Examination of Groundwater Resources in Areas of Wyoming Proposed for the June 2022 BLM Lease Sale

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About PSE Healthy Energy

PSE Healthy Energy is a multidisciplinary, nonprofit research institute dedicated to supplying evidence-based scientific and technical information on the public health, environmental, and climate dimensions of energy production and use.

About the Authors

Dr. DiGiulio is a senior research scientist at Physicians, Scientists, and Engineers (PSE) for Healthy Energy and an affiliate at the Department of Civil, Environmental, and Architectural Engineering at the University of Colorado. Dr. DiGiulio completed a B.S. in environmental engineering at Temple University, a M.S. in environmental science at Drexel University, and a Ph.D. in soil, water, and environmental science at the University of Arizona. During his 31 years with the U.S. Environmental Protection Agency (EPA), he conducted research on gas flow-based subsurface remediation (soil vacuum extraction, bioventing), groundwater sampling methodology, soil-gas sampling methodology, gas permeability testing, intrusion of subsurface vapors into indoor air (vapor intrusion), subsurface methane and carbon dioxide migration (stray gas), and solute transport of contaminants in soil and groundwater including that associated with hydraulic fracturing and pits used to dispose oil and gas waste. He assisted in development of EPA's original guidance on vapor intrusion and the EPA's Class VI Rule on geologic sequestration of carbon dioxide. While with the EPA, he routinely provided technical assistance to EPA regional offices and assisted in numerous enforcement actions. The focus of his current work is on understanding environmental impact from oil and gas development in the United States and abroad, especially in regard to surface and groundwater resources. He served as an expert witness in litigation relevant to oil and gas development, testified before State oil and gas commissions on proposed regulation, and testified before Congress on the impact of oil and gas development on water resources.

Dr. Tisherman completed a B.A. in Environmental Studies from Connecticut College in 2013 and received Ph.D. in Geology and Environmental Science at the University of Pittsburgh in January 2022. Her dissertation focused on the transport and fate of trace metal-contaminated sediments. Specifically, her research focused on the mobilization of contaminated sediments from mining, oil and gas production, and agriculture in the US and in China. Through her research, Dr. Tisherman has worked to create a chemical framework that differentiates between various sources of oil and gas water contamination. Prior to graduate school, Dr. Tisherman researched the impacts of unconventional drilling on surface water in Chengdu, China as a U.S. Fulbright Scholar. Her current work is on the water impacts from oil and gas activities.

Dr. Rossi completed a B.S. in Civil and Environmental Engineering from Penn State in 2009 and received his Ph.D. in Geology and Environmental Science at the University of Pittsburgh in 2016. His dissertation research focused on soil biogeochemistry and how land use and human activities affect hydrologic regimes, and by extension, major and trace metal dynamics. Following the completion of his dissertation, Dr. Rossi was a visiting scholar at the University of Pittsburgh and devised a project to reconstruct the environmental legacy of industrial activities and coal-fired electricity generation in Pittsburgh. Dr. Rossi held his first postdoctoral appointment in 2017 at Temple University, where he examined the impact of land use and green infrastructure on hydrology within the Philadelphia Metropolitan Area. In 2017 Dr. Rossi was awarded a NatureNet Science Fellowship with the Nature Conservancy and conducted postdoctoral research on oxygen dynamics in agricultural soils at Stanford University. Dr. Rossi's current work is on the impact of produced water from oil and gas activities on groundwater systems.

Background

The Bureau of Land Management (BLM) Office is proposing to offer 129 parcels covering approximately 132,771 acres for oil and gas leasing in Wyoming (U.S. Bureau of Land Management, 2022a). The BLM is planning on starting bidding for the parcels on June 21, 2022 and has already started a 30-day public protest period on April 18, 2022. The proposed parcels are located in Big Horn, Campbell, Carbon, Converse, Crook, Fremont, Hot Springs, Johnson, Laramie, Natrona, Niobrara, Park, Sheridan, Sublette, Sweetwater, Uinta, and Washakie counties (Table 1, Figure 1) (U.S. Bureau of Land Management, 2022b). The sale of these parcels for further oil and gas development could impact groundwater resources in Wyoming. The BLM Onshore Oil and Gas Order No. 2 states, "The proposed casing and cementing programs shall be conducted as approved to protect and/or isolate all usable water zones…Determination of casing setting depth shall be based on all relevant factors, including: presence/absence of hydrocarbons; fracture gradients; usable water zones…All indications of usable water shall be reported" (U.S. Bureau of Land Management, 1988). Usable water, according to the BLM Onshore Order No. 2 is "generally those waters containing up to 10,000 ppm (mg/L) of total dissolved solids (TDS)." It is assumed then that for wells constructed on these proposed parcels: 1) the depth of usable water needs to be known and 2) the constructed wells need to have cemented casing at all depths of usable water.

Overall, the Environmental Assessment (EA) for the June 2022 Competitive Lease Sale is contradictory and nebulous in statements regarding protections of usable water, in particular, with depths of cementing and casing. Specifically, section 3.4 of the EA states that "BLM would deny any APD where proposed drilling and/or completion process was deemed to not be protective of usable water zones as required by 43 CFR 3162.5-2(d)," and goes on to require multiple protective barriers: "(1) setting surface casing below all known aquifers and cementing the casing to the surface, and (2) extending the casing from the surface to the production or injection interval and cementing the interval." Contradictorily, the BLM also states in the same section, that "impacts to the quality of groundwater, should they occur, would likely be limited to a near wellbore location due to inferred groundwater flow conditions in the area" In short, the EA says that the BLM would deny proposed drilling if the process was not protecting usable water, but then downplays the potential impacts to usable water. The EA does not state the depths of potential usable water aquifers in proposed parcel areas, nor does it instill confidence that cementing requirements will be enforced to protect these aquifers.

This study aims to identify potential pathways for groundwater impacts based on regional hydrogeology, schematic data of existing federal wells, and identifying aquifers with usable water near proposed parcels.

Table 1 - Proposed oil and gas parcels for competitive lease sale in June 2022 with the BLM field office, the number of parcels per field office, and the acreage of the parcels per field office. Note that the available data from the BLM website used in this analysis has 130 parcels and a total of 136,132 acres in proposed parcels.

Field Office	Number of Parcels	Acres
Buffalo	45	40,257
Casper	16	10,837
Cody	5	4,296 (including 3 parcels/2,869 acres shared with the Worland field office)

Lander	17	15,890
Newcastle	3	681
Pinedale	16	21,095 (including 2 parcels/4,160 acres shared with the Rock Springs field office)
Rawlins	4	2,616
Rock Springs	17	31,850
Worland	7	8,506

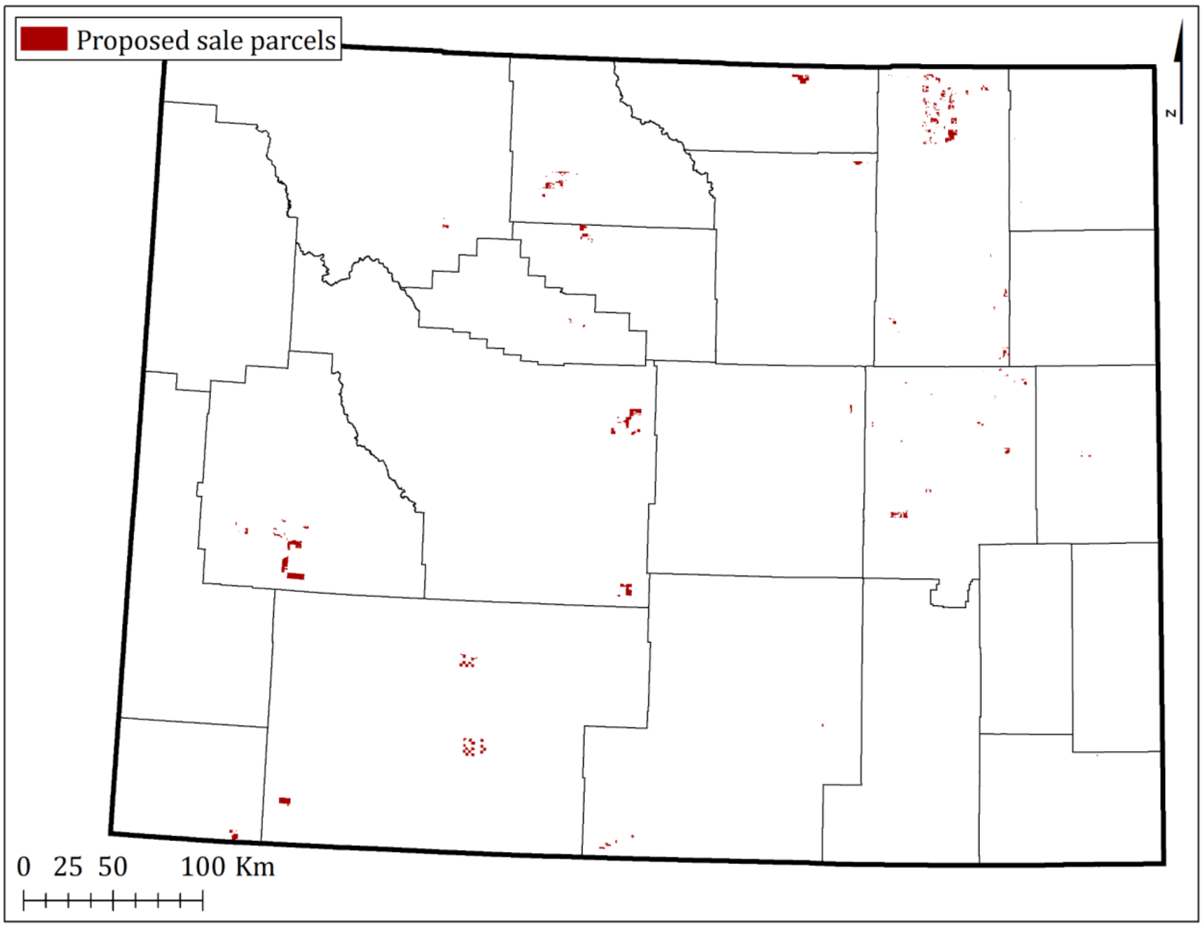

Figure 1 - Proposed oil and gas parcels for competitive lease sale in June 2022.

Methods

The goal of this analysis is to: 1) identify zones of usable water (TDS < 10,000 mg/L) around the proposed parcels and 2) determine if current federal wells are actively protecting usable water in the same areas. To accomplish our first goal, we reviewed peer-reviewed literature and government reports (primarily U.S Geological Survey) to find depths of potential usable water aquifers in the sedimentary basins underneath the proposed parcels. Then, we identified principal aquifers in Wyoming within 3,000 feet below the land surface using the U.S. Geological Survey (USGS) Brackish Water Database (Stanton et al., 2017). The combination of the basin aquifer and principal aquifer analysis will result in a total stratigraphic view of potential usable water aquifers.

After the potential usable water aquifers were identified, data on existing federal oil and gas wells near the proposed parcels was used to find gaps in surface casing and top of cement. These gaps are potential pathways for contamination of usable water in existing wells. Due to time constraints, the well analysis was conducted only for the Powder River basin, which contains the largest number of proposed parcels. First, we reviewed the U.S. Environmental Protection Agency's (EPA) aquifer exemption database to distinguish areas where proposed parcels and aquifer exemptions overlap (U.S Environmental Protection Agency, 2017). An aquifer exemption is necessary for injection of waste fluids in formations with water having TDS concentrations <10,000 mg/L. The lease parcels in aquifer exemption zones were removed from this analysis as those aquifers do not have the same protections as non-exempt aquifers. Next, we found the public land surface system (PLSS) township and range for each proposed parcel in ArcGIS 10.8.1 (Wyoming Geospatial Hub, 2017). Using the PLSS township and range, we identified all federal wells with a proposed parcel on the Wyoming Oil and Gas Conservation Commission (WOGCC) website that was completed after January 1, 2000, and active in the last 5 years (i.e., since January 1, 2017) (WOGCC, 2022). For each well, the bottom of the surface casing and top of cement was extracted from the well completion report, and the uncemented interval was calculated by taking the difference of these two depths.

Hydrogeologic Setting

The proposed oil and gas parcels are in the Bighorn, Powder River, Wind River, Green River, Hanna, and Denver-Cheyenne Basins (Figure 2). The depths of aquifers within these basins are important to consider because the BLM Onshore Oil and Gas Order No. 2 requires proposed casing and cementing programs to protect and/or isolate all usable water zones (U.S. Bureau of Land Management, 1988). This section includes a description of the hydrogeology of the primary basins with proposed parcels.

Powder River Basin

Multiple aquifer systems are present throughout the Powder River Basin, with the two uppermost principal aquifers (in order of depth) being the lower Tertiary and Upper Cretaceous aquifers (Long et al., 2014). These systems contain all groundwater resources in the Powder River Basin (Thamke et al., 2014). With the exception of the basin margins, these are primarily confined units. However, shallow aquifers within the lower Tertiary geologic units are characterized by local flow systems (Whitehead, 1996). Recharge occurs primarily via precipitation falling on outcropping portions of geologic units, or from stream leakage (Whitehead, 1996). Regional groundwater flow is south to north into the adjacent Williston structural basin (Thamke et al., 2014). The depth to water in the unconfined portions of the Lower Tertiary and Upper Cretaceous aquifer systems ranges from 0–2,497 ft (mean depth =228 ft), and is shallow near streams and deeper in upland areas (Long et al., 2014).

The lower Tertiary aquifer system may be as thick as 7,180 feet in the Powder River Basin, and the hydrogeologic units comprising this system (in order of depth) include the Upper Fort Union aquifer (comprised of the Eocene age Wasatch Formation and upper Paleocene age Tongue River Member), the Middle Fort Union hydrogeologic unit (middle Paleocene age Lebo Shale Member), and the Lower Fort Union aquifer (lower Paleocene age Tullock Member) (Long et al., 2014) (Table 2). Thicknesses of the Upper Fort Union aquifer, Middle Fort Union hydrogeologic unit, and Lower Fort Union aquifer, range from 0–4,458, 0–3,643, and 0–2,913, feet, respectively (Thamke et al., 2014) (Table 2). Ranges of hydraulic conductivities are the largest within the Upper Fort Union aquifer (Table 2).

The Upper Fort Union aquifer is comprised of massive cross bedded sandstone, sandy mudstone, gray shale, carbonaceous shale, and thick coal beds (McLelland, 1992) that were deposited in an alluvial plain draining the young Rocky Mountains (Thamke et al., 2014). The Middle Fort Union hydrogeologic unit is comprised of alternating beds of sandstone, siltstone, mudstone, and claystone (Murphy, 2001), which were deposited in a large freshwater lake that received sediments eroded by the Bighorn mountains (McLelland, 1992). The Lower Fort Union aquifer consists of sandstones and sandy mudstones composed of continental, marine, non lignite, and clastic deposits (Cvancara, 1976a). Alternating brown and gray beds of sandstone, siltstone, claystone, mudstone, and lignite are also present (Murphy, 2001; Rigby and Rigby, 1990).

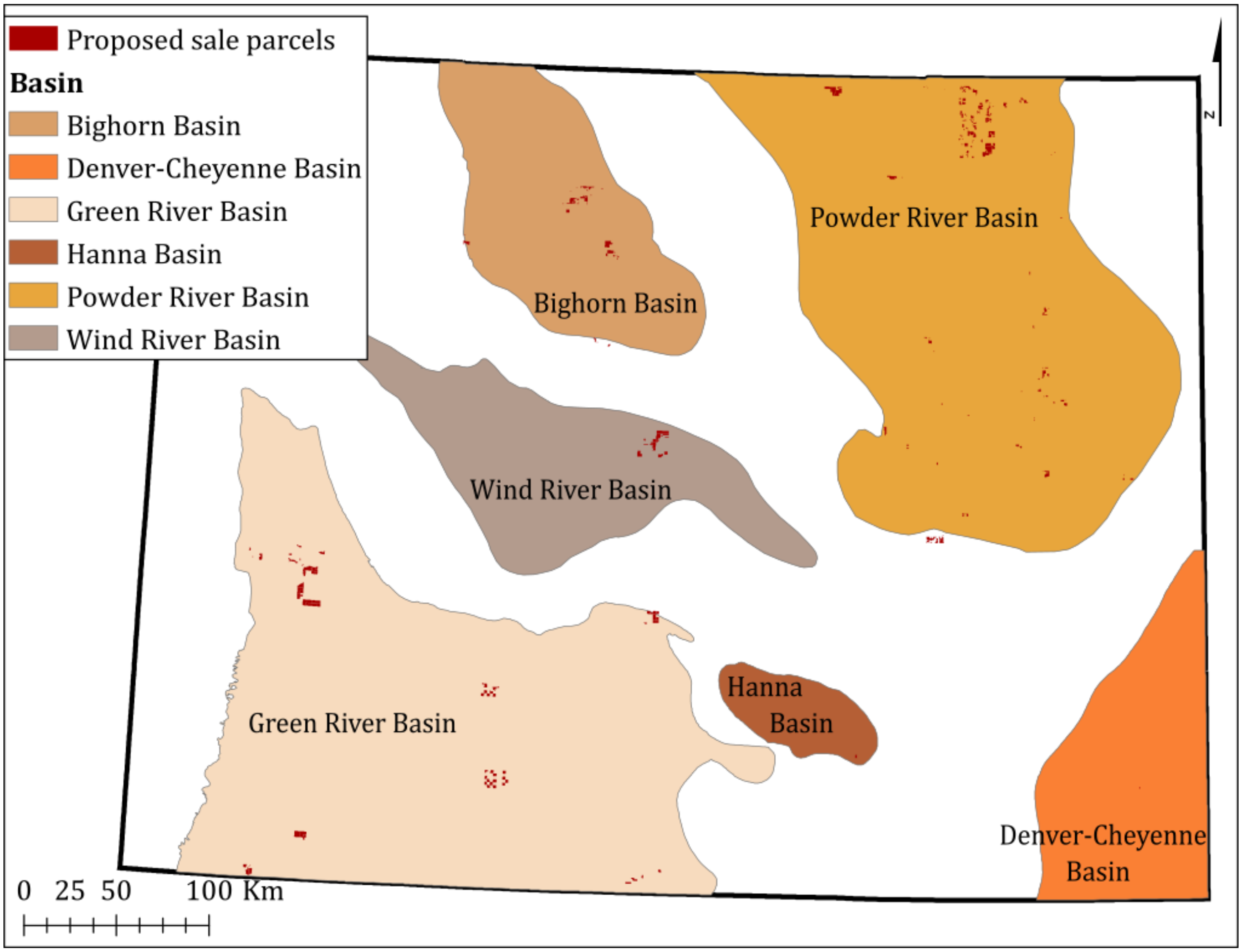

Figure 2 - Wyoming basins with proposed oil and gas parcels.

Table 2. Description of groundwater resources in the Powder River structural basin, modified from Long et al. (2014) and Thamke et al. (2014).

Period[a]	Epoch[a]	Principal aquifer system[a]	Lithostratigraphic unit[a]	Hydrogeologic unit[a]	Thickness (feet)[b]	Horizontal hydraulic conductivity (feet/day)[b]
Tertiary	Eocene	Lower Tertiary aquifer system	***Wasatch Fm***	***Upper Fort Union aquifer***	0–4,458	0.23–11
	Paleocene		***Tongue River Mbr***			
			Lebo Shale Mbr	***Middle Fort Union hydrogeologic unit***	0–3,643	0.10–7.1
			Tullock Mbr	***Lower Fort Union aquifer***	0–2,913	0.26–6.4
Cretaceous	Upper Cretaceous	Upper Cretaceous aquifer system	***Lance Fm (upper part)***	***Upper Hell Creek hydrogeologic unit***	0–3,002	0.03–5.7
			Lance Fm (lower part)	***Lower Hell Creek aquifer***	0–3,274	0.02–1.4
			Fox Hills Fm	***Fox Hills aquifer***		
			Pierre Shale	***Basal confining unit***		

[a]Long et al. (2014)
[b]Thamke et al. (2014)

The Upper Cretaceous aquifer system may be as thick as 5,070 feet in the Powder River Basin, and the hydrogeologic units comprising this system (in order of depth) include the Upper Hell Creek hydrogeologic unit (comprised of the upper part of the Lance Formation), the Lower Hell Creek aquifer (comprised of the lower part of the Lance Formation), and the Fox Hills aquifer (Fox Hills Formation) (Long et al., 2014) (Table 2). Thicknesses of the Upper Hell Creek hydrogeologic unit, and combined Lower Hell Creek aquifer and Fox Hills aquifer (subsurface contacts for these units have not been mapped in the Powder River Basin), range from 0–3,002 and 0–3,274, feet, respectively (Thamke et al., 2014) (Table 2). While minimum hydraulic conductivity values are relatively similar between the Upper Hell Creek and combined Lower Hell Creek/Fox Hills aquifers, the Upper Hell Creek hydrogeologic unit has been observed to have higher maximum hydraulic conductivity values (Thamke et al., 2014) (Table 2).

Both the Upper Hell Creek hydrogeologic unit and Lower Hell Creek aquifer are composed of alternating layers of mudstone, siltstone, sandstone, and sparse lignite beds (Thamke et al., 2014). In general, the relative percentage of sandstone is used to differentiate between these units, with the Upper Hell Creek having smaller percentages than those of the Lower Hell Creek and is determined using resistivity logs (Thamke et al., 2014).The Upper Hell Creek hydrogeologic unit consists of fluvial sediments deposited by meandering channels with point bars and channel plugs, whereas the Lower Hell Creek exhibits channel deposits and erosional surfaces (Flores, 1992). The Fox Hills aquifer consists of marine mudstones, siltstones, and sandstones deposited in a near-shore deltaic plain (Cvancara, 1976b; Murphy, 2001).

Green River Basin

The Green River and Wasatch formations in the Green River structural basin have complex lacustrine and fluvial lithologies deposited from lake-level fluctuations in an ancient lake environment (Bartos et al., 2015). Aquifers in these layered sedimentary rocks are often used as water sources in the Green River basin. The geohydrologic units of Tertiary rocks containing aquifers in the Green River basin consist of four major aquifers (localized and smaller aquifers are considered part of the major aquifer) and two confining units (Martin, 1996). In descending order, the aquifers are: Bridger aquifer, Laney aquifer, New Fork/Farson Sandstone Alkali Creek aquifer, and Wasatch-Fort Union (Martin, 1996). The confining units are the Wilkins Peak and Tipton, separating the Bridger and Laney aquifers from the New Fork/Farson Sandstone Alkali Creek aquifer and Wasatch-Fort Union aquifers (Bartos et al., 2015; Martin, 1996). The Wasatch-Fort Union is subdivided into two zones, the Wasatch zone and the Fort Union zone due to differences in hydrologic properties across the Green River basin (Martin, 1996).

The Bridger aquifer is at the surface and is generally less than 1,000 ft thick but in the southern Green River basin can be up to 1,500 ft thick (Martin, 1996). The Laney aquifer is underneath the Bridger aquifer so it can start at the surface or 1,500 ft bls (below land surface), and is typically 100 to 600 feet thick, but exceeds 1,000 feet thick in the south-central part of the Green River Basin (Martin, 1996). The Wilkins Peak confining unit then separates the Laney aquifer from the New Fork/Farson Sandstone Alkali Creek aquifer (Bartos et al., 2015). The confining unit is generally 100 to 600 feet thick but exceeds 1,000 feet in the southeastern part of the basin (Martin, 1996). The New Fork/Farson Sandstone-Alkali Creek aquifer is typically 350 ft thick and is only located in the central basin. The Tipton confining unit underlies New Fork/Farson Sandstone-Alkali Creek aquifer in the central basin and the Wilkins confining unit elsewhere. The confining unit ranges from 30 to 150 ft thick (Martin, 1996). The rocks in the Wasatch and Fort Union zone have a total thickness of up to 11,000 ft but generally range from 2,000 to 7,000 ft thick (Martin, 1996). Groundwater in the Tertiary aquifer system in general flows from high altitude recharge locations towards lower altitudes in the basin (Bartos et al., 2015). Most wells completed in the lower Tertiary aquifer in the Green River basin are for stock use.

Wind River Basin

The Wind River Basin (WRB) is one of many structural and sedimentary basins that formed in the Western Interior Seaway during the Late Cretaceous through early Eocene(Finn, 2007a, 2007b). The WRB is fault-bounded by Laramide uplifts with Washakie Range, Owl Creek Mountains, and southern Bighorn Mountains to the north, the Wind River Range to the west, the Granite Mountains to the south, and Casper arch to the east (Finn, 2007a, 2007b; Johnson et al., 2007; L. N. R. Roberts et al., 2007). Igneous and metamorphic rocks of Precambrian age comprise the core of the mountain ranges and underlie sedimentary rocks within the basin. The center part of the basin is filled with nearly horizontal fluvial and lacustrine Quaternary and Cenozoic Tertiary age sediment, overlying Paleozoic and Mesozoic age rocks.

Hydrocarbon production in the WRB is primarily from the Paleocene Fort Union and overlying Early Eocene Wind River Formation. The Fort Union Formation is divided into two general lithologic units. The lower unnamed member has conglomerates, sandstone, shale, claystone, and siltstone deposited under various fluvial depositional systems (Courdin and Hubert, 1969; Flores and Keighin, 1993; Johnson et al., 2007; Keefer, 1969). The upper unit is divided into two laterally equivalent members – the Waltman Shale and the Shotgun members (Keefer, 1965). The Waltman Shale is a lacustrine deposit in the central portion of the WRB that formed from an extensive body of water that developed in the basin during late Paleocene time (S. B. Roberts et al., 2007). The Shotgun Member is a marginal lacustrine deposit that formed in fluvial and shoreline areas that expanded during the late Paleocene (Keefer, 1965) and is dominated by siltstones, mudstones, carbonaceous shales, coals, and subordinated sandstones (Flores and Keighin, 1993).

The Wind River and Fort Union Formations are variably saturated fluvial depositional systems characterized by shale and fine-, medium-, and coarse-grained sandstone sequences. Lithology is highly variable and difficult to correlate from borehole data. No laterally continuous confining layers of shale exist below the maximum depth of groundwater used to confine upward solute migration. The Wind River Formation is the major aquifer system in the WRB (Daddow, 1996). The Fort Union Formation is highly productive and permeable where fractured with TDS values from 1,000 to 5,000 mg/L (McGreevy et al., 1969).

Bighorn Basin

In the Bighorn Basin, Cenozoic rocks consist of sandstone and shale with depth to groundwater ranging from 2 to 200 ft bls (Hinckley et al., 1982; Plafcan et al., 1993). The Lance, Mesaverde, and Frontier formations in the Mesozoic bedrocks are the aquifers with the most potential for water supply development in the Bighorn Basin. Wells in these formations range from 5 to 200 ft bls (Plafcan et al., 1993). The Tensleep Sandstone, Madison Limestone, Bighorn Dolomite are in the Paleozoic bedrock and yield the most abundant water supplies (Hinckley et al., 1982; Plafcan et al., 1993). These three aquifers generally recharge from mountains around the Bighorn Basin. The Tensleep sandstone is a well-sorted fine to medium-grained sandstone cemented by carbonate and silica and ranges from 50 to 200 ft thick. Groundwater elevation in the Tensleep sandstone can range from flowing aboveground to 1,000 ft bls (Plafcan et al., 1993). The Madison Limestone contains limestone, dolomite, and thin chert beds, and ranges from 500 to 800 ft thick. The Bighorn Dolomite ranges from 350 to 450 ft thick. The Madison-Bighorn aquifer ranges from 95 to 490 ft bls (Plafcan et al., 1993).

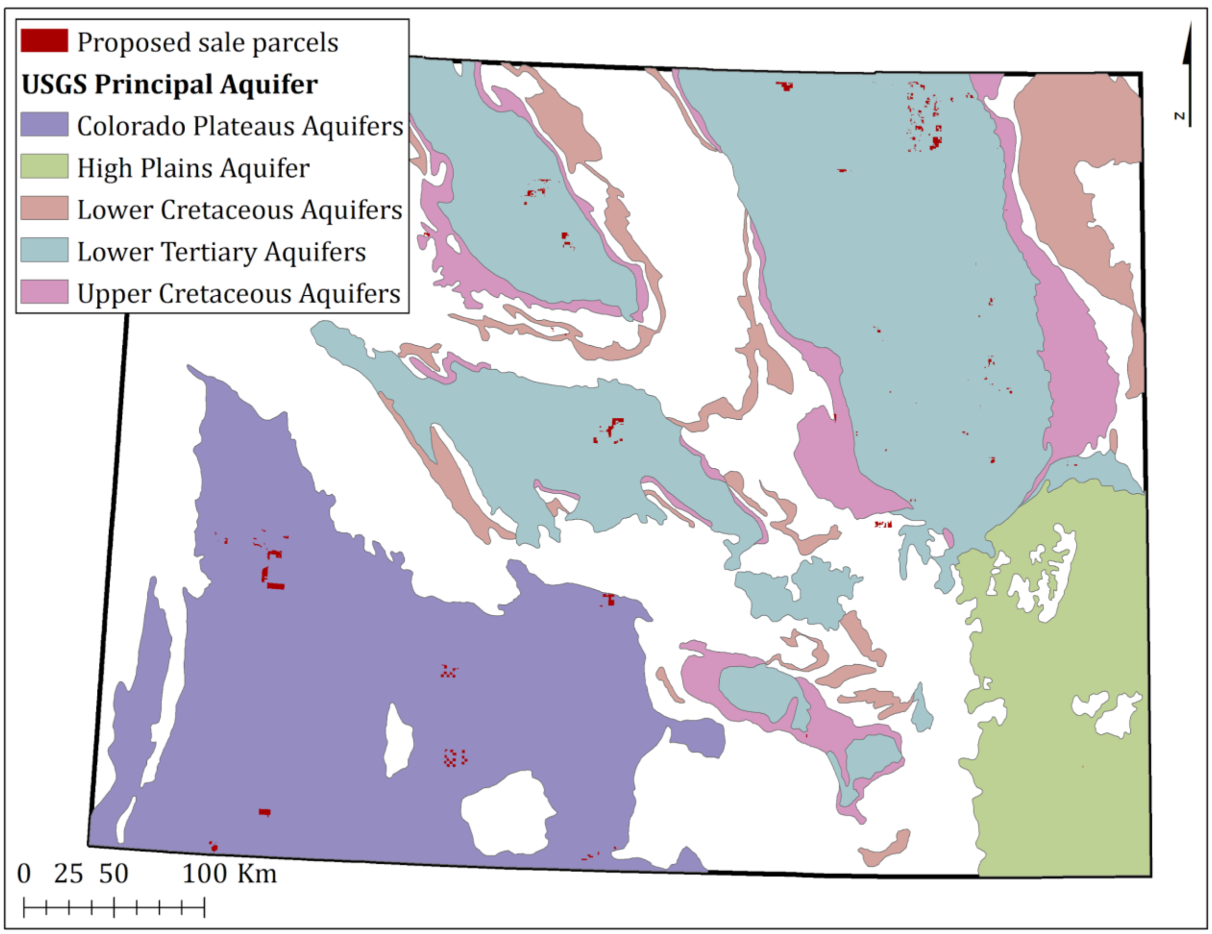

Figure 3 - USGS principal aquifers with the proposed oil and gas parcels (U.S. Geological Survey, 2021).

Identification of Principal Aquifers within 3,000 ft of Surface

Surface aquifers within 3,000 feet of the surface having brackish groundwater resources in the proposed parcel areas were identified using the USGS Brackish Water Database (Stanton et al., 2017). In the USGS report, fresh groundwater is defined as water having less than 1,000 mg/L total dissolved solids (TDS), slightly saline (brackish) has 1,000 to 3,000 mg/L TDS, moderately saline (brackish) has 3,000 to 10,000 mg/L TDS, and highly saline water is >10,00 mg/L TDS. Principal aquifers in lease areas are shown in Figure 3 and minimum and maximum groundwater depths are listed in Table 3 (Qi and Harris, 2017). The Colorado Plateaus aquifers and Lower Cretaceous aquifers exist within 3,000 feet of the surface but also extend below 3,000 feet in some areas.

Table 3 - Principal aquifers with 3,000 feet below land surface from the USGS Brackish Water Database.

Principal aquifer	Number of parcels located in aquifer	Average minimum depth of groundwater (ft bls)	Average maximum depth of groundwater (ft bls)
Colorado Plateaus aquifers	44	5,060	5,398
High Plains aquifers	1	34	185
Lower Cretaceous aquifers	1	3,983	4,296
Lower Tertiary aquifers	76	482	814
Paleozoic aquifers	0	2,278	2,629
Upper Cretaceous aquifers	4	966	1,232

(Note that 4 parcels in proposed sale are not located within available data on USGS principal aquifers)

Data for the wells used in the USGS Brackish Water Database was downloaded to quantify the average minimum and maximum groundwater well depth in the aquifers (Table 3) and to characterize the TDS levels in the aquifers to determine if there is usable water (Qi and Harris, 2017). The majority of the proposed parcel areas are located in the Colorado Plateaus aquifer and the Lower Tertiary aquifers (120 parcels). In the Colorado Plateaus aquifer (which corresponds geographically with the Green River Basin), 65% of the wells from the USGS Brackish Water Database have a TDS concentration below 10,000 mg/L (Figure 4) (Qi and Harris, 2017). Over 99% of wells in the Lower Tertiary aquifer (which corresponds geographically with the Power River, Wind River, Bighorn, and Hanna Basins) have a TDS concentration below 10,000 mg/L (Figure 5). Therefore, wells located in the Colorado Plateaus aquifers (maximum well depth is 21,322 ft bls) and the Lower Tertiary aquifers (maximum well depth is 6,930 ft bls) contain usable water. Future oil and gas wells installed in these areas on the proposed lease parcels will be subject to the requirements of BLM Onshore Oil and Gas Order No. 2.

Current aquifer exemptions exist in some of the proposed lease parcel areas (Table 4, Figure 6). There are 49 proposed parcels located in the same area as 20 aquifer exemptions (Table 4, Figure 6). Usable water as defined in BLM Onshore Order No. 2 encompasses groundwater with an aquifer exemption, and these 49 parcels are, therefore, in areas with usable water. However, the aquifer exemptions mean that such aquifers are not subject to certain requirements of the Safe Drinking Water Act. We therefore have excluded them from our examination of existing federal wells, below.

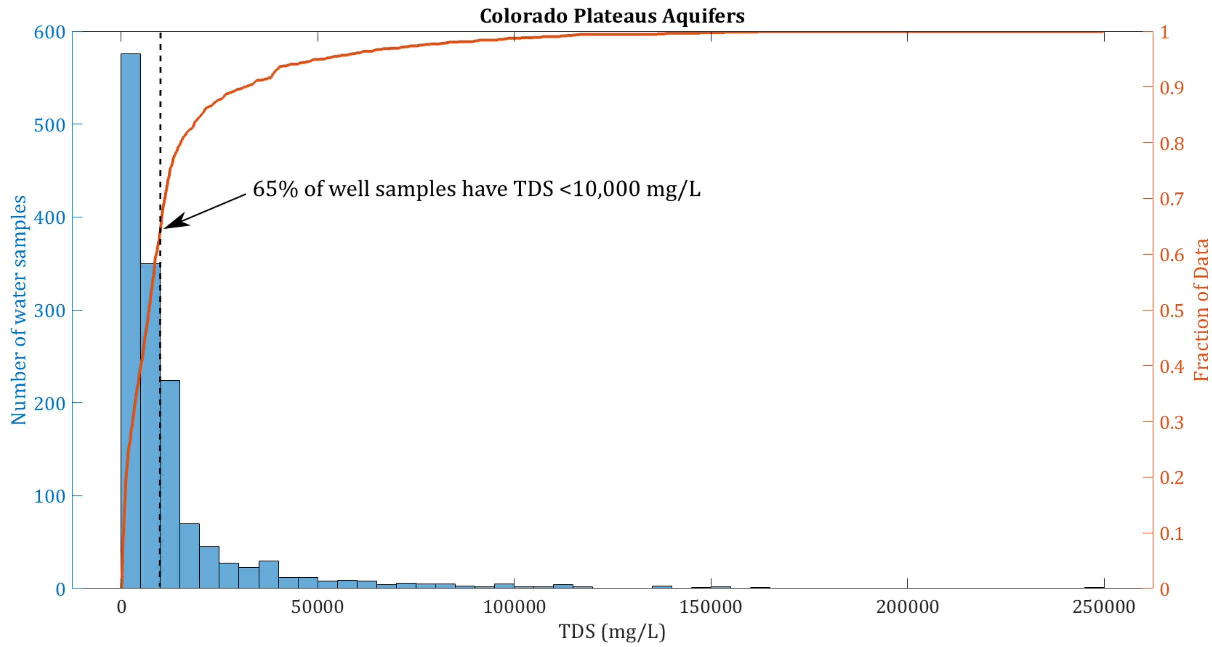

Figure 4- Total dissolved solids (TDS) levels in wells in the Colorado Plateau aquifers from the USGS Brackish Water Database (Qi and Harris, 2017).

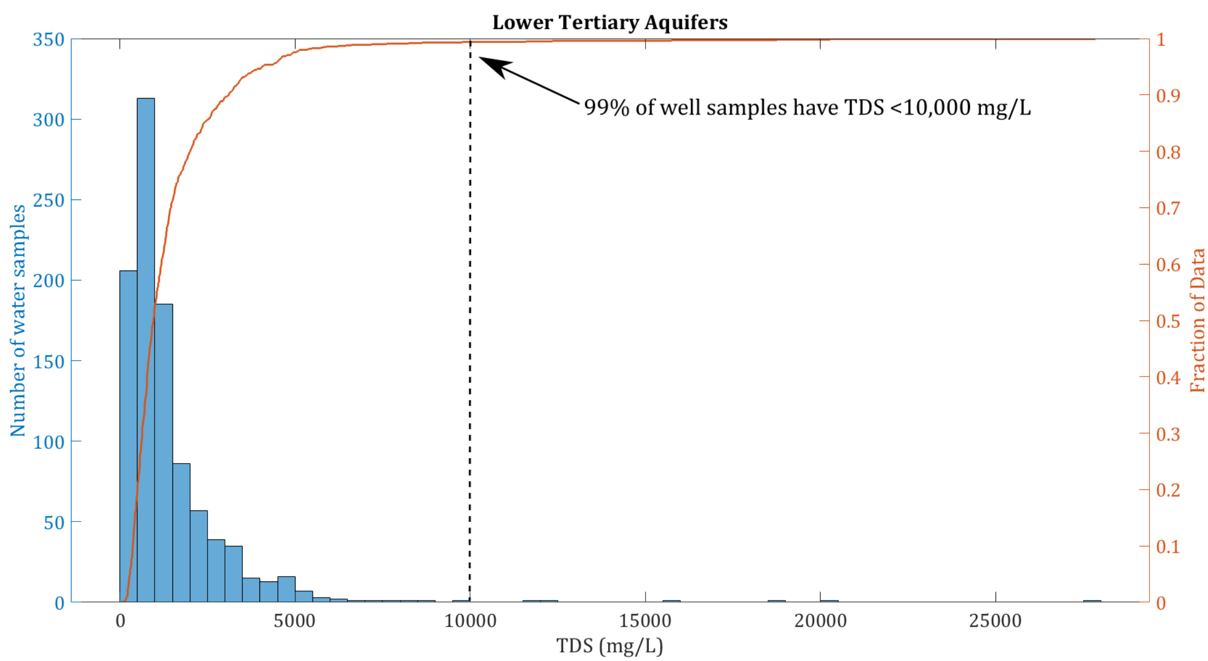

Figure 5- Total dissolved solids (TDS) levels in wells in the Lower Tertiary aquifers from the USGS Brackish Water Database (Qi and Harris, 2017).

Table 4. *Aquifer exemptions in the same locations at the proposed parcels.*

Parcel ID	Basin	Aquifer Exemption ID	Depth (ft bls)	Injection Zone
WY-202X-XX-0904	Green River Basin	8_3903	0	T-5 Sand
WY-202X-XX-0943	Powder River Basin	8_4057	9765	Minnelusa
WY-202X-XX-0950	Powder River Basin	8_3888	7525	Muddy
WY-202X-XX-0953	Powder River Basin	8_4080	6500	Muddy
WY-202X-XX-0958	Powder River Basin	8_3997	7095	Muddy
WY-202X-XX-0960	Powder River Basin	8_3997	7095	Muddy
WY-202X-XX-0966	Powder River Basin	8_4080	6500	Muddy
WY-202X-XX-0967	Powder River Basin	8_4080	6500	Muddy
WY-202X-XX-0968	Powder River Basin	8_3997	7095	Muddy
WY-202X-XX-0974		8_1030	1626	Phosphoria
WY-202X-XX-0977	Powder River Basin	8_3872	1200	1st Wall Creek
WY-202X-XX-1018		8_1886	800	Madison
WY-202X-XX-1032	Powder River Basin	8_3929	7968	Muddy
WY-202X-XX-1036	Powder River Basin	8_3929	7968	Muddy
WY-202X-XX-1043	Powder River Basin	8_3929	7968	Muddy
WY-202X-XX-1054	Powder River Basin	8_3980	7968	Muddy
WY-202X-XX-1132	Powder River Basin	8_3888	7525	Muddy
WY-202X-XX-1201	Wind River Basin	8_1009	4919	Shotgun Member of the Ft Union
WY-202X-XX-1212	Wind River Basin	8_1074	3268	Shotgun Member of the Ft Union
WY-202X-XX-1234	Powder River Basin	8_1052	7243	Minnelusa C
WY-202X-XX-6979	Powder River Basin	8_4093	6299	Dakota
WY-202X-XX-6995	Green River Basin	8_3903	0	T-5 Sand
WY-202X-XX-7000	Green River Basin	8_3903	0	T-5 Sand
WY-202X-XX-7003	Green River Basin	8_3903	0	T-5 Sand
WY-202X-XX-7022	Powder River Basin	8_3888	7525	Muddy
WY-202X-XX-7025	Powder River Basin	8_4080	6500	Muddy
WY-202X-XX-7026	Powder River Basin	8_4068	6350	Muddy
WY-202X-XX-7027	Powder River Basin	8_3997	7095	Muddy

WY-202X-XX-7030	Powder River Basin	8_4080	6500	Muddy
WY-202X-XX-7031	Powder River Basin	8_4080	6500	Muddy
WY-202X-XX-7032	Powder River Basin	8_3929	7968	Muddy
WY-202X-XX-7033	Powder River Basin	8_3980	7968	Muddy
WY-202X-XX-7035	Powder River Basin	8_1062	200	Wasatch "F" Sand
WY-202X-XX-7036	Powder River Basin	8_3888	7525	Muddy
WY-202X-XX-7053	Green River Basin	8_1854	4735	Fort Union Sands
WY-202X-XX-7060	Green River Basin	8_3927	4700	Almond
WY-202X-XX-7074	Powder River Basin	8_3929	7968	Muddy
WY-202X-XX-7100	Green River Basin	8_3927	4700	Almond
WY-202X-XX-7107	Green River Basin	8_3927	4700	Almond
WY-202X-XX-7110	Green River Basin	8_3927	4700	Almond
WY-202X-XX-7122	Powder River Basin	8_3929	7968	Muddy
WY-202X-XX-7134	Powder River Basin	8_3997	7095	Muddy
WY-202X-XX-7135	Powder River Basin	8_3980	7968	Muddy
WY-202X-XX-7173	Powder River Basin	8_3980	7968	Muddy
WY-202X-XX-7174	Powder River Basin	8_3980	7968	Muddy
WY-202X-XX-7177	Powder River Basin	8_3980	7968	Muddy
WY-202X-XX-7192	Green River Basin	8_3914	3640	Almy Stray 3-4
WY-202X-XX-7193	Powder River Basin	8_3991	0	Teckla
WY-202X-XX-7204	Wind River Basin	8_1009	4919	Shotgun Member of the Ft Union

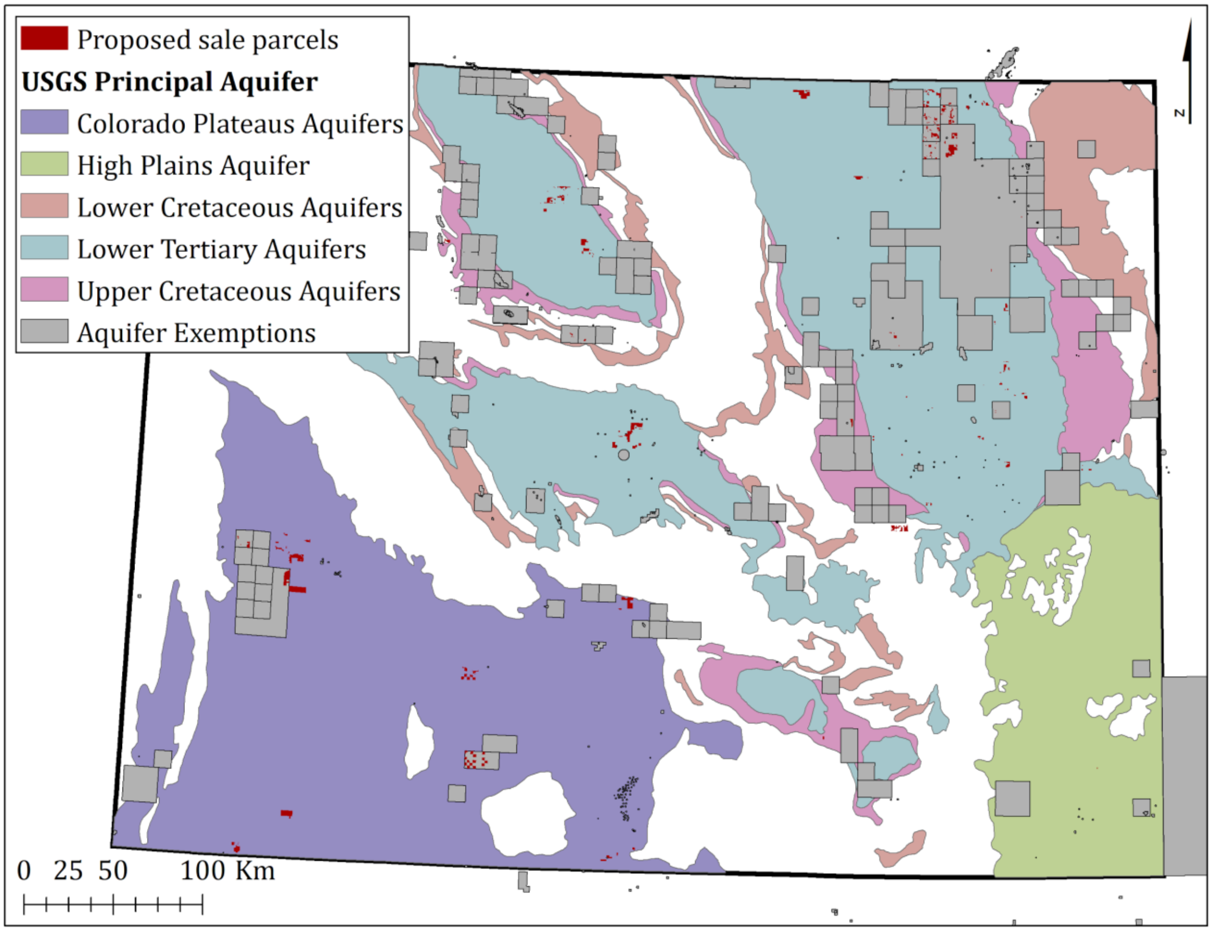

Figure 6 - Aquifer exemptions in Wyoming, shown with the proposed parcels and USGS principal aquifers (U.S Environmental Protection Agency, 2017; U.S. Geological Survey, 2021)

Examination of Current Federal Wells in the Powder River Basin

Onshore Oil and Gas Order No. 2 requires federal wells to protect usable water by properly cementing the casings around usable water zones (U.S. Bureau of Land Management, 1988). The top of cement and bottom of surface casing for active federal well construction logs were analyzed to assess if this requirement was being met, and thus determine if current federal wells are protecting usable water zones near the proposed parcel areas. For any well, if a gap exists between the surface casing and top of cement in a usable water zone, the well is endangering groundwater resources. Moreover, if existing wells have been approved by BLM without protecting all usable water zones as required by Onshore Order No. 2, it appears likely that oil and gas wells also will be approved in the future on the proposed lease parcels without requiring them to be constructed to protect groundwater resources.

In the Powder River basin, there are 62 federal wells that have been completed since January 1, 2000, and remained active within the last 5 years in the same townships and ranges as the proposed lease parcels (outside of areas with aquifer exemptions) (Table 5). Among these 62 identified wells, 36 have a gap between the bottom of surface casing and the top of cement (Figure 7). The length of these gaps' ranges from 275 to 7,714 ft with an average gap length of 2,653 ft. The average depth of surface casing in well with gaps is 2,196 ft bls (minimum 444 ft and maximum 3,550 ft). The average depth of top of cement in well with gaps is 4,850 ft bls (minimum 2,060 ft and maximum 9,970 ft).

These gaps cross usable water zones. Seventeen of the wells have an uncemented gap occurring at less than 3,000 feet below surface (Table 5). This gap is located within the Lower Tertiary principal aquifer, which primarily contains usable water (TDS <10,000 mg/L) (Figures 5 and 7). Therefore, these seventeen wells have a gap in cement and surface casing that is threatening usable water and thus may not be in compliance with Onshore Oil and Gas Order No. 2.

Nineteen of the wells have an uncemented gap occurring more than 3,000 ft bls (Figure 7). These gaps cross the lower Tertiary and upper Cretaceous aquifers. The lower Tertiary aquifer system may be as thick as 7,180 feet in the Powder River Basin so all but 4 of the wells with gaps could be threatening the usable water in that aquifer.

Below the lower Tertiary aquifer system is the upper Cretaceous aquifer, which contains the Lance and Fox Hills formations. While this aquifer system is more than 3,000 ft bls, it also contains usable water. Previous studies found that mean TDS levels estimated from oil and gas wells and produced water records found that water from 3,000-7,000 ft bls in the Powder River basin are all below <10,000 mg/L (Table 5) (Taboga et al., 2018). In wells installed between 1,000-6,000 ft bls, 95% had TDS levels <10,000 mg/L, while 83% of wells installed 6,000-7,000 ft bls had TDS levels <10,000 mg/L (Taboga et al., 2018). Thus, the nineteen wells with uncemented gaps occurring more than 3,000 ft bls are likely also in usable water aquifers.

Conclusion

- Numerous proposed lease parcels are located in areas with usable water, particularly those in the Green River Basin (Colorado Plateaus aquifers) and the Powder River Basin (Lower Tertiary aquifers).

- The EA, however, does not identify the depths of usable water covered by the proposed lease parcels, which creates ambiguity in surface casing and cementing requirements for new wells in WY.

- Existing federal wells in the Powder River basin are not protecting usable water. Of 61 wells reviewed in the same township and ranges as the proposed parcels, most (at least 36) had inadequate construction.

- If current active federal wells (completed since January 1, 2000) are not adequately cased and cemented, then it can be assumed that a significant portion of future wells installed on these proposed parcels will also be inadequately cased/cemented and thus pose a threat to usable water.

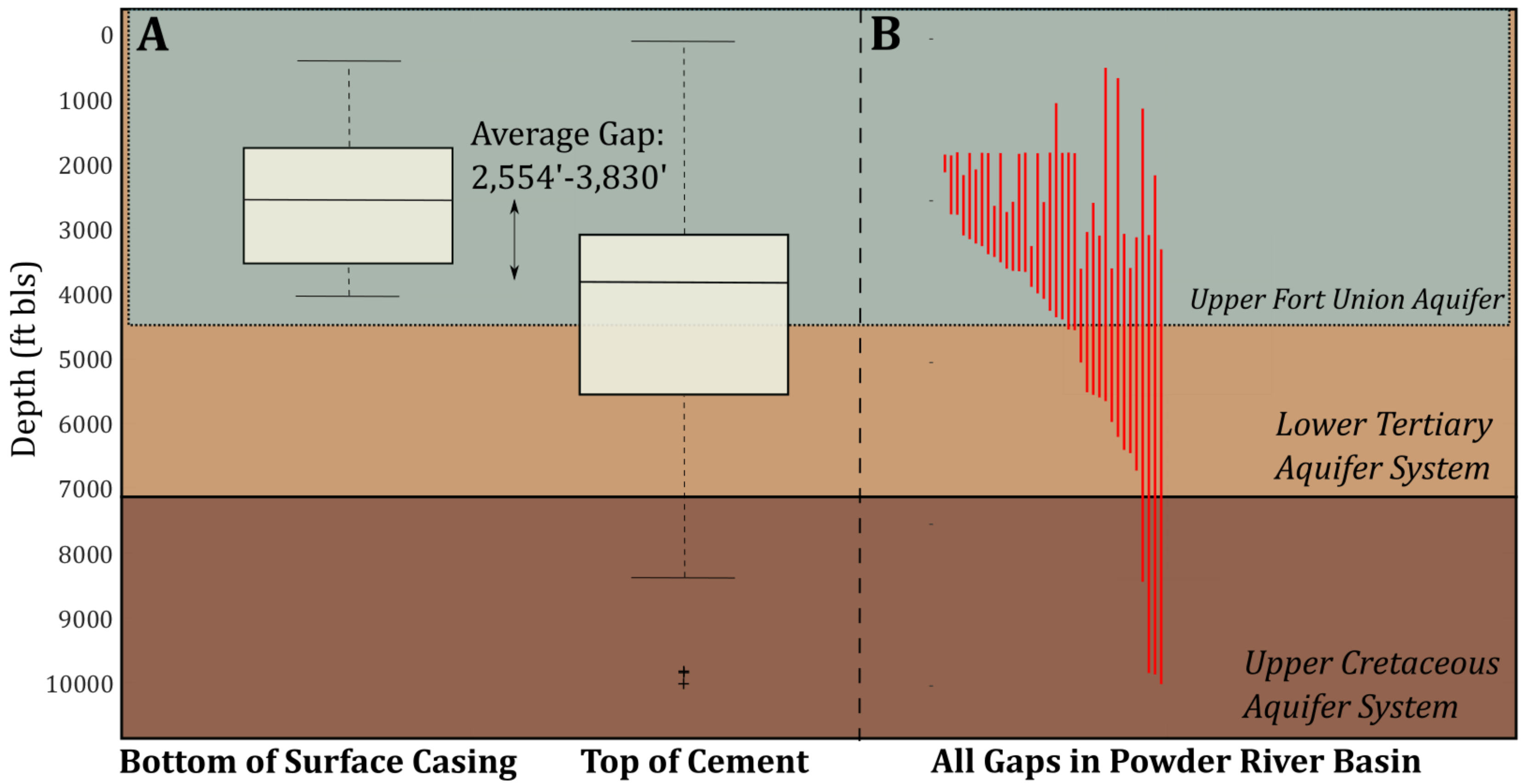

Figure 7. Boxplots with the bottom of surface casing and top of cement depths (ft bls) from the wells in the WOGCC database for the Powder River Basin (panel A) (WOGCC, 2022). A segment plot with all 36 wells in the Powder River Basin that contain gaps between surface casing and top of cement (panel B). The majority of the gaps are through the Upper Fort Union Aquifer, part of the Lower Tertiary Aquifer System. Four of the gaps stretch into the Upper Cretaceous Aquifer System.

Table 5. Federal well surface casing and top of cement data from the WOGCC database. All wells are producing oil wells except 3 that are shut-in (API 49-009-28788, 49-009-28788, and 49-045-22940). All wells had Frac Treatments except wells 49-005-68543 and 49-009-29541 where the treatment was not listed.

Township/ Range	***API***	***Field***	***Reservoir***	***Total Depth (ft bls)***	***Completion Date***	***Last Active Date***	***Depth of Surface Casing (ft bls)***	***Top of Cement (ft bls)***	***Total Uncemented Interval (ft)***	***Uncemented Interval (ft bls)***
36N 68W	49-009-28881	WC	Teapot	6477	1/27/2015	1/31/2022	1765	3931	2166	1765-3931
36N 68W	49-009-29123	WC	Teapot	6410	7/20/2017	1/31/2022	1764	4500	2736	1764-4500
36N 68W	49-009-29468	WC	Teapot	6401	10/3/2014	1/31/2022	1763	3450	1687	1763-3450
36N 68W	49-009-29596	WC	Teapot	6351	2/14/2017	1/31/2022	1763	3325	1562	1763-3325
36N 68W	49-009-29606	WC	Teapot	6222	7/26/2015	1/31/2022	1756	4200	2444	1756-4200
36N 68W	49-009-29646	WC	Teapot	6228	7/25/2015	1/31/2022	1758	3200	1442	1758-3200
36N 68W	49-009-29647	WC	Teapot	6454	1/27/2015	1/31/2022	1761	3093	1332	1761-3093
36N 68W	49-009-29651	WC	Teapot	6351	2/15/2017	1/31/2022	1756	3600	1844	1756-3600
36N 68W	49-009-29707	WC	Teapot	6440	7/27/2017	1/31/2022	1755	4490	2735	1755-4490
36N 68W	49-009-33548	WC	Teapot	6514	10/24/2019	1/31/2022	1760	4334	2574	1760-4334
36N 68W	49-009-33553	WC	Teapot	6347	6/25/2019	1/31/2022	1785	2060	275	1785-2060
36N 68W	49-009-33556	WC	Teapot	6339	6/25/2019	1/31/2022	1774	3590	1816	1774-3590
37N 75W	49-009-30017	Spearhead Ranch	Frontier	12464	08/15/2021	01/31/2022	3512	0		
37N 75W	49-009-30016	Spearhead Ranch	Frontier	12685	01/19/2020	01/31/2022	3545	0		
37N 75W	49-009-28131	WC	Dakota	13615	02/11/2008	05/04/2020	3030	9800	6770	3030-9800
37N 75W	49-009-36496	WC	Frontier	12307	12/19/2019	01/30/2022	3537	0		
37N 75W	49-009-47473	WC	Frontier	12868	01/13/2020	01/31/2022	3559	0		
37N 75W	49-009-28788	WC	Frontier	12213	01/15/2014	12/02/2021	4045	0		
37N 75W	49-009-30832	WC	Frontier	12634	10/01/2019	01/31/2022	3512	0		
37N 75W	49-009-30833	WC	Frontier	12604	09/24/2021	01/30/2022	3530	0		
37N 75W	49-009-29634	WC	Frontier	12659	08/27/2015	01/30/2022	4032	3550		
37N 75W	49-009-29417	Spearhead Ranch	Frontier	12686	09/26/2015	01/08/2022	4043	2390		
37N 75W	49-009-30004	WC	Frontier	12986	09/10/2019	01/31/2022	3582	0		

37N 75W	49-009-30005	WC	Frontier	12956	09/09/2019	01/31/2022	3630	0		
37N 75W	49-009-30020	Spearhead Ranch	Frontier	12557	08/17/2021	01/31/2022	3566	0		
37N 75W	49-009-29573	WC	Frontier	11320	02/27/2019	01/31/2022	3506	0		
37N 75W	49-009-29574	WC	Shannon	11325	02/15/2019	01/30/2022	3517	0		
37N 75W	49-009-30834	WC	Frontier	12296	12/07/2020	01/31/2022	3521	0		
37N 76W	49-009-28788	WC	Frontier	12213	1/15/2014	12/2/2021	4045	2800		
37N 76W	49-009-33872	WC	Frontier	11874	3/14/2018	1/24/2022	2531	5500	2969	2531-5500
38N 70W	49-009-37206	WC	Turner	9988	12/16/2021	1/31/2022	1764	1670		
38N 70W	49-009-47037	WC	Niobrara	9927	7/27/2020	1/31/2022	1787	1572		
38N 70W	49-009-47038	WC	Niobrara	9995	8/4/2020	1/31/2022	1815	1815		
38N 70W	49-009-47039	WC	Niobrara	9953	7/29/2020	1/19/2022	1770	170		
38N 70W	49-009-47079	WC	Turner	10329	8/2/2020	1/31/2022	1798	2710	912	1798-2710
38N 70W	49-009-47080	WC	Turner	10223	7/31/2020	1/31/2022	1751	2715	964	1751-2715
39N 73W	49-009-38135	WC	Frontier-Turner	11855	5/2/2019	1/28/2022	2515	3583	1068	2515-3583
39N 73W	49-009-38140	WC	Frontier-Turner	11855	5/2/2019	1/29/2022	2520	4016	1496	2520-4016
39N 73W	49-009-38776	WC	Turner	11769	11/15/2008	1/31/2022	2102	3035	933	2102-3035
39N 73W	49-009-38778	WC	Turner	11763	11/14/2018	1/27/2022	2106	9820	7714	2106-9820
40N 75W	49-009-41521	WC	Shannon	10696	12/03/2019	02/25/2022	3200	3830	630	3200-3830
40N 75W	49-009-44381	WC	Niobrara	11242	08/01/2019	01/31/2022	3198	0		
40N 75W	49-009-46535	Hornbuckle	Shannon	10839	03/04/2020	02/28/2022	3038	5540	2502	3038-5540
40N 75W	49-009-29614	WC	Frontier	10283	10/18/2019	01/30/2022	2977	0		
40N 75W	49-009-29652	WC	Shannon	10887	06/18/2017	01/26/2022	3550	5000	1450	3550-5000
40N 75W	49-009-45917	WC	Shannon	10676	12/05/2019	10/24/2021	3011	6350	3339	3011-6350
40N 75W	49-009-48481	WC	Shannon	10885	12/17/2020	02/28/2022	2982	5460	2478	2982-5460
40N 75W	49-009-29892	WC	Shannon	10813	02/02/2019	01/30/2022	3250	9970	6720	3250-9970
40N 75W	49-009-29368	Finley Draw	Frontier	12828	12/16/2015	01/30/2022	3545	5918	2373	3545-5918
40N 75W	49-009-31145	Hornbuckle	Shannon	10906	03/05/2020	02/12/2022	3064	6670	3606	3064-6670
40N 75W	49-009-29921	Hornbuckle	Sussex	10223	03/08/2015	02/28/2022	2673	3549	876	2673-3549
40N 75W	49-009-31205	Hornbuckle	Shannon	10761	10/08/2018	02/28/2022	3539	6400	2861	3539-6400
40N 75W	49-009-29541	WC	Sussex	10100	08/30/2018	11/29/2021	10344	6467		

40N 75W	49-009-44138	WC	Niobrara	11815	12/20/2019	01/31/2022	2578	3368	790	2578-3368
41N 69W	49-005-26275	School Creek	Muddy	9906	03/03/2012	12/01/2021	1075	8390	7315	1075-8390
42N 69W	49-005-57862	Thunder Creek	Muddy	9790	04/30/2008	11/06/2018	991	4300	3309	991-4300
44N 69W	49-005-60608	WC	Mowry	11688	11/03/2009	01/17/2022	2015	3160	1145	2015-3160
45N 68W	49-045-22930	Quest		7583	7/31/2000	12/14/2021	414	No CBL		
45N 68W	49-045-22940	Quest	Skull Creek	7600	8/1/2001	10/31/2018	421	No CBL		
45N 68W	49-045-29091	Quest	Muddy	7581	9/13/2006	1/31/2022	444	5596	5152	444-5596
45N 68W	49-045-29273	Quest	Muddy	7650	8/5/2011	1/31/2022	603	6150	5547	603-6150
57N 72W	49-005-68543	Hunter Ranch	Minnelusa	8365	05/23/2019	01/31/2022	1138	115		

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