

# Review of US EPA and USGS Groundwater Sampling Data Reports

## Pavillion, Wyoming

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# Executive Summary

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In response to residents' complaints of objectionable odors and tastes in well water near the town of Pavillion, Wyoming, the United States Environmental Protection Agency (US EPA) initiated a groundwater investigation in 2009. After four phases of sampling, and installing only five monitoring wells (including two deep monitoring wells) over a study area of 50 square miles, US EPA (2011) released its "Draft Investigation of Ground Water Contamination near Pavillion, Wyoming" report ("Study"). On behalf of Halliburton Energy Services Inc., we previously reviewed and critiqued the US EPA Study and concluded that the Study design was flawed, the Study implementation (*i.e.*, field work and data quality evaluation) was very poor, and the analysis of the data was not based on sound science (Gradient & ERM, 2012). Additional investigations, which included resampling of the two deep monitoring wells by US EPA and the United States Geological Survey (USGS) and an optical camera survey of one of the deep monitoring wells (MW02) by the Wyoming Department of Environmental Quality (WDEQ), were undertaken in April 2012. The results of these additional investigations are consistent with and corroborate our prior criticisms. Overall, given these issues, the Study's conclusion that "inorganic and organic constituents associated with hydraulic fracturing have contaminated ground water at and below the depth used for domestic water supply" is flawed and does not have a scientific basis (US EPA, 2011, p. 39). As a result, the Study should not be used as a basis for decision-making.

## A Key Conclusions Based on Our Review of the Prior US EPA Report

### A.1 US EPA's Study Design Was Inherently Flawed

Based on our review of the Study, we previously concluded that the design of the US EPA Study was flawed and was inadequate for determining whether hydraulic fracturing (HF) had impacted groundwater quality "at and below the depth used for domestic water supply" and to "differentiate shallow source terms (pits, septic systems, agricultural and domestic practices) from deeper source terms (gas production wells)." We determined that the following critical flaws render the Study incapable of addressing its stated objectives:

- The Study consisted of installing and sampling three shallow monitoring wells (adjacent to former surface pits used to handle oil and gas drilling-related materials) and two deep monitoring wells, and sampling existing domestic water wells. Understanding the sources of contamination in a complex and heterogeneous setting encompassing 50 square miles, such as the Pavillion study area, requires a significant number of observation points distributed throughout the study area and at a range of depths. A study with so few monitoring wells is inherently incapable of answering basic questions that are paramount when addressing whether HF activities (or other factors, such as the presence of natural gas) have any impact on deep groundwater quality and whether there is any correlation between deep and shallow groundwater quality (*e.g.*, at the domestic water wells).
- Given the extremely limited number of monitoring wells installed for the Study and the lack of any nested wells, the Study was not designed to determine local or regional hydraulic gradients (which determine the direction of groundwater flow – upward *versus* downward). Compounding this problem, US EPA failed to acknowledge or use existing information on the hydrogeological setting in its study design. Although the Study states that "[h]ydraulic gradients are *currently*

*undefined* in the area of investigation" (US EPA, 2011, p. xiii, emphasis added), there is a wealth of information from the USGS and others that clearly indicates the hydraulic gradient in the study area is downward.<sup>1</sup> Despite this information, US EPA's analysis and conclusions presumptively – yet incorrectly – assume that regional groundwater flow is upward.

- The extremely limited number of monitoring wells, and the depths at which they were installed, also compromised US EPA's ability to determine whether "deep source terms" have impacted domestic wells in the study area. The vast majority of domestic wells in the study area (including all municipal wells) are 50 to 160 meters (164 to 525 feet) deep, whereas US EPA installed its two deep monitoring wells far below this zone – at depths of 233 to 299 meters (765 to 960 feet) bgs. Moreover, the strata where US EPA's deep monitoring wells were screened are within or proximate to gas bearing zone(s). Thus, the deep monitoring wells were not installed at depths appropriate to characterize the local drinking water aquifers and data from these wells are not representative of drinking water quality in the Pavillion area.

Finally, US EPA itself acknowledged the limitations of the Study: "[T]he existing data at this time do not establish a definitive link between deep and shallow contamination of the aquifer. An increased number of sampling points (monitoring wells) with vertical profiling in targeted locations are necessary to better define transport and fate characteristics of organic and inorganic contaminants in the ground water system and impact on domestic wells. (p. 27)." The Bureau of Land Management likewise stated that "two rounds of sampling obtained at [these] two locations are not statistically valid to arrive at any reliable conclusion given the reservoir complexities" (Simpson 2012). Regardless, US EPA proceeded to draw far-reaching conclusions, which are not supportable given the limitations of the Study design and other shortcomings, discussed below.

## **A.2 US EPA's Study Implementation Was Very Poor, Undermining the Reliability of the Monitoring Results**

Our review of the Study and related information also showed that US EPA's implementation of the Study (*i.e.*, field work execution and data quality review) did not follow Agency guidance or the project Work Plan for groundwater sample collection (US EPA Region I, 1996, 2010; URS, 2010b). In addition, US EPA failed to install and develop the deep monitoring wells properly, which compromised the groundwater quality data and resulted in faulty interpretations of groundwater chemistry. Furthermore, US EPA did not review the quality of the data adequately prior to using it, such that the Study conclusions are overreaching and unsupported by the data. Some of the Study's key implementation shortcomings we previously identified are summarized below.

- During installation of the deep monitoring wells, US EPA did not keep records of the volume of drilling fluid (*i.e.*, water and mud) used and lost into the formation during the drilling process – a standard industry practice (*e.g.*, US EPA Region IV, 2008; US EPA, 1991; Driscoll, 1986) required by the project Work Plan (URS, 2010b). In addition, US EPA did not use a tracer (*e.g.*, fluorescent dye) in the drilling fluid – another standard industry practice for monitoring wells installed using mud rotary techniques (*e.g.*, Wandrey *et al.*, 2010). The use of drilling fluid volume records (to conduct a fluids balance), or the use of a tracer or dye in the drilling mud, would have enabled steps to be taken to ensure that any drilling fluid remaining in the vicinity of the borehole was removed (a process referred to as well "development") prior to groundwater sample collection.

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<sup>1</sup> US EPA's two deep monitoring wells are nearly two miles apart and may not be hydraulically connected. However, to the extent they provide relevant information on hydraulic gradients, the water levels in these two wells indicate a downward hydraulic gradient.

- US EPA did not install a bentonite seal above the deep monitoring well screens, a requirement of the project Work Plan (URS, 2010b) and standard industry practice for groundwater monitoring wells (US EPA, 1991; Driscoll, 1986). Instead, Portland cement was pumped into the borehole directly above the well screen to create an approximately 15-foot thick cement plug. The lack of an adequate annular seal above the well screen is a major deficiency of the US EPA-installed monitoring wells that, in all likelihood, placed cement grout in direct contact with groundwater sampled from the wells' screen. The cement grout is likely responsible for the elevated pH (~12) and several other elevated constituent concentrations observed in the deep monitoring wells.
- US EPA did not follow standard practice or the project Work Plan (URS, 2010b) during development of the deep monitoring wells. At MW02, less than two (2) well volumes (compared to a standard of five (5) well volumes) were removed before well development was halted due to methane accumulation in the well.
- The groundwater sampling methodology used at the deep monitoring wells was unconventional and did not follow current industry standards or the project Work Plan (URS, 2010b, US EPA Region I, 2010). The monitoring wells were purged at rates between 30 to 50 times higher than the flow rate recommended by US EPA to enable collection of representative aquifer samples (US EPA Region I, 2010).

In addition to these fundamental flaws in the well installation and development, we found that there were inherent data quality limitations that compromise the Study results and conclusions:

- US EPA utilized a non-standard analytical test method to analyze glycols and 2-butoxyethanol (2-BE), without validating the method and confirming that it was capable of producing reliable results (*e.g.*, not prone to false positives). The reliability of the glycols and 2-BE monitoring results are highly questionable, given the use of a non-standard and unproven analytical test method. This is an important deficiency because the Study places significant importance on the glycols and 2-BE data as "implicating" HF activities. The data quality limitations call the validity of this interpretation into serious question.
- A wide variety of compounds (*e.g.*, hydrocarbons, methane, and glycols) were routinely detected in the field, equipment, and trip blank samples. For example, methane was detected in every blank sample (total of five) collected during Phases III and IV of the Study at concentrations ranging from 45 to 76 µg/L. No methane blanks were collected in Phases I and II. The routine and widespread detection of contaminants in the blanks is indicative of substandard field sampling practices. Finally, US EPA did not follow its own data quality assessment guidelines (*e.g.*, US EPA, 2006) and did not take appropriate actions in addressing the presence of blank contamination. If US EPA had followed its own data quality assessment guidance (considering all concentrations less than 5 to 10 times the concentration detected in the blanks as non-detect<sup>2</sup>), a large subset of the data for certain compounds, such as methane and hydrocarbons, would be considered non-detected.

In summary, we concluded that the poor and non-standard practices used in implementing the Study and in assessing the quality of the data severely limit the reliability of the monitoring results for decision making. The Bureau of Land Management also expressed concerns about the quality of the data, stating that "the development of these monitor wells appears to be deficient for sampling purposes and groundwater samples from the wells should not be fully trusted until development activities indicate that

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<sup>2</sup> Minimum detection levels are calculated as 5 times the maximum blank concentration for most compounds, and 10 times for common laboratory contaminants such as toluene, methylene chloride, or bis(2-ethyl)hexylphthalate (US EPA, 1994).

the wells are yielding information untainted by any effects introduced by the drilling, well completion, and sampling process" (Simpson 2012).

### A.3 US EPA's Findings and Conclusions Are Not Based on Sound Science

In the Study, US EPA presented multiple "lines of reasoning" to argue that "inorganic and organic constituents associated with hydraulic fracturing have contaminated groundwater at and below the depth used for domestic water supply" (US EPA, 2011, p. 39). US EPA hypothesized that the presence of inorganic (high pH, potassium, and chloride) and organic (methane, petroleum hydrocarbons, glycols, and alcohols) constituents in the deep monitoring wells is attributable to HF fluids, which the Agency surmises have preferentially migrated along poorly cemented gas production wells. US EPA also alleges that methane detected in domestic water wells is the result of "enhanced" migration – a consequence of HF activities and increased natural gas development in the last two decades. As noted above, the data on which US EPA bases its conclusions are unreliable. Yet, even if those data were considered reliable, our prior review demonstrated that the technical analysis used to support US EPA's lines of reasoning is flawed and does not support US EPA's conclusion for the following reasons:

- **Elevated pH, Potassium, and Chloride:** US EPA asserts that pH, potassium, and/or chloride are elevated at the deep monitoring wells as a result of HF activities. However, these conditions appear to be the result of cement grout intrusion into the screened intervals of the deep monitoring wells, and not due to migration of HF fluids. For example, most of the HF stimulations in Pavillion utilized a CO<sub>2</sub>-based foam fluid, which would have an acidic pH (*i.e.*, < 7) and not the high (caustic) pH values observed in the deep monitoring wells. At the same time, a review of the literature indicates that the pH of cement and associated pore water can range from 12 to 13.8, and the pH in monitoring wells affected by cement grout intrusion can stay high (*e.g.*, > 11) even after multiple attempts to redevelop the well (Gradient & ERM, 2012). Potassium is also a significant component of cement. Chloride was likewise a component of the cement used in constructing MW01 and MW02; calcium chloride was added to the cement mix. In short, the absence of a bentonite seal in the deep monitoring wells installed by US EPA allowed unimpeded flow of cement grout into the screened intervals of the deep monitoring wells and cement-induced geochemical changes to the groundwater sampled from these wells.
- **Petroleum Hydrocarbons:** The elevated petroleum hydrocarbon concentrations detected in the deep monitoring well (MW02) are associated with natural gas present in the formation. The chemical signature of petroleum hydrocarbons such as benzene, toluene, ethylbenzene, and xylenes (BTEX), and tri-methylbenzenes detected in MW02 matches that of a condensate sample collected by US EPA from a natural gas well in Pavillion – an indication that these petroleum hydrocarbons are consistent with and likely derived from the natural source in the area.
- **Synthetic Organic Compounds:** As discussed above, the glycol and 2-BE data are unreliable and not usable for decision making. Other organic constituents, such as hydrocarbons, acetone, isopropanol, and tertiary butyl alcohol (TBA) are naturally produced by microorganisms as breakdown products of natural gas and are unlikely to be associated with HF activities.

- **Incorrect Inferences of Perceived Concentration Gradient of Degradation Products:** US EPA theorizes that the "enriched" concentrations of breakdown or degradation products of petroleum hydrocarbons (*e.g.*, acetate and benzoic acid) at MW01 (shallower well) relative to the same constituents in MW02 (deeper well) is an indication of upward groundwater migration along with degradation. This theory relies upon the (incorrect) presumption that the groundwater flow is upward. However, regional studies indicate that the hydraulic head gradient in Pavillion is downward (Gradient & ERM, 2012). Furthermore, if deep groundwater was a source of "contamination" to the domestic wells, concentrations of natural gas-related compounds (*e.g.*, diesel range organics, or DRO) would be expected to increase with depth in the domestic wells. However, there is no relationship between DRO and depth (Gradient & ERM, 2012).
- **Purported Migration Pathways:** US EPA theorizes that chemicals could migrate upward from the gas-bearing zone through the formation rock and *via* well annuli. These purported pathways for migration of HF fluid do not take into account the nature of HF stimulations or the hydrogeology of the Study area. During an HF stimulation, upward migration through the formation rock is highly unlikely, given that the anticipated direction of fracture propagation is horizontal. Migration of HF fluids to an adjacent production well is similarly unlikely, given the low volume of HF fluids used in the Pavillion area, short duration of the stimulations, and large available pore volume in the subsurface compared to the volume of HF fluids used. Subsequent to an HF stimulation, upward migration *via* any pathway (either through formation rock or *via* well annuli) is not plausible, because the direction of groundwater flow is downward in the Pavillion area and gas extraction causes fluids to flow toward the gas wells (*i.e.*, downward), not away from them.
- **Methane:** The hypothesis presented in the Study that HF activities have enhanced the migration of methane has several flaws. The Wind River Basin (of which the Pavillion Gas Field is part) is a natural gas-rich region, and the presence of methane at shallow depths, before a majority of the gas wells were drilled and hydraulically fractured in the region, is well documented (WOGCC, 2012). In addition, there is no correlation between methane concentrations in domestic wells and proximity to gas production wells or depth. If the gas wells or HF-induced enhanced migration were the source of methane, concentrations would be expected to increase with depth or proximity to gas wells. Finally, the domestic well methane data are unreliable because methane was detected in field blanks and almost all of the methane data would have been qualified as non-detects following US EPA data quality assessment guidance (US EPA, 1994).

In sum, the "lines of reasoning" used by US EPA – the basis for its conclusions – rely on poor quality and unreliable data (*e.g.*, glycol and methane measurements), do not take account of the scientific literature (*e.g.*, effect of cement intrusion on water quality), and do not adequately consider the available data (*e.g.*, incorrect conclusion regarding head gradients and the direction of groundwater flow).

## **B Supplemental USGS and US EPA (Phase V) Sampling**

Due to concerns regarding the poor quality of the analytical results reported in the US EPA Study, the United States Geological Survey (USGS) and US EPA re-sampled the deep monitoring wells (MW01 and MW02) in April 2012 ("Phase V"), using more rigorous quality assurance and quality control measures. In addition, an optical camera survey of deep monitoring well MW02 was performed by WDEQ in April 2012, as summarized below:

- **USGS Sampling:** The USGS collected two groundwater samples from deep monitoring well MW01, after about 1.5 and 3 borehole volumes had been purged from the well. These and additional quality control/quality assurance (QA/QC) samples were analyzed for a wide range of analytes, including field parameters, inorganic constituents, organic constituents, dissolved gases,

stable isotopes of water, and environmental tracers for age dating groundwater. The USGS did not collect a sample from MW02 because the well's yield was extremely low (0.9 gal/hr) and did not satisfy USGS' sampling criteria for ensuring that groundwater samples are representative of the formation being sampled.

- **US EPA Sampling:** US EPA implemented a different sampling program, which was done in parallel with the USGS sampling, and included:
  - Collection of a total of 10 groundwater samples from MW01 throughout the purging process, starting after a purge volume of 1.44 borehole volumes and ending at 3.14 borehole volumes. This series of samples was aimed at providing a better indication of variation in groundwater quality as a function of purge volume removed from the borehole.
  - Collection of two groundwater samples from MW02. One sample was collected at the initiation of purging, and the other sample was collected six days later, after one borehole volume had been purged over four events.
  - Collection of groundwater samples from five domestic wells (all of which had been sampled in one of the prior Study phases) and one municipal well.
  - US EPA's analytical program was comparable to that used during the prior sampling program (US EPA, 2011).
- **WDEQ Camera Survey:** The WDEQ performed a downhole optical camera survey of monitoring well MW02. This survey, which was conducted after the US EPA Phase V groundwater sampling, was undertaken to evaluate the well's integrity and in particular the condition of the well screen (WDEQ, 2012). In response to the findings of the camera survey, US EPA released updated monitoring well construction schematics for its deep monitoring wells, MW01 and MW02.

The USGS and US EPA issued brief data reports presenting the sampling results with limited interpretation (USGS, 2012b; US EPA, 2012). For example, US EPA included only one sentence as an interpretation of the data in which it concludes that the sampling results from the deep monitoring wells are "consistent" with prior results. No further explanation or scientific basis for this statement was given.

## **C Supplemental USGS and US EPA Sampling Results Corroborate Our Prior Conclusions**

The Phase V sampling and camera results provide further support for the criticisms presented in our June 2012 comments that the Study implementation (*i.e.*, field work and data quality evaluation) was very poor and the analysis of the data was not based on sound science. Specifically, these recent data demonstrate the following:

- **Poor Well Installation:** The updated monitoring well construction schematics recently released by US EPA indicate that both monitoring wells MW01 and MW02 have a section of open borehole beneath the well screens. These sections of open borehole violate US EPA's procedures for well installation (US EPA, 2008) since they can act as reservoirs for materials, such as drill cuttings and/or cement grout, thereby affecting groundwater quality at the monitoring wells. Additionally, the updated well schematics also indicate that MW02 was installed 10 feet deeper than intended, which places about half of the well screen in a shale layer and also in the portion of the borehole that was backfilled with drill cuttings. These poor construction practices have led to unreliable data that are not representative of drinking water in the Pavillion area.

- **Cement Intrusion:** Cement grout continues to affect groundwater chemistry at both deep monitoring wells. However, the Phase V temporal monitoring results demonstrate that as more water is purged from the wells, the inorganic water chemistry is trending toward the regional (ambient) groundwater chemistry, especially at MW01. This confirms that the pH readings and the presence of potassium that the Study cites as evidence of the presence of HF fluids are in fact due to impacts from the cement used in constructing the monitoring wells. The low yield at MW02 has not allowed the US EPA or USGS to properly develop and purge the well and therefore, the effects of cement contamination on water chemistry are more persistent at this well.
- **Data Quality and Reliability:** US EPA continues to rely on a method that is under development for glycol analysis. However, even if one assumes that the glycol detections are not an artifact of US EPA's non-standard analytical method, the temporal trend in glycol data is indicative of a near well-bore source, *i.e.*, glycols associated with well construction materials, being flushed out during purging. Glycols are present in cement and the pattern of declining glycol concentrations is identical to the temporal decline of other cement-related constituents. This is very clear evidence that the glycols, if present, are associated with cement and not HF. Furthermore, the Phase V sampling results also confirm that some of the compounds reported in the prior sampling results (*e.g.*, toluene and xylenes at MW01) were false positives, associated with poor sampling practices used during groundwater sample collection.
- **Naturally Occurring Hydrocarbons:** The presence of hydrocarbons in groundwater sampled from the deep monitoring wells is consistent with the geochemistry of this natural gas-rich region. The BLM also indicated in its comments (Simpson, 2012) that the presence of hydrocarbons is "anticipated" and that these data are not an indication of HF fluid migration or leaky gas well casings.

These additional findings further confirm that the two deep monitoring wells were poorly installed and developed by US EPA, groundwater chemistry at these wells for certain analytes (*e.g.*, inorganics, glycols) continues to be affected by poor well installation techniques and is hence unreliable, and the hydrocarbon-related compounds detected in the monitoring wells are consistent with the geochemistry of a natural gas-rich area.

## D Overall Conclusions

US EPA's Study of groundwater quality in Pavillion has significant deficiencies and cannot be relied upon to draw any meaningful conclusions regarding the source of contamination, if any, to the domestic wells or the effect of HF on drinking water quality. Based on a review of the initial US EPA Study and the Phase V sampling results, our overall conclusions are that:

- The US EPA Study design was inherently flawed and relied on only two deep monitoring wells that are completed below the groundwater strata that are commonly used for domestic water supply, not representative of typical potable groundwater in the region, and are screened within or proximate to gas-bearing zone(s).
- The field implementation of the Study was extremely poor, and these problems (*e.g.*, effect of poor well installation and development) continue to plague the quality of the results. The deep monitoring wells were installed using non-standard techniques (including the absence of a bentonite seal above the screened intervals and open borehole below), which resulted in cement grout intrusion into the screened intervals of the wells; this intrusion continues to affect the groundwater quality at these wells. Furthermore, the field sampling techniques used in Phases III and IV of the Study were sub-standard and the resulting data quality was poor (*i.e.*, resulted in a

number of false positives) – a finding that has been confirmed by the more carefully implemented Phase V sampling. Moreover, US EPA's use of un-proven analytical test methods (*e.g.*, for glycols) continues to call into question the reliability of these data.

- Lastly, US EPA's interpretation of the sampling results is flawed and not based on sound science. For example, US EPA's conclusion that there is an upward hydraulic gradient in the region (the central premise of its argument that HF chemicals are migrating upward *via* groundwater) is not consistent with available hydrogeologic data, which clearly demonstrate the gradient to be downward. US EPA's interpretation that elevated levels of certain constituents (*e.g.*, elevated pH, potassium, glycols) are attributable to HF fluids is also incorrect. The Phase V sampling results contradict US EPA's prior conclusions and indicate that elevated concentrations of many constituents previously attributed to HF are actually associated with well construction materials (*e.g.*, cement) and that groundwater quality from the deep monitoring wells is trending towards regional groundwater quality with additional purging. Finally, US EPA's attempt to link the presence of methane and other petroleum hydrocarbons to HF-enhanced migration ignores the fact that the presence of shallow methane in the region is well-documented, even before HF activities began in the area.

To summarize, given the significant Study design, implementation, and data interpretation shortcomings, there is no scientific basis for US EPA's conclusory finding that "inorganic and organic constituents associated with hydraulic fracturing have contaminated groundwater at and below the depth used for domestic water supply." This conclusion is also contrary to public statements made by EPA officials, including EPA Administrator Lisa Jackson, who stated that (Jackson and Assuras, 2011):

"[W]e have absolutely no indication right now that drinking water is at risk."

Based on our scientific review, we would expect that a thorough peer review of the Study will identify its significant shortcomings, deficiencies that are so significant as to reject the premature findings presented in the Study. Others – including the Bureau of Land Management – expressed similar concerns regarding the Study. Overall, the US EPA Study (US EPA, 2011) should not be used for US EPA's broader study of the relationship between hydraulic fracturing and drinking water or any other form of decision making.

# 1 Introduction

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The United States Environmental Protection Agency (US EPA) initiated a ground water investigation near the town of Pavillion, Wyoming in 2009. After four phases of sampling, and installing only two deep monitoring wells, the US EPA (2011) released its "Draft Investigation of Ground Water Contamination near Pavillion, Wyoming" report ("Study"). Gradient and ERM prepared a critical review of the US EPA Study on June 25, 2012 (Gradient and ERM, 2012), on behalf of Halliburton Energy Services, Inc. We identified a number of serious concerns with the Study, including the fact that the Study implementation (*i.e.*, field work and data quality evaluation) was very poor and the analysis of the data was not based on sound science. Others – including the Bureau of Land Management – expressed similar concerns regarding the Study.

Due to concerns regarding the poor quality of analytical results reported by US EPA, the United States Geological Survey (USGS) and US EPA re-sampled the deep monitoring wells (MW01 and MW02) in April 2012, using more rigorous quality assurance and quality control measures ("Phase V"). The USGS and US EPA issued brief data reports presenting the Phase V sampling results (USGS, 2012b; US EPA, 2012). These sampling results provide further support for the criticisms discussed by Gradient and ERM in our June 2012 comments.. For example, although the Phase V sampling did not rectify the inherent shortcomings of the Study design (*e.g.*, lack of vertical profiling, inadequate number of wells), that sampling further demonstrates that the two deep monitoring wells were poorly installed/developed by US EPA, groundwater quality at these wells for certain analytes (*e.g.*, inorganics, glycols) continues to be affected by poor well installation techniques and is hence unreliable, and the hydrocarbon-related compounds detected in the monitoring wells are consistent with the geochemistry of a natural gas-rich area. Overall, the additional data now available confirm that the Study (US EPA, 2011) has a number of significant deficiencies, is unreliable, bases its conclusions on flawed interpretations of the data, and should not be used for decision making.

## 2 Overview of Recent Sampling Activities

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Additional groundwater samples were collected from the two deep monitoring wells (MW01 and MW02) in April 2012 by the USGS and US EPA (USGS, 2012b; US EPA, 2012). The overall scope of the sampling conducted by the USGS and US EPA varied considerably, as discussed below.

In preparation for its work, the USGS reviewed the existing data for these monitoring wells and prepared a work plan describing the sampling methodologies and analytical test methods to be utilized in conducting its work (USGS, 2012a). The USGS collected two groundwater samples from deep monitoring well MW01, after about 1.5 and 3 borehole volumes had been purged from the well. These samples and additional quality control/quality assurance (QA/QC) samples were analyzed for a wide range of analytes, including field parameters, inorganic constituents, organic constituents, dissolved gases, stable isotopes of water, and environmental tracers for age dating groundwater. The USGS did not collect a sample from MW02 because the well's yield was extremely low (0.9 gal/hr) and did not satisfy USGS' sampling criteria.

The US EPA implemented a different sampling program, which was done in parallel with the USGS sampling, and included the following elements:

- Collection of a total of 10 groundwater samples from MW01 throughout the purging process, starting after a purge volume of 1.44 borehole volumes and ending at 3.14 borehole volumes. This series of samples was aimed at providing a better indication of variation in groundwater quality as a function of purge volume removed from the borehole.
- Collection of two groundwater samples from MW02. One sample was collected at the initiation of purging, and the other sample was collected six days later, after one borehole volume had been purged over four events.
- Collection of groundwater samples from five domestic wells (four of which had been previously been sampled) and one municipal well.

US EPA's analytical program was comparable to that used during the Phase IV sampling program (US EPA, 2011).

In addition to the USGS and US EPA sampling activities described above, the Wyoming Department of Environmental Quality (WDEQ) performed a downhole optical camera survey of monitoring well MW02. This survey, which was conducted after the US EPA Phase V groundwater sampling, was undertaken to evaluate the well's integrity and in particular the condition of the well screen (WDEQ, 2012).

The following sections of this report discuss the results of these investigations, placing them in the context of the prior US EPA (2011) report.

### **3 Poor Well Construction Continues to Severely Limit the Reliability of Groundwater Quality Data**

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As discussed below, the new data obtained from the Phase V sampling further demonstrate that the deep monitoring wells were poorly constructed. In the case of MW02, the well was not even installed at an appropriate depth to sample groundwater from the sandstone layer that was targeted. This error is compounded by the substandard well construction practices that US EPA utilized for both deep monitoring wells that allowed cement to intrude into the screened interval. The Phase V data clearly show that both wells continue to suffer from symptoms of contamination by cement. Taken together, these major design and implementation flaws have undermined the monitoring wells' ability to yield a representative groundwater sample and it is questionable whether any remediation efforts would ever be able to rectify these issues so that reliable data could be obtained in the future.

#### **3.1 Camera Survey and Revised Monitoring Well Construction Schematics Provide Additional Evidence That The Deep Monitoring Wells Were Poorly Constructed**

Our prior comments (Gradient and ERM, 2012) and a number of other reviewers identified several significant shortcomings with the installation techniques used by US EPA to construct the two deep monitoring wells. The key deficiencies we identified included: lack of record keeping to document the volume of drilling fluids (*i.e.*, mud and water) being used during well drilling, lack of a bentonite seal to isolate the well screen from the overlying cement seal, failure to use a tracer (*e.g.*, bromide or fluorescent dye) to assess adequacy of well development, and inadequate well development prior to sample collection.

The camera survey of the deep monitoring well MW02 conducted by WDEQ in May 2012 identified additional problems with the construction of this monitoring well (WDEQ, 2012), including:

- MW02 is ten feet deeper than previously reported by US EPA (US EPA, 2011), placing the well screen in a shale-dominant lithologic unit. The installation of the well screen in this low permeability geologic unit limits the ability of the monitoring well to yield a representative groundwater sample from the water bearing unit in the region (typically a higher permeability sandstone layer), as discussed in further detail below.
- Mineral precipitates were found at the bottom of the well indicating that the well casing was not constructed using stainless steel, as previously reported by US EPA. US EPA since has confirmed that the casing used to construct the deep monitoring wells was not stainless steel, contrary to its prior assertion, but was instead carbon steel. Carbon steel is more reactive than stainless steel and reactions with the carbon-steel casing can lead to corrosion and unintended water quality impacts. There is also an unidentified black coating on the outside of the steel casing that may also leach constituents into groundwater being sampled from the deep monitoring wells. The use of carbon steel with an unidentified surface coating may be affecting the representativeness of groundwater samples obtained from the deep monitoring wells.

It appears that the camera survey findings led US EPA to re-examine the available records regarding well installation and to release revised monitoring well completion schematics for the deep monitoring wells on November 6, 2012 (US EPA, 2012). The revised well construction schematics indicate the following differences from the well schematics released in its December 2011 report (US EPA, 2011):

- The presence of a 12-foot section of open borehole (between 797 and 785 ft bgs) beneath the bottom of the well screen at MW01 where mud was "recirculated prior to screen placement." The schematic for MW02 also indicates a section of open borehole beneath the well screen (between 989.5 and 997 ft-bgs). These sections of open borehole violate US EPA's procedures for well installation (US EPA, 2008), which stipulate that additional well casing be installed below the screen to act as a sediment trap, or that the open borehole be backfilled with bentonite or filter pack sand. As constructed, the open borehole below each well screen is a reservoir for drilling mud constituents and cement that will continue to contaminate and bias groundwater samples.
- The well screen for monitoring well MW02 has been modified in the schematic drawing and is now shown as being ten feet deeper than previously reported (US EPA, 2011). As constructed, a portion of the well screen for monitoring well MW02 is drawing water from a shale-dominated lithologic unit, which is likely to yield groundwater with inherently different geochemical characteristics than the sandstone units targeted by drinking water wells in the area.

To summarize, in addition to the previously identified well installation and development deficiencies discussed in our prior report (Gradient and ERM, 2012), the camera survey results and revised schematics for the deep monitoring wells further demonstrate that US EPA did not follow its own guidance for well installation (*e.g.*, left an open section below the well screen with drilling fluids) and did not install monitoring well MW02 in the intended lithologic unit. These shortcomings further limit the reliability of the monitoring wells and affect their ability to yield representative groundwater samples.

### **3.2 The Well Construction Deficiencies at Monitoring Well MW02 Have Affected the Yield of The Well and Undermined the Well's Ability to Provide a Representative Groundwater Sample**

The unconventional and poor practices used during the construction of the deep monitoring wells have significantly affected the ability of these wells to provide water samples that are representative of groundwater quality in the Pavillion region. As discussed in our prior comments (Gradient and ERM, 2012), there are several critical factors that undermine the reliability of any groundwater samples obtained from these wells, such as the migration of cement grout into the screened interval due to the lack of a cement bentonite seal. Additionally, new data have been released that indicate the presence of an "open section" of the borehole beneath the well screen containing drill cuttings and mud and the placement of the well screen for monitoring well MW02 in a shale lithologic unit. Although these factors (with the exception of well screen placement) have affected both deep monitoring wells, the effect at MW02 is clearly much more significant, as indicated by the minimal quantity of water produced from this well [*e.g.*, a yield of 0.88 gal/hour noted during the Phase V sampling after repeated well development (US EPA, 2012)]. The well yield noted at monitoring well MW02 is so small that it would take approximately 15 of these wells to supply the daily water needs of a typical household of 4 people.<sup>3</sup> Clearly, the screened interval of MW02 cannot be considered as being representative of a drinking water source in the Pavillion area.

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<sup>3</sup> The typical daily household consumption for a family of 4 is expected to be 320 gallons - 80 gallons per capita per day, as reported by James Gores and Associates, 2011.

A comparison of the yield of monitoring well MW02 to yields recorded at other water wells in the Pavillion area helps further place the well's low yield in proper perspective. In a hydrogeologic study of the Wind River Basin, Daddow (1996) reported well yields to range from 0.1 to 350 gal/min, depending on formation lithology. Table 1 shows the average daily yields calculated from Daddow (1996) and those observed at the deep monitoring well MW02. These data indicate that the yield from MW02 is approximately seven fold lower than the lowest value (266 total wells) reported by Daddow (1996), *i.e.*, MW02 is an outlier and its characteristics are not consistent with the other wells in the area.<sup>4</sup>

**Table 1 Yields from US EPA MW02 and Other Wells in the Wind River Formation at Pavillion, WY**

Well ID/Source	Yield (gal/min)	Yield (gal/hr)	Daily Yield (gal)
MW02 <sup>1</sup>	0.015	0.9	22
Daddow (1996) Min	0.1	6	144
Daddow (1996) Max	350	21,000	504,000

Notes:

(1) Data reported by US EPA, 2012.

It appears that the problematic low-yield of MW02 can be attributed to improper well construction. As discussed above, about half of the well screen appears to have been constructed in a shale-rich lithologic unit. In addition, given the elevated pH and high concentrations of other cement-related inorganic analytes (see Gradient and ERM, 2012 and Section 3.3, below), it appears that cement grout has infiltrated into a portion of the screened interval, thereby further reducing the well's yield. The USGS attempted to redevelop MW02, but were unsuccessful, stating in its report,

"Well yield was not increased as a result of the redevelopment effort" (USGS, 2012b).

Yields from MW02 were so low that they did not even meet the USGS' (2006) sampling criterion of 90% static water level recovery within a 24-hour period for wells with less than one borehole volume purged. Consequently, the USGS did not collect a sample from monitoring well MW02. However, the US EPA was undeterred by USGS' conclusion and proceeded to collect groundwater samples from MW02 stating that US EPA's guidance permitted collection of a sample after purging a well dry.

US EPA points to several documents to justify its well purging practices, including US EPA guidance (US EPA, 1986, 2002) and several peer-reviewed articles (Humenick *et al.*, 1980; Robin and Gillham, 1987). However, these references do not support the well purging strategy utilized by US EPA at either of its deep monitoring wells in Phases III, IV, and V. For example, US EPA points to the "considerable flexibility in use of purging strategies" allowed by US EPA guidance (US EPA, 1986, 2002). However, US EPA's own guidance (US EPA, 2002) made the following qualifying statement, which US EPA did not acknowledge in its invocation of the guidance:

A sample that is obtained from a *poorly constructed well*, or using improper sampling equipment, or using *poor sampling techniques*, or preserved improperly, can bias the sampling results. Unrepresentative samples can lead to misinterpretations of ground-water-quality data [emphasis added].

The poor well construction practices utilized by US EPA (*e.g.*, lack of a bentonite seal) have allowed cement to intrude into the screened intervals of MW01 and MW02. No amount of "flexibility" in purging

<sup>4</sup> Note, it is possible that the screen lengths of drinking water and stock wells may be somewhat longer than the screen length of monitoring well MW02, but such differences are not expected to span an order of magnitude, *i.e.*, the low yield for well MW02 still is uncharacteristic of the region, even if one were to account for screen length differences.

strategies can account for the poor well construction practices. As we have clearly shown in our prior comments and with the additional data collected in Phase V, both of US EPA's deep monitoring wells are showing symptoms of cement contamination and these symptoms are exacerbated by inadequate purging [see Section 3.3 and our prior comments (Gradient and ERM, 2012)]. The state of science on well purging techniques requires more reliable indications of adequate purging, such as real-time analysis of plots of the logarithm of drawdown *versus* the logarithm of time (Shapiro, 2002). However even these approaches are moot when poor well construction practices have caused groundwater to be contaminated with cement. At MW02, the problem is further complicated by the inability of either US EPA or USGS to adequately develop the well. Therefore, at MW02, in addition to inadequate purging practices, the remnant drilling mud and development water have never been removed from the vicinity of the well screen. These deficiencies constitute fatal flaws in US EPA's monitoring program and clearly indicate that the water samples drawn from MW-02 are not representative of formation water.

### **3.3 The Effects of Cement Intrusion on Groundwater Quality Continue to be Observed at the Deep Monitoring Wells**

As demonstrated in our prior comments (Gradient and ERM, 2012), US EPA (2011) incorrectly attributed the presence of elevated pH and concentrations of certain inorganic constituents to hydraulic fracturing fluids. These effects were in all likelihood associated with cement grout intrusion into the well screens due to the absence of a bentonite seal (Gradient and ERM, 2012). The recent Phase V groundwater sampling results further demonstrate that groundwater quality (*e.g.*, pH, specific conductivity, potassium) at the deep monitoring wells continues to be affected by cement intrusion.

As part of the US EPA Phase V sampling at monitoring well MW01, up to 10 groundwater samples were collected for certain analytes; field parameters were also measured throughout the well-purging and sampling process. These data demonstrate that water quality changed over time during the sampling event. Gradual changes in water chemistry during purging are expected, due to the well drawing from an increasingly large portion of the aquifer as purge volume increases. These gradual changes reflect spatial gradients in groundwater chemistry<sup>5</sup> in the well's zone of influence and are distinct from rapid changes that occur as a result of contamination associated with well construction materials. Contamination due to well construction materials is localized to the vicinity of the well's screened interval, and therefore, purging several borehole volumes will typically reduce contaminant concentrations significantly.

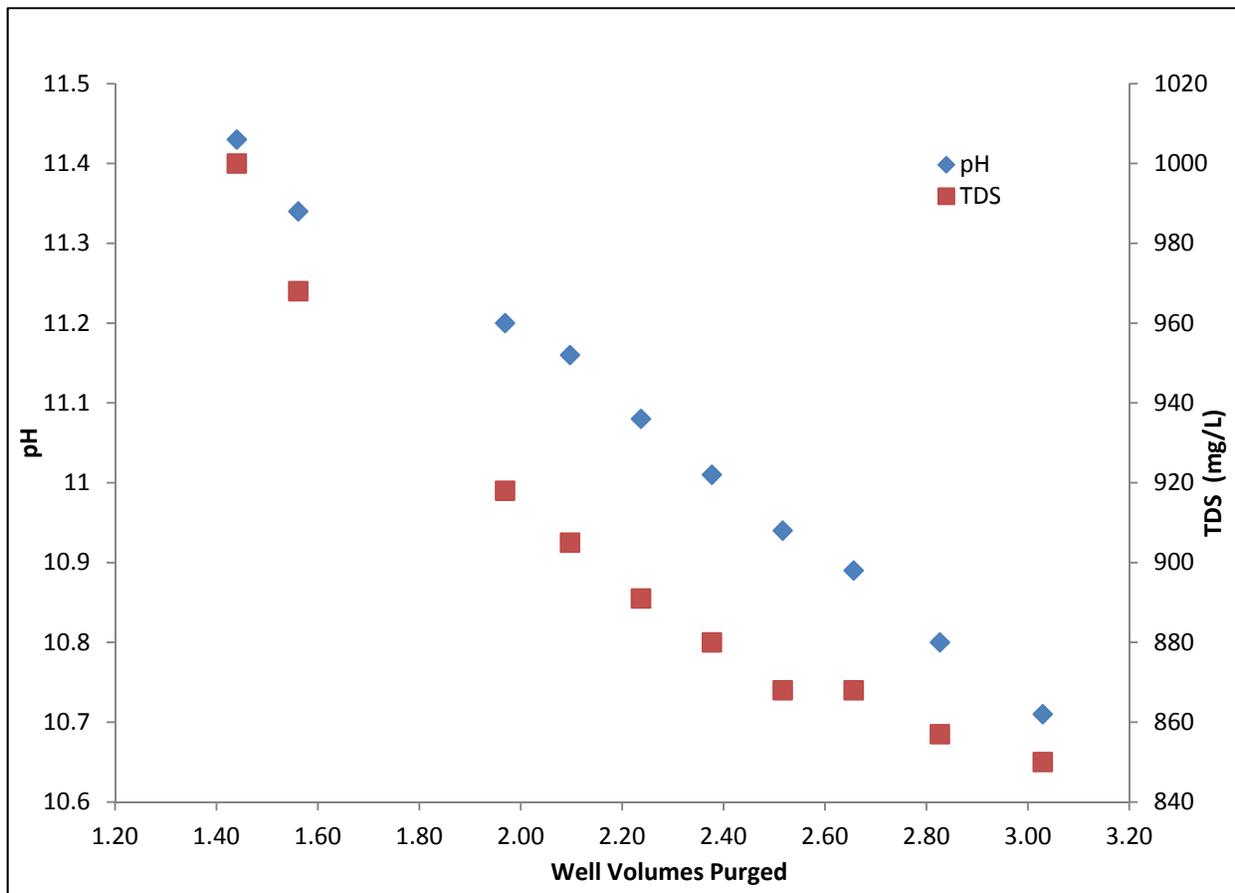
In the case of MW-01, multiple samples taken during the purging process indicated a rapid change in water chemistry over the course of purging several borehole volumes, consistent with contamination due to well construction materials. Further, many of the constituents that changed rapidly are known to be associated with cement contamination (*e.g.*, pH, TDS, potassium). For example, pH declined from 11.4 to 10.7 over the course of purging and sample collection (Figure 1). Similarly, concentrations for total dissolved solids (TDS), an overall indicator of the total amount of dissolved constituents, also declined from approximately 1000 mg/l to 850 mg/l over the 1.5 borehole volumes purged between these samples (Figure 1). The magnitude of these changes in chemistry is large compared to the relatively small amount of water purged. These data indicate that water in the well and its immediate vicinity at the start of sample collection was in equilibrium with the cement grout, causing the initially elevated values of pH and TDS. These concentrations declined as fresh water from the formation flowed into the well and flushed out the cement-impacted water. This behavior is contrary to what would be expected if US EPA's assertion that the elevated pH and other inorganic analytes are attributable to HF fluid migration. If the

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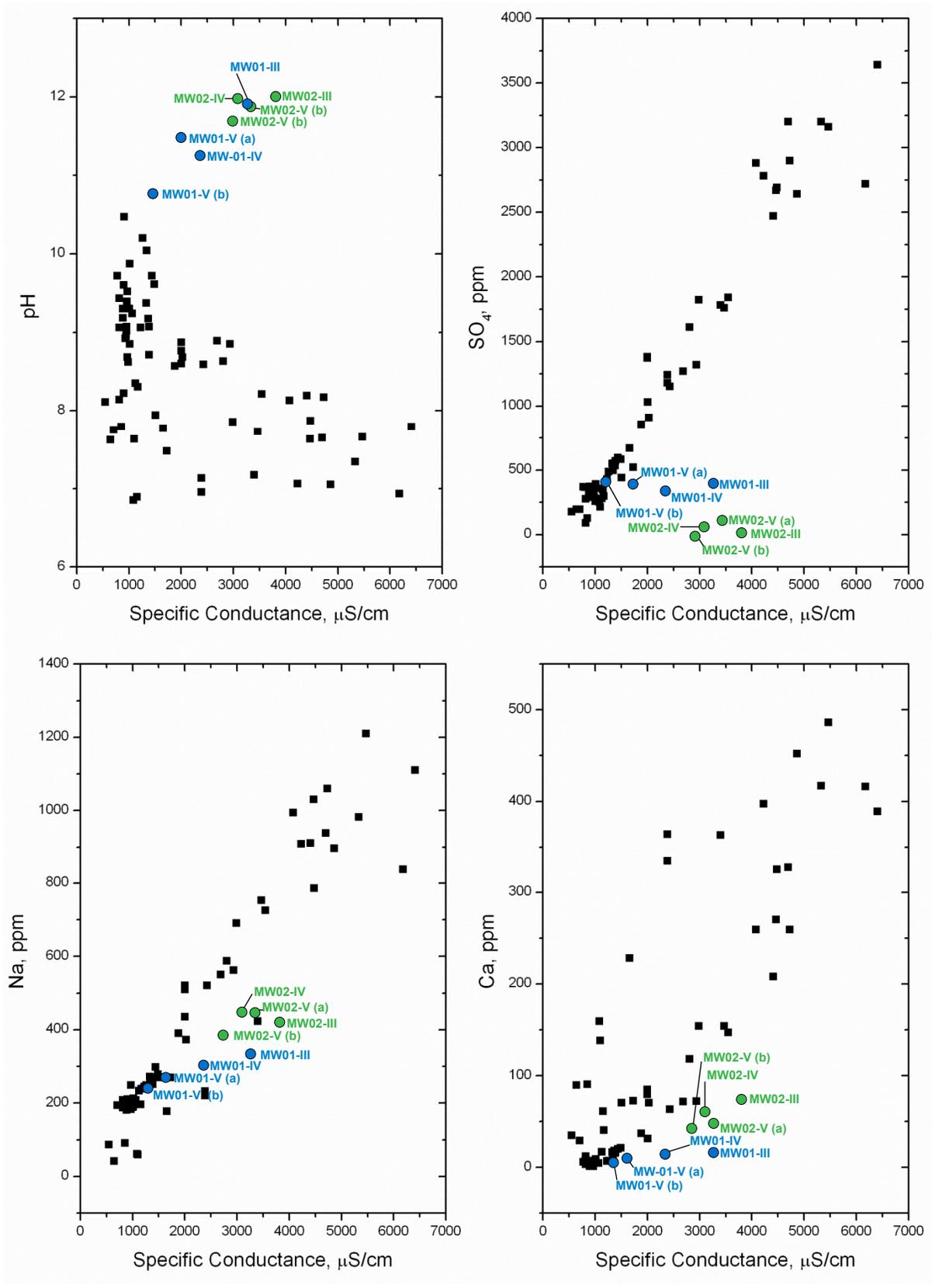
<sup>5</sup> The spatial gradients in groundwater chemistry may be due to variations in lithology or due to differing water chemistry in fractures *versus* pore spaces. Either type of variation may contributed to gradual changes in water chemistry during purging.

aquifer had been affected by HF fluids, the pH and concentrations of inorganic analytes would have remained stable and not declined temporally, as noted above.

In its 2011 report, US EPA had also compared pH and concentrations of inorganic constituents at the deep monitoring wells to corresponding values recorded at private drinking water and stock wells. Based on these comparisons, US EPA concluded that the inorganic water chemistry at the deep monitoring wells was different from the other wells in the area and claimed that this was a result of contamination from HF fluids. However, as additional groundwater has been removed from the monitoring wells (*i.e.*, wells have been purged further), groundwater quality at the monitoring wells has changed and is now becoming similar to the water quality found at the other wells in the Pavillion region. As discussed above, this temporal change in water chemistry is indicative of cement contamination being gradually flushed from the vicinity of the wells as more water is purged. A reproduction of figures from the US EPA (2011) report modified to include the Phase V data clearly shows the temporal progression of groundwater data at the deep monitoring wells (Figure 2). There is an obvious trend in Figure 2 that shows groundwater chemistry at MW01 approaching the regional data set as water is purged during successive sampling events. The water chemistry at MW02 has also trended toward regional groundwater chemistry, but to a lesser degree, because the well is unable to produce a sufficient amount of water to adequately flush contamination caused by the poor well construction practices utilized by US EPA. It is anticipated that as additional water is removed from the monitoring wells, the groundwater chemistry will continue to change as localized effects of cement intrusion on water chemistry dissipate and groundwater quality at the deep monitoring wells becomes further consistent with regional groundwater quality. Overall, US EPA's assertion that elevated pH and other inorganic constituents were attributable to HF fluids has no technical basis.



**Figure 1 Measurements of pH and TDS at MW01 Over the Course of Purging Approximately 1.5 Borehole Volumes**



Sampling Locations	SAMPLING PHASE DATES
<span style="color: blue;">●</span> MW01 Sampling Phase	III - 10/6/2010
<span style="color: green;">●</span> MW02 Sampling Phase	IV - 4/20/2011
<span style="color: black;">■</span> Domestic Well	V MW01 - 4/24/2012
	V MW02 - 4/16/2012 & 4/22/2012
	a: Start of Sampling
	b: End of Sampling

Source: Adapted from Figure 14 of US EPA, 2011.



GRADIENT

Temporal Changes in  
Groundwater Quality at  
MW01 and MW02  
Pavillion, WY

FIGURE  
2

## 4 The Phase V Sampling Results Confirm that the Quality of the Prior Data was Extremely Poor

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The Phase III and IV groundwater quality data from the Study suffered from a multitude of data quality problems (Gradient and ERM, 2012). These deficiencies, which demonstrate a lack of adequate planning and implementation, included the use of non-standard analytical test methods; poor field execution (*e.g.*, routine detection of contaminants in blanks); and disregard of US EPA guidance for assessing the usability of data for decision making (*e.g.*, the Study utilizes data that should have been qualified as non-detect due to the presence of contamination in the blanks). Some of these deficiencies were addressed by the USGS and US EPA during the Phase V sampling, but US EPA is still continuing to use a non-standard analytical method for glycol analysis.

In contrast to the data quality problems in the prior Study, the USGS and Phase V US EPA sampling was more carefully undertaken and included the requisite blanks and replicates to yield a better quality data set. Few compounds were detected in blanks (unlike sampling conducted as part of the prior Study when blank contamination was widespread) and appropriate steps were taken to assess the quality of the data (*e.g.*, applied qualifiers to address blank contamination). A number of organic compounds that were found in the prior US EPA Study (*e.g.*, xylenes and toluene, which had been reported at MW01 in the prior Study) were not detected in the USGS samples, confirming that these data generated as part of the prior US EPA Study are unreliable and should not be used for decision making.

At the same time, there continue to be data quality issues regarding some of US EPA's Phase V data. For example, US EPA is continuing to utilize test methods for glycols, ethoxylates and alkylphenols, and acrylamide that are under development and therefore, unproven. Conversely, the USGS utilized a US EPA approved test method (Method 8015B) for conducting the glycols analyses and did not analyze some of the other analytes targeted by US EPA (*e.g.*, alkylphenols). US EPA's rationale for selecting the method that is still undergoing development was that it offered a much lower reporting limit of 10 µg/l. However, since the method is still under development, the quality of these data, especially the reported concentrations for glycols and 2-BE, is uncertain. This uncertainty in data quality is acknowledged in the appendices to the report (US EPA, 2012, Table B30, pp. B32), such as:

"All sample results with detection greater than the QL [quantitation limit] have had the J qualifier applied because the method is still under development."

The appendices also identify some other data quality issues for glycols (US EPA, 2012, Table B30, pp. B32), noting that:

"Samples analyzed on 4/20 and 4/21 are qualified as J- due to the low MS [Matrix Spike] recoveries."

It is unclear whether the low matrix spike recovery noted in these samples is associated with matrix interferences or due to the fact that the method is under development. US EPA has attempted to defend its methodology by stating "This low level glycol method has been developed by EPA and verified in multiple EPA laboratories. This new method will be submitted for publication in the peer reviewed literature." However, US EPA has not provided the details of the analytical method used or made full laboratory reports available for reviewers to conduct an independent evaluation. Furthermore, the

promise of publishing a method in the peer reviewed literature falls far short of actually accomplishing that feat (which requires a significant amount of work and scientific rigor to surpass the peer review process). Such promises do not supplant the need for US EPA to openly disclose its internal data on method validation or to be transparent about its methodologies. Overall, since the glycol method is still under development, as acknowledged by US EPA, the reported glycol concentrations during Phase V of the Study and prior phases remain highly uncertain and should not be used.

## 5 The Compounds Detected in the USGS and US EPA Sampling Are Not Indicative of Hydraulic Fracturing

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The US EPA report (US EPA, 2011) attributed the presence of a number of constituents and elevated pH in monitoring wells MW01 and MW02 to hydraulic fracturing. With the availability of additional data and with proper consideration of other (*i.e.*, non-HF) sources, EPA's initial observations are clearly related to deficiencies in well construction, sample collection, and sample analysis practices.

### 5.1 Elevated pH and Potassium at MW01 and MW02 are Due to Improper Well Construction

During the installation of MW01 and MW02, US EPA did not install a bentonite seal above the well screens even though standard well construction practices (US EPA Region IV, 2008; Driscoll, 1986) and US EPA's own Work Plan (URS, 2010b) required a bentonite seal. The absence of a bentonite seal has allowed cement grout to infiltrate the formation where MW01 and MW02 are screened. Therefore, cement is in direct contact with the water being sampled at these wells. In our prior comments (Gradient and ERM, 2012) we discussed the significant impacts that cement can have on groundwater quality, including:

- Increased pH (*e.g.*, values >11) that can persist for long periods, despite numerous attempts at well redevelopment (Barcelona and Helfrich, 1986); and
- Increased potassium concentrations associated with the leaching of potassium from cement pore water, which has extremely high potassium concentrations (*e.g.*, 11,800 to 25,300 mg/L; Leemann and Lothenbach, 2008; Gradient and ERM, 2012).

Additionally, we demonstrated that HF fluids used in the Pavillion area are not capable of causing elevated pH in groundwater. HF fluids are inherently buffered and the predominant type of HF fluid used in the Pavillion area is CO<sub>2</sub> foam, which is acidic and would cause pH to decrease, not increase, if it were to come in contact with groundwater.

The additional data collected by USGS and US EPA in Phase V provide further evidence that the elevated pH and potassium concentrations at MW01 and MW02 are due to localized effects of cement and not HF fluid (see Section 3.3). Data collected during the purging of MW01 show that pH decreased throughout the entire purging process—a clear indication that near-borehole water with high pH was being flushed by lower pH formation water. Figures 1 and 2 clearly show that pH in MW01 is trending toward natural groundwater pH as more water is purged from the well. The same trend was observed for potassium concentrations at MW01. At MW02, pH, potassium, and other constituent concentrations related to well installation, although somewhat lower than before, remained elevated in Phase V, as would be expected at this well due to the low yield that has never allowed for proper purging of cement-impacted water.

## 5.2 Synthetic Organic Constituents

US EPA alleges that the presence of "synthetic organic compounds" (glycols, isopropanol, and 2-BE) in the deep monitoring wells is an indication that HF fluids have affected the groundwater quality above the natural gas producing zone. In our prior comments (Gradient and ERM, 2012), we demonstrated that these assertions have no technical basis for several reasons, including:

- The direction of groundwater flow in the area is downward and therefore, it is not physically possible for chemicals to migrate upward;
- Hydraulic fracturing stimulations in the area are low-volume stimulations and there is not enough HF fluid to create hydraulic communication between the fractured formation and shallower groundwater horizons;
- The analytical methods utilized by US EPA were developed on the fly and have not been proven to produce reliable data for concentrations of glycols, 2-BE, and alcohols in groundwater;
- Furthermore, US EPA did not consider that isopropanol is a microbial breakdown product of natural organic matter, including methane and other petroleum hydrocarbons that are naturally occurring in the vicinity of the MW01 and MW02 well screens.

Taken together, these observations indicated that the conclusions in the prior US EPA study are not supported by the Agency's own data. The Phase V data collected by the US EPA and USGS now provide additional evidence that the conclusions reached in the prior US EPA study are invalid, including:

- There continue to be data quality concerns with regard to the analytical methods utilized by US EPA for the analysis of glycols (see Section 4). If the data are taken at face value, however, the glycol concentrations in groundwater are consistent with cement contamination and not hydraulic fracturing. Glycols are commonly used as grinding aids in cement production (Ervanne and Hakanen, 2007). If one assumes that the US EPA glycol data are not artifacts of the non-standard analytical methodology, the data collected by US EPA during the purging of MW-01 show a decreasing trend in glycol concentrations over time (Figure 3), consistent with near-wellbore cement-impacted water being gradually flushed from the vicinity of the well screen. The decreasing trend in glycol concentrations is consistent with decreasing concentrations of other cement-related constituents (*e.g.*, pH, potassium). These observations suggest that the potential presence of glycols, if not an artifact of non-standard analytical methods, is localized to the vicinity of the well screen and associated with contamination due to cement intrusion during well construction and not hydraulic fracturing.
- The same data quality concerns for glycols also apply to 2-BE because US EPA used the same analytical method for this chemical. If the 2-BE data are taken at face value, however, they are also consistent with contamination due to well construction materials and not hydraulic fracturing. During the course of purging MW01, the 2-BE concentrations declined almost identically to glycol concentrations and ultimately dropped below the detection limit at the end of purging (see Figure 3; the 2-BE datum below the detection limit is shown as a green "ND" in this figure). US EPA used carbon steel for the well casing with an unidentified black coating for its deep monitoring wells. These coatings often contain high concentrations of 2-BE (IARC, 2006). The pattern of declining 2-BE concentrations at MW01 is clearly indicative of contamination associated with well construction materials and not hydraulic fracturing.
- Isopropanol is a microbial breakdown product of natural organic matter (including natural gas) and is expected to be naturally present in the gas-rich formation in which MW01 and MW02 were

installed. The detection of isopropanol in Phase V is therefore consistent with the groundwater in a gas-rich horizon. Detection of other organic degradation products (*e.g.*, phenols and ketones) are also consistent with a natural gas-rich area.

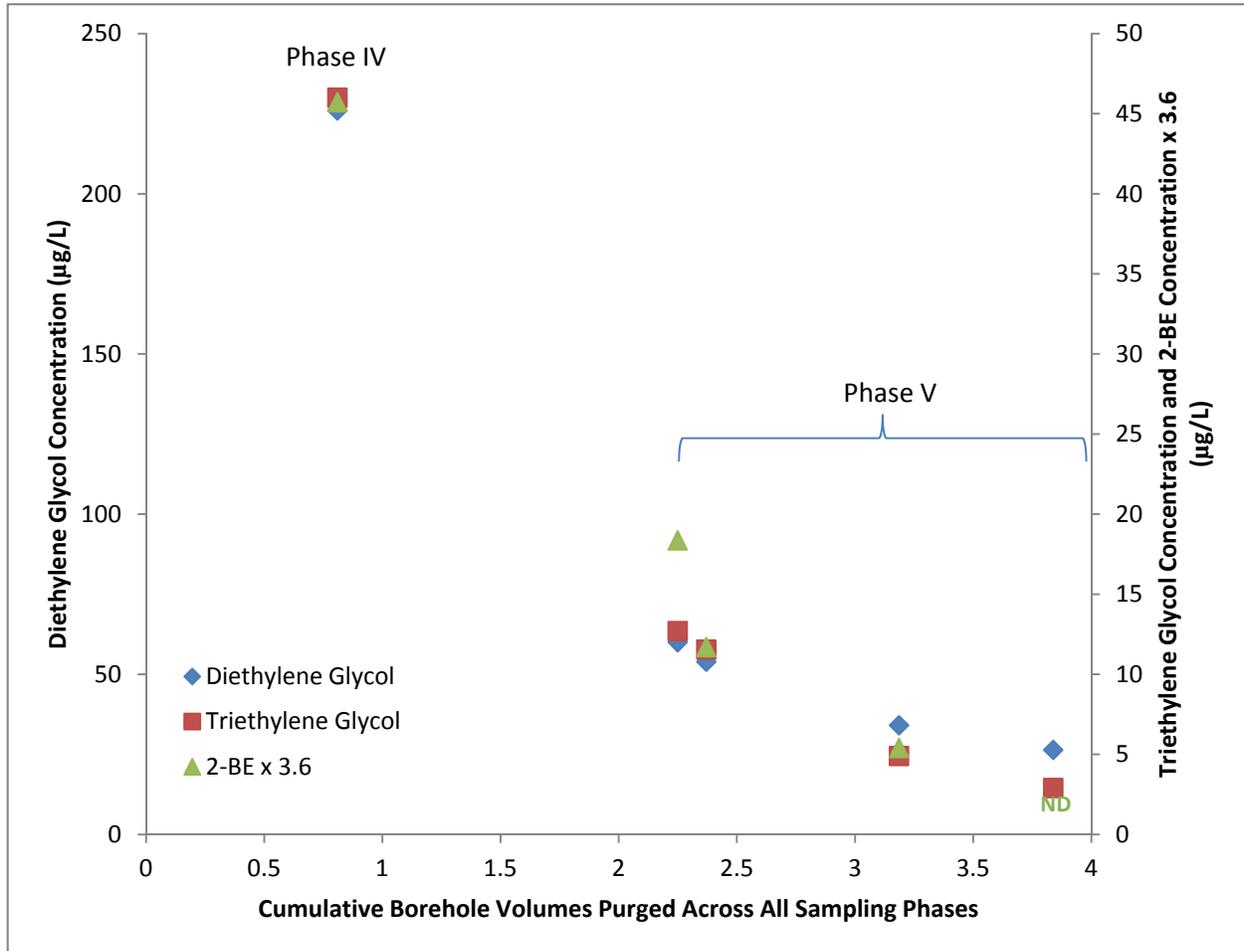


Figure 3 Trend of Decreasing Concentrations of Glycols at MW01 as More Water is Purged from the Well

### 5.3 The Presence of Petroleum Hydrocarbons Is Not Evidence of Hydraulic Fracturing Impacts

More importantly, the continued detection of other petroleum hydrocarbons is not indicative of the presence of hydraulic fracturing fluids. As discussed in our prior comments, the natural occurrence of petroleum hydrocarbons (*e.g.*, methane, ethane, BTEX, GRO, DRO) at shallow depths in the Pavillion area prior to the implementation of HF is well documented. For example, the Plunkett gas field, which draws gas from the Wind River Formation several miles south of the Pavillion Gas Field, has historically yielded natural gas from strata as shallow as 50 to 55 meters (165 to 182 feet) bgs (USGS, 1945). These gas wells date back to the 1920s to 1940s, prior to the advent of HF methods in the 1950s. In addition, methane was found at relatively shallow depths (157 to 326 m or 515 to 1,070 ft bgs) in a number of locations in Pavillion before HF activities began (WOGCC, 2012). Independent review of mud logs available on the WOGCC website and information provided in the US EPA Study indicate at least six (6) independent observations of shallow methane in the Pavillion area at depths ranging from 159 to 326

meters (515 to 1,070 feet). These observations indicate clearly that, given the highly heterogeneous nature of this formation and the age and thermal maturity of the underlying natural gas source rocks, shallow deposits of natural gas were found throughout the Wind River Formation prior to implementation of HF operations in the area in the late 1980s. The US EPA Study also indicates that a natural gas blowout occurred during drilling at 159 m-bgs while drilling adjacent to PGDW05. US EPA utilized blowout preventers during the installation of its deep monitoring wells – an implicit acknowledgement that shallow methane is present in the vicinity of these wells. In addition, the highest FID readings during installation of MW01 were recorded between 152 to 213 meters (500 to 700 feet) – a similar depth range as the blowout at PGDW05 and another indication of natural gas at these intervals. Methane was also noted in MW02 during well development/sampling, and gas samples were also collected at the well. During Phase V sampling, USGS took extreme caution during the collection of groundwater samples to ensure that methane in MW01 did not create a safety (*i.e.*, explosion) hazard – another implicit acknowledgement that the deep monitoring wells were installed in gas-bearing strata. All this information is indicative of gas-rich strata at relatively shallow depths.

The Bureau of Land Management (BLM) has also commented on the prevalence of shallow methane in the Pavillion area (Simpson, 2012):

What is clear is that this is a relatively shallow gas field (1,500 ft +/-), and observations have shown that large amounts of gas have been found in the shallow subsurface at certain locations. These observations are anticipated and should not be prematurely used as a line of evidence that supports EPA's suggestion that gas has migrated to the shallow subsurface due to hydraulic fracturing or improper well completion until more data is collected and analyzed. In addition, there is a question of the nature and extent of shallow gas in relation to the observed "blow-out" at a domestic well drilled earlier at the Meeks' place. This well blew out at about 700 feet. The fact that the gas flowed for a prolonged length of time suggests a significant in-place source rather than gas that just migrated into position from an improperly completed well somewhere in the vicinity, or along some preferential pathway created by hydraulic fracturing.

The presence of other hydrocarbons (*e.g.*, BTEX, GRO, DRO) is also consistent with a natural gas-rich area. As discussed in our prior comments (Gradient and ERM, 2012), the chemical signature of BTEX at MW02 was comparable to the signature of gas condensate obtained from gas wells in Pavillion. Our prior report also demonstrated that the hydrocarbons at MW01 are also consistent with a natural source. This is a naturally gas-rich area with shallow gas pockets that were present before HF activities began in the area.

Overall, the presence of methane and petroleum hydrocarbons at the deep monitoring wells is consistent with the geochemistry of a natural gas-rich area. As indicated in the BLM (2012) comments, the presence of shallow methane in the region is "anticipated." Therefore, hydrocarbons are expected to be naturally present and are not indicative of HF impacts.

#### **5.4 US EPA's Assertion that The Phase V Data Are Consistent with Prior Sampling Phases Is Incorrect**

US EPA has commented that the Phase V data released by the USGS and US EPA are consistent with the prior US EPA sampling. There are some significant differences in the data, however. For example, some compounds (*e.g.*, xylenes and toluene) detected previously by US EPA were not detected by USGS when more rigorous quality assurance and quality control measures were used. Concentrations for other

compounds declined sharply as more water was purged from the wells, including: pH, TDS, potassium, and glycols, among others (see Sections 3.3 and 5.1).

The lack of detection of xylenes and toluene at MW01 in Phase V is one clear instance of inconsistency with prior US EPA data and corroborates our prior criticisms that the data quality in the Study was compromised by poor sample collection practices. The most prominent inconsistency between the data from Phase V and prior phases, however, is with regard to the temporal changes in water chemistry that were observed during the purging of MW01. A number of constituents showed trends of decreasing concentrations during purging, including inorganic (*e.g.*, pH, TDS, potassium) and organic (*e.g.*, glycols, 2-BE) constituents, as demonstrated previously in Sections 3.3, 5.1, and 5.2 (also see Figure 1 through Figure 3). Although only two samples were collected in Phase V during the purging of MW02, similar decreases in constituent concentrations were observed at this well too. These changes in groundwater chemistry across a broad range of constituents, in some cases by more than a factor of 10, clearly cannot be classified as being consistent with prior US EPA data. The dramatic changes in the chemistry of samples also underscores the importance of adequately developing and purging the deep monitoring wells prior to sampling in order to generate representative data.

## 6 Age Dating of Groundwater

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In Phase V, the USGS sampled and analyzed groundwater from MW01 for tracers that can be used to estimate the age of groundwater. However, neither the USGS nor the US EPA provided any interpretation of these data or their relevance for understanding the potential sources of water to MW01. Here, we provide background on the methodology, along with a discussion of some of the difficulties in using it as evidence in the US EPA study. Overall, due to US EPA's substandard practices in drilling, constructing, and developing the well, the groundwater age dating techniques will not be able to answer questions about the source of water at monitoring well MW01.

The USGS analyzed Phase V groundwater samples from MW01 for the following tracers, which are commonly used to estimate the apparent age<sup>6</sup> of groundwater: tritium, sulfur hexafluoride (SF<sub>6</sub>), chlorofluorocarbons (CFCs), and <sup>14</sup>C. Tritium, SF<sub>6</sub>, and CFCs are present at trace concentrations in the atmosphere as a consequence of human activities in recent decades (*e.g.*, nuclear bomb tests, manufacture of electrical equipment, and the use of refrigerants). These chemicals partition into precipitation as it falls to the land surface, where the chemicals are carried with the water as it percolates through soil and into groundwater. The concentration of these tracers in groundwater can then be used to estimate the approximate time when the water entered the groundwater system (*i.e.*, groundwater age). Given their relatively recent introduction to the atmosphere, these tracers are only able to identify groundwater that has recharged in recent decades (*i.e.*, no more than 60 or 70 years ago). <sup>14</sup>C, on the other hand, is a radioactive isotope of carbon that is created naturally in the atmosphere by the interaction of cosmic rays with nitrogen gas<sup>7</sup>. <sup>14</sup>C can partition into precipitation, similar to the other groundwater age tracers, and ultimately be used to estimate groundwater age. Unlike the tracers of more recent groundwater, <sup>14</sup>C is better suited to determining the age of relatively older groundwater (*i.e.*, from 60 to 50,000 years old; Bethke and Johnson, 2008).

Multiple tracers can be used to estimate the age of a single groundwater sample (such as the use of <sup>14</sup>C and tritium). However, when multiple groundwater tracers are used, the different tracers may yield different estimates of the apparent groundwater age for the same sample. For example, in a USGS study in Nebraska (McMahon *et al.*, 2007), detections of tritium in some samples suggested groundwater ages of less than 50 years, whereas <sup>14</sup>C concentrations in the same samples suggested groundwater ages on the order of thousands of years. The seemingly contradictory results have been more recently recognized as the consequence of subsurface mixing of waters with different ages (Bethke and Johnson, 2008). In the case of McMahon *et al.* (2007) relatively older groundwater (*i.e.*, water more consistent with the <sup>14</sup>C age) had likely mixed with younger groundwater (*i.e.*, water more consistent with the tritium age). An individual water sample may be a mixture of waters that recharged at different times and therefore, the waters contributing to a given sample have a range of ages rather than a single age. The information that can be gained from using multiple age tracers has been proposed as a way of gaining insight into the potential contributions of waters that recharged at different times in the past to a given water sample, assuming that the source waters can be identified (Bethke and Johnson, 2008).

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<sup>6</sup> The term "apparent age" is often used in the discussion of groundwater age as an indication that the age estimates are approximate and based on a limiting set of assumptions that may impart some amount of uncertainty to the degree to which the apparent age approximates the true age of a given groundwater sample.

<sup>7</sup> Nuclear bomb tests in the latter half of the 20<sup>th</sup> century also contributed to the pool of <sup>14</sup>C in the atmosphere.

The USGS samples from MW01 were analyzed for three tracers of younger groundwater (*i.e.*, tritium, SF<sub>6</sub>, and CFCs) and one tracer of older groundwater (<sup>14</sup>C). Of these, CFCs and <sup>14</sup>C were detected. The detection of CFCs at MW01 suggests a groundwater age of less than about 60 years, but the <sup>14</sup>C concentration (which was very low) suggests a groundwater age on the order of thousands of years. Natural formation water is expected to be at least several thousand years old, similar to groundwater at comparable depths in nearby arid areas (*e.g.*, Nebraska; McMahon *et al.*, 2011), and is not expected to contain any CFCs (*i.e.*, tracers of younger groundwater would not be expected to be present in this older groundwater). Therefore, the presence of CFCs in groundwater sampled from MW01 raises the question as to what source of young water has mixed with the older formation water.

In its prior comments, Gradient and ERM discussed how US EPA's poor well construction practices have allowed cement and drill cuttings to influence groundwater chemistry at MW01. The Phase V data have further corroborated these initial findings. The water used to mix the cement, the water contained in drill cuttings, and the water surged into the screened interval during well development could potentially contribute younger tracers (*e.g.*, CFCs) to the groundwater being sampled from MW01. As we have shown for several analytes (*e.g.*, pH, potassium), well development and purging have been inadequate for removing near well-bore cement-impacted water and it is therefore likely that other water introduced to the formation during well drilling, construction, and development may also be influencing concentrations of groundwater age tracers at MW01. These water sources, which US EPA introduced to the formation being sampled by MW01, are likely to contain detectable concentrations of younger groundwater tracers (*e.g.*, CFCs). US EPA's substandard practices in drilling, constructing, and developing the well have undoubtedly placed younger groundwater tracers in the formation being sampled by MW01 and made it impossible to interpret data on groundwater age tracers.

## 7 Conclusions

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In response to residents' complaints of objectionable odors and tastes in well water near the town of Pavillion, Wyoming, US EPA initiated a groundwater investigation in 2009. US EPA released its Study after four phases of sampling and installing only a handful of monitoring wells. As we previously indicated in our comments (Gradient and ERM, 2012), the design of the Study was flawed, the Study implementation (*i.e.*, field work and data quality evaluation) was extremely poor, and the analysis of the data was not based on sound science. Consequently, US EPA's methods and data did not support the conclusion reached in its Study that "inorganic and organic constituents associated with hydraulic fracturing have contaminated ground water at and below the depth used for domestic water supply" (US EPA, 2011, p. 39).

### 7.1 Supplemental USGS and US EPA Sampling Results Corroborate Our Prior Conclusions

The Phase V sampling and camera results provide further support for the criticisms presented in our June 2012 comments that the Study implementation (*i.e.*, field work and data quality evaluation) was very poor and the analysis of the data was not based on sound science. Specifically, these recent data demonstrate the following:

- **Poor Well Installation:** The updated monitoring well construction schematics, which were recently released by US EPA, indicate that both monitoring wells MW01 and MW02 have a section of open borehole beneath the well screens. These sections of open borehole violate US EPA's procedures for well installation (US EPA, 2008) since they can act as reservoirs for materials, such as drill cuttings and/or cement grout, thereby affecting groundwater quality at the monitoring wells. Additionally, the updated well schematics also indicate that MW02 was installed 10 feet deeper than intended, which places about half of the well screen in a shale layer and is also in the portion of the borehole that was backfilled with drill cuttings. These poor construction practices have led to unreliable data that are not representative of drinking water in the Pavillion area.
- **Cement Intrusion:** Cement grout continues to affect groundwater chemistry at both deep monitoring wells. The Phase V temporal monitoring results demonstrate that as more water is purged from the wells, the inorganic water chemistry is trending toward the regional (ambient) groundwater chemistry, especially at MW01. This confirms that the pH readings and the presence of potassium that the Study cites as evidence of the presence of HF fluids are in fact due to impacts from the cement used in constructing the monitoring wells. The low yield at MW02 has not allowed the US EPA or USGS to properly develop and purge the well and therefore, the effects of cement contamination on water chemistry are more persistent at this well.
- **Data Quality and Reliability:** US EPA continues to rely on a method that is under development for glycol analysis. However, even if one assumes that the glycol detections are not an artifact of US EPA's non-standard analytical method, the temporal trend in glycol data is indicative of a near well-bore source, *i.e.*, glycols associated with well construction materials being flushed out during purging. Glycols are commonly used in cement production and the pattern of declining glycol concentrations is identical to the temporal decline of other cement-related constituents. This is very clear evidence that the glycols, if present, are associated with cement and not HF.

Furthermore, the Phase V sampling results also confirm that some of the compounds reported in the prior sampling results (*e.g.*, toluene and xylenes at MW01) were false positives, associated with poor sampling practices used during groundwater sample collection.

- **Naturally Occurring Hydrocarbons:** The presence of hydrocarbons in groundwater sampled from the deep monitoring wells is consistent with the geochemistry of this natural gas-rich region. The BLM also indicated in its comments (Simpson, 2012) that the presence of hydrocarbons is "anticipated" and that these data are not an indication of HF fluid migration or leaky gas well casings.
- These additional findings further confirm that the two deep monitoring wells were poorly installed and developed by US EPA, groundwater chemistry at these wells for certain analytes (*e.g.*, inorganics, glycols) continues to be affected by poor well installation techniques and is hence unreliable, and the hydrocarbon-related compounds detected in the monitoring wells are consistent with the geochemistry of a natural gas-rich area.

## 7.2 Overall Conclusions

US EPA's Study of groundwater quality in Pavillion has significant deficiencies and cannot be relied upon to draw any meaningful conclusions regarding the source of contamination, if any, to the domestic wells or the effect of HF on drinking water quality. Based on a review of the initial US EPA Study and the Phase V sampling results, our overall conclusions are that:

- The US EPA Study design was inherently flawed and relied on only two deep monitoring wells that are completed below the groundwater strata that are commonly used for domestic water supply, not representative of typical potable groundwater in the region, and are screened within or proximate to gas-bearing zone(s).
- The field implementation of the Study was extremely poor, and these problems (*e.g.*, effect of poor well installation and development) continue to plague the quality of the results. The deep monitoring wells were installed using non-standard techniques, which resulted in cement grout intrusion into the screened intervals of the wells, that continue to affect the groundwater quality at these wells. Furthermore, the field sampling techniques used in Phases III and IV of the Study were sub-standard and the resulting data quality was poor (*i.e.*, resulted in a number of false positives) – a finding that has been confirmed by the more carefully implemented Phase V sampling. Moreover, US EPA's use of un-proven analytical test methods (*e.g.*, for glycols) continues to call into question the reliability of these data.
- Lastly, US EPA's interpretation of the sampling results is flawed and not based on sound science. For example, US EPA's conclusion that there is an upward hydraulic gradient in the region (the central premise of its argument that HF chemicals are migrating upward *via* groundwater) is not consistent with available hydrogeologic data, which clearly demonstrate the gradient to be downward. US EPA's interpretation that elevated levels of certain constituents (*e.g.*, elevated pH, potassium, glycols) are attributable to HF fluids is also incorrect. The Phase V sampling results contradict US EPA's prior conclusions and indicate that elevated concentrations of many constituents previously attributed to HF are actually associated with well construction materials (*e.g.*, cement) and that groundwater quality from the deep monitoring wells is trending towards regional groundwater quality with additional purging. Finally, US EPA's attempt to link the presence of methane and other petroleum hydrocarbons to HF-enhanced migration ignores the fact that the presence of shallow methane in the region is well-documented, even before HF activities began in the area.

To summarize, given the significant Study design, implementation, and data interpretation shortcomings, there is no scientific basis for US EPA's conclusory finding that "inorganic and organic constituents associated with hydraulic fracturing have contaminated groundwater at and below the depth used for domestic water supply." This conclusion is also contrary to public statements made by EPA officials, including EPA Administrator Lisa Jackson, who stated that:

"[W]e have absolutely no indication right now that drinking water is at risk."

Based on our scientific review, we would expect that a thorough peer review of the Study will identify its significant shortcomings, deficiencies that are so significant as to reject the premature findings presented in the Study. Others – including the Bureau of Land Management – expressed similar concerns regarding the Study. Overall, the US EPA Study (US EPA, 2011) should not be used for US EPA's broader study of the relationship between hydraulic fracturing and drinking water or any other form of decision making.

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