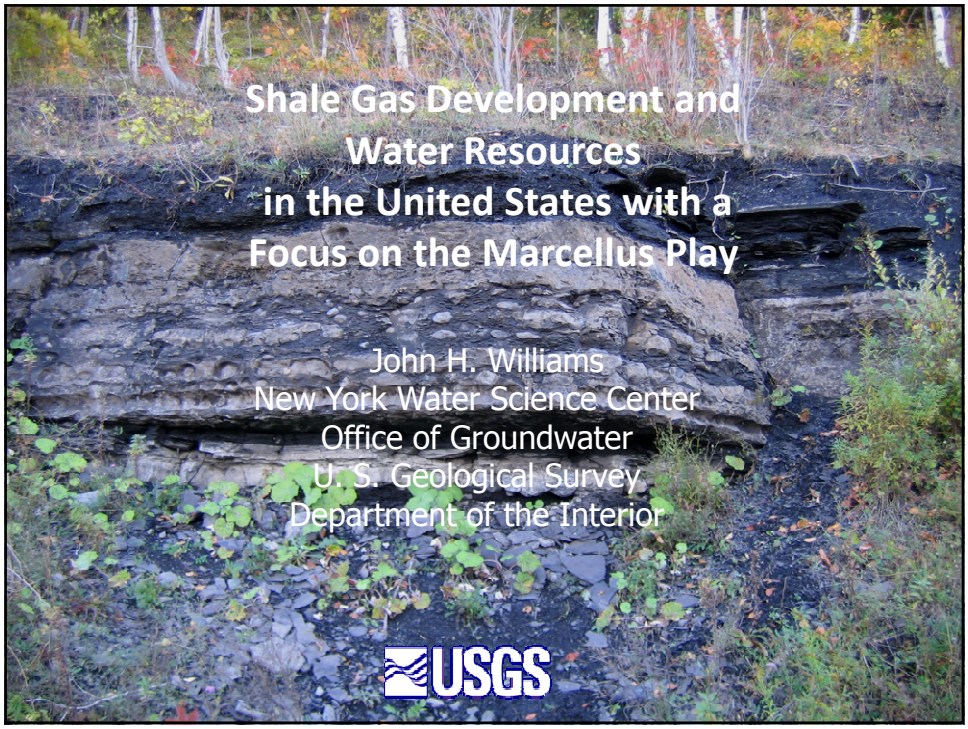


Federal Research on the Environmental Impact of Shale Gas Development

- In 2011, Department of Energy conducted a review of the safety and environmental performance of hydraulic fracturing; presented twenty recommendations in final report

  http://www.shalegas.energy.gov/

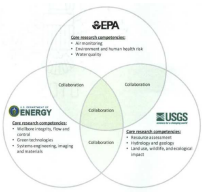
- In 2011, Environmental Protection Agency at the request of Congress began a study of the potential impacts of hydraulic fracturing on drinking water resources; final report due in 2014

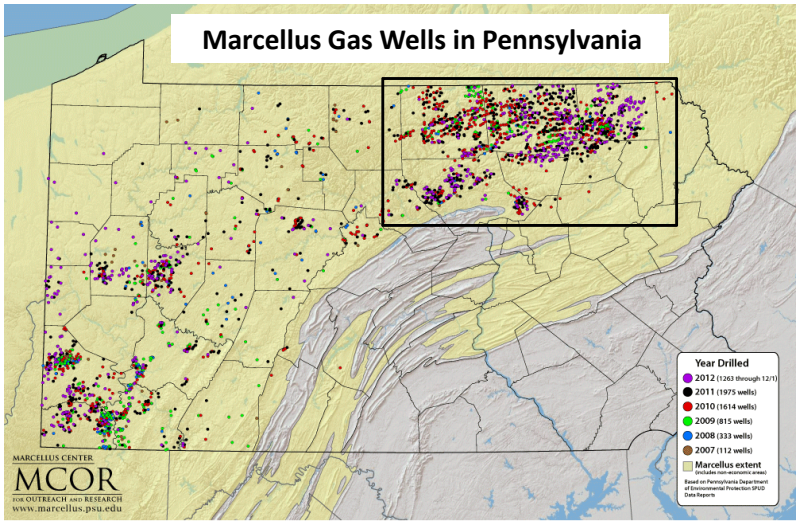
  http://www2.epa.gov/hfstudy

- In 2012, Department of Energy, Department of Interior, and Environmental Protection Agency as directed by the Executive Branch committed to developing a national program for multi-agency collaboration on unconventional oil and gas research; proposed program currently under review by the White House

  http://unconventional.energy.gov/index.html#

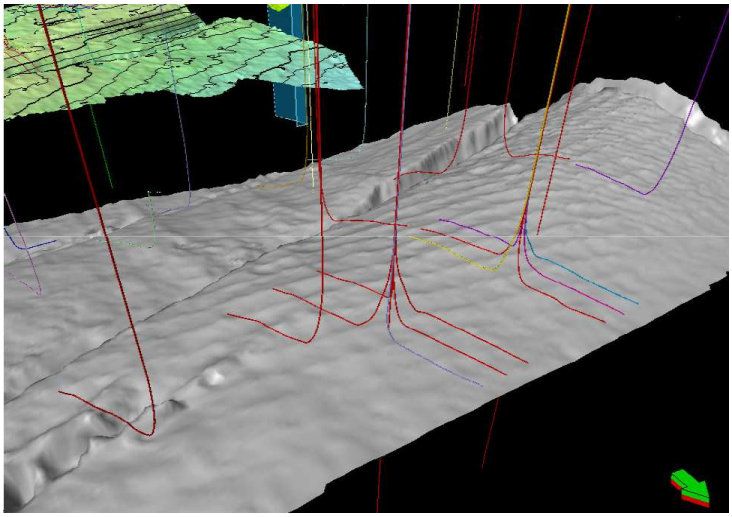
- U.S. Geological Survey, Department of Energy, Environmental Protection Agency, Department of Agriculture, Army Corp of Engineers, Department of Housing and Urban Development, and Center for Disease Control have developed a research and assessment proposal focused on the Marcellus and Utica shale plays; release of draft proposal awaits approval of the national program





- 4,000 Marcellus wells drilled in Pennsylvania, half have been hydraulically fractured
- Majority of wells drilled in the dry gas "hot spot" in north-central PA between 2008 to 2012
- Drilling has shifted to Marcellus wet gas and Utica oil plays in southwest PA and eastern Ohio
- No systematic evaluation of the water-resource impact in the 6-county area in north-central PA
- Insights gained, lessons learned, and evolution of industry practices

Horizontal wells target basal Marcellus Shale

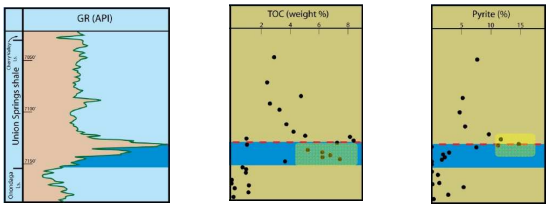


Teff (2011)

- Depths of 4,000 to 7,000 feet below land surface
- Six horizontal laterals 4,500 feet length per multi-well drill pad
- Laterals oriented NW-SE perpendicular to primary joint set and maximum stress

Drill Cuttings from Horizontal Wells

- Multi-horizontal well site will generate more than 500 times the volume of black shale cuttings than single-vertical well site
- Elevated uranium and abundant pyrite in high-TOC black shale cuttings

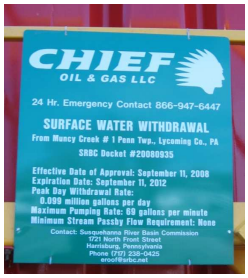


- Past practice was onsite storage and disposal in open pit
- Current best practice is closed loop system and offsite disposal in landfill

Water Withdrawals for Hydraulic Fracturing

- 4 million gallons for each horizontal lateral

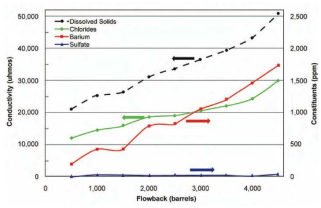
- Past practice was withdrawal from nearest stream regardless of flow conditions
- Current best practice is surface-water withdrawal rates regulated based on low-flow analysis



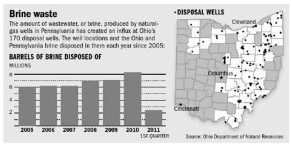
Flowback

• 10 to 30 percent of the hydraulic fracturing fluid returns as flowback with elevated TDS, chlorides, metals, and radioisotopes

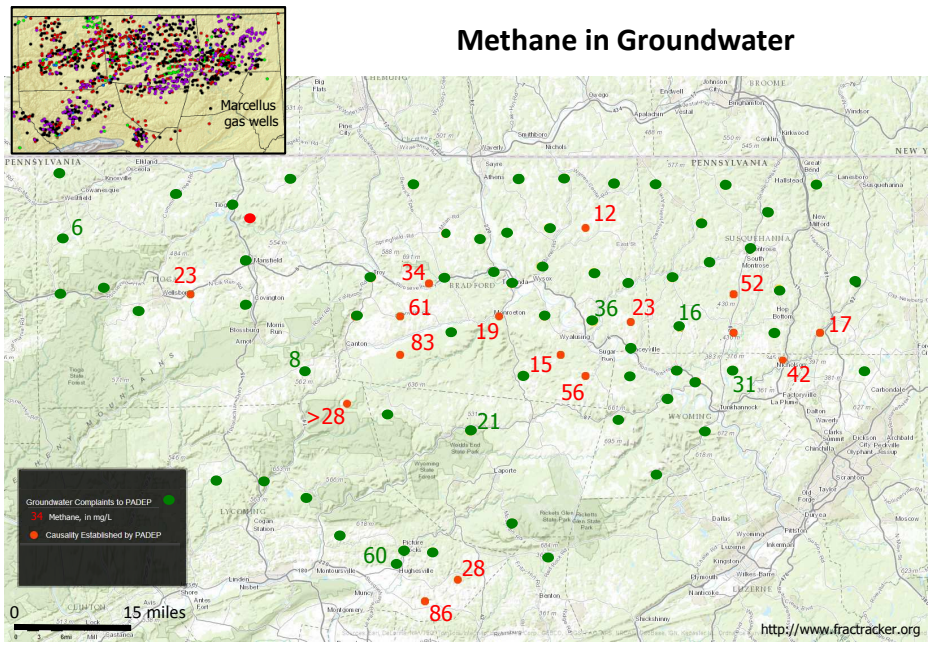
Flowback, bbl	500	2,500	6,000	11,000	15,000
Anions					
P alkalinity, mg/L as $CaCO_3$	0	0	0	0	0
M alkalinity, mg/L as $CaCO_3$	580	580	360	260	160
Chloride, mg/L as Cl^-	2,000	5,800	16,400	53,000	104,000
Sulfate, mg/L as $SO4^{2-}$	1,115	910	588	57	24
Cations					
Sodium, mg/L as Na^{1+}	714	1,470	2,671	9,062	12,830
Potassium, mg/L as K^{1+}	27	40	105	381	544
Calcium, mg/L as Ca^{2+}	240	536	1,960	6,840	9,720
Magnesium, mg/L as Mg^{2+}	44	73	171	541	805
Total hardness, mg/L as $CaCO_3$	780	1,640	5,600	18,500	27,600
Barium, mg/L as Ba^{2+}	0.4	0.5	2.1	7.3	70.2
Strontium, mg/L as Sr^{2+}	16.5	48.4	211	995	1,837
Ferrous iron, mg/L as Fe	1.8	0.8	0.4	0.6	3.3
Total iron, mg/L as Fe	42	27	38	157	78
Miscellaneous					
pH	7.25	8.31	8.54	6.27	5.88
Total suspended solids, mg/L	90	20	201	123	502
Specific gravity, g/ml	1.001	1.016	1.026	1.071	1.087
Conductivity, µO	7,160	16,800	37,800	123,000	173,200
Δ ATP (microbiological content), relative light units	5	6	3	1	1
Microbiological content	Low	Low	Low	Low	Low
Langelier saturation index (LSI)	1.02	2.37	2.94	1.02	0.55
Langelier potential scaling	Scaling	Scaling	Scaling	Mildly	Scaling
Calcium sulfate scaling potential	Positive	Positive	Positive	Positive	Positive



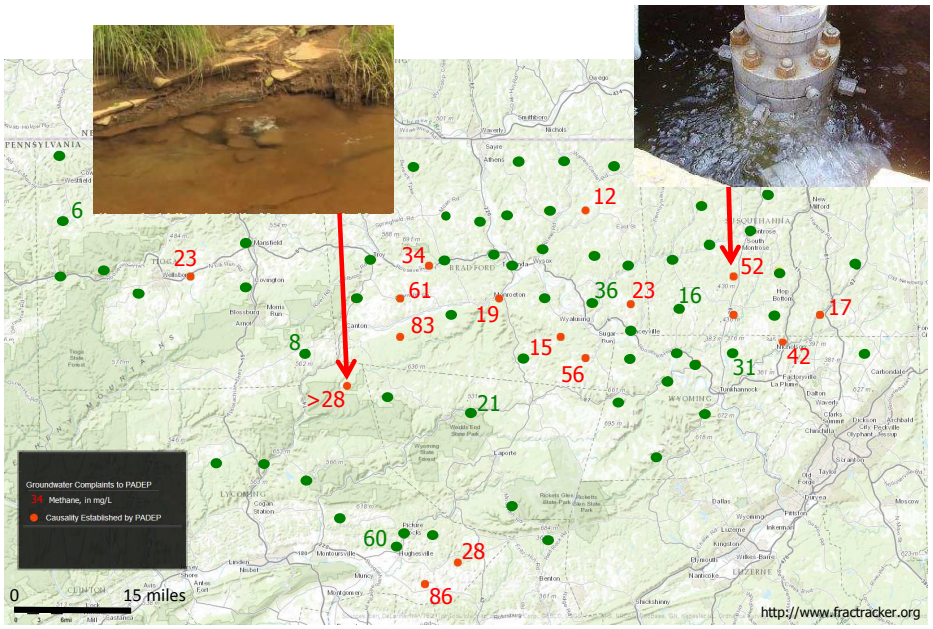
• Past practice was onsite storage in lagoons and offsite disposal in sewage treatment plans or disposal well injection
• Current best practice is to blend with 70 percent freshwater and reuse



Methane in Groundwater

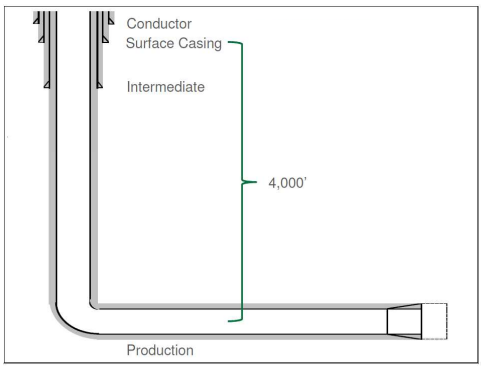


• Cause-and-effect established by PADEP between methane contamination found in water wells and shale gas development in 16 cases during 2008-2012

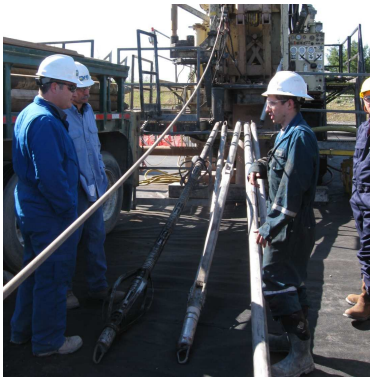


• Lack of proper isolation of freshwater and shallow gas zones due to surface casings with poor cement seals

Protection of Freshwater Aquifer

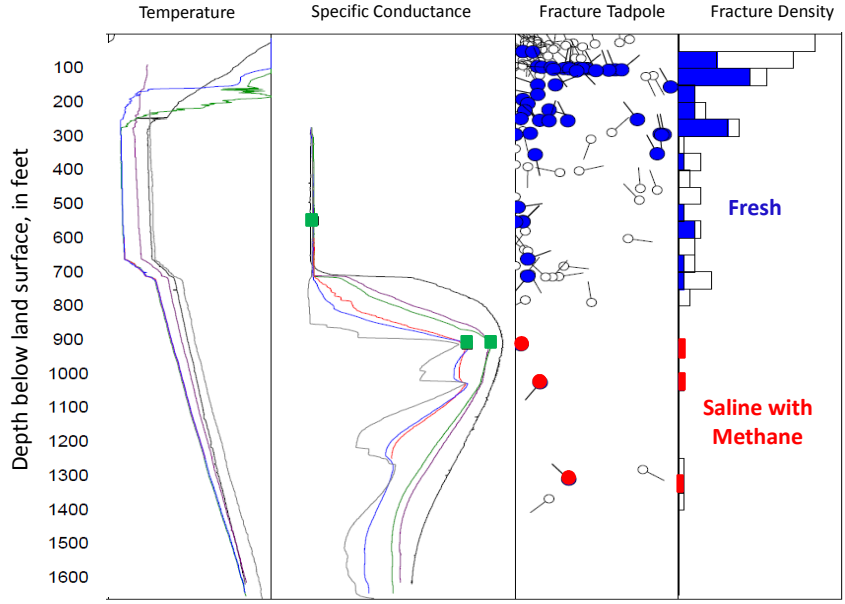


Intermediate casing/cement required in addition to surface casing/cement to better isolate freshwater zones from saline water and gas zones



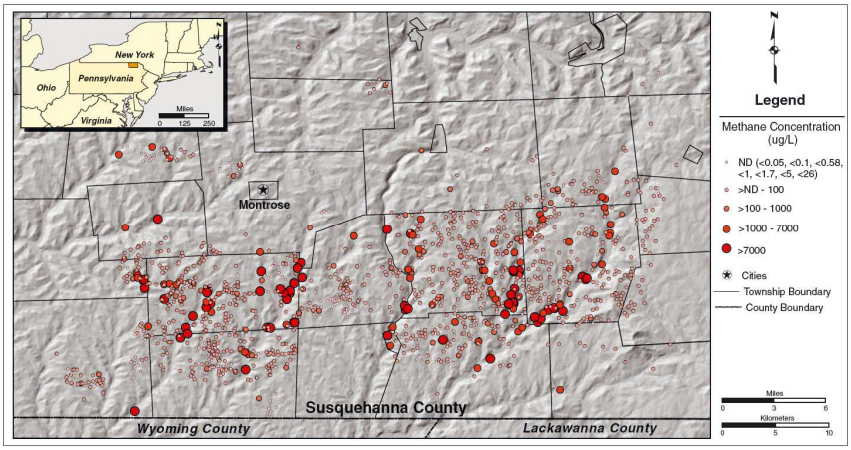
Characterization of deep freshwater and shallow gas and saline water by petrophysical logging methods

Characterization of Freshwater, Saline-Water, and Gas bearing Fractures



Water-Quality Sampling of Water-Supply Wells

- Leading gas-development companies sampling water-supply wells within 4,000 feet of multi-well drill pads before and after drilling/hydraulic fracturing
- Over 15,000 well sites sampled for major cations and anions, metals, and methane



Dissolved methane in 1,700 “pre-drill” well samples (Molofsky and others ,2013)