Baseline geochemical characterization of potential receiving reservoirs for carbon dioxide in the Greater Green River Basin, Wyoming

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ABSTRACT

Geologic sequestration of anthropogenic carbon dioxide (CO_2) will be a necessary part of a carbon management strategy for reducing atmospheric CO_2 emissions so long as fossil fuels are a significant part of the energy mix. Proposed federal and state regulations for underground injection of CO_2 require that underground sources of drinking water be protected. Accordingly, proposed federal regulations require analysis of the suitability of different receiving formations for geologic sequestration.

This study compiles all available water quality data for four potential CO_2 receiving formations in the Greater Green River Basin of southwestern Wyoming. The Greater Green River Basin encompasses two large geologic structures, the Moxa Arch and Rock Springs Uplift, which potentially are capable of storing commercial quantities of CO_2 in a number of formations, including the Nugget Sandstone, Tensleep/Weber Sandstone, Madison Limestone, and Bighorn Dolomite. The data suggest that except along the basin margins, the Tensleep/Weber, Madison, and Bighorn Formations are suitable targets under proposed federal and state geologic sequestration regulations. However, low total dissolved solids in Nugget Sandstone groundwater in parts of the Rock Springs Uplift suggest the potential for local, fracture-assisted recharge in this area. For this reason the Nugget Sandstone is less suitable than the deeper formations for CO_2 storage in the Rock Springs Uplift.

KEYWORDS: Bighorn Dolomite, geologic sequestration, Madison Limestone, Moxa Arch, Nugget Sandstone, Rock Springs Uplift, Tensleep/Weber Sandstone, water quality.

INTRODUCTION

Geologic sequestration of anthropogenic CO_2 is one of a number of strategies for reducing CO_2 emissions to the atmosphere and thus for helping to mitigate anthropogenic climate change. It is part of the process of carbon capture and storage (CCS), in which CO_2 is captured from power plants or other anthropogenic sources, compressed to convert it to a relatively dense supercritical fluid, and delivered to the storage site. It is injected into a subsurface geologic receiving formation at sufficient depth (greater than ~2625 ft (800 m)) to maintain the CO_2 in a supercritical state. Natural subsurface accumulations of CO_2, including many in Wyoming, show that the gas can be trapped for millions of years (Huang et al., 2007; Lu et al., 2009).

Although in the long term it is anticipated that cleaner forms of energy will become competitive with energy from fossil fuels, in the near term geologic sequestration may be considered a bridging technology by which coal-rich nations such as the U.S., China, and India can continue to burn fossil fuels and limit CO_2 emissions to the atmosphere. According to the International Energy Agency (IEA), the least expensive approach to halve expected carbon emissions by 2050 would rely upon CCS to contribute almost 20 percent of the necessary cuts. As noted by Van Noorden (2010), in order to achieve this target, the CCS industry must develop quickly; by mid-century, the volume of supercritical CO_2 that must be injected underground each year would be three times the current amount of petroleum extracted every year. This requires that the regulatory framework for CCS be established as soon as possible.

In 2008 the EPA proposed a new class of injection well, Class VI, under the authority of the Safe Drinking Water Act, that tailors existing Underground Injection Control (UIC) program standards for the geologic sequestration of CO_2 (40 CFR Part 144). The proposed rule outlines minimum technical requirements for geologic site characterization, well construction, operation, monitoring, and post-injection site care, among other criteria for Class VI. The purpose of both the proposed rule and the UIC program is to protect underground sources of drinking water (USDWs) from endangerment. USDWs are defined as an aquifer or a portion of an aquifer that currently supplies, or has sufficient capacity to supply, a public water system and contains less than 10,000 milligrams per liter (mg/L) total dissolved solids (TDS).

Under the EPA proposed geologic sequestration rule, the requirements for obtaining a Class VI injection permit include compiling information on the geochemistry of formation fluids of potential receiving formations within the three-dimensional region that may be impacted by injection activity (i.e., area of review). Pre-injection geochemical data can serve as a baseline against which data obtained throughout the injection phase may be compared. The State of Wyoming has primary enforcement authority (i.e., primacy) for the UIC program; in Wyoming, permits for geologic sequestration of CO_2 will be issued by the Wyoming Department of Environmental Quality (WDEQ) according to its proposed Water Quality Rules and Regulations, Chapter 24 (2010), once primacy for Class VI wells has been delegated to the state by EPA. Like the EPA rule, the WDEQ proposed regulations require baseline geochemical data on subsurface formations, including all USDWs in the area of review.

Demonstration of safe geologic sequestration of CO_2 is a priority for the State of Wyoming because of its dependence upon revenues from the mineral industry. As the producer of 40 percent of the nation's coal, Wyoming has a particular interest in minimizing CO_2 emissions, because coal-fired power plants emit 78 percent more CO_2 per unit of energy than natural gas–fueled plants. Paleozoic saline aquifers in southwestern Wyoming are promising targets for geologic sequestration. Two large geologic structures that have the potential to store commercial amounts of CO_2 in these formations are the Rock Springs Uplift and Moxa Arch (Fig. 1). The Rock Springs Uplift is an intra-basinal, Laramide-age basement uplift within the Rocky Mountain foreland that is flanked to the south by the east–west-trending Uinta Mountains (Mederos et al., 2005). The Moxa Arch is a ~190-km-long, north–south-trending anticline, bounded on the south by the Uinta Mountains and over-ridden in the north by the leading edge of the Wyoming Thrust Belt (Kraig et al., 1987; Stillwell, 1989). Preliminary characterization of the Bighorn and Madison carbonate formations, as well as the Tensleep/Weber and Nugget Sandstone formations at the Rock Springs Uplift and Moxa Arch indicates that they lie at depths and pressures for which CO_2 will be supercritical, and they appear to have the appropriate thickness, reservoir properties, overlying low-permeability lithofacies, and structural integrity to be good candidates for CO_2 storage. The storage units are overlain by a series of shales and other sealing lithologies that are necessary to ensure CO_2 will be contained. These geologic sites are also adjacent to several significant point source emitters of anthropogenic CO_2, including PacifiCorp's Jim Bridger power plant at Point of Rocks on the Rock Springs Uplift and ExxonMobil's Shute Creek natural gas processing facility on the Moxa Arch.

The objective of this study is to compile pre-injection baseline geochemical data for water from four potential receiving formations in the Greater Green River Basin of southwestern Wyoming: the Ordovician Bighorn Dolomite, Mississippian Madison Limestone, Pennsylvanian Tensleep/Weber Sandstone, and Jurassic Nugget Sandstone. These data are used to identify the geochemical character of the water in these formations, the variability of water geochemistry within each formation across the study area, and whether or not these aquifers meet the criteria of USDWs. Data were collected from different sources available in the public domain, including the U.S. Geological Survey and the Wyoming Oil and Gas Conservation Commission.

GEOLOGIC BACKGROUND

The Moxa Arch and Rock Springs Uplift lie within the Greater Green River Basin located in southwestern Wyoming and northwestern Colorado

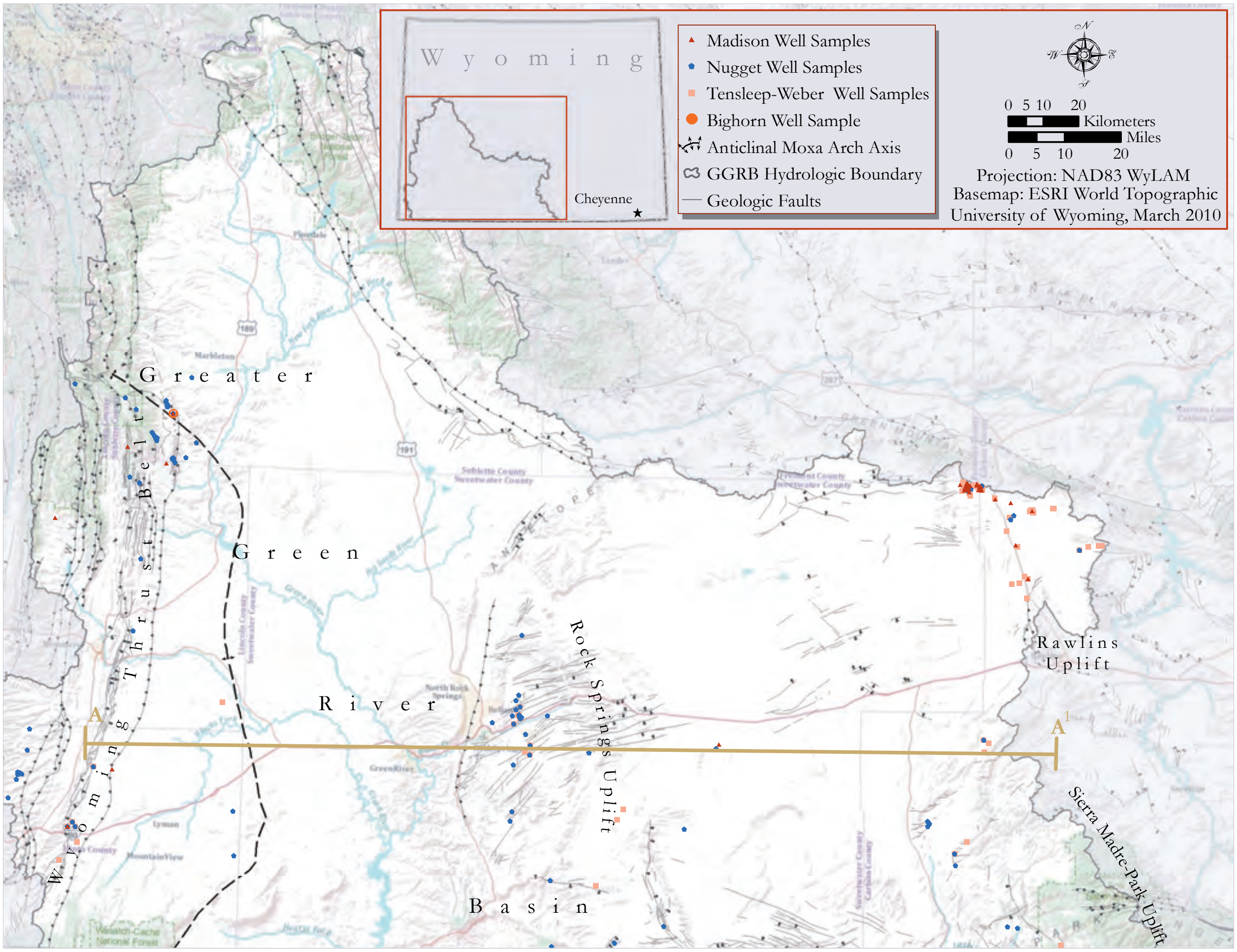


Figure 1. Map of the Wyoming portion of the Greater Green River Basin. Well locations for which water quality data are available are color coded according to the formation from which the geochemical data were collected. The axis of the Moxa Arch is shown by the black dashed line and the location of the cross-section shown in Figure 2 is indicated by line A-A′.

(Fig. 1). It encompasses an area of approximately 21,000 mi^2 (54,000 km^2). The basin is bounded on the west by the western Wyoming Thrust Belt, on the south by the Uinta Mountains and the Axial Basin anticline, on the east by the Sierra Madre and Rawlins Uplift, and on the north and northeast by the Gros Ventre and Wind River Mountains.

The Moxa Arch is a south-plunging, intra-basin, asymmetrical buried anticline about 72 miles (116 km) long and 12 mi (19 km) wide (Figs. 1 and 2). It terminates against the Uinta Mountains of Utah to the south and continues north into the LaBarge Platform. Structural growth of the Moxa Arch began during Frontier Formation deposition and continued into late Campanian time. This movement was contemporaneous with deformation in the western Overthrust Belt during the Sevier orogeny (Lehrer, 2006). Subsequent structural contraction during the late Laramide Orogeny reversed the original northward plunge of the arch and rotated it slightly to the east into its current structural position. This uplift resulted in the erosional truncation of over 3500 ft (1067 m) of Cretaceous Rock Springs and Hilliard Formations (Lehrer, 2006).

The Rock Springs Uplift is a north–south-trending, anticlinal structure in southwest Wyoming that formed in the Late Cretaceous/early Tertiary. The uplift is approximately 60 mi (100 km) long by 40 mi (65 km) wide. The uplift lies in the middle of the Greater Green River Basin and separates the Green River sub-basin to the west from the Washakie and Sandwash sub-basins to the east (Mederos et al.,

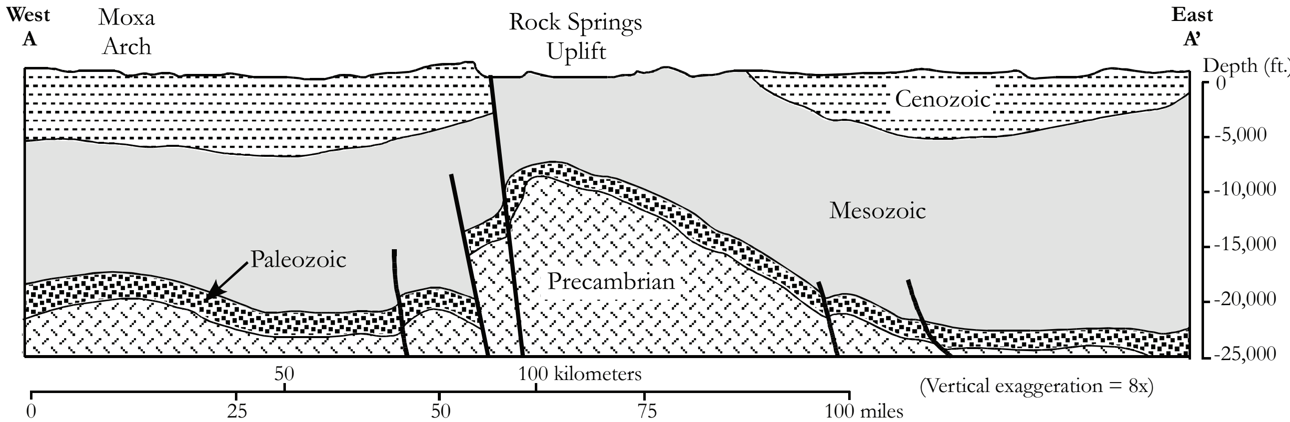


Figure 2. Schematic east–west cross section through the Greater Green River Basin. Vertical exaggeration 8x. Modified from Clarey (2008).

2005). The uplift is characterized by its asymmetric, west-vergent, antiformal shape and doubly plunging geometry. Seismic data suggest that a high-angle, west-vergent reverse fault occurs under the steeper western flank of the anticline and that basement is involved in the uplift (Bradley, 1964; Garing and Tainter, 1985; Montgomery, 1996). The uplift displays 14,800 ft (~4.5 km) of structural relief relative to the surrounding basins (Fig. 2; Montgomery, 1996).

Four geologic formations appear to be the best candidates for CO_2 storage because they may have appropriate porosity, permeability, and capacity to hold large quantities of CO_2, they are overlain by thick shales and other sealing rock types, and they lie at sufficient depth to store CO_2 as a supercritical fluid. These are the Nugget Sandstone, Tensleep/Weber Sandstone, Madison Limestone, and Bighorn Dolomite (Fig. 3).

The Jurassic Nugget Sandstone is a major eolinite that, along with its probable equivalents such as the Navajo Sandstone, spans an area from northern Wyoming southward into Arizona and eastward into Colorado. In the Utah-Wyoming thrust belt, the Nugget is texturally heterogeneous with anisotropic reservoir properties inherited primarily from the eolian depositional environment (Lindquist, 1988). Nugget dune deposits primarily consist of grain-flow and wide-ripple cross-strata, the former of which have the better reservoir quality and the lesser heterogeneity in bedding texture. The thickness of the Nugget Sandstone in southwestern Wyoming varies from around 800 to 1000 ft (240 to 305 m), and porosity is variable (Table 1; Johnson, 2005). Low-permeability, gouge-filled micro-faults compartmentalize the formation, whereas intermittently open fractures provide effective permeability paths locally (Lindquist, 1988).

The Pennsylvanian Tensleep/Weber Sandstone was deposited in a marginal-marine setting of low relief where coastal dunes, marine foreshores and shorefaces, and carbonate shoals shifted positions in response to minor changes in sea level and sediment supply; this fluctuation of environments resulted in a complex package of interfingering lithofacies (Johnson, 2005). The sandstone is called Tensleep throughout much of Wyoming, although it is referred to as the Weber at oil and gas fields on the east side of the Rock Springs Uplift and the Sand Wash Basin. The Weber is approximately equivalent stratigraphically to the Tensleep Sandstone, but the upper part of the Weber is younger than the Tensleep (Johnson, 2005). Numerous dolomite layers exist throughout the Tensleep/Weber Formation, some as much as 12 ft (4 m) thick. The intervening thick bodies of quartz sand exhibit prominent crossbedding, some sets more than 50 ft (15 m) thick, as well as distinctive intervals of large-scale contorted bedding (Boyd, 1993). The formation contains linear and barchan dunes as well as interdunal deposits. The thickness of the formation is highly variable and depends on specific location, but most geologists report an average of about 500–700 ft (150–215 m) (Table 1; e.g., Johnson, 2005).

The Mississippian Madison Limestone was deposited on a carbonate shelf along the western

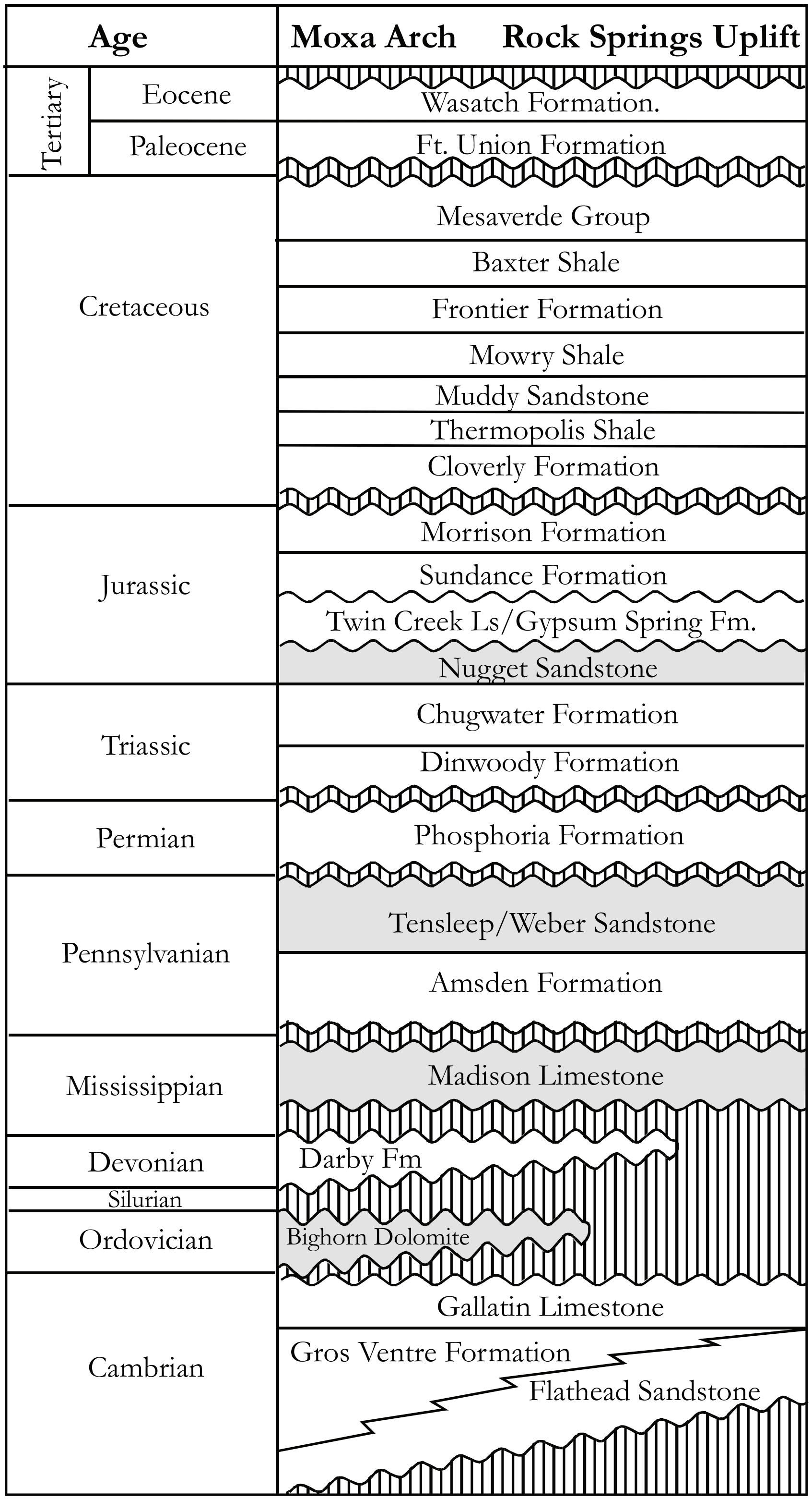


Figure 3. Schematic Phanerozoic stratigraphic chart for southwestern Wyoming, including the Moxa Arch and Rock Springs Uplift. Simplified from Love et al. (1993).

edge of the North American craton. Where exposed at the southern end of the Wind River Mountains, the Madison is at least 215 ft (66 m) thick (Table 1; Berry, 1960). Over most of the state of Wyoming, the Mississippian carbonate strata are given formation rank as the Madison Limestone. Several of the equivalent strata, including Lodgepole Limestone, Mission Canyon Limestone, and Pahasapa Limestone, differ in ratio of dolomite to limestone, bedding type, texture, grain origin, and chert content (Boyd, 1993). The narrow seaway that extended into part of Wyoming in latest Devonian time was reestablished very early in Mississippian time after a brief absence. The limited areas drowned in these incursions received several tens of feet of conodont-bearing dark shale and silty dolomite now recognized as a basal member of the Madison sequence (Boyd, 1993). The Madison is the most productive gas reservoir in the Green River Basin, with an original in-place natural gas resource of 22 trillion standard cubic feet (TSCF; Huang et al., 2007). Production is mainly from the LaBarge Platform at the northern end of the Moxa Arch. The gas is on average composed of 66 percent CO_2, 21 percent methane, 7 percent nitrogen, 5 percent hydrogen sulfide, and 0.6 percent helium. Some CO_2 is separated from natural gas and helium at ExxonMobil's Shute Creek processing facility and supplied for enhanced oil recovery operations within Wyoming and Colorado. The remaining CO_2 is vented or injected into down-dip acid gas injection wells (Huang et al., 2007). The Madison Limestone lies approximately 14,000 ft (4300 m) below ground level on the Moxa Arch near Shute

Table 1. Number of wells with water quality data (Appendix 1) and reservoir properties of formations of interest (Johnson, 2005).

Formation	Number of Wells	Thickness (ft)			Porosity range (%)
		Mean	Max	Min	
Nugget	87	900	1050	800	11–18
Tensleep	87	640	840	500	4–12
Madison	41	250	410	215	10–13
Bighorn	7	450	500	200	2–8

Table 2. Average water quality by formation, in mg/L, for formations of interest. Data from Appendix 1.

Formation	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^-	SO_4^-	Cl^-	TDS	pH
Nugget	960	161	14732	507	1460	1996	23015	42110	7.2
Tensleep	512	131	3431	104	1319	2541	4020	11570	7.6
Madison	613	135	4270	154	1014	2491	5814	14114	7.4
Bighorn	529	98	6037	339	1896	1750	8220	17974	8.1

Creek and 7500 ft (2300 m) below ground level at the crest of the Rock Springs Uplift.

The Bighorn Dolomite is an Upper Ordovician unit that is overlain by the Madison Limestone, Tensleep Sandstone, and the Nugget Sandstone, and like the other formations is also of sufficient thickness and adequate porosity to represent a potential target reservoir for geologic sequestration (Table 1). The Bighorn Dolomite shares stratigraphic, paleontologic, and petrologic similarities with correlative rocks from west Texas to east-central Montana (Zenger, 1996). Sweet (1979, p. 46) describes the lower part of the Upper Ordovician western midcontinent succession as characterized by "…thick-bedded to massive, burrow-mottled skeletal wackestone and packstone, which, in many parts of the area studied have been altered to microcrystalline dolomite with little indication of original limestone fabric." Water quality data from this unit in the Green River Basin are sparse because relatively few wells penetrate this deepest formation.

GEOCHEMICAL DATA

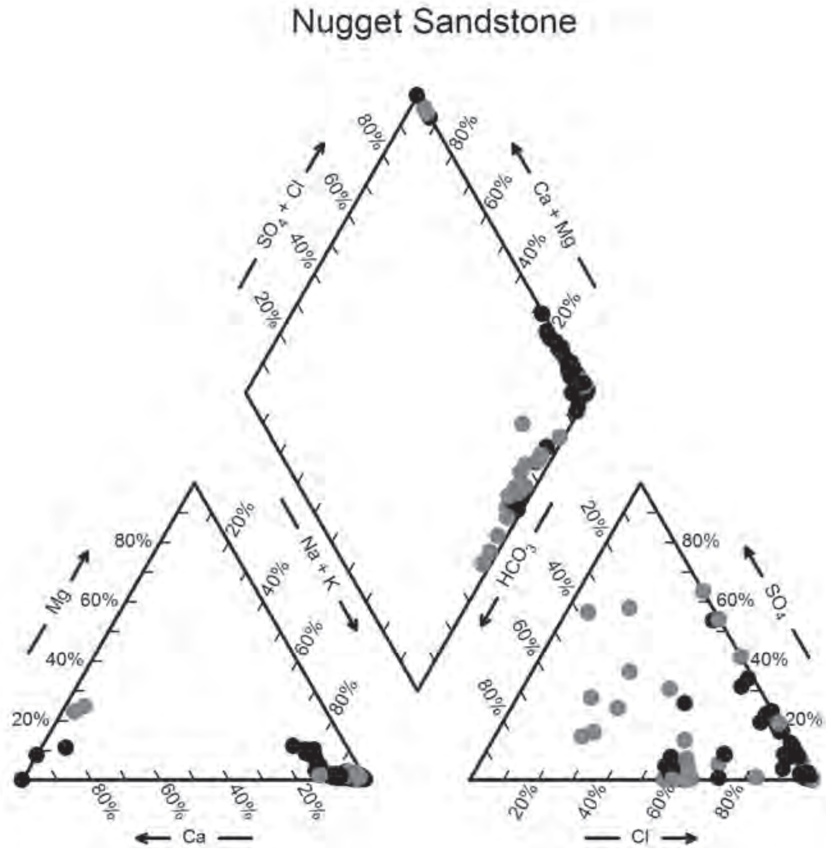
The geochemical data used in this study were compiled from two online sources: the Wyoming Oil and Gas Conservation Commission (http://wogcc.state.wy.us/) and the United States Geological Survey (http://energy.cr.usgs.gov/prov/prodwat/data.htm). Average data for each formation is presented in Table 2; the complete data set are provided in Appendix 1.

Geochemical variation Piper diagrams were created with AqQaChem software (version 1.1.1) from RockWare from the compiled water quality data (Figs. 4–7; Appendix 1). Average water quality for each formation is presented in Table 2. Data for the Nugget, Tensleep/Weber, and Madison Formations are plotted spatially (Figs. 8–10) and contoured using kriging, an interpolation method based on statistical models that use spatial autocorrelation. This method assumes that distance and direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Inspection of the maps reveals that the distribution of data points has a profound effect on the resulting surfaces. With well sample locations distributed sporadically and centering on certain fields, the results skew when a single input point influences the resulting prediction surface.

The waters in this study from the Nugget Sandstone are dominantly Na^+-Cl^- plus a few samples of Ca^{2+}-Cl^- type (Fig. 4). The TDS of Nugget Sandstone waters are highly variable, ranging from 100 to >100,000 TDS (Appendix 1). The waters from the Tensleep/Weber Sandstone are dominantly Na^+-Cl^- to Ca^{2+}-SO_4^- type, with TDS values >10,000 mg/L in the majority of the basin (Fig. 5; Appendix 1). The waters from the Madison Limestone are predominantly Na^+-Cl^- type with a few samples trending to Ca^{2+}-SO_4^- type (Fig. 6). In the majority of the basin, the TDS values are >10,000 mg/L (Appendix 1). On the basis of very limited data, the waters from the Bighorn Dolomite appear to be Na^+-Cl^- type, and TDS values are variable, with three samples >18,000 mg/L and four samples <6000 mg/L (Fig. 7; Appendix 1).

DISCUSSION

The potential receiving formations in the Greater Green River Basin can be divided into two major types: the sandstone



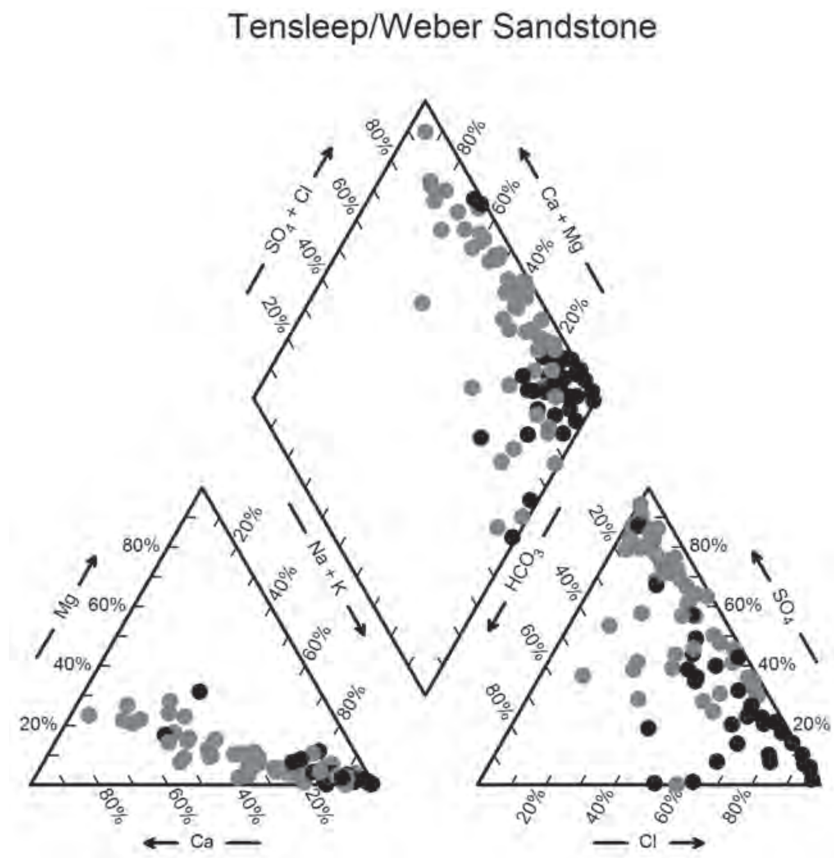
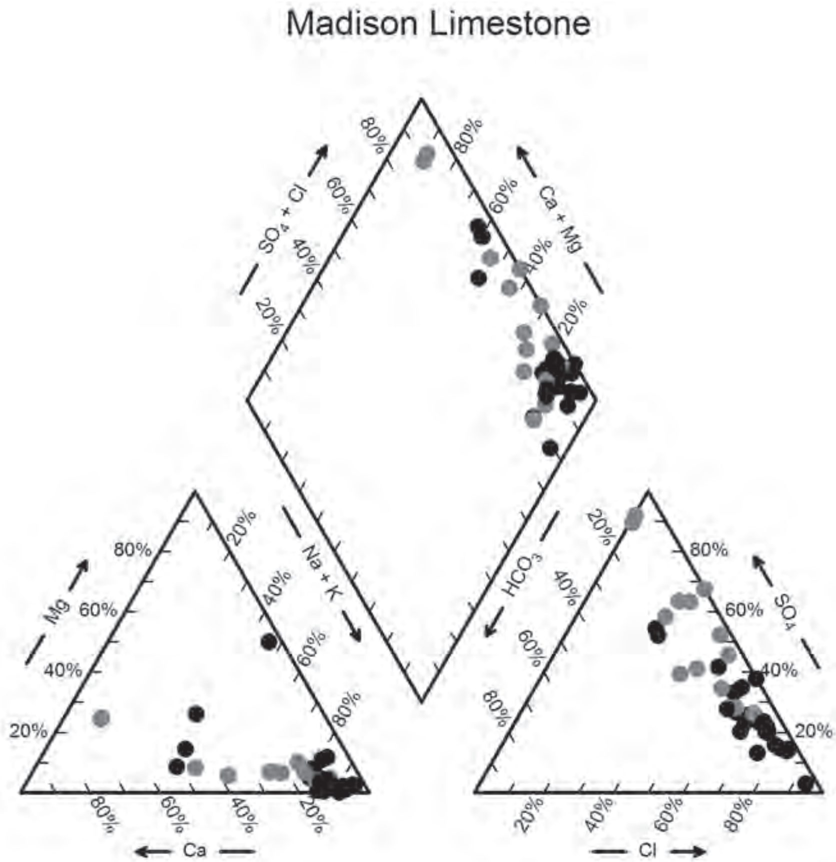


Figure 4 (top). Piper diagram for the Nugget Sandstone showing chemical variation for water quality data from Nugget Sandstone groundwater. Black symbols represent samples with >10,000 mg/L TDS; gray symbols represent samples with <10,000 mg/L TDS.

Figure 5 (bottom). Piper diagram for the Tensleep Sandstone showing chemical variation for water quality data from Tensleep Sandstone groundwater. Black symbols represent samples with >10,000 mg/L TDS; gray symbols represent samples with <10,000 mg/L TDS.

aquifers comprising Nugget and Tensleep, and the carbonate aquifers comprising Madison and Bighorn. A great deal of research has focused on mineral trapping potential of sandstone aquifers. The findings indicate that reactions with Ca/Mg/Fe-bearing silicate minerals neutralize the acidic CO_2 and provide alkali metals that trap the CO_2 through the precipitation of carbonate (Gunter et al., 1997, 1999; Saylor et al., 2001; Hovorka et al., 2001). However, these chemical processes are very slow because of the low chemical reaction rates of the clay and feldspar minerals involved in the reactions. Injection of CO_2 into a sandstone reservoir like the Tensleep or Nugget Sandstone may initiate similar kinds of chemical reactions and utilize the buffering power of aluminosilicate reactions to take up the CO_2 through production of bicarbonates. However, the sandstone thickness, seal strata, grain size, permeability, porosity, and the mineralogy of these sandstones will be the prime determinants of their geologic sequestration potential. Mineralogy is important because the proportion of reactant CO_2 to the proportion



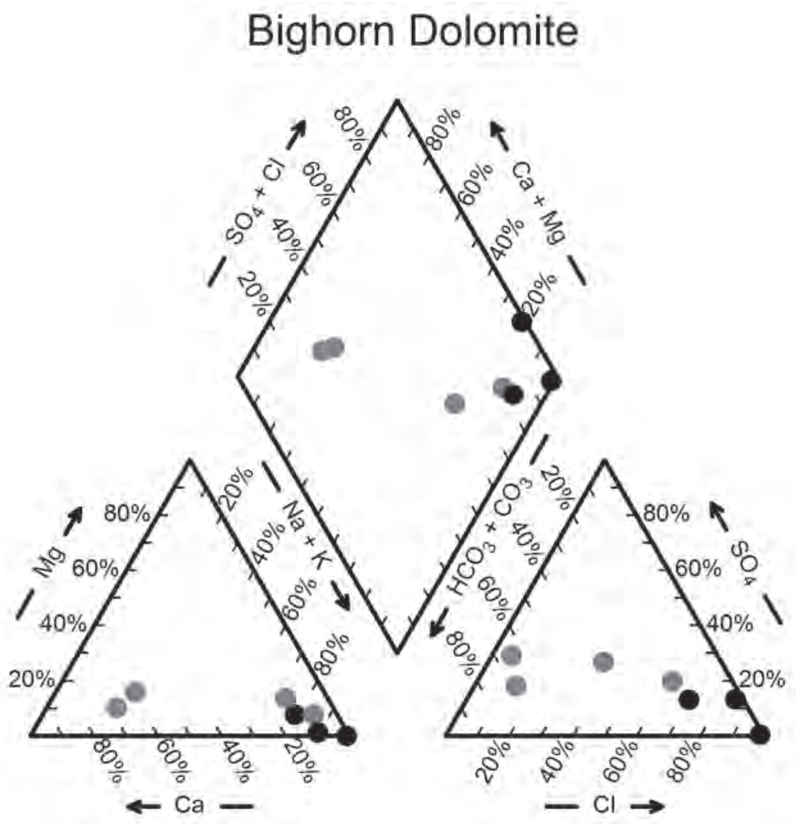


Figure 6 (top). Piper diagram for the Madison Limestone showing chemical variation for water quality data from Madison Limestone groundwater. Black symbols represent samples with >10,000 mg/L TDS; gray symbols represent samples with <10,000 mg/L TDS.

Figure 7 (bottom). Piper diagram for the Bighorn Dolomite showing chemical variation for water quality data from Bighorn Dolomite groundwater. Black symbols represent samples with >10,000 mg/L TDS; gray symbols represent samples with <10,000 mg/L TDS.

of reactant mineral in the rock will determine the amount of CO_2 stored as mineral precipitate. Moreover, the Nugget Sandstone, in which carbonate is the most prevalent cement, will have a different reactive potential than Tensleep Sandstone, which is cemented by quartz overgrowths as well as carbonate (Fox et al., 1975; Knapp, 1978). Much less is known about sequestration of CO_2 in carbonate-rich rocks like those of the Madison and Bighorn Formations. However, it is generally agreed the reactions between CO_2 and carbonate rocks involve dissolution of calcite and adsorption of dissolved calcium on clays and formation of bicarbonate ions neutralizing the dissolution of CO_2 and buffering carbonate dissolution (Gunter et al., 1993).

In both sandstone and carbonate reservoirs the reactions with minerals in the formation are hypothesized to be much slower than reactions with formation water. Therefore, the sequestration resulting from simple CO_2–water interaction is more important on short time scales (Gilfillan et al., 2009). This is mainly because the dissolution of injected CO_2 into formation water produces

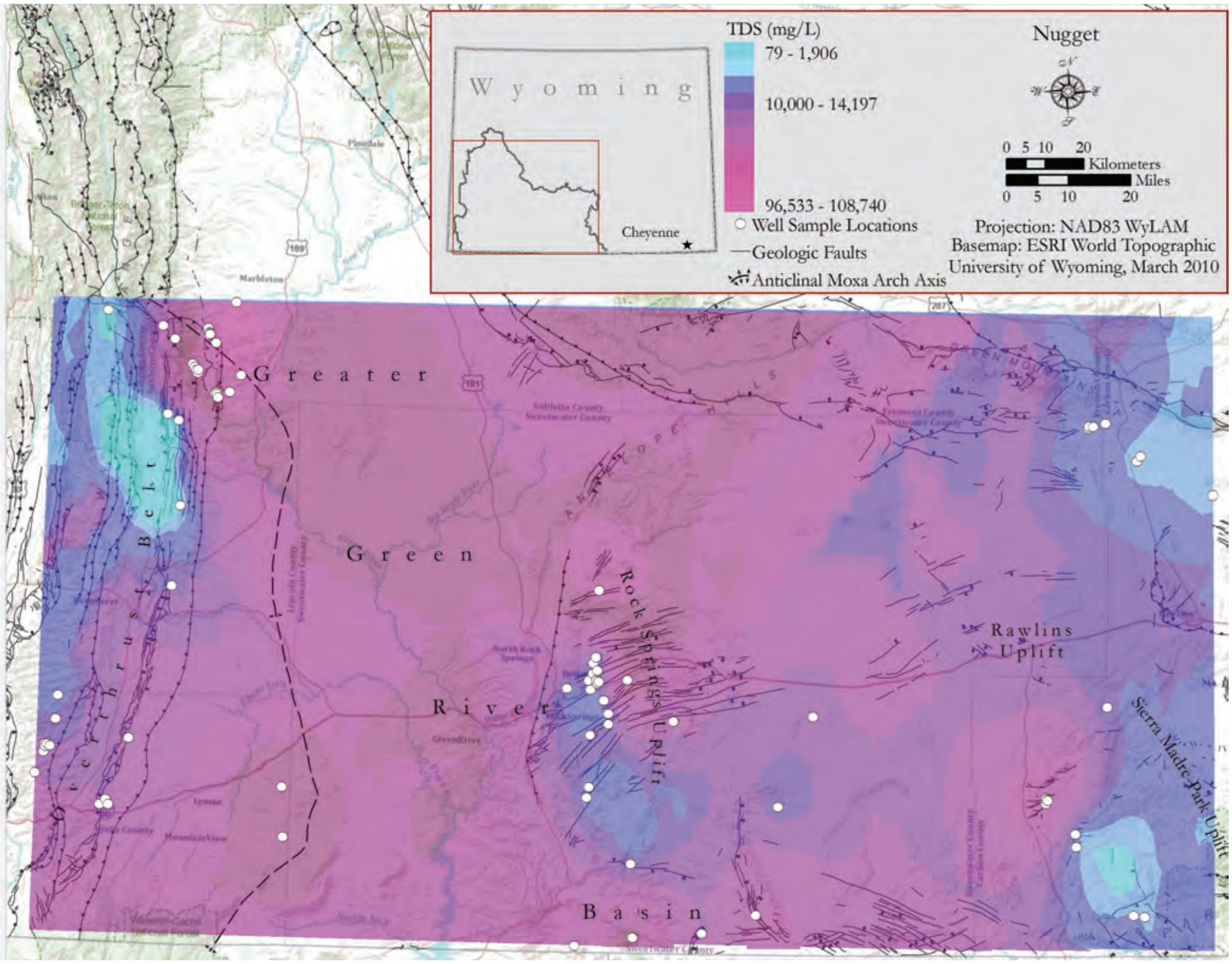


Figure 8. Geospatial map of the Green River Basin for the Nugget Sandstone showing the variation in TDS relative to well locations.

carbonic acid (H_2CO_3), which forms large sinks of CO_2 and initiates other water–rock reactions. The chemical composition of water is important because the solubility of injected CO_2 will be controlled by concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^-, and SO_4^- in the formation water (Duan and Sun, 2003; Chapoy et al., 2004; Duan et al., 2006).

Spatial variability of water quality data

The water quality data for the Nugget Sandstone show spatial variability, as displayed in the TDS geospatial map (Fig. 8). Areas of low TDS indicate potential recharge zones, both along basin margins and in the Rock Springs Uplift area in the central part of the basin. The inferred rock fracture permeability in the Nugget Formation is considered high in the Rock Springs Uplift region (Clarey, 2008), and this could possibly account for the fresh water recharge in the central parts of the basin. It appears that the majority of Nugget wells in the Rock Springs Uplift are near surface faults (Fig. 1), which may provide conduits for fresh water recharge. If true, then the Nugget Sandstone may be a poor receiving formation for CO_2 storage in the Rock Springs Uplift because of the potential for leakage along these pathways.

Water quality data for the other formations studied suggest recharge is limited to the basin margins. The Tensleep/Weber waters with <10,000 mg/L TDS are present along the eastern edge of the basin and probably represent areas of fresh water recharge near the Rawlins and Sierra Madre-Park Uplift (Fig. 9). These waters also have low concentrations of Na^+, Cl^-, and SO_4^-. For the Madison Limestone, the low

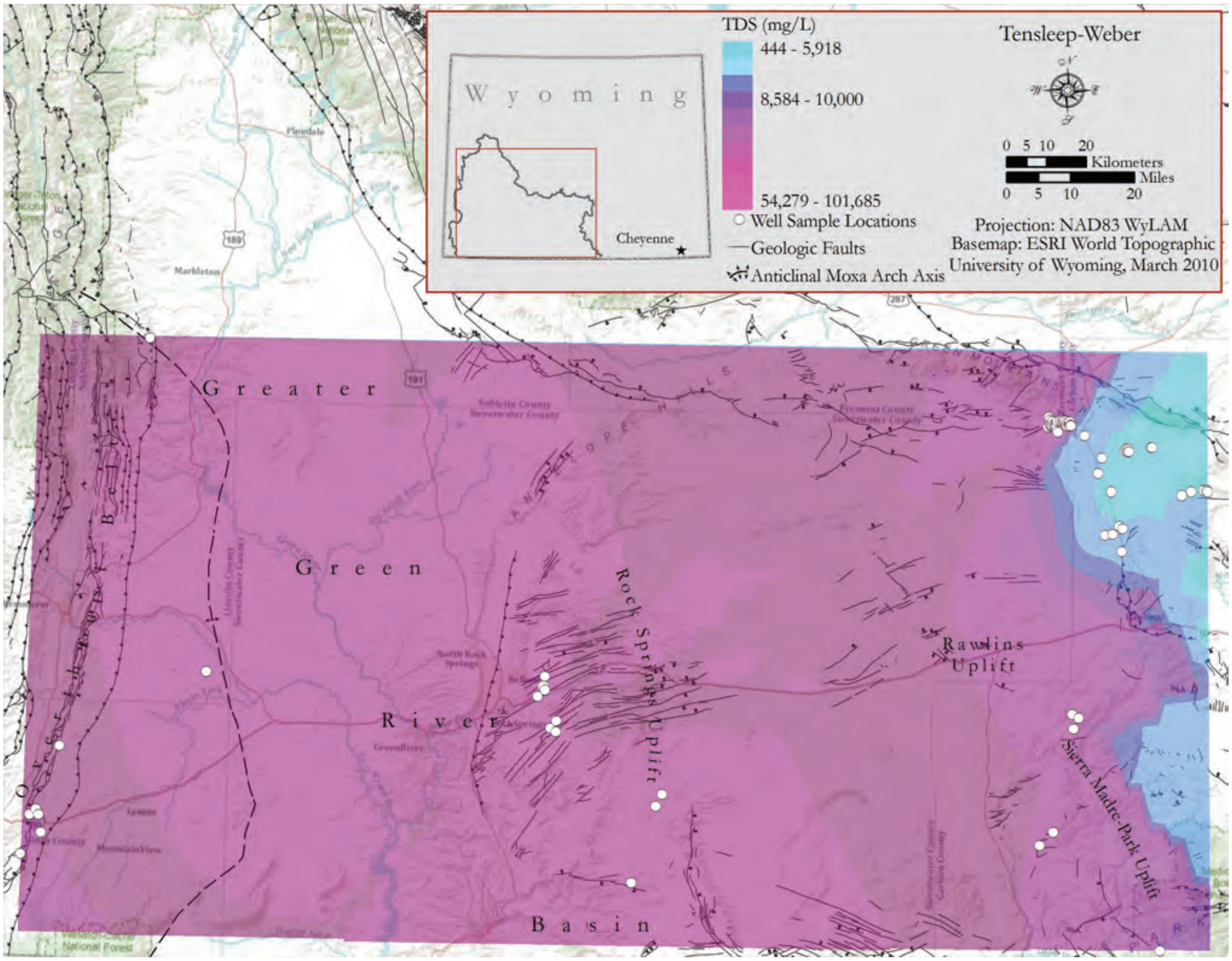


Figure 9. Geospatial map of the Green River Basin for the Tensleep Sandstone showing the variation in TDS relative to well locations.

TDS waters characterize areas receiving fresh water recharge near the eastern and northwestern parts of the basin (Fig. 10). These recharge zones are present in parts of the basin where the Madison Limestone is exposed at or near the surface, such as areas surrounding the Rawlins Uplift in the northeastern part of the basin and the overthrust belt in the northwestern part of the basin. In both Tensleep/Weber Sandstone and Madison Limestone, the Na^+-, Cl^-–, and SO_{4-} concentrations and TDS values tend to increase with increasing distance from recharge areas toward the basin margin. The presence of briny Na^+, Cl^-, and SO_{4-}-rich waters in the deeper central part of the basin indicate that halite and gypsum/anhydrite dissolution was probably an important source of salinity in these formations in addition to, or instead of, evaporated seawater. Bighorn Dolomite water quality data are limited to the western edge of the Green River Basin, where TDS values are variable. Because the data include some high TDS values even on the basin margins, then as was true for the overlying Madison and Tensleep aquifers, it is likely that TDS will exceed the definition of a USDW in the Bighorn Dolomite in the middle of the basin. Therefore the Bighorn Dolomite should be considered a viable target for geologic sequestration along with the other Paleozoic target formations.

The data compiled in this study indicate that the Tensleep/Weber Sandstone, Madison Limestone, and probably also the Bighorn Dolomite, contain water too saline to meet the definition of a USDW except near recharge zones along basin margins. The Nugget Sandstone also exceeds the definition of a USDW except along basin margins and on most of

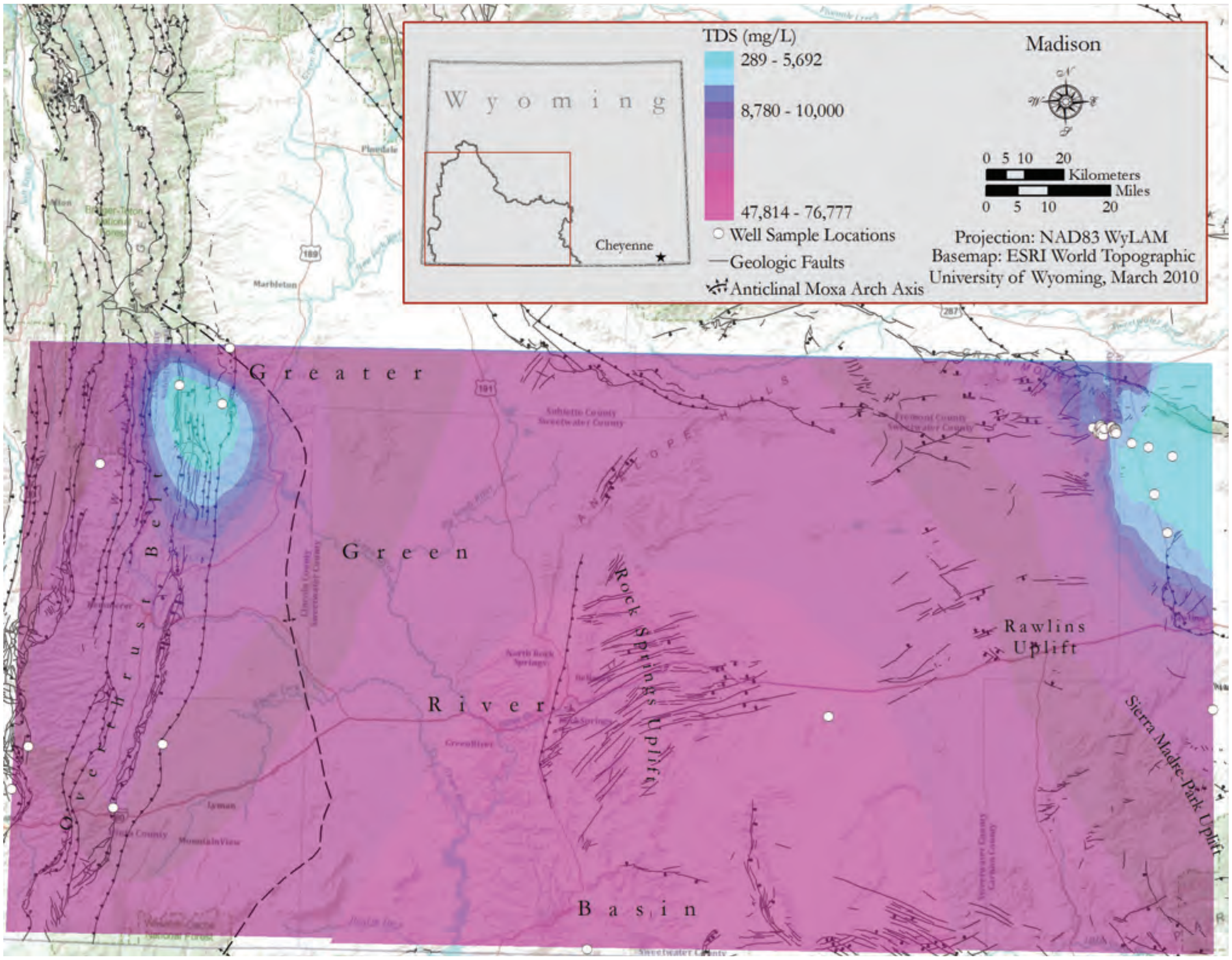


Figure 10. Geospatial map of the Green River Basin for the Madison Limestone showing the variation in TDS relative to well locations.

the Rock Springs Uplift. The relatively high density of mapped surface faults and potential for fault and fracture permeability on the Rock Springs Uplift decreases the suitability of the Nugget Sandstone as a CO_2 storage formation.

CONCLUSION

To assess the long-term CO_2 storage potential of any geological formation it is important to develop a good understanding of these CO_2–water–rock interactions. In order to develop accurate models it is necessary to have baseline chemistry information on the formation waters and rocks into which CO_2 is proposed to be injected. Field experiments are difficult to implement due to the long timescales of these reactions and challenges associated with the sample accessibility. Laboratory experiments and numerical and geochemical models are commonly used for predicting the fate of these CO_2–water–rock interactions. The preliminary geochemical data generated in this study can be used to characterize the chemical composition of formation waters and help to develop realistic geochemical models for these target formations.

Geologic sequestration should be considered in regions where TDS values of brines are greater than 10,000 mg/L and where baseline water quality data are available so that potential chemical reactions between CO_2, the reservoir host-rock, and brines may be modeled and understood. Based on the available geochemical data in this study, the Madison Limestone and Tensleep/Weber Sandstone waters meet the EPA Class

VI requirements for injection in the majority of the Green River Basin. Although water quality data are sparse, the Bighorn Dolomite most likely also exceeds the EPA definition of a USDW. On the other hand, the water quality data for the Nugget Sandstone suggest that groundwater from this formation is below 10,000 mg/L TDS and meets the definition of a USDW on much of the Rock Springs Uplift. TDS on the uplift are variable; this variability may be related to proximity to faults, which may serve as conduits for recharge. The apparent higher fracture permeability for formations nearest the surface suggests caution is appropriate when considering younger units like the Nugget Sandstone for geologic sequestration.

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Appendix 1. Water quality data used in this study. Cation, anion, and total dissolved solids (TDS) concentrations are in mg/L. Data sources: WOGCC = Wyoming Oil and Gas Conservation Commission (http://wogcc.state.wy.us/), USGS = United States Geological Survey (http://energy.cr.usgs.gov/prov/prodwat/data.htm); NA = not available; an entry of -3 = no data; and entry of -1 = trace quantity. Continued on pages 107–111.

Nugget Sandstone:

Well API	LATITUDE	LONGITUDE	Ca	Mg	Na	HCO3	K	SO4	Cl	TDS	pH	Upper Depth (feet)	Lower Depth (feet)	Data source
4904120184	41.386060	-110.841730	865	131	7650	244	232	3500	11200	23698	6.1	NA	NA	USGS
NA	41.4348	-110.8176	478	68	5316	244	157	3450	6700	16289	7.1	7492	7506	USGS
4904120080	41.45364	-110.81339	412	111	5006	195	150	4200	5700	15675	7.3	7956	7968	USGS
4904120113	41.448300	-110.812460	457	56	4801	256	-3	3150	5800	14779	NA	NA	NA	USGS
4904120080	41.453640	-110.807410	467	84	4705	268	-3	3145	5500	14539	NA	NA	NA	USGS
NA	41.4496	-110.7984	467	62	4657	281	130	3450	5600	14504	6.9	7459	7470	USGS
4904120236	41.5128	-110.78346	444	63	3297	154	-3	2800	3900	10658	6.8	8748	8818	USGS
NA	41.5682	-110.7792	356	44	2226	195	-3	3700	1350	7871	6.9	9551	9610	USGS
NA	42.472433	-110.666846	29	5.5	1.4	122	0.6	3690	1.2	168.1	8	NA	NA	USGS
4904105215	41.31693	-110.63675	1065	381	8245	559	-3	4398	12120	26498	7.6	2120	NA	WOGCC
4904105218	41.329300	-110.619010	1093	491	6013	48	-3	3884	9700	21268	7.8	NA	NA	USGS
4904105216	41.317780	-110.610400	929	374	7698	465	-3	4324	11400	25040	NA	NA	NA	USGS
4904105244	41.47508	-110.55462	1045	437	7307	550	-3	4304	10900	24264	7.9	1170	NA	USGS
4903520394	42.44045	-110.49079	330	44	6807	73	275	3280	9000	19772	7	11267	11294	USGS
NA	42.234661	-110.466280	51	11	4.3	210	0.9	2876	3.2	303.3	8	NA	NA	USGS
4903505776	42.41089	-110.45225	777	113	16400	380	-3	2416	25000	44893	7.4	11620	11646	USGS
4902360015	41.83405	-110.43624	568	275	4011	273	-3	5790	3540	14457	NA	2225	2230	USGS
NA	42.220217	-110.431279	50	745	3.6	0	-3	4576	2.5	79	NA	NA	NA	USGS
NA	42.022165	-110.418222	57	24	8.6	0	-3	1498	11	104	NA	NA	NA	USGS
4903520218	42.353210	-110.393010	1862	37	29931	342	-3	1300	50800	86139	NA	NA	NA	USGS
NA	42.5	-110.2622	2650	305	34471	451	2500	1029	60000	101177	6.2	9600	NA	USGS
4903520165	42.338690	-110.381540	1960	276	31269	342	-3	1251	53000	89865	NA	NA	NA	USGS
4903520198	42.33261	-110.37653	2107	239	31884	342	1800	1362	54000	91560	8	11008	11064	USGS
4903520345	42.33979	-110.37522	2167	172	32436	268	1800	1150	55000	92857	7.3	10974	10980	USGS
4903505833	42.433660	-110.349760	390	253	32767	635	-3	936	50000	85259	NA	NA	NA	USGS
4903520169	42.4374	-110.34886	3500	2135	31577	586	2200	1060	62000	102761	6.7	9796	9830	USGS
4903505819	42.42839	-110.34531	2573	214	35489	390	-3	1000	59000	98497	6.8	9770	9808	USGS
4903520058	42.42168	-110.34476	2812	135	31114	622	1860	934	54000	91161	6.8	9432	9464	USGS
4903505812	42.42476	-110.3428	3208	413	38527	236	-3	1145	65331	108740	6.5	9874	9891	USGS
NA	42.4234	-110.3415	2996	386	35973	220	-3	1069	61000	101532	6.5	9874	9891	USGS
4903505746	42.40369	-110.32238	2792	257	36526	403	-3	1078	61000	101851	6.2	10079	10101	USGS
4903505128	42.28565	-110.3215	1869	169	30019	415	1750	950	50800	85772	7.3	11020	11030	USGS
4903506320	42.28741	-110.31922	1674	230	29392	403	1720	400	50000	83614	7	10817	10840	USGS
4903505176	42.288550	-110.316180	1883	209	31412	378	317	1030	53000	89210	8.1	NA	NA	USGS
4903520035	42.28341	-110.31555	1090	109	18936	622	640	371	31400	52852	6.6	NA	NA	USGS

Well API	LATITUDE	LONGITUDE	Ca	Mg	Na	HCO3	K	SO4	Cl	TDS	pH	Upper Depth (feet)	Lower Depth (feet)	Data source
4903520062	42.276180	-110.310260	1961	123	32633	403	-3	848	55000	92629	NA	NA	NA	USGS
NA	42.2905	-110.2738	1850	305	31220	464	2300	868	53500	90272	6.2	10800	NA	USGS
NA	42.5	-110.2622	2650	305	34471	451	2500	1029	60000	101177	6.2	9600	NA	USGS
4903505450	42.3301	-110.23964	2288	320	35532	365	-3	785	59000	98105	6.8	10128	10178	USGS
4904105230	41.37155	-110.07275	1475	139	28645	990	-3	216	46500	77487	6.9	14526	14646	USGS
4904120019	41.25489	-110.06478	1078	239	27816	488	1000	184	46000	76557	7.7	14597	14643	USGS
NA	41.619131	-109.192070	78	37	2700	590	-3	210	3700	7511.1	NA	NA	NA	USGS
4903720754	41.01673	-109.15309	23	14	16781	3123	1127	1320	24200	45003	6.3	12040	12080	USGS
4903720396	41.36402	-109.12415	123	24	2596	2513	140	418	2650	7189	8	3619	3630	USGS
4903705644	41.63844	-109.12385	103	30	5703	6000	-3	918	4899	14004	7	4132	4700	USGS
4903705584	41.61675	-109.1187	80	37	4106	4600	-3	117	3823	10425	NA	4010	4078	USGS
4903705290	41.38876	-109.11855	100	44	2933	3550	203	-1	3000	8038	8.2	3826	3842	USGS
4903705353	41.51061	-109.11662	115	30	4616	4760	-3	59	4600	11764	8	4533	4554	USGS
4903705693	41.65449	-109.112	86	37	4088	4100	-3	-3	3900	10369	7.3	4064	4076	USGS
4903705757	41.67835	-109.11156	125	25	4066	4830	-3	78	3700	10372	7.9	4365	4375	USGS
4903705775	41.69287	-109.10299	39	41	4238	4150	-3	451	3980	10793	8	4577	4587	USGS
4903705660	41.64132	-109.1009	90	44	3936	4700	-3	11	3619	9011	NA	4290	4300	USGS
4903705641	41.63772	-109.10073	61	29	4049	4350	-3	-3	3908	10186	NA	4095	4135	USGS
4903705712	41.66199	-109.09769	48	-1	1613	1155	-3	1067	1115	4998	NA	4169	4223	USGS
4903705622	41.6314	-109.0973	34	37	3782	3375	-3	290	3564	9590	8.15	4015	4034	USGS
4903720156	41.84953	-109.09676	171	50	34887	5124	1550	14489	42000	95670	7.8	8115	8160	USGS
4903705630	41.635080	-109.092440	103	30	2909	2500	-3	443	2695	9111	7	NA	NA	USGS
4903705528	41.59123	-109.07643	106	51	3824	4490	-3	23	3380	9787	8.3	4377	4396	USGS
4903705377	41.53696	-109.06119	20	38	3899	4900	-3	60	3267	9677	NA	3333	3350	USGS
4903705440	41.56126	-109.0611	110	39	3459	3800	-3	9	3429	8916	NA	3542	NA	USGS
4903705658	41.64035	-109.00351	1087	398	26182	781	-3	1375	42000	71823	7.8	4680	4754	USGS
4903705196	41.21016	-108.98377	69	20	3392	3250	-3	34	3500	8617	7.5	7180	7207	USGS
4903720007	41.03787	-108.97443	729	176	21617	1952	1400	3634	32600	61117	7.4	14422	14465	USGS
4903705405	41.54574	-108.85859	207	34	9364	5480	-3	1658	10500	24462	7.4	6673	6683	USGS
4903705405	41.545740	-108.858590	229	27	9662	5620	-3	4850	10800	25276	7.3	NA	NA	USGS
4903705104	41.04986	-108.76042	279	17	6766	964	650	4850	7300	20518	8.6	13790	14253	USGS
4903705131	41.09511	-108.59389	56	8	14349	451	1385	340	23000	39360	6.7	14722	14940	USGS
4903720522	41.34927	-108.52861	25	6	3822	1635	39	57	5000	9754	7.2	NA	NA	USGS
4903706394	41.560680	-108.422340	112	51	5866	4002	285	95	4800	16498	8.6	NA	NA	USGS
4900705087	41.360930	-107.696760	1034	4	18532	476	-3	70	30000	51895	NA	NA	NA	USGS
NA	41.374000	-107.696600	837	26	16256	427	65	109	26600	45947	NA	4776	4816	USGS
NA	41.374000	-107.696600	949	58	19957	464	-3	105	32000	55165	NA	NA	NA	USGS
4900705095	41.370130	-107.693730	798	2	18941	476	24	81	28800	51289	NA	NA	NA	USGS
NA	41.368000	-107.691000	809	364	20483	488	45	106	32800	56427	7.6	3871	3913	USGS
4900705066	41.289980	-107.604120	46	7	1130	1175	-3	98	123	3292	NA	NA	NA	USGS
4900705062	41.259400	-107.601350	42	7	1725	1183	63	91	510	5143	8.1	2883	2918	USGS

Well API	LATITUDE	LONGITUDE	Ca	Mg	Na	HCO3	K	SO4	Cl	TDS	pH	Upper Depth (feet)	Lower Depth (feet)	Data source
4903706001	42.238280	-107.563450	20	38	1521	2318	-3	90	990	3785	NA	NA	NA	WOGCC
NA	42.243200	-107.562300	11	2	1616	2562	-3	104	1080	4015	7.1	NA	NA	USGS
4903720134	42.242260	-107.549330	36	463	1724	2586	-3	1360	1280	4450	7.4	NA	NA	USGS
NA	42.250000	-107.510600	760	32	1826	622	-3	750	4800	8107	NA	3429	3475	USGS
4900720034	41.587190	-107.505120	95	84	3876	6954	26	1040	750	10316	NA	NA	NA	USGS
4900705219	41.098860	-107.423820	25	6	1997	2500	39	2428	630	5213	7.2	4240	4250	USGS
4900705816	42.161640	-107.412240	18	136	1271	1905	-3	1375	900	3132	NA	NA	NA	USGS
4900705816	42.161640	-107.412240	18	3	1275	1911	-3	1235	903	3141	7.6	NA	NA	USGS
4900705830	42.173010	-107.401310	10	74	1271	1320	-3	1500	880	3081	7.1	NA	NA	USGS
4900706984	41.095800	-107.389930	22	7	1716	2611	30	1750	780	4432	8.2	NA	NA	USGS
4900705722	42.081360	-107.173060	72	25	843	1074	-3	1720	316	2421	NA	NA	NA	USGS

Tensleep/Weber Sandstone:

Well API	LATITUDE	LONGITUDE	Ca	Mg	Na	K	HCO3	SO4	Cl	TDS	pH	Upper Depth (feet)	Lower Depth (feet)	Data source
4904105094	41.22818	-110.65982	890	44	4549	-3	5200	4226	2432	15802	8.6	12877	12927	USGS
4904105215	41.31693	-110.63675	1086	105	5854	-3	3050	4172	5454	18979	7.4	12929	12997	USGS
4904105218	41.3293	-110.61901	820	34	4744	-3	3540	4021	5400	17297	8.2	13004	130092	USGS
4904105216	41.31778	-110.6104	526	140	3918	-3	1405	3876	4700	14013	8.2	6280	6305	USGS
4904105164	41.27724	-110.60089	945	75	3761	-3	4014	3647	3650	15619	7.4	6277	6300	USGS
4904105244	41.47508	-110.55462	962	87	4693	-3	1440	4326	6800	16764	7.9	6502	6527	USGS
4903505746	42.40369	-110.32238	43	44	3860	-3	1830	4852	1360	11192	8.6	12877	12927	USGS
4903705584	41.61675	-109.1187	528	-1	3812	-3	3060	697	4522	12619	NA	6502	6527	USGS
4903705655	41.64014	-109.10509	973	47	26637	-3	2013	1267	41000	72300	7.6	5515	5535	USGS
4903705660	41.64132	-109.1009	622	101	3732	-3	2100	1327	4952	12834	NA	6280	6305	USGS
4903705712	41.66199	-109.09769	1245	209	10606	-3	3550	1915	15694	33219	NA	6339	NA	USGS
4903705622	41.6314	-109.0973	921	296	15641	-3	0	1977	23760	42595	NA	6277	6300	USGS
4903705395	41.54499	-109.07796	289	65	5612	0	3050	2647	6831	15918	7.7	6217	6247	USGS
4903705377	41.53696	-109.06119	386	80	2347	-3	1740	3974	594	8237	NA	5339	NA	USGS
4903720724	41.198330	-108.827640	283	47	37646	-3	5514	3746	50000	101685	7.2	NA	NA	USGS
4903720384	41.372060	-108.757740	3410	68	4328	-3	1840	2398	11100	21871	NA	6543	6485	USGS
4903720385	41.398810	-108.738500	6860	35	5570	-3	-3	2765	20500	33003	NA	NA	NA	USGS
4900720209	41.36678	-107.65288	369	60	266	5	744	650	330	2046	6.7	10865	10913	USGS
4900705066	41.28998	-107.60412	98	99	8788	573	2093	2706	11219	25675	8.28	10224	10244	USGS
4903721115	42.25761	-107.58083	464	66	3183	138	793	3100	3300	10642	6.7	6624	6700	WOGCC
4903705994	42.23582	-107.5789	31	15	3919	-3	4404	3	3580	9717	7.6	5163	5575	USGS
NA	42.259	-107.5775	2975	1613	3204	180	281	1380	13900	23392	6.7	6204	6244	USGS
4903706285	42.2593	-107.57647	292	51	4571	210	1074	3400	4800	13858	8.1	7625	7807	USGS
4903706012	42.23924	-107.57218	332	75	3283	-3	1167	3903	2314	10481	7.4	6583	6633	USGS
4903706156	42.24645	-107.5718	362	34	7474	60	1183	3750	8900	21169	8.2	5635	6015	USGS
4903706108	42.24382	-107.57079	560	140	11636	795	878	3240	17200	34009	7.8	6106	6138	USGS
4903706018	42.23984	-107.56592	520	79	4884	450	952	2494	6700	15596	7.1	5420	5530	USGS
4903706281	42.25765	-107.56243	309	36	1968	146	493	1790	1785	6277	7.6	5205	5666	WOGCC

Well API	LATITUDE	LONGITUDE	Ca	Mg	Na	K	HCO3	SO4	Cl	TDS	pH	Upper Depth (feet)	Lower Depth (feet)	Data source
4903706218	42.24999	-107.55919	447	99	4570	287	842	3185	5550	14553	7.6	5270	5585	USGS
4903705997	42.2374	-107.55742	507	105	3644	-3	813	2423	4565	11644	7	4500	NA	USGS
4903705968	42.23192	-107.55583	324	60	3295	-3	752	2818	3313	10179	7.2	NA	NA	USGS
4903705985	42.23404	-107.55514	503	22	1384	34	1318	1625	1160	5378	7.2	5445	5487	USGS
4903706087	42.24272	-107.55483	423	79	1644	-3	605	1828	1813	6392	NA	5262	6449	USGS
4903706146	42.24461	-107.55245	377	83	3114	275	1976	3150	2550	10534	6.8	6812	6916	USGS
NA	42.25	-107.5517	387	87	9404	760	2684	4981	10900	27841	7.9	NA	NA	USGS
4903705961	42.2246	-107.55002	608	61	1847	-3	560	3378	1285	7456	7.6	7081	7164	USGS
4903706273	42.25647	-107.54728	403	202	2731	240	1354	2380	3200	9825	7.3	7209	7270	USGS
4903706228	42.25027	-107.54411	1387	594	8962	805	2538	5850	13000	33146	7.2	7239	7291	USGS
4903706470	42.26008	-107.54	1620	836	1055	60	708	1240	5660	10820	6.4	7142	7176	USGS
4903706222	42.25007	-107.5389	948	431	8950	620	1769	3950	13400	29178	7	6904	7058	USGS
4903706238	42.25169	-107.52964	386	56	5433	-3	2390	5473	3800	16329	7	NA	NA	USGS
4903706214	42.24955	-107.52744	175	32	1908	-3	675	2568	1058	6416	NA	6130	NA	USGS
4903706245	42.25249	-107.52452	357	137	4433	258	1977	3892	4131	15112	7.07	6180	6280	USGS
4903706130	42.24441	-107.52314	410	126	4813	380	2147	4100	4600	15488	7.6	6270	6464	USGS
4900706007	42.25174	-107.52058	432	119	6348	-3	2850	4742	5746	20237		6000	6336	USGS
4900705990	42.24263	-107.51721	354	100	3623	-3	1905	3280	2980	11275	7.6	6022	6193	USGS
4900705985	42.24163	-107.51541	587	134	2441	-3	2087	2746	1956	8891	7.6	5869	5883	USGS
4900705987	42.24197	-107.51359	444	104	4000	-3	2380	3436	3340	12496	7.4	6043	6140	USGS
NA	42.2489	-107.5122	71	29	6767	-3	6686	101	6686	16946	7.8	NA	NA	USGS
4900705982	42.24115	-107.5103	24	11	4808	-3	6167	32	3882	11795	8.1	5754	6103	USGS
4900705978	42.23911	-107.5102	467	92	3404	-3	1995	3084	2909	10937	7.2	5757	6044	USGS
4900720034	41.58719	-107.50512	150	92	15617	1700	4453	3494	21000	44246	7.7	10505	10546	USGS
4900705950	42.21707	-107.46766	304	56	574	-3	241	1661	220	2932	7.2	6966	7320	USGS
4900705945	42.21548	-107.46491	335	58	347	9	156	1490	242	2558	7.6	NA	NA	WOGCC
4900705776	42.13147	-107.42624	411	78	381	-3	185	1551	289	2895	NA	4966	NA	USGS
4900705673	41.99278	-107.40684	344	44	1542	-3	260	1728	1690	5476	7.5	4776	NA	USGS
4900705746	42.09028	-107.38749	406	79	564	-3	100	1556	612	3317	NA	5047	NA	USGS
4900705671	41.99527	-107.38253	466	60	1581	-3	175	1675	2100	5968	7.3	3778	3796	USGS
4900705682	42.01304	-107.36344	421	39	1758	-1	317	2318	1697	6556	7.69	3857	3887	USGS
4900705680	42.00689	-107.35221	654	81	1505	-3	255	3217	1191	6773	NA	3404	NA	USGS
4900705860	42.18321	-107.34484	584	122	221	-3	420	1898	85	3330	NA	4408	4532	USGS
4900705860	42.18321	-107.34484	573	121	173	0	354	1757	132	2930	7.2	4410	4532	USGS
4900705861	42.18396	-107.34036	494	113	1164	-3	65	2567	1067	5470	NA	4293	4505	USGS
4900705867	42.18661	-107.34009	718	217	492	-3	420	2671	447	4965	NA	4346	4536	USGS
4900720385	42.18205	-107.33771	573	174	1129	150	342	2250	1285	5730	7.9	NA	NA	WOGCC
4900705866	42.18644	-107.33535	858	272	765	-3	150	2016	1915	5976	NA	4351	NA	USGS
4900705841	42.1796	-107.3349	556	125	761	-3	240	2270	708	4660	NA	4300	4445	USGS
4900705845	42.18046	-107.33224	494	129	245	-3	178	1833	172	2961	7.4	4324	4433	USGS
4900705280	41.64793	-107.27317	232	58	1808	-3	780	3123	608	6054	7.55	6122	6176	USGS
4900705311	41.6551	-107.27303	226	22	1771	-3	1110	1885	1160	5611	7.1	5750	5935	USGS
4900705338	41.6598	-107.27299	198	-1	2575	-3	1475	1646	2250	8144	7.3	5784	6072	USGS
4900705357	41.66259	-107.27299	78	36	4147	-3	1755	1771	4200	11192	8.4	5855	6084	USGS
4900705893	42.19006	-107.26478	303	66	389	-3	295	1530	29	2612	NA	4447	NA	USGS
4900705893	42.19006	-107.26478	341	70	330	0	250	1554	24	2442	NA	4302	NA	USGS
4900705333	41.65819	-107.26433	29	14	326	-3	334	332	156	1021	6.8	6332	6450	USGS

Well API	LATITUDE	LONGITUDE	Ca	Mg	Na	K	HCO3	SO4	Cl	TDS	pH	Upper Depth (feet)	Lower Depth (feet)	Data source
4900705892	42.18991	-107.26178	530	105	47	-3	115	1680	10	2487	NA	4274	4316	USGS
4900705036	41.05145	-107.24339	130	17	381	19	146	950	100	1669	7.8	7642	7670	USGS
4900705036	41.05145	-107.24339	131	12	463	23	110	1150	90	1979	7.7	7642	7670	USGS
4900705414	41.67365	-107.23027	484	69	2053	-3	660	4123	800	7854	7.4	8176	8208	USGS
4900720110	41.59113	-107.21124	170	34	1203	17	329	2200	468	4421	7.7	5216	5287	USGS
4900705722	42.08136	-107.17306	524	97	1022	-3	307	2306	851	4999	8.6	6383	6454	USGS
4900705722	42.08136	-107.17306	772	139	1171	-3	476	3502	630	6399	8.2	6301	6316	USGS
4900705745	42.08972	-107.14401	433	85	1063	-3	367	2030	945	4737	7	6602	6648	USGS
4900706036	41.9638	-107.10584	593	86	1447	-3	842	2185	1430	6156	8.1	8871	8939	USGS
4900705753	42.09259	-107.09661	475	83	838	-3	236	1613	1048	4173	7.9	6891	7002	USGS
4900705572	41.82907	-107.08697	1035	55	2115	-3	3123	3794	640	9177	7.9	4808	4840	USGS
4900706031	41.76378	-107.01976	528	10	2440	-3	342	5514	460	9120	8.2	3885	3987	USGS

Madison Limestone:

Well API	LATITUDE	LONGITUDE	Ca	Mg	Na	K	HCO 3	SO4	Cl	TDS	pH	Upper Depth (feet)	Lower Depth (feet)	Data source
NA	41.351200	-110.956000	464	72	17092	-3	5185	3863	25100	47124	NA	NA	NA	USGS
4904120117	41.452941	-110.908270	3296	337	3021	-3	1232	2600	10100	21000	7.2	5778	5880	USGS
4902320446	42.121410	-110.718900	80	18	6864	517	1024	1926	1000	22003	8.5	NA	NA	WOGCC
4904105215	41.316930	-110.636750	816	337	6438	-3	2270	9929	8181	20751	7.2	5778	5880	USGS
4904120145	41.470000	-110.490000	536	626	8081	590	1170	1758	11200	23719	6.7	NA	NA	USGS
4903520090	42.312900	-110.477840	577	135	113	2	268	1750	14	2899	7.4	2877	2883	USGS
NA	42.272857	-110.340166	48	13	2.3	-3	190	7465	3.1	289	7.1	NA	NA	USGS
4903505746	42.403690	-110.322380	241	97	8674	-3	5100	2456	3800	25253	7.9	13718	14033	USGS
4903720754	41.016730	-109.153090	848	391	27188	1852	2635	1800	43400	76777	6.9	15840	16097	USGS
4903720948	41.571603	-108.412907	6335	845	11939	1755	378	1800	33400	54545	4.4	NA	NA	WOGCC
NA	42.252200	-107.587500	470	96	2508	-3	780	2180	2960	8483	6.8	NA	NA	USGS
NA	42.238700	-107.572900	569	64	4447	430	866	2495	6100	14450	6.9	7250	7630	USGS
NA	42.241000	-107.571900	385	93	3759	0	756	2432	4950	12218	7.6	NA	NA	USGS
4903706108	42.243820	-107.570790	1344	578	1514	130	549	1878	4820	10618	6.8	6471	6487	USGS
4903706232	42.251100	-107.567300	356	291	4114	0	667	2563	5504	13149	8.4	4794	5410	USGS
4903706232	42.251850	-107.566530	352	288	4073	0	660	2797	5450	13019	8.4	NA	NA	USGS
NA	42.248000	-107.566000	400	97	3510	-3	622	1700	4786	11115	7.65	4794	5410	USGS
4903706258	42.255750	-107.565570	304	60	2842	-3	488	2456	3240	8818	8.1	5570	5863	USGS
4903706281	42.257670	-107.562430	278	88	3871	-3	1305	7000	3800	11725	7.2	NA	NA	USGS
4903706045	42.240930	-107.562400	634	99	5493	271	587	1998	8465	17459	7.3	5814	5841	USGS
4903706011	42.239200	-107.562040	1330	143	6730	254	621	1998	13234	24142	7.4	NA	NA	USGS
4903706253	42.254020	-107.559700	790	17	5258	145	3404	1208	2400	17421	8.6	6047	6122	USGS
4903706084	42.242920	-107.557690	396	71	2816	-3	969	2526	3215	8973		6120	NA	USGS
4903705985	42.234040	-107.555140	396	71	2816	-3	969	2506	3215	9465	NA	NA	NA	USGS
NA	42.250000	-107.551700	666	101	7387	312	537	2534	10750	22937	7.7	4986	5412	USGS
4903706238	42.251690	-107.529640	309	53	997	-3	-3	2828	652	3823	7.7	7046	7102	USGS

Well API	LATITUDE	LONGITUDE	Ca	Mg	Na	K	HCO3	SO4	Cl	TDS	pH	Upper Depth (feet)	Lower Depth (feet)	Data source
4903706262	42.255280	-107.528260	257	56	2173	-3	282	2445	2004	7074	7.2	5100	5600	USGS
4903706262	42.255280	-107.528260	275	68	2643	-3	1724	1812	1895	8255	7	NA	NA	USGS
4903706019	42.239590	-107.522570	112	36	1251	-3	575	3177	950	3888	8.3	7534	7599	USGS
4900706001	42.247650	-107.520670	399	9	3199	-3	848	2528	3301	10440	7.9	6975	7028	USGS
4900706000	42.246520	-107.519240	432	87	3804	-3	1556	1720	3971	12378	6	NA	NA	USGS
4900705990	42.242630	-107.517210	1251	134	1455	-3	549	2556	3260	8090	7	NA	NA	USGS
4900706003	42.249380	-107.516480	536	126	4884	-3	1730	1700	5500	15075	7.4	6670	7028	USGS
4900720380	42.247490	-107.515280	447	80	1610	138	720	1058	1960	6290	7.1	6838	6921	USGS
4900705993	42.243640	-107.514370	1278	131	4008	-3	1450	1058	6000	14820	8.2	6450	6577	USGS
NA	42.238500	-107.513200	437	88	3619	226	1573	2474	4015	12514	5.97	6750	6800	USGS
4900705945	42.215480	-107.464910	262	24	455	0	131	491	379	2242	NA	6604	6905	USGS
4900705934	42.205390	-107.412120	262	24	455	-3	-3	1300	379	2178	NA	6604	6905	USGS
4900706932	42.095610	-107.394300	191	39	1390	-3	172	647	1996	4467	7.8	5935	6015	USGS
4900705680	42.006890	-107.352210	300	79	1779	-3	195	1245	1568	6395	NA	4059	4444	USGS
4900705864	42.184780	-107.336800	54	21	302	-3	170	3423	162	1200	NA	5000	5259	USGS

Bighorn Dolomite:

Well API	LATITUDE	LONGITUDE	Ca	Mg	Na	K	HCO3	SO4	Cl	TDS	pH	Upper Depth (feet)	Lower Depth (feet)	Data source
4120282	41.47328	-110.9215	865	306	4712	2270	159	65	11053	18960	8.85	NA	NA	WOGCC
4902320423	42.25861	-110.1809	49	31	310	4	376	217	218	1046	8.4	NA	NA	WOGCC
4902320423	42.25861	-110.1809	45	29	616	6	323	276	636	1845	8.7	NA	NA	WOGCC
4902320423	42.25861	-110.1809	172	1	25157	92	1067	6900	32600	66198	9.6	NA	NA	WOGCC
NA	42.40369	-110.3224	386	35	145	0	1330	183	100	1504	6.6	15000	15025	USGS
NA	42.40369	-110.3224	1251	202	610	0	4270	1395	230	5791	7.3	15095	15125	USGS
NA	42.40369	-110.3224	938	81	10708	0	5750	3214	12700	30473	7.2	15266	15280	USGS