Report on U.S. EPA's Investigatory Approach to Palatability Issues in Domestic Wells Near Pavillion, WY

Prepared in response to Draft Investigation of Ground Water Contamination near Pavillion, Wyoming, EPA 600/R-00/000 December 2011, prepared by Office of Research and Development, U.S. EPA National Risk Management Research Laboratory, Ada, OK 74280, and Investigation of Ground Water Contamination near Pavillion, Wyoming Phase V Sampling Event, Summary of Methods and Results, September 2012

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by

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Per the Extended Abstract (page xi) of the draft U.S. EPA report, Draft Investigation of Ground Water Contamination near Pavillion, Wyoming, EPA 600/R-00/000 December 2012, prepared by Office of Research and Development, U.S. EPA National Risk Management Research Laboratory, Ada, OK 74280, "In response to complaints by domestic well owners regarding objectionable taste and odor problems in well water, the U.S. Environmental Protection Agency [U.S. EPA] initiated a ground water investigation near the town of Pavillion, Wyoming under authority of the Comprehensive Environmental Response, Compensation, and Liability Act. [CERCLA]"

We were asked by Encana Oil & Gas (USA) Inc. to review the draft report and other available information, and address how we would approach investigating and responding to palatability (such as taste and odor) complaints in water well-source supplies.

We are consulting ground-water professionals who work in water supply hydrogeology (planning, writing specifications for, inspecting and testing wells and wellfields); associated water well and ground-water quality testing and problem solving; and in the prevention, mitigation and reversal of the deterioration of wells and geotechnical drains. Ground-water quality and system deterioration investigations include microbiological as well as hydrogeological and hydrochemical issues. Our resumes are provided (Attachments SC-1A and SC-1B). Documents and files reviewed and used in preparation of this report (in addition to references cited) are listed in attachment SC-2.

I. Our Approach to a Water Well Taste and Odor Complaint

A. "What's the question?" – Establish the nature of the complaint:

When approaching an investigation of taste and odor, it is useful to have some idea of the perceptions of those using a water source. Identifying the objectionable taste and odor helps to focus the investigation. First, we ask "what does it smell or taste like?" "What is the intensity?"

Protocols for investigating taste and odor vary. Some, such as Sections 2150, 2160, and 2170 of *Standard Methods for the Examination of Water and Wastewater* (APHA, AWWA, WEF, 2012), focus on identifying and (to a degree) quantifying tastes and odors. The difficulty in applying such methodology in an investigation is discussed in a Health Canada discussion of taste in water (http://www.hc-sc.gc.ca/ewh-semt/pubs/water-eau/taste-gout/index-eng.php).

A key descriptor is "what does it smell like?" Such descriptions are widely recognized as being subjective (e.g., "smells like hydrogen sulfide" or "smells like diesel") and as discussed by Health Canada, not standardized or quantified in an objective way.

Methods have been developed however, to quantify the intensity of taste and odor that is objectionable, and standards or guidelines have been set for these. The U.S. EPA has established taste thresholds and odor thresholds for a number of constituents, for example, in the "2009 Edition of the Drinking Water Standards and Health Advisories" (http://water.epa.gov/action/advisories/drinking/upload/dwstandards2009.pdf) that was in effect during the U.S. EPA investigation, and consistently throughout prior editions of this publication.

The threshold odor test (TOT, see *Standard Methods* - Method 2150 B, APHA, AWWA, WEF, 2012), in which a volume of odiferous sample is diluted until the odor is no longer detectable, is commonly used to quantify odors. The TOT provides a threshold odor number (TON), an objective number that can be used to quantify the intensity of an odor (*Standard Methods* Section 2150 B). U.S. EPA refers to the TON in discussion of secondary maximum contaminant levels (SMCL) for drinking water (water.epa.gov/drink/contaminants/secondarystandards.cfm) and has established a SMCL for odor of 3 TON (water.epa.gov/drink/contaminants/index.cfm). SMCLs are primarily based on aesthetic concerns. For example, the SMCL taste threshold for sulfate is 250 mg/L.

Other sources in the public literature or available on the Internet provide additional systematic methodologies for approaching taste and odor issues. For example, Khiari (2002), in addressing taste and odor in water supply distribution systems, adds additional methods for defining causes that can be adapted to investigations of a well water problem, and Health Canada referenced previously, lists classic taste-and-odor literature. It does not appear that the U.S. EPA used objective testing such as calculating a TON in evaluating taste and odor complaints in its draft report.

B. Start with the most likely sources of water quality impairment

Once symptoms, and if possible, intensity are established, we can turn to likely causes. To do so requires establishing and following an investigative approach that is logical and as technically valid and complete as possible within time and resource constraints (Section II). We will start with likely (high probability) causes such as:

1) Bacteriological contamination – either environmental or from surface contamination such as septic tank effluent;
2) Likely naturally occurring ground water chemical causes, such as iron or sulfide enriched ground water; and
3) If a human activity such as resource drilling or mining is nearby, we investigate that source, but effluent from that activity would have to be within the capture zone of the well (see following).

II. Technical Process of Addressing the Cause of a Palatability Complaint

In our approach to such an investigation of a well water complaint, once we have established the nature of the complaint, we have a four-step approach, starting first with issues of:

a) water quality (of the problem well),

b) well construction (of the problem well),

c) hydrogeologic environment, and

d) well aging and maintenance history of the problem well.

These four issues are interrelated. Well water quality is the most accessible information and can be collected with no knowledge of the rest by sampling the problem well and conducting water quality analyses. It is necessary to conduct meaningful analyses that shed light on causes of objectionable water quality. Common analyses are as follows:

Parameter	Relevance to objectionable water quality
Ammonia	Taste and odor – U.S. EPA draft taste threshold (but not odor) established. Also corrosive and a source of chlorine demand, which is significant to both taste and odor. Even in the absence of chlorine, compounds that exert chlorine demand chemically reduce compounds in water and this can impart unpleasant taste and odor.
Sodium	Taste – U.S. EPA taste threshold established.
Sulfate	Taste – U.S. EPA taste threshold established.
Sulfide	Dissolved sulfide gas imparts odor, and sulfide is corrosive, reacts with metals to impart taste, and a source of chlorine demand.
Dissolved metals	Iron, copper, zinc, and manganese impart metallic, sometimes described as bitter, tastes.
Bicarbonates	"Limestone" taste often considered pleasant by some but not others.
High TDS	High total dissolved solids is a simple test to confirm that taste and odor is likely, as TDS is composed of many compounds.
High pH	Bitter or soda taste.
Microbiological	Biofilm-forming and corroding bacteria, and high levels of heterotrophic bacteria in general impart taste and odor and degrade water appearance. Microbes are the source of sulfides, ammonia, and some other compounds that cause odors, as well as methane. Some oxidizing biofilms (Fe, Mn and sulfide-oxidizing) may both remove some sources of objectionable taste and odor and harbor others, releasing those harbored when disturbed. Algae and cyanobacteria also impart objectionable tastes, odor, and appearance, but would be rare in well water supplies.
VOC	Including MTBE and other VOC compounds, particularly in the diesel and gasoline ranges, that impart unpleasant taste and odor in addition to potential health impacts.

Comparing this list with Table 3 in the Draft Report, a number of compounds in that table are aromatic and can impart taste and odor in sufficient concentration (e.g., BTEX, gasoline, and diesel-range compounds, phenol, and naphthalene), but the list of analyzed compounds is not focused on resolving a taste and odor complaint.

However, to understand water quality, it is also necessary to understand the influence of well construction and the associated hydrogeologic environment. The purpose of secure well construction (well casing, seals, etc.) is to exclude, to the extent possible, conditions that impair well water quality. We also look for on-site risks to well water quality – those risks that are within the capture zone of the affected water well, including on-site wastewater disposal and treatment.

However, poor water quality is possible even if the ground-water source is pristine and well construction is secure. Lithology and the ground-water environment strongly affect raw well water quality (both in the immediate vicinity and regionally) since earth materials and ground water are in close contact for long periods. Therefore, we look at well construction, lithology, and aquifer environment to evaluate potential influences on well water quality. Finally, we look at the age of the problem well, and how or if the well was maintained.

III. Deficiencies in U.S. EPA's Procedures for Responding to Palatability Complaints

A. Establishing the nature of the complaint

A careful review of the draft U.S. EPA report does not provide an answer to the question: "What is the nature of the palatability complaints that prompted the U.S. EPA investigation?"

The draft U.S. EPA report references "taste and odor problems" but does not describe what these are. Other documents (Attachment SC-2) colloquially describe the nature of complaints. These include "sulfur" and other undefined odors, gray and black discoloration, gas in well water, high TDS (total dissolved solids), sulfates, organic odors, foul odors (draft U.S. EPA report), and also "sheen". We find no systematic, corroborated identification of complaints, and are aware of only a few domestic well owners who have made their concerns known in a public forum.

This report will concern itself with issues of well water quality, and how the U.S. EPA approached these issues in attempting to relate them to hydrofracturing in its draft report. As documented elsewhere, pit and other surface development issues are being addressed by the producers and the State of Wyoming. We also understand that the pits identified in the draft report are not located in the vicinity of the properties with identified domestic water well concerns that are of interest to the study documented in the draft U.S. EPA report.

B. U.S. EPA methodology for addressing the complaint

Without having first firmly establishing the nature of the complaints, and without examining the water quality, well construction, hydrogeologic conditions, and age and condition of the problem wells, U.S. EPA initiated a CERCLA investigation in response to water well taste-and-odor complaints. This approach appears to violate the first principle of such an investigation: *Address the simplest and most likely causes of the complaint first, and then extend outward to less-likely, more-distant, and more tangential potential issues.*

Based on our review of information available to us, features of the wells in question, the formations in which they are completed, regional ground water quality, and possible on-site conditions are the more likely explanations for the problems these domestic well users experienced.

The following illustrates how U.S. EPA could have reasonably followed our four-step approach to arrive at a well-reasoned conclusion about the nature of the source of any water quality degradation in the domestic wells.

IV. An Alternative Methodology for Investigation of Well Water Quality Complaints

A. Likely water-quality causes of palatability issues in the fresh-water zone and in the wells themselves

As our investigative approach starts with water quality itself, it requires an understanding of the causes for a certain water quality. In such an investigation, we look at both the water quality parameters themselves and potential biogeochemical sources and derivations (both physical-chemical and biological). The investigation must recognize that the poor quality of baseline water chemistry increases the importance of proper well construction and good maintenance practices.

1. Water well inorganic water quality: We were provided with an Excel worksheet with water quality data for "PGDW05, PGDW20, PGDW21, PGDW30, and PGDW45". These wells are reportedly 210, 460, 460, 260, and 60 feet deep, respectively. According to U.S. EPA draft report Table A.1, these are domestic water wells. In this worksheet, several water quality parameters can relate to a taste and odor complaint, and specifically to a sulfate or sulfide complaint, as well as producing sheen on a water surface. These are a) some of the organics, which could potentially impart taste and odor, as MTBE does, and sheen b) metal cations (Fe, Mn), c) other significant inorganics (especially sulfate), and d) biological parameters, such as heterotrophic plate count, iron-related bacteria (IRB) and sulfate-reducing bacteria (SRB). Fe and Mn can impart metallic tastes and some Fe oxihydroxides may produce sheen on the water surface, especially if associated with biofilm. Some of the listed inorganics may impart more of a soda or salty taste. Hydrogen sulfide (H_2S), which imparts a rotten egg odor, was detected in domestic well field measurements according to U.S. EPA investigation field notes from September and October 2010.

2. Producing zone water quality: One relevant water quality feature overlooked in Table A.2 (geochemical results) in the draft U.S. EPA report is the aquatic water quality in the hydrocarbon producing zone (Lysite Member of the Wind River Formation). If hydrocarbon-zone water is suspected to be affecting more shallow water wells, this information (and its geochemical analysis) should be indicative.

We were provided with water quality data from four production-zone (that is, deep oil/gas) wells: 22-12 (1997 sample), 31-10 (collected 8/14/2007), 44-03 (collected 8/13/2007), and well 41-10 (collected 8/14/2007). Specific conductance (conductivity) reported were 3,000 to 25,900 µS/cm. TDS reported ranged from 1,830 to 19,000 mg/L. Sulfate ranged from 5 to 4,320 mg/L. Excepting well 41-10 (SC 25,900 µS/cm , TDS 19,000 mg/L, sulfate 2,060 mg/L), the SC and TDS ranges are narrower. There is a large contrast in sulfate between wells 31-10 and 44-3 (6 and 5 mg/L) on the one hand and wells 22-12 and 41-10 (4,630 and 2,060 mg/L) on the other. Fe was rather high, ranging from 4.48 to 70.6 mg/L, probably influenced by the presence of organic compounds (reduction and mobilization of Fe^{2+}). Based on the available data, the ionic profile of the produced zone water is predominantly Na-Cl-HCO_3. A bicarbonate water indicates the likely presence of CO_2 (presumably due to methanotrophy), which may be affecting the carbonate system equilibrium. This is important because CO_2–enriched water enhances corrosion in many water systems, depending on the construction materials used.

Conductivity as low as 3,000 µS/cm (and associated TDS values) is very similar to (and better than some) shallow ground water. Thus, based on that information alone, there would seem to be significant fresh water recharge to the hydrocarbon-producing zone in some areas. This situation is different from many hydrocarbon-rich basins, such as in the Appalachian, where there are very distinct geochemical contrasts between the hydrocarbon-zone and overlying fresh ground water. Water quality testing doctrine in those basins is built around detecting signs of the "alien" produced water infiltrating fresh-water zones.

In contrast, for the situation in the Wind River basin, a review of water quality yields very poor water quality in quite shallow water wells. Well PGDW49 (unpermitted, no depth data recorded, but reportedly about 50 ft) has very high total Fe (11,400 µg/L 1/22/2010; 2,410 µg/L 4/20/2010), and an apparently significant population of IRB and SRB, in addition to extraordinarily high reported sulfate and chloride numbers (3,200,000 µg/L and 54,300 µg/L on 4/20/2010). If the well is indeed shallow, a surficial source for such water quality influence seems more likely. Here, the question arises: what activity on the properties themselves can produce poor water quality?

We also reviewed the report "Groundwater-Quality and Quality-Control Data for Two Monitoring Wells near Pavillion, Wyoming, April and May 2012," Data Series 718, U.S. Geological Survey (Wright et al., 2012). While this sampling and analysis effort occurred after the draft U.S. EPA report was made public, it should inform the final report. Several parameters identified by the USGS can contribute to water palatability issues. For example, extremely low oxidation-reduction (redox) potentials (-236 to -396 mV, much lower than the U.S. EPA-reported -108 mV (for MW02), draft report Figure 9), combined with high dissolved organic carbon (4-6 mg/L) can be the basis for much unpleasantness in ground water should such water be present in the zones tapped by domestic water wells.

3. Notes on methane in water information: The conclusions of the draft U.S. EPA report mention reported widespread occurrence of natural gas in domestic wells in the area (a common occurrence in ground water over gas-producing zones). Yet no follow up was conducted on this information ("An alternate explanation provided and considered by EPA is that other residents in the Pavillion area have always had gas in their wells. Unfortunately, no baseline data exists to verify past levels of gas flux to the surface.")

In contrast, a limited number of citizen's complaints about well water quality ([that] "often serve as the first indication of subsurface contamination and cannot be dismissed without further detailed evaluation, particularly in the absence of routine ground water monitoring prior to and during gas production") triggered a CERCLA investigation, rather than referral to the State of Wyoming. We suggest that if U.S. EPA were to plot these reported occurrences on maps or cross-sections of the structure, this plot may reveal relationships or small stratigraphic traps in the strata that account for some of the reported methane occurrences. The occurrence of petroleum phases throughout the stratigraphic column and methanogenesis are discussed below in the hydrogeologic setting discussion.

B. Domestic well construction issues

Several deficiencies in water well construction can result in a wide range of well water quality problems (cloudiness, silt, color, taste and odor), including breaches in casing or grout, or insufficient well development after drilling. Any of these can permit surface or other undesirable water to reach the intake zone. The symptoms in the above-mentioned case of well PGDW49 support the case that well location and/or construction could be an issue in its poor water quality.

Well construction standards serve to minimize potential deficiencies in construction. Evidence for effectiveness comes more from situations where well standards are weak, rather than where they are strongly applied. It is widely documented that unpermitted wells (or wells similarly not covered by regulatory enforcement) are associated with higher risk of poor water quality (e.g., from Pennsylvania, where there are no domestic well construction rules. The issue of the lack of rules and associated consequences are discussed in www.rural.palegislature.us/documents/reports/drinking_water_quality.pdf and www.rural.palegislature.us/documents/reports/Marcellus_and_drinking_water_2011_rev.pdf).

The Wyoming State Engineer's office provides well design requirements in their Regulations and Instructions, Part III, Water Well Minimum Construction Standards. However, in the State of Wyoming, it is the joint responsibility of the owner and the well driller to comply with the requirements presented in the Construction Standards, including obtaining a well permit and complying with its requirements. Using a list of wells and their characteristics provided for our review, we reviewed the status of water wells involved in the U.S. EPA investigation, and found that several of these wells appear to be either unpermitted, or drilled prior to well permits being required.

Because of the possibility that well construction deficiencies can account for some well water quality issues, the U.S. EPA should have started its investigation by establishing the nature of the complaints, investigating water quality, and evaluating well construction. In review of the draft U.S. EPA document, we do not find any mention of attempts to assess the condition of the water wells in question. Construction data on wells included in the inventory are confined to latitude-longitude and total depth, sometimes approximate. We understand that well construction and lithologic logs do not exist for these unpermitted wells (or if they do exist, U.S. EPA has not provided them); however, several reasonable methods are available to inspect and test the casing integrity of wells, even if construction documentation is unavailable. These inspection methods include dye testing (casing seal integrity), well video logging (internal evidence of casing problems, presumptive identification of biofouling, clogging and corrosion, gas seeps, fill-in and more) and some E-logging tools suitable for detecting casing seal problems.

If a breach in casing seal (grout) integrity is suspected, fluorescent dye can be applied in a trench dug around a well casing and flushed into the subsurface. If detected in pumped water, then an incomplete grout seal or other compromise of the well is to be expected. A protocol is provided in Ohio Department of Health (2000).

Downhole or borehole video inspection has also been available as an inspection method for decades. Borehole cameras for this purpose are widely available from ground water system service providers. Video inspection (usually color in recent years) is conducted to examine well casing, including joints and seals and the well or borehole in general. The camera is inserted into the well (sometimes after treatment to clarify water) and inspection conducted downward to total depth. Typically, both "down" and "side" views are employed to examine features of interest. A recording is made for future reference. Discussion of procedures is widespread in industry literature (e.g., Smith and Comeskey, 2009).

These methods are routinely used by state environmental health and mineral resource management agencies around the USA (some systematically in investigating water well complaints associated with resource development) and certainly available to the U.S. EPA.

C. Hydrogeologic environment influence on water quality

Having evaluated the water quality produced by the problem well, and its construction and physical condition, if no solution to the problem is evident, we move on to the hydrogeologic environment. The environment of the intake area of the well and surrounding ground-water source (immediate vicinity and regional scale) are the second place to look for sources of water quality degradation.

The R.J. Sterrett (2012) review of the U.S. EPA Draft Report provides the necessary geologic and hydrogeologic background to understand what conditions and processes are responsible for the quality of water produced by water wells in the Pavillion Field. Sterrett (2012) stands in stark contrast to the approach utilized by U.S. EPA. U.S. EPA referenced geologic reports of the area: Daddow (1996), Flores & Keighin (1993), Johnson & Keighin (1998), Keefer & Johnson (1993), Johnson et al (2007), Morris et al (1959), Plafcan et al (1995), Single (1969), etc. (references provided in the draft U.S. EPA report and not repeated here) but did not incorporate that information into a conceptual understanding of the basin. Sterrett utilized the available published work on the basin as well as well log data from the oil and gas wells in the field and presents a conceptual model that accounts for the variable water quality across domestic wells in Pavillion Field.

1. Lithology of the ground-water source or aquifer: The term "aquifer" as used in this report has a broad non-regulatory definition, referring to lithologic formation intervals that yield water to a well (essentially the hydrogeologic environment). Lithology is an important component of constituent presence in well water and associated water quality and palatability, as (prior to well development) ground water occurs in contact with formation materials over long time frames, and after development, water moves slowly through aquifer materials. A sulfur, sulfide, or "rotten egg" odor and sheen are common problems in water wells tapping strata with significant organic carbon content in the rock matrix (e.g., the Silurian carbonate aquifer stretching from Wisconsin to the Appalachian Basin, aquifers interbedded with coal sequences, or the shallow portions of the Mississippian Madison Group where it is an aquifer).

As Sterrett points out, the Wind River Basin is composed of interbedded sandstone, conglomerate, siltstone, and shale. Because of the fluvial depositional environment, none of the individual beds exhibit areal extent that can be correlated over any significant distance. Therefore, there are no laterally extensive sandstone units functioning as recognizable aquifer units, nor are there any continuous shale units that function as an extensive confining unit or barrier. As a result, water quality can vary significantly between individual sandstone units, each a result of its own unique environment. In this case of the Wind River basin, shale sequences are common in the shallower zone exploited by water wells. Shales (derived from erosion of surrounding terrestrial highlands with deposition in still waters) often have significant pyrite (Fe sulfide mineral) content in many geologic settings. We are familiar with the presence of both pyrite and evaporites, including the sulfate minerals selenite and gypsum, in stream-laid sandstone-shale sequences in western North Dakota that are equivalent in age and depositional environment to the Wind River and Ft. Union sequences. These can also produce moderately alkaline (higher pH) water, such as encountered in Pavillion Field domestic wells.

It is not unusual for more shallow wells to have worse water quality than deeper wells. This situation is often related to lithology. For example, one of us (Comeskey) notes that, in western North Dakota, water quality in the Fort Union Group. was appreciably less desirable than water quality in the Cretaceous Fox Hills units below. We have the same situation in the Great Lakes region in the Silurian carbonate aquifer, with more shallow formations having more pyrite, evaporites, and organic carbon in the matrix than deeper, lower Silurian units.

In reviewing the draft U.S. EPA report (a more in-depth hydrogeologic review is supplied in Sterrett, 2012), a significant omission that relates directly to diagnosing a water quality issue is the lack of lithologic and significant vertical-dimension information. The report references various regional geologic reports, yet the report contains only one low-quality cross-section illustration that does a poor job placing the wells illustrated in the context of geologic structure i.e., the dome that is the stratigraphic trap for the hydrocarbons.

Sterrett corrects this inexplicable deficiency (inexplicable because the information is readily available) by compiling his own cross-section through the basin (Figure RSJ10) (corresponding closely to the cross-section provided by U.S. EPA) utilizing additional oil well logs not used by U.S. EPA. The geologic structure of the area is presented in the section, as well as the geophysical and mud log gas curve for each hole. The mud log gas data reveals the ubiquitous and significant occurrence of gas in the lower third of the Lost Cabin Member. This natural occurrence of gas probably occurs throughout the Lost Cabin Member and is the simplest explanation for the occurrence of gas in domestic wells. This gas is likely an important carbon source for bio-mediated processes resulting in degraded water quality.

A review of the draft report does not reveal a detailed lithologic log for U.S. EPA monitoring wells MW01 or MW02 (see further discussion of these wells and their construction in Section IV following), which would inform the reader about the formation materials actually encountered and screened by these wells. Having been provided with the lithologic field logs of MW01 and MW02, we note the preponderance of gray and dark gray finely interbedded shale and sandstone. These indicate a low oxidation-reduction-potential (redox) environment, consistent with measurements made by the USGS in Phase 5 of the investigation, (in contrast to brown coloration, which may indicate oxidation) of the shallow zone (< 60 ft in MW02)). MW01 looks like a more complex situation, with mixed brown and gray-black zones (and the occasional green). We have the disadvantage of not having the drilling samples in our hands. However, one of us (Comeskey) logged borehole in the Fort Union Group in western North Dakota that contains significant lignite, which presents itself as a poorly structured, soft rock that could be logged as very loose brown shale or mudstone. An example in the Wind River drilling is at the 560-foot depth in the MW01 log. If not lignite per se, the unit described can be organic-rich mudstone originating as deposits in pools and stream margins. Water from wells with such deposits may have a hydrocarbon odor and sheen. In the same log, there is a gas kick at 950 ft upon encountering a sandstone below a thick gray shale zone and above 25 ft of soft brown-gray "shale". That would be consistent with an organic-rich lignitic source rock and shale stratigraphic trap.

As we also do not have water well construction logs for the water wells in question, we do not really know what lithologic zones they contact (total depth values, where available, are *not* sufficient well construction information). However, given the depths of some reported wells of interest (PGDW05, 20, 21, and 30), they are very likely exposed to these low-redox and potentially carbon-rich zones (the MW01 log describes organic content in shale zones). PGDW05 (see Section D) is described in documentation supplied to us as having a diesel-type odor but analyses were inconclusive.

2. Hydrologic and lithologic environment influences on water quality: A related topic is the ground-water environment, which is related to lithology but has additional influences, including hydrology and biogeochemical factors. The dominant factor in the environment is hydrologic relationships. Any consideration of water quality influences resulting from a zone distant from a water well (such as an oil and gasbearing layer) depends on head relationships. *If neither long-term nor intense transient head gradients can be shown to move water having undesirable water quality toward a given sampled well, then water quality in the distant zone is irrelevant.*

Tables of well data in the draft U.S. EPA 2011 report lack static water levels, land surface elevation, and well construction data. These omissions make it difficult to put data in a hydrologic framework. The report lacks any potentiometric surface map or illustration of head relationships. Water levels and head relations are absent, so consideration of any indications of the gradients and flow system appear to be avoided. Water quality data are diminished in usefulness without reference to vertical and horizontal flow systems. Wells and their features such as static water levels and producing intervals should be plotted on topographic maps so elevation relationships would be evident.

Correcting these omissions, Sterrett (2012) demonstrates that the ground water flow relationships revealed by head data precludes contamination from below. Vertical heads are such that flow is from the surface downward. Thus influences from hydraulic fracturing or the deep hydrocarbon-producing zone are unlikely. Surface causes can be involved in degraded water quality.

3. Sulfur-cycle and other biogeochemistry contributions to palatability issues: A significant relationship between water quality encountered in wells and environment is found in biogeochemical transformations common in the subsurface. Beyond a few months after well development, the influences of these transformations often overwhelm direct lithology influences and alter ground-water quality.

Most significant, related to a sulfur odor are Fe and sulfate. With the presence of abundant sulfate in the presence of labile organic carbon (e.g., methane and short-chain hydrocarbons), microbial sulfate reduction can be expected under the right oxidation-reduction (redox) conditions, which appear to exist, based on the 2012 USGS water quality data from MW01 mentioned previously (redox potential less than – 200 mV at moderate pH). Given the depths of the wells, sulfate-reducing redox conditions can be expected. Indeed, sulfate-reducing bacteria (SRB) are listed on the worksheet supplied as present in a number of samples and these are confirmed in data reported in 2010 Microbial Insights CENSUS (biochemical) analyses (see notes in Section IV following for explanation) documented in CENSUS-038HA_36989673.pdf and CENSUS-038HA_59451752.pdf provided to us (Attachments SC-2 and SC-3).

Sulfate is indeed quite high (251-1,370 mg/L) in the shallow aquifer zones. If a small fraction of that sulfate is reduced to sulfide, so that sulfide is present in the fractional-mg/L (100-µg/L) range, then a sulfide odor and corrosion are to be expected. Iron levels reported in most (not all) shallow water samples are quite low, suggesting that Fe may be removed in the water column (combined with sulfide to form FeS_x minerals), or if Fe is naturally low, sulfide odor formation would be unimpeded. The presence of black "specks" in shales and organic inclusions (e.g., as described in the lithologic log of MW01) would suggest iron removal in the water column. Where microbial transformation of iron occurs (as is expected from confirmation of IRB in the above-referenced CENSUS results), it is common for oily sheens to appear on well water and sample surfaces due to polymers in the biofilms. When microbial sulfide oxidation occurs in the water well column (not unusual in pumped wells with sulfide in well water), the associated polymer-rich biofilms produce unpleasant appearance and coatings.

As carbon dioxide and methane are also detected in some water samples, other redox transformations are occurring in addition to sulfate reduction. Methanogenesis (formation of methane) is to be expected. Methanogens, microorganisms that generate methane, are obligate anaerobes requiring a redox potential of less than -300 mV to be active. Indeed, USGS (2012 data report) reports redox potentials less than -300 mV in well MW01.

Presumably CO_2 is present due to methanotrophy (oxidation of methane at higher redox potentials). According to the U.S. EPA draft report, thermogenic methane is present, so across the shallow (aquifer) sequence, there are likely to be complex exchanges of electrons and biological communities; at least methanotrophy and sulfate-reduction. In fact, the above-referenced CENSUS data confirm methanogens throughout a range of water well samples, as expected. So, it should be expected that microbial methane generation is also likely to be part of the mix. High total Fe levels in deep ground water, mentioned above, may indicate iron reduction (another respiration pathway) in the deep zone. Ehrlich and Newman (2009) provide an authoritative description of geomicrobiological transformations and cycles in the environment. Some of these transformations can affect water palatability and appearance.

D. Possible on-site influences on well water quality

As has long been known in environmental health management of domestic water supplies, on-site activities can contribute to problems with domestic well water quality. These are exacerbated by well construction deficiencies as discussed previously in Section IV.B., but can also affect properly constructed wells under the right circumstances. We have no information on on-site wastewater systems or other on-site risks. However, a set of information is available that can shed insight and suggest that on-site influences may play a role in degraded well water quality: a series of chemical analytical instrument peaks labeled "ChromaLynx XS Component Report, supplied to us as Attachment RJV-14 to the Affidavit of Rock J. Vitale, CEAC. We do not interpret these results, but note the interpretations, attributed to U.S. EPA Region 8 chemists, based on consulting the National Institute of Science and Technology (NIST) mass spectral library.

As noted by Mr. Vitale (his affidavit, paragraph RJV-15, "The US EPA Region 8 review yielded a variety of compounds representing fragrance-related compounds, herbicides, surfactants, pesticides, fungicides, antipsychotic pharmaceuticals, antihypertension pharmaceuticals, vitamin agents, disinfectants, paint products, and a variety of fatty acids (Attachment RJV-14)). The presence of these types of compounds in the groundwater, as interpreted by US EPA Region 8 chemists, suggests alternate pollutant sources, including but not limited to, agricultural runoff/infiltration and septic infiltration."

While not interpreting results of mass spectrographic and other analytical output, we did conduct an inspection of raw information provided (see Attachment SC-2) to confirm that these results and hand-written interpretations exist, and to satisfy ourselves that results can be from domestic household and agricultural products. If these compounds are present in measurable quantity in ground water samples, then domestic sources on the properties of interest should be considered in evaluating causes of water quality problems in domestic water wells.

A review of the draft U.S. EPA report did not show an effort to identify on-site sources for these compounds that can be found in the home and farm inventory. Given that the analyses do exist, and were analyzed by Region 8 chemists, there must have been a decision within U.S. EPA not to pursue that reasonable line of inquiry.

E. The role of well aging and maintenance

It is widely documented (e.g., Borch et al., 1993; Cullimore, 2008; Roscoe Moss Co., 1990; Smith and Comeskey, 2009, among many others – numerous references in the latter book) that wells age, developing accumulations of biological and chemical (and mixed) deposits and corrosion of metal components. These are worldwide problems (e.g., Gariboglio and Smith, 1993; MacLaughlan, 1996, among many others). One common manifestation of well aging is accumulation of low-redox biochemical deposits that readily impart unpleasant taste. In the described water quality situation (favoring growth of SRB and sulfate reduction), it is a common occurrence that sulfide deposits accumulate on pumps and in pipes from the pumps and into structures. SRB accumulate preferentially in water heaters, especially where anode rods are installed and at bi-metallic junctions (such as galvanized-to-brass). We understand that the water wells in question are at least several years old and one is more than 30 years old (PGDW05). We do not have documentation on the ages of other unpermitted wells. Several years of operation (and especially 30+ years) in the above-described well environment is time for appearance, taste, and odor issues to begin to make themselves evident.

1. Available history of well PGDW05 related to palatability issues: A description of analyses and sampling events for well PGDW05 provides indication that this well has experienced deterioration. According to an "e-permit" on file, construction may have occurred in the 1973-1976 period. The total depth was 210 ft and a static water level of 190 ft was recorded. Its reported appropriation amount was 10 gpm, but no pumping test results are available for an actual yield value. Total coliform bacteria (TC) analyses (an indication of water well hygiene) were negative in 2004 and 2005, but values for IRB and HPC (note disclaimers about such values in the previous discussion) are significant but irregular in 2005 laboratory results. Previously unreported, SRB are significant by July 2006, when 1.3 mg/L total sulfide was also reported. With limited results like this, it is impossible to establish a trend for bacterial accumulation. A letter report from Cordilleran Compliance Services Inc. (letter 7/15/2005) describes a low-production well (pumping off in 14 min. at 5.7 gal/min) with an apparent change in depth from that recorded in the "e-permit." The depth was reportedly 198 ft, at the start of this test instead of 210 ft as reported on the e-permit. The static water level at the time of the 2005 test was estimated by the inspectors as being 131 ft (not directly measured for some reason). When the pump was removed and bailer inserted for sampling, the SWL was about 143 ft and total depth 187 ft (11 ft less than the 198 ft previously reported). There was a hydrocarbon odor described as "lube oil" but other water quality did not indicate biofouling issues. If organic-rich deposits were present in the well (see Section C.1 above), then the hydrocarbon odor (and probably a sulfide odor, although not mentioned) could be associated with that. The circumstances of the depth change should have been investigated, as 12 to 23 ft of in-fill can have significant influence on water quality. With various laboratories, samplers, and analysis methods involved, and so few microbiological results, an analysis of deterioration over time is difficult to make, but the conditions are present to cause taste and odor issues.

2. Well maintenance: Wells are structures with large surface areas constructed in uncontrolled, diverse, wet environments, equipped with electro-mechanical and fluid-handling equipment, and then typically expected to operate without attention indefinitely. However, as discussed in this report and exhaustively elsewhere, wells are subject to conditions that degrade water quality and performance. Other systems (e.g., vehicles and teeth) operating under similar circumstances are widely understood to benefit from routine maintenance to delay or prevent degradation.

In the case of wells, rehabilitation and maintenance practices (including methods for detecting degradation and cleaning) have been available for decades (and centuries if one considers dug wells) and in routine practice (e.g., Smith and Comeskey, 2009). Interest in these methods has increased in recent decades and they are commonly used in municipal and other high-value wells.

The practice of well maintenance is still rare for domestic wells (cost and the fragile nature of many domestic wells are issues), but cleaning such wells and removing accumulated deposits reduces or eliminates the occurrence of bacterial accumulations, and poor palatability and appearance issues, reduces pressure on water treatment, and can extend well life. For wells completed in these kinds of ground-water conditions (sulfate reduction and hydrocarbons in the water column), well maintenance may need to begin within a few years of new construction and be conducted every few years.

F. Summarizing an approach to a taste-and-odor investigation

First, we focus on the wells themselves, starting with both physical-chemical and biological water quality analyses and focusing on the well and adjacent environment and most-likely proximal causes. Second, we focus on proximal lithologic/aquifer environment causes (including those on site on the property, such as domestic wastewater infiltration). Third, we consider hydrologic head relationships, ruling out second-order (i.e., more distant) influence possibilities if head relationships make their influence unlikely. Then, if these options are exhausted, we proceed further afield, looking for example for an organic contaminant plume. Again, hydrologic relationships are most important; a hydrologic relationship has to be established between a potential external cause and problems in the wells of interest.

The study described in the draft U.S. EPA report violates the principle of starting with proximal causes. It overlooks local, proximal causes that can explain taste and odor problems (*which are not described*). Probable causes of a sulfide issue (including SRB) and potential sources of other unpleasant tastes and odors are found in the wells and ground water tapped by the drinking water wells. The U.S. EPA study made an attempt to employ environmental microbiology methods, but how they were used is not apparent, and the usage appears to be unsystematic and not in line with the recommendations of experienced practitioners (e.g., Smith, 1992; Cullimore, 2008; *Standard Methods* Section 9240). For further discussion on how methods were used, see following section V.B. Some physical-chemical parameters associated with potential palatability issues *must* be analyzed in the field, at the water source, and not at the laboratory. Among these are hydrogen sulfide, redox potential, dissolved oxygen, and pH. Sulfide, redox potential and DO (all relevant to a sulfide complaint) are not reported for the public in the draft U.S. EPA report, although they were analyzed at times in test results we examined.

So, summarizing, how would we improve on the investigative methodology behind the draft U.S. EPA report that we criticize? To begin, we have to construct a working hypothesis. In this case, using the information available, develop a working hypothesis that is plausible, and does not by necessity presume hydraulic fracturing is the cause.

- First, there is a ground water system that (without human intervention) can provide water that has unpleasant taste, odor, and color, and that is also corrosive to metal components in wells.

- Second, due to the hydrogeology (low hydraulic conductivity, and limited capture zones), deep pumping water levels (PWL) are common. This is relevant to water quality, as deep PWL expose rock surfaces to dewatering and development of biofouling, and reduces hydrostatic pressure so that naturally present dissolved gases (methane, carbon dioxide or sulfide) can enter water wells and affect well water quality.

- Third, we may have wells of uncertain original construction quality, possibly with incomplete grout and therefore pathways along the outside of the casing. If that is the case, corrosion along the length of the casing is possible, especially where a steel casing is anodic in relation to adjacent formations or biofilms on the surface of the casing.

- Fourth, due to the age of some of the wells, there is time for corroding and other deteriorating mechanisms to act, and also for debris to collect in the bottom of a well, affecting water collected by the well pump (see description of well PGDW05 inspection above).

- Fifth, well owners (typical of domestic well owners anywhere in the USA) have performed limited, if any, preventative or restorative maintenance on their wells.

- Six, if on-site wastewater collection and treatment systems are malfunctioning, and wastewater effluent can reach the well and enter the well annulus, this effluent can both aggravate corrosion and enter shallow corrosion windows into the casing, and contribute to poor well water quality.

Given this hypothetical scenario, we would suspect a corroded casing that may be leaking, with a well that may have in-filling of debris and reaction products that would contribute to poor water quality. With that hypothesis, if we were asked to investigate a well water quality complaint, rather than drilling deep monitoring wells and starting a CERCLA investigation, we would go straight to a downhole video survey, consistent with the four-step process, to inspect the well for problems and conduct dye testing of the wastewater system and casing annulus. Based on the information collected in this process, we would recommend corrective action.

V. Other Issues with the Investigation Methodology

A. Note on monitoring well construction

The monitoring well construction diagrams in the draft U.S. EPA report are somewhat ambiguous. A crucial point is whether there are bentonite pellets installed above the screen before grouting the casing, otherwise there may be infiltration of grout into the filter pack around the screen, even if it is pre-packed. *And there is no lithologic log from the drilling included with the report.* We were subsequently provided the useful lithologic field logs from the drilling program for our review. We are also curious about the cementing back of the bottom of the borehole and the practice of leaving cuttings in place (Sterrett, 2012). We cannot ascertain whether or not the screen is isolated from the cement grout by bentonite pellets, or just resting on or in it. Despite U.S. EPA disclaimers to the contrary, all this cementing around a pre-packed screen in a narrow annulus presents a high likelihood of influencing pH and water quality in samples. Finally, development of a 230- to 300-m 4-inch-diameter well has a high probability of being incomplete. Using the single-pipe airlift methods (as illustrated in draft U.S. EPA report Figure C23), it is difficult to project development force that is sufficient to remove drilling damage at these depths and through a 0.020-inch-slot pre-packed screen, even when using the described mud dispersant. Difficulties with redeveloping MW02, prior to unsuccessful attempts to resample this well in 2012, described in the USGS Open File Report 2012–1197, "Sampling and Analysis Plan for the Characterization of Groundwater Quality in Two Monitoring Wells near Pavillion, Wyoming" (Wright and McMahon, 2012), reinforce this point about development difficulty.

Further criticism of monitoring well construction and development is provided by Sterrett (2012), who is editor of *Groundwater and Wells*, Third Edition. Sterrett explores inconsistencies in the well logs further and comes to the same conclusions as we do linking high alkalinity with construction procedures. Very high pH persists in well MW01, according to the 2012 USGS data. Figure RJS11 in Sterrett (2012) presents the relationship of the monitoring wells screen intervals to the occurrence of gas in the stratigraphy. As Sterrett points out, the wells are screened in gas producing intervals, which accounts for the occurrence of gas in the wells and other water quality issues.

B. A note on the biological tests

Based on terminology used in reporting water quality results in the worksheet data supplied to us, SRB and iron-related bacteria (IRB) were analyzed for using the BART Method (Droycon Bioconcepts, Regina, SK, Canada). Cullimore (2008) described methodology for these tests. We address use of the BART test and complementary methods in Smith (1992) and Smith and Comeskey (2009).

1. Application of BART culturing: The BART (Biological Activity Reaction Test) method is now newly a part of Section 9240, Iron and Sulfur Bacteria, *Standard Methods for the Examination of Water and Wastewater* (22nd edition) (APHA, AWWA, WEF, 2012). However, actual use and methodology in practice is decidedly nonstandard in our experience. One of us (Smith) is chair of Section 9240's Joint Technical Group, and one of the early adopters and documenters of the BART method (e.g., Smith, 1992). A significant feature of this type of test is that it is qualitative to semi-quantitative in nature. Analysis is typically subject to the interpretation of the reaction by an observer. Interpretation is based on 1) time until reaction and 2) appearance. The SRB-BART– essentially the Postgate Test (see Section 9240) – is rather straightforward (turns black when SRB develop in the medium). The IRB-BART (a modification of Winogradsky's medium (see Section 9240) is not straightforward. Most IRB-BART reactions are actually a non-iron-oxidizing heterotrophic reaction, variously anaerobic or aerobic. A "present" reaction may be heterotrophic only, and anaerobic heterotrophic reactions (dark in color) can easily be mistaken for actual IRB (presence of heterotrophic, neutralphilic iron-precipitating bacteria). The positive SRB reaction and an anaerobic heterotrophic IRB-BART reaction are typical in a well environment dominated by SRB. Where these microflora flourish, there is certainly a source of undesirable palatability in well water.

We have employed both these methods in investigations since they were developed (sometimes in association with laboratory collaborators), often supplementing BART results with microscopy and other Section 9240 culturing. The SRB-BART is in our opinion highly useful, and the preferred method to detect viable SRB in a qualitative way for most operational applications. Where feasible, we supplement IRB-BART testing with the DN-BART to make a case for Fe oxidation by nitrate reduction, other culturing methods from Section 9240, and microscopy. Some indicative iron-related biofilm development is difficult to test by culturing and is often best analyzed simply by observation. Unfortunately a BART specific for sulfide-oxidizing bacteria (SOB) is not available. Culturing and microscopy methods for SOB analysis are described in Section 9240.

Unfortunately, the BART methods appear to have been applied in an unsystematic manner by U.S. EPA investigators. Certain wells were tested, and for some wells, BART testing was conducted for some samples and not others. Other wells were not sampled for BART analysis. Consequently, we do not have a complete picture of SRB and IRB occurrence among basin water wells of interest. Also, there are simply not enough replicates. Our experience (Smith, 1992 and forward) is that BART are best interpreted if used multiple times on the same sample point to avoid putting too much weight on a single, semi-qualitative test.

In a situation where the problems are unknown or incompletely known, a reasonable protocol is to sample and culture in the available suite of BART types, which can be thought of as spanning a portion of the redox range of active aquatic microflora (SRB-BART, DN-BART, IRB-BART, and HAB-BART). DN-BART and HAB-BART are not considered in *Standard Methods* (APHA, AWWA, WEF, 2012) but are useful in filling out the ecological range of viable microflora in aqueous samples. In addition to providing the range of culturing, culturing in duplicate reduces the reliance on single, complex culturing methods. In our practice, single samples are collected in sterile bottles and split among culture bottles that take 15 ml of fluid each. These are then cultured according to the developer's recommendations, including temperatures close to the temperature of the source water. Instructions and recommendations for BART use are found in the above-cited references, on the Droycon Bioconcepts web site, and in readily available publications (e.g., Smith-Comeskey Ground Water Science, 2012).

2. Sampling for BART analysis. Another unknown is sampling. We do not know how samples were collected. All such SRB and IRB occur predominantly in biofilms, yet the sample is typically collected by pumping (along with other water samples) to collect detached viable bacteria. With multiple tests, the intensity of microbial activity can be better understood. Cullimore (2008) describes a time-series sampling method (widely adopted by others, including in our practice) that is intended to overcome the problems of sampling biofilm bacteria detached in water, but we do not see any evidence that this approach was attempted.

Given the widespread experience with BART culturing, their demonstrated value in diagnosing well water odor complaints, and their relatively low expense, a more systematic application would have been illustrative. However, as 1) SRB and IRB that may be in grab samples collected for analysis are detached from biofilms and 2) energy generated by domestic water well pump suction is only sufficient to detach biofilm bacteria from a small radius, the SRB, IRB, or other cultured microflora detected by BART culturing most likely originate in the water well sampled.

3. Comment on heterotrophic plate count results: Also notable were low number results for heterotrophic plate count in most of the water wells. Some HPC methods are poorly suited for testing ground water, which would explain the dissonance between rather high BART activity levels and the low HPC results. The HAB-BART mentioned previously (essentially the methylene blue test) provides a way to calibrate between HPC methods used and other BART.

4. Biochemical methods for comparing and confirming cultural analytical methods for microflora: How could the environmental microbiological components of the study be significantly improved? As described, BART testing could have been conducted more systematically, using methods well-demonstrated in well water investigations. Also, as discussed here and in the cited literature (especially Smith, 1992; Smith and Comeskey, 2009; and Smith-Comeskey Ground Water Science, 2012), BART results are also best interpreted when comparative analytical methods are used. We have mentioned simple light microscopy and alternative culturing methods (summarized for application in this type of investigation in Smith and Comeskey, 2009 and also described in *Standard Methods* Section 9240).

A variety of biochemical methods are available for assessing subsurface microbial communities, including those involved in the transformation of methane, CO_2, iron and sulfur species. In our practice, we have employed phospholipid fatty acid (PLFA) analysis in assessing microbial community composition of both grout and aquifer materials (services provided by Microbial Insights Inc., Rockford, TN), and found that this method detects the presence of SRB and metal (including Fe) oxidizing and reducing bacteria.

PLFA and another Microbial Insights method (CENSUS) are employed in microbially induced corrosion assessment, which includes SRB determination. Given the resources in this investigation devoted to organic chemistry and isotope analysis, microbial biochemical analysis would not be out of proportion to the body of work.

As described in Section IV.C.3 and subsequently above, during the U.S. EPA investigation described in the draft U.S. EPA report, CENSUS testing was conducted by Encana on samples dated February 2010 for a variety of wells and related samples (including surface water, field blanks, and duplicates). These are reported in documents CENSUS-038HA_36989673.pdf and CENSUS-038HA_59451752.pdf, provided attached to this report (Attachments SC-3 and SC-4). These results provide 1) numerical results that can be compared over time and 2) provide contrast between surface and ground water samples. Consistently in the results supplied, well water samples are positive for 1) IRB/SRB (probably pH-neutralphilic iron-precipitating bacteria and sulfate-reducing bacteria) and 2) methanogens, and 3) surface water samples and field blanks are negative for these. CENSUS and associated biochemical methods (described in Microbial Insights Inc. in the references) are not yet part of Section 9240 of *Standard Methods* but should be the wave of the future.

5. Summary: In short, we would have very little confidence in the environmental microbiological results provided as part of the U.S. EPA investigation. As it is, these results were not reported to the public in the draft U.S. EPA report. From that, we infer that U.S. EPA also was unsatisfied with the microbiological methodology or uncertain results. However unsatisfactory the method application, SRB positives are consistent with a sulfide complaint, other likely microbial transformations and biofouling can explain other unpleasant sheens, odors, taste and appearance. *The most likely location of these microbial transformations is in the well water columns themselves.*

VI. Conclusions and Recommendations

We conclude that the elaborate U.S. EPA investigation was poorly suited to answering the original question "What causes the reported taste and odor problems?" Causes for appearance, taste and odor complaints can easily be found in the Lost Cabin member tapped by water wells without invoking a less-likely cause originating in the hydrocarbon-producing zone.

Our analysis is that the U.S. EPA bypassed a large body of hydrogeologic and geochemical information on the Wind River Basin and ignored obvious lithologic and other hydrogeologic environment causes for water quality problems. They spent resources on poorly executed monitoring wells that could have been spent on systematically conducting biogeochemical testing and well inspections such as those that are routinely conducted by states in response to domestic well water complaints linked to resource development. Such investigations were conducted by others in part as follow up investigations in response to the draft US EPA reports, using methods that the U.S. EPA could have used in the first place. We do not see any purpose in establishing, or ever considering additional deep monitoring wells, at least until after the four-step approach to investigating domestic well water complaints is implemented and the resulting information has been rigorously evaluated.

We would recommend that a systematic investigation along the lines described above be conducted to address the likely proximal causes of taste and odor problems, before and after an attempt at cleaning wells that may have problems due to accumulations of biofouling and associated deposits. Then have the US EPA focus on aiding the State of Wyoming (if that help is requested) in addressing proximal surficial causes of water quality problems.

Respectfully submitted,

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Attachments:

SC-1A. Resume, Stuart A. Smith

SC-1B. Resume, Allen E. Comeskey

SC-2. Documents Reviewed in Preparation of Report

SC-3. Document CENSUS-038HA_36989673.pdf

SC-4. Document CENSUS-038HA_59451752.pdf