Blackout in the Gas Patch CASE STUDY

JEANNIE MOTEN Avella, Washington County PA

Summary

The reasons why Carol Jean (Jeannie) Moten continues to live in Avella are the same ones that kept her parents there for decades. Country life in a tight-knit community means neighbors are willing to help each other out, and just up the hill there's a county park with space for families to walk and play.

But times have changed quickly in recent years as dozens of gas wells and facilities have sprung up nearby. Jeannie, her sister, and her mother live in separate homes within a block of each other, and the water problems they've each reported have been similar. Starting in 2008, the water from their private wells began running orange and black, fizzing, and tasting salty. Everyone developed red blotches on their skin after showering or washing their face.

The Motens then realized that they weren't the only ones in the area having shortness of breath, burning eyes and throat, rashes, dizziness, muscle cramps, and disorientation. A neighbor also said fine sand had started coming through pipes into her sink and washing machine. At night, the air would often get hazy and the smells of burning, chemicals, and sulfur would waft down from the park.

Our research on gas development in the area shows that there have been significant pollution events, blatant evasion of permitting requirements, and an absence of site planning and erosion and sedimentation controls. Although DEP has conducted inspections and issued violations, the agency never restricted operations or limited the expansion of well sites even when problems occurred.

Several of the wells near the Motens are adjacent to Cross Creek County Park and in a special protection watershed. Yet in permitting and overseeing the sites, the Department of Environmental Protection (DEP) appears to have ignored the heightened environmental protection that this designation implies. In particular, DEP issued a stream distance waiver to Atlas Energy—in effect giving a stamp of approval for not having obtained the proper

For more about the Motens, see:

Article on health and drilling links
http://stateimpact.npr.org/pennsylvania/2012/04/27/doctors-in-shale-country-search-for-answers-but-come-up-short/

Videos and documents on drilling in Cross Creek County Park
www.marcellus-shale.us/Cross-Creek-Park-Gas-Wells.htm

PHOTOS

ABOVE: Jeannie Moten and her mother Edna at home in Avella. Photo by Martha Rial

BELOW LEFT – RIGHT:

Capture from FLIR video of RR Lbros well pad. Photo by Frank Finan

Waste pit at well site. Photo by Frank Finan

Tanks venting. Photo by Frank Finan

Well site development. Photo by Frank Finan



permit *after* the company had already begun constructing wells just 76 feet from a stream designated as a High Quality Warm Water Fishery. DEP then took another "after the fact" action by issuing an erosion and sedimentation (E&S) permit long after one of the well sites was already far larger than the regulatory threshold.

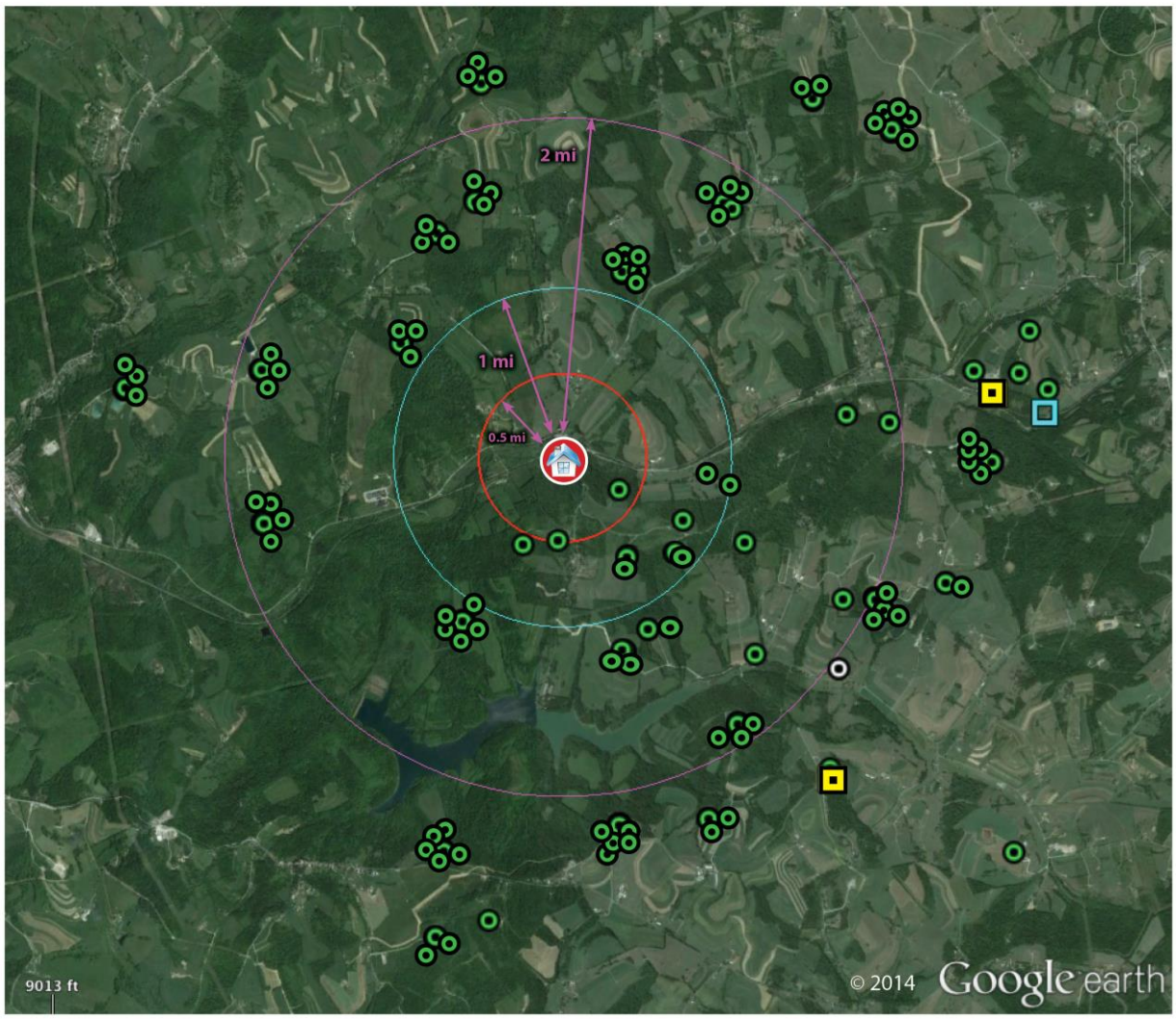
Documents found in hard copy gas well files indicate that several drilling pits containing contaminated waste have been buried near the Motens, but we did not find any evidence that DEP took steps to ensure that the waste was properly solidified and encapsulated, or that the pits haven't leaked and polluted groundwater. Over time, more development across the area has meant an increase in air emissions, including of substances with known health impacts like those reported by Jeannie Moten and others in her neighborhood.

The pollution and other environmental hazards caused by a cluster of nearby wells was clearly enough to get the attention of the US Environmental Protection Agency (EPA), which cited Atlas Energy in 2012 for violating both the US Clean Air Act through "accidental releases of hazardous substances" and the US Emergency Planning and Community Right-to-Know Act (EPCRA) by neglecting to "inform the public and emergency responders about hazardous and toxic chemicals in their communities."[1]

Despite the violations of both federal and state laws and a large number of complaints from residents in the area for several years, DEP has never conducted an investigation into potential damage to the area's drinking water supplies or conducted air testing near current drilling operations. Nor have the Motens and their neighbors been provided with any information or assistance regarding the potential impact of development and particular events on their water, air, and health. But thanks to private donations, Jeannie recently received an indoor air filter and her mother now has a "water buffalo" with monthly deliveries of clean water—steps that have helped the family to feel better.

Wells and Facilities Around the Moten home

Starting in July 2007 and ending in January 2009, nine unconventional gas wells were drilled within one mile of the Moten home. The number of unconventional wells jumps to 54 at a distance of 1-2 miles; these were drilled starting in February 2006 and continuing into July 2013.



KEY

- Unconventional gas well
- Conventional gas well
- Compressor station
- Gas processing plant
- House

Inspections and Violations

The following table shows inspections at oil and gas wells in the vicinity of the Moten home that DEP conducted from 2008-2013. Compared to other areas that Earthworks has analyzed, the number of inspections near the Motens has been moderate—but is still far below what would be expected given the DEP's own inspection policy.[2]

Table 1. Inspections at facilities in the vicinity of Jeannie Moten's home (2008-2013)

	Unconventional wells within 1 mile	Unconventional wells between 1 and 2 miles
Number of drilled wells	9	54
Number of Inspections	46	248
Average inspections per well	5.1	4.6
Wells with zero inspections	0	0
% of wells with zero inspections	0	0
Complaint inspections	7	32

Moten Events Timeline

The following events related to natural gas development occurring within one mile of the Moten home have been compiled from DEP inspection reports and other information available through file reviews, included in Pennsylvania's Environment Facility Application Compliance Tracking System (eFACTS) and Oil and Gas Compliance Database, and provided by local residents. Given that some inspection reports were missing from files and other documents are unavailable to the public, this timeline is not necessarily complete. For example, three inspection reports for the Cowden 48H well are listed in eFACTS but were not in the hard copy well file we reviewed, and DEP denied our Right-to-Know Law (RTKL) request to see them.

Table 2. Events related to natural gas development within one mile of the Moten home

	Event
10/1/08 & 10/29/08	**Cowden 46, 47, 48, 51, 53:** A DEP inspector realizes that although wells at this Cowden site have been drilled and are being constructed, Atlas Resources never obtained an Erosion and Sedimentation (E&S) control permit even though the "total disturbed area of this project is approximately 15 acres." (Such permits are required for sites 5 acres and larger.) He also notes that existing site stabilization measures are inadequate and issues violations. One month later, he notes that sediment is running off the site and that Atlas still doesn't have an E&S permit or a stream distance waiver; violations are issued.

10/29/08	**Cowden 46:** An inspection report indicates that at some point "A slide occurred at the site" and work has been done to stabilize the lower portions. It is working for now but a site of this size should be controlled by a more capable BMP [Best Management Practice]."
12/4/08	**Cowden 46, 47, 48, 51, 53:** A DEP inspector notes that E&S conditions at the site have been improved and that Atlas has submitted applications for both an E&S permit and a stream distance waiver "to construct a well site "less than 100 feet from the south fork of Cross Creek. Cross Creek is classified as HQ [High Quality] WWF [Warm Water Fishery]." The inspector notes he will approve the stream distance waiver. By this point, the site was already constructed and operational just 76 feet from the creek. DEP issues violations but also grants the waiver, noting "After the Fact" on the form. At the same time, DEP also approved a waiver for the burial of solid waste onsite.
1/20/09	**Cowden 47:** Atlas Energy notifies DEP about a spill of 50-75 gallons of diesel, after a piece of steel punctured a fuel tank. According to inspection notes, the well services company "reports that they were able to recover most of the spill…No fuel can be observed on the surface. Atlas will ensure that the affected soil is removed… I also noted an unrelated diesel spill that they state was caused by an overflow of the compressor fuel tank…I instructed them to address this small spill immediately." No violations are issued.
3/30/09	**Cowden 46:** A DEP inspector visits the site more than one month after a citizen complaint was filed about a condensate gas release. Despite the time lag, he notes that he "did not observe any contaminated areas" and "will contact Atlas to confirm cleanup." A violation is recorded but given the designation of "immediately corrected." Atlas' incident report confirms that the incident occurred on 2/20/09 and that 146 tons of contaminated soil was eventually removed from the site.
11/9/09	**Cowden 48H:** In response to a citizen's complaint, a DEP inspector samples his drinking water, but despite elevated manganese and iron, states that the results "did not suggest any impact from well drilling operations."
11/12/09	**Cowden 48H or 76** *(these wells are on the same pad and are both listed in DEP documents in relation to this event)***:** A DEP inspector conducting a routine inspection arrives to find a truck onsite cleaning up a condensate gas spill. According to his notes, it took four hours to remove more than 4,700 gallons of spilled gas. The sedimentation trap where the gas pooled was less than 50 feet from a drinking water imply s, but the inspector noted it "did not show any signs of contamination" and suggested that a barrier should be installed.
3/8/10	**Cowden 50, 51, 53:** Identical well restoration reports are filed that indicate the burial of 135x60x10 foot waste pits containing solidified drilling fluid, frac water, cement, and gel. This was done using a thinner (20 mil) liner than liners required by state oil and gas regulations (30 mil), part of a waste management waiver issued by DEP.
3/24/10	**Cowden 75:** A routine DEP inspection shows that the well site hasn't been properly restored in the required timeframe. Subsequent inspections in June and October indicate that this violation still hasn't been resolved. However, one year earlier, DEP had granted Atlas an "inactive status" permit for this well, under which restoration should have been completed.

4/1/10	**Cowden 47H:** A DEP inspector responds to notification by Atlas of a spill of "less than 5 gallons" of condensate gas. According to an inspection report, the operator "dug a pit, lined it, and placed all contaminated soil inside and covered it." Violations are issued. In a follow up visit over three weeks later, the inspector notes that, "the violations were handled promptly."
6/15/10	**Cowden 48, 50, 53, 76:** In response to a citizen complaint, a DEP inspector samples the complainant's water, noting that it is "clear with no odor" but that a towel used to wipe a water pitcher was stained brown. Test results show elevated manganese but the inspector concludes this "could not be connected to any drilling operation" and that the 5.6 mg/liter of methane detected was too low to warrant investigation.
7/29/10	**Cowden 47, 48H, 76:** Well restoration reports are filed for all three wells indicating the burial of 135x60x10 foot waste pits containing solidified drilling fluid, frac water, cement, and gel. This was done using a thinner (20 mil) liner than liners required by state oil and gas regulations (30 mil), part of a waste management waiver issued by DEP.
3/17/11	**Cowden 48H, 50, 53:** DEP conducts a "routine inspection" as a follow-up to a citizen complaint about noise, finding that the site and equipment all look fine.
7/5/11	**Cowden 47H:** Atlas and DEP enter into a Consent Assessment of Civil Penalty pertaining to the operator causing or allowing the discharge of production fluid/condensate gas onto the ground on 3/29/10.
1/17/13	**Atlas sends an "inactive well status" request letter to DEP** for 17 Cowden wells (including many of those near the Motens), stating that, "work is being performed on these wells in accordance with a Consent Agreement between Atlas and the US Environmental Protection Agency (EPA). Once the required work is complete, Atlas plans to return these wells to production." DEP grants the request on March 4. According to the EPA, Atlas paid about $85,000 to settle "alleged air and hazardous chemical violations" at sites in Cross Creek and Hopewell Townships and will audit them to ensure future compliance with federal and state environmental standards.[3]

Seven inspections were conducted in response to citizen complaints at wells within 1 mile of the Moten home. One of these inspections, at Cowden 46 in 2009, resulted in DEP issuing a violation to the operator. At wells located 1-2 miles from the Motens, DEP conducted 32 inspections in response to complaints and one of these, at the Cross Creek County Park 9H-A well, resulted in DEP issuing a violation. Both violations were related to the potential for polluting substances to reach waters of the Commonwealth.

In all, DEP has issued 12 violations for 8 wells within 1 mile of the Moten home (including the Cowden 46, 47H, 48, 48H, 51, 53, 75, and 76 wells). These violations were for several problems, including spills and sedimentation resulting in water pollution, drilling too close to surface water or a wetland, spills of residual waste, and failure to restore the well site within the required timeframe.[4]

Water Quality

In 2013, the Scranton Times-Tribune obtained DEP data on complaints filed by residents who suspected oil and gas drilling activities polluted or diminished the flow of water to their drinking water wells, which the FracTracker Alliance later compiled in a map.[5] According to DEP, the closest water complaint to the Moten home occurred 1.69 miles away—even though DEP has responded to complaints from the Motens and their neighbors and tested their water. Two records were included in the DEP data for water pollution complaints in the area (in December 2009 and January 2010); in both cases, DEP noted that water tests met drinking water standards except for manganese and did not find a link to oil and gas development.

In addition, according to a spreadsheet provided to Earthworks by DEP, between 2009 and 2013, 24 oil and gas-related complaints were filed for problems with water supplies in Cross Creek Township and classified as "resolved." An additional 15 such complaints were filed in Hopewell Township, including several less than 2 miles from the Moten. However, we were unable to obtain any information on the nature of the problems, how DEP responded, or what was meant by "resolved."

DEP has tested the water at the Moten family's three homes. The EPA also tested their water, but (according to Jeannie) has not provided any results to the family. Earthworks conducted two water tests at Edna Moten's (in November 2013 and January 2014), as well as at Debbie and Jeannie's homes in April 2014. The results from these tests and DEP date are summarized in Table 3.

Several of the tests conducted show iron, manganese, and pH at levels that exceeded federal secondary drinking water standards, which are set to protect aesthetic considerations such as taste, color, and odor but aren't considered to present a risk to human health.[6] EPA has also established a health advisory for manganese of 0.3 mg/L, stating that, "The health effects from over-exposure of manganese are dependent on the route of exposure, the chemical form, the age at exposure, and an individual's nutritional status. Regardless, the nervous system has been determined to be the primary target organ with neurological effects generally observed."[7]

EPA has also developed a one-day and 10-day health advisory of 1 mg/L of manganese for acute exposure.[8] The Edna Moten sample from January 2014 contained manganese at close to the one-day acute exposure level (0.95 mg/L), while the sample from her daughter's home (Debbie Peeples) from April 2014 exceeded this concentration.

It is also notable that tests of Edna Moten's water conducted by DEP in 2009 and Earthworks in 2013 showed similar results, including high pH, low iron, relatively low calcium, high sodium, and high methane concentrations. By the time of Earthworks' 2014 test at Edna Moten's, iron and calcium remained high, but pH, sodium, and methane had gone down. It's not clear what happened between the 2009/2013 and 2014 tests to cause the change in water quality, although (as described in the events timeline above) some nearby wells have been placed in inactive status since 2013.

Table 3. Moten family water tests. Earthworks (EW) and DEP samples compared to drinking water (DW) standards.

Parameter (mg/L)	E. Moten (9/7/09) DEP	E. Moten (11/13/13) EW	E. Moten (1/13/14)EW	D. Peeples (4/10/14) EW	J. Moten (4/10/14) EW	Approx. median concentration in typical PA groundwater*	Federal Maximum Contaminant Level (MCL) in Drinking Water	Federal or DEP Secondary MCL; Federal DW Health Advisory
Arsenic	NT	<0.0010	ND	ND	ND	No data	0.01 mg/L	
Barium	0.158	0.188	0.650	0.475	0.127	0.070	2.0 mg/L	
Bromide	NT	1.64	ND	ND	ND	0.016	None	
Calcium	1.9	3	33	47	57	No data	None	None
Iron	<0.2	0.2	4.5	7.5	0.1	0.20	None	FED: 0.3 mg/L
Magnesium	0.8	1.2	11.0	16.1	10.9	No data	None	None
Manganese	0.41	0.03	0.96	1.08	ND	0.01	None	0.05 mg/L
Potassium	<1.0	NT	NT	NT	NT	No data	None	None
Sodium	175	174	73	34	37	6.87	None	None
Strontium	0.09	0.11	0.43	0.36	0.23	0.26	None	FED HA: 4 mg/L
Chloride	34	34	52	65	131	5.3	None	FED: 250 mg/L
Nitrate	NT	NT	NT	ND	1.5	0.5	10 mg/L	None
Alkalinity	372	371	200	131	60	No data	None	DEP: 20 mg/L min.
TDS	482	460	339	348	104	No data	None	DEP: <500 mg/L av/mnth
pH	8.9	8.6	6.9	6.57	6.31	7.5	None	FED: 6.5 - 8.5
Methane	6.41	4.14	1.30	0.23	0.006	No data	None	None
Ethane	0.045	0.042	ND	ND	ND	No data	None	None

ND: not detected; NT: not tested. TDS: total dissolved solids. pH: measure of acidity/alkalinity (lower values are more acid).
* Pennsylvania State University. 2011. Summary of Drinking Water Samples Tested by the Penn State Agricultural Analytical Services Laboratory, 2007-2011.

Barium, bromide, strontium, methane, and other chemicals were detected at levels well below federal drinking water standards (which exist for only some of these substances). However, as summarized in Table 4, water from at least one, and in some cases all, of the samples from Edna, Debbie, and Jeannie's homes had **concentrations of barium, iron, manganese, sodium, strontium, and chloride higher than the median concentration typically found in Pennsylvania groundwater**.[9] It is possible that the area's groundwater is naturally high in these constituents—but it is also possible that gas development has had an impact, particularly in light of periodic fluctuations in concentrations.

Marcellus shale wastewater contains many different constituents, including chloride, sodium, barium, strontium and iron.[10] Barium was detected in Edna Moten's water at between 2.69 and 9.29 times the median concentration found in typical Pennsylvania groundwater, while bromide was more than 100

times the typical level.[11] Bromide is not usually found in undisturbed drinking water, but has been detected at relatively high concentrations in drilling wastes.[12]

According to the Center for Rural Pennsylvania, drilling activities can increase concentrations of iron and manganese in groundwater by disturbing aquifers.[13] Scientific study is currently underway to identify the chemical changes that can occur when methane enters water supplies and triggers sulfate reduction, a common anaerobic process that in turn increases pH levels and the production of both iron and manganese.[14]

Table 4. Chemicals detected above median concentration found in typical Pennsylvania groundwater.[15]

Parameter	E. Moten sample: 11/13/13 (expressed as a % of the median concentration in PA groundwater)	E. Moten sample: 1/13/14 (expressed as a % of the median concentration in PA groundwater)
Barium	269	929
Bromide	10,250	ND
Iron	100	2,250
Manganese	300	9,600
Sodium	2,533	1,063
Strontium	42	165
Chloride	6	10

ND: not detected; NT: not tested.

In 2012, Earthworks conducted water testing around 11 homes in Bradford, Sullivan, and Butler counties.[16] The levels of barium, methane, and ethane detected in the November 2013 Moten water test were higher than in any of the samples taken in that study, including methane at concentrations of 1.3 and 4.1 mg/L. There is no federal or Pennsylvania state standard for methane in drinking water. According to the US Geological Survery, concentrations of dissolved methane greater than 28 mg/L are potentially explosive, but concentrations greater than 10 mg/L can indicate that methane may be increasing to dangerous levels.[17] According to Penn State Extension, "Wells with methane concentrations below 10 mg/L are generally considered safe for use. However, any water well with a detectable concentration of methane should be routinely tested to ensure that the methane concentration is not increasing to a dangerous level."[18]

Air Quality

Emissions from wells within one mile of the Moten family are relatively low compared to other locations that Earthworks has studied. However, when compared to emissions from other facilities in Washington County, it becomes clear that nearby natural gas wells are significant sources of certain air contaminants. For example, in 2011, wells near the Moten family emitted 11.53 tons of Volatile Organic Compounds (VOCs)—more than the 11.18 tons of VOCs released from Allegheny Energy Supply's Mitchell Power Station.[19]

A single well site within a mile of the Moten family, Cowden 47H, has been a significant poilluter; according to detailed emissions data provided to Earthworks by DEP, a single tank at that site emitted

9.6 tons of VOC emissions in 2011.[20] If this well site were a different type of industrial emissions source, the operator would have had to have obtain a "state-only" permit or approval.[21] But DEP did not require such approvals, or related permit reviews, for unconventional gas wells until 2013.[22]

While there are no large facilities (e.g., compressor stations or gas processing plants) within two miles of the Moten family, four compressor stations and a gas plant are located 2.5-5 miles away. In 2012, these facilities together released more than 200 tons of Nitrogen Oxide (NOx), 75 tons of Carbon Monoxide (CO), and 82 tons of VOCs. When the gas wells within two miles of the Moten family are added in, emissions increased to 297 tons of NOx, 161 tons of CO, and 96 tons of VOCs. Such figures leave no doubt that regional air quality has been affected by gas development.[23]

Table 5. Emissions from compressor/gas plant facilities within 5 miles of the Moten home (DEP Emissions Inventory, 2012)

Compressor	Distance from Moten	CO	NOx	PM10	PM2.5	SOx	VOCs	Benzene	Ethyl-benzene	Formal-dehyde	n-Hexane	Toluene	Xylene	2,2,4-TMB*
Lowry	2.57	25	92	2.1	2.1	0.1	22	0.05	0.00	4.6	0.18	0.10	0.09	0.00
Nancy Stewart	2.58	16	61	1.9	1.9	0.1	25	0.10	0.01	3.3	0.41	0.15	0.19	0.00
Stewart Plant	2.86	20	11	0.7	0.7	0.0	12	0.09	0.01	4.4	0.35	0.15	0.17	0.01
Three Brothers	3.91	3	3	0.8	0.8	0.0	5	0.07	0.01	0.1	0.30	0.13	0.16	0.01
Dryer	4.70	11	42	1.2	1.2	0.1	17	0.11	0.07	2.2	0.53	0.13	0.10	0.02
TOTAL		**75**	**208**	**6.7**	**6.7**	**0.4**	**82**	**0.4**	**0.1**	**14.7**	**1.8**	**0.7**	**0.7**	**0.05**

TMB - trimethylbenzene

As seen in Table 6, when compared to emissions from other major facilities included in DEP's eFACTS database, the natural gas compressors and gas plant facilities within five miles of the Motens were among the top emitters of NOx, VOCs, benzene, formaldehyde, and n-Hexane in Washington County in 2012. All of these pollutants are associated with known health impacts, such as respiratory and lung function problems from the formation of ozone[24] and eye, nose, and throat irritation from formaldehyde.[25]

Table 6. Natural gas facilities near Moten as compared to eFACTS top emitters in Washington County, PA (DEP eFACTS database, 2012)

Rank	NOx	VOC	Benzene	Formaldehyde	n-Hexane
1	Mitchell Power Station	Regal Metal Manufacturing	Mitchell Power Station	Lowry Compressor	Dryer Compressor
2	Elrama Power Plant	Nancy Stewart Compressor	Dryer Compressor	Stewart Gas Plant	Nancy Stewart Compressor
3	Donora Chemical Plant	Lowry Compressor	Nancy Stewart Compressor	Nancy Stewart Compressor	Stewart Gas Plant
4	Lowry Compressor	Dryer Compressor	Stewart Gas Plant	Dryer Compressor	Three Brothers Compressor
5	Nancy Stewart Compressor	Mitchell Power Station	Three Brothers Compressor	Hartson	Washington Steel Plant

Earthworks conducted air canister tests at Jeannie Moten's house in both 2011 and 2013. Out of all of the household case studies developed for the associated report *Blackout in the Gas Patch*, one of these tests had the highest single benzene measurement (1.5 ug/m^3 in October 2011). On three of the sampling dates, toluene was also detected.

It is difficult to conclusively connect the benzene in the Moten air to natural gas development, in part because at the time of writing, DEP had not yet released 2013 air emissions data. We do know, however, that wells within two miles of the Motens released 0.04 tons of benzene in 2011 and 0.07 tons in 2012—volumes that were higher than benzene emissions from most other major facilities in Washington County in those years.[26]

EPA estimates that breathing air containing benzene at levels lower than those detected in Earthworks' samples over an entire lifetime would barely increase the risk of developing cancer.[27] However, given that our sampling represents a "moment in time," levels of benzene and other chemicals around the Moten family could well have been higher at other times. For example, certain emission events—such as surges in drilling, the venting and flaring of wells, and intense trucking of water and waste—could have triggered the onset of health symptoms. The Motens' health symptoms may also have been more acute than would be indicated by sporadic air testing, since 24-hour canisters potentially underestimate exposures and continual exposure to low levels of multiple chemicals can have an additive negative effect on health over time.[28]

Endnotes

[1] U.S. Environmental Protection Agency. "Atlas Resources to Pay $84,506 Penalty to Settle Alleged Environmental Violations." News Release, October 18, 2012. http://yosemite.epa.gov/opa/admpress.nsf/0/DB0B17030A4E369D85257A9B0055155F.

[2] The recommended frequency and type of inspections are outlined in DEP's "Inspection Policy Regarding Oil and Gas Well Activities," which was incorporated into the Pennsylvania State Code in 1989, prior to the unconventional shale gas boom. See Pennsylvania Code, Title 25, §78.901-906. www.pacode.com/secure/data/025/chapter78/subchapXtoc.html.http://www.pacode.com/secure/data/025/chapter78/subchapXtoc.html.

[3] US Environmental Protection Agency. "Atlas Resources to Pay $84,506 Penalty to Settle Alleged Environmental Violations." News Release, October 18, 2012. http://yosemite.epa.gov/opa/admpress.nsf/0/DB0B17030A4E369D85257A9B0055155F.

[4] Data from documents obtained through file reviews at DEP's Southwest Regional Office and DEP's eFACTS database (www.ahs.dep.pa.gov/eFACTSWeb/), Oil and Gas Compliance Report Database) and Compliance Database (www.depreportingservices.state.pa.us/ReportServer/Pages/ReportViewer.aspx?/Oil_Gas/OG_Compliance).

[5] Scranton Times-Tribune, May 19, 2013. "Gas Drilling Complaints Map." http://thetimes-tribune.com/news/gas-drilling-complaints-map-1.1490926

[6] US Environmental Protection Agency. "Secondary Drinking Water Regulations: Guidance for Nuisance Chemicals." http://water.epa.gov/drink/contaminants/secondarystandards.cfm.

[7] US Environmental Protection Agency. January 2004. "Drinking Water Health Advisory for Manganese." EPA-822-R-04-003. www.epa.gov/safewater/ccl/pdfs/reg_determine1/support_cc1_magnese_dwreport.pdf

[8] Ibid.

[9] The median concentrations for Pennsylvania are from Boyer, E., Swistock, B. ,Clark, J., Madden, M. and Rizzo, D. 2012. The Impact of Marcellus Gas Drilling on Rural Drinking Water Supplies. Center for Rural Pennsylvania.

[10] Hayes, T. 2009. Sampling and Analysis of Water Streams Associated with the Development of Marcellus Shale Gas. Final Report for Marcellus Shale Coalition prepared by Gas Technology Institute.

[11] The median concentrations for Pennsylvania are from Boyer, E., Swistock, B. ,Clark, J., Madden, M. and Rizzo, D. 2012. The Impact of Marcellus Gas Drilling on Rural Drinking Water Supplies. Center for Rural Pennsylvania.

[12] Ibid.

[13] Ibid.

[14] Glenn Miller and Ann Maest. Considerations for Determining the Source of Groundwater Contamination Associated with Hydraulic Fracturing. Paper prepared for the US EPA, 2013.

[15] The median concentrations for Pennsylvania are from Boyer, E., Swistock, B. ,Clark, J., Madden, M. and Rizzo, D. 2012. The Impact of Marcellus Gas Drilling on Rural Drinking Water Supplies. Center for Rural Pennsylvania.

[16] Earthworks 2012. Gas Patch Roulette: How shale gas development risks public health in Pennsylvania. http://health.earthworksaction.org.

[17] US Geological Survey. "Methane in West Virginia Groundwater." 2006. http://pubs.usgs.gov/fs/2006/3011/.

[18] Penn State Extension. "Methane Gas and Its Removal from Wells in Pennsylvania." http://extension.psu.edu/natural-resources/water/drinking-water/water-testing/pollutants/methane-gas-and-its-removal-from-wells-in-pennsylvania

[19] DEP eFACTS database. Search Facility Emissions using criteria for year, county, and pollutant. www.ahs.dep.pa.gov/eFACTSWeb/criteria_facilityemissions.aspx.

[20] Emissions data provided by DEP included data on operator and facility, and broke down emissions by source (e.g., tanks, fugitives, drill rig, completion, engines, blowdown/vent, heater, dehydrator).

[21] The DEP brochure "Understanding Air Permits in PA" says that a state-only permit is required if a facility has the "potential to emit" less than 50 tons of VOCs/year, but actually emits more than 8 tons per year. See www.dep.state.pa.us/dep/deputate/pollprev/Iso14001/Tools/Facility%20Environmental%20Issues%20Toolbox/AE%20Air%20Emissions/AE3%20Understanding%20Air%20Permits%20in%20PA.pdf.

[22] DEP. August 8, 2013. "DEP Finalizes Air Quality Permit Criteria for Unconventional Gas Well Sites." www.portal.state.pa.us/portal/server.pt/community/newsroom/14287?id=20104&typeid=1

[23] The five facilities are: Lowry Compressor Station (2.57 miles away), Nancy Steward Compressor Station (2.58 miles away); Stewart Compressor Station (2.86 miles away); Three Brothers Compressor Station (3.91 miles away); and Dryer Compressor (4.7 miles away). Data on emissions from these facilities can be found in DEP's "Air Emissions Inventory Data for the Unconventional Natural Gas

Industry." See www.dep.state.pa.us/dep/deputate/airwaste/aq/emission/marcellus/Nat%20Gas%20Emissions%202012%20-WellFarmStation_20140324.xlsx.

[24] US Environmental Protection Agency. "Health effects of ozone in the general population." www.epa.gov/apti/ozonehealth/population.html.

[25] US Environmental Protection Agency. "Formaldehyde." www.epa.gov/ttn/atw/hlthef/formalde.html.

[26] Facility with the highest benzene emissions in 2011: Allegheny Energy Supply Mitchell Power Station, 0.2316 tons; the next highest was 0.0002 tons from Dyno Nobel Inc. Facility with highest benzene in 2012: Allegheny Energy Supply Mitchell Power Station, 0.34 tons; the next highest was 0.01 tons from Regal Industrial Corp's Donora plant. Source: DEP eFACTS. Search Facility Emissions by year, county, and pollutant. See www.ahs.dep.pa.gov/eFACTSWeb/criteria_facilityemissions.aspx.

[27] US Environmental Protection Agency. "Benzene." www.epa.gov/ttn/atw/hlthef/benzene.html.

[28] David Brown, Beth Weinberger, Celia Lewis, and Heather Bonaparte. "Understanding exposure from natural gas drilling puts current air standards to the test." Reviews on Environmental Health, March 2014.