EPA provides the following detailed technical comments on the *Pavillion, Wyoming Area Domestic Water Wells Draft Final Report and Palatability Study* (Report). Each topic area is introduced with a general discussion of the issue, and in some cases is followed by bulleted points addressing more specific or detailed items related to that issue.

<u>Domestic Well Water Quality Concerns</u>

The Report indicates that the groundwater is generally suitable for domestic use, despite exceedances of some health-based comparison values (CV) and despite some significant uncertainties in the ability to evaluate the effects of drinking the water. The Executive Summary states that “Exceedances of drinking water standards or comparison values are generally limited to naturally occurring dissolved salts, metals, and radionuclides. Only two organic compounds…were detected at concentrations exceeding the applicable drinking water standard or comparison value.” (p. 3) EPA suggests that a more comprehensive evaluation and discussion of the potential health risks and the associated uncertainties would be important additions to the Executive Summary and Section 5.5 of the Report. The Report’s characterization of the exceedances of standards or comparison values as a palatability concern rather than a health concern may leave readers unclear regarding the significance of these exceedances. Further, the Report does not provide a clear discussion of the uncertainties associated with the evaluation of potential health concerns. Of the 19 organic constituents identified in domestic wells, nine do not have CVs identified in the Report. This is an information gap that EPA suggests be discussed in the Report as it discloses the limitations to reaching definitive conclusions about potential health risks from drinking the water. Given the number of detected compounds with no CV, uncertainty remains with respect to statements about health risk and suitability, and EPA suggests that any such statements be qualified accordingly.

- The Report indicates that only two organic compounds exceeded a Maximum Contaminant Level (MCL) or comparison value (p. 3). As mentioned, nearly half of the organics detected have no CV, contributing to the uncertainty involved in making a definitive statement about health risks associated with drinking the water from domestic wells. The WDEQ data in combination with previous sampling done by EPA highlights the spatial and temporal variability of detections in the domestic wells, another source of uncertainty in making definitive health risk statements. MCLs were developed for use in evaluating compliance of treated water from public water systems, which are routinely monitored, and take into account other factors unrelated to health (e.g. treatment cost and capability, analytical method availability and cost). EPA also notes that additional MCL exceedances (i.e. benzene) have been documented in shallow groundwater based on monitoring well data from pits enrolled in Wyoming’s Voluntary Remediation Program (VRP). Absent ongoing regular monitoring for detected constituents, it is difficult to predict what concentrations will occur in domestic wells in the future. EPA suggests this finding regarding organics exceedances be qualified to reflect these uncertainties.

- The Report concludes that “exceedances of drinking water standards or comparison values are generally limited to naturally occurring dissolved salts, metals and radionuclides” (p. 3), but there is limited supporting evidence demonstrating that all of these constituents were present historically in the area, and that they were present at similar concentrations to those detected. There is limited discussion in the Report that compares ranges of concentrations for the components found in historical data to components and concentrations in the wells studied. Historic data are primarily available for general chemistry parameters, and that data does indicate that the high levels of sodium and sulfate are characteristic regionally for the Wind River formation. However, there is limited or no historic data in the references cited in the Report to document naturally occurring levels of many other inorganic constituents such as arsenic, thallium, lithium and uranium, and the limited data suggest that the values seen in water wells are not consistent with background concentrations. For example, the WSGS Basin Study (WSGS 2012) shows that the median concentration observed in the six wells sampled for uranium was 0.54 ug/L, where the Report indicates that four water wells exceed the much higher value of 30 ug/L (Table 14A). Similarly, the 1995 USGS report on Fremont County water quality (USGS 1995) shows five arsenic samples, four with non-detects and one with 2 ug/L of arsenic, whereas the Report indicates that two of the sampled water wells exceeded the MCL of 10 ug/L. These values do not seem to corroborate that exceedances of inorganics are due to naturally occurring concentrations of these compounds. And there was no data for thallium or lithium in the references, so it is difficult to support a statement about naturally occurring levels with regard to the six wells exceeding the lithium CV and the five wells exceeding the thallium CV.

- The Report also states that "there is a potential for inorganic compounds (e.g. chloride, potassium, sulfate) from gas pits to be contributing to the high levels of salts and other compounds reported in the water supply wells" (p. 75). It should be noted that the altered reducing and associated oxidizing conditions resulting from the introduction of hydrocarbons and other organics can mobilize arsenic and other inorganic compounds, and could contribute to elevated concentrations. EPA notes that the highest levels of arsenic detected were in samples from a pit monitoring well where hydrocarbons were present at elevated concentrations (EPA 2010). Finally, EPA suggests that, in addition to the inorganics mentioned above, barium concentrations in water supply wells could also have been impacted by releases from pits. In EPA's Phase II sampling, barium in one of the domestic wells was anomalously high as compared to other domestic wells. This well is located near a pit location. Arsenic above the MCL and high barium were detected in the VRP pit monitoring wells.

- EPA recommends the Report include a discussion of the analytical detection limits and the implications of those limits with respect to characterizing health risk concerns. The 2014 semi-volatile organic compounds (SVOC) analyses were performed using an analytical method with a method detection limit greater than the EPA MCL for several constituents including hexachlorobenzene, pentachlorophenol, and benzo(a)pyrene. Tables 19A and 19B do flag the analytical results for these compounds as insufficient to determine whether the MCL was exceeded; however, the Report lacks a discussion of this issue in the text of Section 4. The analytical detection limits are not discussed until the end of Chapter 5 (Section 5.9.4) and that discussion seems to focus primarily on whether the SVOCs identified were associated with oil and gas production or hydraulic fracturing. The Report would benefit from a discussion of the analytical detection limits and highlighting of instances where the method detection limit exceeds federal or state standards or other CVs, perhaps in a separate table. We understand that WDEQ is planning to pursue further analyses to address this question; EPA recommends that the Report discuss the plan for resampling to better characterize water quality in instances where the method detection limit exceeds federal or state standards or health comparison values.

- The Report states that "the US EPA concluded that most water supply wells did not have apparent health concerns" (p. 7). We suggest this statement should be qualified or omitted. This observation was made by EPA in a public presentation reporting Phase I results (https://www.epa.gov/region8/pavillion-wyoming-epa-sampling-results-january-2010-sampling). It was in reference only to the sampled wells that did not show detections of organics, metals or Tentatively Identified Compounds (TICs). EPA also stated that for 11 other wells there was insufficient data to support a finding regarding health concerns. Additionally, this observation was made by EPA after a single phase of sampling, and did not reflect the totality of the data now available.

- The Report discusses potential point-of-use treatment options that could be employed by residents, but only for inorganic compounds. Although "problematic water quality constituents" (p. 100) is not defined in the Report, constituents such as petroleum constituents, isopropyl benzene, tert-butyl alcohol, pesticide compounds, naphthalene, 2-butoxyethanol, methane and adamantanes might be considered problematic constituents and are missing from the table. EPA recommends the discussion of treatment options include treatment for organic contaminants present in water supply wells. The presence of both organic and inorganic compounds complicates potential treatment and typically requires multi-step treatment, which may be more costly and more difficult for homeowners to manage and maintain to achieve effective treatment.

Conceptual Model of Geology/Hydrogeology

EPA agrees with the statement in this Report (p. 75) and statements in WOGCC's previous reports regarding the need for a conceptual model that brings together available information on geology, geohydrology and potential pathways for movement of free gas and other dissolved contaminants.

> "A comprehensive geologic and hydrologic study of the Wind River Formation within the Pavillion Field should be undertaken using all available well logs, cores, and other pertinent data in order to better understand the structural and stratigraphic relationship between individual reservoirs, and to more accurately predict natural fluid flow pathways." (p. 10, WOGCC Pavillion Field Well Integrity Review, October 2014)
>
> "A comprehensive geologic and hydrologic study of the Pavillion Field area should be undertaken." (WOGCC Pavillion Field Pit Review, June 2015)

The Report contains statements that imply incongruent conceptual models. For example:

> "Investigation, monitoring and remediation at the pit locations are often limited to the zone of shallowest groundwater, reflecting the judgment that the relatively deep sandstone lenses in which most water supply wells are completed **are likely not in hydraulic connection** with the shallow alluvial/colluvial or Wind River deposits in which the pits are located." (p. 75)

> "…groundwater has been shown in past Wind River aquifer studies to move through the less permeable materials." (p. 75)
>
> "…existing **data is insufficient to characterize groundwater flow patterns and gradients and to assess the degree of hydraulic connection** between the surficial deposits and the Wind River aquifers in the vicinity of the water supply wells." (p. 75)

These inconsistencies point to the need for development of a clearly articulated and consistent conceptual site model based on existing data or on conclusions in published reports that are based on data. A conceptual site model can help provide a context and some predictive ability for movement of gas and liquid contaminants from any potential source (e.g. pits, open gas wellbores, etc.). A clear conceptual model could help better integrate all of the disparate pieces of information regarding potential contaminant movement, frame specific questions and data needs for future investigation, and might provide better support for statements regarding source attribution. In order to assist with understanding potential contaminant migration associated with open gas well annuli, EPA recommends the conceptual model encompass deeper subsurface zones below depths of water supply wells. A conceptual model would need to be based on all available data and published studies, and would benefit from testing of key hypotheses to confirm or refine its accuracy. Such testing could involve collection of data and the use of reservoir and aquifer modelling tools to confirm or refine the conceptual model.

- The Report indicates that Wyoming's groundwater classification system identifies water suitable for domestic, irrigation and livestock use (Class 1, 2 and 3) as groundwater with <5,000 mg/L TDS, and states that it is equivalent to EPA's definition of an Underground Source of Drinking Water (USDW) (p. 26). The Safe Drinking Water Act defines a USDW as: "…an aquifer or its portion (a)(1) Which supplies any public water system; or (2) Which contains a sufficient quantity of ground water to supply a public water system; and (i) Currently supplies drinking water for human consumption; or (ii) Contains fewer than 10,000 mg/l total dissolved solids; and (b) Which is not an exempted aquifer." (40 CFR Part 144.3) Based on available data, the Wind River formation appears to meet the definition of a USDW as it has sufficient yield and is <10,000 mg/L TDS throughout, is the principal source of water for domestic and livestock use in the area and is widely used as such, and is a single aquifer system given the demonstration of hydraulic connectivity within the aquifer system during the Riverton pump test (USGS 1959). The Report would benefit from a discussion of how the Wind River aquifer system within the study area is classified, and how that aligns with or differs from EPA's definition of a USDW. The Report states that EPA "delegated administration of the federal Underground Injection Control program to the state of Wyoming on July 15, 1983 and accepted Wyoming's regulations describing its groundwater classification system" (p. 25). EPA offers several suggestions for clarification on this point. First, the EPA approved (as distinct from delegated) Wyoming's UIC Class II program (wells related to injection of oil and gas production wastewater) on November 22, 1982, and Wyoming's UIC Class I-III and Class V program in July 1983[1]. Second, EPA did not approve regulatory language identifying groundwater with >5,000 mg/L as unusable or unsuitable for drinking water use; rather, the Wyoming program language that EPA approved contained a narrative reference that groundwater may be

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[1] Consistent with our cover letter note, EPA's comments on the State's groundwater classification system should not be construed as setting forth any position regarding the exterior boundaries of the Wind River Indian Reservation or the exercise of State authorities in this area. EPA's approvals of Wyoming's UIC programs do not extend to Indian country as defined at 18 U.S.C. § 1151.

"unusable or unsuitable" "[d]ue to excessive concentration of total dissolved solids or specific constituents." (Wyoming Code R.020-080-008 § 4(ix)(A)) EPA could not, through approval of a state's primacy program, change the regulatory definition of USDW.

- The Report generally does not distinguish between free methane and dissolved methane when characterizing analytical results or discussing how dissolved phase and gas phase methane move within the subsurface. Understanding the behavior of methane in the subsurface is critical to the development of a conceptual model for contaminant fate and transport. Free gas can and does migrate through rock strata and liquids as a buoyant fluid. Alternatively, or additionally, dissolved methane would move according to the hydrologic conditions at the site. Methane in the gas phase would naturally migrate upward from deeper reservoirs. However, liquids containing dissolved methane could move according to groundwater flow direction both horizontally and vertically depending on the pressure gradient. For example, dissolved constituents including methane could move upward under an induced pressure drive from a high pressure zone to low pressure zone, as is reflected in some bradenhead pressure measurements or from pressures induced through hydraulic fracturing.

- The Report characterizes the Pavillion gas field as a conventional reservoir (p.2). This statement should be modified or explained. Although there is some conventional development elsewhere in the Wind River Basin, Pavillion field development is from Cretaceous-Lower Tertiary tight sands, which is generally considered unconventional (see US Energy Information Administration https://www.eia.gov/oil_gas/rpd/tight_gas.pdf).

- The Report (and documents referenced and reviewed in the Report) reference various distances that were used to define the scope of domestic wells, gas wells and pits to be evaluated in Wyoming's investigation. Some examples include:
  - "…determine if wellbore construction is adequate to protect those water supply wells within 1,320 feet of the oil and natural gas wellbore…" (June 20, 2013 framework document). Similar language is used to describe the pits evaluation process.
  - "Fifty-two of the 169 Pavillion Gas Field oil and gas wells are located within 1,420 feet (one-quarter mile or 1,320 feet plus a 100-feet buffer; surface distance) of the 14 water supply wells included in the study" (p. 30)
  - "The WDEQ used the following criteria to establish areas of interest (AOIs) within which water-supply wells would be considered for further study: … The water-supply well was within 1,000 feet of an earthen drilling or production pit…" (p. 10)

  The Report lacks a clear explanation of when these varying distances were applied to determine inclusion or exclusion of a gas well, pit or water-supply well in the investigation, and could benefit from a discussion of the technical basis for these setback distances.

<u>Fluid Migration/Gas Well Integrity</u>

The Report generally concludes gas is present in the shallow Wind River formation as a result of natural upward migration from source rock (though acknowledging that some potential contribution may have come from movement up gas wellbores); that gas was widely present in the shallow subsurface prior to energy development; and that there is negligible likelihood that hydraulic fracturing fluids have migrated upward to depths utilized by water supply wells. All of these conclusions would benefit from additional support.

Widespread historic presence of methane in shallow subsurface

The Report states that gas was widely present in the shallow subsurface prior to gas development (e.g. pp. 2, 77-79). To definitively conclude this one needs to be able to determine what the gas flux was prior to development and the present day flux. Current flux can be determined but it is, as the Report notes, extremely difficult to directly substantiate historical gas flux. There is limited data to support the conclusion that gas was widely present in the shallow subsurface. Reference is made to a 3-page excerpt from a 1951 Bureau of Reclamation annual report, which contains this single statement: "a satisfactory aquifer was found near the 500 foot depth, but potability of the water was destroyed by gas". The well in question is 2.5 miles from the nearest water supply well study area (PGDW20). The excerpt does not contain or reference any supporting data or information, and there is no indication as to whether the gas was in fact methane, or something else (such as hydrogen sulfide). A USGS report covering the Midvale Irrigation District (a larger area encompassing the Pavillion field) noted the presence of hydrogen sulfide in the area: "The water from well A3-3-6cc, 270 feet deep, had a moderately low mineral content (272 ppm) but was reported unsatisfactory for drinking because of the strong hydrogen sulfide odor and the precipitation of sulfur... Although no gas analyses were made, the problem of hydrogen sulfide in water supplies, particularly in deep wells, was observed for new supplies in other tracts." (USGS 1959). Within the irrigation project area the USGS report identifies less than 20 water wells out of 359 water well logs that reported either "bad water" (eight well logs), "sulfur water" (nine well logs), or "sulfur water with gas" (two well logs). None of the wells with bad water, sulfur or gas were located within the Pavillion study area. In addition, the report evaluated over 50 water well logs from Township 3 North, Range 2 East which has a large portion of the study area. None of these wells recorded issues with water including no reports of "sulfur water" or "gas" within this area.

The Report further points to the indication of gas-filled porosity at depths between 600 and 900 feet from three mud logs from gas wells drilled between 1965 and 1973 as evidence of widespread gas at shallower depths (p. 26), and cites EPA's 2011 Draft Report as the source. EPA was able to locate and review ten mud logs from wells drilled before 1995; the logs did not indicate gas shows within 300 meters of the surface. (EPA 2011).

The final line of evidence referred to as supporting this conclusion is a 2007 letter from WOGCC, which the Report characterizes as stating a finding that most of the wells had exhibited gas just below surface casing, with many around 500 feet, based upon cement bond and porosity logs for 29 gas wells. The letter is not included as an attachment, nor could EPA locate it on the WOGCC website. EPA suggests that the logs and analysis used to reach this conclusion be made available to public reviewers of this Report. It should be noted that cement bond logs are not relevant to identifying gas presence, as they are run after there is casing and cement in the wellbore. Porosity logs by themselves have limited ability to distinguish between freshwater and gas zones, as both hydrocarbons and fresh water are non-conductive; additional information beyond porosity logs would be needed to determine if non-conductive zones identified were fresh water or gas.

If in fact the presence of natural gas in the intermediate zone was known or believed, this would have alerted the permitting agency to the potential for pressures above hydrostatic head gradients to be present, highlighting the necessity for the entire wellbore to be cased and cemented to the surface (or above the surface casing shoe) in order to prevent gas and liquid migration either from the production zone or intermediate zones to shallower zones used for drinking water: "…sufficient surface casing shall be set to reach a depth below all known or reasonably estimated utilizable domestic freshwater levels…and shall be set in or through an impervious formation and shall be cemented…with sufficient cement to fill the annulus to the top of the hole…" (Rules and Regulations of the Oil and Gas Conservation Commission promulgated July 23, 1951; effective August 21, 1951). This regulatory language was applicable to most of the wells drilled in the field. Also, rules promulgated in 1993 and 2000 required that "surface casing shall be run to reach a depth below all known or reasonably estimated utilizable domestic fresh water levels and to prevent blowouts **or uncontrolled flows**" (Wyoming Chapter 3, General Drilling Rules, 1993 and 2000). Many wells in the area are Tribal mineral wells subject to BLM's Onshore Order #2 requirement for isolation of water containing up to 10,000 ppm of TDS, which is generally the case for the entire Wind River formation. The gas well integrity expert retained by Wyoming, Maurice B. Dusseault, says the following in his report: "In modern well completion practice, this space [the bradenhead annulus] is intended to be cemented to the surface, or at least cemented a substantial distance above the surface casing shoe so that an effective flow seal exists between the two casings. Data from Pavillion Field reports show that primary cementing operations in many wells failed to lead to cement rising into the surface casing … In general, leaving an open annular space between the top of the production casing cement and the bottom (shoe) of the surface casing is not considered good practice (annum 2015), but wells drilled in the 2004-2005 campaign in Pavillion were not all cemented to above the surface casing shoe" (p. 13 Appendix G).

Source of gas in domestic water wells

The Report concludes that it is "almost certain" that part of the methane observed in water supply wells in the WDEQ investigation is naturally occurring and not a result of gas production (p. 78). This conclusion appears to be based solely on the limited data described above. There is often a question about prior gas migration or flux in regions producing hydrocarbon, particularly with gas reservoirs such as the Pavillion field that lack a clear confining layer above the hydrocarbon zone. In some cases it has been determined that even though there was prior migration of gas, energy development activities had increased the migration rate and volume causing noticeable increase in impacts (Coalbed Methane Development in the Northern San Juan Basin of Colorado-BLM 1999). The Report would benefit from a more robust basis for this conclusion and we encourage the development of a consistent conceptual model for the study area, and additional study to test key statements of finding. It would require multiple lines of evidence to distinguish whether the gas appearing in water wells is present due to natural migration or via movement up gas wellbores. Absent this, EPA recommends this conclusion be qualified to reflect the uncertainties inherent in the limited supporting data currently provided.

Source of gas in bradenheads

The Report concludes that bradenhead pressure and gas are most likely from non-producing intermediate zones within the Wind River formation. The Report states that the composition and isotope signature of the bradenhead gas is similar to the tubing or production gas, but then dismisses the potential for the gas to be sourced from the production zone without providing supporting information (pp. 70-73). The Report does not acknowledge or discuss the potential for gas to migrate up the wellbore from the production zone either through uncemented or poorly cemented annuli, or even to bypass sections of good cement by migrating through the formation around the wellbore. The Report points out that producing wells would be unlikely to allow gas migration due to the pressure sink induced by production, but does not consider shut in wells or wells that have been plugged and abandoned that do not have the induced pressure sink of a producing well. According to the information provided in Figures 12A-12K, four gas wells within the study area have been temporarily shut in, and nine have been plugged and abandoned, suggesting the importance of addressing the potential for gas wells not in producing status to allow gas migration up annuli.

This conclusion would benefit from additional investigation to provide a higher level of certainty. Improving the certainty of this conclusion is important for remediation already performed or under consideration as part of WOGCC's gas well integrity evaluation and follow-up. If the gas or liquids are sourced from intermediate zones placement of remedial cement would be located differently than if fluid from the production zone fluids is migrating up an open or poorly cemented bradenhead annulus.

EPA suggests the Report include a table identifying the gas wells exhibiting sustained bradenhead pressure. That information only appears to be presented in Appendix G.

Likelihood of movement of hydraulic fracturing fluids into shallower zones

The Report concludes that hydraulic fracturing fluids had a "negligible likelihood" of reaching shallower zones used for drinking water. This conclusion relies primarily on the relatively small fracturing fluid volumes reportedly used in the field- "often less than 200 bbls". No data or reference is provided for the fracturing volumes. This conclusion lacks supporting data, and given the short vertical distances between water supply well depths and gas well fracture depths relative to other production areas across the country, may need qualification. The study did not provide any additional data to evaluate the chemistry of the interval between water supply well depths and hydraulic fracturing depths to assist in evaluating the potential for hydraulic fracturing impacts in this deeper zone, and existing data for this interval from USGS and EPA were not considered in the Report. If this existing data is not used, the Report could benefit from development of additional data from this interval to evaluate the potential for impacts of hydraulic fracturing in this deeper zone.

Some wells in the field exhibit shallow surface casing and uncemented annular intervals; although the Report acknowledges that these conditions increase the likelihood of movement of groundwater or gas, it does not discuss or acknowledge the potential that these conditions could similarly enable movement of hydraulic fracturing fluids. In particular, the Report does not acknowledge or evaluate situations where older wells with shallow surface casing and open bradenhead annulus existed in close proximity to newer wells with hydraulically fractured zones at similar depths. For example, gas wells 44-10 (API 49-013-20879, http://wogcc.state.wy.us/Wellapi.cfm?Oops=ID6869&nAPINO=1320879) and 43-10B (API 49-013-22420, http://wogcc.state.wy.us/Wellapi.cfm?Oops=ID87031&nAPINO=1322420) are approximately 520 feet apart. Well 44-10 was constructed in 1978 and although the top of cement is at 1918 feet below ground surface (bgs), top of good cement is located 404 feet deeper at 2322 feet bgs. The nearby well 43-10B constructed in 2004 was perforated and stimulated at 1810 feet which is 555 feet (adjusted for elevation difference of 46 feet) above the top of good cement in nearby 44-10. In addition, PGDW23, a domestic water supply well, is approximately 780 feet from gas well 44-10 and PGDW44 is approximately 1775 feet from 44-10. It should be noted that 44-10 exhibited bradenhead pressure of 150 psi when tested, and flowed liquid from the bradenhead during the entire 15-day test, including 410 barrels of liquid in the first 8 hours. Bradenhead monitoring in nearby wells was not conducted during hydraulic fracturing to detect pressure changes in the bradenhead annulus of these offset wells. As a result, there is no data to determine whether such inter-well communication may have occurred under a hydraulic fracturing pressure regime. EPA was unable to locate any bradenhead pressure monitoring data collected from the Pavillion field prior to the beginning of EPA's investigation; when WOGCC initiated bradenhead monitoring efforts in 2012, some of the gas wells were found to have bradenheads which were not accessible and had clearly not been previously open.

There are some inconsistencies in the Report with respect to information on hydraulic fracturing depths: "hydraulic fracturing intervals typically start below 1,500 feet bgs but have been performed as shallow as 1,060 feet bgs…" and that the "shallowest depth that was hydraulically fractured within 1,420 feet of the 14 water-supply wells included in the study is 1,397 feet bgs". This is followed by a statement in the next paragraph that likelihood is negligible that hydraulic fracturing treatments have led to fluids interacting with shallow groundwater in the study wells based on volume of treatments and depth with "shallowest hydraulic fracturing is generally deeper than 1,500 feet bgs" (p. 2). These statements are inconsistent and the reader would benefit from clarification. EPA further notes that there are some inconsistencies between Table 4 of the Report and data available on the WOGCC website or contained in the WOGCC Gas Well Integrity Review Report. Tribal 44-3 is identified in the Gas Well Integrity Review Report as being located within 797 feet of PGDW30, yet it is omitted from Table 4 of this Report, "Oil & Gas Wells within 1,420 feet of Water Supply Wells". The WOGCC report also indicates that Tribal 44-3 was perforated and acid stimulated with 500 gallons of 15% HCl at 699-711 feet in 1999. Though a cement squeeze was subsequently performed and this interval cemented off, it indicates stimulation occurred at a substantially shallower depth. Additionally, the data for depth of shallowest perforation in Table 4 of the Report do not all match data posted in the corresponding well files on the WOGCC website.

In summary, the data limitations and uncertainties discussed above suggest a need for additional investigation to provide support for many of the Report's conclusions related to fluid movement, gas source and well integrity. In addition to the specific points raised above, we encourage the state to consider recommendations for additional data collection provided previously by EPA in our comments on WOGCC's gas well integrity report (EPA 2014), which included:

- Additional sampling and analysis of bradenhead gas composition to improve the certainty of source identification
- Additional testing and analysis of bradenheads, including determination of hydrostatic head within the annulus, to better support an understanding about potential for and likelihood of fluid movement
- Additional evaluation of external mechanical integrity of wells exhibiting sustained bradenhead pressure using tools such as noise logs, temperature logs, or oxygen activation logs.

Groundwater Chemistry and Source Evaluation

One of the stated objectives of the investigation was to "assess the potential for impacts to the quality of water in the water-supply wells by oil and gas wells, related pits and other sources as appropriate." (p. 9) EPA suggests that additional lines of evidence would be needed to bolster many of the Report's conclusions regarding potential sources of constituents in water supply wells. Additionally, all data that might be pertinent to detections in a particular water supply well were not brought together to evaluate with respect to those specific detections. Such data might include, for example, existing production gas and bradenhead gas and liquid analyses from proximal gas wells conducted by WOGCC, EPA or the operator, as well as available soil and groundwater monitoring data from proximal pit sites.

- For example, there are shallow groundwater monitoring wells located at the VRP pit sites. The data from these wells (as well as soil sampling results from VRP pits) provides valuable information that would assist with understanding the hydrocarbon compounds detected in water supply wells throughout the area. The VRP information was not included in the contractor document summaries nor was it brought into the evaluation and synthesis. These sites have dedicated monitoring wells, which is described by WDEQ's independent petroleum engineering expert as a preferable source of groundwater information (Appendix G, p. i). EPA's previous comments on the WOGCC pits review advised inclusion of this information in the analysis.

- The Report does not accurately characterize the USGS sampling of MW01 (p. 8), stating that pH did not reach stability during sampling. The USGS report indicated that stabilization criteria were met: "…sample collection started as soon as values for both SC and pH met stabilization criteria (table 1). The stabilization criterion for temperature was not used because the water line was exposed to solar heating and air temperature, so by the time water temperature was measured it was not a good indication of conditions in the well" (USGS 2012 p. 4); thus, their samples from this well represent valid data. USGS and EPA data from MW01 provide data regarding groundwater quality deeper in the subsurface than most of the domestic wells, and as such these validated and quality assured data are an important source of groundwater chemistry information at depth. Additionally this data helps to inform the conceptual model regarding fate and transport pathways for contaminants in the subsurface and the question of potential sources of constituents observed in water supply wells.

- A number of USGS and WSGS reports have reviewed and synthesized historical data on general water chemistry. It would be helpful to undertake a comparison of pre- and post-oil and gas development general water chemistry to assess whether general groundwater chemistry parameters have undergone statistically significant changes since energy development began. Additionally, the discussion of historic and current groundwater chemistry in the area could be supplemented with ion concentration data from the producing gas wells in the study area, either from WOGCC or from the U.S. Geological Survey produced water database (http://energy.usgs.gov/EnvironmentalAspects/EnvironmentalAspectsofEnergyProductionandUse/ProducedWaters.aspx).

- The Report posits that detections of Diesel Range Organics (DRO) and Gasoline Range Organics (GRO) could reflect naturally occurring compounds rather than petroleum hydrocarbons. EPA believes additional analysis is needed to support this hypothesis, which seems to be based largely on the fact that the DRO chromatograms from domestic well water samples do not resemble chromatograms from laboratory standards for diesel fuel. In the Pavillion area shallow hydrocarbon sources have been present over an extended time. It would be unlikely that petroleum hydrocarbons released from pits or other sources and subject to environmental weathering and degradation over time would resemble a fresh diesel chromatogram. EPA compared chromatograms from DRO and GRO in the VRP pit monitoring wells to fresh diesel chromatograms and found them to differ significantly. EPA's Phase II analysis also identified the presence of C2-C10 straight chain hydrocarbons in domestic wells with DRO and GRO, confirming a hydrocarbon source for the DRO and GRO detections (EPA 2010). EPA suggests this Report is premature in suggesting that DRO and GRO detections may reflect naturally occurring organic matter rather than originating from the hydrocarbon reservoir.

- The Report further observes that fresh petroleum fuels such as DRO and GRO consist almost entirely of non-polar compounds, and presents data from well water analysis done using a Silica Gel Clean-up (SGCU) method, which screens out polar compounds. Without understanding what those polar compounds are and whether they may be associated breakdown products of hydrocarbon compounds, EPA suggests that screening out those compounds does not provide an accurate understanding of what is in domestic wells water nor assist in discerning the source of the polar fraction.

  The Report states that "reported DRO concentrations with SGCU compared with reported DRO concentrations without SGCU in groundwater samples collected in June and August 2014 reveals that in most cases, the reported DRO concentration with SGCU was less than the MDL (Table 14). This suggests that the reported DRO concentrations in many of the samples are attributable to, or were predominantly non-polar compounds." (p. 87) It appears that the authors may have meant to say that the remaining DRO exhibits chromatogram peaks reflective of predominantly polar compounds.

- DRO and GRO were found in conjunction with other hydrocarbon compounds in previous EPA sampling (EPA 2009; 2010; 2014). EPA notes that the highest DRO and GRO concentrations were identified in gas well fluids sampled at the wellhead, and from shallow groundwater monitoring wells at VRP pit sites with demonstrated hydrocarbon contamination in groundwater. Additionally, products containing diesel fuel were used in hydraulic fracturing at Pavillion (EPA 2010). Encana, WYDEQ and EPA have all detected tentatively identified organic compounds for various wells tested in the study area. This may be another indication that hydrocarbon compounds have been degraded to by-products that are not easily identified with standard methods. For example, adamantane compounds were originally detected as Tentatively Identified Compounds (TICs) in domestic wells in EPA Phase I (EPA 2009). Subsequent sampling of water supply wells and VRP pit monitoring wells In EPA Phase II (EPA 2010) confirmed and quantified these compounds. Based on these observations, there may be more lines of evidence to suggest the DRO and GRO detections are associated with oil and gas activity.

- The Report seems to suggest that biodegradation of dissolved unknown organic constituents by bacteria is a source of palatability concerns in domestic wells (p. 4). EPA notes that the highest levels of both DRO/GRO and of iron-related and other heterotrophic bacteria are those found in the shallow monitoring wells associated with VRP pits (EPA 2010). EPA concurs with the observed correlation between dissolved organic constituents and the proliferation of bacteria, but notes that the correlation does not establish that the source is degradation of non-hydrocarbon compounds. The Report notes that the dissolved organic compounds in some water wells (including dissolved gas) may be contributing to deteriorating water quality by promoting microbially-mediated reducing conditions resulting in increased mobilization of other constituents such as arsenic, and production of hydrogen sulfide (pp. 4 and 108). EPA concurs with this observation; however, the fact sheet accompanying the Report states: "…bradenhead pressures in several gas wells provide strong indication that gas and possibly liquid migration may be happening; however, there is no evidence that this migration has caused water quality issues." These statements appear to be contradictory, and EPA recommends the fact sheet statement be modified to reflect the lack of data demonstrating that the observed gas migration is not impacting water quality. EPA also notes that the highest arsenic levels were present in the VRP pit monitoring wells, which also had high concentrations of dissolved organics including petroleum hydrocarbons. This suggests that contaminant plumes from pits are a likely source of constituents such as arsenic and merit additional investigation (such as the installation of nested monitoring wells) to provide more definitive understanding of the vertical and lateral extent and the chemical composition of plumes associated with pits and their effect on domestic wells.

- The Report mentions that TICs in PGDW05 were attributed to decaying organic matter (p. 7). There is no data or analysis to support this statement, and EPA recommends it be removed or qualified. For example, adamantane compounds were detected in PGDW05 and originally identified as TICs, and confirmed and quantified in subsequent EPA sampling. The Report further states that adamantanes, because they are widely recognized as a component of petroleum hydrocarbons, "…may be from naturally occurring gas." (p. 90) EPA notes that adamantanes were also found in VRP pit monitoring wells and in production fluids (Phase II Analytical Results Report, August 2010), suggesting those as likely sources. EPA recommends this statement be modified accordingly.

- Although fuel spills can be a source of hydrocarbon contamination, there is no source comparability between a 50 gallon fuel tank that may have experienced incidental spillage, and a single unlined reserve or production fluid pit that received hundreds to thousands of barrels of fluids over a period of years and often decades (Figures 12A-12K illustrate that a number of oil-based mud reserve/production pits in the study area were operative for decades). In addition, there are at least eight pits that have been enrolled in the VRP cleanup program, reflecting documented groundwater contamination associated with these sources. It is important when assessing possible sources to consider the potential for those sources to impact groundwater based on constituents, volumes and duration of potential releases from those sources, and to reflect that potential in discussion and conclusions regarding potential sources. For example, if septic systems were a source of water supply well palatability problems, nitrate would be anticipated as a major constituent in sampling results. However, nitrate has not been a constituent of concern for most wells in the area, suggesting that domestic waste and fertilizer use are not contaminating groundwater within the study area.

- The Report states that "2-butoxyethanol (2-BE) was reported at an estimated concentration of 3,100 J ug/L in the June 2014 sample collected from PGDW33. However, the reported concentration was near the MDL of 2,300 ug/l, and the analytical method employed (US EPA 8015A) uses a non-specific detector, so compound identification is less certain" (p. 89). The measured value is ~35% above the MDL, and it is unclear from the information provided why the identification of this compound is "less certain". The Report also states that "if present, potential sources of the 2-butoxyethanol reported in the sample from PGDW32 (sic) include the septic systems and surface releases" (p. 89). EPA notes that this reference to PGDW32 rather than PGDW33 appears to be a typo as 2-BE was not detected in PGDW32. EPA further notes that the pit located 577 feet from PGDW33 was utilized as an oil-based mud reserve pit and subsequently as a produced water/flowback pit for more than 20 years (Figure 12G). 2-BE was used as a constituent in fracturing fluids at Pavillion (EPA 2010) and may thus have been present in flowback managed in pits. It should also be noted that 2-BE was detected at 765-785 feet bgs in MW01 (EPA 2011). Given that there were no detections of E. coli and only low levels of nitrate (2.1 mg/L) in PGDW33, it seems that the pit may be a more likely source of this detection than septic system releases.

- EPA notes that some results for DRO and GRO were qualified as not detected (U) due to reported concentrations in the associated method blank or trip blank samples. The "B" qualifier should be used instead to avoid confusion and put the data in its proper context. EPA suggests these results be reviewed with respect to the magnitude of difference between the quality assurance (QA) sample detections (which could be due to lab issues) and the environmental samples, and reevaluated if that difference in magnitude is sufficiently large. EPA quality assurance and data validation protocols allow use of qualified data where the environmental sample detections exceed the concentration found in the blank based on the judgment of the investigator (http://www.epa.gov/sites/production/files/2015-03/documents/somnfg.pdf). In addition, prior to discounting DRO results with associated blank detections, EPA suggests previous sampling events be reviewed to determine if DRO or GRO detections were seen only during events with blank contamination.

- The inorganic chemistry data presented in the Report may not provide sufficient sensitivity for distinguishing sources of water potentially impacting the shallow zones used for drinking water and evaluating whether facilitated transport of formation water is or has occurred from deeper zones into shallower zones. Stable isotopes of strontium have been successful in this type of analysis, and

EPA recommends consideration of more targeted tracers such as these to assess potential migration of formation water into shallow zones.

- It may be useful to analyze irrigation water chemistry relative to data collected for water supply wells (e.g., included in Figure 17A). The chemistry of shallow groundwater is often influenced by irrigation in arid basins such as this, particularly if large-scale irrigation practices have been in place for many years. Evaluation of deviations from this anticipated pattern would be useful both for the pit investigations, as well as for assessing potential impacts from localized migration of groundwater from deeper zones. Incorporation of SAR data from soils or shallow groundwater from VRP pits investigations could help inform this evaluation and address resident concerns regarding potential impacts of garden irrigation using water from domestic wells. EPA notes that the framework document called for pre- and post-irrigation season sampling because of the potential effect of irrigation on shallow groundwater, yet both rounds of sampling occurred during irrigation season (due to concerns regarding weather). EPA recommends the Report discuss how results might be influenced by irrigation and if they are influenced, how that might be expected to influence conclusions.

- EPA offers some clarification with respect to domestic well sampling conducted by the Agency. EPA did not sample PGDW41B in 2009 as the Report indicates (p. 48). In January 2010, EPA's sample at PGDW41 was collected from the deeper well present at this location, rather than being a mixture of water from PGDW41A and PGDW41B, as the Report states (p. 59). Finally, the Report indicates that EPA hired a well service contractor to install a temporary pump/discharge line for PGDW41, and that this work may have contributed to DRO and TPH results in this sample (p. 88). EPA does not believe this to be the case. This sample was collected utilizing a SOP that called for flushing the water wells three well casing volumes to prevent sampling stagnant water so as to ensure there would be no artifacts from sampling components. These results were reviewed and validated without data flags and thus are considered valid data. Further, if artifacts from temporary sampling equipment were the source of DRO and TPH, it would not explain the fact that DRO is still present four years later.

<u>Pits</u>

The Report statement that "a pit without known groundwater contamination is no guarantee that it has not or will not cause groundwater contamination to a nearby well" and that a limited investigation conducted at a certain point in time is not likely to be fully representative (p. 74). EPA concurs, and notes that previous EPA input to WOGCC regarding pits (EPA 2013b and 2015) expressed concern about reliance solely on Total Petroleum Hydrocarbon (TPH) data to conclude that no further investigation is needed, and pointed out that the subsequent discovery of groundwater contamination in association with pits that had met TPH clean-up values seems to indicate that the initial investigation and closure was not sufficient to detect and address groundwater impacts. The Report authors acknowledge the validity of this EPA observation regarding data limitations (Appendix I, Section V-16). The Report additionally states that "further analysis is needed to assess whether investigations and/or remediation at pit locations was sufficient to protect groundwater quality at the water supply wells" (p. 75). EPA concurs, and has previously provided suggestions on additional investigation that would be helpful.

The Report observes that monitoring and remediation at the pit locations are often limited to the zone of shallowest groundwater, reflecting the judgment that these zones are not hydraulically connected to the somewhat deeper sandstone lenses in which many domestic wells are completed. Yet, as is also pointed out, pump tests conducted in the area reflected hydraulic impacts (drawdown) in wells as deep as 662 feet and as much as a mile away. Without further analysis and the development of a conceptual model as described above, the pump test results suggest that investigation and/or remediation at pit locations needs to encompass deeper groundwater, preferably by employing nested monitoring wells at pit sites with known groundwater contamination to enable characterization of the plume depth profile The lack of sufficient data to characterize groundwater flow patterns and gradients that the Report notes makes it difficult to assess over what distance impacts to groundwater from pits might occur.

- The Report states that 1984 Wyoming regulations prohibit the use of reserve pits as production pits. It subsequently states that "records indicate that some of these pre-existing production pits continued to be used [as production pits to store produced water] until approximately the mid-1990s" (p. 28). An explanation of the significance of this would be helpful.

- The Report states that WOGCC has primary regulatory authority over gas well pits and waste materials contained in the pits. Since BLM has authorities with respect to Tribal mineral wells, we suggest BLM's authorities with regard to those pits that are associated with tribal mineral wells be addressed.

- The Report discusses the lack of correlation between potassium and chloride concentrations in domestic wells and proximity to a KCl polymer type pit; however, though it does acknowledge that other factors such as well depth, transport pathway and natural variability of these constituents would affect migration and concentrations of potassium and chloride (p. 82). Given the significance of these factors (well depth and proximity and constituent concentrations in particular), EPA believes that some KCL pits might pose risks to water wells and merit further investigation. The intent of this discussion could benefit from clarification, and as EPA has previously commented, additional investigation of KCL pits could help establish a stronger basis for a conclusion about their potential contribution to groundwater contamination. The Report further notes that if these factors are considered, it will be more difficult to identify any spatial trends. This may be true when attempting to identify a trend that would hold true for a large spatial region; however, these are factors that would be useful in evaluation of whether a particular pit is a viable potential source of contamination for a nearby water well. EPA also notes that the Report refers to Figures 20 and 21 as a demonstration of this lack of correlation; however, Figure 20 presents Na + K, so it isn't possible to differentiate the contribution of K from wells close to KCL or other pits from this figure.

- The Report states that "additional analysis could be performed using existing data (e.g. groundwater results from WDEQ Voluntary Remediation Program (VRP) investigations[2])" (p. 4). EPA, as noted elsewhere, concurs with the need to incorporate such analyses into this Report to assess potential

[2] Consistent with our cover letter note, EPA's comments regarding the surface pits in the VRP are for technical purposes only and should not be construed as setting forth any position regarding the exterior boundaries of the Wind River Reservation or the exercise of State authorities in this area.

contributions from specific pits to constituents detected in proximal water wells and to better inform the overall conceptual model.

Analytical Methods

- Some of the analytical methods quoted aren't the most recent versions of the methods. The following refers to methods in Table 8A:
    - SVOCs Organochlorine pesticides – current method is 8081B (Feb. 2007) yet C&T lab used 8081A
    - SVOCs Organophosphorus compounds – current method is 8141B (Feb. 2007) yet C&T/APPL lab used 8141A
    - SVOCs – current method is 8270D (Jan. 2014) yet C&T used 8270C
    - Trace metal – current method is 6010D (July 2014) yet C&T used 6010B
    - Trace metals (Li and U) – current method is 6020B(July 2014) yet C&T used 6020A
    - VOCs – current method is 8260C (Aug. 2006) yet C&T used 8260B
    - VOCs (GRO and glycols) – current method is 8015D (June 2003) yet C&T and C&T/Weck used 8015B (or 8015A – page 89) (See comments below regarding Method 8015)

  The use of current methods might invoke different sections, caveats, and perhaps QA changes to the method.

- Method 8015 does not list glycols as tested compounds so the method would have to be adapted to analyze for these compounds. The sample introduction method is missing in the discussion.

- Method 8015 has known interferences for the glycols leading to low biased results. Here are some related references:
    - Baffi, P.; Elneser, S.; Baffi, M.; De Melin, M.; Baffi, P.; Elneser, S.; Baffi, M.; De Melin, M., Quantitative determination of diethylene glycol contamination in pharmaceutical products. J. AOAC Int. 2000, 83, 793-801.
    - Lawrence, J. F.; Chadha, R. K.; Lau, B. P.; Weber, D. F., Simplified routine method for the determination of diethylene glycol in wines by capillary gas chromatography with flame ionization detection. J. Chromatogr. 1986, 367, 213-6.
    - Yamini, Y.; Hojjati, M.; Haji-Hosseini, M.; Shamsipur, M., Headspace solvent microextraction A new method applied to the preconcentration of 2-butoxyethanol from aqueous solutions into a single microdrop. Talanta 2004, 62, 265-70.

- Section 4.2.12 discusses QA/QC samples but only for the field collected samples – field and trip blanks. The discussion of laboratory QA/QC is interspersed with each class of compounds and consists of initial calibration, continuing calibration verification, method blanks, MS/MSD, serial dilution and post-digestion spikes, and lab control samples. The discussion only indicates when a failure has occurred. For the accuracy samples MS/MSD and LCS, it would be helpful to include information on (1) how big the acceptance window was and (2) whether samples were biased all to the low side (or high side) but perhaps within the acceptance limits. Please see discussion on glycols.

- The measured turbidity of -6.1 NTU in PGDW45 is identified as artifact of meter calibration (p. 50). This is not an insignificant deviation from zero and may call into question the reliability of turbidity measurements.

Additional Work

Both of the WOGCC prior reports recommended numerous general and specific additional investigation steps, many of which EPA supported. EPA also provided additional specific input on investigation and data collection for both pits and gas well integrity, as expressed in our prior input to Wyoming on gas well integrity and pits (EPA 2013a, EPA 2013b, EPA 2014, EPA 2015). While this Report does offer a short discussion of considerations for additional work, including evaluation of methane seepage along gas wellbores and the contribution of pits to water quality concerns in domestic wells, the discussion is limited and general. EPA suggests that the final Report provide a more complete and detailed description of specific investigation and data collection that will be undertaken to address the uncertainties and questions discussed throughout this draft, including additional consideration of the suggested investigation steps previously described by EPA. As discussed above, we recommend that a specific plan for additional investigation be based on a thoughtful conceptual model of geology/hydrogeology and contaminant fate/transport pathways, from which specific data quality objectives could be derived for any additional investigation.

Further, EPA suggests that the Report include a discussion of remediation work already underway to address identified concerns with gas wellbores and pits, as well as additional work that Wyoming intends to undertake to further investigate and address these potential sources. For example, EPA notes that Pavillion Fee 12-11W, which exhibited bradenhead pressure of 150 psi and flowed 4,303 barrels of water from the bradenhead, underwent an attempt to place additional cement in the annulus in May 2013. (WOGCC 2014). It appears that this may have been in an effort to remediate the bradenhead pressure and fluid flow, but neither the WOGCC report nor the well file are specific regarding the purpose of the cementing or whether it achieved the intended purpose. Similarly, of the eight pits enrolled in Wyoming's VRP program, four have been given certificates of completion (p. 32). EPA was unable to locate information on WDEQ's website describing the nature and extent of contamination, the remedial action performed, or the groundwater clean-up levels achieved. To enhance public understanding and transparency regarding the full scope of investigation and remediation of pit and wellbore sources, the Report would benefit from a comprehensive discussion of these efforts.

Document Clarity and Readability

EPA suggests that the Report be revised to improve the clarity and readability of the document, particularly for a non-technical audience. Specific suggestions for improvement include:

- Reduce the length of the Executive Summary and focus it on a description of what was done in the study, what was found, what was concluded, and what were the unanswered questions, data gaps and uncertainties in those conclusions.
- Integrate tables and figures into the text of the document in the appropriate location. It is very difficult to find them in the large attachments and toggle back and forth between the text and the tables/figures.

- Reduce the length and complexity of the Report by pulling more of the detailed technical information into appendices- a specific example would be the sample collection methods but there are a number of others.
- Separate each appendix into a separate attachment to better enable readers to find material in the appendices.

REFERENCES

EPA 2009. Phase I Site Investigation Analytical Results Report, August 2009

EPA 2010. Phase II Expanded Site Investigation Analytical Results Report, August 30, 2010

EPA 2011. Investigation of Groundwater Contamination near Pavillion, Wyoming, December 2011

EPA 2013a. Pavillion Gas Well Integrity Evaluation, EPA Region 8, July 25, 2013

EPA 2013b. Pavillion Oil and Gas Field Pits Evaluation, July 25, 2013

EPA 2014. Letter to Grant Black dated September 5, 2014 transmitting EPA comments on WOGCC Pavillion Field Well Integrity Review report

EPA 2015. Letter to Mark Watson, WOGCC, dated January 16, 2015 transmitting EPA comments on WOGCC Pavillion Field Pit Review report

USGS 1959. D.A. Morris, O.M. Hackett, K.E. Vanlier and E.A. Moulder, Ground-Water Resources of Riverton Irrigation Project Area, Wyoming Geological Survey Water-Supply Paper 1375

USGS 1995. Maria Plafcan, Cheryl A. Eddy-Miller, George F. Ritz, and John P.R. Holland II, Water Resources of Fremont County, Wyoming, U.S. Geological Survey Water-Resources Investigations Report 95-4095

USGS 2013. Wright, P.R., McMahon, P.B., Mueller, D.K., Clark, M.L., 2012, Groundwater-quality and quality-control data for two monitoring wells near Pavillion, Wyoming, April and May 2012: U.S. Geological Survey Data Series 718

WOGCC 2014. Pavillion Field Well Integrity Review, October 8, 2014

WSGS 2012. Paul Taucher, Timothy T. Bartos, Keith E. Clarey, Scott A. Quillinan, Laura L. Hallberg, Melanie L. Clark, Melissa Thompson, Nikolaus Gribb, Brett Worman, and Tomas Gracias, Wind/Bighorn River Basin Water Plan Update Groundwater Study Level 1, Wyoming State Geological Survey, http://waterplan.state.wy.us/plan/bighorn/bighorn-plan.html