Groundwater

Issue Paper/

Analysis of the Groundwater Monitoring Controversy at the Pavillion, Wyoming Natural Gas Field

by Daniel B. Stephens

Abstract

The U.S. Environmental Protection Agency (EPA) was contacted by citizens of Pavillion, Wyoming 6 years ago regarding taste and odor in their water wells in an area where hydraulic fracturing operations were occurring. EPA conducted a field investigation, including drilling two deep monitor wells, and concluded in a draft report that constituents associated with hydraulic fracturing had impacted the drinking water aquifer. Following extensive media coverage, pressure from state and other federal agencies, and extensive technical criticism from industry, EPA stated the draft report would not undergo peer review, that it would not rely on the conclusions, and that it had relinquished its lead role in the investigation to the State of Wyoming for further investigation without resolving the source of the taste and odor problem. Review of the events leading up to EPA's decision suggests that much of the criticism could have been avoided through improved preproject planning with clear objectives. Such planning would have identified the high national significance and potential implications of the proposed work. Expanded stakeholder involvement and technical input could have eliminated some of the difficulties that plagued the investigation. However, collecting baseline groundwater quality data prior to initiating hydraulic fracturing likely would have been an effective way to evaluate potential impacts. The Pavillion groundwater investigation provides an excellent opportunity for improving field methods, report transparency, clarity of communication, and the peer review process in future investigations of the impacts of hydraulic fracturing on groundwater.

Introduction

In an area of natural gas development, citizens complained to the Environmental Protection Agency (EPA) Region 8 about the quality of water in their wells. The EPA conducted a field investigation and released a draft report believed to be the first (ProPublica 2011) to document groundwater contamination by hydraulic fracturing: "Investigation of Ground Water Contamination near Pavillion, Wyoming" (U.S. EPA 2011a). After several years and expending considerable federal dollars, in the face of severe criticism from many different sectors, the EPA abruptly halted the public review of the report and turned the investigation over to the State without determining the source of the problem in the citizens' wells.

This study reviews the events leading up to and following the issuance of this important draft report by EPA, including a summary of the main criticisms of it. The primary intent of this issue paper, however, is to explore what may have led to EPA's decision to essentially withdraw its report and to identify lessons to be derived from this case study which could better guide future site investigations and research efforts related to hydraulic fracturing and groundwater protection.

Site Description and Groundwater Conditions

The Pavillion gas field is in the western portion of the Wind River Basin in Fremont County near the town of Pavillion, population 231, in west central Wyoming

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within the Wind River Indian Reservation (Wright et al. 2012) (Figure S1, Supporting information). The basin is flanked by the Wind River Range, the Absaroka Range, and the Owl Creek Mountains. The area near Pavillion is on the floor of the basin where precipitation is only 6 to 8 inches per year (Daddow 1996).

Natural gas is produced from the Wind River and underlying Upper Fort Union Formations (Itasca Denver Inc. 2012). The zone of particular interest here is the Wind River formation, described as a 1040-m (3400 feet) thick (Itasca Denver Inc. 2012) complexly bedded series of largely fluvial and over-bank deposits consisting of variegated clay-stones, sandstones, and conglomerates with discontinuous thin beds of coal and carbonaceous shales (BLM 2012). In places near Pavillion, the Wind River Formation occurs at land surface. The shallow sandstone lenses of the upper portion of the Wind River Formation, the Lost Cabin Member, comprise a source of potable water, whereas natural gas has accumulated in the deeper sandstone units of this formation, the Lysite Member of the Wind River Formation (Itasca Denver Inc. 2012). The gas migrated upward naturally from the underlying Cody Shale to the Wind River and Fort Union Formations where it accumulated in the porous sandstone lenses (Itasca Denver Inc. 2012).

The Town of Pavillion is situated near the apex of the Wind River-Fort Union structural dome (S.S. Papadopulos & Associates, Inc. [SSPA] 2012). Noncommercial zones of natural gas accumulation have been identified at depths of less than 305 m (1000 feet) (SSPA 2012). In addition to the shallow depth of occurrence, a unique aspect of the Pavillion gas field is that there is no extensive impervious stratum or caprock to trap the gas other than the shale, siltstone, and claystone that surround the permeable lenses of sandstone.

Natural gas exploration began here in the 1950s, and the first commercial wells were completed in 1960. Production expanded considerably by 2000, and currently, daily gas production is about 10 million cubic feet. In 2004, Encana Corporation (Encana) acquired the mineral rights and drilled 44 production wells between 2004 and 2007 (BusinessWire 2011). Surface casing of the wells is reported to be typically from about 98 to 210 meters below ground surface (mbgs) (320 to 690 feet) (Encana 2011). Hydraulic fracturing was performed in vertical wells as shallow as 372 mbgs (1220 feet), but most hydraulic fracturing intervals start below 457 mbgs (1500 feet) (EPA 2011a). In the Pavillion area, there are approximately 211 active gas wells, 30 plugged and abandoned wells, and 20 temporarily closed wells (Agency for Toxic Substances and Disease Registry [ATSDR] 2010). Also, there are at least 33 surface pits previously used for drilling fluids and flowback water (EPA 2011a).

Groundwater for domestic use is produced from wells completed in the Wind River Formation, generally within 152 m (500 feet) of the land surface. Water wells less than about 27 mbgs (90 feet) produce from unconfined sandstone layers where the depth to groundwater in the basin averages nearly 5 mbgs (16 feet). Water wells greater than about 30 mbgs (100 feet) produce from confined sandstone layers where the groundwater levels average about 14 mbgs (45 feet) but may be flowing artesian wells in places (Daddow 1996).

The shallow aquifer is considered an Underground Source of Drinking Water under the Safe Drinking Water Act (EPA 2011a). However, the quality of the groundwater is naturally variable, with total dissolved solids (TDS) concentrations ranging from 200 to more than 5000 mg/L. Sulfate and sodium concentrations tend to be elevated where the water is poor in quality and has bad taste. TDS is greater in the lower part of the Wind River Formation where, for example, in the Lysite Member, TDS exceeds 10,000 mg/L and chloride is elevated. Native groundwater in places contains natural gas, as found by the U.S. Bureau of Reclamation in 1951 while drilling a water supply well prior to the production of natural gas (Itasca Denver Inc. 2012).

Groundwater Contamination Claim

Sometime during 2005, a local land owner noted that his 64-m (210 feet) deep domestic well produced water which had a petroleum-like odor and taste. While drilling and developing the replacement well, the land owner stated he began smelling gas at 49 to 55 mbgs (160 to 180 feet) (Shaw Environmental and Infrastructure (Shaw) 2010). On developing the 168-m (550 feet) deep replacement well, on December 19, 2005, the driller reported a methane gas blowout (Shaw 2010), indicating shallow gas present above the commercial zones.

In 2005, following acquisition of the leases, Encana reported to the state regulatory authority, Wyoming Department of Environmental Quality (WDEQ), that they were investigating the potential for soil and groundwater contamination caused by surface pits inherited through their acquisition. The results showed only localized impacts and no impacts to drinking water wells (BusinessWire 2011). Remedial action was implemented for groundwater contamination near some of the pits.

In early 2008, EPA received complaints from several domestic well owners near Pavillion about objectionable taste and odor problems in their well water (EPA 2011a). There were also claims of other health issues (Earthworks 2009). On July 15, 2008, Pavillion citizens and environmental activists wrote a letter to EPA Region 8, U.S. Bureau of Land Management, Encana, and Devon Energy requesting a human health impact assessment of natural gas development in Fremont County (Pavillion Landowners 2008).

EPA Sampling Activities

In response to the complaints, a field sampling program at Pavillion was conducted with Superfund protocol under the supervision of EPA Region 8 in Denver and was supported by the scientific arm of EPA, the Office of Research and Development and its National Risk Management Research Laboratory in Ada, Oklahoma

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(EPA 2011a). EPA retained contractors to create planning documents and implement the field work.

EPA conducted four phases of sampling. In phase 1, from March to May 2009, EPA contractors collected water samples from 37 residential water wells and two municipal water wells in Pavillion, Wyoming (URS Operating Services Inc. 2010) (Figure S2). EPA concluded at this stage that most water wells have no apparent health concerns but that there is "potentially a connection between our results and oil and gas production activities. We cannot pinpoint any specific source at this time" (EPA 2009). Because methane was detected in several of the samples, in phase 2, EPA contractors sampled 23 wells in January 2010, including 10 previously sampled, as well as three shallow monitor wells near three drill site surface pits.

In August 2009, after meeting with citizens of Pavillion and reviewing the phase 1 and 2 test data, ATSDR, at EPA's request, reviewed groundwater quality data from water wells and found 20 of 41 private wells contained compounds that ATSDR associated with petroleum products including tentatively identified compounds (TICs) and low levels of diesel range organics (DRO) in water which were less than the state cleanup level, as well as methane that was below the explosive limit. Between 5 and 11 wells contained what ATSDR considered to be man-made organic compounds that were either present below health based screening levels or for which there were no screening levels available. ATSDR found that the presence of sulfate and iron and sulfur bacteria may be associated with the odor and foul taste of the water. That agency recommended additional monitoring, expanded chemical analyses, and that residents use alternate or treated water supplies until further studies could be completed, but the root cause of the problem was not identified (ATSDR 2010).

In 2010, a stakeholder group called the Pavillion Working Group was formed to provide input to EPA's groundwater investigation, especially in examining pits and gas well integrity. The group included the Wyoming Oil and Gas Conservation Commission (WOGCC) and WDEQ, EPA, Bureau of Land Management (BLM), Encana, Wyoming Geological Survey, Wyoming State Engineer Office, and local land owners (BusinessWire 2011). Representatives of the Wind River Indian Reservation also participated. Through this cooperative working group, Encana began supplying bottled water to affected residents as the EPA investigation progressed (ATSDR 2011; BusinessWire 2011).

Between June and September 2010, based on the phase 2 finding of methane, TICs, and low levels of DRO in domestic wells, EPA retained a consulting engineering firm and driller to construct, using mud rotary drilling, two new deep monitor wells, MW01 and MW02, to depths of 239 to 299 mbgs (785 to 980 feet), respectively (EPA 2011a) (Figure S2). The two deep monitor wells were completed in the lower Lost Cabin member and Upper Lysite member, respectively (Itasca Denver Inc. 2012), below the depth of almost all domestic wells in the area and just above the top of the main zone of natural gas production at about 335 mbgs (1100 feet). The monitor well screen intervals were planned to target white coarse-grained sandstone zones that were noted in a water well drillers log from a well on a nearby property at 259 to 267 mbgs (850 to 875 feet) and 305 to 320 mbgs (1000 to 1050 feet) (EPA 2011a). In the phase 3 sampling of September 2010, EPA collected water samples from these two new deep monitor wells.

In the phase 4 sampling of April 2011, EPA again sampled the two deep monitor wells along with other wells, but tested the water for an expanded list of analytes (EPA 2011a). EPA released that data at a public meeting on November 9, 2011, and shortly afterward Lisa Jackson, EPA Administrator, stated to the media that there is "no indication drinking water is at risk" (Fugleberg 2011).

EPA Draft Report Disseminated

On December 8, 2011, EPA published a draft report containing data collected during the four phases of water sampling (EPA 2011a). According to that draft report, EPA's objective in the investigation was "to determine the presence, not extent, of groundwater contamination in the formation and if possible to differentiate shallow source terms (pits, septic systems, agricultural, and domestic practices) from deeper source terms (gas production wells)."

The primary conclusion from the draft report was that "constituents associated with hydraulic fracturing have been released into the Wind River drinking water aquifer at depths above the current production zone." The bases for this conclusion in the draft report were water quality data collected from the two new deep monitor wells, MW01 and MW02, and various different lines of reasoning EPA used based on those data including: high pH, elevated potassium and chloride, detection of synthetic organic compounds (e.g., isopropanol, glycols, *tert*-butyl alcohol [TBA], 2-butoxyethanol, and phenols), detection of petroleum hydrocarbons (benzene, toluene, ethylbenzene, and xylenes [BTEX], gasoline and diesel range total petroleum hydrocarbons), and breakdown products of organic compounds such as acetate and benzoic acid. EPA suggested upward migration of inorganic and organic constituents to the drinking water aquifer occurred because of problems with some production well casings and geologic factors. EPA also concluded that gas migrated to domestic wells also because of gas-production activities. Regarding the citizens' complaints about their residential wells, EPA concluded that the "taste and odor problems reported concurrent or after hydraulic fracturing are internally consistent" with EPA's other lines of reasoning that constituents associated with hydraulic fracturing impacted the drinking water aquifer (EPA 2011a).

Response to EPA Report

The importance of EPA's draft report was clear to the media. On December 8, the Associated Press ran a

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story with the heading "EPA theorizes fracking-pollution link." The Associated Press article pointed out that "[t]he finding could have a chilling effect in states trying to determine how to regulate the controversial process . . . " and that "EPA's announcement has major implications for a vast increase in gas drilling in the U.S. in recent years." Another headline about the study appeared: "Feds Link Water Contamination to Fracking for the First Time" (ProPublica 2011). In less than 24 h after the release of the report, nearly a thousand different news stories were generated in 12 countries (Tucker 2013).

On January 16, 2012, Wyoming Governor Matt Mead wrote to Lisa Jackson requesting an extension of the 45-d public comment period on the draft which began December 14 and asking EPA to take steps to ensure an unbiased and scientifically supportable finding open to the public.

On January 20, 2012, 11 U.S. Senators signed a letter to EPA's Administrator asking that this investigation be considered a *highly influential scientific assessment (HISA)*, because its dissemination has the potential financial impact of more than $500 million per year, because the information is controversial, and because it has significant interagency interest with the U.S. Departments of Energy and Interior (U.S. Senate Committee on Environment and Public Works 2011).

On the heels of a letter from the BLM to EPA criticizing the draft report (BLM 2012), on March 8, 2012, the State of Wyoming and EPA announced that the peer review panel to evaluate the draft report will be delayed and the public comment period further extended while additional sampling of EPA's two deep monitor wells is conducted (EPA 2012c). In what has been referred to as phase 5, the USGS was tasked to undertake this sampling (Wright and McMahon 2012) and report the results of data collected in April and May 2012 (Wright et al. 2012).

The oil and gas industry provided extensive, thorough, and consistently critical comments on almost every aspect of EPA's two deep monitor wells. The severe criticisms, some of which are summarized in Table S1, pertain to the objectives of the investigation, its design, monitor well construction, adherence to work plans, decontamination procedures, sampling protocol, transparency in data collected, and most importantly, the scientific conclusions (Itasca Denver Inc. 2012; Stimulation Petrophysics Consulting, LLC 2012; SSPA 2012; Gradient and ERM Resources Management 2012; Gradient 2013; American Petroleum Institute [API] 2013). Taken together, the reports reach the conclusion that the data collected by EPA in its two deep monitor wells are not reliable, and therefore, the findings of EPA in their draft report, that hydraulic fracturing fluids impacted the aquifer, should be dismissed.

Without providing rebuttal to these comments, on June 20, 2013, EPA announced that the agency has no plans to finalize the draft report or seek peer review, and later terminated its request for public comment. While EPA stated that it stands by its work and the data (EPA 2013), the agency, indicated that it does not "plan to rely upon the conclusions of the draft report." There is a concern that EPA's retreat from Pavillion, following its investigations in Parker County, Texas (U.S. District Court 2012), and Dimock, Pennsylvania (EPA 2012b), is part of a policy trend that EPA is disengaging from research related to questioning the safety of hydraulic fracturing (Lustgarten 2013). Others speculate there may have been political factors influencing EPA's decisions (Soraghan 2013).

Analysis

Considering only the technical and managerial factors, what are the lessons to be learned from a process which, after 4 years and expenditures through 2011 of $1.7 million (R. Mylott, personal communication, 2014), still has not definitively determined the cause of taste and odor problems in domestic wells in Pavillion, Wyoming? Three key aspects are identified, including failure to recognize the broader significance of the investigation, insufficient planning and peer review, and unclear communication of findings.

Significance of Investigation

Natural gas development in Wyoming has a significant impact on the state economy. In 2012, Wyoming's petroleum industry directly used approximately 25,500 people with an annual payroll more than $1.4 billion and generated approximately $2.4 billion in taxes royalties and other revenue for the state (Petroleum Association of Wyoming 2013).

Heretofore, it had been believed there had been no conclusive scientific evidence that deep hydraulic fracturing caused shallow groundwater contamination anywhere in the United States. Thus, the Pavillion findings, potentially the first to contradict this belief, would be significant indeed.

It is clear from EPA's contractor work plans that the investigators were looking for a connection between the affected domestic wells and the deeper gas producing part of the system, including a connection caused by "gas well completion and enhancement techniques" (Shaw 2010). However, the implications of finding such an unprecedented linkage on the petroleum industry and economies of Wyoming and other states apparently were not fully considered. Had EPA's team recognized the national importance of the Pavillion project, prepublication peer review may have been more rigorous, and EPA contractors likely would have developed a more robust work plan to ensure that more of the questions that should have been anticipated could be answered in a thoroughly documented and transparent manner. The Pavillion investigation likely could have benefited by designating it as a HISA at the onset.

Planning and Peer Review

EPA's pathway from planning to publishing the draft report did not fully use stakeholder input. Throughout this process, EPA belonged to the Pavillion Working

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Group, a broad stakeholder group established in 2010 to work cooperatively on the groundwater problem. The process leading up to disseminating the draft EPA report likely could have benefited if this group, perhaps with the addition of selected other independent experts, served as an advisory group to EPA providing peer input in the design, oversight on implementation of the work plan, as well as more in-depth peer review of the initial draft report. No doubt the group's representatives from industry and state government also would have recognized the potential implications of EPA's report.

In the absence of input from an advisory panel of stakeholders, there were predictable difficulties with EPA's relatively fast track field investigation, which formed the basis of the December 2011 draft report. With respect to the field program design, there were only two monitor wells and two sampling dates, usually an insufficient number to be definitive for identifying the source of deep contamination. This number is especially limiting because there was no baseline monitoring prior to when hydraulic fracturing began. And, one of the EPA monitor wells was such a poor producer that the USGS could not collect sufficient water for a complete analysis. Furthermore, these two deep monitor wells were drilled near the apex of a known structural dome in a gas reservoir that has no regionally extensive gas-trapping caprock in the Pavillion area. Finding hydrocarbons here should be no surprise, especially because methane was known to accumulate naturally in sand lenses and was present in shallower wells prior to gas production.

How to design a field program to identify definitively the cause of the impaired shallow domestic wells situated above a natural gas reservoir with 40 years of prior development, and where the wells are near former surface pits, would have been a legitimate question for a technical advisory panel aware of the potential significance of the findings. Panel input prior to initiating field work likely could have prevented many of the shortcomings of the agency's investigation, such as those identified in Table S1.

The EPA predraft report review process did include input from four reviewers, one internal and three external. Significantly, the Wyoming Oil and Gas Conservation Commission (WOCCD), also a Pavillion Working Group participant, submitted extensive technical comments on EPA's data on November 22, 2011, before the draft report was issued to the public (Fugleberg 2011). But, the process EPA chose to follow on this project only allowed for stakeholder input following the issuance of the draft report during the formal public comment period.

Careful external technical review of the draft report by industry and consultants suggests that EPA's prepublication review process was insufficient. During the formal public comment period, inconsistencies were found between the EPA work plan, the actual field work, and the draft report (Table S1). Only after the supporting information, the actual field methods and monitor well construction materials, and testing results, including the quality assurance data, were evaluated in great detail and compared with the work plans and the draft report did discrepancies become apparent. The charge assigned to EPA's four reviewers of the prepublication draft is not known, but if they examined the supporting information in similar detail, the draft report released to the public likely would have been much less controversial.

EPA's objectives creeped from initially to determine the cause of the taste and odor complaints to a report focused on detecting hydrofracking chemicals in a drinking water aquifer and domestic wells. The planning documents emphasized the latter objective. And, likely due in part to budget constraints, project design, and technical issues, there currently are no firm conclusions for either objective. External peer review during the investigation could have helped keep the objective and plans better aligned.

The detailed review also revealed a lack of transparency in the EPA process (API 2013). For example, shortly after the draft report was issued, the Governor of the State of Wyoming and Encana requested specific information and data from EPA that was not provided on EPA's website, raising questions to the U.S. House of Representatives (2012) about why such information was withheld. Additionally, the draft report was silent on the release of glycol-containing antifreeze during drilling of one of the monitor wells, a potentially relevant fact when developing conclusions about the source of glycol in groundwater samples. Disclosure of all key and pertinent information is essential in order for proper and unbiased peer review and for building confidence in the conclusions.

Communication

EPA may have avoided some criticism, especially from the media and public, had it communicated the conclusions in the report and their significance more clearly. Conclusions should be supported by the data, unambiguous, and internally consistent within the report. However, some key statements in the report indicate otherwise. For example, in the draft report, EPA found that "the existing data at this time do not establish a definitive link between the deep and shallow contamination of the aquifer." This critical finding, buried on page 27 of the report, would not appear to comport with the more widely read conclusion on page xiii of the Extended Abstract: "... the data indicates likely impact to groundwater that can be explained by hydraulic fracturing." It is this latter statement that apparently was picked up by the media, the public, and industry and lies at the heart of the controversy. However, the headline grabber appears to have been in reference to EPA's conclusion about inorganic and organic sample results from its two deep monitor wells which are within an underground source of drinking water as defined by the Safe Drinking Water Act but are not actually domestic wells. In fact, EPA (2013) clearly concluded in its news release that "... efforts to evaluate potential migration pathways from deeper gas production zones to shallower domestic water wells in the Pavillion gas field are inconclusive."

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EPA did not communicate in the draft report all of its findings from the field investigation. The initial objective of EPA's investigation was to determine the cause of the taste and odor in the domestic wells. Multiple approaches were implemented, but EPA's draft report focused primarily on findings in the two deep monitor wells, rather than on a comprehensive interpretation of the data from the shallower domestic well sampling, samples from the monitor wells installed near the pits by Encana, and a soil-gas survey. The soil-gas survey that was designed to detect the migration of gases from the deep subsurface, would also appear useful to identifying the source of shallow groundwater impacts such as from the pits, but there was no discussion of the findings in the draft report, even though the soil-gas survey was a significant part of the work plan (Shaw 2010). The shallow soil-gas information could have been highly relevant to answering the initial question about the source of the taste and odor problems in the domestic wells.

Important information to disclose early in the draft report was that there were no organic chemicals found in domestic wells exceeding established federal drinking water standards, although many of the domestic wells showed DRO, and gasoline range organics (GRO) and methane, and some wells had trace levels of exotic compounds (adamantanes, 2-butoxyethanol phosphate, phenols, naphthalene, and toluene) (EPA 2011a). From industry's perspective, EPA's tests on the domestic wells from the residents found no indication of oil and gas impacts and no connection to hydraulic fracturing (Encana 2011). In domestic wells, many organic constituents detected in phase 1 and 2 sampling were not detected in phase 4 sampling such as 2-butoxyethanol phosphate, phenol, and toluene. Some initial detections of constituents were not confirmed, including adamantanes because of detections in blank samples, whereas other chemicals present, such as toluene, have multiple potential sources (SSPA 2012). More emphasis could have been placed in the draft report, as stated by EPA's Administrator, that there is no indication that drinking water is at risk (Fugleberg 2011).

The draft report also failed to communicate that the Pavillion site has unique characteristics. Even if EPA's conclusions were correct, recognizing the uniqueness of the Pavillion site is important to stress in a report of this nature, so that more far reaching implications would not be construed about the risks of hydraulic fracturing in general. For example, wells at Pavillion are not drilled using directional drilling as in many other hydraulically fractured shale gas reservoirs. The gas reservoir at Pavillion, which starts at about 335 mbgs (1100 feet), is much shallower than most shale gas reservoirs where producing zones may be a mile or more deep. Additionally, the gas sand bodies are not laterally continuous, and there is no regional caprock separating the gas producing zone from fresh water. In a prereport dissemination interview, EPA's Administrator guarded against extrapolating the findings from Pavillion to other sites, owing to the shallow nature of the Pavillion gas reservoir (Fugleberg 2011), but unfortunately, the unique conditions were not discussed in the conclusions of the draft report.

The concept of a *draft* report as only a tentative and preliminary work product with conclusions subject to change was lost on the public and media. The disclaimer at the beginning of the draft report that the contents do not "necessarily reflect the views and policies of the agency . . ." did little to hold back wide-spread criticism of the report pending completion of the formal peer review.

Following the EPA draft report, there was also insufficient communication of the findings in phase 5 sampling of the two deep monitor wells during April and May 2012 (Wright et al. 2012). The USGS report, issued in September 2012, is essentially void of interpretation, significance of results, and conclusions. Analysis of the data indicates that many chemicals detected in early sampling phases declined significantly with increasing borehole purging, indicating problems with representativeness of earlier results (Gradient 2013). It is not clear why the USGS was not charged with interpreting their data and conveying that to the public. Such an analysis could have had a timely impact on some reactions to EPA's draft report and possibly on EPA's decision to withdraw from its lead in the investigation.

Recent Status

Although EPA has relinquished the lead to the State of Wyoming for continuing the Pavillion groundwater investigation, EPA will still be conducting a national research project on the potential impacts of hydraulic fracturing on drinking-water resources (EPA 2011b). The project has been designated as a HISA (EPA 2014). The plan is broad in scope and addresses each stage of the water cycle pertaining to the hydraulic fracturing process. The research questions to be addressed by the case studies related to chemical mixing are, for example: "How effective are current well construction practices at containing gases and fluids before, during, and after hydraulic fracturing? Can subsurface migration of fluids or gases to drinking water resources occur, and what local geologic or man-made features allow this?" (EPA 2012a). Based on stakeholder nominations, five sites were chosen for retrospective case studies in North Dakota, Colorado, Texas, and Pennsylvania. The data collection effort involves primarily sampling domestic wells, springs, and surface water bodies, not unlike the phase 1 and 2 investigations at Pavillion.

In spite of its apparent flaws, the Pavillion investigation appears relevant to answering some of these questions, yet it will not be considered in the national study. In the interest of sound science and full transparency, it would appear beneficial for EPA, its research team, and the public to learn something from the recent controversial work at Pavillion, as well as at sites EPA investigated at Dimock, Pennsylvania and Parker County,

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Texas, on how to improve the investigative methods to be applied in evaluating the nominated case studies. The extensive technical comments received by EPA on Pavillion also could be invaluable in assisting state agencies that are developing hydraulic fracturing regulations and guidance on how to conduct appropriate groundwater monitoring and sampling investigations where hydraulic fracturing operations occur.

For instance, to establish a link to hydraulic fracturing in the deep monitor wells, the EPA draft report relied heavily on the detection of exotic organics chemicals such as glycols and 2-butoxyethanol in the deep groundwater monitor wells, some of which were present at very low or trace concentrations, at least initially. If the detection of such low chemical concentrations is to be used as a criterion to show impacts from hydraulic fracturing, it is important to exercise extreme care in decontaminating drilling tools, well casings, and screens placed in the well, in the use during drilling of hydrocarbon-based fluids and lubricants, in eliminating the potential for well construction materials to leach chemicals into the water, in conducting thorough well development, in confirmation sampling, and in robust laboratory QA/QC protocols.

The WDEQ and the WOGCC are now coordinating the field investigation of groundwater at Pavillion. The scope of work involves a review of the well files and well tests on production wells within 402 m (1320 feet) of 14 domestic wells targeted for additional water quality testing, reviewing the water quality data previously collected by EPA and USGS, compiling and reviewing other data not previously considered, and retaining experts to assist in the review of all available data and information (State of Wyoming, Office of the Governor Mead 2013). EPA indicates that Wyoming's efforts will build on EPA's monitoring results (EPA 2013). However, rather than focusing on detection monitoring for constituents found in hydraulic fracturing fluids, the WDEQ will evaluate the need for additional sampling based on exceedances of established EPA primary and secondary contaminant levels and WDEQ Rules and Regulations as a trigger (EPA 2013). One element of the investigation, a report on production well integrity near the sampled water wells was just released for comment, with recommendations for further study and improved data collection (WOGCC 2014). Also, a final report on the investigation is scheduled for September 30, 2014 (State of Wyoming, Office of the Governor Mead 2013).

It is somewhat ironic now that after EPA relinquished its lead role to the State, it is the key stakeholders at the state level in the Pavillion Working Group anyway, led by the WDEQ and WOCCD, that are currently guiding the investigation. Significant funding for the work will now be provided at least in part by private sources, rather than federal dollars, through a $1.5 million grant from Encana to the Wyoming Natural Resources Foundation which could be allocated to the investigation (State of Wyoming, Office of the Governor Mead 2013).

Summary and Conclusions

EPA's draft report on groundwater contamination at Pavillion, Wyoming brought forth a clash of science, environmental regulations, politics, and public opinion over hydraulic fracturing for natural gas development. After nearly 6 years, the citizens' question about the cause of taste and odor in their groundwater wells is unanswered.

Controversy over whether the source of objectionable taste and odor in residential wells was attributable to natural sources, abandoned or leaky surface pits, hydraulic fracturing, or other causes likely could have been avoided had there been baseline samples collected from existing residential wells or monitor wells prior to the expansion of operations near Pavillion in 2005 (e.g., NGWA 2010).

Following the citizen complaints about water quality, EPA took initiative in sampling domestic wells and attempting to collect representative water samples from two deep monitor wells constructed for the first time in a zone between most of the domestic wells and the hydraulically fractured zone. Unfortunately, the planning, construction of the monitor wells, and sampling methods have come under such extreme criticism that the validity in EPA's data as well as the results and conclusions appear to be compromised and unreliable.

Field work at sites where there is the potential for significant influence on important national issues such as deep groundwater monitoring at hydraulic fracturing sites requires a high degree of technical care in monitor well design, well construction, and sampling to ensure that the water samples are representative of the formation fluids. The effects of hydraulic fracturing on groundwater may be difficult to detect unambiguously, especially in low-yield formations, where there are very low concentrations of chemicals of concern which could have multiple sources, including natural sources as well as the materials used in monitoring and well construction.

The detailed technical assessments by industry of EPA's groundwater investigation at Pavillion should be carefully considered by state agencies developing their own groundwater monitoring requirements at hydraulically fractured sites. The lessons learned from the groundwater investigation at Pavillion could be valuable for improving existing guidance documents and best suggested practices on deep groundwater monitoring and sampling in complex situations, as well as for improving the peer review process.

Some of the controversy created by the draft EPA report could have been defused or avoided through the inclusion of a peer review panel or advisory board which included technical members of stakeholder groups to provide input on the planning, implementation, and development of a draft report, before the field work was initiated and before the draft report was released to the public for comment.

Because EPA's Pavillion project team apparently underestimated the national significance and potential economic impact of its investigation to link deep hydraulic fracturing with groundwater impacts, the work

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was not conducted as a HISA, which would have required the highest technical standards and most stringent peer review. Based on the response to EPA's draft report at Pavillion, a high level of peer review is necessary to fully verify conclusions of similar investigations in the future, especially prior to dissemination of draft reports to the public.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Site location map.
Figure S2. Well location map.
Table S1. Summary of key technical review comments from industry and consultants.

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