NATURE | NEWS: EXPLAINER

Is fracking behind contamination in Wyoming groundwater?

Questions about whether hydraulic 'fracking' is to blame remain as the US EPA prepares for peer review.

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04 October 2012 Clarified: 10 October 2012

Natural gas extraction via hydraulic fracturing has been linked to contamination in groundwater.
GETTY IMAGES

The US Environmental Protection Agency (EPA) sparked a firestorm in December last year when it released a draft report[1] suggesting that the use of hydraulic fracturing — or 'fracking' — to extract natural gas had contaminated groundwater near Pavillion, Wyoming. Industry officials have long denied that fracking affects groundwater, and Pavillion has become the first high-profile test of this claim. On 26 September, the US Geological Survey (USGS) released data showing the presence of groundwater contamination in the region[2]. Although the data would seem to support the EPA's assessment — as does an independent analysis released by environmental groups this week[3] — the survey did not seek to determine the source of the contamination. *Nature* examines the on-going debate and how it relates to broader questions about groundwater contamination from fracking across the United States.

How did this investigation begin?

After local landowners complained about the smell and taste of their water, the EPA began in 2009 to analyse the groundwater outside Pavillion. The agency tested the water in the shallow wells that tap the groundwater above the 169 gas-producing wells in the field; in two municipal wells in the town; and in several surface and deep wells that it drilled for monitoring purposes. It found evidence of contamination in both the shallow and deep wells, and attributed the shallow contamination to the 33 or so nearby surface pits used to store drilling wastes[1]. The pits could not, however, explain the contamination in the deeper groundwater.

What is the evidence that fracking contaminated the deep groundwater?

A range of hydrocarbons showed up in the deep wells, as did some synthetic organic chemicals associated with fracking fluids and drilling activities. The EPA also found high pH levels that could be explained by

potassium hydroxide, which was used in a solvent at the site. The agency also analyzed the evolution of the pollution plume to determine that groundwater seems to be migrating upward, suggesting that the source of contamination came from the gas production zone rather than the surface pits.

Officials with both industry and the state of Wyoming questioned the EPA's data as well as its interpretation, arguing that some hydrocarbons are to be expected through natural migration from the gas field. The state then asked the USGS to conduct a new analysis and provide the data to the state. The USGS provided those data last week[2]; it also sent samples to the EPA, which is conducting its own analysis.

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What do the latest results suggest?

The USGS provided only the raw data and no interpretation. An analysis released this week by two environmental groups found that the data support the EPA's original conclusion. A scientist who has investigated possible contamination at other sites, Rob Jackson of Duke University in Durham, North Carolina, says that multiple lines of evidence are certainly "suggestive" of fracking as a source of contamination.

Does this settle the debate?

No. Encana Corporation, an energy producer based in Calgary, Canada, that has wells in the field near Pavillion, maintains that neither the EPA draft report nor the USGS results provide any proof that drilling operations are to blame.

Is this case unique?

There have been allegations of groundwater contamination at other locations where fracking has taken place, but it is not yet clear how common the problem might be. It is less likely, for instance, in regions where the gas is very deep in the ground, such as in Pennsylvania, where production takes place at depths of 1,500 meters or more. In Pavillion, the gas wells are as shallow as 372 metres, while wells tapping groundwater are up to 244 metres deep; this makes communication between the two zones much easier.

A report in February by the University of Texas at Austin's Energy Institute found no evidence of contamination from fracking near wells in Texas, Pennsylvania or New York, but the university is currently reviewing that report after the lead scientist, Charles Groat, was accused of having a conflict of interest (see 'Unfortunate oversight').

A 2011 study in the *Proceedings of the National Academy of Sciences* by Jackson and his colleagues[4] documented high concentrations of methane and other hydrocarbons in groundwater close to fracking operations in Pennsylvania and New York. But Jackson says that the contamination may have come not from the fracking but from the wells themselves, which can serve as a conduit between geological formations if

not properly sealed.

What comes next?

The EPA plans to complete its analysis of the water samples and then turn over all of the data for an independent peer review later this year. In a press conference on Tuesday, Wyoming Governor Matt Mead said that the state would analyse the USGS data and then determine whether it needs to change its rules on fracking operations.

In parallel, the EPA is conducting a national assessment of environmental and public-health issues associated with fracking and expects to produce an initial report later this year.

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Clarifications

Clarified: An earlier version of this story did not make clear that an analysis of USGS data by environmental groups found that the data are consistent with but do not confirm - with EPA conclusions about water contamination due to fracking. This has been clarified.

References

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Comments

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Sherif Hindi said: Induced hydraulic fracturing is a technique used to increase the released petroleum and/or natural gas. This type of fracturing creates fractures from a wellbore drilled into reservoir rock formations. Potential environmental impacts, including contamination of ground water, risks to air quality, the migration of gases and hydraulic fracturing chemicals to the surface, surface contamination from spills and flowback and the health effects of these factors. For these reasons, hydraulic fracturing has come under scrutiny internationally, with some countries suspending or even banning it. Hydraulic fracturing has raised environmental concerns and is challenging the adequacy of existing regulatory regimes. These concerns have included ground water contamination, risks to air quality, migration of gases and hydraulic fracturing chemicals to the surface, mishandling of waste, and the health effects of all these. Accordingly, a fair decision must be regarded for selecting either profit or human health, especially when the petroleum projects approaches to residential communities. However, accurate fracturing monitoring must be regarded by measuring of the pressure and rate during the growth of a hydraulic fracture, the fluid properties along with geology information that provide the simplest monitoring method. In addition, injection of radioactive tracers is sometimes used for this monitoring task. Furthermore, microseismic monitoring is sometimes used to estimate the size and orientation of hydraulically induced fractures by placing an array of geophones in a nearby wellbore. Tiltmeter arrays, deployed on the surface or down a well, provide another technology for monitoring the strains produced by hydraulic fracturing. Dr. Sherif Shawki Zaki Hindi King Abdull-Aziz Univ. Saudi Arabia

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TECHNICAL MEMORANDUM

April 30, 2012

Review of DRAFT: Investigation of Ground Water Contamination near Pavillion Wyoming
Prepared by the Environmental Protection Agency, Ada OK

Prepared by: Tom Myers, Ph.D.
Hydrologic Consultant
Reno NV

SUMMARY AND RECOMMENDATIONS

After consideration of the evidence presented in the EPA report and in URS (2009 and 2010), it is clear that hydraulic fracturing (fracking (Kramer 2011)) has caused pollution of the Wind River formation and aquifer. The EPA documents that pollution with up to four sample events in the domestic water wells and two sample events in two monitoring well constructed by the EPA between the level of the domestic water wells and the gas production zone. The EPA's conclusion is sound.

Three factors combine to make Pavillion-area aquifers especially vulnerable to vertical contaminant transport from the gas production zone or the gas wells – the geology, the well design, and the well construction. Natural flow barriers are not prevalent in this area, so there are likely many pathways for gas and contaminants to move to the surface, regardless of the source. There is also a vertical gradient, evidenced by flowing water wells, although its magnitude and extend are undefined, to drive advective vertical transport. The entire formation is considered an underground source of drinking water, but 169 gas wells have been constructed into it; this is fracking fluid injection directly into an underground source of drinking water.

The well design is poor because the surface casing does not extend below the level of the water wells, as is required in many other states, and because the wells contain substantial borehole lengths without surface casing or cement between the production casing and the edge of the borehole. This allows vertical transport of gas and fluids and decreases the protection against leakage during fracking or gas production. Third, the EPA documented many instances of sporadic bonding, which simply means the cement does not completely seal the annulus between the production casing and the edge of the borehole. This provides pathways which could allow gas and contaminant transport along the well bore.

The EPA also appropriately accounted for the potential that their monitoring well construction could have explained the contamination. "Since inorganic and organic concentration patterns measured in the drilling additives do not match patterns observed in the deep monitoring wells and because large volumes of ground water were extracted from the wells during development and prior to sampling, it is unlikely that ground-water chemistry was at all impacted by drilling additives."(EPA, 2011, p 7).

The EPA also demonstrated that the inorganic geochemistry in the monitoring wells is substantially different than that which would occur naturally in the area, and that the enrichment of numerous constituents is most likely due to the interaction of fracking fluid with the groundwater near the sampled well. This is particularly true for the elevated levels of potassium, chloride, and pH.

Any of the three contaminant transport pathways suggested by the EPA could be responsible for the contamination moving from the fracking zone to the drinking water wells. The EPA has also presented evidence that contamination in surface ponds has not caused the contamination in the water wells or their monitoring wells.

The situation at Pavillion is not an analogue for other gas plays because the geology and regulatory framework may be different. The vertical distance between water wells and fracking wells is much less at Pavillion than in other areas, so the transport time through the pathways may also be low compared to other gas plays. It is important, however, to consider that the pathways identified at Pavillion could be applicable elsewhere (Myers, 2012; Osborn et al, 2011). In addition to improving and enforcing the relevant regulations, monitoring the pathways between the target formation and aquifers should be standard at all gas plays with fracking.

The following recommendations would improve the analysis and continue the study into the future made throughout this review.

1. The EPA should continue data collection to better verify the sources and map the potential contaminant plumes.
2. EPA should map the gas production wells according to their construction date. The EPA should also compare the locations of observed contamination with the nearby well construction dates to estimate the travel times from the sources to the well receptors.
3. The EPA should map the depth to water prior to sampling in the water wells. Using this, they should map vertical gradients and correlate these gradients to areas with contaminants most likely sourced to deep aquifers.
4. The EPA should install deeper monitoring wells near the shallow pits to better map the depth of the plume emanating from those pits.
5. Data collection should continue so the results can be replicated. An additional, deeper monitoring well should be constructed in the gas production zone between the existing monitoring wells to determine the vertical gradient and estimate the rate of vertical flow.
6. The EPA presents no evidence regarding the extent that fracturing extends above targeted formations. It may not be possible to prove whether this occurred at this site, but the EPA should at least discuss the possibility. It would be useful to perform some simple testing to map the extent of fractures, as described by Fisher and Warpinski (2010).

INTRODUCTION

The Environmental Protection Agency (EPA) has released a study of groundwater contamination in the Pavillion gas play in west-central Wyoming. Their preliminary conclusion is that gas well development and hydraulic fracturing (fracking (Kramer, 2011)) has caused the contamination. The EPA report is in draft form and is open for comment until March 12, 2012. This technical memorandum reviews the EPA report. This review was prepared with support from the Natural Resources Defense Council, Wyoming Outdoor Council, Earthworks, Oil and Gas Accountability Project and Sierra Club.

This review discusses in detail the appropriateness of the study design, methodology, execution, results, and interpretation and the reasonableness of the conclusions. It specifically follows and considers the EPA's "lines of reasoning" approach used to reach its conclusion.

STUDY AREA

The study area is in the Pavillion gas field in west-central Wyoming. It lies northeast of the Wind River Range. The general geology for uppermost 1000 meters (m) is the Eocene-aged ((56 to 34 million years before present) Wind River Formation, which is interbedded sandstone and shale with coarse-grained meandering stream channel deposits. The presence of stream channel deposits indicates that the formation has been carved by river beds which left fluvial deposits interspersed among formation layers These fluvial deposits often provide connectivity among formation layers and can fragment otherwise continuous sedimentary layers.

The area has experienced gas development since the 1960s, with 169 gas wells constructed in the study area. EPA Figure 2 shows the gas well construction chronology. There were three main periods of construction – 1963-65, 1975-83, and 1998 – 2006, with each subsequent period having more new wells constructed than the previous period. EPA does not specify when fracking first occurred, however.

Recommendation: Add a map of gas production wells coded for the year or time period during which the well was completed (or fracking occurred if substantially different). This would allow an assessment of travel time for contaminants to flow from production zones to the monitoring wells and domestic wells.

The US Geological Survey studied the water resources on the Wind River Reservation (Daddow 1996), which surround this study area (but does not include it). The Wind River Formation is the primary source of drinking water on the reservation. Daddow's (1996) description of the formation indicates that the formation consists of interbedded shale and sandstone with extremely variable permeability that could lead to highly variable contaminant loads throughout the formation (Osiensky et al 1984).

Recommendation: A more detailed description of the geology and hydrogeology of the area, perhaps based on the relevant Geological Survey reports would provide more insight regarding geochemical trends as found by the USGS.

STUDY LAYOUT AND DESIGN

EPA started this study in response to citizen complaints regarding contamination in their water wells. EPA established dedicated monitoring wells after two rounds of sampling various water wells rather than prior to construction of the gas wells. For much of their study data, the EPA had to use sample data collected from existing water wells. Water wells are not the best tool for monitoring groundwater quality because, even if the well construction is of similar quality to a dedicated monitoring well, water wells have much longer screens, or open intervals, than do monitoring wells. They screen the most productive formation layers, usually based on observations made during drilling, to maximize the pumping rate while minimizing the drawdown. Wells drilled specifically for monitoring wells also screen productive zones, but target the screen to a specific zone, usually 20 feet or less thick, so that the sample represents a given aquifer level.

Samples from water wells are therefore a mixture of water from all productive zones of the entire open interval, weighted according to the transmissivity of each zone. A domestic water well sample is useful for determining whether a contaminant exists at some point in the aquifer, but a dedicated monitoring well is necessary to determine which layer is contaminated.

EPA established two dedicated monitoring wells to supplement the data obtained from the water wells. The new monitoring wells were primarily screened below the level of the water wells (Figure 1) and above the gas production wells to "differentiate potential deep (e.g., gas production related) versus shallow (e.g., pits) sources of groundwater contamination" (EPA p 5). The EPA established just two monitoring wells due to a limited budget (Id.). EPA placed the monitoring wells' screened interval along the conceptualized vertical pathway between the potential contaminant source (i.e. the production wells and/or zone) and the water wells. The monitoring wells were designed appropriately to detect and monitor contaminant movement upward from the production zone to the water wells; if the monitoring wells had been constructed at the same depth as the water wells, they would not have added substantial useful information.

Figure 1 (EPA Figure 3) shows that domestic water wells in the regions are screened at all levels down to about 250 m, or more than 800 feet, with half of the wells being deeper than 300 feet, similar to the depths found by Daddow (1996) in other areas of the aquifer. However, the EPA states the information source was from the State Engineer *and* homeowner interviews (EPA p 2). It is unclear whether both were used for each well. It is my experience that homeowners have a poor concept of the depth of their well unless they have paperwork that documents it.

Recommendation: The EPA should provide more information about the source of its water well construction data, showing it in EPA Table A1.

The following table summarizes in general terms the wells that were sampled during each sampling phase (other media were also sampled but not included in this table). It is apparent that the wells sampled in phases subsequent to the first phase depended in part on the results of the prior phases.

Phase	Date	Domestic and Stock Wells	Municipal Wells	Stock Wells	Monitoring Wells	Comments
I	3/09	35	2	0	0	
II	1/10	17 (10 previously sampled)	2	4	0	This phase came about because EPA had detected methane and dissolved hydrocarbons during Phase I.
III	10/10	3 (2 previously sampled)	0	0	2	Gas samples also collected from the well casing of EPA's two deep monitoring wells.
IV	4/11	8 previously sampled	0	3 previously sampled	2	Added glycols, alcohols, low molecular weight acids

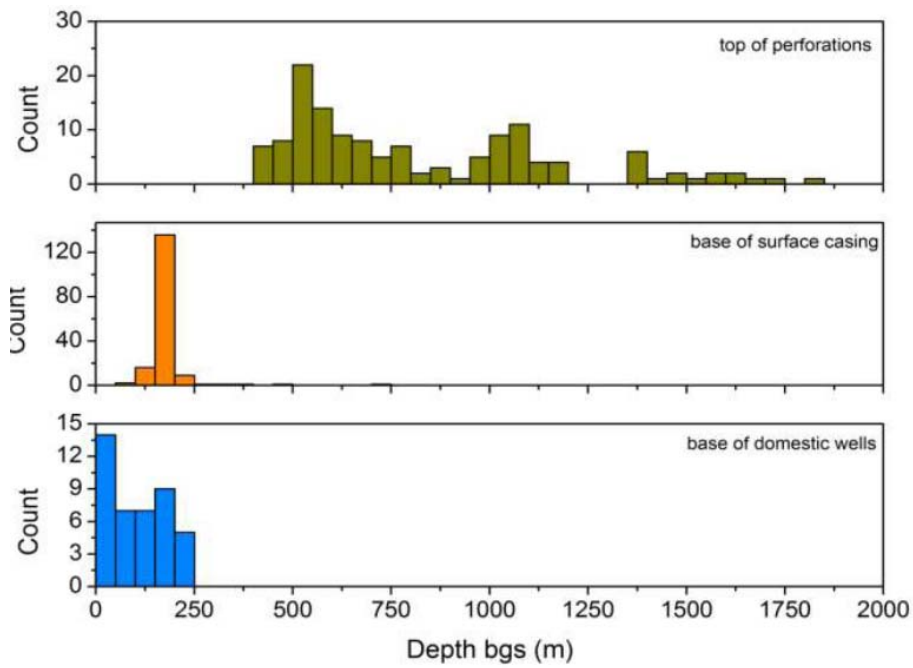

Figure 1: Snapshot from EPA (2011) Figure 3 showing frequency of depth for gas wells (top), surface casing for gas wells, and base of domestic wells.

EPA Table A1 lists the wells and the phase during which they were sampled, broken into eight data types.

1. anions and alkalinity
2. metals
3. alcohols and VOCs
4. low molecular weight acids and glycols
5. semi-volatile organic compounds (SVOCs), pesticides, PCBs, and tentatively identified compounds (TICs);

6. gas/diesel related compounds, and hydrocarbons
7. bacteria
8. fixed gases, heavy hydrocarbons, dissolved carbon, and gas and water isotopic ratios

EPA Table A2a presents the geochemical results – anions, cations, and alkalinity. Unfortunately, this table does not consistently state in which phase the initial sample was taken. Additional samples are identified with a suffix on the sample number. The other data tables in Appendix A provide results by phase, but some results are found only in other reports, including URS (2009 and 2010).

URS (2009) reports the Phase 1 sampling (water wells only) in their Table 9, which shows concentration of SVOC contaminants, including caprolactam at 1.4 ug/l at PGDW20, dimethylphthalate detected at nine wells, and Bis (2-ethylhexyl)phthata at 9.8, 6.4 and 12 ug/l in PGDW25, -20 and -14[1], respectively, and detect levels at ten other wells. Total purgeable hydrocarbons were 26 and 25 ug/l in wells PGDW05 and PGDW30, respectively. Measurable methane concentrations were found in 8 wells. Total purgeable organics are generally gasoline and diesel range organics. PGDW25 is one of the deeper wells at 243.8 m below ground surface (bgs) and PGDW05 and -30 are at 64.0 and 79.2 m bgs, respectively. URS (2010) reports the Phase 2 sampling in more detail. It shows more than 20 wells with detectable levels of a variety of semi-volatile organics (URS 2010, Table 9). The report does not assess these detects with the depth of the well, but a quick glance suggests that most of them are on the deeper half of the domestic wells. An exception is PGDW39, reported to be just 6.1 m deep, although the EPA should consider whether "6.1" is correct because if so it would be tens of meters shallower than any other water well in the aquifer.

Recommendation: The EPA should present and discuss the correlation of contaminant detects in the domestic wells with depth.

EPA based this study on four sample events including various subsets of domestic, municipal, and stock wells and two sample events in the monitoring wells. A reasonable question is whether the number of samples is sufficient for developing an opinion? A time series would help to identify a trend, but is not necessary to establish presence/absence. Objections to this data on the basis of there being just two samples are without merit – simple presence of a substance that would not naturally occur in the aquifer, if other causes can be eliminated, is sufficient to reach a preliminary conclusion that fracking fluid has affected the aquifer. However, the EPA should continue the sampling to determine whether the concentrations are trending higher, or not, and determine how or whether the plume expands.

TRANSPORT PATHWAYS

The EPA identifies three potential pathways for contaminants to reach the water wells from the fracking (EPA, p 32).

- Fluid and gas movement up compromised gas wells.

[1] The table did not highlight the values at PGDW14 and -20 as being exceedences.

- Fluid excursion from thin discontinuous tight sandstone units into sandstone units of greater permeability.
- Out-of-formation fracking, whereby new fractures are created or existing fractures are enlarged above the target formation, increasing the connectivity of the fracture system.

The EPA does not conclude which or whether any of these pathways actually facilitated the contamination at Pavillion, although arguments throughout the document (and reviewed in this report) support the potential for any of them. EPA correctly notes that for all three pathways there would be a correlation between the concentration of gas in the water wells and the proximity to gas well, as found by Osborn et al (2011) in the Marcellus shale in Pennsylvania. They also note that for all three pathways, "advective/dispersive transport would be accompanied by degradation causing a vertical chemical gradient" (EPA, p 32) as discussed in other portions of the report. In other words, with increasing distance from the source, both vertical and horizontal, the contaminant concentration would decrease. This would be due in part to chemical degradation, dispersion of a finite mass over a larger volume, attenuation due to chemicals adsorbing to soil particles, and dilution by mixing with groundwater..

The following sections consider evidence from various aspects of the EPA report in context of the pathways.

Lithologic Barriers

Very low permeability layers can prevent or impede the upward movement of fluid or gas from depth to the water well zone, which in the Wind River Formation is the upper 250 meters (based on the reported water well depth). Extensive layers of shale are often sources of gas and/or capstones, which prevent gas in underlying sandstone from escaping to the surface. However, the shale must be horizontally extensive and not fractured to be an effective seal, which is not the situation in the Pavillion field as quoted above. The formation is most productive (for gas) at its base with gas trapping occurring in "localized stratigraphic sandstone pinchouts on the crest and along flanks of a broad dome" (EPA p 2).

Hypothesis: The lithology in the Pavillion area does not prevent the vertical movement of gas or contaminants to the surface because it is either not sufficiently extensive or impervious. EPA claims there is no "lithologic barrier … to stop upward vertical migration" (EPA p viii) and also that "there is little lateral and vertical continuity of hydraulically fractured tight sandstones" (Id.).

Evidence: EPA presented a lithologic cross-section (Figure 20) showing mapped shale layers, production, water, and monitoring wells and the points where the production wells had been fracked. EPA found that the lithology is "highly variable and difficult to correlate from borehole to borehole" (EPA p 15). "Sandstone and shale layers appeared thin and of limited lateral extent" (Id.). Pathways could go around the intermittent shale so that contaminants in a given monitoring well may not result from the nearest production well. Pathways for movement through sandstone could be tortuous (EPA p 37); vertical pathways through sandstone could be more tortuous than horizontal pathways because the particles in sandstone tend to be elongated with the longer side being horizontal.

Fracking has occurred for up to 45 years, so there is potential for many pathways from various sources to a receptor well. The travel time to a given point could be any time period up to 45 years. Additionally, out-of-formation fracking occurring at any time could have shortened the pathway.

Conclusion: The lithology in most areas would not prevent the vertical movement of contaminants to the water wells because of the lateral variation.

Vertical flow and gradient

In order for contaminants to move from the fracked zones or from deep well bores to surface aquifers, there should be a vertical hydraulic gradient. Lacking such a gradient, movement could still be possible due to lateral dispersion and upward concentration gradients, but it would be much slower.

Hypothesis: There is upward flow in the Pavillion gas field that would support advection of contaminants associated with fracking fluids to the monitoring and water wells.

Evidence: In the Pavillion area, there are flowing wells, which would indicate an upward gradient, at least at depth, which could drive vertical advection, or contaminant transport with the groundwater flow . Daddow (1996) also documented flowing wells in other areas of the Wind River Range, with the depth range from 225 to 450 feet bgs. EPA uses PGDW44 as an example (p 36). This water well lies near the middle of the field near MW01. MW01 showed a depth to water equal to 61.2 m at the beginning of a purge for sampling (p 11 and Figure 8). MW02 had depth to water of 80.5 m (p 12). The depth to water in the monitoring wells does not support the idea of an upward gradient, but being the only wells at that depth, the data is not conclusive. Table A1 reports the PGDW44 well depth is 228.6 m; PGDW25 is deeper, at 243.8 m bgs. MW01 is just 10 m deeper. There is apparently an upward gradient at that point because the well is flowing, but the analysis could be improved, as follows.

EPA documents that the shallower monitoring well has more natural breakdown products of the organic contaminant like BTEX or glycol that are found in the deeper monitoring well and in fracking fluids (p 36). It suggests that the contaminants in the shallow well are derived from the natural breakdown of the contaminants found in the deeper well. This could only occur if the wells represent a vertical flow path, which they do and therefore these findings support the hypothesis of upward movement.

The gas found in the deep Wind River Formation is chemically similar to gas in the underlying Fort Union Formation suggesting that gas in the Wind River Formation has naturally moved upward until captured in localized capstones, or “localized stratigraphic sandstone pinchouts” (EPA, p 2). EPA concludes that differences in gas composition and isotopes support the hypothesis of upward migration through the various layers in the Wind River formation (p 29). The fraction of ethane and propane in the gas from domestic wells is mostly less than in the produced gas, but the isotopic composition is clearly thermogenic, which suggest there is an ongoing “preferential loss of ethane and propane relative to methane” (p 29, 38). This evidence supports the hypothesis of upward fluid and gas movement.

Vertical movement could occur in the absence of a vertical gradient, if the pressurization caused by the fracking is sufficient and there is a poorly developed well bore nearby. Contaminants can migrate

quickly upward through a leaky borehole due to the transient pressure gradient across an aquitard created by the fracking pressure (Lacombe et al, 1995).

Conclusion: There is evidence to support the concept of upward movement in the area, but it is not conclusive. The EPA should complete more studies documenting the vertical hydraulic gradient throughout the area.

Recommendation: The EPA report should document the depth to water in the domestic wells prior to sampling so that they could map water levels for different well depths and determine the zones of upward gradient.

Contamination from shallow pits

The presence of shallow disposal pits is an alternative source of contamination. EPA notes that there are 33 shallow pits that had been used for the "storage/disposal of drilling wastes, produced water, and flowback fluids in the area of investigation" (EPA p 17). As part of this study, the EPA communicated with stakeholders to further determine the location of pits. Shallow monitoring wells have found very high concentrations of several contaminants that were also found in deeper water wells and the EPA monitoring wells. These pits could have received the detritus of fracking operations in the past.

Hypothesis: Contaminated water seeping from these pits could be responsible for the observed contamination.

Evidence: Shallow monitoring wells that had been installed previously for reasons not associated with this project (EPA, p 11) are reported to have very high contaminant concentrations, although this data is not well summarized in the report. The shallow monitoring wells are only 4.6 m bgs (EPA p 17), so there is little information about how deep the contamination extends beneath the pits. Assuming the pits are some distance away from homes and people avoided them when constructing their water wells, it is possible the shallow disposal pits are sources of contamination beyond the level the EPA considers shallow, or 31 m bgs (Id.).

Irrigation could help to contain the contamination near the shallow pits because they would be located in low recharge areas, either by design or in comparison with irrigated fields. It would be unlikely that the pits would have been constructed within irrigated fields, so the seepage from the pits may be much less than the seepage beneath irrigated fields because of the continuous application of water to the field, and for a much shorter time period. Irrigation water would have seeped deeper and faster due to the likely higher rate of application and effectively diluted or prevented the deeper circulation of seepage from the pit.

Conclusion: The EPA concludes that these shallow pits are not the source of contaminants found in deeper water wells. Because there is little contamination in intermediate-depth wells, their conclusion is sound, but the document would benefit from more analysis and discussion.

Recommendation: The EPA should document more fully the contaminant plumes near the pits. Specifically, deeper monitoring wells near the pits should be constructed to construct a contamination

profile beneath the pits. Better investigation of the pits as a source would also facilitate the remediation of the groundwater near those pits.

LINES OF REASONING

The EPA used a line of reasoning analysis regarding the presence of fracking fluid constituents and gas in monitoring wells in support of their preliminary conclusion that fracking has contaminated aquifers in Pavillion Wyoming. This is critical because the conclusion is not just that leakage from the wells or spills caused contamination, but that the fracking process itself caused the contamination. EPA deemed the multiple lines of reasoning approach necessary due to the complexity in detecting contaminants in groundwater from deep sources. This section critically reviews each of the EPA's lines of reasoning.

High pH Values

The EPA monitoring wells both have very high pH, ranging from 11.2 to 12.0, which is much higher than the level seen in the domestic water wells in the Wind River formation. EPA concluded the high pH was due to hydroxide (OH) which indicated the addition of a strong base to the background water (EPA p xii). EPA's reaction path modeling suggested that the addition of just a small amount of potassium hydroxide to the sodium-sulfate waters typical of deep portions of the Wind River formation would cause such a pH change; EPA concludes from the modeling that the typical groundwater in the Pavillion aquifer "is especially vulnerable to the addition of a strong base" (EPA p 20).

Potassium hydroxide was used as a crosslinker and solvent for fracking the production wells in the area (EPA p 33), which could be a source of the OH to increase the pH of the water in the area of the production wells.

The use of soda ash as a drilling additive when drilling the monitoring wells, often to control the pH, is a possible alternate explanation for the elevated pH[2]. Soda ash is 100% Na_2CO_3. At a 1:100 mixing ratio with water, the pH of dense soda ash was 11.2 (EPA Table 2). The recommended ratio for use in fracking fluid is 1:100 to 1:50 (EPA Table 1). The pH of drilling mud varied between 8 and 9. The concentrations of neither sodium nor carbonate are abnormal in the monitoring wells. If the soda ash did separate from the drilling mud, mixing with background groundwater would further dilute it so that the pH would be less than observed at the 1:100 mixing ratio.

EPA Figure 12 verifies these pH values are higher than in the domestic wells, but also shows they fall on the general trend of pH with elevation of the well open interval. Based on this information, it is not possible to conclude that the high pH is not natural, but the EPA's conclusion appears to be justified based cumulatively on all of the facts concerning pH. EPA should consider geophysical logging completed by the industry if it includes pH logs to improve their analysis; such logs could provide pH values for deeper areas that could be compared with the pH values for their monitoring wells.

[2] http://www.halliburton.com/ps/default.aspx?navid=125&pageid=60&prodgrpid=MSE%3a%3a1053024648177449, visited 1/13/12

Chemistry in the shallow wells has been affected by irrigation with Wind River water. This irrigation water has very low total dissolved solids (TDS) and neutral pH (<8) (EPA Figure 11) but the other shallow groundwater wells show that the irrigation water picks up contaminants as it seeps.

The methods used to collect samples probably minimized contamination causing high pH in the monitoring wells. EPA purged the monitor wells until pH stabilized, a process which would minimize the potential that any residual contamination from well development would have been sampled.

EPA's analysis associated with Figures 11 and 12, explaining the shallow water geochemistry, is accurate and useful. It utilizes data from all of the wells in the area and surface waters to show water chemistry trends through the study area. It also shows how EPA's monitoring wells differ substantially from the general trends, supporting the conclusion that elevated pH in water samples from EPA's deep monitoring wells was likely caused by contamination with hydraulic fracturing chemicals.

Elevated potassium and chloride

The monitoring wells both have concentrations of K and Cl much higher, 14 to 18 times, than the domestic water wells (EPA p 34). Potassium concentration ranged from 43.6 to 53.9 mg/l and Cl concentration averaged 466 mg/l (Id.). The drilling additives reported by EPA to have been used at Pavillion had a much lower concentration for both anions. The fracking fluid contained several compounds with high concentrations of both ions (Id.). Therefore, the high concentrations of K and Cl suggest contamination with fracking fluid.

The chloride concentration data plotted in EPA Figure 12 shows clearly that Cl concentration in two of the three samples from EPA's deep monitoring wells are much higher than those in domestic wells, and EPA correctly assesses there must be a cause other than natural variation for the high concentrations. However, in this case I disagree with EPA's assessment that "regional anion trends tend to show decreasing Cl concentrations with depth" (EPA p 19) because EPA Figure 12 shows little variation with depth although there are a couple of high concentration outliers near the surface. Regardless of the interpretation of trend, concentrations from the EPA monitoring wells plot far higher than the Cl data from domestic wells.

The chloride concentrations reported from the EPA monitoring wells are also much higher than reported by the USGS in their Wind River study (Daddow 1996). He describes the formation water as having TDS concentration as high as 5000 mg/l, but Cl is a small proportion of that. He also reported that the highest Cl concentration on surface water sites was less than about 30 mg/l, so assuming the river recharges the alluvial aquifer, the source of the groundwater is relatively clean with respect to chloride. Cl concentrations at EPA's monitoring wells are much higher than the regional values reported by USGS in either ground or surface water on the Wind River Reservation, and are unlikely to be properly considered "naturally occurring".

For potassium, it is much clearer that the monitoring well concentrations exceed the domestic water well concentrations by many times (EPA Figure 12, p 20).

There is too little of either K or Cl in drilling mud or additives for it to have been the source or cause of the enrichment in the monitoring wells. Also, purging prior to sampling occurred until the specific conductivity (SC) of the purged water reached a relative steady state (EPA Figure 9). K and Cl both contribute to the SC of the water being sampled. Any potential contamination due to well construction or development has most likely been purged from the system.

The high K and Cl concentrations are clearly present in the formation water near the monitoring wells. Without a natural source as explanation, the mostly likely source is the fracking fluid which used compounds that have high concentrations of both anions. EPA has reasonably concluded the most likely source of elevated K and Cl is fracking fluid.

Detection of synthetic organic compounds

The EPA found in the monitoring wells significant concentrations of isopropanol, diethylene glycol, triethylene glycol, and tert-butyl alcohol (TBA) (in MW02). TBA was not directly used as a fracking fluid, but "is a known breakdown product of methyl tert-butyl ether and tert-butyl hydroperoxide". The first three products are found in fracking fluid based on the material safety data sheets (MSDSs) analyzed by EPA, but the parent compounds of TBA have not been reported as such; importantly, MSDSs, which are the source of the fracking fluid additives lists in the report, do not list all chemicals because the formulas are proprietary. That a chemical is missing from the list of additives is not evidence they were never in fracking fluid.

Isopropanol was found in "concentrated solutions of drilling additives" at concentrations much lower than detected in the monitoring wells (EPA p 35) and the others, glycols and alcohols, were not used for drilling.

None of these compounds naturally occur in groundwater. The EPA is correct in its conclusion that there is no acceptable alternative explanation and the most likely source of these contaminants is fracking fluid.

Detection of petroleum hydrocarbons

EPA detected benzene, toluene, ethylbenzene, and xylenes (BTEX), trimethylbenzenes, and naphthalene at MW02 (EPA, p 35). They detected gasoline and diesel range organics at both monitoring wells (Id.). These are not found in drilling additives, but the MSDSs showed a long list of additives in the fracking fluid that could be the source of the contamination just cited (EPA p 35, 36). For example, a BTEX mixture had been used in the fracking fluid as a breaker and a diesel oil mixture was used in guar polymer slurry (Id.).

EPA rejects alternative explanations that claim that substances, used on the well or pump, caused these contaminant detections. Specifically, the agency points out that the contact time for water with the well or pump during purging and sampling would be so low that contamination would be unlikely, especially after purging. This would be especially true for the Phase 4 sampling which would have occurred after

the well had been purged for sampling twice and had several months of natural groundwater flow through it.

An alternate explanation considered by EPA is that the constituents are due to the groundwater being above a natural gas field. In fact, the EPA has noted that historically some wells encountered gas at levels shallower than the monitoring wells. EPA encountered methane while logging MW01 (EPA p 11). EPA notes that the gas from the Wind River formation is "dry and unlikely to yield liquid condensates" (EPA p 36). They also argue that the monitoring wells have substantially different compositions of liquid condensates, which would not result if they came from a common source of gas. The explanation is reasonable, unless there is a variation with depth. Because these contaminants occur only at low concentrations in the deepest domestic wells, the data does not rule out a natural gradient from the gas sources at depth to the shallower zones of the formation. However, the EPA explanation is supported by the fact that the monitoring wells are far enough apart, more than a mile, that they must have different gas well sources and represent different pathways..

Recommendation: To further decrease the uncertainty, the EPA should complete an additional sampling event with more domestic wells sampled. It would also be desirable to have another monitor well screened at the level of the gas wells. The EPA could then develop a concentration profile as a function of depth and formation layer.

Breakdown products of organic compounds

EPA verified a vertical pathway by showing that organic compounds in the shallower monitoring wells are daughter products of the organic compounds found in the deeper monitoring wells. This supports the concept of upward migration with ongoing biologic transformation or natural degradation. It supports the concept of an upward flow gradient. It cannot be asserted that the EPA monitoring wells are on the same flow pathway, as they are more than a mile apart, therefore, the presence of contaminants in the monitoring wells is evidence that there are multiple sources of contaminants at the level of the gas production wells.

As part of this line of reasoning, the EPA presents the "hypothetical conceptual model" that "highly concentrated contaminant plumes exist within the zone of injection with dispersed lower concentration areas vertically and laterally distant from the injection points". This refers to how the fracking fluids, once injected, simply disperse in all directions because there are no confinements, similar to how they disperse from coal seam fracking. It is consistent with the lower concentrations found further from the source.

EPA's hypothesis is reasonable and explains the vertical movement of contaminants from a broad zone of production wells. Its simplicity indicates that fracking in such a formation will eventually lead to contamination moving vertically from the gas wells – it is only a matter of time (Myers, 2012).

Sporadic bonding outside of production casing and hydraulic fracturing in thin discontinuous sandstone

The last two lines of reasoning are considered together because they describe two pathways for fracking fluid to get into the aquifer. The fracking that occurs in the Pavillion gas field directly injects fracking fluid into an underground source of drinking water. Fracking occurs as little as 150 m below the bottom of the deeper water wells. The sandstone and intervening shale zones are discontinuous, which suggests there are no significant continuous barriers to a vertical component of flow and contaminant movement. Fracking has also occurred for up to 40 years, so the pathways could have required up to 40 years for transport. Sporadic bonding above the zone being fracked basically means the annulus between the production zone and surface casing may not be fully sealed with cement which may allow gas or fluids to move vertically among formation layers. During fracking, the high pressure could force some of the fracking fluid through improperly sealed well bores to contaminate formations nearer the water wells.

Both of these lines of reasoning correctly describe potential pathways and sources of fluids in the aquifer. The EPA's conclusions in this regard are reasonable and appropriate and conform to the available facts and data.

Gas in Monitoring and Shallow Wells

Many shallow water wells have gas concentrations that exceed expected background levels. EPA also uses several lines of reasoning to conclude that gas has migrated to domestic wells from the fracked zones, in addition to or instead of it occurring naturally in those wells.

Isotopic composition of gas samples from shallow wells, deeper monitoring wells and produced gas are all similar in that all have a thermogenic origin. However, the shallower domestic water wells have very little higher chain carbon-based gas, which suggests some dispersion and decomposition with vertical movement (ethane and propane degrade faster). The isotopic composition of most wells is thermogenic and indicative of a deep source; URS (2010) noted that methane in one domestic well of eight sampled with measurable methane had biogenic origins.

EPA also found that the concentration of methane in domestic water wells was generally higher in areas of higher gas production, as counted by the number of gas wells. Although it could be coincidental because more gas wells are constructed where more gas naturally occurs, this seems unlikely because the presence of gas in domestic water wells shows that gas is occurring outside of the production zones deep in the Wind River Formation or high in the underlying Fort Union Formation. Gas would only move naturally from depth to areas near the surface if there is a lack of containment which would have depleted the gas source at some point in the last 40,000,000 years. Thus, the gas wells have apparently provided a migration pathway for gas released by fracking into overlying formations; this migration occurred at a rate sufficient to allow gas to accumulate to a concentration capable of causing a blowout at 159 m bgs near well PDGW05.

The area also generally has gas well designs that are below current industry standards in some states, with surface casing not extending below the maximum depth of water wells and with a "lack of cement or sporadic bonding of cement outside of production casing" (EPA p 38). This would provide a pathway from depth to at least the bottom of the surface casing, and allow gas leakage to higher levels in the

aquifer. Many states and areas require surface casing to extend below the maximum depth of USDWs (a USDW must generally have TDS less than10,000 mg/l). The gas well design in Pavillion appears to be below industry standards because the surface casing does not extend even below the bottom of the zone of domestic wells. The pathways discussed above for fluid movement would also facilitate gas movement (Id.).

The EPA acknowledges that poorly sealed domestic wells could also be a pathway (EPA p 38-39). This is true but not a relevant argument because the gas wells are much deeper and actually tap formation layers with gas. Once gas reaches a domestic well, it is possible that the well provides an additional pathway, but it is not the source of the contamination or the primary pathway from the gas source zone to the aquifers.

The EPA also references the fact of citizen's complaints (EPA p 39) as an indicator that gas contamination started after fracking. Citizens do not complain until a problem occurs. Assuming their water well was initially acceptable, they would complain when they noticed a change.

DISCUSSION OF CONTAMINANT TRANSPORT PATHWAYS

The general dispersion of contaminants upward from the fracking zone would result from either well bore transport or transport through overlying higher permeability sandstone. Transport through wellbores that cross multiple aquifer layers, as the gas wells do near Pavillion, would allow contaminants to reach the different levels. However, the concentration reaching shallower formations would be much less because the contaminants bleed off to the deeper aquifer zones (Nordbotten et al 2004). Fracking could also create the vertical gradient to temporarily cause contaminants to move vertically upward through wellbores to contaminate shallower aquifer layers (Lacombe et al 1995).

Because there are not any significant horizontal confining units within the Pavillion Field, the upward vertical contaminant transport is partially due to dispersion through relatively porous media. In areas with extensive horizontal confining layers, such as the Marcellus shale areas, transport through vertical fractures, similar to that through wellbores, could transport substantial contaminant mass through the impervious zones (Myers, 2012). If the bulk media bounding the fractures have conductivity less than one hundredth that in the fracture, the contaminants will transport with little dispersion, or loss, into the bulk media (Zheng and Gorelick, 2003).

This appears to be the case in the Pavillion Field, given the existing geology. Thus, unless fracking is very carefully done, and well bores are solidly (not intermittently) bonded, this result is to be expected. In the case of the Pavillion Field, sporadic bonding is revealed and reported for 9 of the wells that EPA examined well bore data made available to them. To the extent that this is indicative of the entire field, it would greatly increase the likelihood that transport of contaminants from the gas wells to the water wells of the rural Pavillion residents would occur.

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Region 8

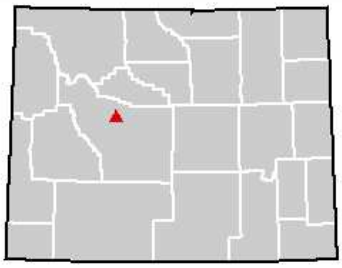
Pavillion

DRAFT REPORT

EPA has released a draft report outlining findings from the Pavillion, Wyoming groundwater investigation for public comment and independent scientific peer review. The draft report will be available for public comment through September 2013. A subsequent peer-review process will be led by a panel of independent scientists.

- Draft Report, December 8, 2011
- Press Release
- Tables and Charts
- Appendix C Figures
- Appendix D Figures
- Appendix E Figures
- Supplemental Information and Data

Groundwater Investigation



Site Type: Non-NPL
City: Pavillion
County: Fremont
ZIP Code: 82523
EPA ID: WYN000802735
SSID: 08QV
Congressional District: At Large

On this page:

- **What's New?**
- **Site Description**
- **Site Reports and Public Presentations**
- **Contacts**
- **Photo/Video Gallery**

On other pages:

- **Site Documents:** more than 800 documents related to quality assurance, monitoring well drilling information, raw laboratory data, well sampling information, lab standard operating procedures, and lab-produced reports

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What's New?

June 20, 2013
EPA has announced that it will be supporting the State of Wyoming in its further investigation of drinking water quality in the rural area east of Pavillion, Wyoming. While EPA stands behind its work and data, the agency recognizes the State of Wyoming's commitment to further investigation and efforts to provide clean water and does not plan to finalize or seek peer review of its draft Pavillion groundwater report released in December 2011.

The sampling data obtained throughout EPA's groundwater investigation will be considered in Wyoming's further investigation, and EPA will have the opportunity to provide input to the State of Wyoming and recommend third-party experts for the State's consideration. The State intends to conclude its investigation and release a final report by September 30, 2014.

- View the press release
- View the state investigation document (PDF) (6 pp, 369 K, About PDF)

January 11, 2013
EPA is extending the public comment period for the draft research report to September 30, 2013. During this time, EPA will continue its public outreach activities including meeting with key stakeholders and posting additional technical information on this website. This extension will allow the public additional opportunity to comment on EPA's draft report and the latest round of sampling conducted by EPA and USGS. The Agency will take into account new data, further stakeholder input, and public comment as it continues to review the status of the Pavillion investigation and considers options for moving forward. View the Federal Register notice announcing the extension of the public comment period (PDF) (2 pp, 203 K).

November 6, 2012
EPA has updated and corrected the well completion schematics for Monitoring Wells 01 and 02 based on a detailed review of the drillers logs and field notes. View the updated schematics here:

- Monitoring Well 01 Completion Schematic (PDF) (1 pg, 202 K)
- Monitoring Well 02 Completion Schematic (PDF) (1 pg, 193 K)

October 16, 2012
EPA has extended the public comment period on the Draft Report until January 15, 2013. View the Federal Register Notice announcing the extension of the public comment period.

October 10, 2012
EPA released the methodology and results for samples collected during April 2012. Click here for more information.

September 26, 2012
The U.S. Geological Survey has released data from samples taken from a Pavillion area monitoring well earlier this year. USGS conducted this sampling at the request of the State of Wyoming and in coordination with EPA. This data will be made available to the independent peer review panel that will review EPA's draft Pavillion groundwater report beginning later this year.

- Groundwater-Quality and Quality-Control Data for Two Monitoring Wells near Pavillion, Wyoming, April and May 2012
- Sampling and Analysis Plan for the Characterization of Groundwater Quality in Two Monitoring Wells near Pavillion, Wyoming

June: Update on 2012 sampling activity
EPA, in cooperation with the U.S. Geological Survey, the Tribes, and the State of Wyoming, is re-sampling two monitoring wells the Agency installed in the Pavillion area in the summer of 2010. EPA is also collecting samples from four private and one public water supply well. Sample results, which are expected later this summer, will be posted on this web page. These data will be made available for public comment and included in the peer review process.

March 8: EPA extending public comment period and delaying peer review to consider additional sampling
EPA and the State of Wyoming recognize the value of further sampling of the deep monitoring wells drilled for the Agency's ground water study in Pavillion, Wyoming. EPA will partner with the U.S. Geological Survey (USGS), the State, and the Tribes to complete this sampling as soon as possible.

To ensure that the results of this next phase of testing are available for the peer review process, EPA has delayed convening the peer review panel on the Pavillion Draft Report until a report containing the USGS data are publicly available. In addition, EPA

is extending the public comment period on the Draft Report through October 2012 to provide additional time for the public to review and comment on the new data. View Federal Register Notice announcing public comment period (PDF) (5 pp, 75 K)

View the full joint statement from EPA Administrator Lisa Jackson, Governor Matt Mead and the Northern Arapaho and Eastern Shoshone Tribes.

February 8: The public comment period on the Draft Peer Review Charge opened on February 8; the comment period has closed. View public comments on the Draft Peer Review Charge that were received during the public comment period:

- Comment from Lloyd Hetrick
- Comment from John Corra
- Comment from David Stewart
- Comment from Nancy Tujague

January 31: 622 files have been added to the Site Documents page. The files include additional analytical data and QA documentation.

January 23:

- Op-ed from EPA Regional Administrator Jim Martin in the Casper Star-Tribune (1/22)
- Letter from EPA Administrator Lisa Jackson to Governor Matt Mead (1/19)

January 18: EPA is inviting the public to nominate scientific experts to be considered as peer reviewers of a draft report on the Pavillion ground water investigation. Nominations will be accepted through February 17. Details can be found in the Federal Register notice (PDF). (2 pp, 156 K)

View more information on the peer review process.

December 14, 2011: EPA has released a draft report outlining findings from the Pavillion, Wyoming groundwater investigation for public comment and independent scientific peer-review. See the box at the top right of this page for more information.

November 9, 2011: EPA released the latest data from Pavillion-area domestic and monitoring wells at a public meeting on November 9, 2011. We are sharing this data with the community, Encana, the state, tribes and federal partners as part of an ongoing process to develop sound science about contamination in the aquifer used by Pavillion residents for drinking water.

EPA will release a draft research report summarizing investigation findings. This report will be available for public comment as part of an independent peer-review process coordinated by our Office of Research and Development.

Public Documents and Presentations

- Methods, Graphics, and Data Tables Handout, November 8, 2011
- 2010-2011 Sampling Summary of Results and Next Steps Presentation, November 9, 2011
- Workgroup Meeting Presentation, November 30, 2011

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Site Description

Pavillion, Wyoming is located in Fremont County, about 20 miles northwest of Riverton. In 2003, the estimated population was 166 residents. The concern at the site is potential groundwater contamination, based on resident complaints about smells, tastes and adverse changes in water quality of their domestic wells. Community members contacted EPA in spring 2008.

The Pavillion area has approximately 80 domestic wells. The town of Pavillion provides municipal water to residents through eight groundwater wells. Private water wells just outside the town of Pavillion are used for drinking water, irrigation, and stock watering, and are completed at depths from 50 feet to 750 feet or more. Pavillion is within the Wind River Indian Reservation as described by the Northern Arapaho and Eastern Shoshone Tribes in a pending application for treatment in a similar manner as a state under the Clean Air Act. The site is located west of Boysen State Park.

January 2010 sampling

In March 2009 EPA sampled 39 individual wells (37 residential wells and two municipal wells). The purpose of this sampling was to collect data to assess groundwater conditions and evaluate potential threats to human health and the environment. EPA conducted additional sampling in Pavillion in January 2010. This effort included sampling 21 domestic wells within the area of concern, two municipal wells, and sediment and water from a nearby creek. EPA has also sampled groundwater and soil from pit remediation sites, produced water, and condensate from five production wells operated by the primary natural gas operator in the area. EPA installed two monitoring wells in the Pavillion area in 2010. Data collected from these wells will build upon prior sampling events and help us further assess groundwater hydrology and contamination in the aquifer. EPA released the latest data from domestic and monitoring wells at a public meeting on November 9, 2011.

The Pavillion groundwater investigation is being conducted by EPA's regional office in Denver in collaboration with scientists from our Office of Research and Development.

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Site Reports and Public Presentations

You will need Adobe Acrobat Reader to view some of the files on this page. See EPA's PDF page to learn more.

Best way to open a **very large file**: right-click and **save it to a folder**

Documents related to August 31, 2010 public meeting:

- Public Meeting Presentation of Phase 2 Sampling Results
- Press Release: EPA releases results of Pavillion, Wyo. water well testing
- Agency for Toxic Substances and Disease Registry Health Consultation Document (PDF) (2.2 MB)
- Fact Sheet: January 2010 Sampling Results and Site Update
- Final Analytical Results Report for the Pavillion Area Groundwater Investigation Site
    - Results Report Appendices: Lab Data, Photos, Figures, Chemicals Used
    - Figure 1: Site Location Map
    - Figure 2: Sampling Location Map of the January 2010 Event
    - Figure 3: Area of Influence and Well Locations
    - Figure 4: Conceptual Site Model of the Pavillion Area Groundwater Plume
    - Pavillion Area Groundwater Investigation: ALL tables

Phase 2 Field Sampling Plan, January 2010

Public Meeting Presentation of Phase 1 Sampling Results, August 11, 2009

Groundwater Investigation Analytical Results Report and Phase I Maps, August 2009

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Photo/Video Gallery

Click on a thumbnail below to view the full size image.

Pavillion, Wyoming landscape

January 2010 sampling

January 2010 sampling

Collecting January 2010 samples

Preparing January 2010 samples

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Contact Us to ask a question, provide feedback, or report a problem.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION III
1650 Arch Street
Philadelphia, Pennsylvania 19103-2029

Subject: Action Memorandum - Request for Funding for a Removal Action at the Dimock Residential Groundwater Site, Intersection of PA Routes 29 & 2024 Dimock Township, Susquehanna County, Pennsylvania

From: Richard M. Fetzer, On-Scene Coordinator
Eastern Response Branch (3HS31)

To: Dennis P. Carney, Associate Division Director
Hazardous Site Cleanup Division (3HS30)

JAN 19 2012

I. PURPOSE

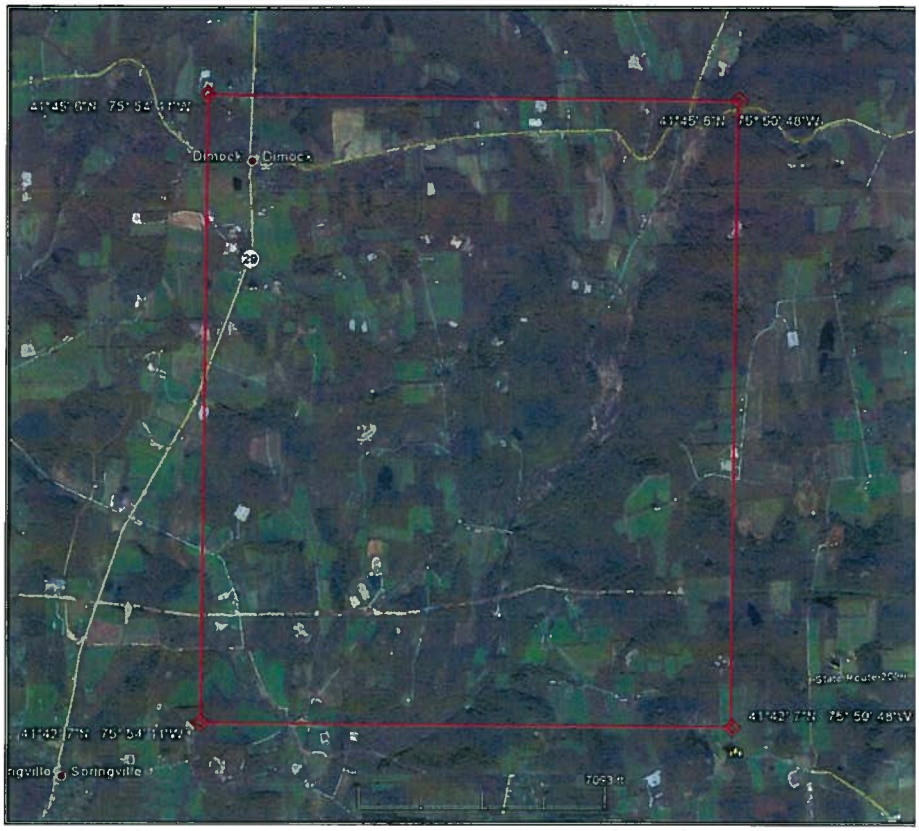
The purpose of this Action Memorandum is to request and document approval of an emergency removal action to prevent, limit, or mitigate the threats posed by the presence of hazardous substances at the Dimock Residential Groundwater Site (the "Site"), pursuant to Section 104(a) of the Comprehensive Environmental Response, Compensation and Liability Act, 42 U.S.C. § 9604(a) (CERCLA). The Site is located in Dimock Township, Susquehanna County, Pennsylvania. The OSC has initiated a removal site evaluation in accordance with the National Oil and Hazardous Substances Pollution Contingency Plan (NCP), 40 C.F.R. Part 300. The OSC has determined, based on Pennsylvania Department of Environmental Protection (PADEP) and Cabot Oil and Gas Corporation (Cabot) sampling information, consultation with an EPA toxicologist, the Agency for Toxic Substances and Disease Registry (ATSDR) Record Of Activity (AROA), issued 12/28/11, and the recent EPA well survey effort, that a number of home wells in the Dimock area contain hazardous substances, some of which are not naturally found in the environment. Inorganic hazardous substances are present in four home wells at levels that present a public health concern. These four specific homes have been dependent upon donated water for drinking and/or household use and the reliability of the sources for donated water is at this point uncertain.

Historic drilling activities in the Dimock area may have used materials containing hazardous substances. Spills and other releases have been documented by PADEP from these drilling activities. There is reason to believe that a release of hazardous substances has occurred. The presence of hazardous substances in the four home wells constitutes a release or substantial threat of a release and the situation meets the criteria for conducting a removal action under Section 300.415 of the NCP. The OSC has determined that funds in the amount of $100,000 are needed to mitigate the human health concern initially at four homes and therefore proposes the actions included in this Action Memorandum. This action includes provision of alternate water to four homes and home well sampling at approximately 61 homes within the Site area.

II. SITE CONDITIONS AND BACKGROUND

A. Background

1. Site Description - The Site area is located in Dimock, a rural area of northeastern Pennsylvania in Susquehanna County. A map of the area is included below.



2. History - Cabot began drilling for natural gas in the Dimock area in 2008. Methane contamination was detected in private wells thereafter in concentrations exceeding those previously found. PADEP had the lead in investigating the environmental complaints in Dimock. PADEP entered into a Consent Order and Agreement (CO&A) with Cabot which required permanent restoration or replacement of the affected water supply. A public water line was initially considered. PADEP later modified the CO&A to require installation of "gas mitigation" systems for 19 homes served by 18 private wells in the Site area.[1] Until the gas mitigation systems were installed, Cabot was to provide a temporary water source. Some well owners, within the scope of the PADEP CO&A, have gas mitigation systems installed, but others do not. While the gas mitigation systems were designed to remove methane, a potential exists that they may remove some hazardous substances as a by-product of their operation. Regardless, EPA does not know what, if any, hazardous substances these "gas mitigation" systems, originally designed to address methane, are removing. Therefore, EPA is including both pre- and post-treatment sampling in the scope of this action. Furthermore, there are

[1] It had originally been reported that 19 homes were served by the 18 wells included within the scope of the CO&A but the door-to-door home well survey conducted to date by EPA has identified that there are currently 21 homes served by 20 wells on those same properties.

other homes served by private wells that were not covered by the scope of the PADEP CO&A, but are within this Site area.

III. Quantities/Types of Substances Present

1. Arsenic* – Arsenic is a naturally occurring element widely distributed in the earth's crust. Arsenic may also be present at elevated concentrations in the groundwater due to the use and effects of drilling fluids. Arsenic is classified as a known human carcinogen. This classification is based on animal and human studies, which indicate an increased risk for developing cancers of the skin, lung, bladder, kidney, liver, and prostate from consuming arsenic containing water. Non-cancer health effects associated with ingestion of arsenic include circulatory problems and skin damage.
2. Barium – Barium is a silvery-white metal that exists in nature only in ores containing mixtures of elements. It combines with other chemicals such as sulfur or carbon and oxygen to form barium compounds. Barium sulfate is sometimes used by doctors to perform medical tests and to take x-rays of the gastrointestinal tract. Ingesting drinking water containing levels of barium above the EPA drinking water guidelines for relatively short periods of time can cause gastrointestinal disturbances and muscle weakness. Ingesting high levels for a long time can damage the kidneys. Barium is known to be a common constituent of drilling fluids.
3. Bis(2-ethylhexyl)phthalate (DEHP)* - DEHP is a manufactured chemical that is commonly added to plastics to make them flexible. The phthalates are generally considered to be of slight to moderate toxicity. DEHP may be irritating to the eyes, skin, and mucous membranes. Mild gastric disturbances and diarrhea may occur following ingestion of larger doses. Central nervous system (CNS) depression may occur if large amounts of phthalate acid esters are absorbed. EPA has determined that DEHP is a probable human carcinogen. These determinations were based entirely on liver cancer in rats and mice. DEHP is known to be associated with drilling activities.
4. Glycol Compounds (including Ethylene Glycol* and 2-Methoxyethanol) – Glycol compounds are a class of organic compounds belonging to the alcohol family. Exposure to large amounts of ethylene glycol can damage the kidneys, nervous system, lungs, and heart. Exposure to high concentrations of 2-methoxyethanol is associated with testicular damage, impaired nervous system, and anemia. Glycols are known to be common in drilling fluids.
5. Manganese* – Manganese is a naturally occurring substance found in many types of rock and soil. Manganese is also known to be a constituent of some specialized drilling fluids. Eating a small amount of manganese from food or water is needed to stay healthy. At high levels, it can cause damage to the nervous system.

6. Phenol* - Phenol is both a manufactured chemical and a natural substance. Phenol is used as a disinfectant and is found in a number of consumer products. Skin exposure to high amounts can produce skin burns, liver damage, dark urine, and irregular heart beat. Various phenols are commonly associated with drilling fluids.
7. Sodium* – Sodium is an essential nutrient and occurs naturally in most foods. Excessive sodium intake is associated with high blood pressure. Various sodium containing compounds are associated with drilling fluids.

*A hazardous substance, as defined under CERCLA Section 101(14) and designated in Section 302.4 of the National Contingency Plan (NCP), 40 C.F.R. Section 302.4.

B. National Priorities List

The Dimock Residential Groundwater Site is not on the CERCLA National Priorities List (NPL).

C. State and Local Authorities' Roles

Cabot had been sampling the home wells and providing bottled drinking water and alternate water for non-potable use, through a Consent Order and Agreement (CO&A) with PADEP. The CO&A applies only to a specific list of homes, and does not include other homes, also located within the same geographic area. Some of these additional homes have had limited sampling conducted by Cabot and/or PADEP. PADEP determined that Cabot has complied with the terms of the CO&A, as it applies to the provision of temporary water, and subsequently approved Cabot's request to stop the delivery of alternate water.

IV. THREATS TO PUBLIC HEALTH OR WELFARE OR THE ENVIRONMENT

Section 300.415 of the NCP lists the factors to be considered in determining the appropriateness of a Removal Action. Paragraphs (b)(2)(i), (ii), and (vii) of Section 300.415 directly apply to the conditions found at the Dimock Residential Groundwater Site.

In evaluating the situation, the OSC first considered whether hazardous substances were present in a home well. The levels of those hazardous substances were then considered against primary Maximum Contaminant Levels (MCLs). They were also considered for non-cancer risk to determine if the levels generate a hazard quotient greater than 2. The presence of inorganic and organic chemicals in a number of wells supports the need for this action.

300.415 (b)(2)(i) "Actual or potential exposure to nearby human populations, animals or the food chain from hazardous substances or pollutants or contaminants"

The hazardous substances listed above, present in water from home wells at this Site based on sampling data described below, could cause adverse health impacts when chronic exposure through drinking water or other uses of water in the home occurs. There are other contaminants discussed in the Agency for Toxic Substances and Disease Registry's (ATSDR) Record of Activity (AROA) issued on December 28, 2011, which could also cause adverse health impacts. ATSDR has concluded for the area originally included with the PADEP/Cabot CO&A, which includes the four homes being considered here for alternate water, that a chronic health risk exists for most wells and that the situation supports a "Do Not Use the Water" action including the consideration of alternative home water supplies until further characterization is completed. An EPA Region III toxicologist's opinion is that, of the homes evaluated to date in an on-going effort, that four home wells contain contaminants at levels that present a public health concern. In one home, manganese was detected at 628 ug/L. Exposure to this concentration would yield a Hazard Quotient of approximately 2. In another home, manganese (1360 ug/L) was detected at a level that generates a Hazard Quotient of approximately 4. Note that children reside at this location. In the third home, arsenic was observed at a concentration (37 ug/L) that exceeds its MCL of (10 ug/L) and would pose a long-term cancer risk of 8E-04. Note that children reside at this location. In the fourth home, manganese was detected at 669 ug/L. Exposure to this concentration would yield a Hazard Quotient of approximately 2.3. Available data also indicate that hazardous substances may be present in a number of other homes. Because the available data is not complete and is of uncertain quality, additional sampling is needed to facilitate a further evaluation of any potential health concerns from the drinking water at home wells in the Site area.

EPA is providing water based upon a risk of exposure to hazardous substances above health-based levels. Furthermore, the OSC notes that for those homes where the EPA toxicologist has not identified contaminants that present a public health concern, that the limited data available does identify the existence of hazardous substances. In addition, PADEP's CO&A determined that 18 home wells were impacted by drilling activities; such impact may be evidence of the migration of hazardous substances.

Again, it is noted that this determination is based upon data which was collected by parties other than EPA (Cabot and PADEP). The quality assurance/quality control (QA/QC) information has not been verified. However, what is clear is that this data strongly suggests that hazardous substances have been released and are present in some home wells at levels that may present a public health concern. Current data does show arsenic and manganese at higher levels than may be typically found, in post drilling samples. Since arsenic and manganese are naturally occurring substances, EPA's assessment will include comparisons of background concentrations and post drilling concentrations present. EPA routinely acts under CERCLA to protect public health first while it acts to further define contamination. Thus, within this action, EPA will complete an assessment of the water quality of the home wells in the Site area to close information gaps as soon as possible. This sampling will be focused initially on evaluating those homes in the Site area that have been sampled in the past. Beyond that, sampling at homes will be based upon a sampling rationale using information regarding alleged health impacts and

data gaps. In addition, EPA will continue to evaluate the updated data, and may revise its actions to provide water to any of the additional homes, or to cease provision of water, as warranted by the data.

300.415 (b)(2)(ii) "Actual or potential contamination of drinking water supplies or sensitive ecosystems"

The discussion of 300.415 (b) (2) (i) above applies to this factor. Both organic and inorganic contaminants have been detected in home wells. Although this action is predominantly based upon inorganic data at the four homes, it should be noted that organic compounds have been detected at other homes as detailed in the ATSDR AROA. Glycol detections included ethylene glycol, triethylene glycol, and 2,2'oxybisethanol (diethylene glycol). Some wells had all three reported glycols present in their wells but no exceedances of risk based screening criteria (note: the analytical detection level used appeared to be higher than screening levels). Bis(2-ethylhexyl) phthalate (DEHP) was detected in five samples and ranged from 0.14 μg/L to 22 ug/L. 2-methoxyethanol concentrations (ranging from 880 ug/L to 1,300 ug/L) were detected in each of six wells.

300.415 (b) (2) (vii) "The availability of other appropriate federal or state response mechanisms to respond to the release"

The four homes being considered for alternate water under this action were all dependent upon donated water, either bottled, water buffaloes (temporary storage tanks) or both. It is the OSC's understanding that the last delivery of bulk water from those organizations ceased on January 3, 2012. In any case the reliability of sources for donated water is at best uncertain.

V. PROPOSED ACTIONS AND ESTIMATED COSTS

A. Proposed Action

1. Proposed Action Description

Throughout the duration of Site activities, all personnel involved with execution of this proposed action will comply with the requirements of CERCLA and with all other applicable Federal and State regulations to the extent practicable considering the exigencies of the situation in accordance with 40 CFR § 300.415(j). Available data indicate that a number of homes in the area have hazardous substances present in the home wells, but only four indicate concentrations identified by the EPA toxicologist at a level of concern. Thus, those four homes will be immediately supplied with water. At the same time, approximately 61 home wells will be sampled by EPA to obtain data of known quality assurance to support future evaluations and response decisions. EPA will continue to evaluate the updated data, and may revise its actions to provide water to any of the additional homes, or to cease provision of water, as warranted by the data. The Removal activities at the Site will include the following:

1. Mobilize and demobilize personnel and equipment to conduct the action;
2. Delivery of a temporary source of clean water for household use to the four (4) homes with wells that contain contaminants at levels of public health concern. This provision of temporary water will continue until potential exposures are further understood and mitigated as needed.
3. The sampling program will include analysis for a broad range of parameters with a special priority being placed on quick turnaround for those parameters which are most frequently observed in the data available to EPA at this time. The Agency will also do some limited sampling for methane and bacteriological constituents. Home well water sampling will be performed by EPA in the Site area using the following assigned priority:

    i. The four (4) homes considered for provision of alternate water, to assess the potential exposure to hazardous substances and to determine whether continued temporary provision of clean water for household use is required.
    ii. The seventeen (17) remaining homes located on properties included in the PADEP/Cabot CO&A[2], which were identified as being impacted by drilling activities.
    iii. Approximately thirty (30) additional homes in the immediate area that have been sampled in the past.
    iv. Additional homes in the Site area where one or more of the factors below supports sampling.
        1. Direct observation or other evidence (home well surveys) of adverse health effects potentially attributable to contaminated groundwater use.
        2. Where data gaps in groundwater measurement or sampling need to be filled to gain an adequate understanding of Site conditions.

    Approximately ten (10) homes are currently identified from well surveys, but more could be added based upon data review.
4. Maintain necessary documentation of Site activities.
5. Develop and implement appropriate health and safety protocols for the removal activity.

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[2] It had originally been reported that 19 homes were served by the 18 wells included within the scope of the CO&A but the door-to-door home well survey conducted to date by EPA has identified that there are currently 21 homes served by 20 wells on those same properties.

2. Contribution to Remedial Performance

A remedial action is not anticipated and therefore this removal action is not inconsistent with any proposed remedial action.

3. Applicable or Relevant and Appropriate Requirements ("ARARs")

Actions will be conducted in compliance with Applicable or Relevant and Appropriate Regulations (ARARs) to the extent practicable considering the exigencies of the situation, in accordance with 40 CFR 300.415(j).

B. Estimated Costs

Extramural Costs	Total
Regional Allowance Costs: (ERRs Contractors and Subcontractors)	$ 50,000
Other Extramural Costs Not Funded From the Regional Allowance: START Contractor	$ 25,000
Subtotal, Extramural	$ 75,000
Extramural Costs Contingency	$ 25,000
Total Removal Action Project Ceiling	**$100,000**

VI. EXPECTED CHANGE IN SITUATION SHOULD ACTION BE DELAYED OR NOT TAKEN

If no action is taken, the residents may utilize well water which poses a potential public health concern.

VII. OUTSTANDING POLICY ISSUES

Because this response action could be considered nationally significant or precedent setting, it requires the prior concurrence of the Assistant Administrator, Office of Solid Waste and Emergency Response (AA-OSWER). Furthermore, because the action appears to be nationally significant and/or precedent-setting, the Region will continue to coordinate closely with Headquarters. EPA also will maintain coordination and communications with PADEP. In taking this action, EPA is aware of and has considered the potential applicability of the natural gas exclusion under CERCLA, the Bentsen Amendment under the Resource Conservation and Recovery Act (RCRA), and the exclusions to the definition of 'underground injection' under the Safe Drinking Water Act (SDWA). EPA has concluded that this action is appropriate under CERCLA at this time.

VIII. ENFORCEMENT

The total EPA costs for this removal action based upon full-cost accounting practices that will be eligible for cost recovery are estimated below as follows:[3]

Direct Extramural Costs	$100,000
Direct Intramural Costs	$ 25,000
Total Direct Costs	$125,000
Indirect Cost (67.13% x Direct Costs)	$ 83,912
Total Costs (Direct and Indirect)	$208,912

IX. RECOMMENDATION

This Action Memorandum represents the selected Removal Action for the Dimock Residential Groundwater Site in Dimock Township, Susquehanna County, Pennsylvania, developed in accordance with CERCLA, as amended, and is consistent with the NCP. This decision is based on the administrative record for the Site. The administrative record consists of the following documents

1. 1/13/12 "Dimock Home Well Data" memo from EPA Toxicologist Dawn Ioven.
2. ATSDR AROA Issued 12/28/11.
3. Summary of Portions of data received by EPA and reviewed by the OSC.
4. PADEP Consent Order and Agreement, dated December 15, 2010.
5. EPA Data Review Memo, January 13, 2012.
6. EPA 104e request to Cabot, January 6, 2012

Conditions at the Site meet the Removal Action requirements of Section 300.415(b) of the NCP and I recommend your approval of the proposed removal action and exemption from the statutory limits. The total project ceiling, if approved, will be $100,000. Of this, as much as, $50,000 comes from the Regional removal allowance. Please indicate your approval or disapproval below.

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[3] Direct Costs include direct extramural costs and direct intramural costs. Indirect costs are calculated based on an estimated indirect cost rate expressed as a percentage of site-specific direct costs, consistent with the full cost accounting methodology effective October 2, 2000. These estimates do not include pre-judgment interest, do not take into account other enforcement costs, including Department of Justice costs, and may be adjusted during the course of a removal action. The estimates are for illustrative purposes only and their use in not intended to create any rights for responsible parties. Neither the lack of a total cost estimate nor deviation of actual total costs from this estimate will affect the United States' right to cost recovery.

Action by the Approving Official:

I have reviewed the above-stated facts and, based upon those facts and the information compiled in the documents described above, I hereby approve/disapprove the selected removal action.

APPROVED: Dennis P. Carney **DATE** 1/19/2012

Dennis P. Carney, Associate Division Director
Hazardous Site Cleanup Division
EPA Region 3

DISAPPROVED: _____ **DATE** _____

Dennis P. Carney, Associate Division Director
Hazardous Site Cleanup Division
EPA Region 3