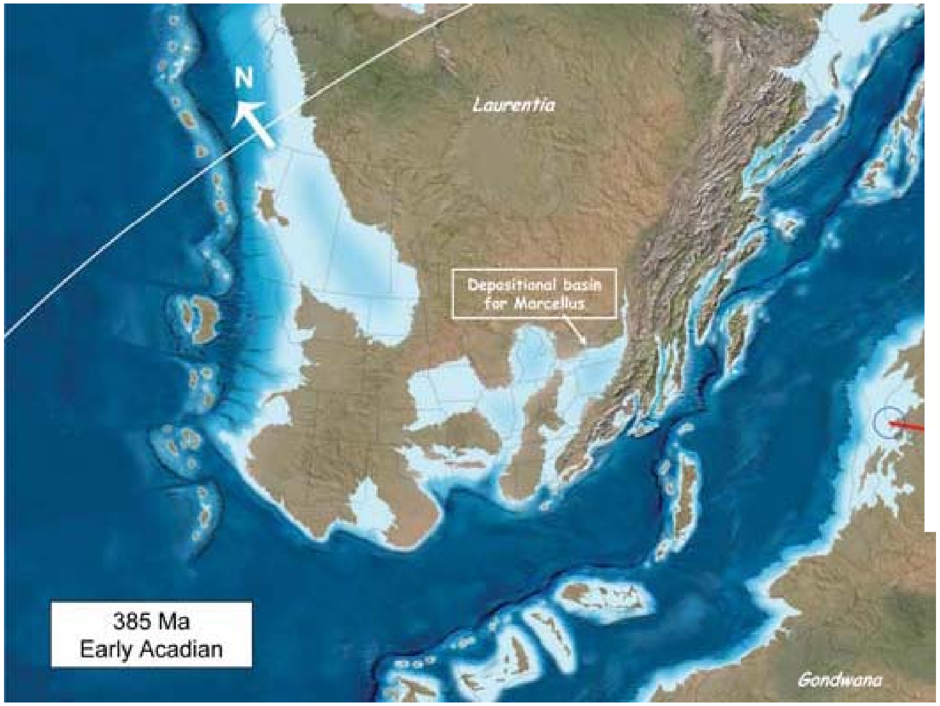
The natural gas is present as nonadsorbed and adsorbed gas

(Montgomery et al., 2005)

- Adsorbed gas: methane physically or chemically attached to surfaces of organic and mineral material
- Non-adsorbed gas: free gas in pores + dissolved gas in a liquid

MONTGOMERY, S.L., JARVIE, D.M., BOWKER, K.A., AND POLLASTRO, R.M., 2005, Mississippian Barnett Shale, Fort Worth Basin, north-central Texas: gas-shale play with multi-trillion cubic foot potential: American Association of Petroleum Geologists, Bulletin, v. 89, p. 155–175.

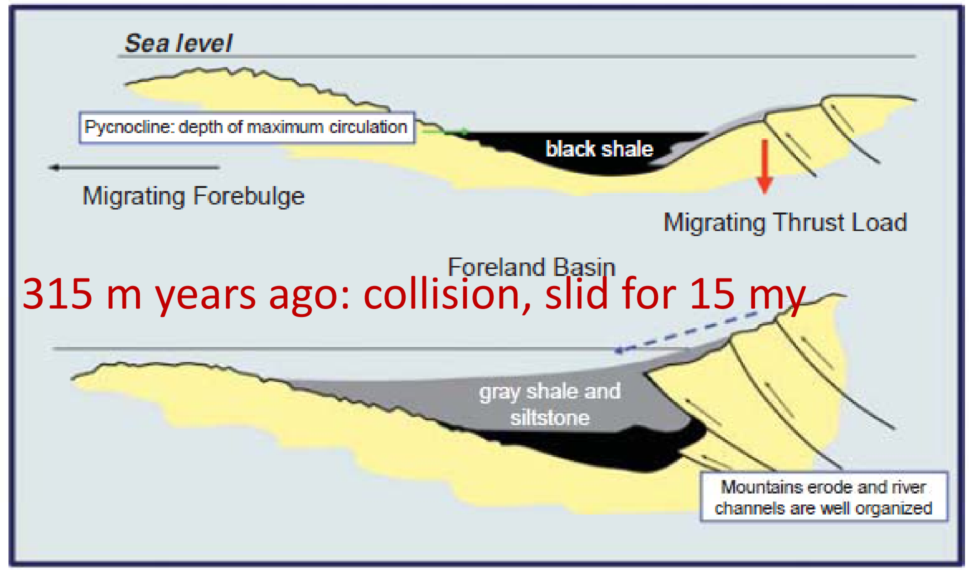
Marcellus shale deposition



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 Ettsenohn, 1994

Sinking Of Appalachian Basin Seabed



315 m years ago: collision, slid for 15 my

Source: Ettsenohn (1994)

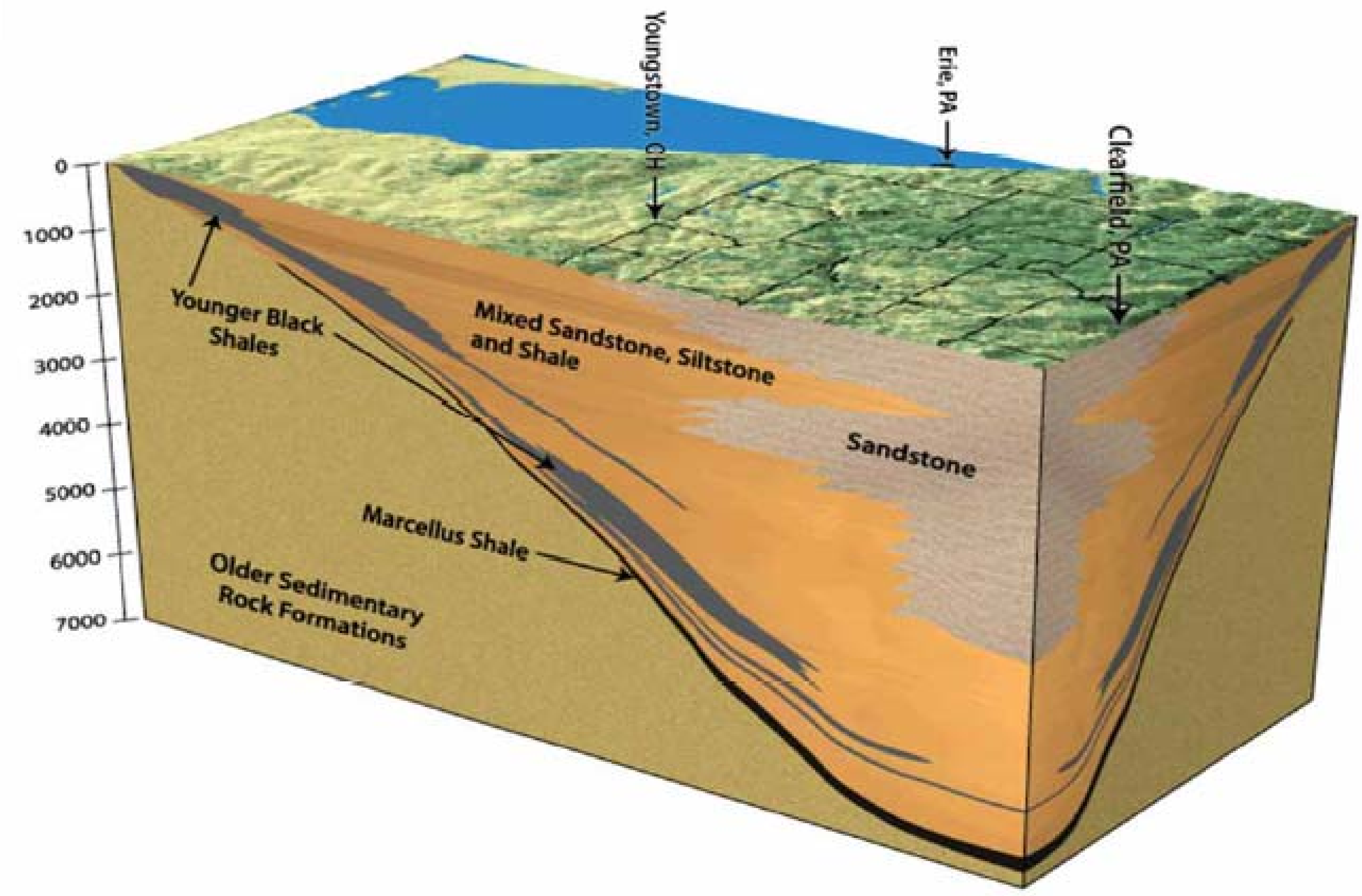
389 million years ago: clay + organic matter + quartz + Fe oxides deposited

300 million years ago: entered the oil window

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

Depth to Marcellus

Generalized Geologic Cross Section Showing Marcellus Shale in Western Pennsylvania

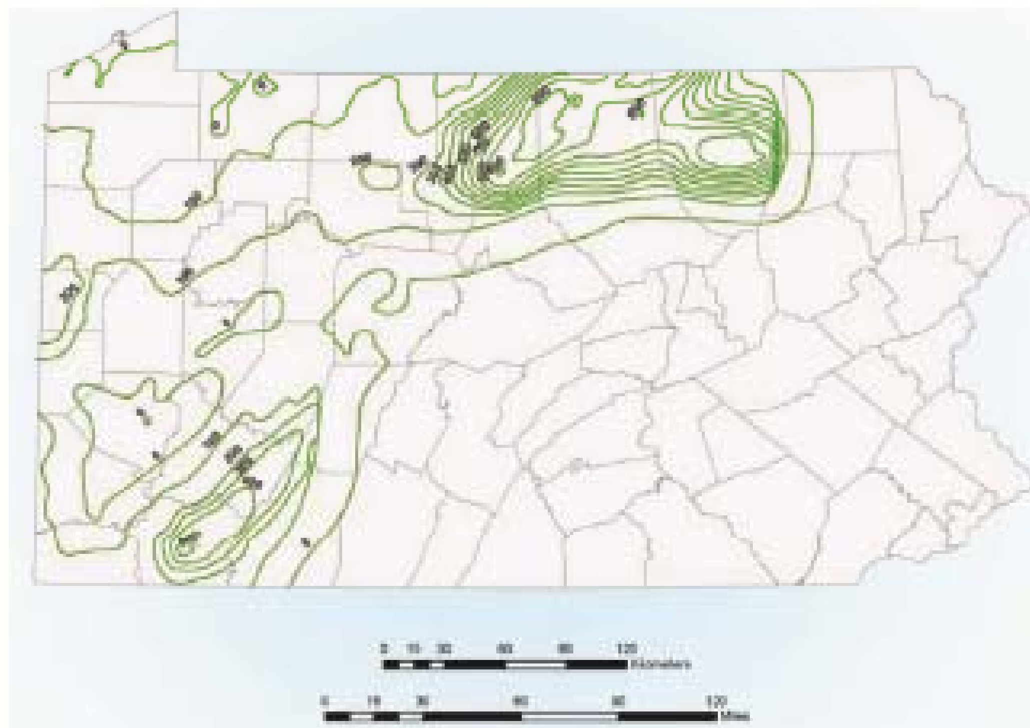


Slide from Rudy Slingerland, Penn State

Basin Stratigraphy

- Salina Gp.

Salt Thickness (ft)



Net salt thickness of the Salina Group in Pennsylvania (www.dcnr.state.pa.us/info/carbon/mastercstareport2.pdf).

Marcellus porosity ~5%; 60% gas-saturated; 36% water-saturated

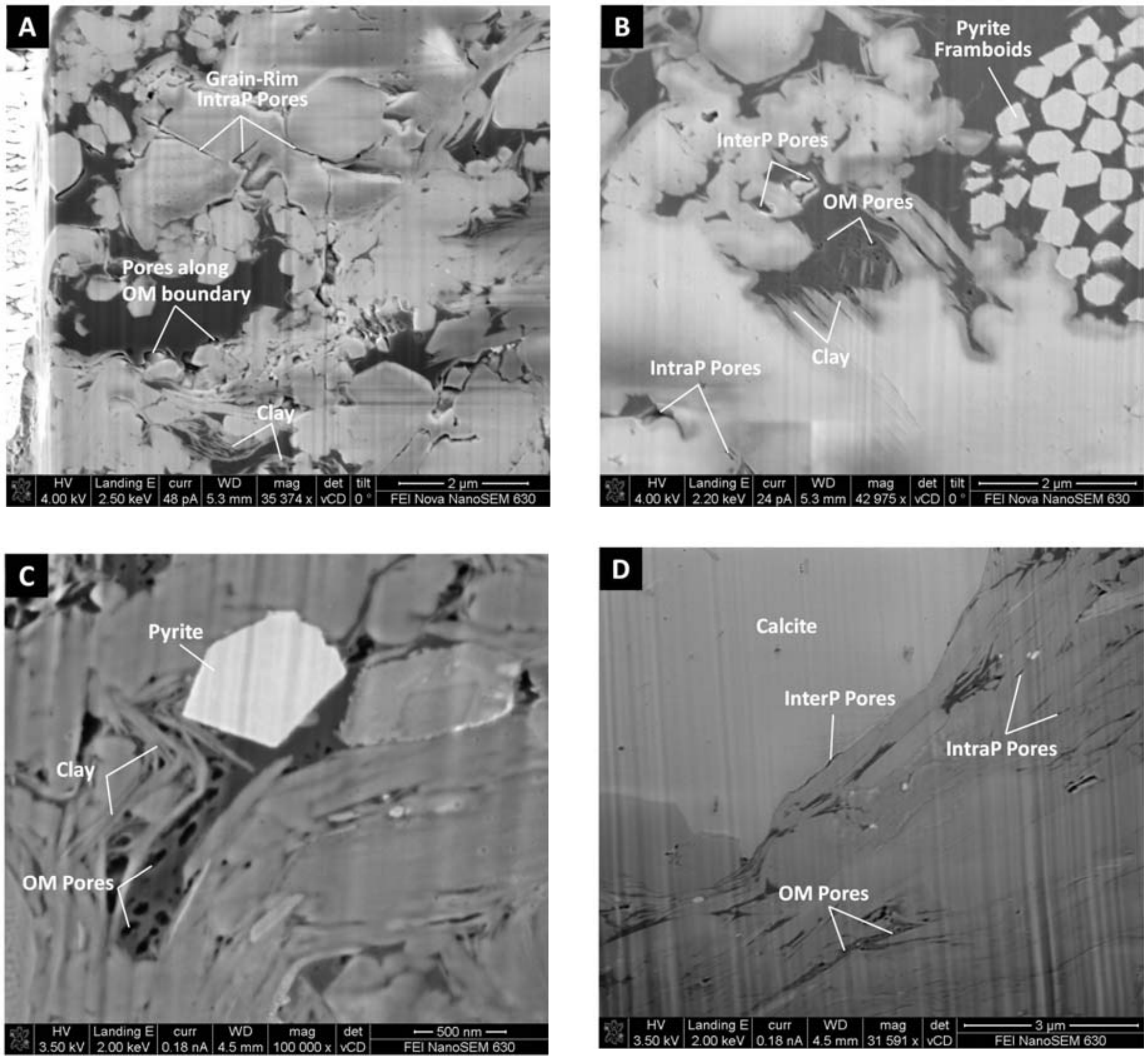
Oil-wet porosity (hydrophobic)

- Pores in the organic matter
- Formed during maturation of the organic matter (thus does not show extensive compaction)

Water-wet porosity (hydrophilic)

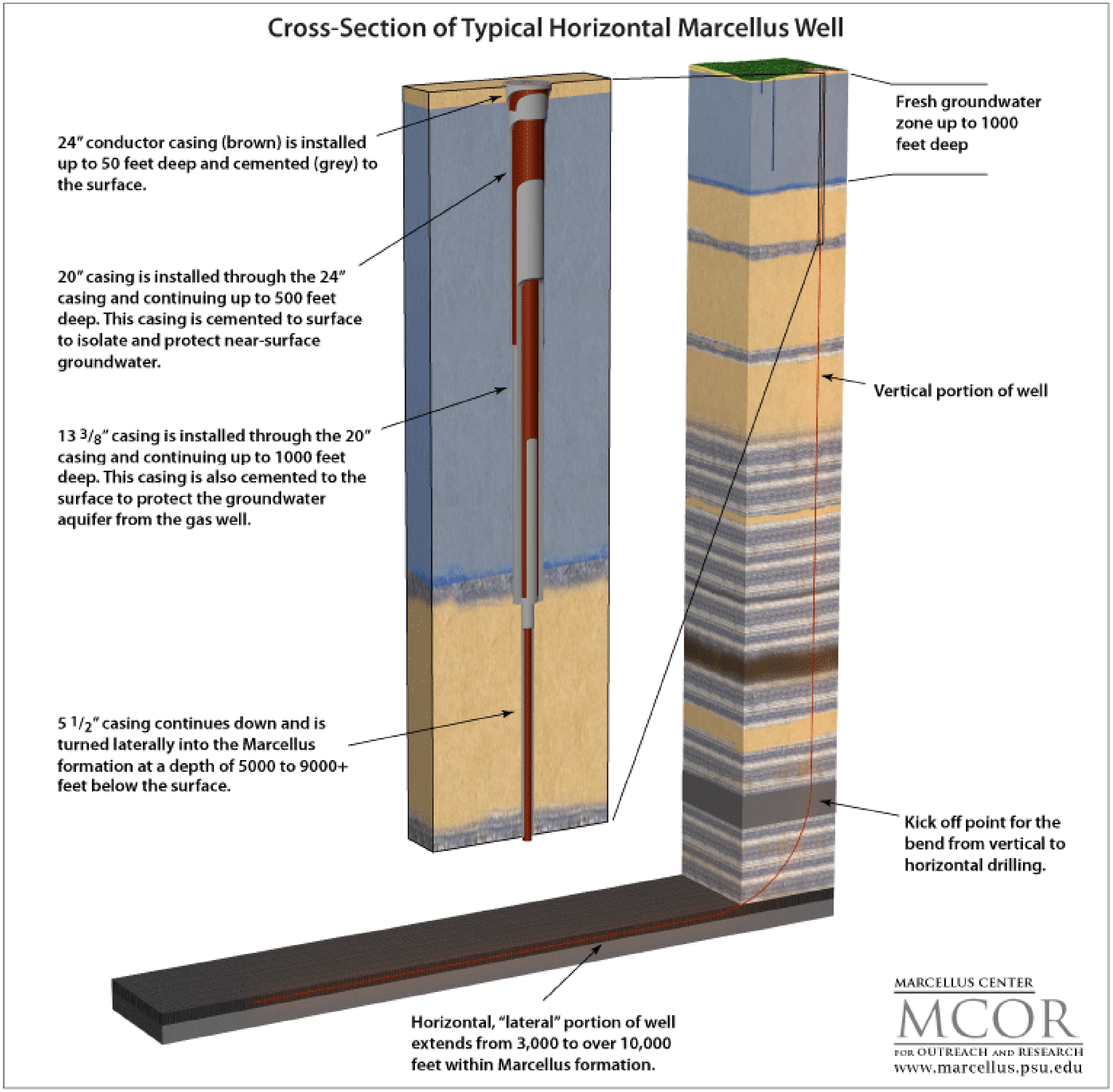
- Pores in the matrix silicate material
- Formed during deposition but shows the effect of compaction

FIB SEM image of Marcellus shale (X. Gu, Penn State)



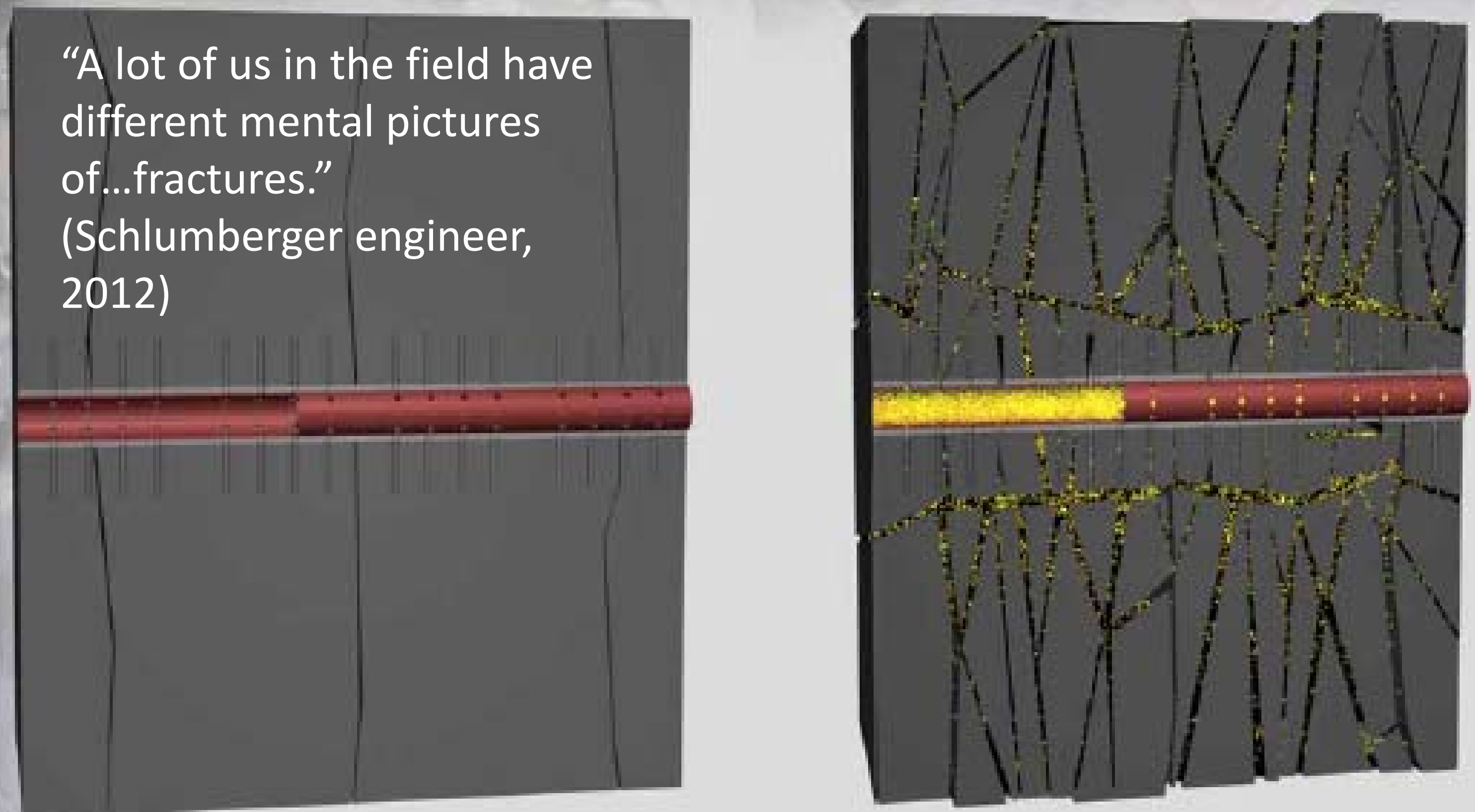
Unconventional gas wells use horizontal drilling + hydraulic fracturing

Average total water use per well in PA equals 4 million gallons ..and only about 10-20% usually returns to the surface



Pre and Post Hydraulic Fracturing

"A lot of us in the field have different mental pictures of…fractures."
(Schlumberger engineer, 2012)



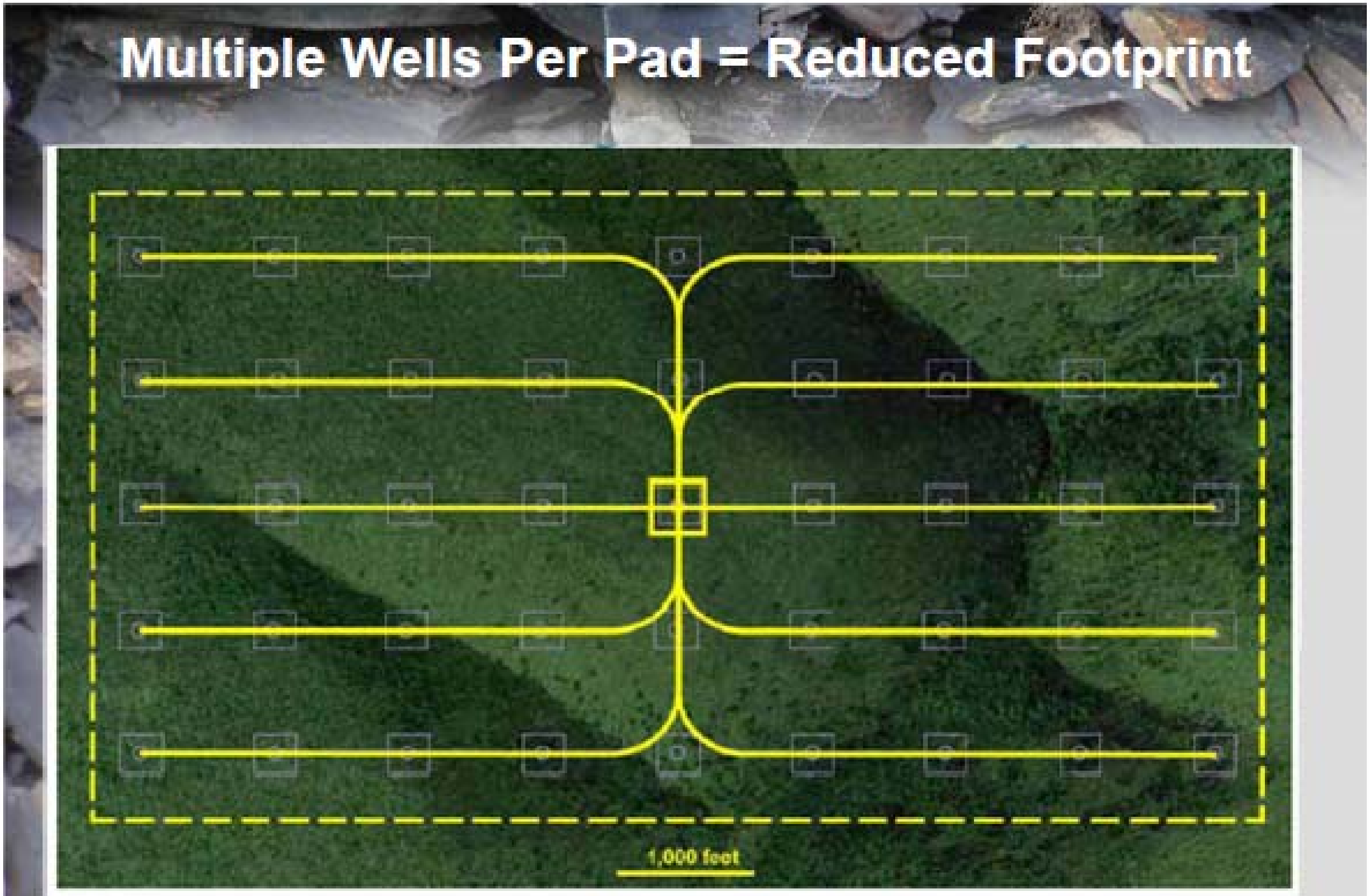
Every 300-500 feet of casing is perforated to inject fluids into the shale for hydraulic Fracturing.

Approximately 300,000 to 500,000 gallons of fluids are injected into each stage.

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%.

Well Site in Operation

Marcellus Center for Outreach and Research



Now the 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)

Hydraulic Fracturing Fluid Product Component Information Disclosure

Fracture Date	8/25/2011
State:	Pennsylvania
County:	Centre
API Number:	37-027-61661
Operator Name:	Williams
Well Name and Number:	Resource Recovery 3-2H
Longitude:	-78.056658
Latitude:	41.020439
Long/Lat Projection:	NAD83
Production Type:	Gas
True Vertical Depth (TVD):	8,517
Total Water Volume (gal)*:	5,663,806

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

FracFocus Chemical Disclosure Registry

Hydraulic Fracturing Fluid Composition:

Trade Name	Supplier	Purpose	Ingredients	Chemical Abstract Service Number (CAS #)	Maximum Ingredient Concentration in Additive (% by mass)**	Maximum Ingredient Concentration in HF Fluid (% by mass)**	Comments
Water	ARM - Moshannon Creek SR53	Carrier/Base Fluid	Water		100.00%	86.8502%	
Sand- Silica Sand	Halliburton	Proppant	Crystalline Silica Quartz	14808-60-7	100.00%	12.9850%	
LP-65	Halliburton	Scale Inhibitor	Ammonium Chloride	12125-02-9	10.00%	0.0034%	
WG-36 Gelling Agent	Halliburton	Gel					
			Guar Gum	9000-30-0	100.00%	0.0024%	
BE-9M	Halliburton	Biocide					
			Tributyl Tetradecyl Phosphonium Chloride	81741-28-8	10.00%	0.0026%	
			Methanol	67-56-1	30.00%	0.0079%	
FR-66	Halliburton	Friction Reducer	Hydrotreated Petroleum Distillate	64742-47-8	30.00%	0.0187%	
SP Breaker	Halliburton	Breaker	Sodium Persulfate	7775-27-1	100.00%	0.0014%	
HCl	Halliburton	Acid	Hydrochloric Acid	7647-01-0	30.00%	0.1111%	
GBW-30 Breaker	Halliburton	Breaker					
			Carbohydrates	Trade Ingredient	95.00%	0.0013%	
			Hemicellulase Enzyme	9012-54-8	15.00%	0.0002%	
BA-40L	Halliburton	Buffer	Potassium Carbonate	584-08-7	60.00%	0.0158%	

* Total Water Volume sources may include fresh water, produced water, and/or recycled water

** Information is based on the maximum potential for concentration and thus the total may be over 100%

All component information listed was obtained from the supplier's Material Safety Data Sheets (MSDS). As such, the Operator is not responsible for inaccurate and/or incomplete information. Any questions regarding the content of the MSDS should be directed to the supplier who provided it. The Occupational Safety and Health Administration's (OSHA) regulations govern the criteria for the disclosure of this information. Please note that Federal Law protects "proprietary", "trade secret", and "confidential business information" and the criteria for how this information is reported

UNITED STATES HOUSE OF REPRESENTATIVES
COMMITTEE ON ENERGY AND COMMERCE
MINORITY STAFF
APRIL 2011

CHEMICALS USED IN HYDRAULIC FRACTURING

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.

The 29

Table 3. Chemicals Components of Concern: Carcinogens, SDWA-Regulated Chemicals, and Hazardous Air Pollutants		
Chemical Component	**Chemical Category**	**No. of Products**
Methanol (Methyl alcohol)	HAP	342
Ethylene glycol (1,2-ethanediol)	HAP	119
Diesel[19]	Carcinogen, SDWA, HAP	51
Naphthalene	Carcinogen, HAP	44
Xylene	SDWA, HAP	44
Hydrogen chloride (Hydrochloric acid)	HAP	42
Toluene	SDWA, HAP	29
Ethylbenzene	SDWA, HAP	28
Diethanolamine (2,2-iminodiethanol)	HAP	14
Formaldehyde	Carcinogen, HAP	12
Sulfuric acid	Carcinogen	9
Thiourea	Carcinogen	9
Benzyl chloride	Carcinogen, HAP	8
Cumene	HAP	6
Nitrilotriacetic acid	Carcinogen	6
Dimethyl formamide	HAP	5
Phenol	HAP	5
Benzene	Carcinogen, SDWA, HAP	3
Di (2-ethylhexyl) phthalate	Carcinogen, SDWA, HAP	3
Acrylamide	Carcinogen, SDWA, HAP	2
Hydrogen fluoride (Hydrofluoric acid)	HAP	2
Phthalic anhydride	HAP	2
Acetaldehyde	Carcinogen, HAP	1
Acetophenone	HAP	1
Copper	SDWA	1
Ethylene oxide	Carcinogen, HAP	1
Lead	Carcinogen, SDWA, HAP	1
Propylene oxide	Carcinogen, HAP	1
p-Xylene	HAP	1
Number of Products Containing a Component of Concern		**652**

Vidic, Brantley, Science 2013

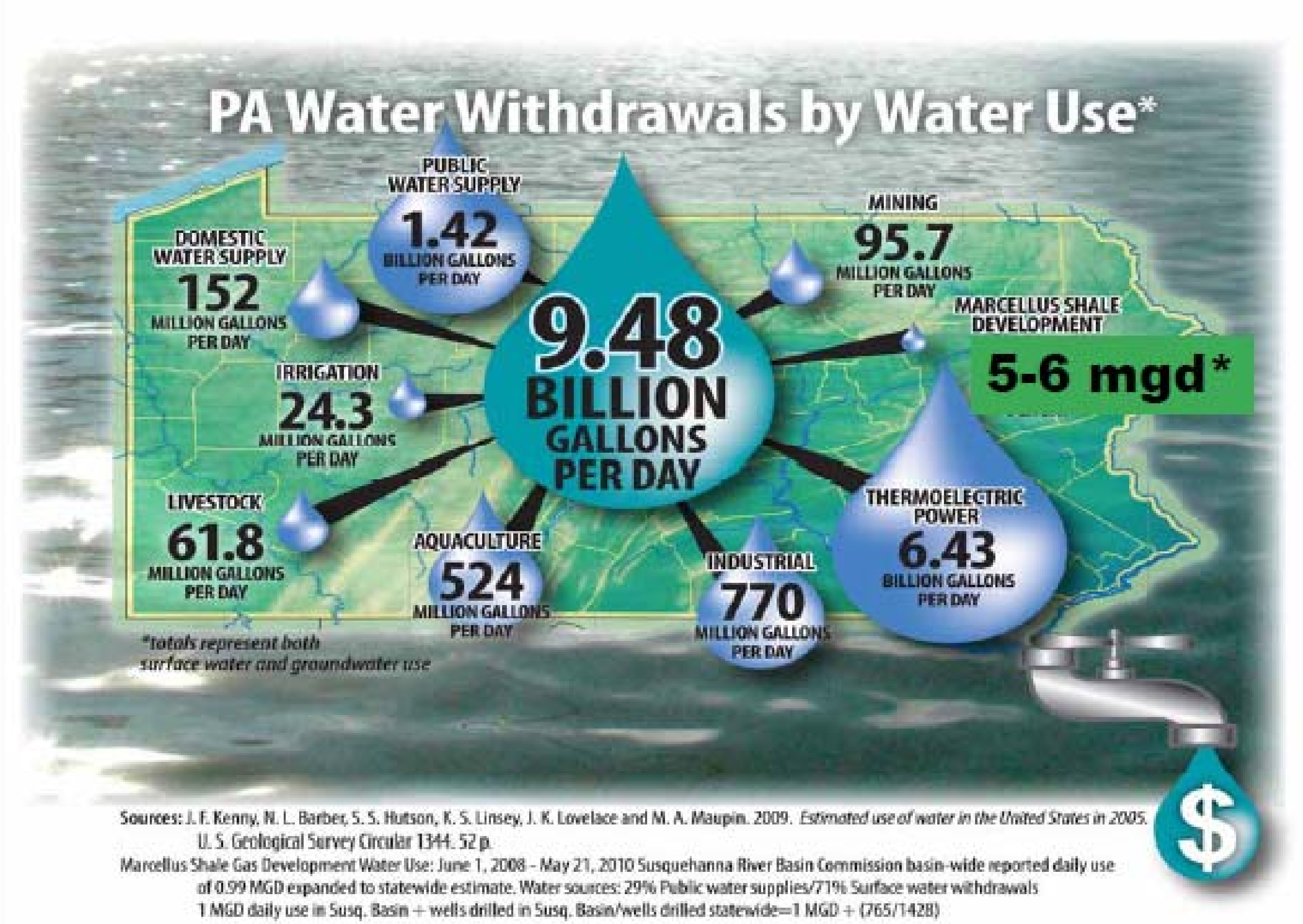
Table 1. Common chemical additives for hydraulic fracturing.

Additive type	Example compounds	Purpose
Acid	Hydrochloric acid	Clean out the wellbore, dissolve minerals, and initiate cracks in rock
Friction reducer	Polyacrylamide, petroleum distillate	Minimize friction between the fluid and the pipe
Corrosion inhibitor	Isopropanol, acetaldehyde	Prevent corrosion of pipe by diluted acid
Iron control	Citric acid, thioglycolic acid	Prevent precipitation of metal oxides
Biocide	Glutaraldehyde, 2,2-dibromo-3-nitrilopropionamide (DBNPA)	Bacterial control
Gelling agent	Guar/xantham gum or hydroxyethyl cellulose	Thicken water to suspend the sand
Crosslinker	Borate salts	Maximize fluid viscosity at high temperatures
Breaker	Ammonium persulfate, magnesium peroxide	Promote breakdown of gel polymers
Oxygen scavenger	Ammonium bisulfite	Remove oxygen from fluid to reduce pipe corrosion
pH adjustment	Potassium or sodium hydroxide or carbonate	Maintain effectiveness of other compounds (such as crosslinker)
Proppant	Silica quartz sand	Keep fractures open
Scale inhibitor	Ethylene glycol	Reduce deposition on pipes
Surfactant	Ethanol, isopropyl alcohol, 2-butoxyethanol	Decrease surface tension to allow water recovery

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?

EPA/600/R-11/122
November 2011



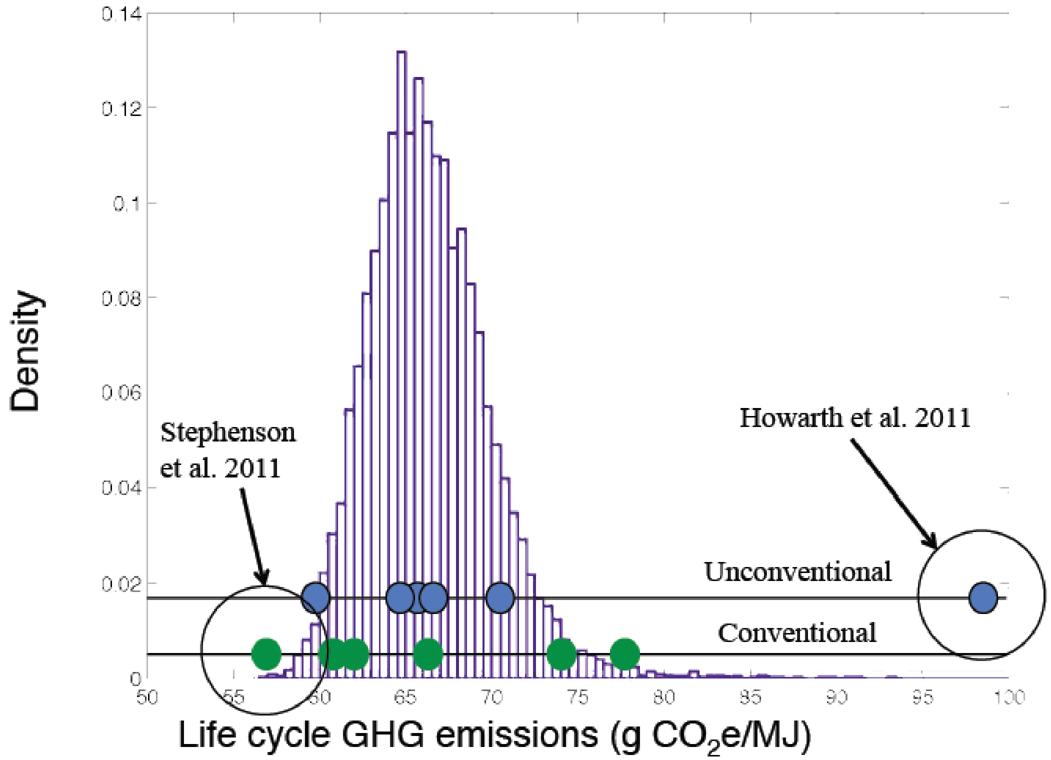
Source: Pa Fish and Boat Commission *Estimated based on recent SRBC/DEP data

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



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.

www.shalenetwork.org

- 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 allows access to database (download from www.cuahsi.org))

Potential Contaminants

- Drilling muds, cuttings
- Frack fluids

Drilling and hydraulic fracturing lasts only about 2 months, then the equipment and activity is gone

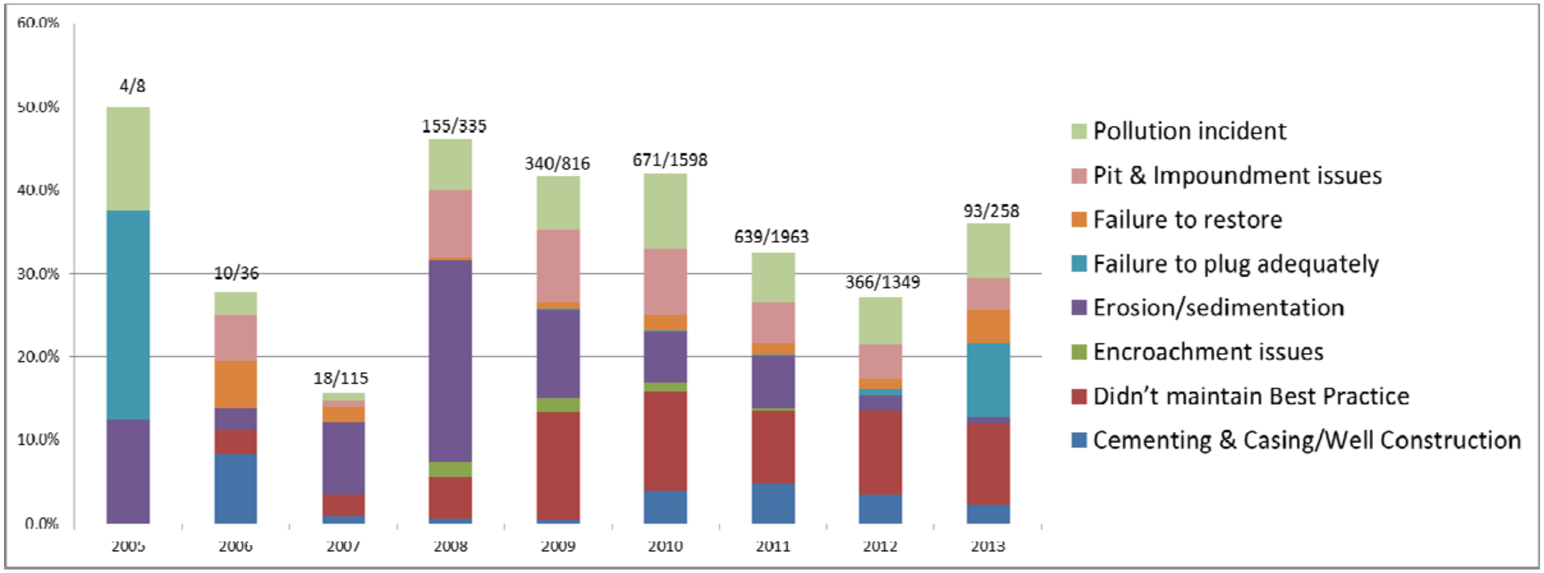
- Emissions from diesel motors/electric generators into air, some impact on water
- Natural sediments
- Methane
- Natural contaminants from flowback and production fluids

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

Percent of wells drilled each year since 2005 that received at least one Notice of Violation (NOV) in PA has stayed roughly constant

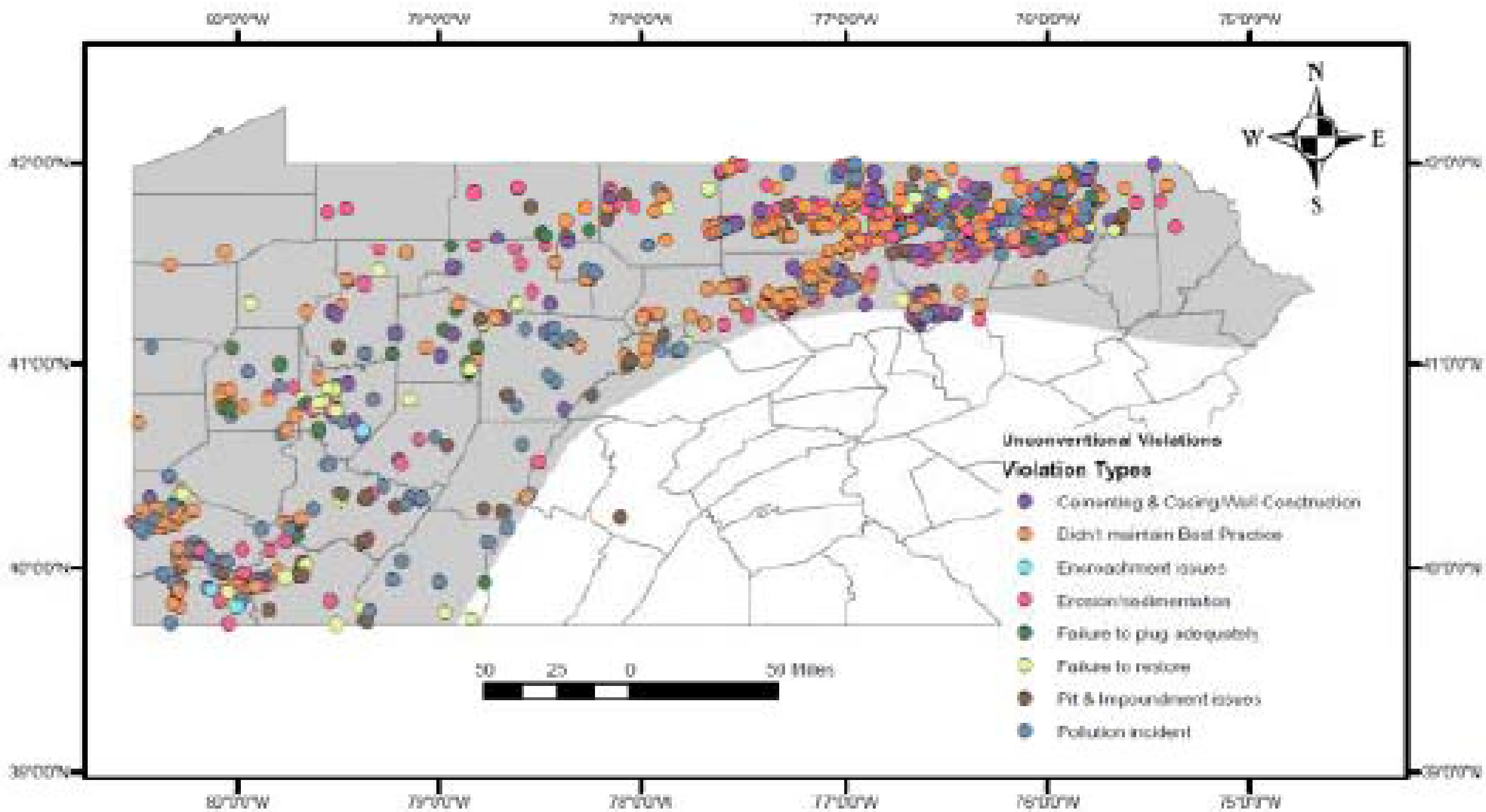
http://www.portal.state.pa.us/portal/server.pt/community/oil_and_gas_compliance_report/20299



Brantley et al., 2013, subm.
Int. J. Coal Geology

Figure 3. Percent of unconventional shale-gas wells in PA drilled each year that received at least one NOV. Colors indicate each category of violation shown in Table 1from onset of inspections for unconventional drilling (5/2005) until 3/2013, after permitting and reporting violations were removed. The percent (shown as a fraction above each bar) was calculated from the number of violations per category after duplicates were removed divided by the number of wells drilled during the calendar year. Notices of violations reported by PA DEP were categorized into 9 categories as shown in Table 1 (see also, Appendix). The average percent of wells with at least one NOV per year is 35.4 ± 10.8 % and the fraction of wells with NOVs has neither increased nor decreased with time. Since 2008 the relative importance of erosion/sedimentation issues has decreased. In contrast, the relative fraction of issues related to well construction, pollution events, or pits and impoundments have remained relatively constant. (Brantley et al. subm.)

Map showing locations of all wells with violations recorded by PA DEP (permitting or recording violations are not shown). Each well is shown only once even if it has multiple violations



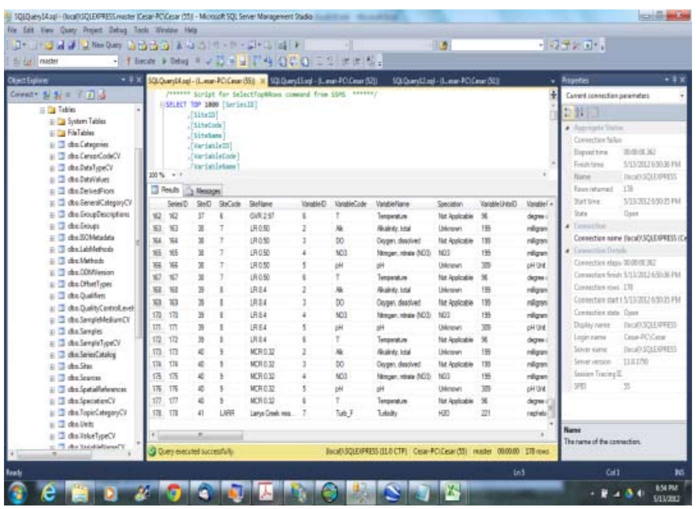
Brantley et al., 2013, subm.
Int. J. Coal Geology

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

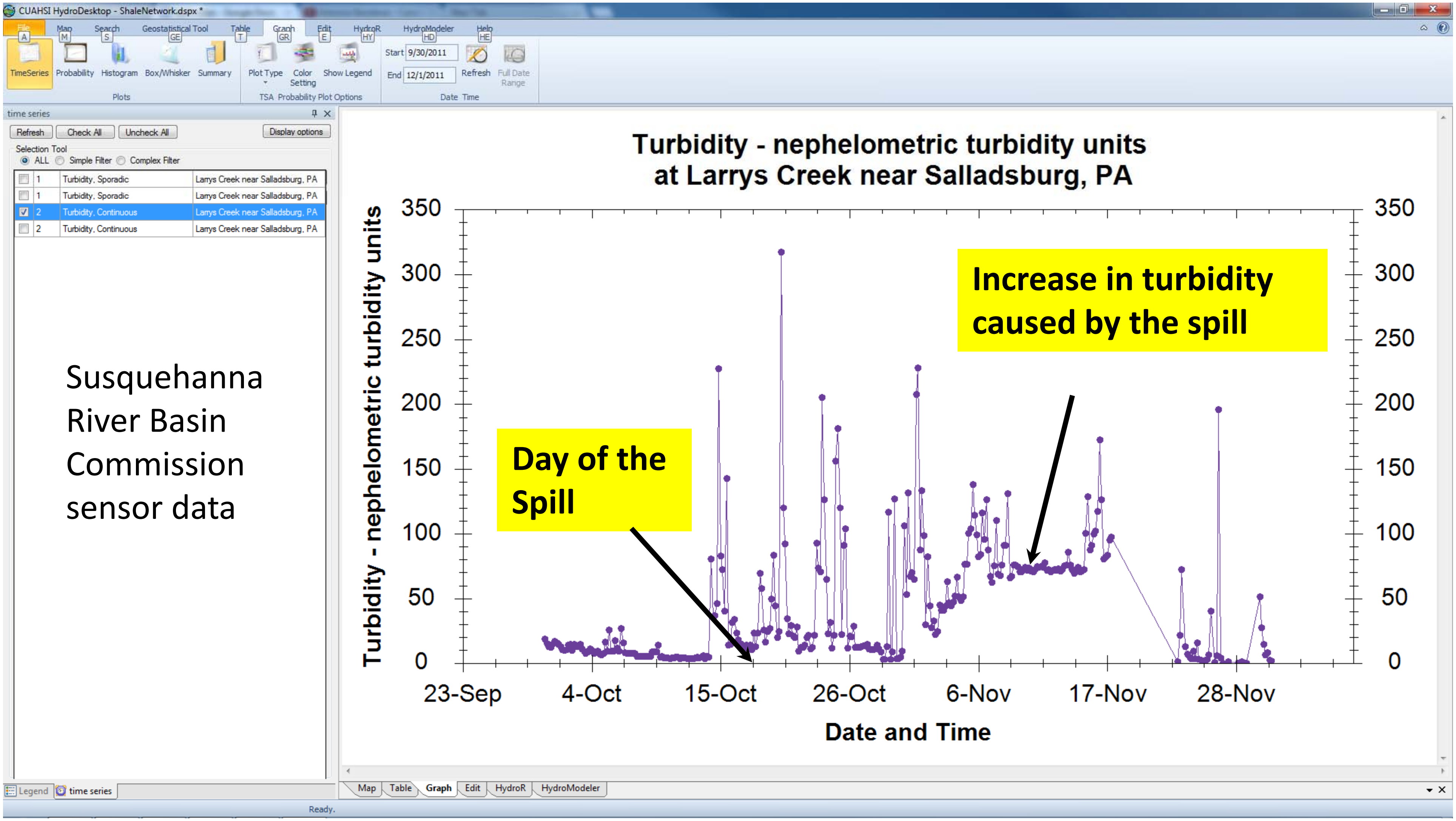
- The week of 10/19/2011, Larry's Creek, near a drilling site, was running rich with clay but the settling process was working very well. Then a mud release occurred.
- SRBC saw an increase in conductivity/turbidity in the creek



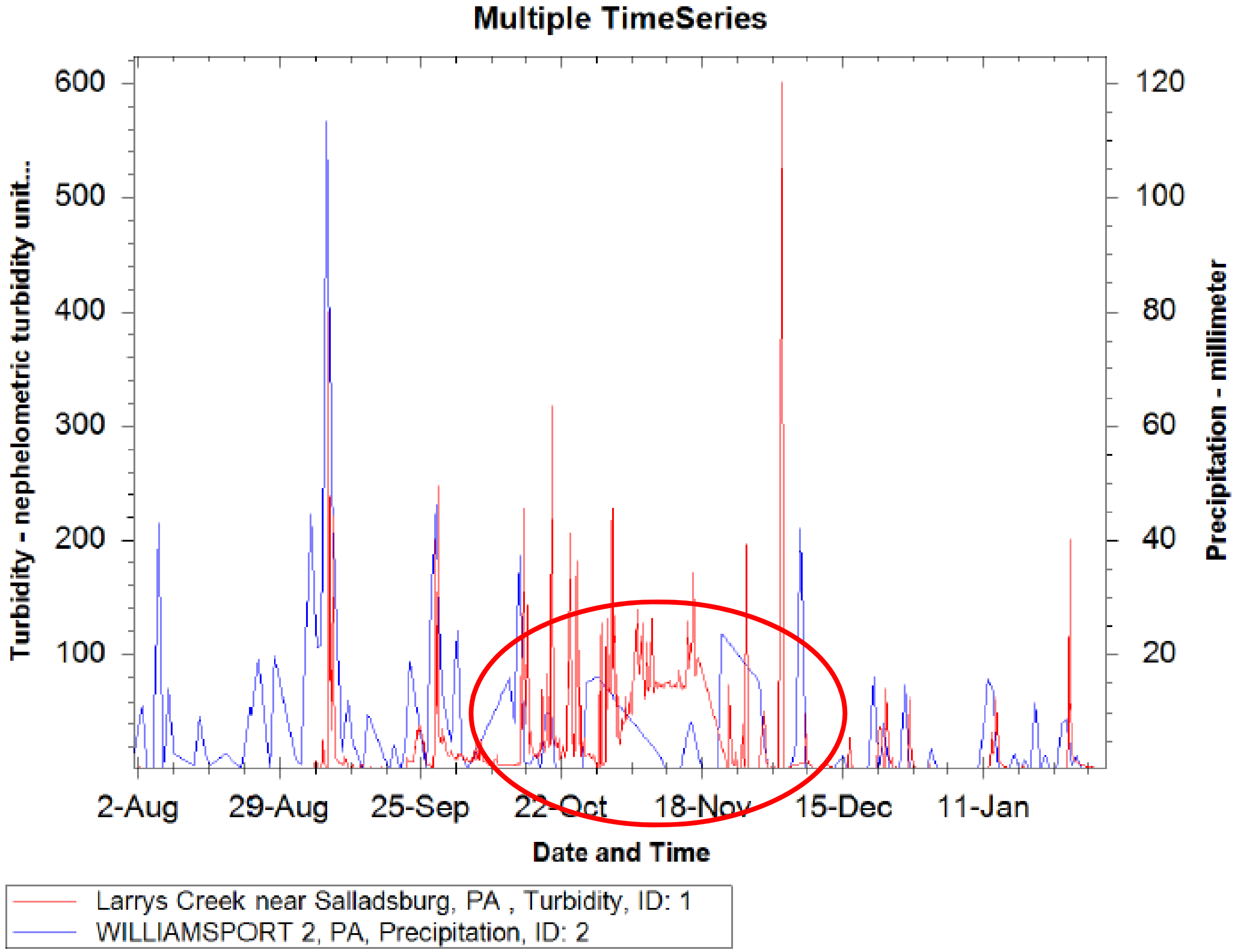
Larry's Creek is near *Salladsburg*, *PA,* located in Mifflin Twp., Lycoming Co., PA. Off route 287, north of Jersey Shore, above the junction of Routes 220 and 287

Detail of the days after the incident on 10/19/2011

(Shale Network database, HydroDesktop graph)



Comparison of turbidity to precipitation in Larrys Creek

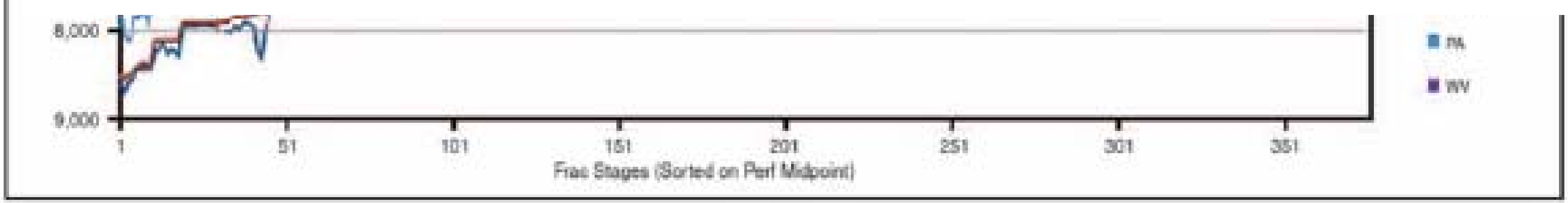


Will advective transport of contaminants through porous media or fractures bring fracking constituents or subsurface brines into near-surface drinking water resources?

Hydraulic Fracture Vertical Growth

Marcellus Shale Mapped Fracture Treatments (TVD)

- "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



Graphic from Fisher, 2010, Data Confirm Safety Of Well Fracturing, American Oil and Gas Reporter.

groundwater

Potential Contaminant Pathways from Hydraulically Fractured Shale to Aquifers

by Tom Myers

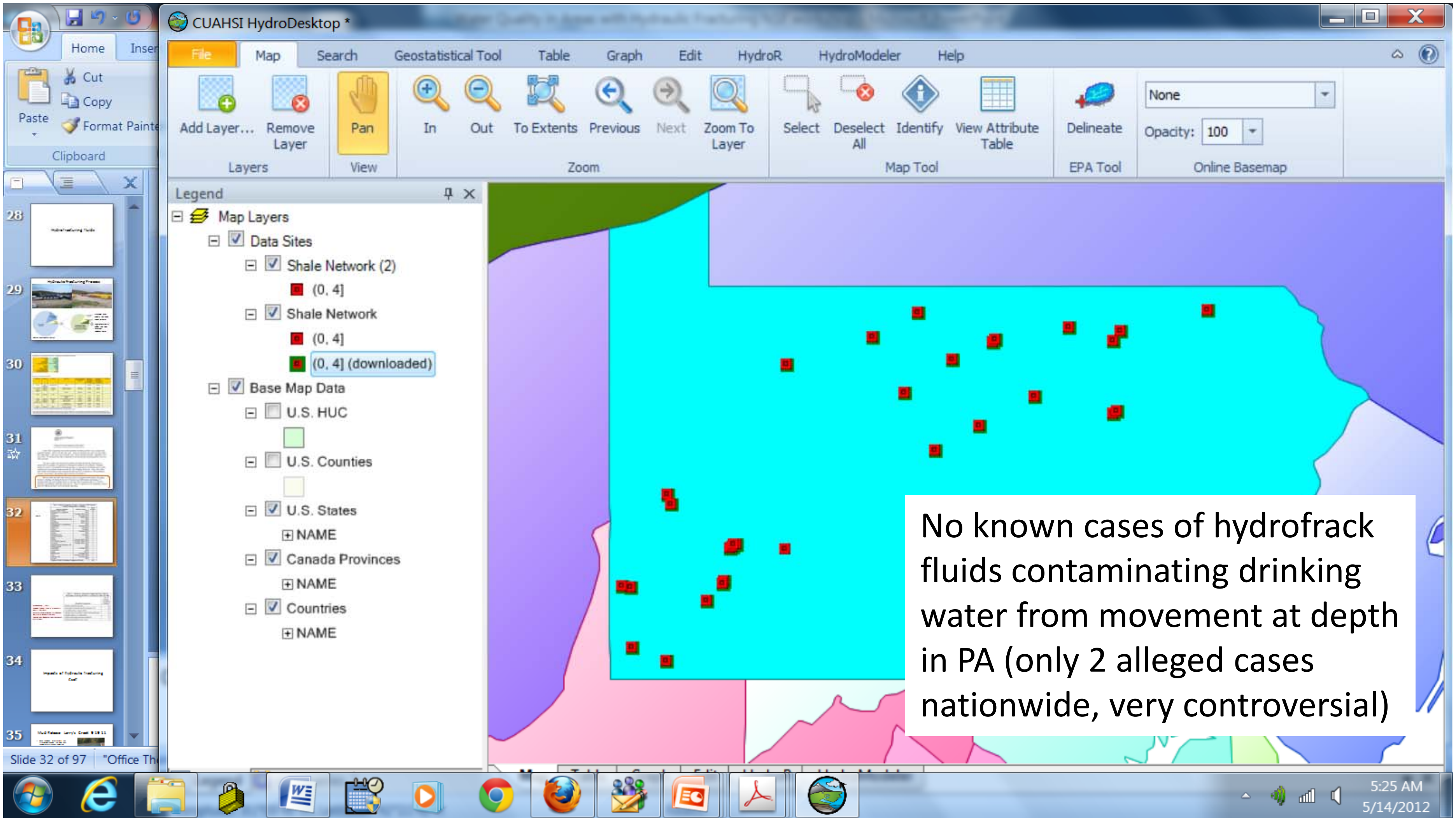
Myers 2012 concludes that transport to the surface could require 10 to 10s of thousands of years. He simulated pressure of fluids after injection into a well.

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.

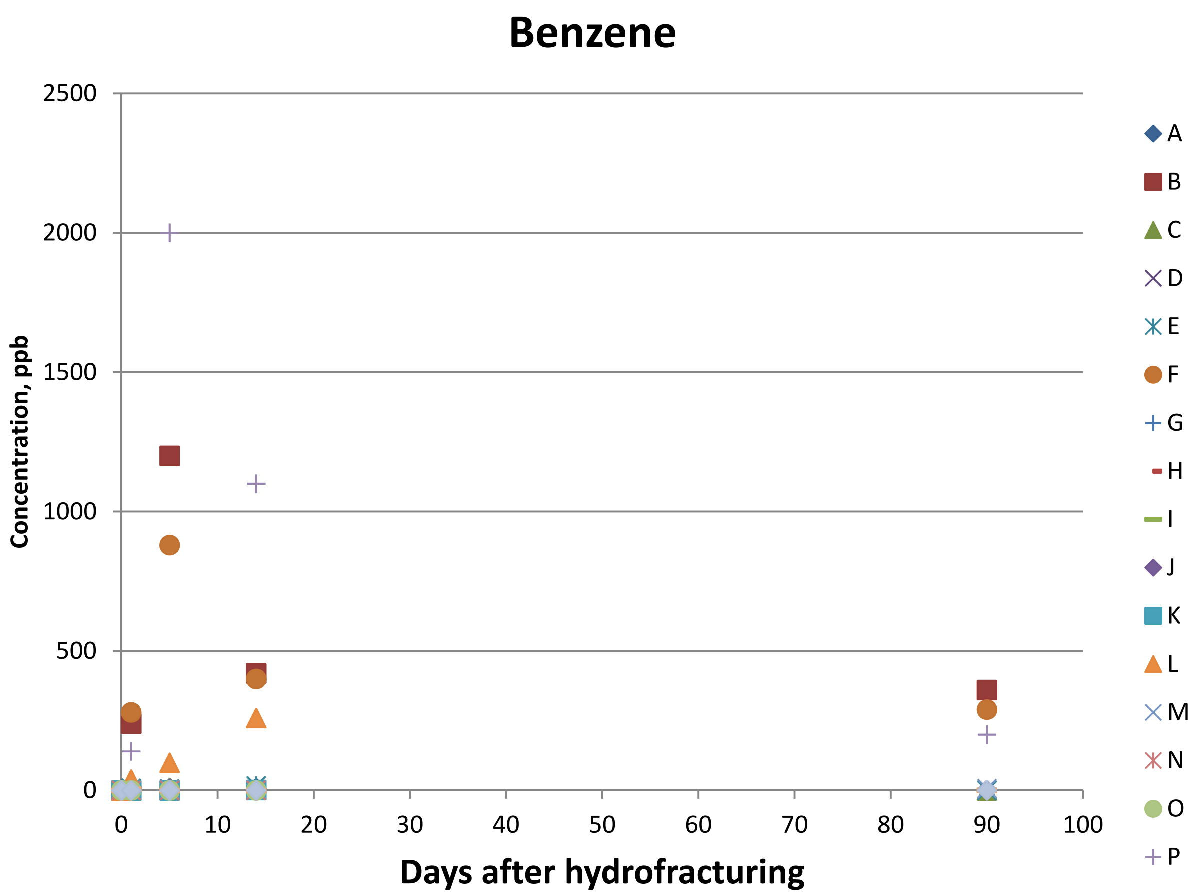
Hydrofrack constituents do come back up in flowback

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))



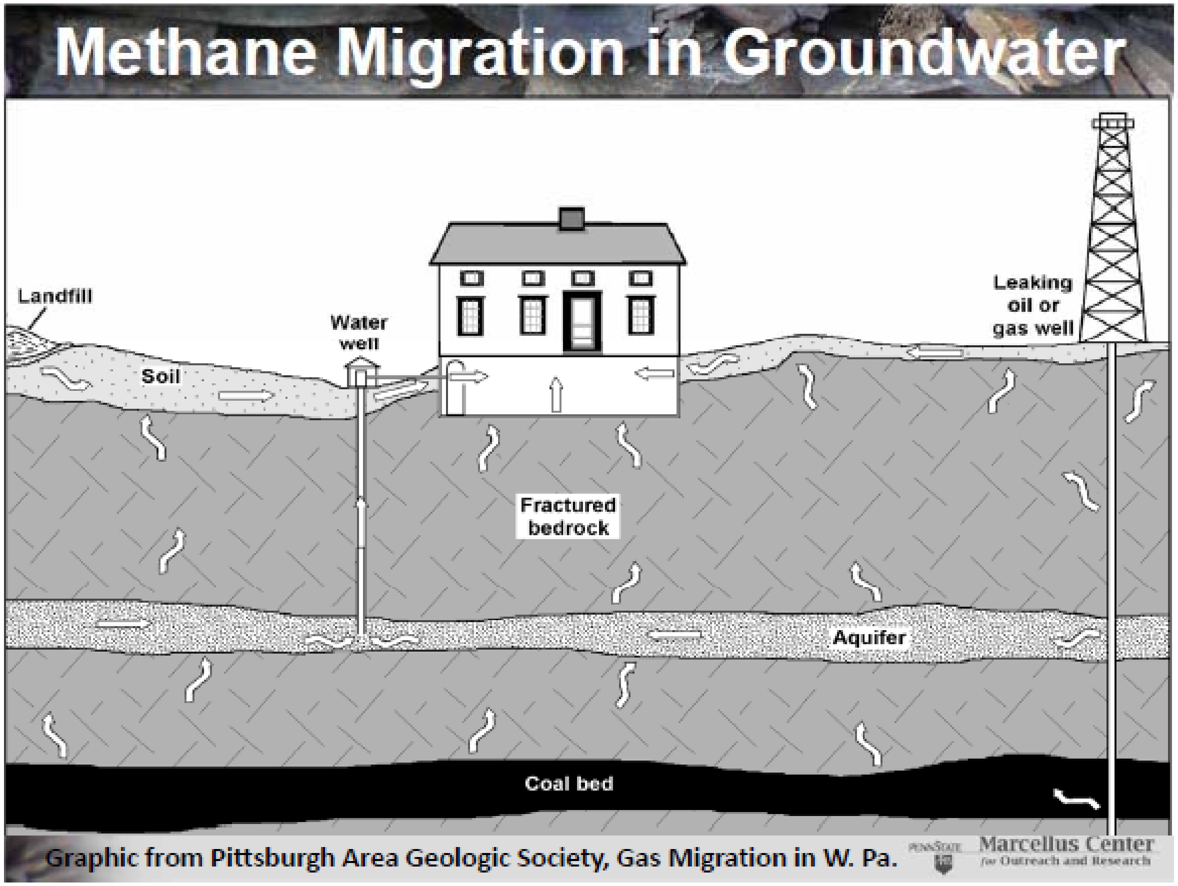
No reports in PA of constituents in hydrofrack fluids going into drinking waters due to hydrofracturing itself

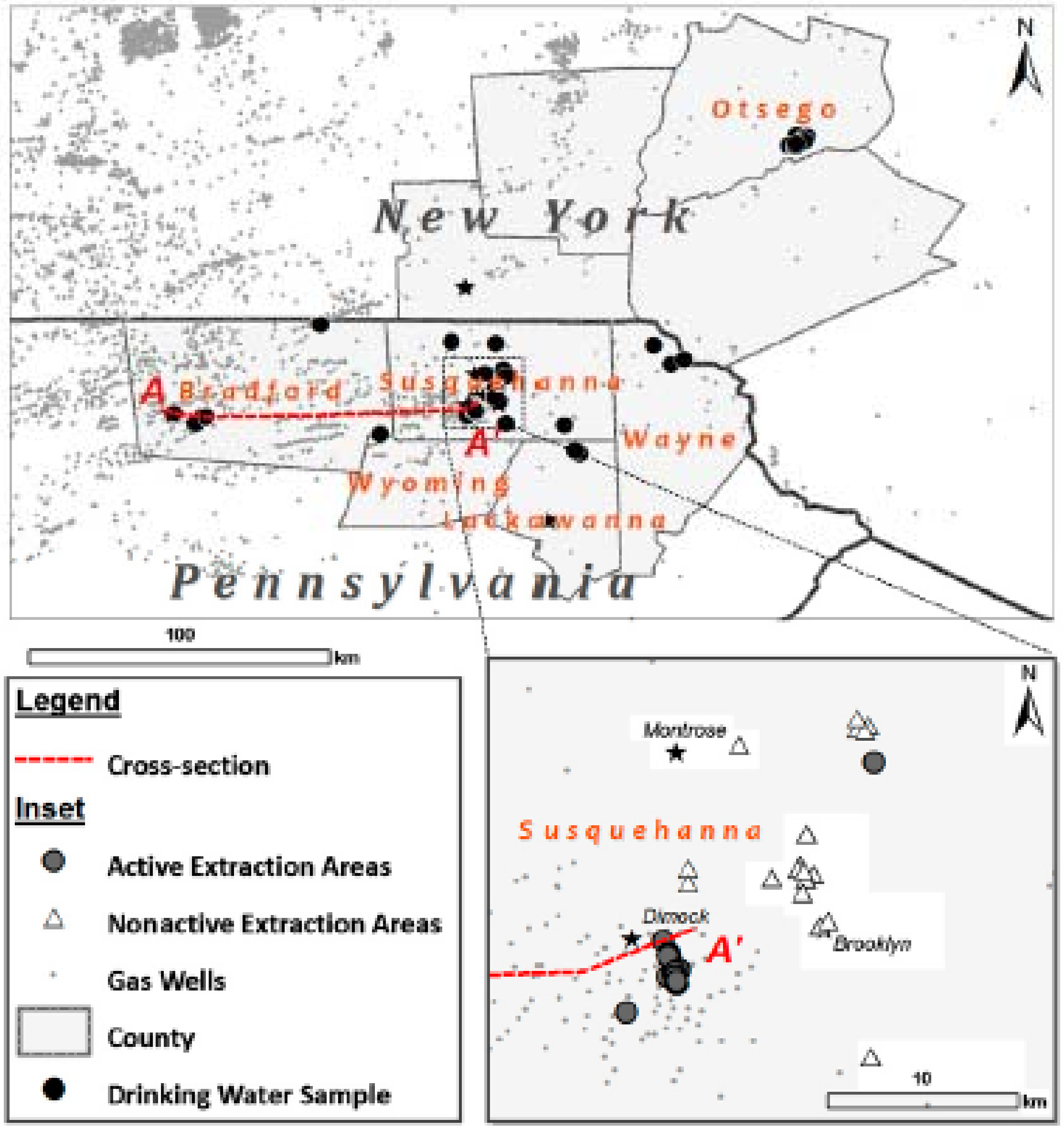
Graph from Carl Kirby, Bucknell Univ

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)

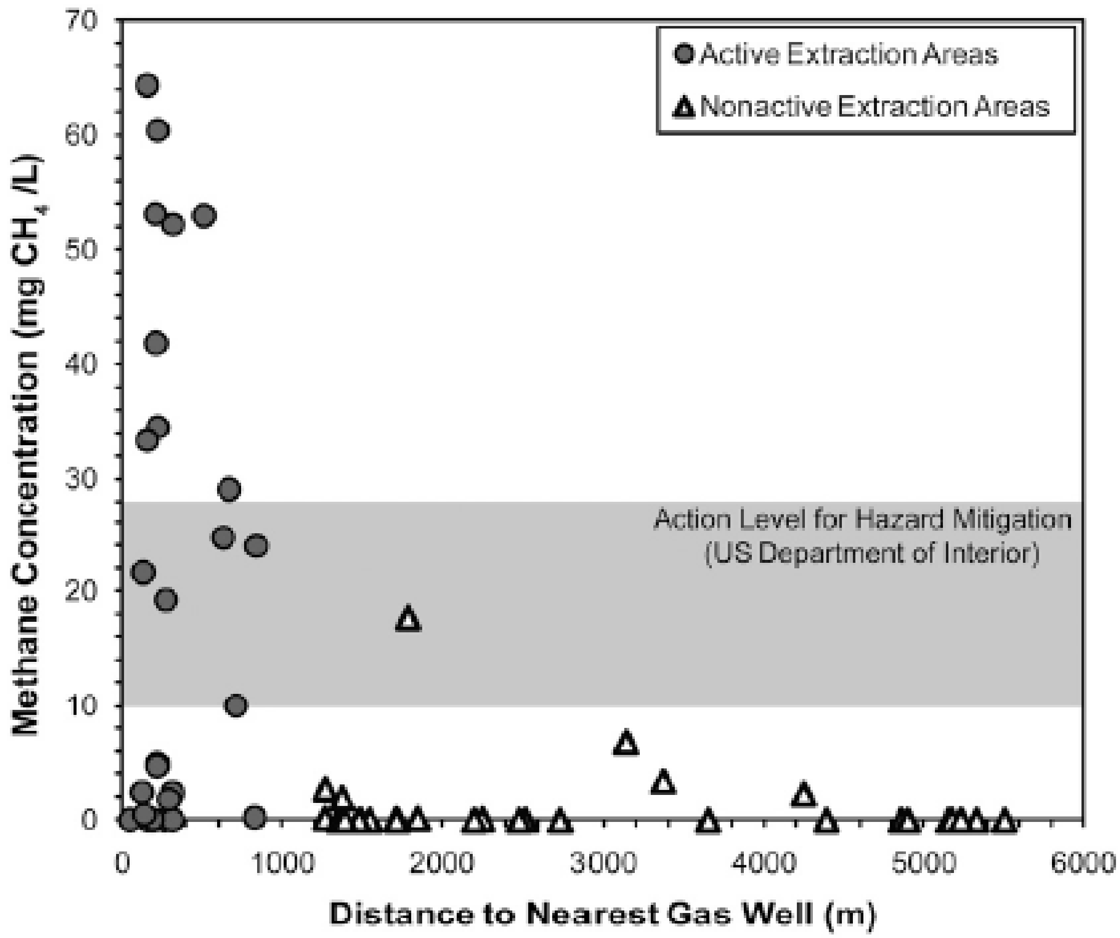




- Locations of sampling in active sites (within 1 km of drilling) and nonactive sites reported by Osborn et al.

Osborn S.G., Vengosh A., Warner N.R. (2011) Methane contamination of drinking water accompanying gas well-drilling and hydraulic fracturing. *Proceedings of the National Academy of Sciences.* 108: 8172-8176.

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



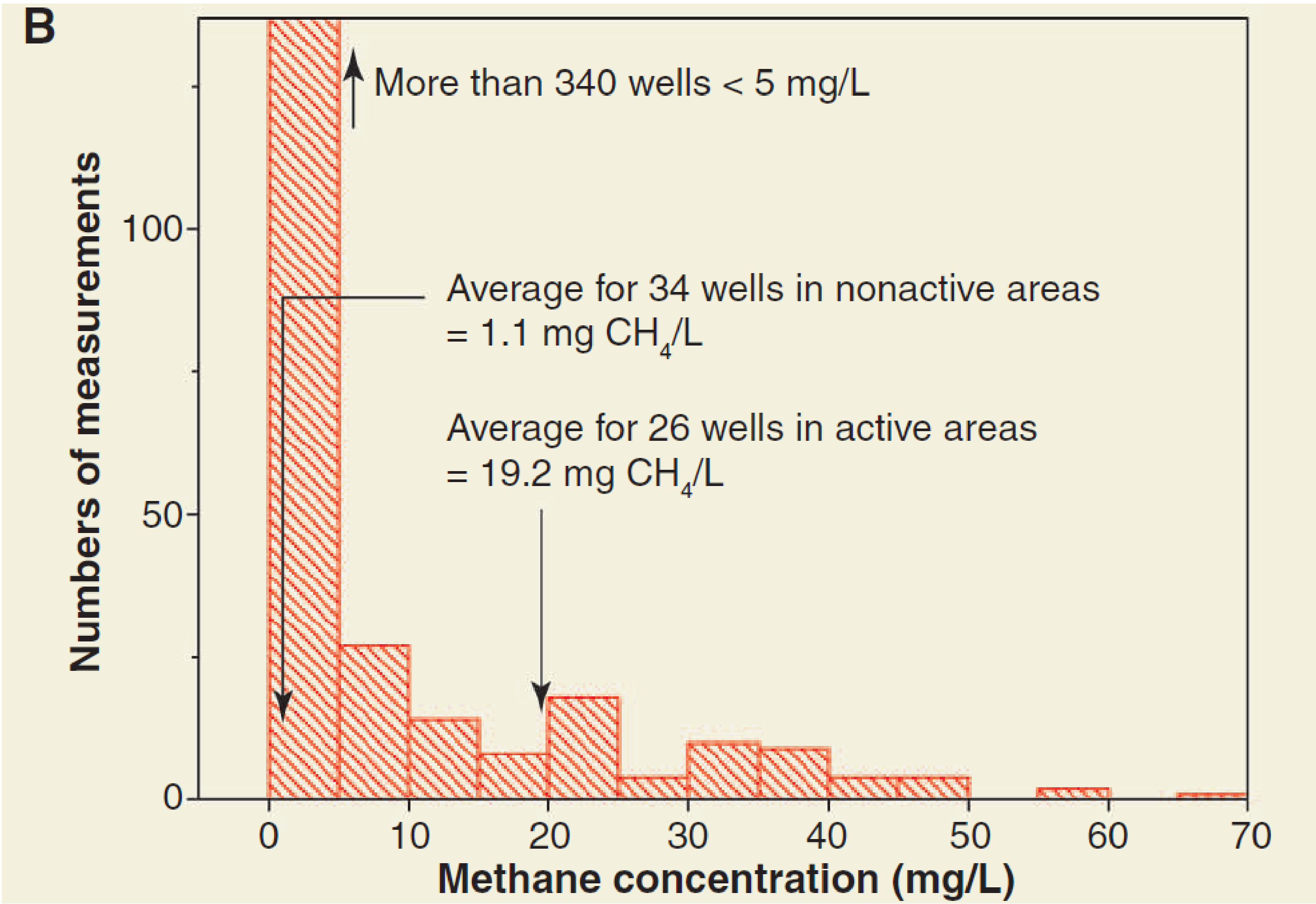
[Methane] plotted versus distance from drilling, not taking into account underground horizontal activity

Methane saturation at atm pressure = 26 mg CH_4/L (20°C) and 42 mg/L (10°C).

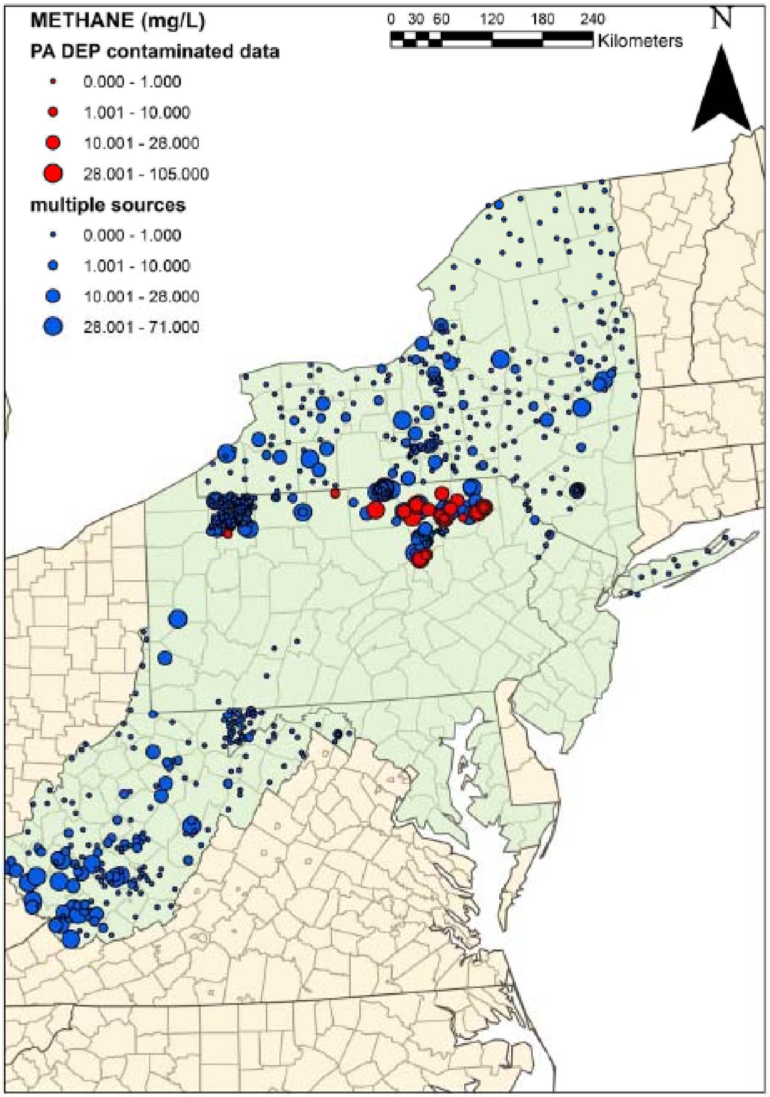
Study of Groundwater Quality Before and After Drilling in PA Marcellus drilling area

- 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

Vidic, Brantley et al., Science 2013

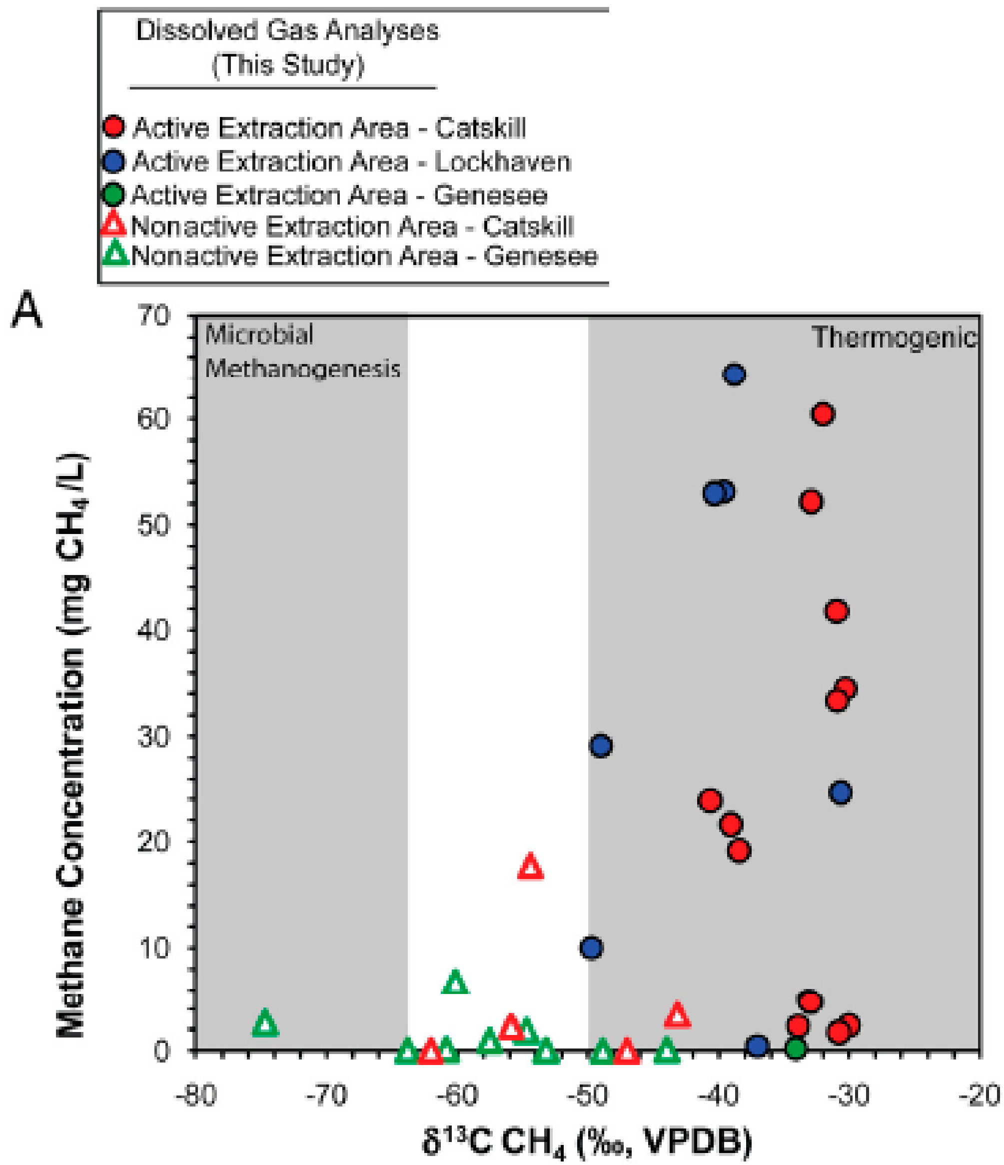


Methane concentrations in groundwaters



Most data are in ShaleNetwork database; figure made by PSU grad student Paul Grieve. Similar figure published in Vidic, Brantley et al., Science 2013

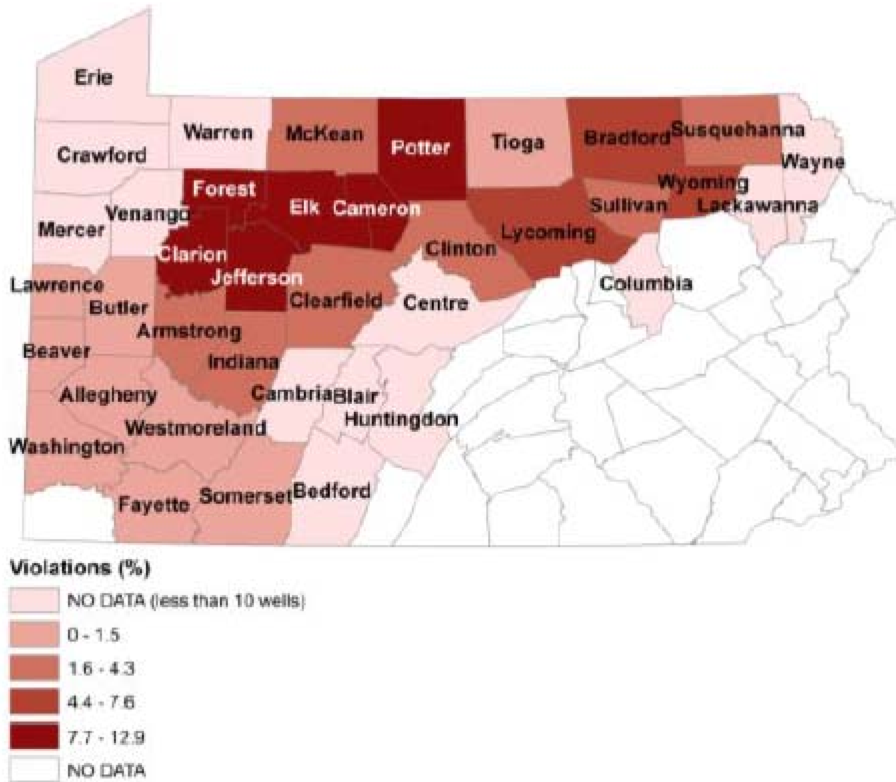
Osborn et al.



- 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)

Map documenting the % of 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



Brantley et al., 2013, subm.
Int. J. Coal Geology

PA Regulations

- In PA, unconventional gas companies are presumed responsible for water contamination within 2500 ft and 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
- 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. PA DEP has shared some of this data with ShaleNetwork under an MOU between the state and Penn State

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)

(1) Wilson, J. M. and VanBriesen, J. M., 2012. Oil and gas produced water management and surface drinking water sources in Pennsylvania. *Environmental Practice* ***doi:10.1017/S1466046612000427.***

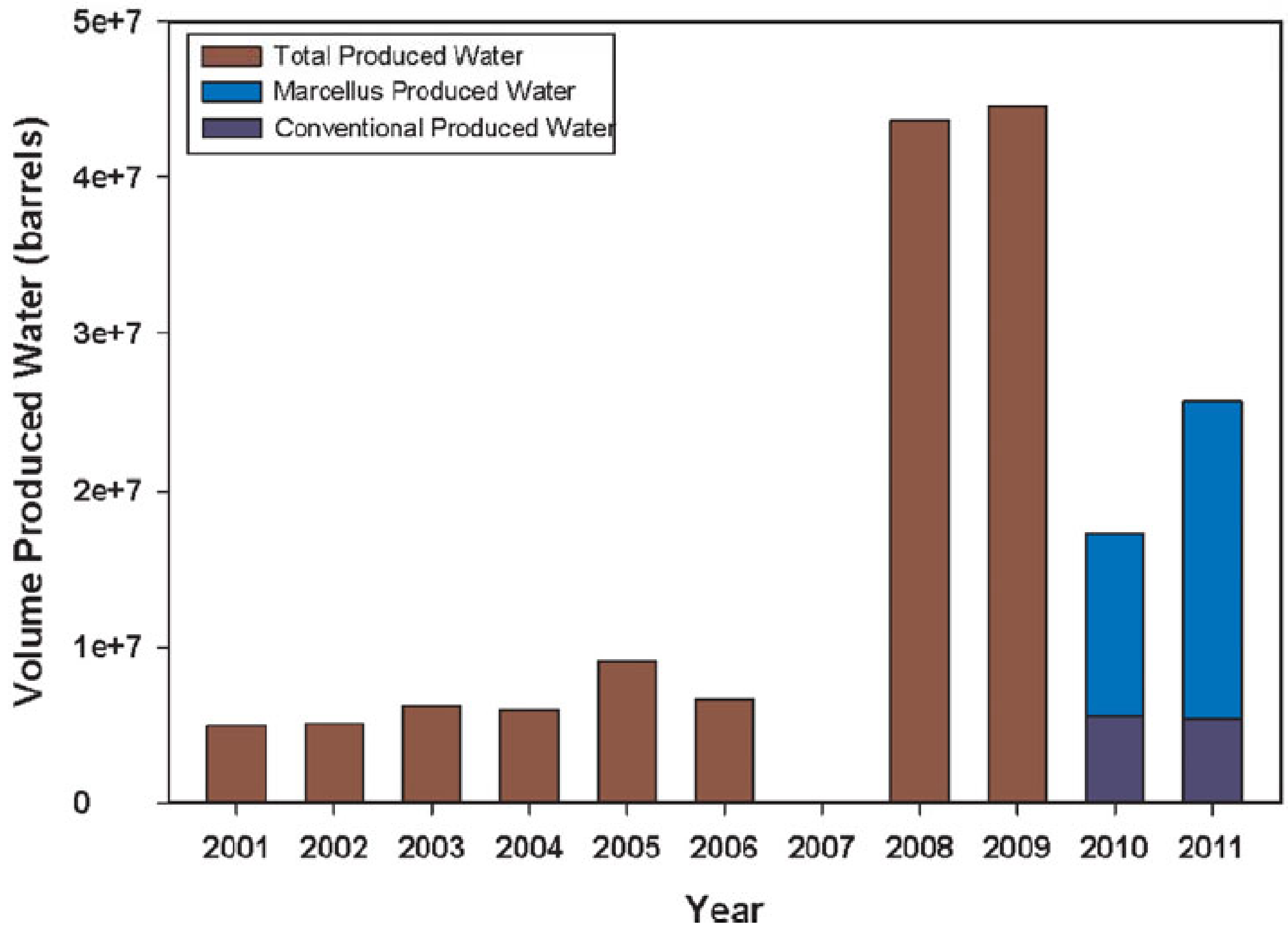
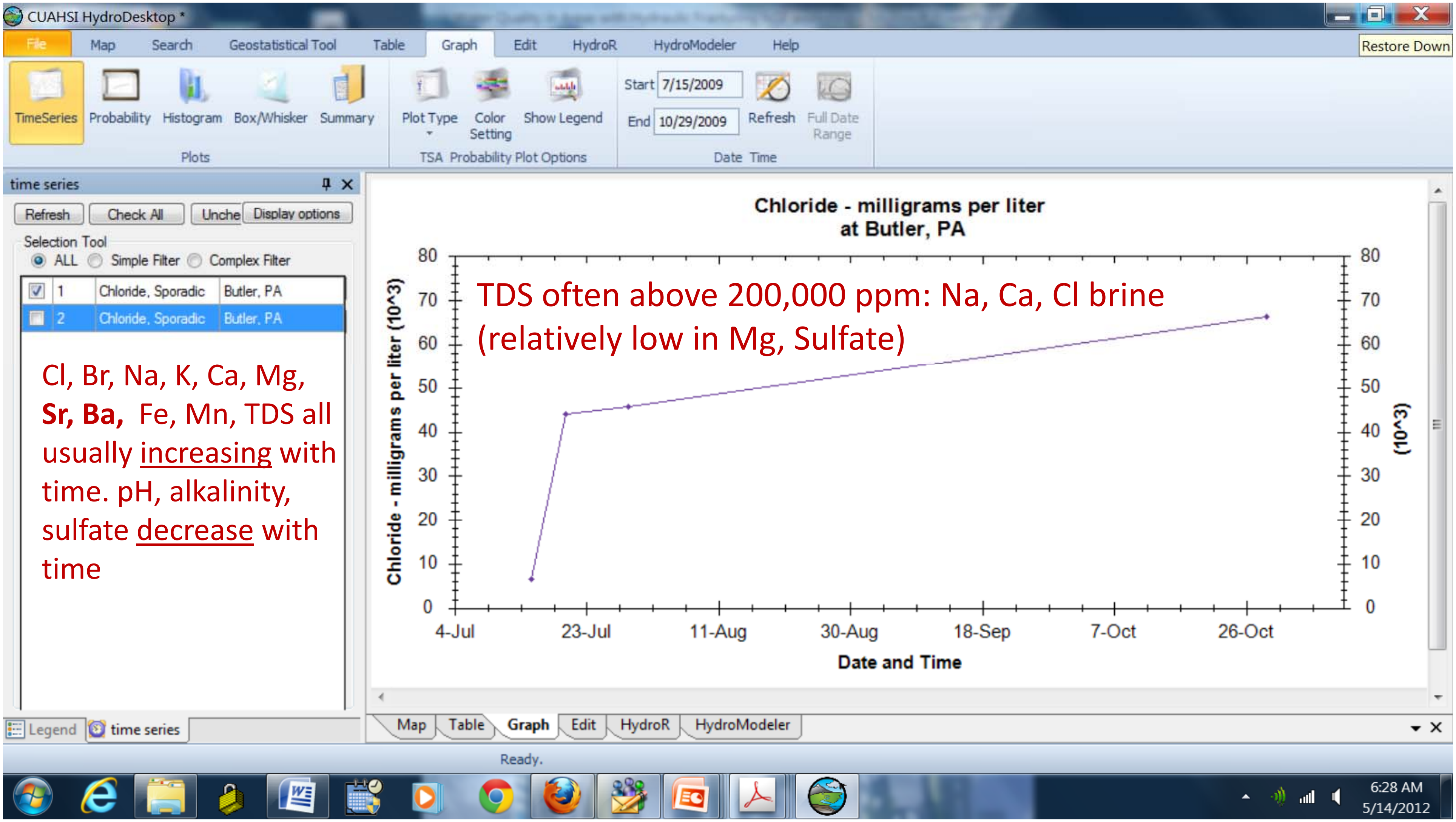


Figure 1. Produced water volumes in Pennsylvania, 2001–11.

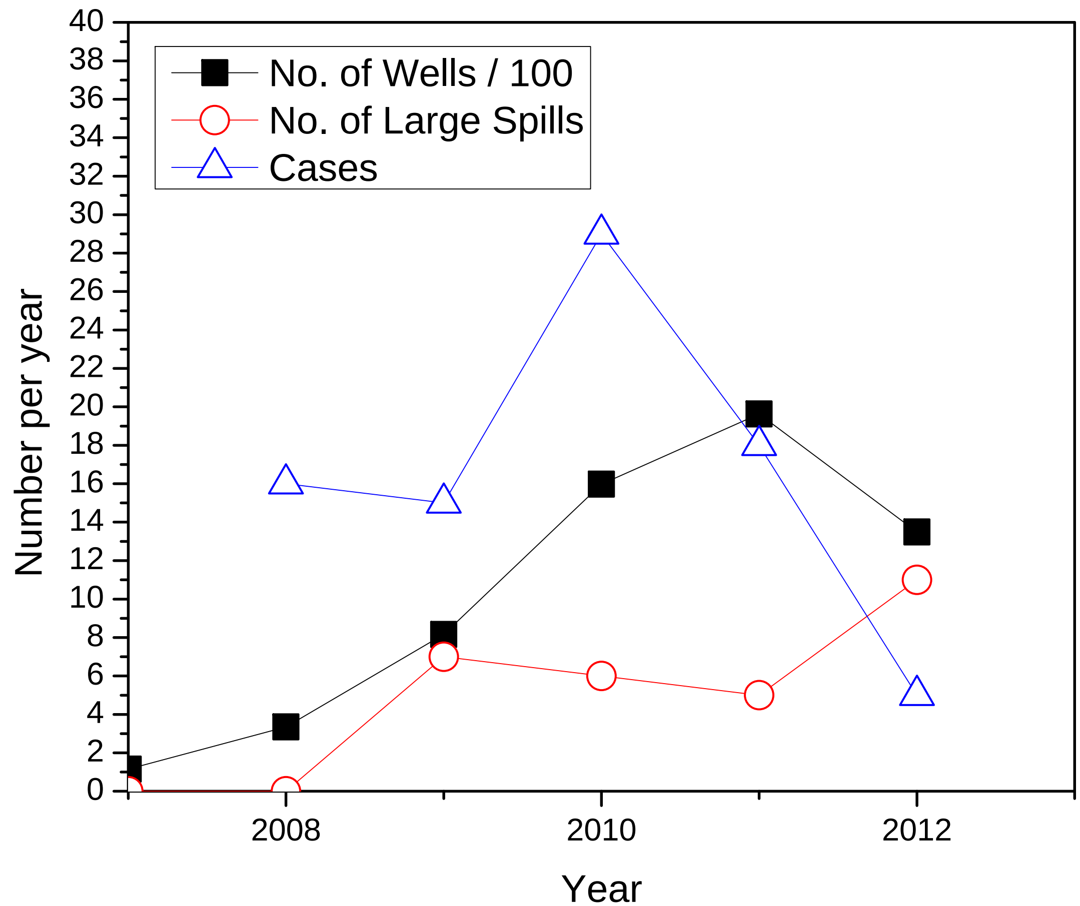
Flowback chemistry versus time from ShaleNetwork in HydroDesktop



TDS often above 200,000 ppm: Na, Ca, Cl brine (relatively low in Mg, Sulfate)

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

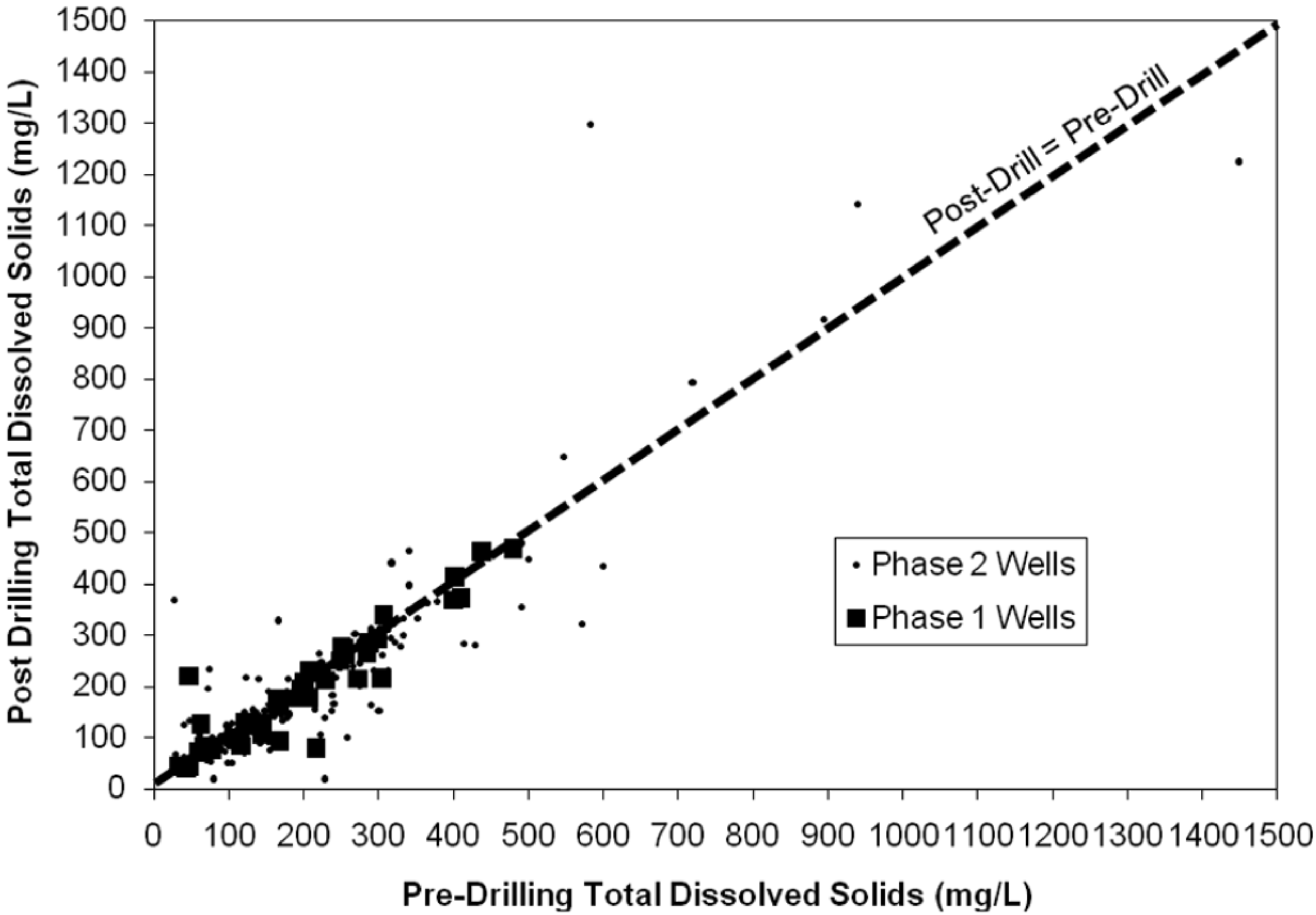
31 Spills :
Diesel (1)
Discharge (1)
Airfoam (1)
Hydrost. test water (2)
Sediment (3)
Frack fluids or components (6)
Drilling muds or fluids (9)
Flowback, prod. water or brine (9)



Brantley et al., 2013, subm.
Int. J. Coal Geology

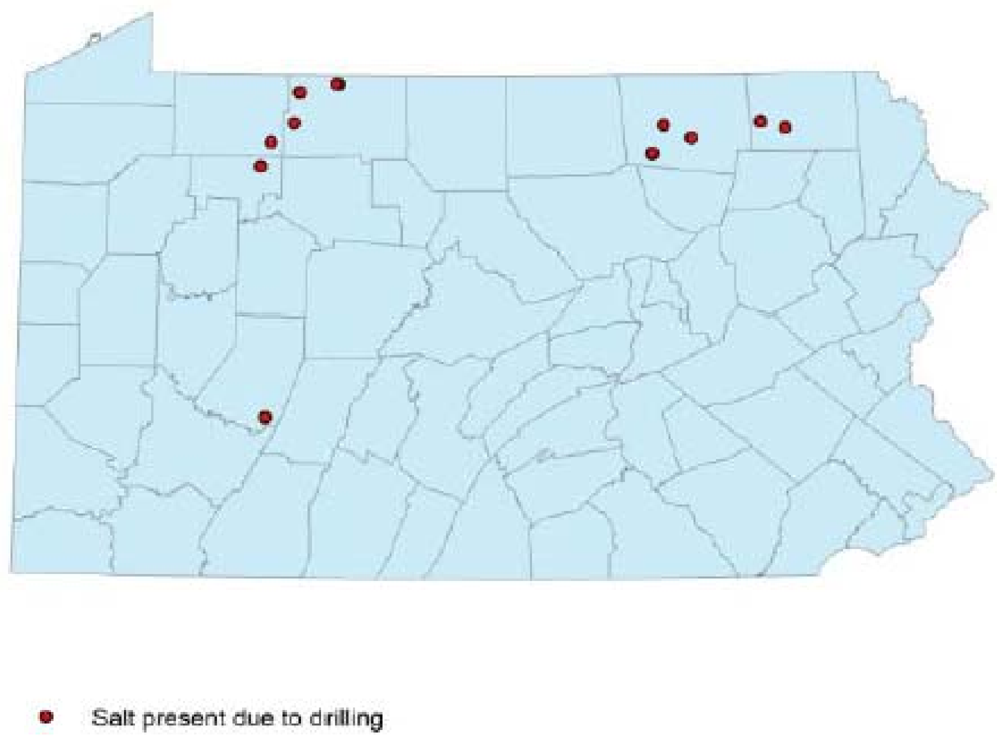
Figure 2. Number of unconventional shale-gas wells drilled in PA since 2004 (black squares, plotted after division by 100) and number of major spills reported for PA (red circles). Data from PA DEP and media reports. Blue triangles indicate the number of broad cases reported by PA DEP where oil or gas development activity was presumed to have caused impact of one or more water supplies. Cases may include more than one water supply and/or more than one gas well.

Private Well TDS Pre- and Post-Drilling



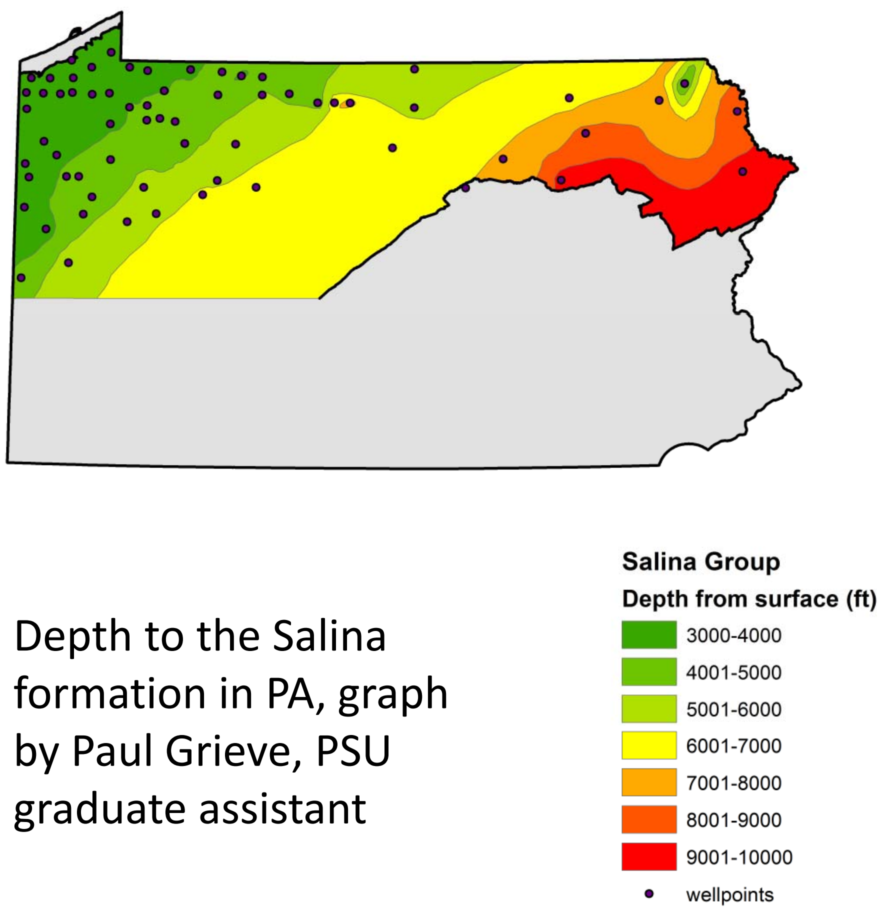
The Impact of Marcellus Gas Drilling on Rural Drinking Water Supplies, Center for Rural PA, October 2011

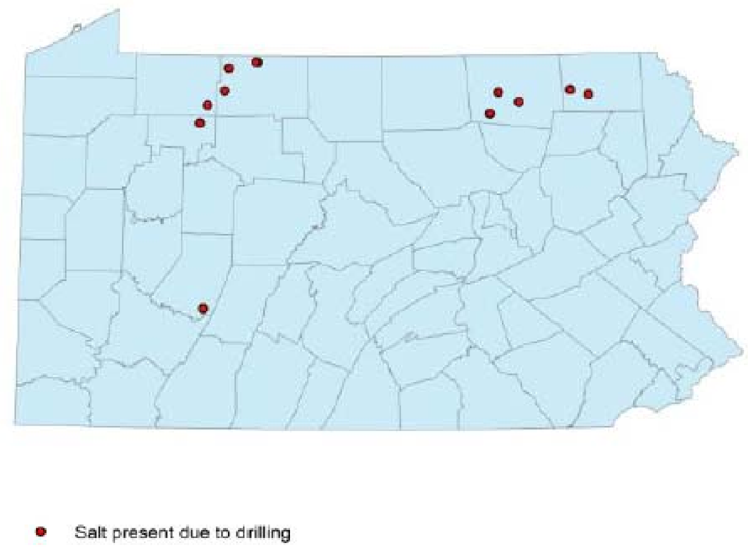
In contrast to low concentration constituents such as hydrofracking compounds, salts are present in flowback/production waters at much higher concentrations. A spill or leakage would therefore most likely be identified by analyzing salts. Here are all locations where PA DEP determined that shale gas development could be presumed responsible for contamination of drinking water supplies with dissolved salts



Brantley et al., 2013, subm.
Int. J. Coal Geology

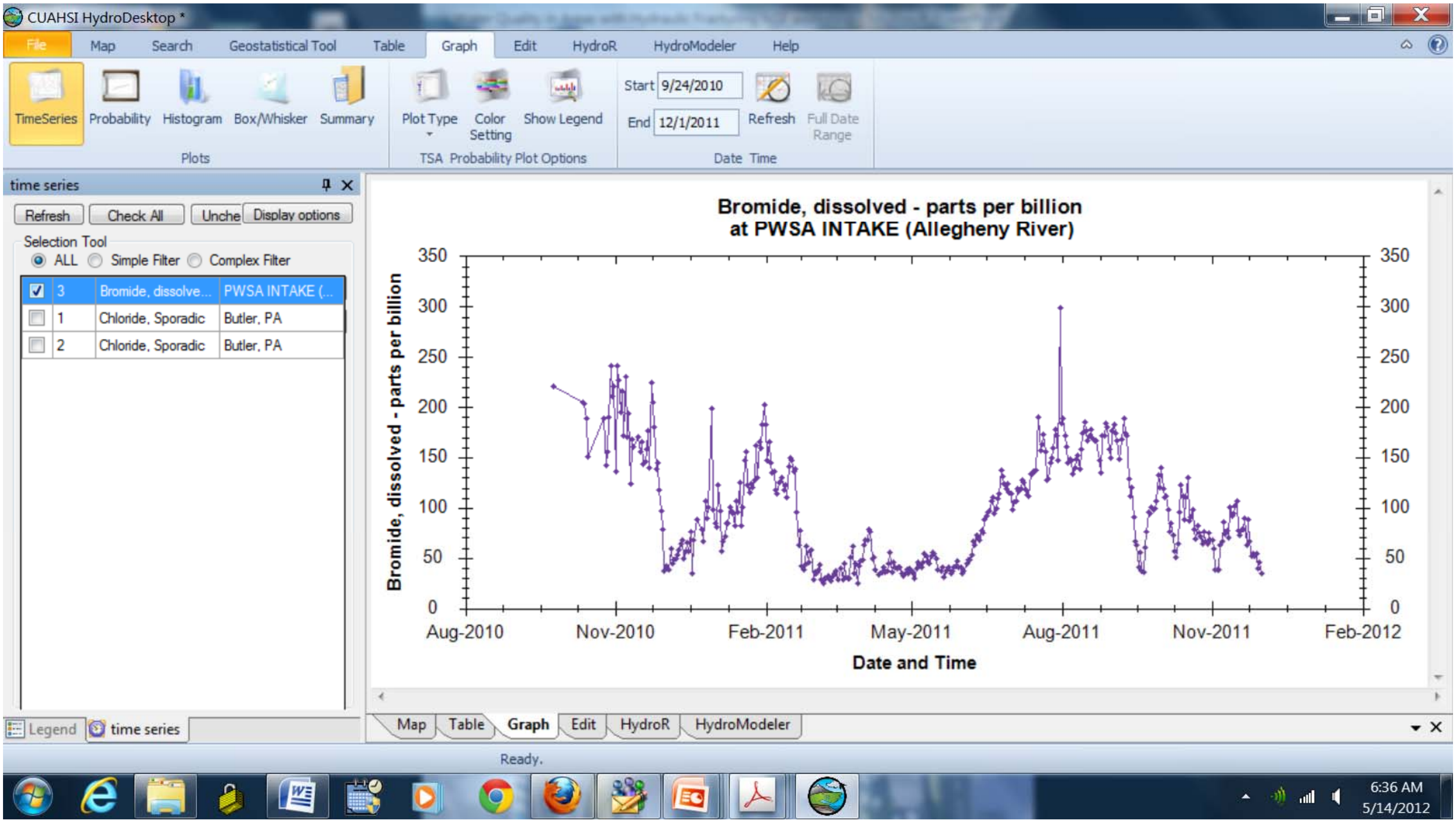
But, is this contamination due to leakage of flowback in subsurface, due to spills, or due to shale gas development-related movement of shallow, natural brines?



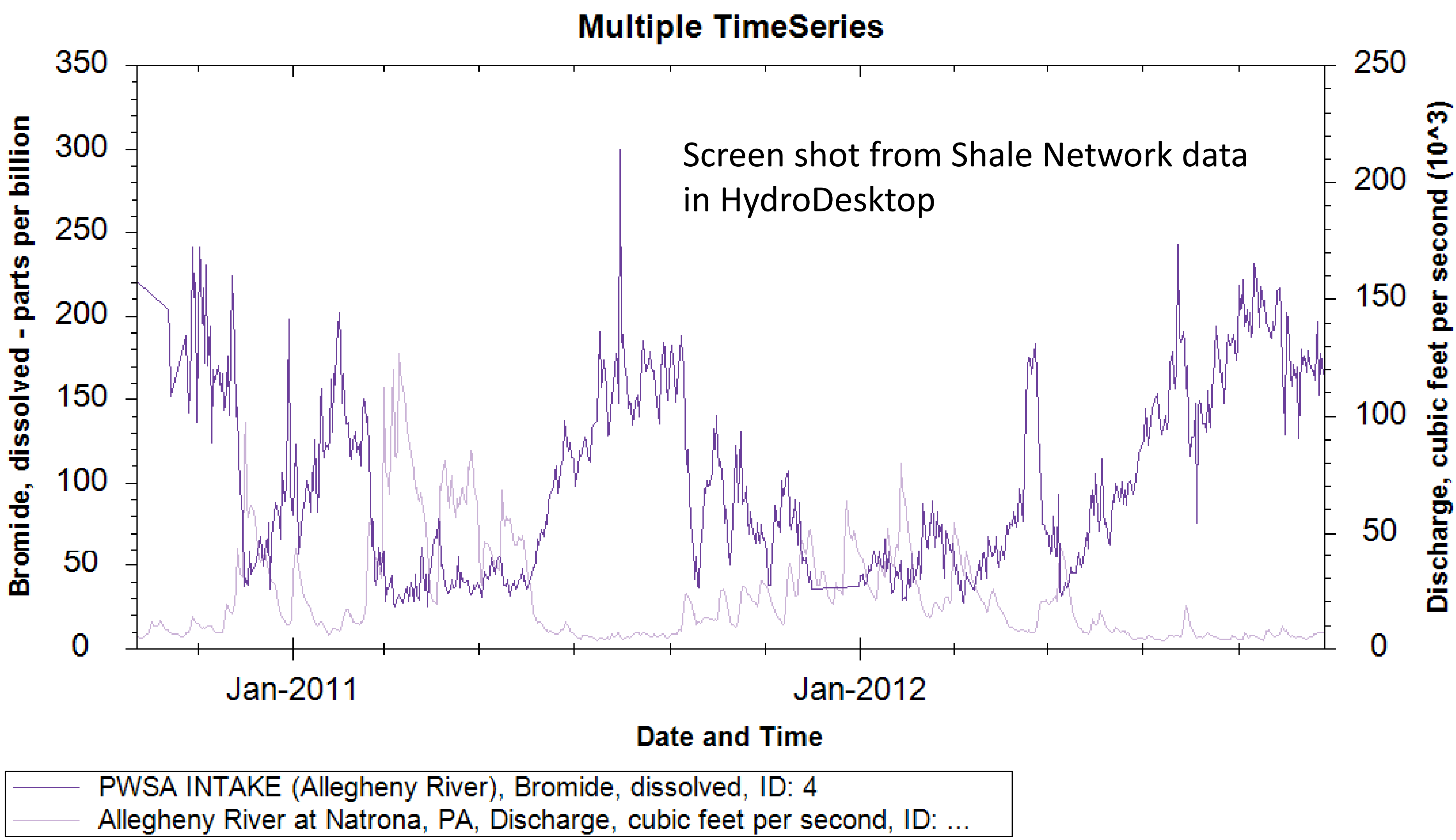


Depth to the Salina formation in PA, graph by Paul Grieve, PSU graduate assistant

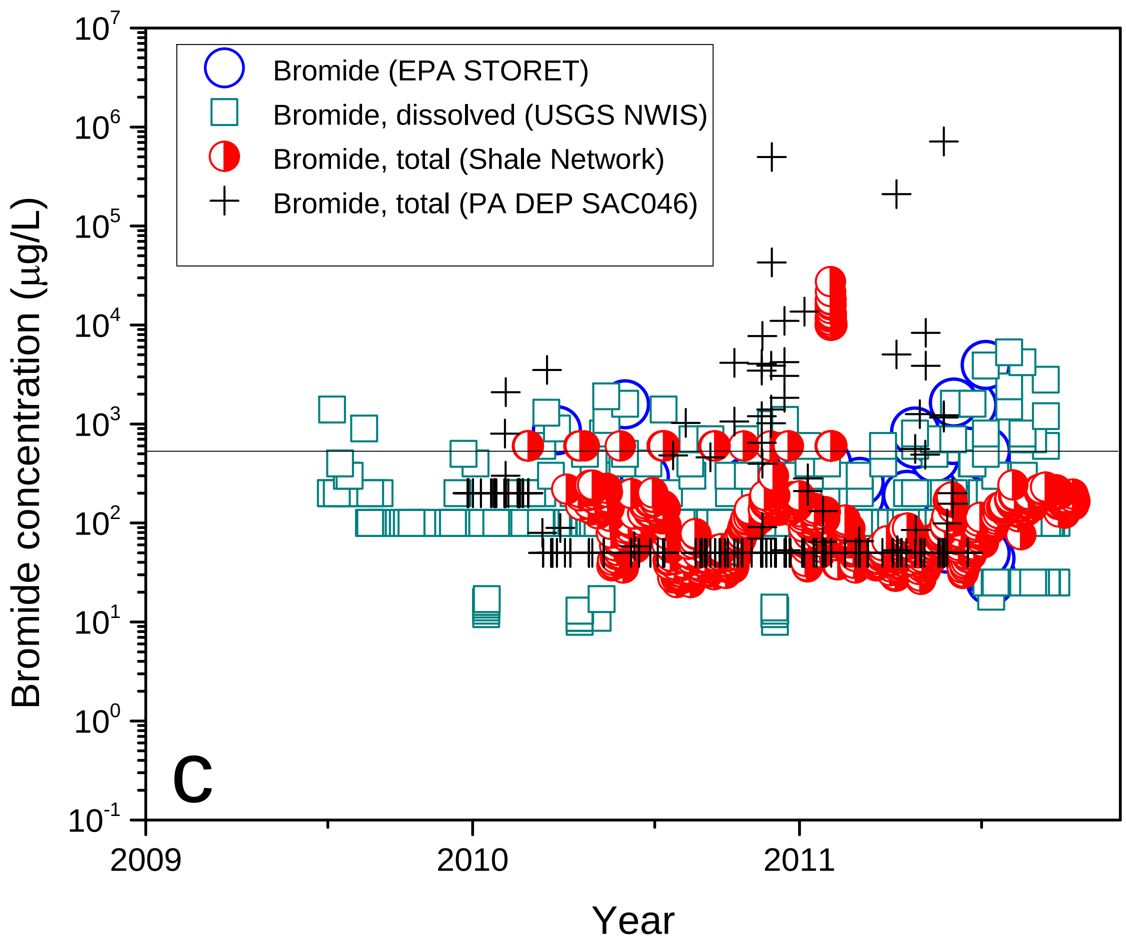
In early 2011, several noticed that Br in intake for PWSA was high enough to be problematic…at that time it was legal to send flowback waters to municipal water treatment plants for river discharge



Br in Allegheny River water at Pittsburgh Water and Sewer Authority intake



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 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, Science 2013

Naturally Occurring Radioactive Materials (NORMs) also increase with time in flowback (Rowan et al. 2011)

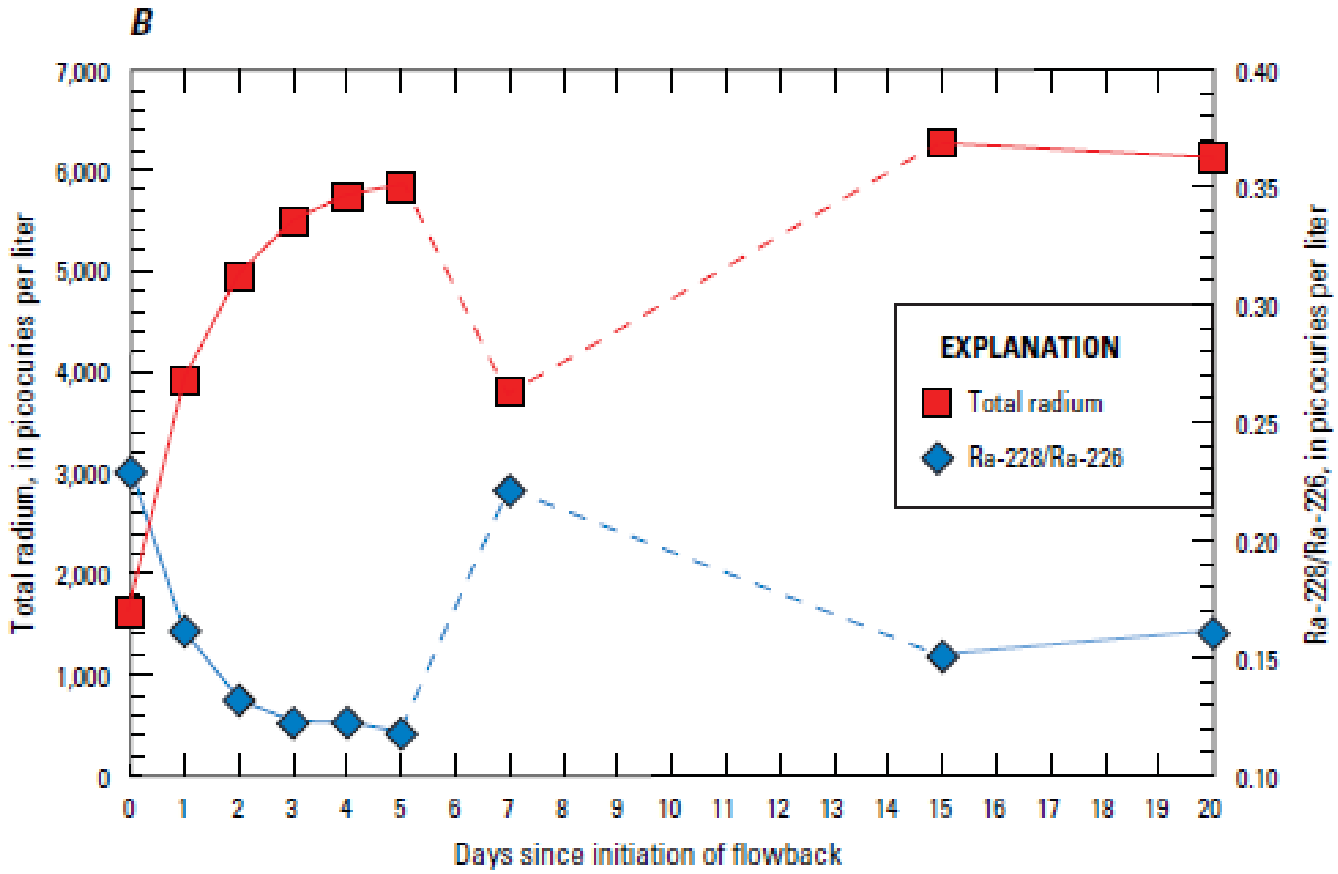
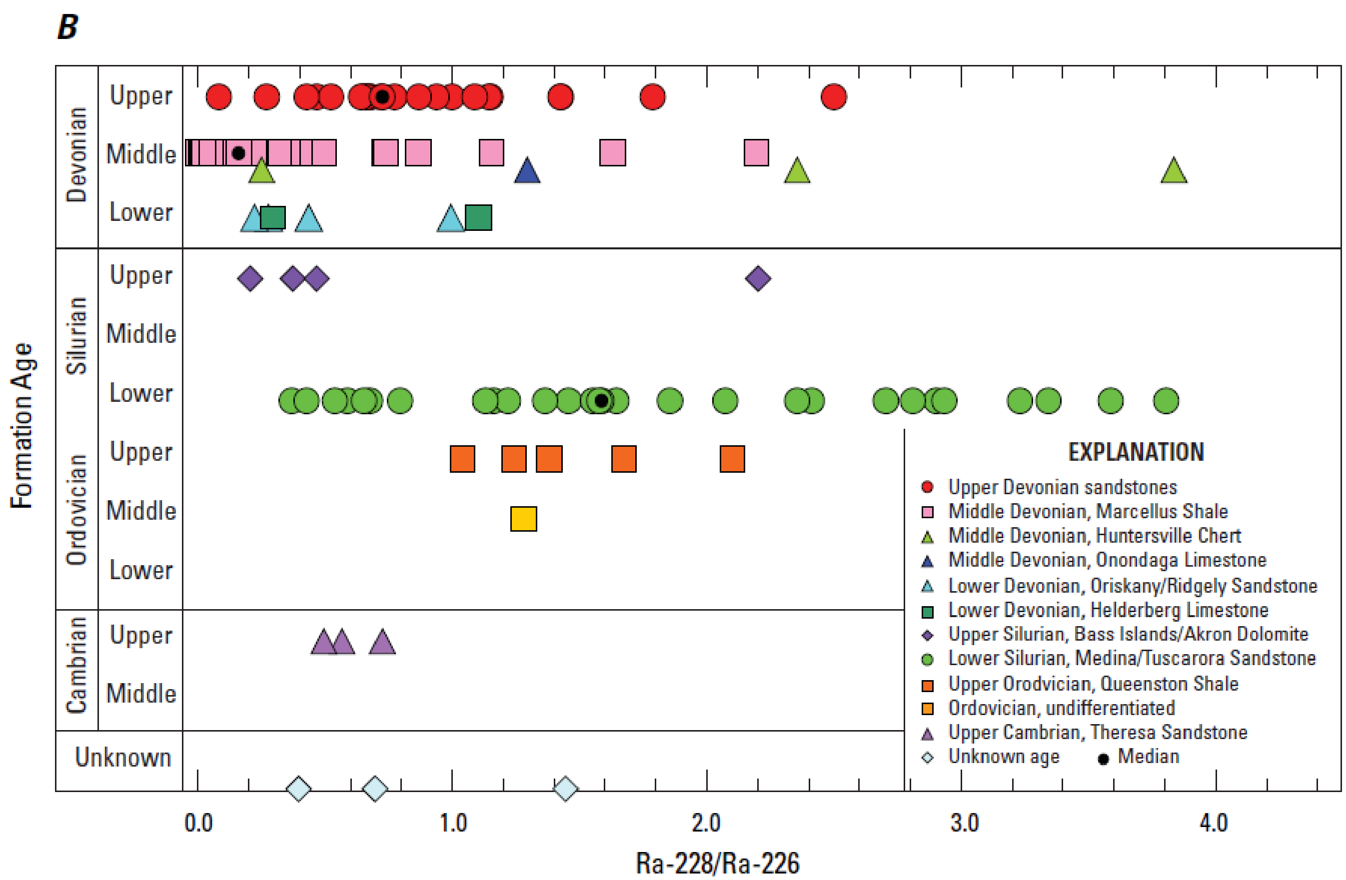


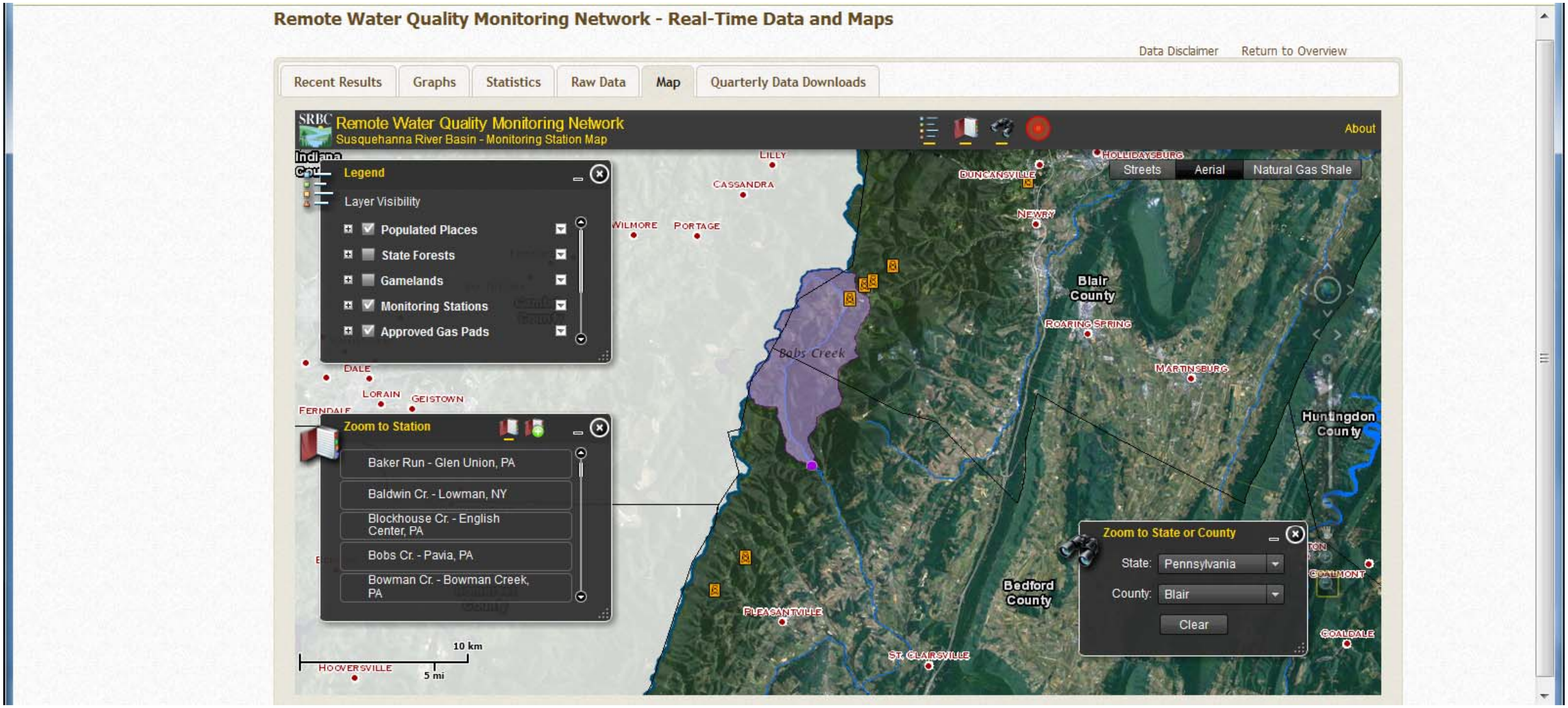
Figure 6. (*A*) Total radium activity and total dissolved solids related to time since initiation of flowback for well no. 11, Washington County, Pa. (*B*) Total radium activity (left axis, squares) and Ra-228/Ra-226 (right axis, diamonds) related to time since initiation of flowback for well no. 132, Greene County, Pa.

Rowan, E.L., Engle, M.A., Kirby, C.S., and Kraemer, T.F., 2011, Radium content of oil- and gas-field produced waters in the northern Appalachian Basin (USA)—Summary and discussion of data: U.S. Geological Survey Scientific Investigations Report 2011–5135, 31 p.
(Available online at http://pubs.usgs.gov/sir/2011/5135/)

(Rowan et al. 2011)

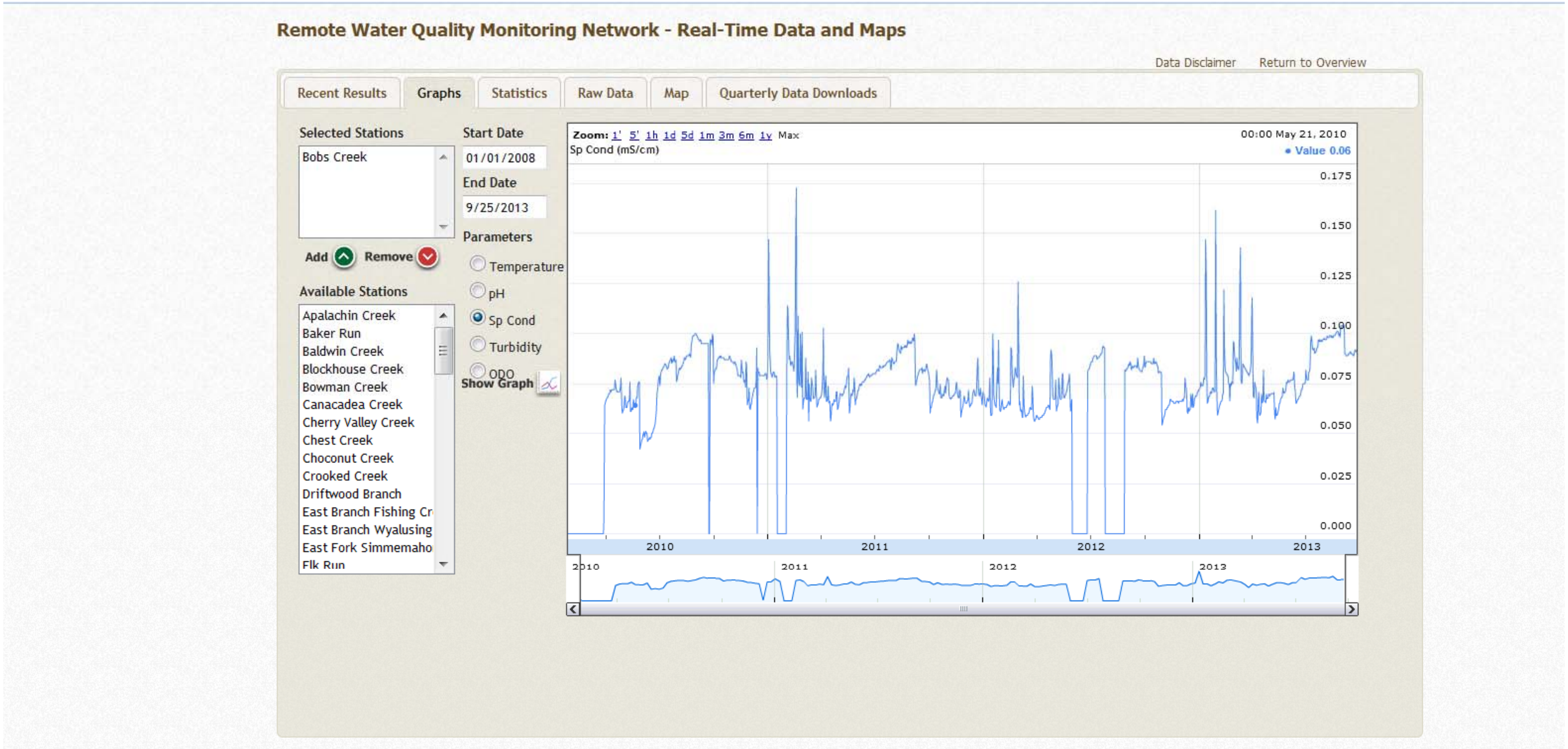


Very few contamination incidents in Shale Network database due to shale gas industry (why?)
Example: SRBC RWQMN at Bob's Creek
(http://mdw.srbc.net/remotewaterquality/data_viewer.aspx)



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: SRBC RWQMN
(http://mdw.srbc.net/remotewaterquality/data_viewer.aspx)



Water Management Trends

- Use of alternative water sources
  - Groundwater supply wells closer to drilling
  - Municipal wastewater use (3 plants in permitting process)
  - Acid mine drainage
- Use of above ground temporary storage
- Flowback water reuse is increasing
  - Up to ~90% PA industry-wide now, was ~10% just a couple years ago.
- Field recycling and fixed site treatment being utilized increasingly
  - Field recycling ~1.6 mgd (40,000 bpd) in 2011
  - Fixed treatment plant use ~400,000 gpd (10,500 bpd) in 2011
- Closed loop drilling and fluids storage
- Lined well pads to minimize releases
- Additional centralized treatment facilities in various stages of permitting/construction
- Beneficial reuse of sludges and solids for landfill cover is occurring at some facilities
- UIC disposal well use increasing in OH
  - Was ~5% a year ago, now ~20%
- UIC well sites being pursued in PA

Slide from Dave Yoxtheimer, Penn State Marcellus Center for Outreach and Research

Summary

- Data sharing is enabling better understanding of issues related to shale gas development.
- 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).

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

Information from Osborn et al.

http://www.nicholas.duke.edu/cgc/HydraulicFracturingWhitepaper2011.pdf