Low pH Wells in the Vicinity of the City of Gillette's Madison Wellfield
Report of Investigation

by

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for

The Gillette Madison Wellfield Executive Committee:
Wyoming Department of Environmental Quality,
Wyoming Oil and Gas Conservation Commission,
Wyoming State Engineer's Office,
Wyoming Water Development Office, and
City of Gillette

May 2019

Abstract: Following the construction of five Madison Aquifer water-supply wells for the City of Gillette north of Moorcroft, Wyoming in 2011-2017, water level and low pH problems were observed for select domestic water wells in the adjacent area in July 2017 and reported to the Wyoming Department of Environmental Quality (WDEQ) in August 2017. The WDEQ conducted a detailed water-quality sampling program and began hydrogeologic investigations in Fall 2017. The low pH condition in the domestic wells was determined to not be associated with the hydrochloric acid used to stimulate Madison Aquifer production, but is consistent with the in-situ oxidation of native iron pyrite, producing local occurrences of sulfuric acid. Hydraulic relationships between the Madison Aquifer and the much shallower water-bearing strata utilized by domestic wells (Lakota and Sundance Formations) were found to preclude negative water-level impacts associated with the construction of the Madison wells. Low pH conditions were identified in domestic wells and springs both adjacent to and remote from the City wells. Potential sources of groundwater oxygen available for pyrite oxidation include long-term natural recharge, natural and pumping-induced fluctuations in groundwater levels, local impacts of domestic well construction, and locally enhanced recharge from the drilling and testing discharges of the City wells. The final report and supporting documentation can be found on the WDEQ Gillette-Madison Well Field Project website at:

http://deq.wyoming.gov/wqd/gillette-madison-well-field-project/

This report has been prepared by Hinckley Consulting, with substantial contributions from the staff of the Wyoming Department of Environmental Quality – Water Quality Division (DEQ)[1] and assistance from the Wyoming State Engineer's Office (SEO).

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[1] DEQ has conducted all water-quality sampling, overseen all laboratory analysis and conducted all public meetings and well-owner interviews. The contents of Sections 2, 4, 5 and 6, the identification of acid type in Section 7, and the report appendices were developed by DEQ staff.

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DEFINITIONS AND ACRONYMS

The following abbreviations, acronyms, and terminology are used in this report.

ac-ft	Acre-foot
aquifer	any geologic unit from which useful supplies of groundwater can be economically extracted
City	City of Gillette
City wells	the City of Gillette Madison Aquifer municipal supply wells M-11, M-12, M-13, M-14, and M-15
^{o}C	degrees Celsius
CFU/ml	colony forming units per milliliter
DO	Dissolved Oxygen
domestic wells	the relatively shallow, small-yield wells in the study area used for domestic supplies and stock watering, may or may not be explicitly permitted as “STO” or “DOM”
DWA	Drinking Water Advisory
FSP	Field Sampling Plan
formations	“the primary unit for lithostratigraphy, consisting of a succession of strata useful for mapping or description”. Named formations may or may not correspond with “aquifers” or other hydrologically meaningful groupings of individual rock units
ft.	feet
gm	grams
gpm	Gallons per minute
ID #	Data point Identification Number
IRB	Iron reducing bacteria
J	When the concentration of an analyte is between the MDL and the RL, there is confidence that the analyte is present but the exact concentration is not known; therefore, concentrations reported between the MDL and RL are noted as estimated using a “J” flag
LMWL	local meteoric water line
Madison, Lakota, etc.	These are formal geologic Formations, the word “Formation” may be omitted for brevity.
MCL	Maximum Contaminant Level
MDL	method detection limit
Mg	million gallons
MM	Morrison & Maierle
mV	millivolts
Mg	million gallons
mg/L	milligrams per liter

ND	Analyte was not detected greater than the reporting limit
NTU	Nephelometric Turbidity Unit
O^{18}	Stable isotope of oxygen
ORP	oxidation reduction potential
pH	the units in which pH is measured are called "standard units" (the negative logarithm of the hydrogen ion activity in moles per liter); the "s.u." designation may be omitted for brevity.
pCi/L	pico Curies per liter
PVC	polyvinyl chloride
RPD	Relative percent difference
RL	Reporting Limit
SAP	Sampling and Analysis Plan
SDWS	Secondary Drinking Water Standards
SEO	Wyoming State Engineer's Office
SOC	Statement of Completion (The report on well construction and aquifer conditions filed with the State Engineer's Office in association with obtaining a groundwater right. These documents are available electronically through the SEO "e-permit" system.)
Specific capacity	a basic measure of well productivity, expressing the rate of water production per unit of drawdown required to induce inflow from the formation in which the well is completed; gpm/ft
s.u.	Standard Units (used for measurements of pH)
TDS	Total Dissolved Solids
UJ	laboratory flag for concentrations that were not detected because the samples were diluted
QAPP	Quality Assurance Project Plan
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WDEQ	Wyoming Department of Environmental Quality
WOGCC	Wyoming Oil and Gas Conservation Commission
WQD	Water Quality Division
WQRR	Water Quality Rules and Regulations
WWDO	Wyoming Water Development Office
WYPDES	Wyoming Pollution Discharge Elimination Systems

1.0 INTRODUCTION

The Wyoming Department of Environmental Quality (WDEQ) Water Quality Division (WQD) received notification from landowners in mid-August 2017 of domestic and stock well issues in the vicinity of the City of Gillette Madison wellfield north of Moorcroft, Crook County, Wyoming. Figure 1 presents the general study area location. Figure 2 provides identification numbers for individual points of investigation, including the City wells, local domestic/stock wells, springs, etc. along with pH ranges for the various points sampled. The primary concern identified was with a previously adequate domestic/stock well in which the water level had fallen to a point no longer able to sustain production in July 2017. The groundwater from two deeper, replacement wells at and near this location was found to have low pH (between 3 and 4 standard units (s.u.)). (WDEQ considers groundwater having pH ranging from 6.5 to 8.5 s.u. as suitable for domestic and livestock consumption.) Additional testing by landowners identified a limited number of wells in the surrounding area as having low pH levels. Many of the wells in the area with low pH are the only local water source for domestic and livestock use by these landowners.

This report first reviews the initial observations of low pH that precipitated the current investigation. Section 2 provides related site information; Section 3 presents an analysis of the local hydrogeologic setting; Section 4 estimates natural runoff rates and volumes for the Gillette wellfield area; Sections 5 and 6 describe the methodology and results of comprehensive water-quality sampling; Section 7 is an evaluation of acidity in the domestic wells of the study area; and Sections 8 and 9 summarize the conclusions of this investigation and suggest directions for further study. Appendices provide basic data, permits, and a discussion of water-treatment options for domestic wells.

1.1 PROJECT HISTORY

At the time water level problems and low pH conditions were first reported for two domestic wells in the study area, the City of Gillette (City) was completing construction and initial testing activities associated with installation of five new municipal water supply wells (M-11, M-12, M-13, M-14 and M-15) on the adjacent State Section, Section 36, Township 52 North, Range 67 West (Figure 2). The City project is an expansion of an earlier wellfield (completed 1980 - 1996; Wells M1 - M10), constructed in the section immediately to the southeast (Section 6). Section 6 is the section in which many of the domestic wells of interest to the present study are located. The current well-construction project has been ongoing since 2011. It consists of deep well construction (approx. 3,000 feet), acid stimulation to improve production characteristics, and discharge of drilling and testing water to local surface drainages under Wyoming Pollution Discharge Elimination System (WYPDES) permits (Appendix A).

The WDEQ held a public meeting in Moorcroft Wyoming on October 12, 2017 to meet with concerned landowners in the vicinity of the City project. Public concerns with low pH groundwater looked to the on-going well construction activities in the adjacent City wellfield due to the use of

hydrochloric acid to stimulate production[2]. General concerns related to water quality in private wells included reports of water taste, odor, and clarity changes, watered gardens that died, and instances of cattle refusing to drink from established supplies. Specific concerns are tabulated in Appendix B (see Figure 2 for locations). Based on the public meeting, the WDEQ obtained permission from 42 landowners to sample 54 water wells and one spring. All interested landowners were invited to provide information on their well(s), and to provide access to the WDEQ to collect groundwater samples. Well locations were mapped and those wells in the vicinity of the wells generating the initial complaint and near the City wellfield were targeted for sampling. In general, all landowners who volunteered access to WDEQ had their wells sampled as part of the initial investigation.

As is common with studies of this type, there is a pervasive lack of baseline data with which to assess changes in water quality. In general, United States groundwater pH levels range from 6 to 8.5 s.u. (Hem, 1970; p. 93). Thus, the pH values in the 3 to 4 s.u. range reported from some of the wells and springs of the study area are unusual. Whether these measurements identify recent changes or simply quantify longstanding conditions, however, is unclear.

Similarly, the only groundwater level information routinely available is what was reported at the time of well completion, provided a report was filed. Subsequent measurements typically only occur in connection with a well failure.

After the public meeting, the WDEQ/WQD developed a scope of work to investigate the complaint of low pH groundwater. The WDEQ/WQD collected groundwater samples from 54 water wells and one spring between October 25 and November 16, 2017. Water samples were collected for analysis of field parameters, major cations and anions, select Water Quality Rules and Regulations (WQRR) Chapter 8, Table 1 parameters for metals and radionuclides, bacterial analysis (iron reducing and total coliform), and isotopic analysis of deuterium and oxygen-18. This list was based on quickly gathering sufficient data to assess whether low pH conditions had mobilized constituents that might pose health hazards.

While WDEQ staff were onsite, landowner interviews were conducted regarding septic system locations, known dump sites, chemical storage/usage, and surrounding land uses. Additional questions, as necessary, were posed to landowners throughout the investigation during public meetings, through email, or by phone call (Appendix B).

In November 2017, stakeholders including the WDEQ, the State Engineer's Office (SEO), Wyoming Water Development Office (WWDO), Wyoming Oil and Gas Conservation Commission (WOGCC) and the City of Gillette, formed an Executive Committee to establish work groups to apply science-based approaches to the investigation of potential impacts of City of Gillette wells on private water wells in the wellfield area. Four work groups were formed: Work Group #1 to assess the integrity of the five new City of Gillette wells; Work Group #2 to identify abandoned wells in the study area;

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[2] Acid stimulation is a common practice in water wells completed in the Madison Aquifer in the Black Hills. The strong reaction of the injected acid with the limestone of the aquifer commonly dramatically improves groundwater production.

Work Group #3 to identify and evaluate potential and known sources of low pH; and Work Group #4 to establish baseline water quality information for wells completed in the Madison Formation. The Executive Committee also identified the need to hire an independent third-party to assist with the evaluations conducted by the work groups. This report addresses the objectives of Work Group #3.

In early February, 2018, Hinckley Consulting was retained to assist the Executive Committee and work groups with: 1) investigating well integrity of the five new City of Gillette water wells, 2) developing a conceptual hydrogeologic model of the study area, 3) providing recommendations for additional investigation as necessary, and 4) drafting a report detailing the results of the investigation into the low pH conditions of study area wells.

Based on recommendations from the Executive Committee and the consultant, additional tasks for the work groups were developed, including state-of-the-industry integrity testing for the five City Madison wells (Work Group #1); follow-up sampling of select previously sampled wells; sampling of newly identified wells and select surface water locations, and collection of water levels from select wells (Work Group #3). The WDEQ in conjunction with the consultant and SEO personnel conducted the additional sampling and water-level work in July 2018. Work included collecting samples for a limited set of water quality parameters from previously sampled wells and one spring with low pH conditions, collecting surface water samples along Spring Creek, and collecting water quality samples (as was done in 2017) from select wells and one spring not previously sampled in the study area.

In parallel with this investigation of water quality in domestic wells, investigation and review of the adequacy of the sealing of well casings in the City Madison wells has been critically reviewed by Work Group #1 and the consultants. Those investigations are documented in separate reports, which will be available on the WDEQ Gillette-Madison Well Field Project website (http://deq.wyoming.gov/wqd/gillette-madison-well-field-project).

1.2 INITIAL NOTIFICATION AND ASSOCIATED WELLS

The specific incident that precipitated this study was the identification of low pH in two wells drilled in July of 2017 (identification numbers (ID #) 45.1 and 47.1 on Figure 2) to replace a well in which the water level was no longer sufficient to sustain production (ID #45). Because the small group of associated wells at this location illustrates several relevant features of this aquifer, the history of this particular site is presented in detail.

There are four wells at this site, IDs #45, 45.1, 47, and 79. The detailed locations and well construction, lithology, and water-level details are presented on Figure 3. All four wells are completed primarily in the Lakota Formation, albeit in different individual strata within that formation.

The first well (ID #47) was drilled in 1975 and equipped with a 10 gallon per minute (gpm) pump to serve the adjacent residence. This well was constructed under SEO permit 28851, for stock use up to 15 gpm. It was completed in a small well vault alongside the intermittent stream channel that runs past this site. According to the owner, this well was subsequently replaced due to occurrence of “red algae”

and the well's substandard completion (i.e., coarse perforations rather than well screen). The well is no longer in use and is difficult to access due to piping changes to accommodate the replacement well, but has not been plugged and abandoned.

In 2001, well ID #45 was completed to replace the 1975 well, and equipped with a 13-gpm pump set at 100 feet to supply water to two residences (the second residence is 1/4 mile east-southeast of the well; at ID #47.1). This well was constructed under SEO permit 133080, for stock and domestic use for 2 houses, up to 25 gpm and 4 acre-foot (ac-ft) per year.

In 2002, well ID #79 was completed as a backup for well ID #45. The owner remembers a nearly identical construction to #45, but no permit or other written records for this well have been located. The 5-inch PVC well casing was capped upon completion and the well has not been used since construction.

Water service from well ID #45 was subsequently extended to a third residence, located between the previous two, and then to a rental unit located near the ID #47.1 site. Note, an additional well in this ¼ ¼ Section was approved under SEO permit 173020 in 2006, for domestic use for 3 houses, up to 25 gpm and 3 ac-ft per year, but was apparently never completed.

According to the owner, water levels in ID #45 were periodically observed by the owner in association with pump replacements and found to be approximately the same as originally reported (i.e., around 50 ft). The most recent observation was reported as occurring approximately 4 or 5 years ago.

The pump in ID #45 was set at approximately 100 feet (ft.), i.e. at, or near the bottom of the well. As is typical of domestic groundwater systems, the well pump was activated by a pressure switch, so was simply pumped as necessary to meet demands. This setup provides no water level information beyond sufficient or insufficient to meet demands.

According to the owner, on July 13, 2017 the groundwater produced by well ID #45 became "silty". On July 14, the well was unable to meet demand for the first time since its completion in 2001 (i.e. the well "went dry"). Local well driller (Bob Taylor) was asked to investigate. He reports that he measured the water level with an electric sounder and found the water level to be at approximately 96 ft., which provided insufficient water to support useful production. At the driller's (Taylor's) suggestion, the well owner attempted to develop the well with compressed air circulated from the bottom of the well, but without success.

Without a water supply, the affected property owners constructed two new wells in late July, 2017; ID #45.1 and ID #47.1. These wells were constructed under SEO permit 207609 for stock and domestic use for 2 houses up to 25 gpm and 4 ac-ft per-year, and permit 207610 for domestic use for 1 house up to 25 gpm and 1 ac-ft per year, respectively. The first, well ID #45.1, was drilled adjacent to well ID #'s 45, 47, and 79; the second was drilled at the nearby residence (ID #47.1) which had previously been supplied by the failed well. Over the following two weeks of use, the owners observed that groundwater from these two wells was of very poor quality, as manifested by corrosion in the water

system and the negative impacts on a garden at ID #47.1, and water that was unpalatable. Measurement of pH by the owners on August 4, 2017 found a pH of 3.96 s.u. in well ID #45.1 and a pH of 3.97 s.u. in well ID #47.1. These values were confirmed by sampling conducted by the WDEQ on Oct. 25, 2017 (i.e., pH of 3.90 and 3.97 s.u., respectively).

According to the well owner, in October or November 2017 the water level in ID #45 was observed to still be near or at the bottom of the well.

In January 2018, a third replacement well (ID #76, see Figure 2) was completed substantially further east, across Highway 16. This well was constructed under SEO permit 208312, for miscellaneous use for 4 houses up to 25 gpm and 5 ac-ft per year. The well was completed in the deeper, Sundance Formation. The water quality was found to be satisfactory and the well remains in use to supply the previous users of well ID #45 as of issuance of this report.

As discussed in detail below, re-examination of wells ID #45 and #79 in July, 2018 found water-levels sufficient to support 16-gpm pumping and near-neutral pH (i.e ~ 7.0 s.u.).

1.3 OBJECTIVES OF STUDY

The objectives of this study were to:

- Evaluate the potential association between acid stimulation of the 2011 – 2017 Gillette Madison wells and the discovery of low-pH conditions in certain domestic wells in adjacent areas;
- Evaluate the potential association between construction and testing of the 2011 – 2017 Gillette Madison wells and the decline in water levels in certain domestic wells in the adjacent areas;
- Develop a conceptual hydro-geologic model for the water-bearing zones of the study area that have been developed by domestic wells, including stratigraphy, structure, water-bearing characteristics, aquifer relationships, and groundwater flow patterns;
- Identify and evaluate other potential causes of low pH groundwater in the domestic wells of the study area, including potential for pH changes due to discharge of Madison drilling, pump test and well treatment/development water;
- Review and assess the site history; and
- Compile and review groundwater-quality data, including available background information, data collected by the WDEQ, and data provided by homeowners.

2.0 STUDY AREA INFORMATION

The study area is located 14 miles north of Moorcroft, Wyoming (Figure 1), Crook County, Wyoming and encompasses the existing (M-1 through M-10) and newly constructed (M-11 through M-15) City of Gillette Madison Wellfields.

Land use in the study area is largely rural residential and agricultural. The predominant land use is agriculture, comprised of hay fields and livestock grazing. Some fields in the area have been terraced to capture natural precipitation in lieu of widespread irrigation and to decrease soil erosion. Land ownership in the study area is largely private. The City Madison wells M-11 through M-15 are located on a section owned by the State of Wyoming Section 36, Township 52 North, Range 67 West.

3.0 HYDROGEOLOGIC SETTING

This section reviews the geology, hydrogeology, and groundwater development experience of the study area with a focus on the relatively low-yield wells serving domestic and stock demands. These are the wells in which low pH conditions have been observed and the wells potentially subject to impacts from the deeper, high-production wells constructed to serve the City of Gillette.

This evaluation is based on previous investigations by the U.S. and Wyoming Geological Surveys, reports prepared for the City of Gillette and the WWDO, discussions with local residents and City personnel and consultants, and field investigations conducted by the DEQ in the fall of 2017 and summer of 2018. This work has been substantially informed by review of Wyoming SEO individual Statements of Completion (SOC) for groundwater permits in the study area, with the correlation of sampling points and specific SOCs having been developed by WDEQ staff.

Figure 2 presents the location of the study area, the City wells (M-1 through M-15), the individual domestic wells investigated for this study, and related data points. Basic data for these features are provided in Table 1.

3.1. STRATIGRAPHY / AQUIFERS

Figure 4 presents a county-scale geologic column for the strata of interest to this investigation, i.e., from the Lower Cretaceous-age Newcastle Sandstone to the Ordovician-age Whitewood Dolomite, from Whitcomb and Morris (1964). As discussed in detail below, domestic wells in the study area are completed in the Fall River, Lakota, and/or Sundance Formations. The City wells are completed in the Madison (also called Pahasapa or Englewood) Limestone and the Whitewood Dolomite.

Figures 5 and 6 present a more detailed local stratigraphy. Figure 5 covers the strata developed by the domestic wells in the study area. This figure is from the 7.5-minute Geologic Quadrangle map (Carlile Quad) that covers the study area (Bergendahl et al., 1961). Figure 6 is a diagram from the City of Gillette files, illustrating the lithology and formation thicknesses for a typical Madison well-constructed by the City. Additional lithologic detail is provided by the SOCs for individual domestic wells and by the comprehensive descriptions of drill cuttings developed by the City's consultants in association with the construction of the City wells.

The "formations" presented on these columns, and referred to throughout this report, are primarily distinguished through mapping of surface outcrops. Conspicuous mapping features include outcrop topography (e.g., cliff or valley forming), color, weathering character, and in some cases, fossil

assemblages. These features commonly reflect the basic composition of the rock (e.g., sandstone, shale, siltstone, or mudstone). Thus, while the boundaries of a geologic "formation" may generally encompass strata of similar groundwater-bearing characteristics, those characteristics are not the primary features upon which formations are distinguished and "formations" may or may not coincide with individual "aquifers" in detail. For example, the City wells are consistently completed through the Madison Limestone and underlying Whitewood Dolomite, which are distinguished by mineral composition and geologic age, but which are considered to function as a single carbonate aquifer system.

As used in this report, an "aquifer" is any geologic unit from which useful supplies of groundwater can be economically extracted. Thus, this designation is strongly dependent upon the type of use, the desired quantity of water, and the necessary water quality. As depicted on the Figure 5 schematic, particularly within the Fall River, Lakota, and Morrison Formations there may be many discrete water-bearing units within a single formation. The stippled patterns on the column represent sandstone units, which are typically the most productive; the dashed patterns represent clay and shale layers that generally yield poorly and impede groundwater flow.

The major aquifers of the region are the Madison Limestone (and associated strata) and the Minnelusa Formation. These provide important municipal and industrial supplies throughout the Black Hills in Wyoming and South Dakota and are the subject of extensive research. Above the Minnelusa, the United States Geological Survey study of northern and western Crook County by Whitcomb and Morris (1964) concluded that "relatively few strata are sufficiently permeable to be considered aquifers." Although water-bearing strata are recognized in the Sundance, Morrison, and Spearfish Formations, only the Lakota is described as a "principal aquifer."

Similarly, the WWDO Northeast Wyoming Basin Plan (HKM Engineering, 2002) identifies only the Lakota/Dakota as a major aquifer system above the Madison and Minnelusa Formations.

Review of SOCs for the wells sampled by WDEQ for this project, where available, confirms the above general observations, finding nearly all local wells are completed in either the Lakota or the Sundance Formation. (A few wells appear to be completed in the Fall River Formation or in discrete water-bearing units within the Morrison Formation.) Due to multiple-zone completions and the absence of sealing material around well casings, many wells may receive groundwater over extended intervals. The primary production strata are those considered in this report.

The following formation descriptions (Sections 3.1.1 through 3.1.9) are drawn from U.S. Geological Survey quadrangle-scale geologic mapping (Bergendahl et al., 1961), well logs prepared by City consultants, and SOCs filed with the SEO as part of obtaining a Wyoming water right. The reader is referred to those sources for details beyond the summaries provided here.

3.1.1 NEWCASTLE SANDSTONE

The youngest bedrock unit exposed in the study area is the Newcastle Sandstone - “Kn” on Figure 7. As the uppermost (i.e. youngest) bedrock formation, it outcrops only on top of Green Hill. It plays no significant role in the hydrogeology of the study area.

3.1.2 SKULL CREEK SHALE

This formation outcrops around Green Hill, in the north central portion of the study area, and where the strata have been downwarped by the Eggie Creek Syncline in the southern portion of the study area - “Ksc” on Figure 7. No wells have been identified as producing from this low permeability formation. It has been subject to extensive and continuing landslide activity on the sides of Green Hill, the disturbance from which may be responsible for the low pH spring at location ID #77.

3.1.3 FALL RIVER FORMATION

The Fall River and Lakota Formations are lithologically similar and are commonly grouped together as the Inyan Kara Group, “a controversial collection of enigmatic units ... composed of complexly interfingering sandstones, mud-stones, claystones, and siltstones of continental and possibly fluvio-marine origin.” (Bergendahl et al., 1961, p. 625) On Figure 7, the Fall River is identified by symbol “Kf” and the Lakota by symbol “Kl”.

As aptly depicted on Figure 5, these formations are far from simple stacks of continuous layers of consistent composition. Despite the variations, Bergendahl et al. (1961) divide the Fall River into four generalized members:

- upper member (“Kfu” in the background map symbols of Figure 6)
- sandstone member (“Kfss”)
- mudstone member (“Kfm”)
- siltstone member (“Kfsi”)

and suggest a total thickness of “125 - >150 ft." (p. 629). Measured outcrop sections of the lower three members in the study area by Bergendahl et al. (1961) range from 113 to 135 ft.

City well M-9 logged the greatest penetration of the Fall River, with a nearly complete section of 210 ft., and provided drill-cuttings descriptions in 10-ft increments. At that location (Figure 2), the sandstone units are described as very fine to medium grained and non-calcareous. A “trace” of pyrite (i.e. iron sulfide) is noted in only one sample. Carbonaceous material (even “wood fragments” in one sample) are noted in the interbedded siltstones. “Coal seams” were found in samples from M-8 and M-11.

From outcrop of the Fall River sandstone unit southeast of ID #s 59 and 19, Bergendahl et al. (1961) describe "abundant spherical pyrite concretions" (p. 636) and "abundant weathered pyrite concretions" (p. 638), respectively. Concretions of "calcite-cemented sandstone" are noted in the sandstone unit, and the lowermost stratum is described as "sandstone cemented with calcite" (p. 631). Siltstone laminae in the mudstone unit "commonly are calcareous" (p. 630). In the individual outcrop descriptions, calcareous material is commonly noted.

Study area groundwater wells identified with the Fall River have water rights from 4 to 10 gpm. However, particularly for domestic wells, these permit-listed yields may be the maximum allowed under that permitting category, or the hoped-for yields, rather than reflecting the actual productivity of the aquifer.

Only one of the local water wells apparently completed in the Fall River provided test data as part of the SOC reporting. Well ID #5 was air-lifted at 10 gpm for 30 minutes. The maximum possible drawdown was 70 ft., for a specific capacity of >0.15 gpm/ft. (0.30 gpm/ft if the effective drawdown was 50% of the airlift submergence). "Specific capacity" is a basic measure of well productivity, expressing the rate of water production per unit of drawdown required to induce inflow from the formation in which the well is completed. For comparison, note that specific capacities for the Gillette Madison wells are commonly 10 – 40 gpm/ft.

3.1.4 LAKOTA FORMATION

Despite the mixed lithology displayed on Figure 5, Bergendahl et al. (1961) divide the Lakota into two generalized members:

- mudstone unit ("Klm" in the background map symbols of Figure 7)
- sandstone unit ("Kls" in the background map symbols, including a "basal conglomeratic sandstone" (p. 622) and local "channels probably cut into the [underlying] Morrison" (p. 628).

They state, "Within the quadrangle boundaries, measured sections of the Lakota range from 81 to 166 feet in thickness. The thickness throughout most of the quadrangle is between 120 and 140 feet; the formation thins abruptly towards the southwest corner." (Bergendahl et al., p. 626), i.e. 5 miles south-southwest of the present study area.

The City wells logged from 85 ft. (M-13) to 140 ft. (M-11) of Lakota, demonstrating a significant variation over this small area, with a thinning toward the southwest, consistent with the quad-scale observation of Bergendahl et al. (1961). Wells M-9 and M-10, at the northeast edge of the earlier City wellfield, posted Lakota thicknesses of 100 ft. and 80 ft., respectively. These values are approximately the same as in Wells M-12 and M-14 to the northwest, i.e. suggesting a pattern of more consistent formation thickness along a northwest-southeast trend.

With respect to the two members identified by Bergendahl et al. (1961), the geologists that logged the drill cuttings from the City wells identified from 45% (M-11) to 80% (M-15) of the total thickness of

the Lakota Formation with the lower, sandstone unit. This is consistent with the substantial variations in lithology indicated on Figure 5.

Detailed examination of wells ID #s 45, 45.1, 47, and 79 illustrates the stratigraphic complexity of the Lakota Formation at this particular location and documents temporal changes in water levels (Figure 3):

- The water-bearing unit was described by the respective drillers as "sandstone" and "sandstone and shale" in well ID #47 and as "sandstone stringers" in well ID #45. The "shale" and "stringers" references are consistent with the discharge of "silt" from ID #45 in 2017 reported by the owner and observed when ID #79 was pumped for this investigation in July 2018. In the latter case, the well twice drew down rapidly, but then recovered as silt was cleared from the perforations.

- These same depth intervals were logged as "gray shale" in ID #45.1, suggesting a lack of lateral continuity, even over this short distance.

- The water level difference between the upper water-bearing zone (ID #45) and the lower water-bearing zone (ID #45.1) was 67 ft., measured in July 2018 by the SEO, demonstrating the hydraulic separation of these two zones within the Lakota Formation.

- The water level in ID #45 recovered approximately 34 ft. over the period of non-use from July, 2017 to July, 2018 (to a level 16 ft. lower than when originally reported (2001)).

- In contrast, the water level in ID #45.1 <u>declined</u> approximately 13 ft, i.e. from 120 ft. to 133 ft., over the same time period and under the same conditions of non-use

- The pH in ID #45.1 improved somewhat between July 2017 and July 2018, from 3.9 s.u. to 4.61 s.u.

Bergendahl et al. (1961) primarily investigated the occurrence of uranium minerals associated with the Carlile mine (approximately 5 miles to the east of the new City wellfield). They identified an association between those minerals and the occurrence of pyrite in the Lakota Formation:

> The factors responsible for ore localization are not clear, but probably a combination of three lithologic and structural elements contributed to provide a favorable environment for precipitating uranium from aqueous solutions: abundant carbonaceous material or pyrite in a thin, permeable sandstone enclosed within relatively thick impermeable clays; local structural basins; and a regional structural setting involving a broad syncline between two anticlines. The structural features controlled the regional flow of ground water and the lithologic features controlled the local rate of flow and provided the proper chemical environment for uranium deposition. (Bergendahl et al., p. 614)

The Lakota sandstone units in the City wells are described as very fine to coarse grained and noted as "well-sorted" in M-9. Pyrite is noted in many samples including "4-5% pyrite concretions up to 4 mm [millimeters]" (M-11), "10-95% pyrite cement" (M-11), "locally pyritic" (M-9), "10-12% pyrite cement" (M-12), "locally pyritic" (M-10), "abundant pyrite" (M-15, M-13).

In marked contrast with the Fall River Formation, Bergendahl et al. (1961) include no general description of calcareous material in the Lakota and provide only one mention in their detailed outcrop section descriptions, a "calcareous sandstone near the middle" of the Lakota mudstone unit at one location. This is consistent with the limited observations during field work conducted for the present study which identified no Lakota samples with perceptible calcite reaction

Because it is the shallowest formation with fairly consistent production (from various water-bearing zones) the Lakota is the source for most of the domestic wells in the study area. Study area groundwater wells identified with the Lakota have water rights from 2 to 25 gpm.

Actual test yields are reported for seven of the Lakota wells sampled. These vary from 3 to 23 gpm, with specific capacities from 0.08 to 10 gpm/ft. For this investigation, a short pump test was performed on one Lakota well (ID #79) on July 20, 2018. That test included two observation wells, ID #s 45 at a distance of 180 feet, and #45.1, at a distance of 135 feet (Figure 3). Well ID #79 was pumped at a rate of 16 gpm to open discharge for two hours. Although the duration of the pump test was insufficient to evaluate a large portion of the local aquifer, a transmissivity of 1,400 gallons per day/ft and a storage coefficient of 0.0001 were indicated, with a 2-hour specific capacity of 1.6 gpm/ft.

Figure 8 presents the drawdown data from this short test, including a plot of the Theis Equation for the indicated aquifer parameters. The rapid drawdown in the production well (ID #79) at the beginning of the pumping period was similar to the experience of the initial installation of a pump in this well the previous evening. On that occasion, the well, which had not been pumped previously, discharged silty water and quickly drew down to near the pump setting at the bottom of the well. However, the water level immediately recovered to its pre-pumping level and a second start quickly produced relatively clear water with modest drawdown. The test depicted on Figure 8 was conducted 16 hours later and was able to clear silty material from the wellbore and establish apparently uninhibited communication with the surrounding aquifer after approximately 10 minutes without requiring multiple starts. The observation well (ID #45) did not suffer from the compromising impact of silt production, so responded to aquifer hydraulics from the start of the test.

The storage coefficient indicated by the rapid response at the observation well is typical of a "confined" aquifer, i.e. one from which water is produced by widespread pressure reduction rather than by physical drainage. This is a surprising indication for an aquifer at this relatively shallow depth. It is assumed to be a function of some combination of the overlying "gray shale" (Figure 3), of heterogeneities in the aquifer (e.g. fractures), and of the short duration of the test. A longer test would be instructive.

Observation well ID #45.1, completed in a slightly deeper zone, experienced no significant drawdown during this short test. The lack of response in this deeper well demonstrate the individual water-bearing zones in the Lakota at this location are hydraulically isolated to some extent by intervening low-permeability strata. However, the respective water levels demonstrate that to the extent there is groundwater flow through the intervening strata, such flow will be downward, from the upper into the lower zone.

The wide variations in well performance and the suggestion of locally confining conditions are both consistent with the highly variable lithology of the Lakota Formation observed in the study area. The Lakota Formation is clearly not a single "aquifer," but a complex assemblage of water-bearing units and low-permeability deposits, as depicted on Figure 5.

3.1.5 MORRISON FORMATION

Generally, the Morrison is not considered to have significant water-bearing potential, although it includes scattered lenses of sandstone and limestone, as depicted on Figure 5. Bergendahl et al. (1961) state, "The upper contact of the Morrison is sharp and unconformable at most places. The basal conglomeratic sandstone of the Lakota formation lies on carbonaceous claystone of the Morrison with no gradational interval." (p. 622), and "The lower contact of the Morrison is rather sharp. An interval of 3 to 4 inches of sandy claystone separates the wavy-laminated limestone from the buff sandstone of the Redwater shale member of the Sundance." (p. 622). A local driller (Tim Barritt) describes that "once you hit the Morrison, you're done" with respect to seeking additional water-bearing strata by drilling deeper wells.

Bergendahl et al. (1961) describe a thickness of 80 to 100 ft. for the Morrison. The measured outcrop section closest to our area of interest found a thickness of 100 ft. The City wells logged 90 – 100 ft. of Morrison, i.e., a more consistent thickness than observed in the overlying Lakota or Fall River.

In the City well logs, the Morrison is consistently described as claystone, with minor sandstone strata in some cases, and limestone in the lowest section (noted in M-9 and M-11). Pyrite is not common, with only "traces" noted in some drilling samples from M-10 and M-12. Black shales and mudstones indicate carbon content. The measured Morrison outcrop sections of Bergendahl et al. (1961) include common reference to calcareous units.

No wells in this study for which test data are available were identified as producing from the Morrison Formation. As suggested above, the Morrison primarily serves as an aquitard between the Lakota and Sundance Formations.

3.1.6 SUNDANCE FORMATION

The Sundance Formation, and specifically the Hulett Sandstone member, is commonly identified as a minor aquifer in the Black Hills region. Whitcomb and Morris (1964) subdivide the Sundance into five members:

- Redwater Shale
- Lak
- Hulett Sandstone
- Stockade Beaver Shale
- Canyon Springs Sandstone

and state, “The Hulett is the only member of the formation having favorable water-bearing characteristics," and "Additional water might be obtained from the Stockade Beaver and underlying Canyon Springs Member, but its chemical quality may make it objectionable for some uses." (p. 24). (Examination of the full Sundance thickness was beyond the scope of the more detailed Bergendahl et al. (1961) study referred to above.)

Whitcomb and Morris (1964) report a measured outcrop section of Sundance 410 ft. thick. The City wells logged the Sundance from 430 ft. thick (M-1) to 556 ft. thick (M-15), describing lithologies from “black shale” to “massive gypsum” to “very fine sandstone.” Mudstone, claystone, and siltstone predominate, but sandstone strata up to 60 ft. thick are present as well. Trace amounts of pyrite were observed in a small number of samples, with only one sample presenting more than a trace: “10% pyrite in ss [sandstone] matrix” from 390 ft. in well M-12.

Of the private wells sampled by WDEQ, 13 are identified as producing from the Sundance. Although substantially deeper than the Lakota, local experience is that the Sundance provides the next reasonably reliable source of small quantities of groundwater beneath the Lakota. Drillers’ logs describe water supplies from fine-grained sandstones interbedded with shales and siltstones.

Study area groundwater wells identified with the Sundance have water rights from 3 to 15 gpm. There are three local water wells identified with the Sundance for which test data were provided with the Statement of Completion (SOC). Well ID #9 reported 43 ft. of drawdown after 12 hours of pumping at a rate of 15 gpm, for a specific capacity of 0.35 gpm/ft. Well ID #14 reported 280 ft. of drawdown after 6-hours of pumping at a rate of 6 gpm, for a specific capacity of 0.02 gpm/ft. Well ID #4 was air-lifted at 5 gpm for 2 hours. Based on the depth of the airline, the drawdown was no more than 40 ft., i.e. a specific capacity of >0.13 gpm/ft.

3.1.7 SPEARFISH, MINNEKAHTA, AND OPECHE FORMATIONS

Below the Sundance Formation are the Spearfish, Minnekahta, and Opeche Formations. These strata are not known to provide water to wells in the study area. For example, Whitcomb and Morris (1964, p. 27) state, “Drilling should be terminated at the base of the Hulett Member because of the relative impermeability of strata below it and the generally poor quality of water contained in them.”

The Spearfish, Minnekahta, and Opeche Formations separate the aquifers of the Fall River, Lakota, and Sundance from the productive aquifers of Paleozoic age, e.g., the Madison. This is a mudstone-dominated section. In terms of formation thickness, the lithologic log for well M-11 (MMI, 2013b), for example, identified thicknesses of 700, 20, and 40 ft. for the three formations, respectively.

The Spearfish Formation consists of "red siltstone, and silty claystone and sandstone. The lower part of the formation is made up of thin-bedded red siltstone and silty claystone interbedded with white gypsum/anhydrite beds more than 10 feet (3 m) thick that are accompanied by minor thin discontinuous limestones" (Sutherland, 2007).

The Minnekahta Limestone consists of "light gray, finely crystalline, thin-bedded limestone and purplish to pinkish gray dolomitic limestone." (Sutherland, 2007) The Minnekahta was logged from 20 to 45 ft thick in the City wells. "The formation persists over a wide area in Crook County, but is not considered to be a source of ground water because it is relatively impermeable and the water contained in it is reported to be of poor quality" (Whitcomb and Morris, 1964; p. 23).

The Opeche Shale consists of "alternating nonresistant beds of maroon and reddish brown shale, fine-grained to silty sandstone, siltstone, and claystone, and thin-bedded anhydrite and gypsum" (Sutherland, 2007). The Opeche was logged from 33 to 80 ft thick in the City wells.

3.1.8 MINNELUSA FORMATION

The Minnelusa is described as "thick, massive, white to yellowish and reddish gray, varying to gray, light-brown and red; well-sorted and cemented; cross-bedded; fine- to coarse-grained sandstone accompanied by varying amounts of red and white solution breccia, purplish gray to pink limestone and dolomite, and red, purple, and black shale" (Sutherland, 2007). The upper part of the Minnelusa Formation "contains dolomite, anhydrite, eolian sandstone, siltstone, and cherty dolomite" whereas the lower part of the formation "consists of shale, dolomite, radioactive black shale, anhydrite, and sandstone" (DeWitt et al., 1986, p. 35). Thicknesses of the Minnelusa have been reported in the range of 700 to 1,000 ft. In general, researchers consider the upper portion of the Minnelusa to be an aquifer, and the lower portion to be a confining unit within the Black Hills area (e.g., Bartos et al., 2017).

The thickness of the Minnelusa logged in the City wells (M-11 through M-15) varies substantially, from 690 ft (M-15) to 862 ft (M-12), reflecting the irregularity of the Madison surface upon which the Minnelusa was deposited.

Based on observations from drilling of the City wells the primary geologist for that project characterized the Minnelusa stratigraphy in the wellfield area as follows:

> "The Minnelusa lithology is somewhat variable from one well to another in Section 36 of the Madison wellfield; however, it may be generally characterized in three parts: (1) an upper, soft, caving sandstone aquifer that produces very poor quality groundwater, (2) a "red zone" containing abundant red clay and very fine siltstone layers interbedded with harder sandstone

and dolomite, but generally acting as a barrier to vertical groundwater movement, and (3) a lower part with a mixture of sandstone and abundant dolomite layers. This three-part division was persistent across the wellfield in Section 36 and differs somewhat from the description given above, if only in detail; however, the conclusion that the upper portion is an aquifer and the lower portion is a confining unit agrees with the findings in Section 36." (Kazmarek, pers. comm. 11/29/18)

3.1.9 MADISON AND WHITEWOOD FORMATIONS

Beneath the Minnelusa are the Madison Limestone (also known as the Pahasapa or Englewood) and the Whitewood Dolomite. These formations can provide a very productive aquifer, which is why they have been extensively developed by the City of Gillette and other entities throughout the Black Hills region. Detailed descriptions, including test data and water quality are available in many regional and local reports.

The City wells have water rights ranging from 650 to 1,225 gpm and have been tested at discharge rates in excess of 1,400 gpm.

3.2. STRUCTURE / TOPOGRAPHY

The occurrence of the various formations at the ground surface and their depth below the surface at any point is a function of the intersection of the surface topography and the geologic structure (i.e., folds and faults in these originally horizontal formations; hills and valleys in the ground surface). The most detailed geologic mapping available for the study area is by Bergendahl et al. (1961), a portion of which is reproduced on Figure 7.

The red lines in the background on Figure 7 are contour lines drawn by Bergendahl et al. (1961) on the base of the Fall River Formation. Like surface contours, these "structure" contours define subsurface "hills" and "valleys" in the shape of that surface, called "anticlines" and "synclines," respectively. Where rock strata are deformed along the axes of folds is a likely place to encounter fractures that enhance permeability and groundwater productivity. The original 10 City wells were drilled near the axis of the Eggie Creek Syncline. The newer City wellfield is being constructed near the crest of the Oil Butte Anticline (the axes of these folds are included on Figure 7). As a result of these folds and erosion by Spring Creek and its tributaries, formations from the Newcastle Sandstone to the Morrison Formation are exposed at the ground surface, as shown on this geologic map.

The geologic structure of the study area is dominated by the Oil Butte and Pine Ridge Anticlines, a pair of echelon folds superimposed on the regional, west-dipping Black Hills Monocline. Associated with these folds are joint sets (i.e. fractures) "conspicuous in the sandstone unit of the Fall River formation" (Bergendahl et al. (1961), p. 659). The orientation of these joints (bearing N55W- N75W) are presented on the inset of Figure 7. The only fault (i.e. a fracture with observable displacement)

mapped in the area is in the Fall River Formation, at the north end of the Pine Ridge Anticline, also with a northwest to southeast orientation. (The "U" and "D" on this fault indicate the relative displacement across the fault, i.e. southwest side "up" and northeast side "down".)

Although not noted by Bergendahl et al. (1961), the general orientation of these structural features is reflected topographically in the roughly parallel channels of the streams of the study area, ie., Eggie Creek, Little Spring Creek, Spring Creek, and Black Gulch (Figure 2).

Morrison-Maierle (2017, p. 18-19) identified a "strong topographical lineament" bearing N45W through the Gillette wellfields (i.e. through the City well locations of M-2 and M-8) "interpreted as the possible location of a solution enlarged fracture in the Madison aquifer that acts as a constant head boundary and zone of high transmissivity embedded in the porous carbonate rock matrix of the aquifer." Structural association between the fractures mapped in surface outcrops and the suggested fractures at depth is inferred by the similar orientations. Extension of the fracture suggested by Morrison-Maierle to the south coincides with the channel of Little Spring Creek and passes through the spring at ID #62 (Figure 2). Wetstein (2017) refers to the mapped fracture orientation and suggests a possible hydraulic connection between wells ID #s 45.1 and 47.1 and the Gillette wellfield to the northwest.

Morrison Maierle (2013, p. 11) noted the location of M-12 (i.e. Test Wells ID #s 2 and 2A) is "in an area where a long lineament to the south has become indistinct, but projects to an intersection with a strong fracture pattern on the nose of the Oil Butte Anticline" and state that these wells were "sited on the projected trends of one strong regional lineament and at least one smaller lineament as well as numerous smaller local fractures that are present at least in the shallower strata."

Following construction and testing of these wells, however, the author of the Morrison-Maierle report cited above concluded "None of the five new wells encountered such a feature and the hydraulic responses during aquifer testing do not indicate such a feature in the Madison, even though we tried to target such a feature, if it were present" (Kazmarek; pers comm. 11/29/18).

Significantly, Bergendahl et al. (1961, p. 659) state that the fractures they mapped in the Fall River and Lakota (i.e. the "shallower strata" referred to above) "are not traceable through the rocks above and below," suggesting confinement to brittle sandstone strata rather than penetration through the more ductile overlying and underlying silt and clay-dominated strata. The substantial differences in water levels between the various formations of the study area, discussed in detail below, support this observation. Although potentially aligned in response to similar stress fields, fracture systems in different formations do not appear to have sufficient vertical continuity to significantly facilitate vertical groundwater flow.

The two City wells that most conspicuously encountered lost-circulation conditions are Test Hole-2 (next to completed well M-12) and well M-14. The occurrences were at depth of 1,600 ft. in Test Hole-2, in the upper Minnelusa; and around 2,300 ft. in M-14, in the lower Minnelusa. These

conditions were interpreted by the City consultants as the borehole intersecting ohigh-permeability fractures (MM, 2013).

A line passing through these two locations bears N53W, generally consistent with the patterns discussed above, and directly along northwestward extension of the lineament plotted by Morrison-Maierle (MM) (2013) (e.g., "Test Well #2 penetrated a vertical fracture in the upper Minnelusa, consistent with the location of the borehole on the projected lineament trends."). A near-vertical orientation for this fracture is supported by the conditions encountered at the M-12 location: "Test Hole-2A, 178.9 feet from Test Hole-2, was offset to the west of the fracture alignment by 80 feet, assuming Test Hole-2 is on the alignment. It did not penetrate the type of open fractures encountered in the Minnelusa by Test Hole-2" (MM, 2013, p. 11).

3.3 GROUNDWATER RECHARGE, ELEVATIONS AND FLOW

Groundwater flows from areas of recharge to areas of discharge. Recharge occurs as the infiltration of rainfall, snowmelt, and streamflow moves downward to the local water table. Discharge occurs via springs, seeps, groundwater flow up through streambeds, evapotranspiration at the surface, and extraction by groundwater wells. In between recharge and discharge points, groundwater moves both horizontally and vertically, in response to the gradients within and between water-bearing units, and at rates depending on the permeability of the various strata involved. Thus, groundwater pathways can become extremely complex and the time between recharge and discharge can be days, years, decades, centuries, or longer.

The water level (or pressure, in a confined aquifer) at any point in space and time is a complex function of the location and timing of recharge to outcrops, lateral flow, leakage in and out of the zone of interest to overlying and underlying units, pumping or spring flow removal of groundwater, and the 3-dimensional distribution of permeability and storage characteristics of all the associated geologic materials (and of the "short-circuiting" impacts of any wells or boreholes).

3.3.1 LOCAL RECHARGE

Absent detailed water-level monitoring, groundwater modeling, or other specific analysis of recharge rates, a generic recharge rate of 5 - 10% of precipitation provides an approximation of average input to groundwater. The average annual rainfall at the Devils Tower station is 17.8 inches; for the Moorcroft station, the average is 16 inches. Thus, a first approximation of the annual groundwater recharge to the shallow aquifers of the study area is 15-30,000,000 gallons per square mile; i.e. an average input of 28 to 57 gpm to each square mile. Whether local recharge is sufficient to sustain domestic and stock withdrawals depends on the local details of aquifer connections, well completions, recharge, the volume of productive aquifer material available to a particular well, and, of course, the production load placed on a particular well. Local aquifer depletion may occur. The history of groundwater development in the study area includes multiple examples of wells being replaced, relocated, or deepened to improve groundwater production or quality.

3.3.2 GROUNDWATER FLOW

In general, for water table (i.e. unconfined) aquifers, water table contours are a subdued reflection of surface contours, and groundwater flow follows those contours "downhill". However, groundwater flows in three dimensions, and heterogeneities within a geologic unit, as well as between units, influence both the horizontal and the vertical flow. Geologic structures such as folds, faults, joints, fractured zones, stratification, and solution channels can have additional major influence on local groundwater flow conditions in bedrock aquifers. In addition, erosional features that deeply incise geologic units can impact flow conditions, isolating sections of an aquifer, for example.

To investigate groundwater flow in the study area, the depths-to-water reported for the City wells and for the domestic wells shown on Figure 2 were subtracted from the surface elevation[3] of each well to determine a groundwater elevation. For example, the surface elevation at well ID #45.1 is 4,239 ft., the depth-to-water reported with the SOC for the well was 120 ft., for a groundwater elevation of 4,119 ft. Because of installed pumping equipment and active use, very few water-level measurements are available beyond those reported upon the initial completion of the well. Self-reported by the respective drillers, those values reflect different years, different seasons, and varying levels of accuracy. Thus, care should be exercised in the use of individual SOC values beyond identification of broad patterns.

Additional groundwater elevations are provided by the occurrence of perennial springs, which indicate the near-surface presence of the prevailing water table. These elevations do not change over time and can be measured with accuracy.

The groundwater elevations described above are plotted on Figure 9, along with the primary formation supplying water to the well. In the case of the City wells, the supplying formation is the Madison. For the domestic wells, the supplying formation has been interpreted based on the location and depth of the well relative to the geologic mapping shown on Figure 7, adjusted by examination of lithology reported by the driller as part of the SEO SOC.

Figure 10 presents a representative group of wells for comparison between the various formations of the study area. The blue shading marks the static (without pumping) water level in the well. The horizontal line patterns in the wells identify the depths at which the well was completed (most commonly perforations or well screen) to withdraw groundwater[4].

Given the stratigraphy described above, it is not surprising that groundwater flow in the study area is also complex. The following paragraphs describe groundwater flow by formation, with the understanding that there are substantial variations among the various water-bearing units <u>within</u> a

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[3] Reconnaissance-level estimates of surface elevation were obtained from Google Earth® imagery. Spot checking this approach against surveyed elevations in this area suggests such elevations are within approximately 10 ft. of the correct value. No surveying was done for this study.

[4] Figure 10 does not include the material around the casing, i.e. between the casing and borehole wall. This space is filled with gravel, sand, bentonite, cement, formation slough, drilling mud, or nothing, depending on the particular well.

named formation. The most comprehensive discussion is focused on the Lakota, the formation from which the majority of domestic wells in the area draw water.

3.3.2.1 MADISON

Groundwater elevations reported for the Madison wells average 3,847 ft., varying between 3,830 ft. in City well M-10 and 3,860 ft. in City well M-5, without sufficient pattern to discern horizontal gradients or groundwater flow directions within or between the two wellfields. (These values were reported from different years as well as different times of the year.) Test data (e.g. MMI, 2017) indicate high permeability for the Madison in this area and relatively flat gradients (i.e., groundwater elevation at any one time is likely quite similar throughout the wellfields area).

The Madison receives recharge to limited outcrop areas 20-miles east of the study area, in the Bear Lodge Mountains, and to extensive outcrops around the core of the Black Hills another 10 miles further east. Regionally, groundwater flow in the Madison is westward off the core of the Black Hills, then northward and eventually northeastward beneath the Great Plains (Kyllonen and Peter, 1987).

No nearby monitoring wells provide long-term records of water-level fluctuations in the Madison, but the USGS M-1 well (30 miles north), with 40 years of recorded monitoring data, shows long-term fluctuations of approximately 40 ft. The somewhat closer Vista West No. 2 well (20-miles east) shows a smaller fluctuation of 15 ft. over its shorter, 24-year record (SEO, 2018).

Water-level measurements from the original City wellfield (M-1 through M-10) were compiled by MM (2007) for the period 1986 to 2007. During pumping of the City wells, water levels in a well declined by anywhere from 20 to 300 ft. depending on the pumping rate and the characteristics of the particular well. However, despite sustained production rates from 500 to 1400 gpm, the static water levels (the water level to which the well recovers after pumping ceases) show little systematic, long-term change. The authors concluded (p. 5-136) that "if there is in fact any long-term drawdown associated with operation of these wells, it is obscured by the long-term fluctuation in groundwater levels in the Madison aquifer due to natural fluctuations in recharge and discharge in the regional Madison aquifer system." The new wellfield (M-11 through M-15) has yet to be produced beyond short-term pump testing, so cannot have significantly impacted Madison groundwater levels in that area.

The most important observation with respect to Madison water levels for the present study is that elevations are mostly greater than 200 ft. lower than in the upper aquifers (Fall River, Lakota, and Sundance Formations) in this area (Figure 10). Thus, groundwater cannot flow from the Madison upward through the overlying formations, either naturally or through wellbores. Rather, there is a downward gradient between the upper aquifers and the Madison, but the permeability of the intervening units (e.g., in the Spearfish Formation) are low enough to maintain the higher water elevations of the upper strata. This condition also insulates the upper aquifers from the impacts of drawdown in the Madison due to groundwater production from the City wells.

3.3.2.2 MINNELUSA

Recharge to the Minnelusa formation is primarily from infiltration of precipitation on outcrop areas and from stream losses where streams cross outcrop areas (Bartos et al., 2002). The majority of the outcrops areas responsible for recharge are to the east of the study area along the Wyoming-South Dakota border.

Only two water level values for the Minnelusa have been identified in the study area, both approximate; one from the upper Minnelusa, recorded during the unsuccessful drilling of Test Hole-2 (adjacent to City well M-12), and one from the lower Minnelusa, recorded during the attempts to seal M-14. (MMI, 2013, 2017) In both cases, the values were nearly the same as for the Madison Formation at those locations. This indicates that the Minnelusa likely has the same basic relationship to the upper aquifers as does the Madison (i.e., substantial hydraulic separation and a downward natural groundwater gradient).

Across Crook County, paired Madison / Minnelusa monitor wells find grossly similar patterns in long-term water-level changes, i.e, water levels in both formations go up and down in response to the same climatic factors across their recharge areas. The differences in water levels between the two formations, however, vary substantially both in magnitude and direction. For example Minnelusa water levels are as much as 100 ft higher than in the Madison at the well pair: “CCMOW-2" and “-2a”on the South Dakota stateline; The Madison water levels are as much as 200 ft. higher than in the Minnelusa at the well pair:“CCMOW-5" and “-5a”,10 miles southwest of that; and the Minnelusa water levels are as much as 300 ft. higher than in the Madison at the well pair: “CCMOW-6" and “-6A” in the southeast corner of Crook County (SEO, 2018). The hydraulic relationship between the two formations is logically a function of the relative elevations of the outcrops receiving recharge, the relative permeability and storage characteristics of the two formations, the opportunities for groundwater discharge, and the distance over which those parameters impact groundwater flow. Data are insufficient to estimate head relationships in the present study area beyond the limited observations cited above.

3.3.2.3 SUNDANCE

Recharge to the Sundance from within the study area likely occurs primarily via drainage from the overlying strata. (Additional groundwater movement into and out of the study area likely occurs within the wider extent of the Sundance Formation in the subsurface.) Within the study area, reported Sundance water level elevations vary substantially. The relatively low elevation for ID #76 (Figures 2 and 9) may suggest a southward gradient, but that data point is the most recent in the dataset and may just reflect the different measurement years and local conditions.

Water level elevations in the identified Sundance wells average 3,959 ft. For other wells in the same areas, water elevations in the Sundance are consistently lower than in the Lakota (and lower in the Lakota than the Fall River). Groundwater elevations from Sundance wells in the northeast portion of the study area (ID #s 3, 4, 6, 7, 8, 9, 10, 15, 16) average 3,941 ft., whereas groundwater elevations

reported for the Lakota wells in the same area (ID #s 17, 18, 13) average 4,138 ft. In the pair of proximal wells ID #s 32 and 76, the first one is a Lakota well, with a groundwater elevation of 4,088 ft., whereas the second is a Sundance well with a groundwater elevation of 3,908 ft. Water level differences on the order of 200 feet likely exceed what would occur simply as a function of different years of measurement. A study area groundwater gradient downward from the Lakota to the Sundance is clear.

The upper-aquifers (Fall River, Dakota, Sundance) water level elevation data point closest to the City wellfield is from well ID #22, just west of M-14. That elevation, 4,023 ft., is from an apparent Sundance well completion. This is approximately 300 ft. lower than the bottom of the Lakota Formation in the wellfield. This is generally similar to the groundwater elevations in the Sundance wells east of the wellfield, suggesting similar hydraulic relationships between the formations both east and west of the wellfield.

Thus, the pattern of downward groundwater gradients appears to be maintained among the upper aquifers (Fall River, Dakota, Sundance) as well as between those aquifers as a group and the Madison/Minnelusa. Also, the shale and siltstone strata within and between the upper aquifers, (e.g., the Morrison between the Lakota and the Sundance), have sufficiently low permeability that water-bearing zones in the Lakota and Fall River Formations can maintain a substantially higher groundwater elevations than in the Sundance.

3.3.2.4 LAKOTA

The Lakota is the lowest formation able to receive significant direct recharge from the surface in the study area. As shown on Figure 7, the Lakota is exposed in the bottoms of the drainage channels on Pine Ridge, providing opportunity for direct recharge to outcrop. Over the great majority of the area, however, the Lakota is overlain by the Fall River and receives recharge primarily by groundwater draining downward through the Fall River.

Because recharge is a function of local precipitation, it will reflect general precipitation patterns in terms of both seasonality and long-term cycles. Review of precipitation records from Devils Tower, 12-miles northeast, at elevation 3,835 ft., identifies April, May, and June as the wettest months of the year in this area. As this period precedes the higher evaporation/evapotranspiration months of summer, it is likely the primary period for groundwater recharge. Over the period 1959 to 2018, the total precipitation for those months has varied from 2.67 to 14.67 inches, averaging 7.57 inches.

In both 2016 and 2017, the total precipitation for these three months was less than the long-term average. In 2016, it was only 50% of average. A relatively low recharge rate may have contributed to the inadequate performance of well ID #45 in July 2017.

Significant variations in recharge to the Lakota are also indicated by temporal variations in water levels. An initial depth-to-water measurement is generally reported along with the completion information filed by the driller in association with SEO permitting. These values are compiled in the

well information in Table 1. The method and accuracy of measurement is rarely documented, and the relationship of the reported water level to any recent pumping or development of the well is not reported, but an approximate water level is a relatively simple measurement and is assumed to be generally representative of conditions at the time of drilling.

Table 2 reviews the much sparser subsequent depths-to-water measured, if any, for each well. The incidence of wells "going dry" or otherwise failing to meet demands was discussed above. Wells ID #s 45, 79, and 45.1 provide a specific, well-documented example. These wells were primarily completed in two zones of the Lakota Formation. Wells ID #s 45 and 79 were drilled in 2001, at which time a depth-to-water of 51 ft. was reported[5]. Both wells were reported to have depths-to-water of approximately 98 ft. in July 2017, then to have recovered to a depth-to-water of 66 and 72 ft., respectively, in July 2018.

Well ID #45.1 was completed in the lower aquifer at this location in July 2017, at which time a depth-to-water of 120 ft. was reported. That well was found to have a depth-to-water of 133 ft. in July 2018. None of these wells, nor any other close by, had been used for approximately one year prior to the July 2018 measurements, yet one zone experienced a water-level rise and the next lower zone experienced a water-level decline.

Based on the owner interview, well (ID #53) was initially productive and was used for approximately 20 years. The water level fell below the pump setting, reportedly 385 ft., in approximately 2000, and the well has not been used since. An acoustic sounder measurement of the depth to water of 244 ft. in July 2018 as part of the present study suggests significant water-level recovery over the period since the well was last used[6].

Figure 7 shows where the Lakota is exposed at the ground surface (i.e., where it receives direct infiltration of rainfall, snowmelt and streamflow). Most conspicuous are the outcrops where stream channels pass across bare Lakota outcrops, creating opportunities for focused recharge where runoff from the surrounding area (or upstream well discharge) crosses zones of high-permeability. Inspection of the channel upstream from ID #45 in July 2018 observed outcrops of porous, coarse-grained sandstone along the channel bottom, beginning at the contact between the mudstone and sandstone units of the Lakota and continuing upstream. Because the formation strata are dipping downward to the southeast at this location, moving upstream (northwest) encounters increasing "lower" strata. Fractured outcrops potentially receptive to substantial recharge are present at this same stratigraphic level (i.e., the Lakota mudstone / sandstone contact) in the stream channel immediately below City well M-15.

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[5] This is the depth-to-water reported for well ID #45; there was no permit for ID #79, but it is reported by the owner to be virtually identical to ID #45.

[6] The owner-reported depth of this well (400 ft.) at this location suggests a Sundance completion. No SOC for this well has been identified.

The streams of the study area are all intermittent, flowing water primarily during isolated runoff events. Thus, recharge directly to aquifer exposures in the stream channels primarily occurs during periodic precipitation events. Examination of the small drainages of the study area by SEO personnel on June 25, 2018 following an unusual period of sustained rainfall observed evidence of substantial flow in the preceding days in Spring Creek and in the small draws north of Highway 14. Those near ID #51 and below ID #47 were specifically examined. Small residual flows were measured in the draw near ID #51 (8.5 gpm) and in Spring Creek near ID #52 (15 gpm).

Review of the streamflow gage on the Belle Fourche River at Moorcroft shows the occurrence of runoff-generating storms at the scale of that river basin. No comparable gage data are available for the study area, but the storm period between June 20 and 26, 2018 is obvious in the Belle Fourche gage. June 2018 rainfall at the Devils Tower station was 3.96 inches, approximately 30% above average.

The drainage above ID #45 is known to have experienced flows up to 1,400 gpm during the test discharges from the City wells. The lack of signs of erosion or other channel disturbance (beyond the immediate well site) suggests flows of this magnitude can be readily accommodated. Discharge to this drainage of 400 gpm as recently as May, 2017 occurred as part of City well M-15 testing. Direct recharge to aquifer exposures in the stream channels below the City wells is discussed extensively in Section 7.3.1, below.

Figure 11 provides a topographic and geologic cross section along the line A- A' shown on Figure 7. Due to the topography of the wellfield area, the Fall River and Lakota are locally entirely dissected by the drainages between the various City wells (i.e., where Morrison ("Jm") outcrops are noted on Figure 7). Thus, infiltration within the City wellfield will primarily drain down through the Fall River and upper Lakota Formations rather than flowing significantly laterally to surrounding areas.

Figure 12 provides a similar profile along a NW-SE orientation to illustrate the relationship between the Lakota in the wellfield area and in the adjacent, down-dip area of domestic wells. Infiltration to the Lakota that does not drain laterally into the drainages dissecting the wellfield (Figure 11) will flow down the dip of the formation (towards the southeast) to contribute recharge to the strata developed by the domestic wells.

The perennial seep at elevation 4,347 (ID #74) is likely the practical maximum for Lakota Formation saturated groundwater gradients on the scale of the present study area.

This seep is the highest groundwater elevation observed in the Lakota in the study area. This spring likely reflects the expression of seasonal local recharge to the ground surface where the formation has been dissected by topography. This situation is described in general by Whitcomb and Morris (1964, p. 30), "In the areas of outcrop of the Lakota Formation, the sandstone in the upper part of the formation is generally dry. Springs and seeps, which are common along the contact with the underlying Morrison Formation, are fed by water moving downward through sandstone of the Lakota. Consequently, wells drilled near the contact of the Lakota and Morrison Formations generally are unsuccessful because much of the water has been drained from the Lakota. Except for these areas of

local drainage, however, most of the water in the Lakota Formation moves downdip, away from the areas of outcrop, and the saturated thickness of the formation generally increases."

When inspected in July 2018, there was no output from this spring (ID #74) beyond the immediate evaporation and evapotranspiration through riparian vegetation. Again, significant saturation of the Lakota within the City wellfield is not indicated.

Consideration of water level elevations measured in the Lakota wells of the study area suggests average elevations around 4,120 ft. in the area immediately east of the Gillette wellfield (i.e., ID #s 28, 28.1, 21, 24); 4,140 ft. in the area further northeast (ID #s 18, 13, 17); 4,150 ft. southeast of the wellfield (ID #s 44, 48, 49, 50, 45.1, 47), 4,100 ft. along Spring Creek to the east of that (ID #s 46, 54 through 57), and continuing to decline to the southeast through ID #'s 58, 59, and 82 (average 4071 ft.).

Estimated Lakota water levels southwest of the City wellfield, 3,998 to 4,123 ft., are too variable to suggest a representative elevation in that area.

Thus, groundwater in the Lakota appears to flow east and southeast in the near vicinity of the City wellfield, and southeast toward Spring Creek at the scale of the study area. The base of the Lakota outcrops around 4,020 ft. at the mouth of Spring Creek, 1 mile southeast of ID #82. This may serve as the base elevation for the lateral Lakota groundwater flow in the study area.

Groundwater flow in the Lakota to the northeast, south, or southwest from the City wellfield area is less likely, given the measured groundwater level elevations relative to areas to the southeast.

Structurally, groundwater flow to the southeast from the wellfield area may be facilitated by enhanced permeability associated with the fracture patterns observed in the Lakota, as discussed above in Section 3.2.

The average groundwater elevation reported for wells identified with the Lakota Formation across the study area is 4,120 ft., approximately 100+ ft. higher than in the Sundance. Thus, groundwater will generally move downward from the Lakota as permeability allows, and opportunities for inter-formation flow (e.g., fracture zones, poorly-sealed wells, multiple completions, etc. will result in downward movement of Lakota groundwater into the Sundance).

Within the Lakota, reported water elevations are variable between wells, and between water-bearing zones at the same location. The example detailed above (Figure 3) documented a nearly 70-ft. difference in groundwater elevation between two water-bearing zones within the Lakota, separated vertically by only 40 ft. of "gray shale."

The history of groundwater development in the Lakota in this area includes reports of wells being relocated or deepened in search of better yields, suggesting even the small withdrawals by these domestic-supply wells may have been sufficient to alter water levels locally.

3.3.2.5 FALL RIVER

The Fall River Formation outcrops across most of the study area. This provides abundant opportunity for direct recharge through infiltration of rainfall and snowmelt. In most cases, the Fall River has not been found to contain sufficient groundwater to support successful well completions. Rather, most of its recharge proceeds downward into the underlying Lakota, precluding development of a useful water table in the Fall River.

Figure 14 presents a Fall River: Lakota comparison. The three wells depicted are all within approximately 300 ft. of one another. Wells ID #s 25 and 26 found useful water supplies in the Fall River at approximate water elevation 4,230 ft. Well ID #24 passed through this zone to develop water from the Lakota, with a groundwater elevation of 4,098 ft., 130 ft. lower. This was apparently a successful strategy (discounting the additional pumping costs), as ID #24 reported a test discharge of 23 gpm, whereas ID #25 reported only a 10-gpm test yield.

Figure 13 presents a similar situation. The original (2002, #28) well under this permit was completed with perforations in two water-bearing zones. The upper zone, from 40 to 60 feet, is in the lowermost Fall River according to the structure contouring of the base of the Fall River by Bergendahl et al. (1961). The lower zone, from 140 to 190 feet is at a depth indicating a Lakota completion. The reported groundwater level for the combined zones was 40 ft. The "relocate" (2016, #28.1) well under this permit was completed only in the lower zone, from 120 to160 feet, and reported a water level of 120 ft. Thus, it appears the Fall River has the higher water elevation, and was likely draining down the 2002 well into the Lakota.

The spring at ID #62 appears to reflect drainage from the Fall River Formation to the surface rather than down into the underlying Lakota. This perennial spring issues from the base of a conspicuous sandstone unit in the lower Fall River (i.e., the "sandstone unit" of Bergendahl et al., 1961). It is presumably the result of recharge to the surrounding Fall River outcrops east, north, and west collecting in the sandstone unit, infiltrating downward until the underlying siltstone is encountered, and then migrating laterally to discharge where Little Spring Creek has eroded a channel through the sandstone unit.

The 4,156 ft. elevation of this spring is approximately the same as the average of the primarily Lakota wells at ID #s 45, 45.1, 47, 79; and is 60 ft. higher than the groundwater elevations in the wells along Spring Creek to the northeast (ID #s 46, 52 through 59; average elevation of 4,090 ft.). Thus, the pattern of downward groundwater gradients between the aquifers of interest appears to be maintained, and there is limited opportunity for Lakota water to make its way into the overlying Fall River. The average groundwater elevation for those few wells identified as producing from the Fall River suggest lateral flow, if present, to the south and southeast, as in the Lakota.

3.3.2.6 SKULL CREEK

Although largely peripheral to the present investigation, a natural spring on the north side of Green Hill (ID #77) provides a local groundwater elevation for the Skull Creek Shale. At 4,379 ft., the groundwater is several hundred feet higher than found in Sundance wells to the east and in Lakota wells to the south. Like the spring at ID #62, this groundwater discharge point appears to be the result of local recharge. Only the adjacent slopes of Green Hill provide sufficient surface elevation to accept recharge bound for this discharge point. While the groundwater gradients would support flow from this low pH source to adjacent areas, the permeability is assumed to be quite low. Neither the hydrogeology of the Skull Creek nor its relationship with underlying aquifers has been evaluated for this report.

3.4 GENERAL GROUNDWATER QUALITY

Groundwater quality is strongly influenced by the geology of the formations the water moves through and the residence time of the water within those formations. As water moves through geological materials, various minerals are dissolved into the groundwater. The longer water is in contact with geologic materials, the more opportunity there is for various minerals to dissolve into or precipitate out of the groundwater. Water quality can vary considerably within an aquifer due to localized geologic conditions.

Whitcomb and Morris (1964, p. 2) concluded that, with the exception of the Madison and Minnelusa Formations, in Crook County, "Most of the ground water contains iron, sulfate, and dissolved solids in excess of the recommended concentration limits for domestic use. The water is harder, more alkaline, and more highly mineralized, and it contains more iron than is recommended for many industrial applications. Most ground water in the area is suitable for stock watering; however, its use for irrigation is limited because of its high to very high salinity hazard and low to medium sodium hazard." Water quality in the Fall River and Lakota formations is generally described as a sodium sulfate type (high sodium and high sulfates), while water quality from the Minnelusa is described as either calcium bicarbonate or calcium sulfate type, no water type is considered dominant for the Hulett sandstone (Hodson et al., 1973).

In their discussion of groundwater quality in Crook County, Whitcomb and Morris (1964) include a small set of pH measurements. For the five samples from the Lakota and Fall River, the pH values range from 7.3 to 8.0 s.u. However, in a high-iron sample from a Lakota well near Newcastle (Weston County) a pH of 5.5 s.u. was measured.

Many wells have been completed since the 1964 USGS work, but their general conclusions are consistent with the 2017/2018 sampling of 59 wells in the study area by WDEQ. The full results of the DEQ sampling are presented in report Section 6. Figure 15 presents summary data for select constituents for the Fall River, Lakota, and Sundance Formations. Formation assignments are based on location, depth, structure contouring by Bergendhal et al. (1961), and the lithologic descriptions filed with SEO SOCs.

Figure 15 includes water-quality classifications by WDEQ and the U.S. Environmental Protection Agency (USEPA). The WDEQ taxonomy defines three general "classes" of groundwater based on suitability for specific uses – I. human consumption, II. irrigation, and III. livestock watering (WDEQ, 2005). The USEPA "Primary" standards are based on human health considerations and are enforceable standards for Public Water Supplies. There are no enforceable standards for domestic wells. The USEPA "Secondary" standards are largely based on aesthetic considerations such as color, odor, taste, staining, corrosivity, etc. and are largely advisory rather than enforceable for Public Water Supplies.

These data demonstrate that, with rare exceptions, groundwater developed from these aquifers (Fall River, Lakota, Sundance) exceed USEPA Drinking Water standards and WDEQ WQRR Chapter 8 Class I standards for the graphed constituents (TDS, sulfate, iron, manganese). As with the basic lithology, groundwater production, and water levels of these aquifers, water quality is also quite variable. Furthermore, the range of concentrations of these constituents overlap considerably between the three formations.

Local reports are qualitatively consistent with the measured mineral concentrations. Use of bottled water for drinking is common in the area. Many users comment on taste and odor issues, and wells have been relocated or deepened in pursuit of improved water quality. High iron concentrations in groundwater are commonly associated with "rusty" deposits and orange bacterial mats. Local examples include the seeps below the small reservoir at ID #84 and in the spring area at ID #62 (Figure 16).

3.5 GROUNDWATER DEVELOPMENT

The first use of groundwater in the study area occurred via natural springs. Of the three springs investigated during the present investigation, two are relatively inaccessible (ID #s 74 and 77). The third (ID #62) is reported to have been an important source of water in pioneer days, drawing users from across a wide area (Altaffer, pers. comm, July 2018), and it remains a developed source for stock watering. This spring has recently been measured to have a pH of 5.03 s.u. (2017) and 4.0 s.u. (2018). Absent previous measurements, it is unclear if this is a recent condition, or if the difference in pH experienced over the one year of measurement reflects natural fluctuations or some sort of trend.

The oldest permitted well in the study area was drilled in 1934 (ID #13) with only nine wells being drilled prior to 1980. Table 3 provides the general timeline of groundwater development in the study area, including drilling of the City wells and of domestic wells for local homeowners.

The prolific Madison Aquifer has been the target for municipal-supply well construction in the study area, with the first well constructed in 1980. The original wellfield consisted of Wells M-1 through M-8. Wells M-9 and M-10 were added in 1996. Development of this wellfield included acid stimulation of select wells to enhance production characteristics (MM, 2007). Groundwater production has averaged 1,211 million gallons (Mg) per year (HDR, 2009).

A second wellfield has been under development for municipal use by Gillette since 2011, but has yet to be brought into production. Maximum withdrawal for testing was 7.8 Mg over three days in 2013, from M-11. Maximum withdrawal in 2017 was 1.4 Mg from well M-14 over the June 30 – July 9 period. By way of comparison, the City production reporting to the SEO for July 2017 lists 12 Mg production from well M-1, 28 Mg from well M-2, 19 Mg from well M-5, etc.

Figure 2 shows the locations of the various City wells ("M" labels) relative to the other locations of interest in this investigation.

The various water-bearing members of the Lakota have been the primary groundwater target for domestic well construction, with wells reaching the deeper Sundance Formation beginning in 1989.

The typical domestic well in this area has been drilled with air or mud-rotary equipment, with some cable tool wells prior to 2003. Casing is most commonly 5-inch diameter PVC, with factory slotted well screen and, since 2003, a gravel pack. Completion intervals range widely, including a short section of screen through a single water-bearing zone (e.g., ID #26), long screened intervals within one formation (e.g., ID #9), or multiple screened sections in different formations (e.g., ID #14). Relative to the water table encountered in a well, open intervals vary similarly, including starting well below the water level (e.g., ID #52), starting at the water level (e.g., ID #57), and starting well above the water level (e.g., ID #36).

4.0 RUNOFF MODELING

All the streams of the study area are intermittent, flowing primarily in response to runoff-generating rainfall or snowmelt events (or direct input from the groundwater production of adjacent wells). No quantitative streamflow records have been identified for the present investigation. Local landowners report occasional flow in these channels. Runoff is obviously sufficient to justify the construction of the many small reservoirs of the study area, the utility of which were obvious during field investigations for this study and can be examined through time via available imagery. One specific runoff event was investigated by SEO personnel, as described above (p. 33).

To provide quantitative estimates of the runoff potentially available to produce streamflow and attendant groundwater recharge in the wellfield area, DEQ staff have applied conventional rainfall / runoff models based on basic hydrologic parameters (Appendix F). Figure 17 shows the points for which runoff estimates were developed. These points were chosen to correspond with stream reaches receiving the drilling and testing discharge of groundwater from City wells M-11 (Estimation Point 105), M-12, 14, and 15 (Estimation Point 104), and M-13 (Estimation Point 100).

Analysis was done using a similar approach to what the Wyoming Department of Transportation Hydraulic Section uses to calculate design flows and volumes for culvert design in ungauged watersheds. Annual peak flows were calculated using a worksheet for recurrence intervals of 1.5 to 500 years, as described in Miller (2003). The method used to estimate runoff volumes is described in The Analysis of Runoff from Small Drainage Basins in Wyoming (Craig and Rankel, 1978).

Table 4 summarizes the results of these runoff calculations. The peak discharges from the relevant wells, for both flow rate and discharge volume, are included for comparison (see Table 3 for well discharge details).

These small drainage basins are at the lower end of the basin sizes for which the estimation techniques were developed. Thus, the results should be considered only as general guidance on the order of magnitude of flows one might reasonably anticipate. Also, recurrence intervals are statistical. Over an extended period of time, the calculated flows can be expected to occur, on average, at the listed interval.

In summary, estimated peak runoff values suggest the flow rates (cubic feet per second or gpm) associated with the groundwater discharges during drilling and testing of the City wells are comparable to those that may occur naturally on the order of annually. More significant are the peak volumes (ac-ft, Mg), i.e., while a summer cloudburst can produce high flow rates, those rates are unlikely to be sustained. The estimated peak runoff volumes suggest the groundwater discharges associated with the drilling and testing of the City wells are comparable to those that may occur naturally on the order of once every 2-5 years for the channel below well M-13, approximately every 5 years for the channel below well M-12, and approximately every 10+ years for the channel below M-11.

5.0 INVESTIGATION METHODOLOGY

Information on procedures followed during the collection of groundwater samples, including measurements of depth-to-groundwater, sample collection, field measurements, sample custody, and quality assurance/quality control are described in the sampling and analysis plan (SAP) and the quality assurance project plan (QAPP) which are components of the Field Sampling Plan (FSP). This section describes the general procedures followed for data collection.

5.1 WATER WELL SAMPLING

The initial list of water wells selected for sampling in November 2017 was based on access agreements granted by private landowners during the October 2017 public meeting and the location of the interested landowners relative to the wells initially identified with low pH conditions (Wells ID #s 45.1 and 47.1). Locations outside of an approximately 3-mile radius from the initial complaint wells were selected on a case-by-basis. One well owner who initially agreed to have their well sampled, declined when the field team arrived. Water samples were collected for field parameters, major cations and anions, select Water Quality Rules and Regulations (WQRR) Chapter 8, Table 1 parameters for metals and radionuclides, bacterial analysis (iron reducing and total coliform), and isotopic analysis of deuterium and O^{18}.

The selection of wells sampled in July 2018 included the wells previously sampled that had pH levels less than 6.5 s.u., a control well with a normal-range pH (6.5 to 8.5 s.u.) in the vicinity of the low pH wells, and additional wells in the low pH area that had not been sampled in 2017. In addition to the water wells, surface water samples were collected along Spring Creek. Due to low flows and/or algae, only two samples were collected from Spring Creek in July 2018. An additional surface water sample

was collected from a spring located on Green Hill (ID #77). In general, samples that were collected from wells sampled in November 2017 were sampled for a targeted list of analytes determined to be indicator parameters (major cations, anions, field parameters, total and dissolved aluminum, iron and manganese), and new locations in 2018 were sampled for the same list as the initial November 2017 sampling (Table 5).

Sampling and analytical activities were completed as prescribed in the FSP, unless noted below.

5.2 DATA VALIDATION

The samples were analyzed by Energy Labs in Gillette, the State Water Quality Lab in Cheyenne, and Pace Labs in Pittsburg, PA. The analytical reports from each lab were reviewed for accuracy, precision, representativeness of actual conditions, and comparability with other data during the validation process. Data validation was conducted by WDEQ / WQD staff. The reviewer performed a Level II data quality review on each report (see Section 6.7).

6.0 RESULTS

This section includes the results from the November 2017 and the July 2018 sampling of private water wells and surface water locations. Copies of the analytical reports are included in Appendix C. The tabulated analytical results were compared to drinking water standards and other comparison values that include:

- The USEPA Maximum Contaminant Level (MCL) is the greatest concentration of a constituent that is allowed in public drinking water supplies. MCL concentrations are set as low as is feasible using the best available analytical and treatment technologies and taking cost into consideration. MCLs are enforceable standards for public water supplies (USEPA, 2018).
- State of Wyoming WQRR, Chapter 8, Quality Standards for Wyoming Groundwaters, Table 1, Class I Groundwater Quality (Class I Domestic). Wyoming WQRR, Chapter 8, Table 1 standards are used to determine the suitability of groundwater for domestic uses (domestic, agricultural, and livestock), but are not used as regulatory standards for private wells.
- The USEPA Secondary Drinking Water Standards (SDWS) are non-enforceable federal guidelines regarding cosmetic effects (tooth or skin discoloration), aesthetic effects (taste, odor, or color), or corrosion potential (pH) of drinking water (USEPA, 2018).
- USEPA Drinking Water Health Advisory (HA). The USEPA HA is a non-enforceable concentration of a constituent in water that is likely to be without adverse effects on health and aesthetics (USEPA, 2018).

As noted in the tables of laboratory analytical results (Tables 6 to 11), when the value of an analytical result is less than the method detection limit (MDL) or less than the reporting limit (RL), or in other

words, it was not detected, then the value of the MDL or RL is listed after the "<" symbol. The MDL and RL are defined as:

- MDL: MDLs are always lower than reporting limits and are statistically derived for each laboratory. However, because the MDL is below the initial calibration curve, any concentration above the MDL, but below the reporting limit, is only an estimate (WDEQ, 2016).
- RL: Typically, a reporting limit represents the lowest point of the initial calibration curve for a particular analysis and instrument. Typically, concentrations below the reporting limit should not be reported by the laboratory unless they are qualified as estimated values (WDEQ, 2016).

When the concentration of an analyte is between the MDL and the RL, there is confidence that the analyte is present but the exact concentration is not known; therefore, concentrations reported between the MDL and RL are noted as estimated using a "J" flag.

In the tables with measurements of field parameters and laboratory analytical results (Tables 6 to 11), when a reported concentration is greater than a drinking water standard or comparison value, the result value is highlighted with color and a special font, or color alone, in accordance with notes in the tables. For consistency, when a reported laboratory analytical result is less than the MDL or RL, and the MDL or RL is greater than a drinking water standard or comparison value, that result is also highlighted.

A letter was sent to each well owner that participated in the sampling events, that included information regarding parameters that were outside of the suitable uses for the well as identified by the SEO-permitted well uses. A copy of the analytical lab report was also provided.

6.1 FIELD PARAMETERS

Water quality parameters measured in the field consisted of dissolved oxygen, ferrous iron, oxidation reduction potential (ORP), specific conductance, total dissolved solids (TDS), pH and temperature. Field parameter readings on Table 6 are the final measured results prior to sample collection.

Measured DO concentrations ranged from 0 (multiple locations) to 31.9 mg/L (ID #62). The reading of 31.9 mg/L is significantly higher than the theoretical saturation limit of oxygen in water, and is considered to be an outlier. In general, DO concentrations ranged between 0 and 4 mg/L.

Ferrous iron concentrations measured in the field ranged from 0 to greater than 3 mg/L. Ninety-two samples were collected, of those 92 samples, 4 samples were from surface water and did not have ferrous iron readings collected, and 10 samples from water-wells did not have recorded ferrous iron data. Ferrous iron was detected at concentrations greater than the Class I Domestic standard of 0.3 mg/L in 30 samples, of these 30 samples, 19 samples were greater than the upper limit (3 mg/L) on the ferrous iron meter. Thirty-four samples had ferrous iron detected between 0 and 0.3 mg/L.

The field pH measured in groundwater ranged from 3.54 s.u. (sample 071818-1130, ID #28.1) to 9.69 s.u (sample 1-11217-1245, ID #39). In general, field pH measurements for the 12 locations that were sampled in November 2017 and July 2018, were within a 10% relative percent difference (RPD), only 3 paired samples were outside of the 10% RPD. Samples collected from two springs, not on the Spring Creek drainage, had pH values of 3.12 s.u. (sample Spring-1, ID #77) and 5.03 s.u. (sample 1-11717-1130, ID #62). Samples collected from the Spring Creek drainage ranged from 6.91 s.u. (sample SW-2, ID #81) to 7.47 s.u. (sample SW-1-071918, ID #74), with pH measurements in general getting lower further down the drainage.

The ORP measured between -264 and 364 millivolts (mV). ORP is used to measure the reducing or oxidizing potential of groundwater, and is not a measurement used for health effects. The more positive the ORP value, the more oxidizing the groundwater.

Groundwater temperatures measured between 7.4 (ID #24) and 13.43 (ID #38) degrees Celsius (^{o}C) during the November 2017 sampling event, and between 9.79 (ID #80) and 14.27 ^{o}C (ID #34) in July 2018. Temperatures at the spring, ID #62 measured 3.61 ^{o}C in November 2017 and 24.19 ^{o}C in July 2018.

The measured turbidity of the groundwater samples ranged from -30.5 Nephelometric Turbidity Unit (NTU) (ID #46, July 2018) to 39.6 NTU (ID #14, November 2017). Turbidity readings less than zero appeared to be a result of problems with the sensor or calibration issues. There were 33 non-zero turbidity measurements from water-supply wells. Of these 33 results, the measured turbidity exceeded the USEPA water treatment technique standard of 5 NTU in 20 samples.

Field measurements of TDS were only recorded for 10 locations during the November 2017 sampling event. TDS was not included on the field forms for recording. Measurements of TDS ranged from 541 mg/L (ID #43) to 1,380 mg/L (ID #45.1). All field measured values of TDS were greater than the WQRR Chapter 8, Table 1, Class I domestic use standards. The electrical conductivity (EC) is a measurement of the ionic activity of a solution in terms of ability to transmit current, and in a relatively dilute solution, can be used to estimate a TDS concentration.

6.2 MAJOR CATIONS, MAJOR ANIONS, AND TOTAL DISSOLVED SOLIDS

Major cations consisted of: calcium, magnesium, potassium, and sodium. Major anions included: alkalinity (various forms), bromide, chloride, fluoride, nitrate-nitrite, and sulfate. Results are included in Table 7

Calcium, magnesium, and potassium were detected in every water sample analyzed. There are no screening standards for these constituents. The measurement of calcium and magnesium in groundwater is related to the hardness of the water. In addition, alkalinity and bromide do not have screening standards. In general bromide concentrations in fresh water are less than 0.5 mg/L. There were no detections of bromide greater than 0.2 mg/L. Alkalinity is a measurement of the buffering capacity of groundwater and is related to the presence of bicarbonates and carbonates in the groundwater.

Sodium was detected in every groundwater sample collected at concentrations ranging from 41 mg/L (ID #21) to 684 mg/L (ID #63). The reported concentrations of sodium exceeded the USEPA HA of 20 mg/L (20 mg/L for individuals on a sodium-restricted diet, otherwise 30 to 60 mg/L for all others) in all samples.

Chloride, fluoride and sulfate were detected in every groundwater sample analyzed. Concentrations of chloride ranged from 4 (J) mg/L (ID #33) to 58 mg/L (ID #17). Chloride was not detected at concentrations greater than the WQRR Chapter 8, Table 1, Class I domestic use standard of 250 mg/L. Fluoride was detected at concentrations ranging from 0.2 mg/L (multiple wells) to 4.2 mg/L (ID #38). Fluoride was detected at greater than the EPA MCL and the WQRR Chapter 8, Table 1, Class I domestic use standard of 4 mg/L in one sample (ID #38). Sulfate was detected at concentrations ranging from 48 mg/L (ID #38) to 2,640 mg/L (ID #25). Sulfate was detected at a concentration of 4,550 mg/L from one spring sample (ID #77). Sulfate was detected at concentrations greater than the USEPA HA (taste threshold) of 250 mg/L in all but two samples. Sulfate was detected at concentrations greater than the USEPA HA (health based) of 500 mg/L in all but fourteen samples.

Nitrate-nitrite as nitrogen (nitrate-nitrite) was detected in 15 samples at concentrations ranging from 0.1 mg/L (ID #4) to 4.58 mg/L (ID #26). Nitrate-nitrite was not detected in groundwater samples greater than the WQRR Chapter 8, Table 1, Class I domestic use standard of 10 mg/L. Not all samples were analyzed for nitrate-nitrite due to preservative issues, matrix interferences, or sample bottles not received by the laboratory.

Concentrations of TDS ranged from 428 mg/L (ID# 21) to 6,600 mg/L (ID #77). Major cations and anions account for most of the TDS present in the water samples. The TDS of well ID #21 was found to be suitable for domestic use as defined in WQRR Chapter 8, Table 1, Class I domestic use standards (500 mg/L). All other wells exceeded this value.

In general, the detected values of major cations and anions can be used to describe the 'type' of waters. Based on analytical results, groundwater in the study area can generally be classified as a calcium-sulfate or sodium-sulfate water. This agrees with previous groundwater classifications from the area conducted by the USGS (e.g. USGS HA-465)

6.3 GENERAL CHEMISTRY

General chemistry analysis included ammonia as nitrogen (ammonia), cyanide, sulfide, laboratory pH, and isotopes (O^{18} and deuterium) (Table 8). Total cyanide was not detected at concentrations greater than the laboratory reporting limit of 0.005 mg/L in any groundwater sample. There were 50 reported detections of ammonia in groundwater samples, with 7 detections in domestic or domestick/stock water samples greater than the WQRR Chapter 8, Table 1 domestic standard of 0.5 mg/L. Detections of ammonia in groundwater samples ranged from 0.06 mg/L (ID #14) to 1.1 mg/L (ID #34). Ammonia was detected in the sample from spring ID #62 at a concentration of 5.2 mg/L in Fall 2017 and 2.46 mg/L in July 2018.

Sulfide was detected in six groundwater samples at concentrations greater than the laboratory reporting limit of 0.04 mg/L. Detections of sulfide ranged from 0.19 mg/L (ID #83) to 1.07 mg/L (ID #19).

WDEQ requested that the laboratory analyze for pH although the lab results would be out of hold time and qualified as estimated. Some homeowners were able to supply laboratory reports of pH, so these values could be used for direct comparison. Eleven groundwater samples had laboratory pH values greater than the Class I domestic use standard identified in WQRR Chapter 8, Table 1 of 8.5 s.u. Twenty-five groundwater samples had pH values that were below the Class I domestic use standard of 6.5 s.u. identified in WQRR Chapter 8, Table 1. Three surface water samples collected from two spring locations (ID #s 62 and 77) had laboratory pH values less than 6.5 s.u.; 4.41 (J) and 3.97 (H) s.u., and 3.38 (H) s.u., respectively.

The isotopes O^{18} and deuterium are included in the general chemistry section since they are measurements used to assist in determining water ages, and potential surface water influences. In general it appears that the majority of samples analyzed for O^{18} and deuterium fall along a local meteoric water line (LMWL), independent of pH, including the downstream surface water sample collected from Spring Creek (ID # SW-2). This indicates that the waters are generally sourced from precipitation. Samples from four locations plotted significantly off the LMWL, these are two surface water samples (ID #s SW-1 and Spring-1) and two shallow wells that are less than 50 ft. deep (ID #s 25 and 26). These data are provided to assist future research relating to the study area groundwater, but that research is beyond the scope of the present study.

6.4 TRACE METALS

Metals were analyzed for both total and dissolved species and included the following metals analysis: aluminum, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, mercury, nickel, selenium, silver, strontium, vanadium, and zinc. Mercury and silver were the only trace metals that were not detected in any groundwater sample (dissolved or total). Results of trace metals analysis are included in Table 9.

Arsenic, barium, boron, cadmium, cobalt, copper, lead, lithium, nickel, selenium, strontium, vanadium and zinc were not detected in groundwater samples at concentrations greater than their respective screening standards.

Total aluminum was detected in 34 groundwater samples, with concentrations ranging from 0.067 mg/L to 92.4 (J) mg/L. Total aluminum was detected in four surface water/spring samples at concentrations ranging from 0.209 to 72.8 mg/L. Dissolved aluminum was detected in 17 groundwater samples, with concentration ranging from 0.091 mg/L to 94.9 mg/L. Dissolved aluminum was detected in three surface water/spring samples at concentrations ranging from 28.2 to 72.7 mg/L. All detected concentrations of total and dissolved aluminum were greater than the USEPA SDWS lower limit of 0.05 mg/L. There is no health based standard for aluminum in groundwater.

Total beryllium was detected in seven groundwater samples and one spring sample at concentrations ranging from 0.001 to 0.012 mg/L. Dissolved beryllium was detected in ten groundwater samples and

one spring sample at concentrations ranging from 0.002 mg/L to 0.015 mg/L. Four dissolved beryllium and two total beryllium results were greater than the USEPA MCL of 0.004 mg/L. Ingestion of beryllium has not been reported to cause health effects in humans.

Total and dissolved chromium were detected in one groundwater sample at concentrations of 0.077 mg/L and 0.067 mg/L, respectively. The detected concentrations of chromium were not greater than the USEPA MCL of 0.1 mg/L. Prolonged exposure to chromium in water can result in allergic dermatitis (skin reaction).

Total iron was detected in 55 groundwater samples at concentration ranging from 0.02 mg/L to 139.038 mg/L. Total iron was detected in five surface water/spring samples at concentrations ranging from 0.168 mg/L to 17.4 mg/L. Dissolved iron was detected in 44 groundwater samples at concentrations ranging from 0.1 mg/l to 40.4 mg/L. Dissolved iron was detected in four surface water/spring samples at concentrations ranging from 0.063 mg/L to 10.37 mg/L. Thirty two total iron results and 23 dissolved iron results were greater than the WQRR Chapter 8, Table 1, Class I domestic use standard of 0.3 mg/L. Iron is considered a “nuisance” constituent that can effect taste and or odor of groundwater and staining of fixtures.

Total manganese was detected in 67 groundwater samples at concentrations ranging from 0.001 mg/L to 1.29 mg/L. Total manganese was detected in five surface water/spring samples at concentrations ranging from 0.21 mg/L to 61.1 mg/L. Dissolved manganese was detected in 63 groundwater samples at concentration ranging from 0.001 mg/L to 1.36 mg/L and in five surface water/spring samples at concentrations ranging from 0.055 mg/L to 54.6 mg/L. Thirty three total manganese samples and thirty one dissolved manganese samples had concentrations greater than the WQRR Chapter 8, Table 1, Class I domestic use standard of 0.05 mg/L. Manganese is considered to be a “nuisance” constituent that can effect taste and or odor of groundwater and staining of fixtures.

6.5 BACTERIA

Groundwater samples were collected for total coliform bacteria, e-coli bacteria, and iron reducing bacteria (IRB) (Table 8). For locations that were sampled in November 2017 and then resampled in July2018, bacteria were not analyzed again, per the SAP.

Sixteen groundwater samples did not have IRB detected at concentrations greater than the laboratory reporting limit of 1 colony forming units per milliliter (CFU/ml). Iron reducing bacteria were detected in the remaining groundwater samples between 25 and 35,000 CFU/ml. In addition, IRB were detected in two of the four surface water samples analyzed for IRB; both are locations from the Spring Creek drainage.

Total coliform bacteria were detected in 15 groundwater samples, and one spring sample. Surface water samples collected in July 2018 were not analyzed for total coliform bacteria. No samples were positive for E. coli bacteria.

6.6 RADIONUCLIDES

Groundwater samples were analyzed for radionuclides including gross alpha minus radon and uranium (adjusted gross alpha), radium 226 (Ra226), gross alpha minus radon and uranium and adding radium 226 (calculated value, gross alpha+Ra226), radium 226 plus radium 228 (Ra226+Ra228), radium 228 (Ra228), and strontium 90. Groundwater samples were only analyzed for radionuclides during one event, per the SAP. Surface water samples, with the exception of ID #62, were not analyzed for radionuclides. Results are tabulated on Table 10.

Gross alpha was detected in 45 samples at concentrations ranging from 0.5 (ID #26) pico Curies per liter (pCi/L) to 16 pCi/L (ID #34). Gross alpha was also detected in the one spring sample (ID #62) analyzed. Gross alpha was not detected above the laboratory reporting limit in 12 samples.

Radium 226 was detected in 51 samples at concentrations ranging from 0.2 pCi/L (ID #7) to 13.8 pCi/L (ID #34). Radium 226 was also detected in the one spring sample (ID #62) analyzed. Radium 226 was not detected above the laboratory detection limit in seven samples.

Gross alpha+Ra226 was detected in 58 samples at concentrations ranging from 0.13 pCi/L (ID #79) to 29.8 pCi/L (ID #34). Gross alpha+Ra226 was also detected in the one spring sample (ID #62) analyzed. Two sample locations had detections of gross alpha+Ra226 greater than the WQRR Chapter 8, Table 1, Class I domestic use standard of 15 pCi/L. Concentrations greater than the domestic standard were 29.8 piC/L (ID #34) and 25.3 pCi/L (ID #83).

Combined Ra226+Ra228 was detected in 21 groundwater samples at concentrations ranging from 1.6 pCi/L (ID #41) to 14.3 pCi/L (ID #34). Five sample locations (ID#s 32, 34, 56, 44, 83) had detections of Ra226+Ra228 greater than the WQRR Chapter 8, Table 1, Class I domestic use standard of 5 pCi/L.

Strontium 90 was detected in five groundwater samples at concentrations ranging from 2.9 pCi/L (ID #s 35 and 82) to 5.8 pCi/L (ID #25). Strontium 90 was not detected in any sample greater than the domestic screening standard of 8 pCi/L.

6.7 DATA VALIDATION AND REPORTING

Data validation reports prepared by DEQ are in Appendix D. Five thousand, two-hundred eighty-seven (5,287) analytical results were reviewed during the data verification and validation process. Thirty four (34) data points were rejected and six hundred four (604) data points were qualified and are acceptable for use. The remaining data points (4,649) met project criteria and did not require qualification. A summary of data qualifications is discussed below for each analysis group. The table included as Appendix E lists specific data points that were qualified and rejected.

Field duplicate samples, field filter blanks, and laboratory quality control samples were within acceptable quality control limits unless stated otherwise. RPD for duplicate and parent sample concentrations are listed in Table 11.

Five samples were not analyzed for ammonia or nitrate-nitrite because they were not properly preserved upon arrival at the laboratory. Three samples were not analyzed for dissolved metals because filters were not operational and samples could not be filtered in the field. "Missed" (i.e. not collected or analyzed) samples are listed in Table 12.

Where applicable detected values were qualified with a "J" where non-detected values were qualified with a "U" or "UJ" to indicate the value is estimated. Rejected values were qualified with an "R".

6.7.1 MAJOR IONS AND GENERAL CHEMISTRY

Fifty-two (52) results for major ions and general chemistry parameters were qualified during data validation.

Thirty-three (33) results for nitrate-nitrite were rejected because "matrix interference caused inverted peak and value was not reported." Nitrate-nitrite results for these samples could not be reported.

Eighteen (18) results for alkalinity, bicarbonates, and carbonates were analyzed past the recommended holding time; and therefore, detected concentrations were qualified with a "J".

One (1) ammonia (as Nitrogen) result was qualified with a "J" because low spike recovery suggested slight matrix interference.

6.7.2 TRACE METALS

A total of 212 metals results were qualified with either a "J" or "UJ." No metals results were rejected.

One-hundred ninety-eight results for trace meals (total and dissolved fractions) were qualified with a "J" because the dissolved fraction was greater than the total fraction, and the relative percent different (of the total and dissolved concentrations) is outside of quality control limits. Sixteen (16) of the 198 samples were diluted samples.

Note, dissolved metals results greater than total metals results are within 5% of the total metals value. This is within expected experimental variation and is acceptable.

Eight (8) of the 212 results were qualified with "UJ" because the continuing calibration control recovery was outside of QC limits.

Six (6) of the 212 qualified metals results were qualified with a "J" because the field duplicate RPD was outside of quality control limits.

6.7.3 pH

pH was measured in the field when samples were collected and in the laboratory before samples were analyzed. All laboratory pH values (79) were qualified with a "J" for estimated values because samples were analyzed past the recommended holding time (i.e. immediate analysis). However, pH was measured in the field and the laboratory pH was used only for comparison to the field pH.

6.7.4 BACTERIA

Ninety six (96) results for bacteria samples (e-coli, total coliform, and iron-related) were qualified with a "J" or "UJ" to reflect estimated results because the samples were analyzed past the recommended holding times (i.e. 28-hours).

6.7.5 RADIOCHEMISTRY

One-hundred sixty-four (164) radiochemistry analytes (Gross Alpha minus Rn & U, Radium 226, Radium 226 + Radium 228, and Radium 228) were qualified by the laboratory with "U" for "not detected at minimum detectable concentration."

7.0 EVALUATION OF ACIDITY IN DOMESTIC WELLS

Acidity is measured as pH. pH is a measure of hydrogen ion activity. A pH of 7.0 is considered chemically neutral, neither acidic nor basic. Values below 7.0 are increasingly acidic. Values above 7.0 are increasingly basic. Table 13 provides a typical listing of the pH of natural materials.

Normal precipitation has a pH of approximately 5.5. It is weak carbonic acid resulting from natural equilibrium with atmospheric carbon dioxide. Upon reaching the earth surface, precipitation typically quickly reacts with surface and near-surface materials to establish near neutral pH. "River water in areas not significantly influenced by pollution generally has a pH between about 6.5 and 8.5" and "most ground waters found in the United States have pH values ranging from around 6.0 to 8.5." (Hem, 1970; p. 93)

In terms of drinking water, EPA has established "Secondary" standards of 6.5 to 8.5 for pH for public water supplies. (Private water wells are not considered 'public water supplies' and are not subject to EPA drinking water standards.) The secondary standards are not requirements. "They are established as guidelines to assist public water systems in managing their drinking water for aesthetic considerations, such as taste[7], color, and odor. These contaminants are not considered to present a risk to human health..." For pH, the "noticeable effects" of water outside the standards, are "low pH: bitter metallic taste, corrosion; high pH: slippery feel, soda taste, deposits" (USEPA, 2018).

Wyoming DEQ regulations establish similar ranges, classifying waters with pH between 6.5 and 8.5 as Class I suitable for "Domestic" consumption, pH between 4.5 and 9.0 as Class II, suitable for "Agricultural" use; and pH between 6.5 and 8.5 as Class III, suitable for "Livestock" use.

7.1 LOW PH IN THE GILLETTE WELLFIELD STUDY AREA

There are 12 wells and two natural springs in the study area in which pH of less than 6.5 s.u. has been measured. Of these, 7 wells and one spring have been measured at pH less than 5.0 s.u.

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[7] According to Vitz et al. (2018), low pH becomes perceptible to human taste between 4 and 5 s.u.

Figure 18 provides a summary of the pH measurements made by DEQ from the domestic wells in the study area around the City wellfields. For wells where data were collected in 2017 and 2018, the 2017 dataset is used for this comparison.. With respect to pH, 44% of these samples fall outside DEQ domestic-water standards, either due to low pH (20%) or high pH (24%). As discussed above, groundwater in this area presents a variety of other water-quality challenges with respect to drinking-water standards and general suitability. Our focus here is on the specific parameter of pH and the occurrence of groundwater with pH values less than 6.5.

Figure 19 presents the stratigraphic and geographic distribution of the DEQ pH samples. The locations are color-coded to the formation judged to host the primary water-bearing unit(s) for each well[8], and the fall 2017 measured pH is listed. A subset of these wells were re-sampled in July, 2018. The 2018 values are posted in the absence of a 2017 value.

Stratigraphically, all of the wells with pH < 6.5 for which a formation has been identified are drawing water from the Lakota Formation. The two low pH springs (ID #s 77 and 62) issue from the Skull Creek Shale and the Fall River Formation, respectively.

As discussed above, however, the "Lakota" is not a single, homogeneous stratum. Based on reported completion information, low pH wells are more commonly associated with the lower strata within the Lakota (i.e. the lower approximately 50% of the formation). However, many wells drawing from the lower Lakota strata do not produce low pH groundwater. They produce pH values greater than 6.5, like those drawing from the upper portions of the formation. More specific stratigraphic correlations are not apparent, and as detailed above, adjacent strata within the Lakota at the same location may have measured pH values as different as 6.9 s.u. (ID #45) and 3.9 s.u. (ID #45.1). In this case, the two wells were completed in the upper and lower-middle of the Lakota, with the lower pH in the lower stratum. In the case of ID #s 46 and 54, two Lakota wells 1,000 ft. apart, the measured pH values are 7.01 and 6.25 s.u., respectively. The former is completed in the lower Lakota; the latter is completed in the lower-middle portion of the aquifer (i.e., the reverse of the relationship for the ID #45 / ID #45.1 pair). Finally, ID #s 45.1 and 47.1 were both constructed in response to the production failure of ID #45. Both encountered low pH conditions, i.e., DEQ 2017 measurements of 3.90 and 3.91 s.u., respectively, suggesting penetration of the same, low pH stratum. However, ID #45.1 had nearly twice the sulfate concentration and an 80% higher Total Dissolved Solids concentration than ID #47.1, suggesting significant stratigraphic difference[9] .

The majority of the low pH wells are located southeast of the new City wellfield (i.e. M-11 through M-15), but this area has a preponderance of Lakota wells. To the extent low pH conditions are more prevalent in the Lakota, low pH occurrences will be more common where Lakota wells predominate. In the area east of the Gillette wellfield, the majority of the wells are completed in the Sundance.

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[8] These assignments are approximate, as some wells are completed in more than one unit or provide only minimal completion information upon which to base formation interpretation.
[9] No construction or lithologic details have been made available for ID #47.1 as of this writing.

(Reported static water levels in that area are most commonly below the base of the Lakota.) However, the one Lakota well in this area (ID #18) had a pH of 5.93 s.u.

Geographically, the low pH wells and springs include occurrences both proximal to and remote from the City wellfield, where associated impacts are quite unlikely, or even impossible. Given the indicated flow directions, for example, it would be quite difficult for activity in the City wellfield to contribute to low pH at IDs #18 and #32. The low pH spring at #77 cannot possibly receive input from the wellfield area due to the elevation difference, and it would take extraordinary "plumbing" to deliver wellfield-associated groundwater to the low pH spring at #62. Low pH groundwater samples from #59 and #82 are located in the area apparently down-gradient from the City wellfield, but multiple wells in between there and the wellfield and at similar depths, provide near-neutral pH groundwater (e.g. #55, 56, 57, 58).

Evidence for changes in pH over time is sparse. Very few private landowners had detailed water quality results for their wells prior to this study. Over the limited time-span (10 months) of the quality-controlled WDEQ sampling events, there were noticeable differences in certain wells, although in general, there was little change in groundwater chemistry. Sample locations that showed significant changes over the 10-month time period include:

- Dissolved oxygen (DO) concentration in ID #47.1 decreased from 10.5 to 1.9 milligrams per liter (mg/L) (pH increased somewhat, from 3.9 to 4.2 s.u.);
- pH in ID #45.1 increased from 3.9 to 4.6 s.u.;
- pH in ID #44 decreased from 5.3 to 4.7 s.u.;
- pH in ID #18 decreased from 5.9 to 5.4 s.u., and DO increased from 5.8 to 12.2 mg/L;
- pH in ID #62 (a natural spring) decreased from 5.0 to 4.0 s.u.

With respect to pH measurements prior to the present study, the following historical data were compiled over the course of WDEQ interviews and include data over a longer time span than the 10-month difference between the two WDEQ sampling events:

- ID #59 - a homeowner measurement on February 21, 2016 of 7.6 s.u. (field), compares to the WDEQ November 16, 2017 measurement of 4.6 s.u. (laboratory).
- ID#82 - a homeowner measurement of 6.8 in January 2016 compares with WDEQ measurement of 4.79 in July 2018, suggesting the observed decrease at nearby well #59 may identify a local area of lowered pH. Wells ID#59 and #82 are the only two instances of paired measurements documenting a specific pH decrease in the study area in the same well.
- ID #9 - a homeowner measurement on May 10, 2001 of 8.17 s.u. (field) is consistent with the WDEQ 11/16/17 measurement of 8.07 s.u. (laboratory).

- ID #52 - homeowner measurements of 6.5 s.u. on April 5, 1994, 6.5 s.u. on May 22, 1996, 6.1 s.u. on April 20, 2007, and 6.13 s.u. on February 7, 2013 (all field), suggest a small variation, but are generally consistent with the WDEQ November 16, 2017 measurement of 6.47 s.u. (laboratory).

- ID #45 - homeowner measurements of 7.4 s.u. on August 10, 2000, 7.5 s.u. on April 23, 2009, and 6.6 s.u. on September 1, 2016 (all field) suggest variation of approximately one full pH s.u. but are generally consistent with the WDEQ July 19, 2018 measurement of 7.2 s.u. (laboratory). The deeper well at this location, ID #45.1, was found to have pH of 4.2 s.u. during the WDEQ sampling on July 20, 2018.

7.2 SOURCES OF GROUNDWATER ACIDITY

Two hypotheses have been advanced to explain the occurrence of low pH in the domestic wells of the study area:

1. Hydrochloric acid injection associated with the stimulation of the Gillette Madison wells was not confined to the target formation, but was forced into the overlying strata.

   Stimulation procedures were applied to several of the original Gillette wells pre-2000 (M-1 through M-10) and to four of the more recent Gillette wells, between 2013 and 2017 (M-11, M-12, M-13, M-15). Although requiring extraordinary acid migration and persistence, the association with the acidity encountered in domestic wells was not an unreasonable suggestion, given the sequence of activity and observations.

   Table 14 summarizes the relevant results from laboratory analysis of samples from 59 domestic water wells in the study area. Were hydrochloric acid the source of the observed low pH conditions, the chloride concentration in those wells would be elevated relative to the normal-pH wells in the study area. In fact, the average chloride concentration in the low pH wells is lower than in the normal-pH wells. The hydrochloric acid used to stimulate the City wells is not the source of acidity in the domestic wells.

2. Local generation of acidity has occurred through the oxidation of naturally-occurring pyrite (iron sulfide) within the effected strata.

   Pyrite oxidation as a source of groundwater acidity is a well-established geochemical process (e.g., Rimstidt and Vaughan, 2003; Hammarstrom et al., 2004; Sullivan et al., 1988). It has been most extensively studied in connection with “acid mine drainage” where a man-made disturbance (mine shafts, spoil piles, etc.) has brought sulfide-bearing materials into contact with oxygen-rich waters. The term “acid rock drainage” has been applied to the broader occurrence of this process including undisturbed, natural settings. (See Downing and Mills, 2000, for an overview and bibliography.)

   The chemical reaction is:

$$FeS_2\ (S) + 8H_2O \rightleftharpoons Fe^{2+} + 2SO_4^{2-} + 16H^+ + 14e^-$$

$$7/2O_2 + 14e^- + 14H^+ \rightleftharpoons 7H_2O$$

Net Reaction:

$$FeS_2 + 7/2O_2 + H_2O \rightleftharpoons Fe^{2+} + 2SO_4^{2-} + 2H^+$$

The expected products of this reaction are elevated iron and sulfate and lower pH (i.e. more acidic). The products of this reaction are a good match with the elevated levels of sulfate and iron observed in the low pH wells of the study area, as compared with area wells without low pH. As shown in Table 14, groundwater in non-acidic wells contain an average of 22.86 mg/L sulfate and very low, or non-detectable, iron. Wells with low pH contain an average of 887.4 sulfate and 22.86 mg/L iron. This represents an approximately 40 fold increase in sulfate and an approximately 450 fold increase in iron values between acidic and non-acidic wells.

This reaction is the geochemical process most consistent with the laboratory analyses of this investigation. Given this geochemical conclusion, our investigation subsequently focused on the availability of oxygenated groundwater to stimulate the production of acidity in the water-bearing strata tapped by the domestic wells of the study area.

The necessary ingredients for this geochemical reaction to proceed are: 1) pyrite, which is relatively abundant in the Lakota Formation (see Section 3), and 2) oxygen in the groundwater of the host strata. Thus, the possible association with the City wells lies in the circumstances of the discharge from those wells over the course of drilling and testing[10], i.e., the potential for such discharge to have enhanced the natural processes through which pyrite (and associated minerals) are degraded in the subsurface, with attendant decrease in groundwater pH.

An additional chemical reaction relevant to the formation of acidic conditions is the buffering impact of groundwater alkalinity:

$$H^+ + HCO_3^- \rightarrow H_2CO_3 \rightarrow CO_2\uparrow + H_2O$$

Through this process, acid production is neutralized, maintaining non-acidic pH values. The mineral calcite (CaCO3) is the predominant source of groundwater alkalinity, as it is commonly found either as limestone or as a cementing material in sandstones. As discussed above (Section 3), calcite is relatively uncommon in the Lakota of the study area. The distribution of calcite in the strata of the

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[10] The potential for groundwater from the Madison invading higher formations through poorly sealed well casings was examined, but found to be inconsistent with the substantially lower groundwater elevations in the Madison (Section 3).

study area – both between the various formations and within the Lakota - may be a contributing factor in the diverse occurrence of low pH groundwater.

The general process of formation of acidic conditions through the oxidation of pyrite was examined briefly with a simple benchtop experiment for this investigation. 125 grams (gm) of distilled water was added to two 100-gm crushed rock samples of a weathered, pyrite-rich porphyry from a Black Hills ore-body. To one of these samples was added 10 gm of crushed limestone (CaCO3). The measured pH of the water in the porphyry sample decreased to 5.13 almost immediately, to 4.7 over one day, and remained stable near that level over the 9 days of observation. The measured pH of the water from the porphyry + limestone sample rose slowly from 6.97 to 7.96 over the observation period. Both the potential rapidity of the acid-forming reaction with pyrite (weathered) and the buffering impact of available calcite were demonstrated.

The potential buffering effect of groundwater alkalinity was further investigated in this process by comparing the effect of distilled water to that of groundwater from the Casper Formation, a limestone/sandstone aquifer with bicarbonate concentration of approximately 230 mg/L. (The bicarbonate concentration of Madison groundwater discharged by the City wells is approximately 220 mg/l; Table 18.) In this case, the nearly immediate drop in pH was to 4.32 and 6.58, for distilled and formation water, respectively. Over a 37-hour period, those values fell to 4.07 and 5.36, respectively; and after 3 days, were measured at 4.17 and 4.70, respectively, as the buffering capacity of the natural groundwater was exhausted.

Hammarstrom et al., 2004 document the rapidity with which exposure of pyrite-rich material to oxygenated water can generate groundwater acidity. In that study, pyritic sandstone (calcite free) was exposed by a large road cut in central Pennsylvania. “Wet/dry cycles associated with intermittent rainfall promoted oxidative weathering and dissolution of primary sulfides and their oxidation products. Resulting sulfate solutions evaporated during dry periods to form intermittent “blooms” of soluble, yellow and white efflorescent sulfate salts (copiapite, melanterite, and halotrichite) on exposed rock and other surfaces. Salts coating the cut face incorporated Fe, Al, S, and minor Zn. They readily dissolved in deionized water in the laboratory to form solutions with pH <2.5, consistent with field observations. … Episodic salt dissolution then contributes pulses of contamination including acid to surface runoff and ground water.” (p. 3). Thus, while the original oxidation of pyrite may have taken considerable time to develop, through the formation of intermediate compounds, the system was primed for a flushing event to create locally acidic groundwater recharge.

Note that the above discussion of pyrite oxidation examples are not specific to the Gillette wellfield. While the potentially relevant factors of the occurrence of pyrite, calcite, and groundwater alkalinity have been investigated in the study area, neither the specific geochemical evolution of groundwater recharge nor the availability of pyrite weathering products in potential recharge pathways have been examined for this investigation.

7.3 GROUNDWATER FLOW, DISSOLVED OXYGEN, AND FOCUSED RECHARGE

The following paragraphs describe the lateral and stratigraphic distribution of low pH wells and qualitatively evaluate potential exposure to oxygen-rich groundwaters in the study area.

Groundwater aquifers are recharged as precipitation infiltrates through the soil and vadose zone to fill available pore space. The maximum dissolved oxygen concentration of water exposed to the atmosphere, whether precipitation or groundwater discharged to the surface from a well, is a function of altitude and temperature. At this location, the saturated dissolved oxygen concentration is approximately 10 mg/l. Dissolved oxygen levels typically decrease with depth below the water table, as oxygen is consumed through chemical reactions with soil and rock organic matter, reduction of minerals like pyrite, etc., although the depths and distances involved vary greatly (Appelo and Postma, 1996).

As discussed previously, groundwater recharge in the study area occurs as diffuse infiltration of precipitation in excess of soil-water evapotranspiration across the landscape, and in a more concentrated manner along drainages where precipitation or snowmelt is sufficient to generate runoff. Because part of the focus of this investigation is the potential association of low pH groundwater with discharges from the City wells, the following discussion of recharge primarily addresses the concentrated recharge associated with those discharges occurring along study area drainage channels.

7.3.1 CITY WELL DISCHARGE

Within the study area, natural recharge through stream channels has potentially been substantially augmented locally for short periods of time by discharge of Madison groundwater during the drilling and testing of the City wells. Figure 20 identifies the drainages into which each of the five most-recent City wells have discharged. Included on the map are the stock reservoirs which contained well discharge water in those drainages.

Wells M-12, M-14, and M-15 produced water available for infiltration from the point of discharge at each well to the stock reservoir in the southwest corner of Section 31. Well M-13 produced water available for infiltration from the point of discharge from the well to the stock reservoir at the east edge of Section 1. Well M-11 produced water available for infiltration from the point of discharge from the well to an unidentified point downstream on Spring Creek.

As shown on Figure7, the portions of the drainages below M-12, M-14, and M-15 that received discharge from the Gillette wells provide direct access to recharge water-bearing units in the Lakota Formation and the lowest strata in the Fall River. The drainage below M-13 runs across outcrops of Lakota and most of the Fall River Formation. Depending on how far flow persisted down Spring Creek, discharge from M-11 could have provided direct recharge to the Lakota and Fall River Formations.

Neither the Sundance Formation nor any underlying formation is exposed at the ground surface in these drainages. Recharge to those formations likely occurs within the study area, but only through the downward migration of groundwater through overlying units. Additional recharge may occur by lateral movement of groundwater from outside the study area.

To reduce erosion at the point of discharge, water discharged from the Gillette wells was dispersed rather than being released in a concentrated stream. Water produced during airlift drilling and development was simply discharged into the air and naturally accumulated into the local drainages. Water produced during pump testing was discharged to the local surface, with rock and hay-bale structures provided to reduce erosion. These procedures likely resulted in bringing dissolved oxygen levels up to near saturation, i.e. comparable to that of normal precipitation. The recharge occurring from Gillette well discharges was considerably more mineralized than precipitation, but considerably less mineralized than ambient groundwater in the receiving formations. Table 15 provides a summary comparison of general water chemistry from the Madison, Lakota, and Fall River Formations. Differences are most pronounced in TDS, sodium and sulfate concentrations.

Figure 21 provides photos of select features in the discharge path of the City wells, including where fractured bedrock is exposed in the stream channel. Whether these fractures are simply surface weathering features or are connected to more deep-seated potential recharge pathways is unknown. Figure 22 provides observations of streamflow produced during the construction and testing of M-14 and of the receiving reservoir plotted on Figure 20. These photographs clearly show substantial flow across and beyond (downstream of) bedrock exposures.

Table 3 summarizes the timeline, rates (gpm) and volumes (Mg) of discharges from the City wells. These data are approximate, compiled from a combination of formal discharge reports under WYPDES permits, formal reports by City consultants, and field notes and related information provided directly by City staff and consultants. Minor discrepancies were found between sources, but those discrepancies are relatively small and do not impact the basic analysis.

There are few quantitative data available on the fate of these discharges with respect to how much remained as surface runoff vs. how much (and where) water infiltrated to provide recharge to the strata underlying the stream channels. The following information is based on interviews with, and field notes and photos received from Morrison-Maierle staff on site at the times of discharge (e.g. Pat Eller, personal communication, 11/5/18).

Well discharge from M-11 occurred in February through May of 2013. The highest average rate was 1,600 gpm; the highest volume was 7.8 Mg; both from the post-stimulation pump test. These discharges followed the natural channel into the upper reaches of Spring Creek. How far down the channel surface flow was maintained (i.e., before infiltration reduced the flow to zero) was not observed. This discharge occurred during May, so there was likely loss to evapotranspiration along the stream channel.

Well discharge from M-12 occurred from October through December 2012, and in April 2013. The highest average rate was 1,500 gpm, during the post-stimulation testing in 2012. The highest volume was 5.3 Mg (16.3 ac-ft), from the subsequent testing in 2013. Water flowed into the small reservoir identified on Figure 18. (Because M-12 was the first well tested (2012), there was considerable concern with overtopping the reservoir and creating an erosion/flooding hazard.)

The surface area of this reservoir appears to be approximately 0.9 acres (September 2, 2011 Google Earth® image). There is a reservoir of similar geometry and surface area located 1.1 miles to the northeast. It has a permitted capacity of 9.75 ac-ft. Using that value as a surrogate for the reservoir below M-12 suggests a total volume of approximately 3.2 Mg. Thus, even if this reservoir was entirely empty at the beginning of well testing, upstream and reservoir infiltration must have been on the order of 2 Mg over the 2.6-day discharge period in 2013.

The reservoir is located at the top of the siltstone member of the Fall River Formation (Figure 6 symbol "Kfsi"), but the sandstone member of the Lakota Formation (Figure 6 symbol "Kls") is exposed in most of the 1-mile channel between the pond and M-12. This exposure provided opportunity for direct recharge to the Lakota. Reservoir seepage would contribute to water loss, but observations of reservoir contents in July 2018 suggest this was a minor factor.

Infiltration of M-12 discharge water may have been enhanced by the aggressive efforts of testing personnel to reduce channel erosion risk by placing rocks and logs in the channel to slow down the flow.

Well discharge from M-13 occurred in April, May, and June 2016. The highest average rate was approximately 900 gpm, during testing. The highest volume was 2.2 Mg (6.8 ac-ft), during drilling. Water flowed into the small reservoir identified on Figure 20. The reservoir was observed during the M-13 drilling and testing; it did not fill to the point of spilling.

The surface area of this reservoir appears to be approximately 0.5 acres (September 3, 2011 Google Earth® image). There is a reservoir of similar geometry and surface area located 0.35 miles to the west-southwest. It has a permitted capacity of 2.2 ac-ft. Using that value as a surrogate for the reservoir below M-13 suggests a total volume of approximately 0.7 Mg

Thus, even if this reservoir was empty at the beginning of well testing, upstream and reservoir infiltration must have been on the order of 1.5 Mg over the 1.3-days of discharge. City consultants report there was "a large flow of seepage emerging into the surface flow immediately downstream from the dam" during this test (Kazmarek; pers. comm. 11/29/18), indicating not all well discharge was infiltrating at or above that point.

This pond is located on the mudstone member of the Fall River Formation (Figure 7 symbol "Kfm"), but the sandstone member of the Lakota Formation (Figure 7 symbol "Kls") is exposed in most of the 1-mile channel between the pond and M-13. This exposure provided opportunity for direct recharge to the Lakota. Reservoir seepage would also have contributed to water loss.

Well discharge from M-14 occurred in October and November 2016 and June, July, Oct. and Nov. 2017. The highest average rate was 715 gpm, during pre-stimulation testing. (Stimulation has not yet been applied to this well.) The highest volume was 1.4 Mg (4.3 ac-ft), from the Minnelusa Formation, during 2017 work to complete a casing seal in the well. Water flowed into the same reservoir as was used earlier to contain discharge from M-12 (Figure 18). The reservoir level was observed during the M-14 construction and testing; it did not fill to the point of spilling.

Morrison-Maerlie diary entries for the M-14 discharge periods provide the following additional information:

- October 9, 2016: following "approximately 12 hours of continuous drilling" discharge water had yet to arrive at the reservoir below M-14. This discharge was estimated at 400 gpm. Apparently, "charging" the previously dry stream channel and deep infiltration was sufficient to take up the entire discharge.
- October 10, 2016: by the next day, the reservoir had begun receiving water, and the water level was recorded October 11, 2016, 24 hours later. Based on the recorded change in pond level and a rough planimetering of the pond area (Google Earth® image dated July 16, 2014), inflow on the order of 300 gpm is suggested. The associated well discharge was reported as 400 gpm, for an infiltration rate on the order of 100 gpm (25% of discharge rate). Subsequent measurement indicates this as a stabilized loss rate.
- July 7, 2017: "water from on-site operations have not made it to the pond."

Discharge from well M-15 occurred in May and June 2017. The highest average rate was 1,010 gpm, during pre-stimulation testing. The highest volume was 0.8 Mg (2.5 ac-ft), at the same time. Water flowed into the same reservoir as was used earlier to contain discharge from M-12 and M-14 (Figure 20). The reservoir level was observed during the M-15 drilling and testing; it did not fill to the point of spilling.

Morrison-Maierle diary entries for this period provide the following additional information:

- May 4, 2017: "estimate that development increased water levels in pond 2 feet from start to finish of test". At the calculated pond area, 0.5 Mg arrived at the pond. The reported discharge for this 1.2-day period was 0.7 million gallons per day, for a loss of 0.2 Mg and a rate of 114 gpm (30% of discharge rate) for this episode.

The discharges closest prior in time to the reported "drying up" of well ID #45 (July 13, 2017) and the subsequent discovery of low pH in a deeper zone of the Lakota, were those from the Minnelusa annulus in well M-14, one to two weeks previously. This water was air-lifted from the annulus at a rate of approximately 200 gpm in association with operations to rehabilitate the annular cement seal in that well. The annulus of the well was open to the formation behind 16-inch diameter casing from 1610 feet to approximately 2,060 feet at the time, i.e. through the upper 2/3 of the Minnelusa. This water

was of distinctly poorer quality than that from the Madison, with TDS of 3,210 mg/l and sulfate of 2,190 mg/L; a pH of 8.0 was measured (City files rec'd 11/2018).

During the discharge events associated with the construction and testing of the City wells, a degree of groundwater mounding likely occurred directly beneath outcrop recharge features. Applied to one square mile of aquifer, for example, even the largest discharge volume (M-12's 5.3 Mg) would only raise groundwater levels by an average of 2-inches (at an assumed porosity of 15%). Such small changes in water levels are unlikely to produce groundwater gradients forcing recharge water into new portions of the aquifer. However, fracture systems may have served to concentrate and guide well-discharge based recharge, just as they would the infiltration associated with natural runoff events.

In the highest reaches of these drainages (i.e., significantly above the estimation points on Figure 17), where the natural catchments are relatively small, the discharges associated with the City wells likely exceeded anything that would be expected to occur naturally. However, the analyses of Section 4 of this report indicate opportunity for comparable episodes of natural recharge in the middle and lower reaches of these channels. Whether or not such recharge processes led to the formation of acidic conditions that would not otherwise have occurred is unknown.

Based on the analysis of groundwater flow presented earlier, groundwater recharge in the wellfield area, both natural and associated with the City well discharges, moves east and southeast in the immediate vicinity the wellfield, and southeast toward and along Spring Creek at the scale of the study area. As discussed above, there are also pervasive downward gradients to move groundwater into lower strata as permeability allows. (While groundwater flow need not follow surface topography, it cannot flow "uphill" with respect to the relative groundwater elevations reviewed in Section 3.3.2.)

Thus, the low pH conditions observed at points ID #s 62, 32, 33, 77, and 18 (Figure 2) appear to be beyond the potential influence of recharge associated with the Gillette wells. These points demonstrate the occurrence of low pH conditions in the aquifers of the study area due to causes clearly not associated with the City wellfield.

The location and water levels of those wells east and southeast of the City wellfield in which low pH has been identified (ID #s 34, 44, 45.1, and 47.1) are such that an association is hydraulically possible with recharge resulting from drilling and testing activity in 2012, 2016 and 2017 for M-12, M-13 and M-14, and M-15, respectively. The largest of these discharge events occurred in April 2013, with the 5.3 Mg testing discharge from M-12. (Subsequent discharges to this channel were less than one half this volume.) Low pH well #28.1 is geographically remote from these potential recharge areas, but is in a position potentially to experience an effect from M-11 discharges in 2013.

7.3.2 POTENTIAL SOURCES OF OXIDIZING GROUNDWATER

In addition to dissolved oxygen introduced into an aquifer as part of recharge (natural or artificial), strata are exposed to atmospheric oxygen in the unsaturated zone above the water table and as a result of water well construction and operation. With a decline in groundwater level, the atmosphere -

groundwater interface moves downward, moving oxygen into portions of the aquifer previously less exposed to full oxygen saturation, with attendant chemical adjustments. When the water level rebounds, the opposite occurs, with aquifer chemistry again adjusting toward new equilibrium conditions. Natural fluctuations in groundwater levels are an example of the cycles described by Hammarstrom et al, (2004), who observed, "In general, it is the exposure of pyritic rocks to repeated wet/dry cycles and the action of bacteria present at the earth surface that generates acid."

Although we have located no detailed records of natural water-level fluctuations in the aquifers of the study area, seasonal and long-term fluctuations are likely given the precipitation record. The sparse data available for study-area wells demonstrate such fluctuations at certain locations. The detailed measurements at wells ID #s 45 and 45.1, for example, demonstrated one-year net changes in water level of +30 ft. and -13 ft., respectively, both under no-pumping conditions. The former change was likely, at least partially, a function of cessation of pumping, but the latter reflected no-pumping conditions for both "before" and "after" measurements.

Well ID #28 reported a depth-to-water of 40 ft. when completed in 2002. The depth-to-water was measured at 26.77 ft. on July 19, 2018.

The owner of well ID #53 reports that the pump was set at 385 ft. and produced satisfactorily until "the well went dry" in approximately 2000. He has not used the well since, but recovery to a depth-to-water of 244 ft. is suggested by a sonic water level measurement on July 20, 2018.

In contrast, at wells ID #s 54 and 28.1, the July 2018 depths-to-water are nearly identical to those reported upon completion of the wells in 2002 and 2016, respectively.

Construction and operation of a water well can also introduce atmospheric oxygen into the subsurface in several ways:

1. Of the domestic wells for which data were compiled, 30% were drilled with air-rotary equipment. In this method, drill cuttings and formation water are continuously expelled from the hole by circulation of compressed air. This is a short-lived impact, however, as it only occurs during drilling and, to some extent, during well "development", when groundwater is expelled from the finished well to carry away loose sediment in the well. Our review of this limited dataset found no correlation between drilling method and the subsequent identification of low pH wells.

2. During the pumping of a well, the water level is drawn down, the extent of which is a function of the rate of pumping and the permeability of the supplying aquifer. Following pumping, the water level recovers. Thus, the simple process of repeated pumping cycles moves the water/air interface up and down in a well. If the interval through which that interface moves is exposed to the aquifer, portions of the aquifer which would not be otherwise, are cyclically exposed to the atmosphere. This is an effect largely confined to the immediate vicinity of the well, but continues as long as the well is in use.

3. Particularly in a limited aquifer, the pumping of a well can draw the water table down more generally. If the average pumping rate exceeds the average recharge rate, the water level in an aquifer will gradually decline, potentially exposing aquifer material to atmospheric oxygen that may experience such exposure very rarely, if at all, under natural circumstances. This is basically an artificial version of the natural groundwater level fluctuations discussed above. Given the relatively low pumping rates of the wells of this study, this effect is likely confined to select areas in which the developed aquifer is of limited extent, without abundant recharge. Locations at which wells have "dried up" or otherwise been found to lose their original productivity may be examples of local aquifer depletion due to pumping, with attendant drops in water level and potential introduction of increased oxygen levels into strata not otherwise exposed. (Figure 13 presents a schematic of the "cone of depression" created during well pumping.)

4. Regardless of pumping effects, the basic construction of a well may change aquifer oxygen levels through the comingling of different water-bearing zones. As discussed above, the aquifers of this area consist of many discrete water-bearing zones within the generalized formations. In detail, each such zone almost certainly has a discrete water level and discrete groundwater chemistry. Thus, any well that creates pathways between multiple zones almost certainly produces some extent of inter-zone transfer, and this transfer occurs constantly, whether or not the well is pumped. Water will move through the wellbore, from zones with higher water-level elevation (pressure) into zones with lower water-level elevation (pressure). The rate of transfer, and the measured water level in the now-combined aquifer system, will be a function of the difference in water-level elevation and the relative permeability of the different zones.

The group of wells diagramed on Figure 23 (ID #s 9, 12, 14, and 17) illustrates these concepts. Completion data and water levels are taken from the SOCs filed for the wells; formations are assigned based on location and depth. These wells are all in a relatively small area (see Figure 2).

Well ID #9 is completed through a 213-ft. section of sandstones and shale units in the Sundance Fm. The reported depth-to-water is at elevation 3,924 ft. similar to that of nearby Sundance wells, ID #s 8 and 10.

Well ID #17 is completed in a 50-ft. section of sandstone in the Lakota Fm. The reported depth-to-water is at elevation 4,147 ft. The completion interval starts at the water level, i.e. exposing the aquifer to cyclic wetting and drying, as discussed above.

Well ID #14 is completed in two zones, an upper zone; 222 to 241 ft., in the Lakota, and a lower zone; 636 to 684 ft., in the Sundance. Thus, the well provides a pathway between the two formations. Comparison of the water level of ID #14 with the water level elevations of ID #9 and ID #17 indicates water flows down the well, from the Lakota into the Sundance. The relatively small difference in groundwater elevation between ID #17 and ID #14 is consistent with the reported depth-to-water in ID #14 (elevation 4,137 ft.) being a mix of Sundance and Lakota pressures, but is too small to clearly distinguish such effects given the different dates of water level reporting between 1988 until 2007.

Well ID #12.1 is also completed in two zones - an upper zone; 50 to 65 ft in the Fall River - and a lower zone - 130 to 160 ft. in the Lakota. Similar to ID #17, the upper completion interval starts at the water level (i.e., exposing the aquifer to cyclic wetting and drying during drawdown). Thus, well ID #12.1 provides a pathway between the two formations. Comparison of the water level in ID #12.1 with the water level elevation of ID #17 indicates that in the absence of pumping (i.e., most of the time) groundwater will flow into well ID #12.1 from the Fall River Fm., then down the well, to flow out into the Lakota. This occurs due to the 155-ft. difference in groundwater elevation between the two wells and the well construction "short-circuiting" the natural gradient.

There are insufficient data to directly assess the impact of aquifer comingling on dissolved oxygen levels or individual well chemistry, but given the generally downward groundwater gradients discussed above, the general effect of any comingling opportunities will be to carry shallow, likely more oxygenated, groundwater into deeper, likely less oxygenated, water-bearing zones.

A well-by-well analysis across the study area is beyond the scope of this study. However, to provide a general view of potentially relevant well-completion information, Figure 24 compiles data extracted from SEO SOCs to identify: 1) wells in which the reported water level is approximately the same as the top of the open interval, i.e. those wells subject to cyclic introduction of atmospheric oxygen through pumping drawdown; and 2) wells completed with open intervals in multiple water-bearing zones. "Open intervals" are those in which screen or perforations are reported. No evaluation has been made of the potential for groundwater movement between water-bearing zones via poor or absent well seals or the installation of gravel packs across long intervals.

8.0 CONCLUSIONS

Potential connections between the construction of City wells M-11 through M-15 and water-quantity / water-quality issues with the domestic and stock groundwater-supply wells in the surrounding area have presented four questions:

1. Has the construction and testing of the City wells reduced water levels in the neighboring domestic wells?

   No. The domestic wells are completed in the Fall River, Lakota, and Sundance Formations. The Gillette wells draw from the Madison Limestone, an aquifer hydraulically separated from the aquifers serving the domestic wells by approximately 1,000 feet of low-permeability strata in the Spearfish, Opeche, and Minnelusa Formations. That hydraulic separation is demonstrated by the groundwater elevation in the Madison Limestone being 200 feet or more lower than in the aquifers serving the neighboring domestic wells. Even under aggressive production from the Madison aquifer by the City wells (only short-term test production has occurred to date), it is highly unlikely significant drawdown impacts could be realized through the intervening strata.

The Fall River and Lakota Formations are penetrated by the Gillette Madison wells at locations unlikely to provide saturated conditions, precluding potentially poor well seals in the Madison wells facilitating drainage of upper-aquifer groundwater. Wells reported to have suffered declining water levels have partially recovered, a condition incompatible with continued drainage via a Madison well seal failure. There have been no reports of declining water levels in the Sundance Formation. (The condition of the Gillette Madison well seals is the subject of a separate set of detailed bond logging reports.)

2. Has the acid stimulation of the City wells created low pH conditions in the neighboring domestic wells?

   No. Production in four of the five recent Gillette wells has been stimulated through the pressure injection of hydrochloric acid. However, the acidic conditions encountered in neighboring domestic wells have been consistently identified with sulfuric rather than hydrochloric acid. Low pH conditions in the domestic wells are likely the result of oxidation of native pyrite deposits in the host aquifers that supply water to these wells.

3. Have construction and test discharges from the City wells enhanced recharge to the aquifers supplying the neighboring domestic wells in a manner that has created or contributed to low pH conditions at certain of those neighboring wells?

   Unknown. Discharges from the City wells has had opportunity to directly recharge the aquifers serving neighboring domestic wells where those aquifers outcrop in the drainage channels into which these discharges occurred. Estimates of natural runoff events in the lower and middle portions of these drainages indicate City well discharges have been of a magnitude and duration comparable to natural runoff events with recurrence intervals on the order of 5 to 10 years. In the upper reaches of these drainages, natural events of a magnitude comparable to well discharges are increasingly extraordinary.

   Recharge from surface sources, whether natural or artificial, is likely to have higher dissolved oxygen concentrations than native groundwater, providing the potential for acid-production via reaction with local pyritic material. Such acid production has been observed in the study area under clearly natural conditions (e.g. spring at ID#77) and in wells clearly hydraulically removed (e.g. well IDs#18) from potential impacts by the City wells. Whether those natural processes have been locally and temporarily enhanced through discharge from the City wells cannot be determined without substantial additional research.

   Low pH conditions in local groundwater are known to occur naturally, and baseline (i.e. prior to Gillette well discharges) groundwater quality data are entirely insufficient to distinguish temporal changes in pH conditions potentially associated with the City well discharges.

4. What is the cause of low pH conditions in the neighboring domestic wells?

   Local oxidation of native sulfide minerals, chiefly pyrite, is the most reasonable source of the low pH conditions observed in some domestic wells and two natural springs of the study area. Although multiple opportunities for enhancement of that natural process have been identified in the completion and operation of domestic wells, no specific occurrence of low pH groundwater has been linked with specific local mechanisms. Groundwater quality is naturally poor throughout the study area. One element of that poor groundwater quality in select wells is low pH.

9.0 CONSIDERATIONS FOR FUTURE STUDY

The investigation presented in this report could be usefully extended in various ways, depending on levels of interest, cooperation of associated landowners, timeline, and availability of funding.

To assess the potential (yet unlikely) impacts on water levels in overlying strata from pumping of the City wells, long-term monitoring could be established in a "domestic" well proximal to the wellfield and aligned with potentially implicated facture systems. Well ID #34, for example, is relatively deep, close to the wellfield, appropriately oriented, and subject to relatively little pumping of its own.

Better in this regard would be to construct a dedicated water-level monitoring well into the Minnelusa Formation in the City wellfield, for which companion water-level measurements could be taken with an adjacent Madison well in an appropriate orientation.

Due to the complexities of local groundwater flow, significant variations in stratigraphy, and a pervasive lack of background water-quality data, our investigations have been unable to positively identify the mechanisms for development of low pH conditions in any specific study-area well or any specific associations with adjacent groundwater development activity. Providing long-term serial sampling for relevant parameters from an existing well, with correlation to precipitation and streamflow records to monitor changes over time and potential correlation with recharge events, could be instructive.

The specific phenomena of pyrite oxidation as a source of groundwater acidity could be further investigated through construction of exploratory boreholes and monitor well(s) adjacent to a known occurrence of low pH groundwater, careful logging of formation mineralogy, assessment of the head relationships among the individual strata penetrated, and provision of long-term serial analysis of relevant groundwater quality parameters (e.g. pH, sulfate, iron, DO) of each water-bearing zone. Specific association with City well discharges could be further investigated through detailed examination of recharge pathways, including surface and subsurface sampling for pyrite and pyrite weathering products, and sufficient groundwater sampling to examine the evolution of groundwater quality through the recharge and groundwater transport processes.

Assessment of groundwater flow patterns for the present study was hindered by the absence of synoptic water-level data, restricting our analysis to broad conclusions based on self-reported data from the disparate times of well completions. Consistent, synoptic measurement of groundwater levels could contribute important details to understanding recharge relationships and the chemical evolution of groundwater as it moves through the subsurface. In the absence of dedicated monitoring wells, existing wells for which discrete-aquifer completions can be identified should be given priority in such research.

The identification of a low-pH (3.1 s.u.) spring on the north side of Green Hill (ID#77) at elevation 4379 ft. presents the possibility of this area sourcing low-pH groundwater beneath the surrounding area. Continuing landslide activity is obvious in the topography and consistent with the reports of local residents. Landslides may provide the mechanism for mobilizing deleterious water-quality factors in the Skull Creek Shale. Further study of this possibility may be useful in understanding local groundwater quality.

Guidance for the future construction of domestic wells in the study area and further investigation of the low pH conditions in certain strata of the study area could potentially be developed by detailed assessment of the water-quality data assembled under the present investigation. For example, specific water-quality parameters – pH and/or others – could be more closely examined for correlations with locations, depths, well design details, water levels, use history, and construction methods. Also, analyses of oxygen and hydrogen isotopes can be used in evaluation of groundwater age and potential surface water influences.

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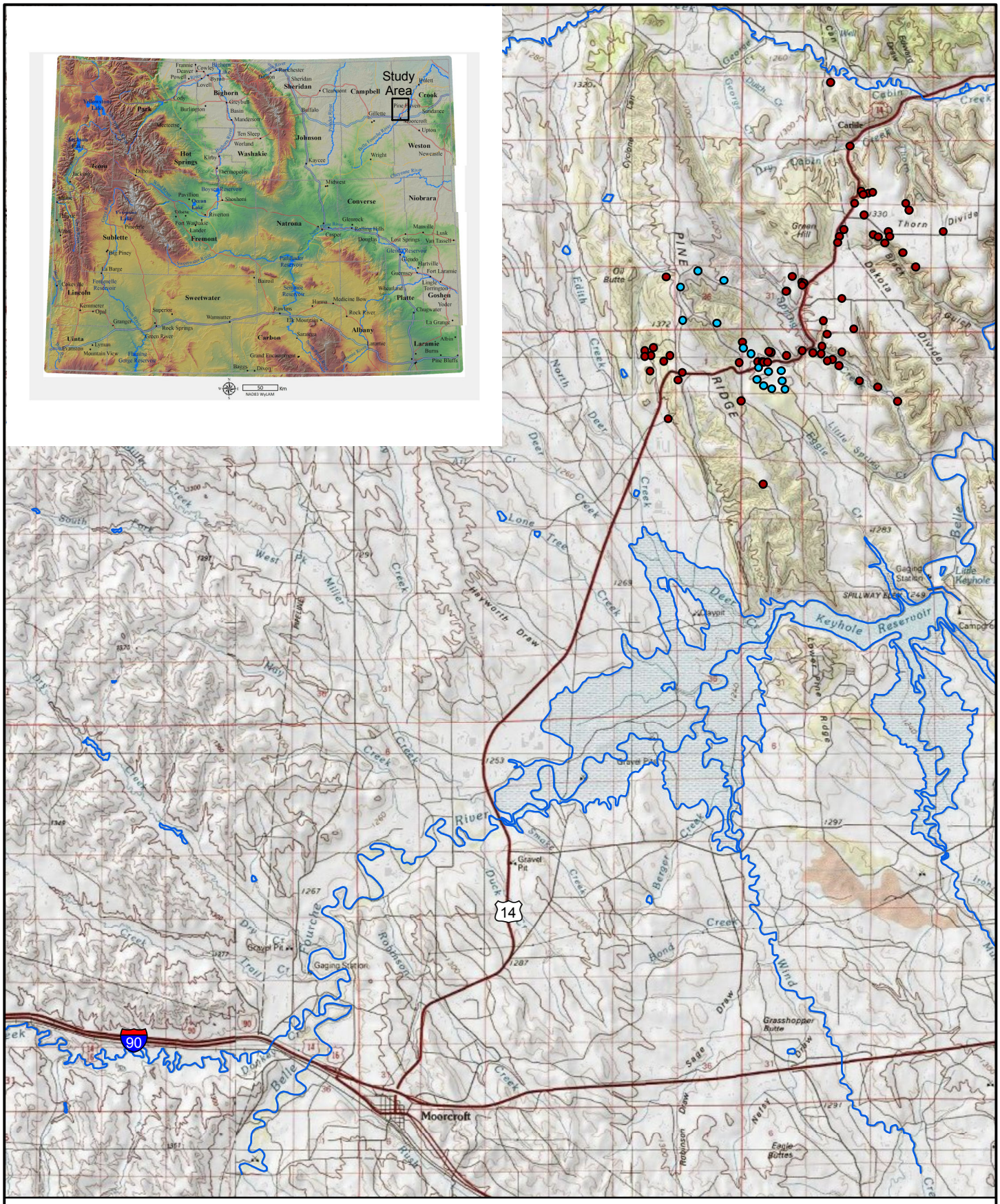
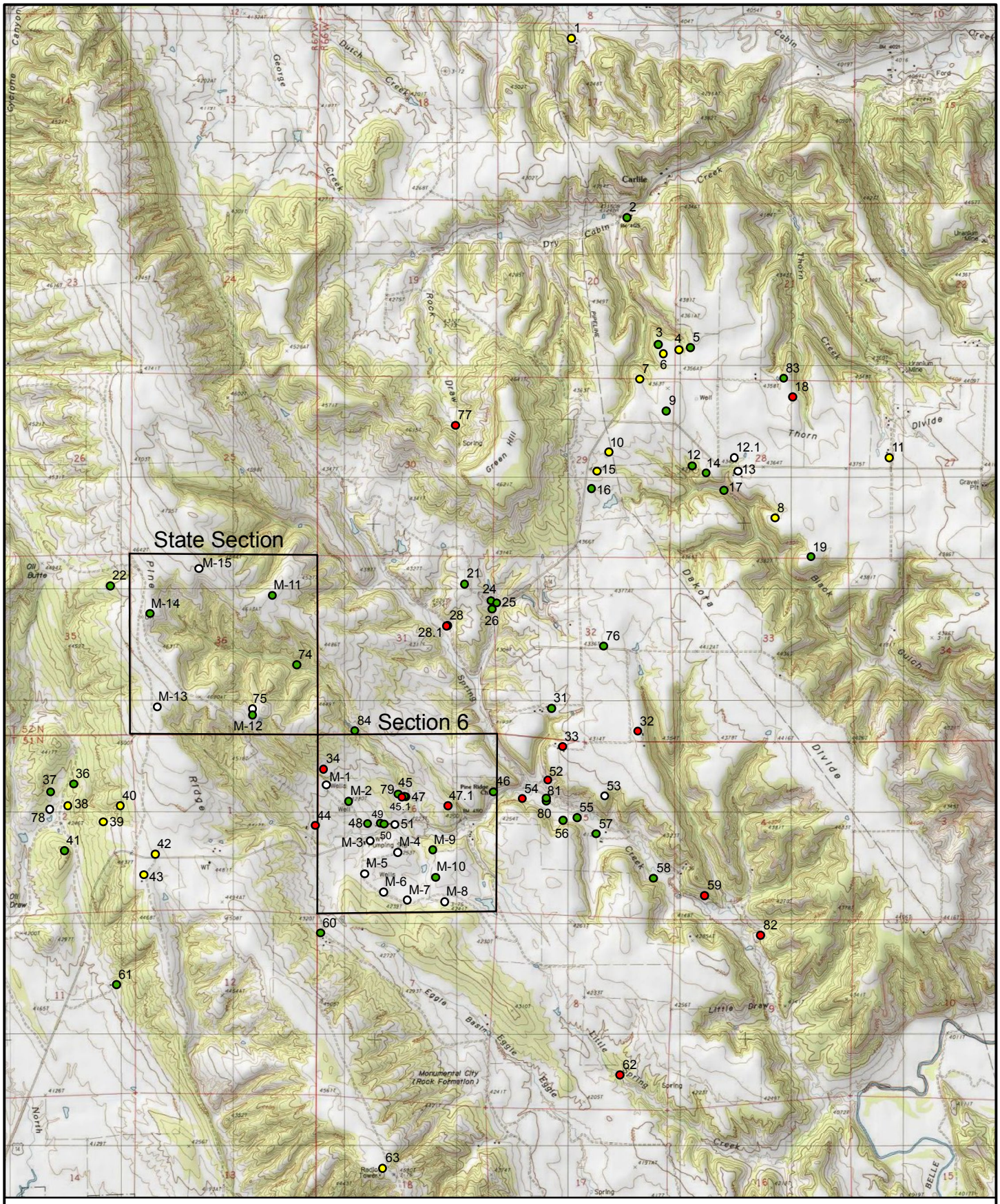
FIGURES



- Select Domestic-Supply Wells
- City of Gillette Madison Wells

Figure 1 - Study Area Location



Study Data Point M-1 through M-15 - Gillette Madison Wells

Field pH

- > 8.5
- 6.5 - 8.5
- < 6.5
- no data

Figure 2 - Study Area Data Points (ID)

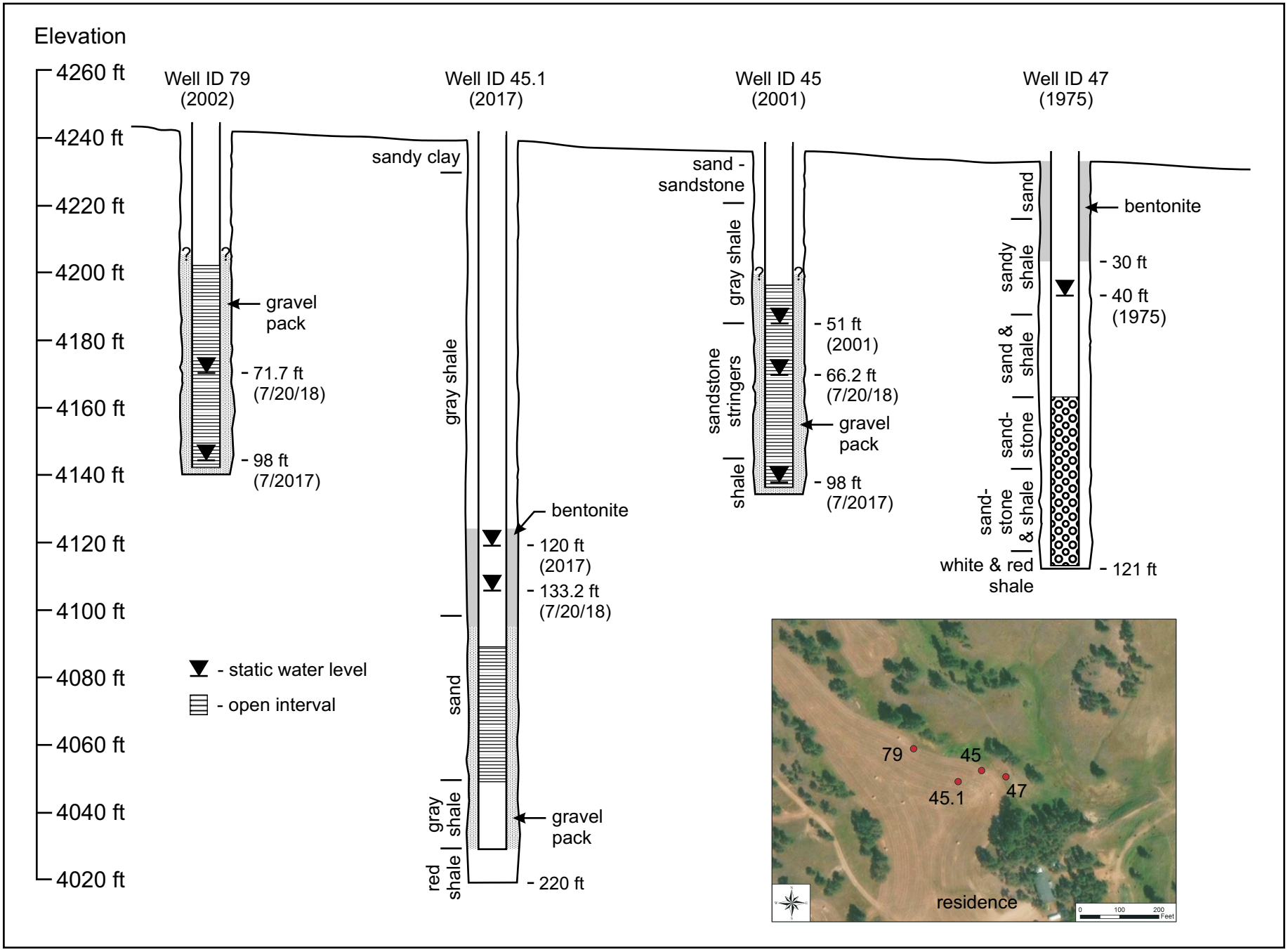


Figure 3 - Well IDs 45, 45.1, 47, and 79

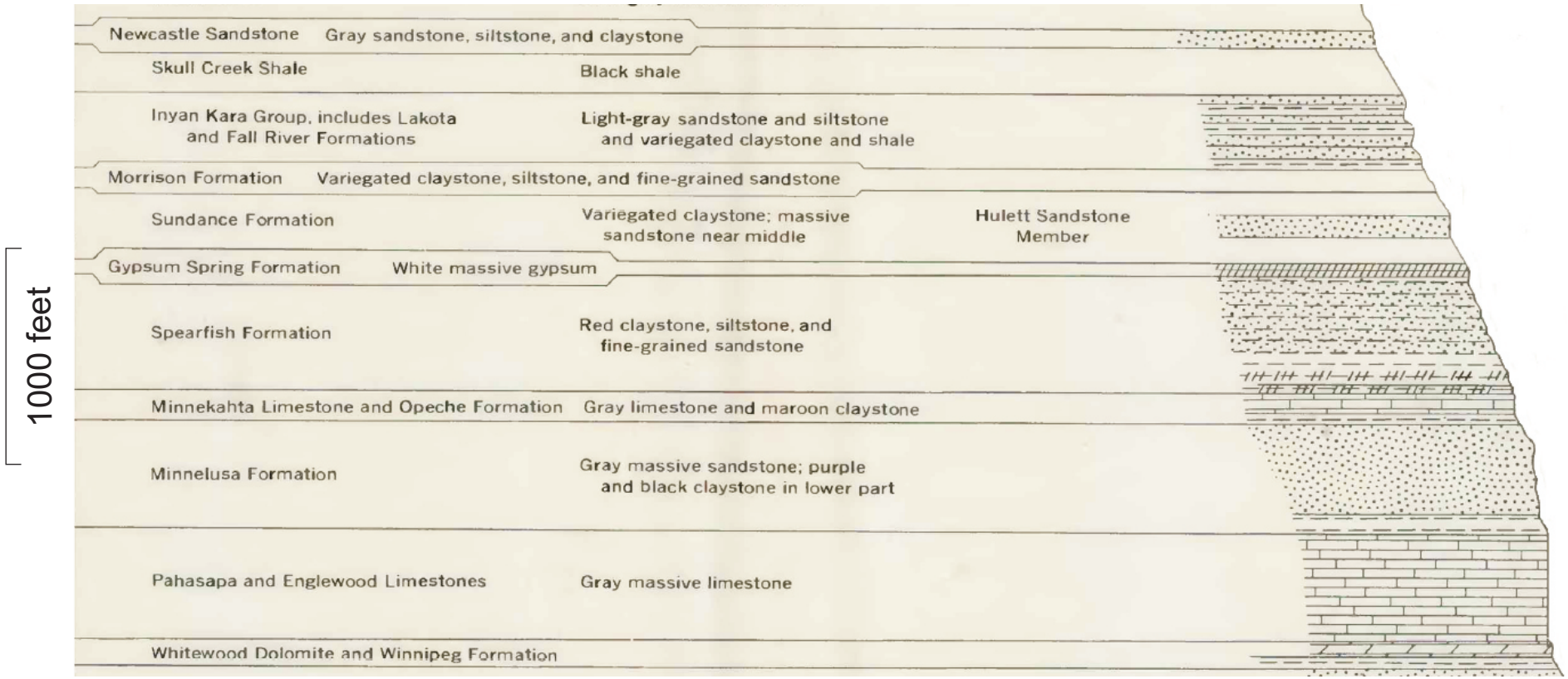


Figure 4 - Crook County Partial Geologic Column
(from Whitcomb and Morris, 1964)

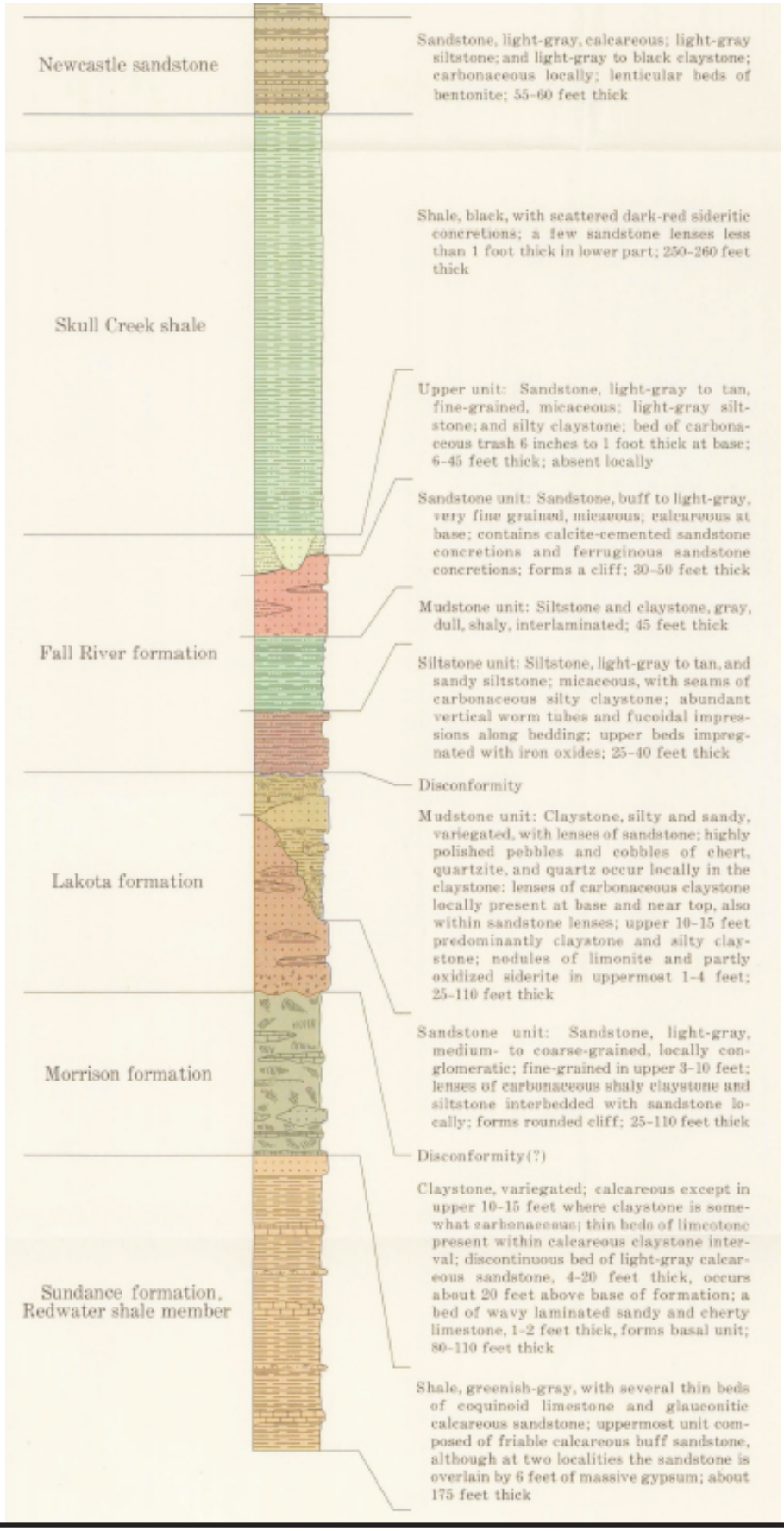


Figure 5 - Carlile Quadrangle Geologic Column
(from Bergendahl et al., 1961)

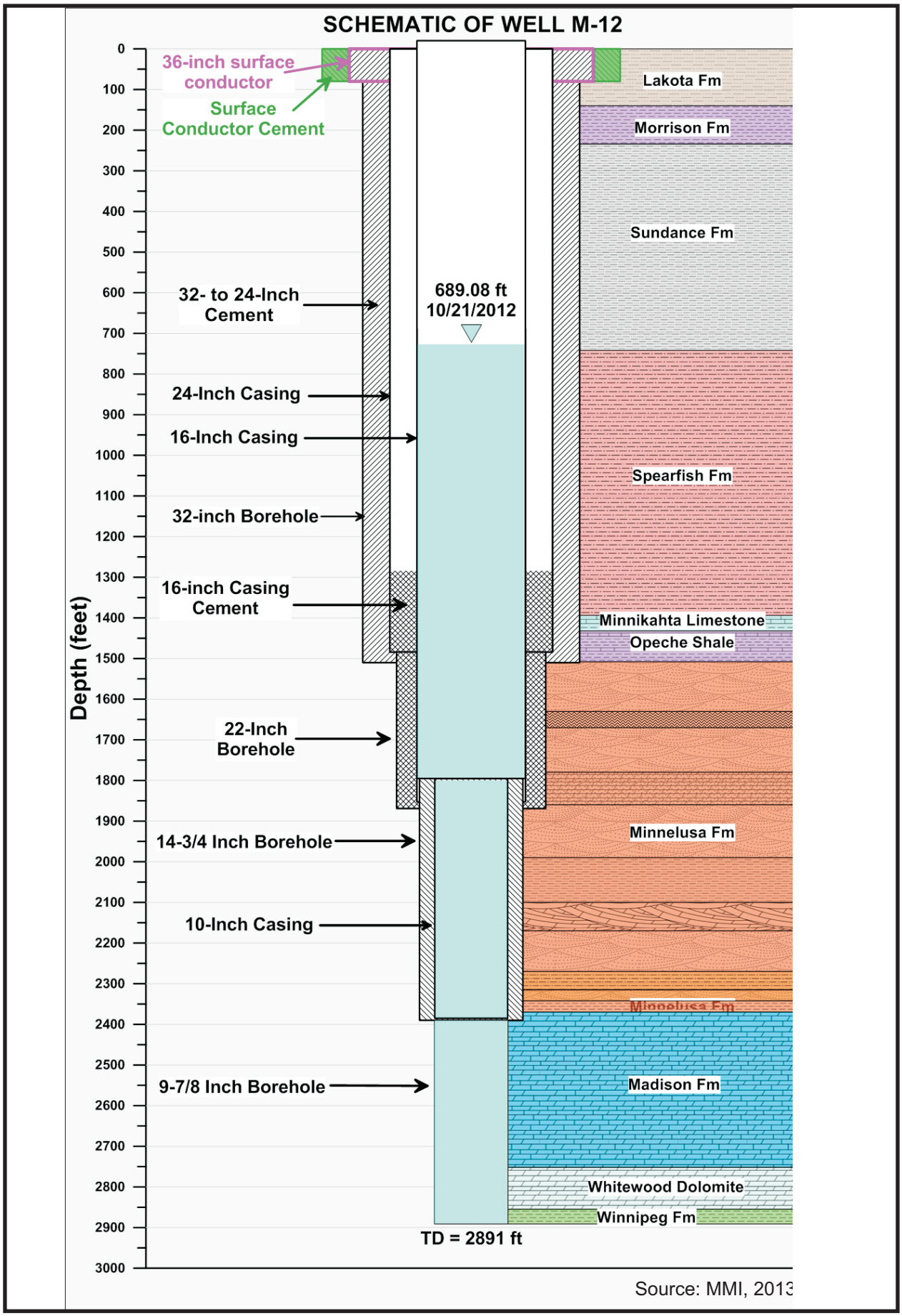
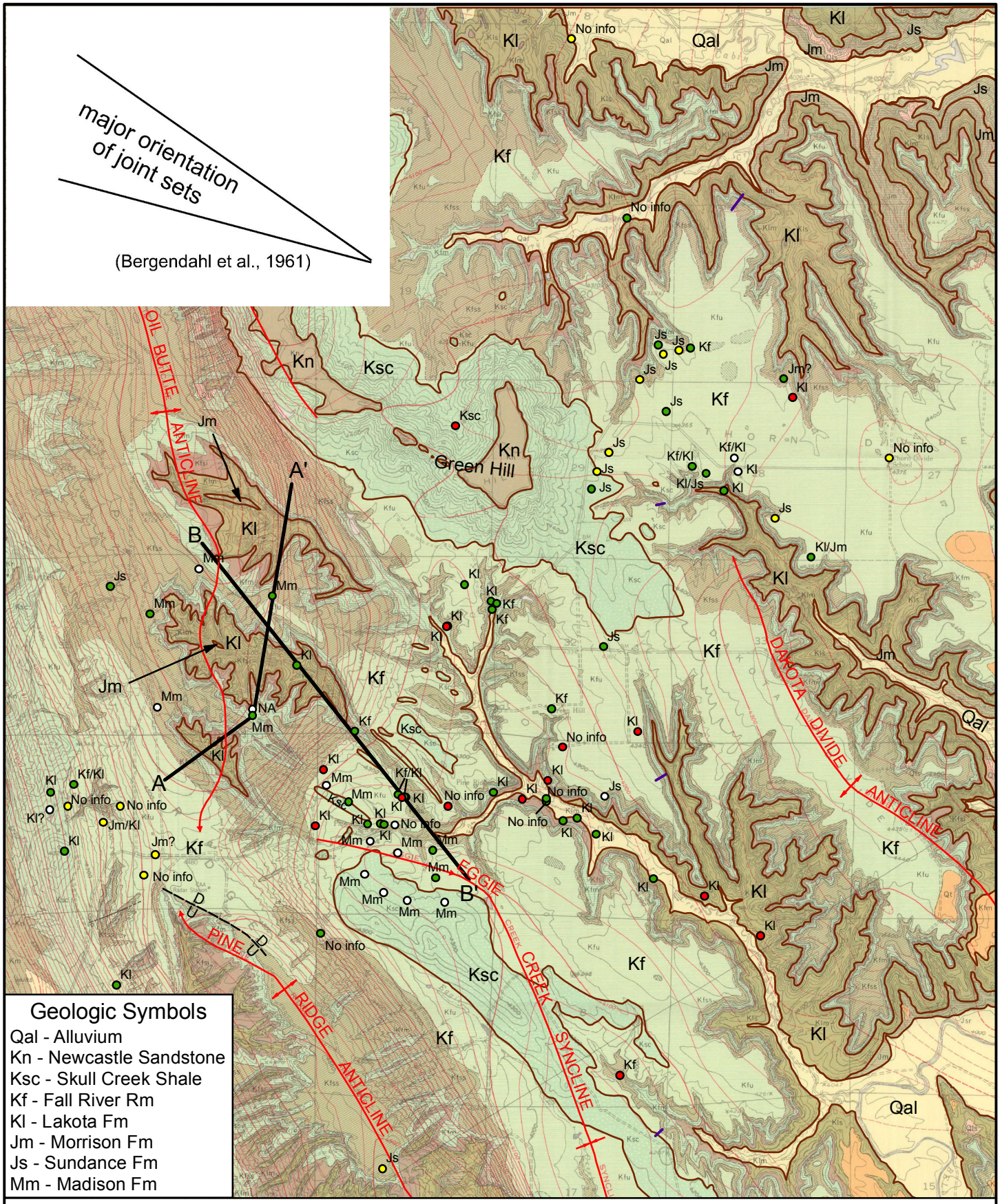


Figure 6 - Typical City Well Stratigraphy



Field pH
- > 8.5
- 6.5 - 8.5
- < 6.5
- no data

- Measured outcrop sections (Bergendahl et al., 1961)
- Lines of Section (Figures 11 and 12)
- Formation Contacts

Geology source: Bergendahl et al., 1961
Structure contours on base of Fall River

Figure 7 - Study Area Geology with pH and Estimated Well Completion Formation

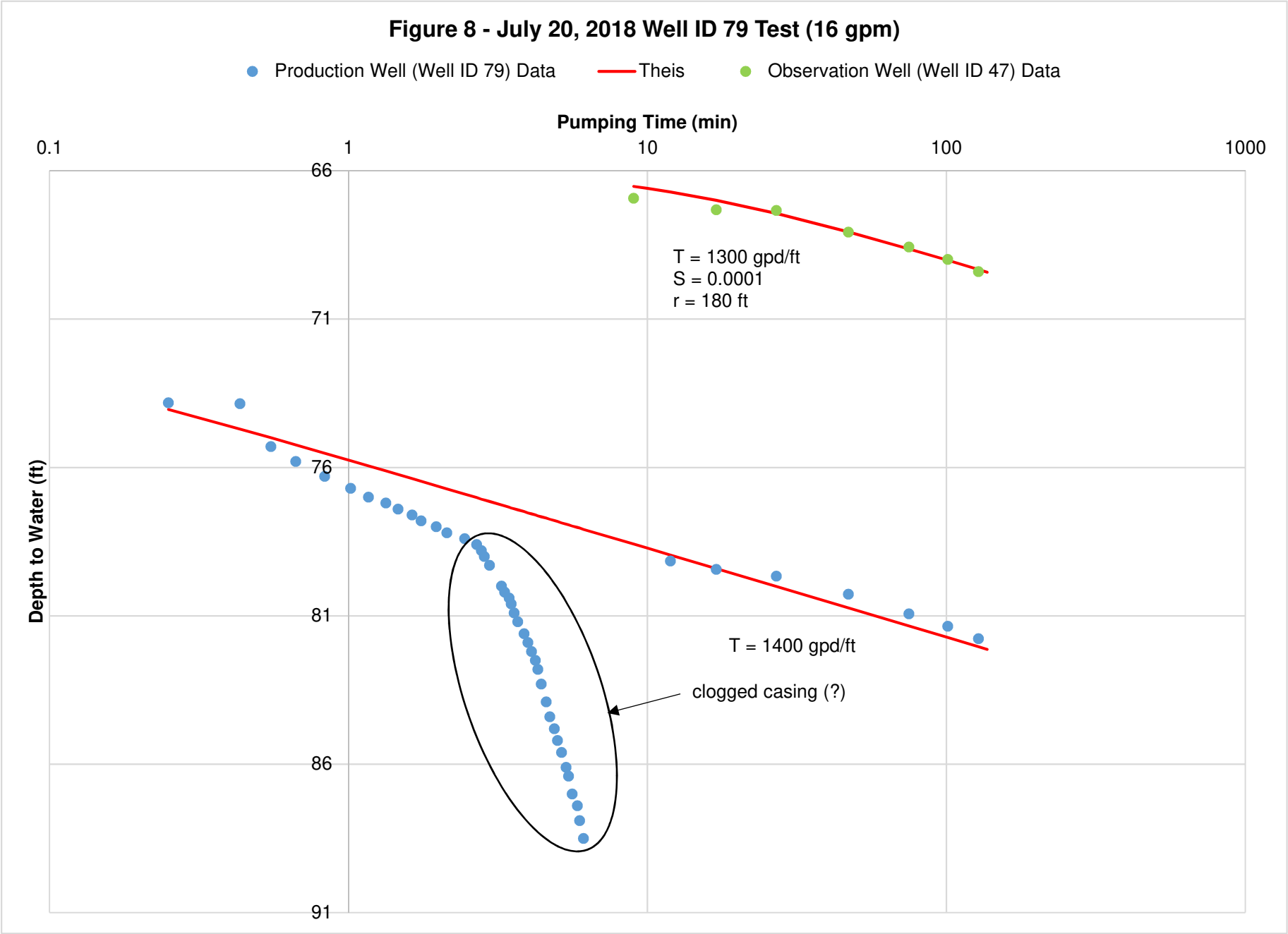
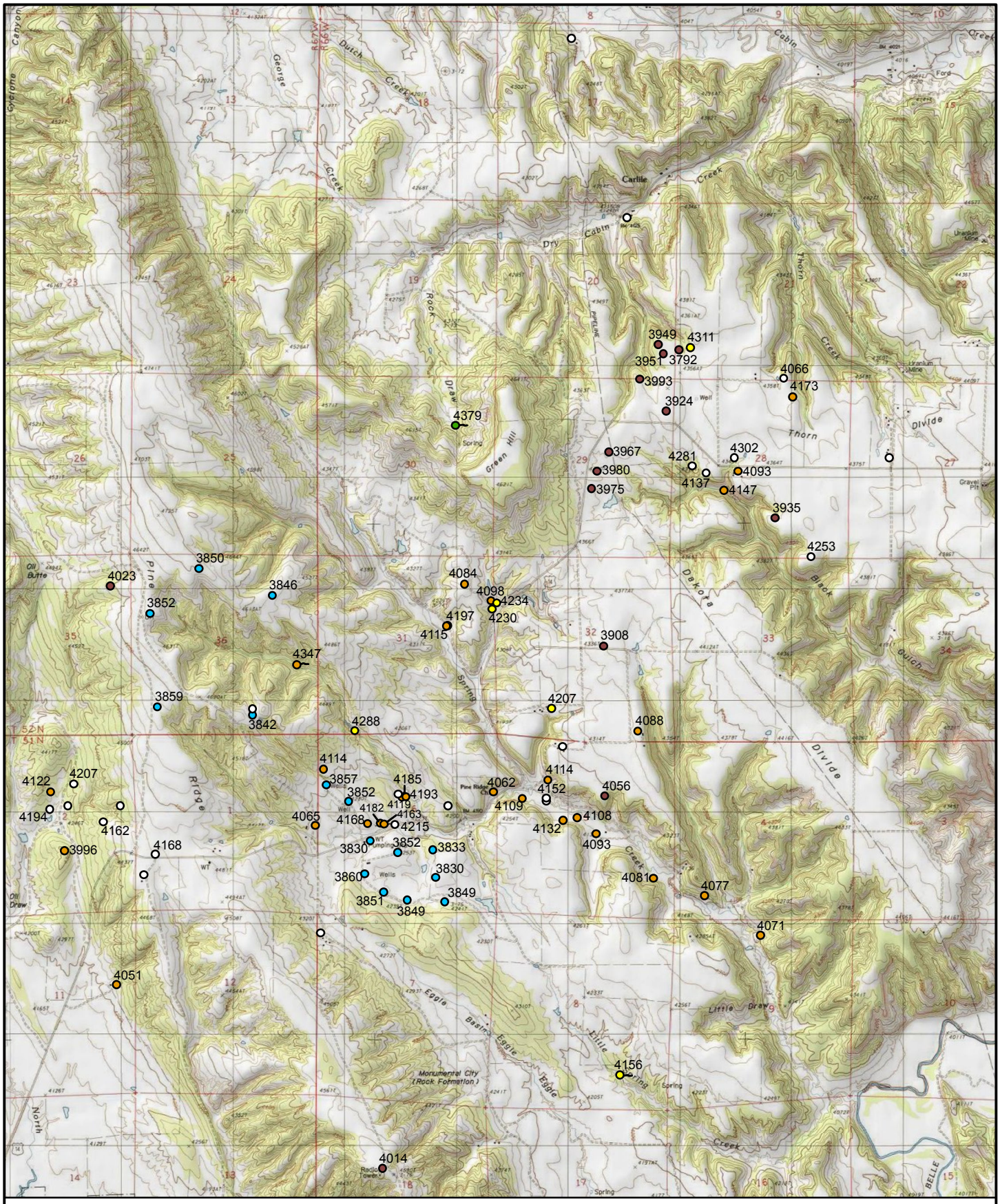


Figure 8 - July 20, 2018 Well ID 79 Test (16 gpm)
Production Well (Well ID 79) Data
Theis
Observation Well (Well ID 47) Data
Pumping Time (min)
0.1
1
10
100
1000
Depth to Water (ft)
66
71
76
81
86
91
T = 1300 gpd/ft
S = 0.0001
r = 180 ft
T = 1400 gpd/ft
clogged casing (?)



Completion Formation

- Skull Creek Shale
- Fall River
- Lakota
- Sundance
- Madison
- unknown

Figure 9 - Study Area Estimated Groundwater Level Elevations

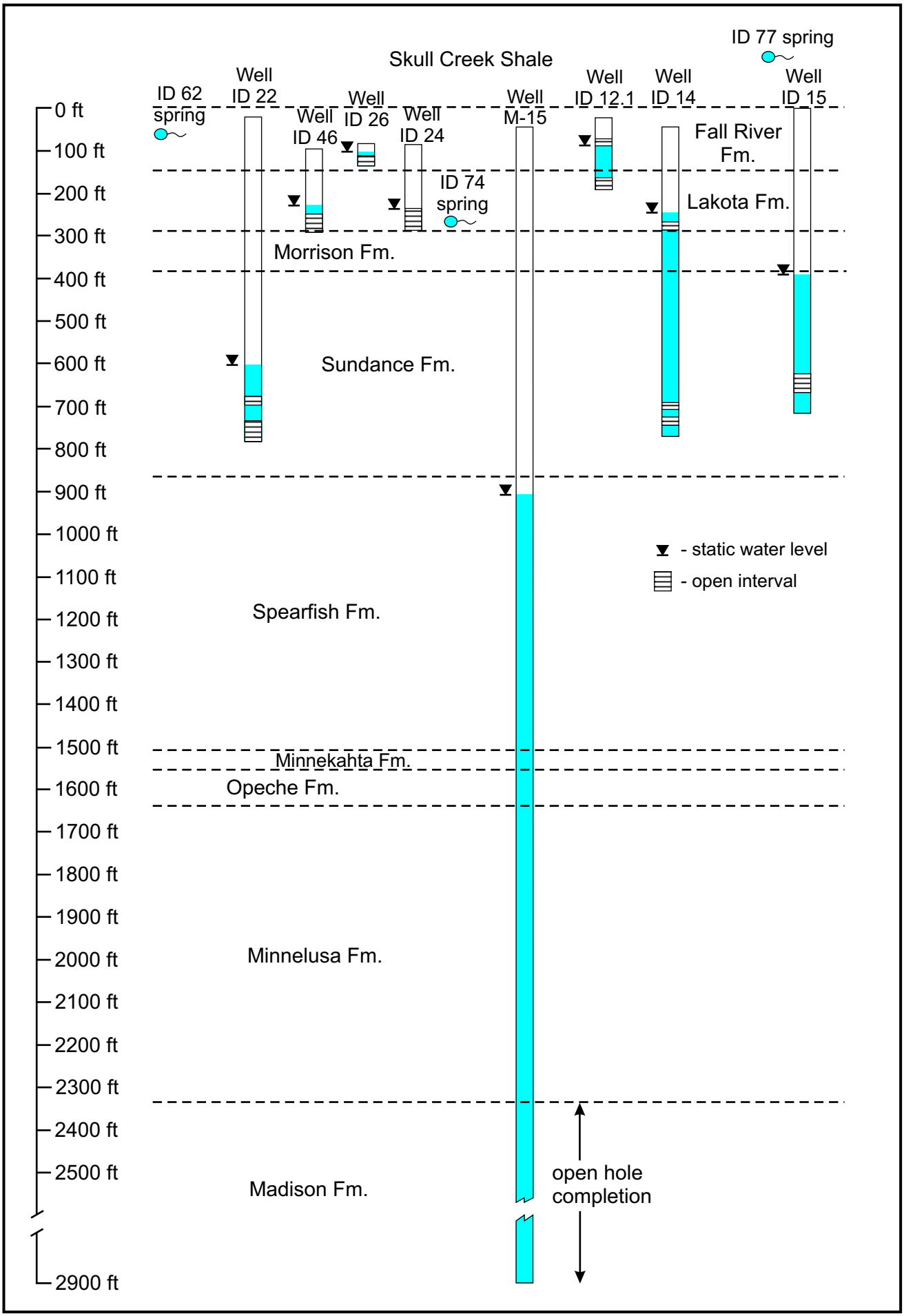


Figure 10 - Stratigraphy and Water Levels

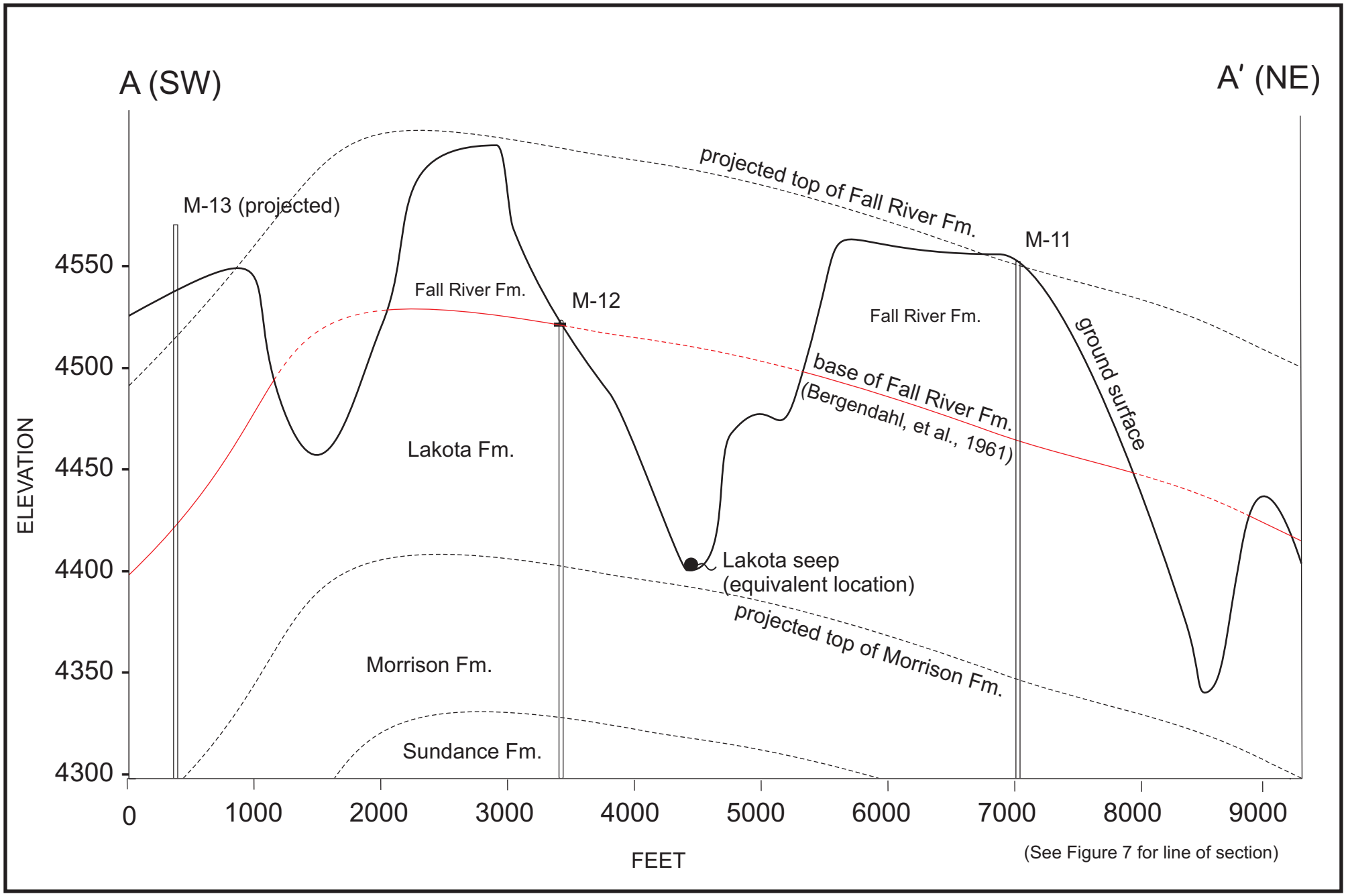


Figure 11 - Schematic A - A′ Cross-Section Through Gillette Wellfield

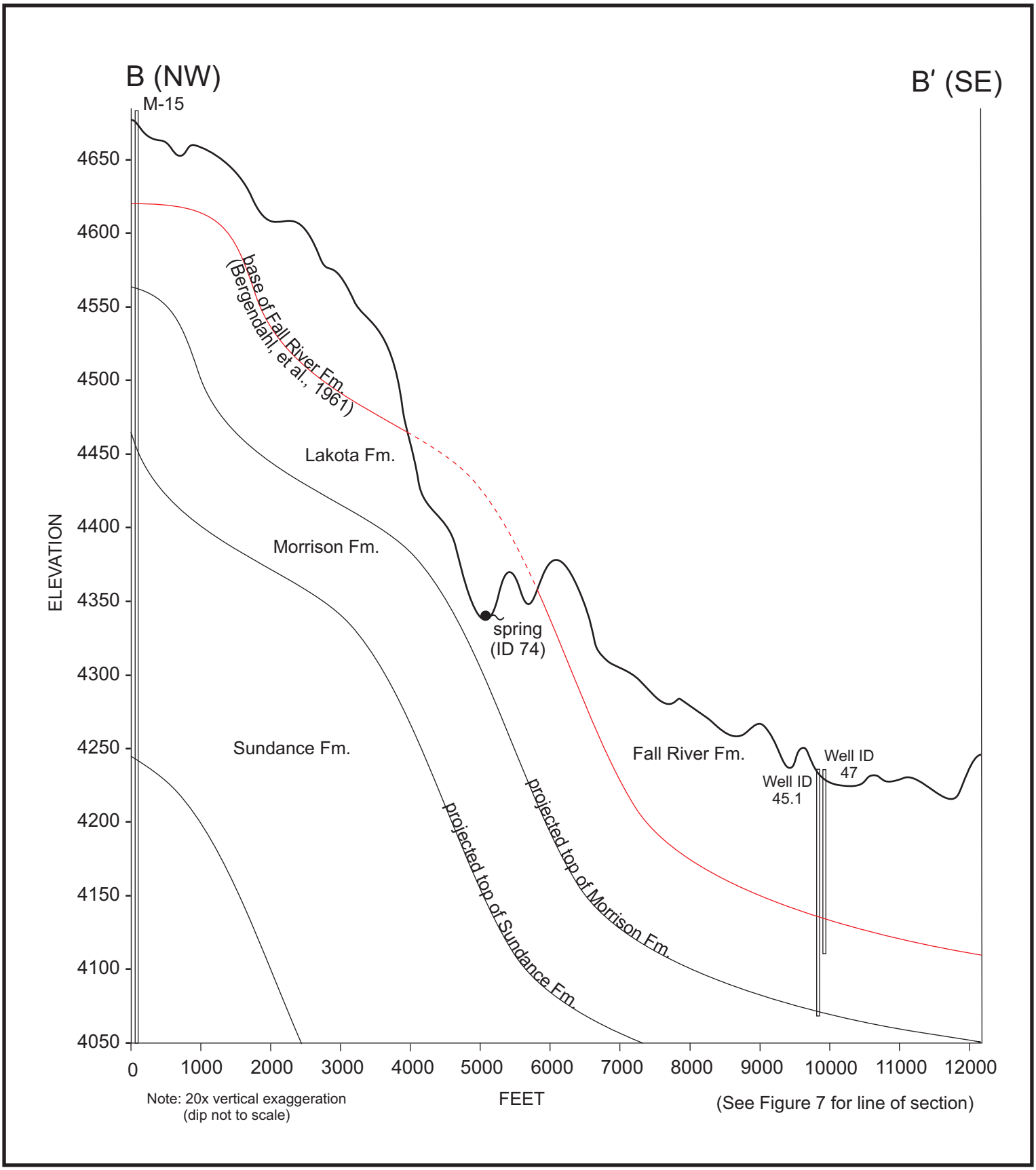


Figure 12 - Schematic B - B′
Cross-Section Through Gillette Wellfield

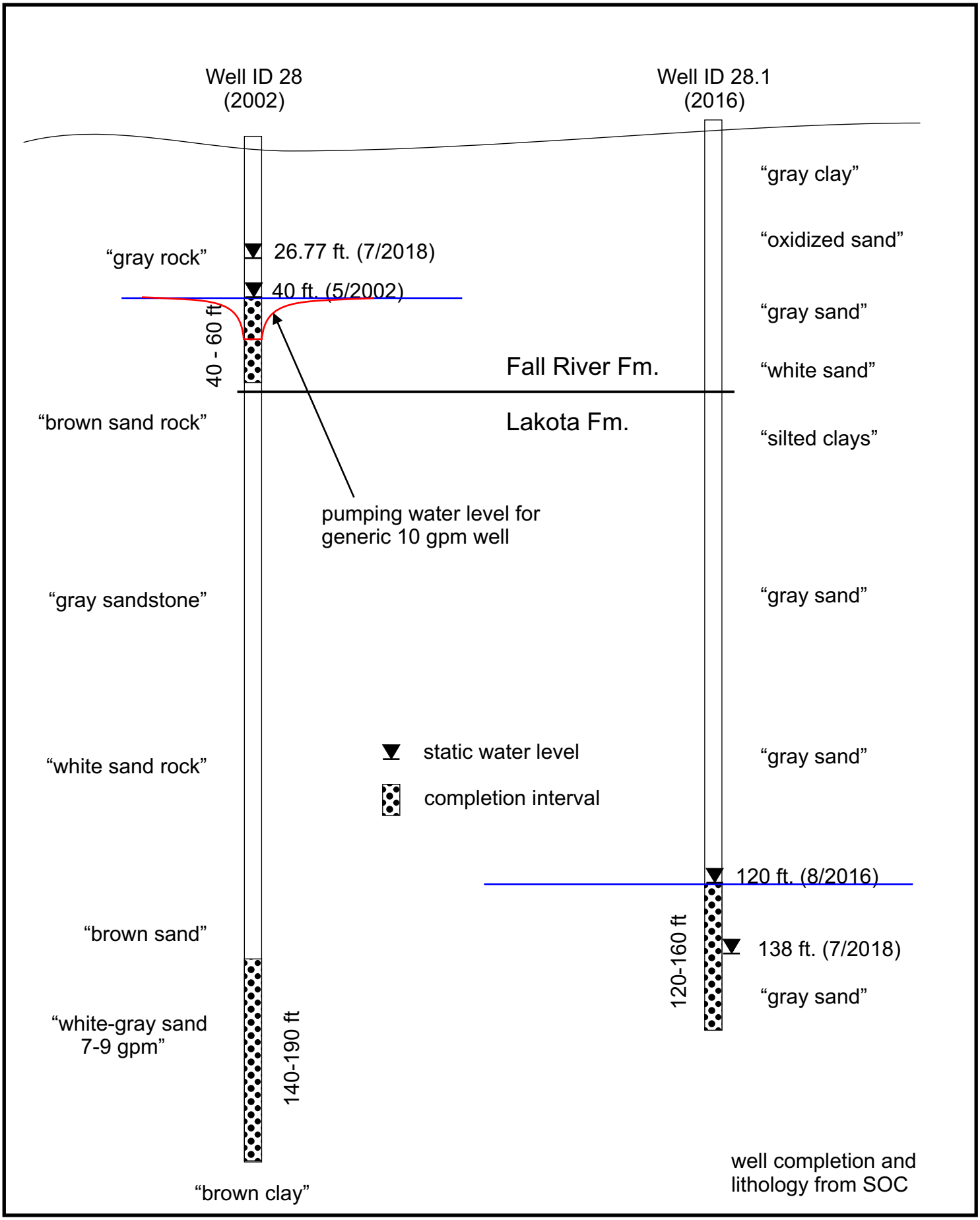


Figure 13 - Well IDs 28 and 28.1

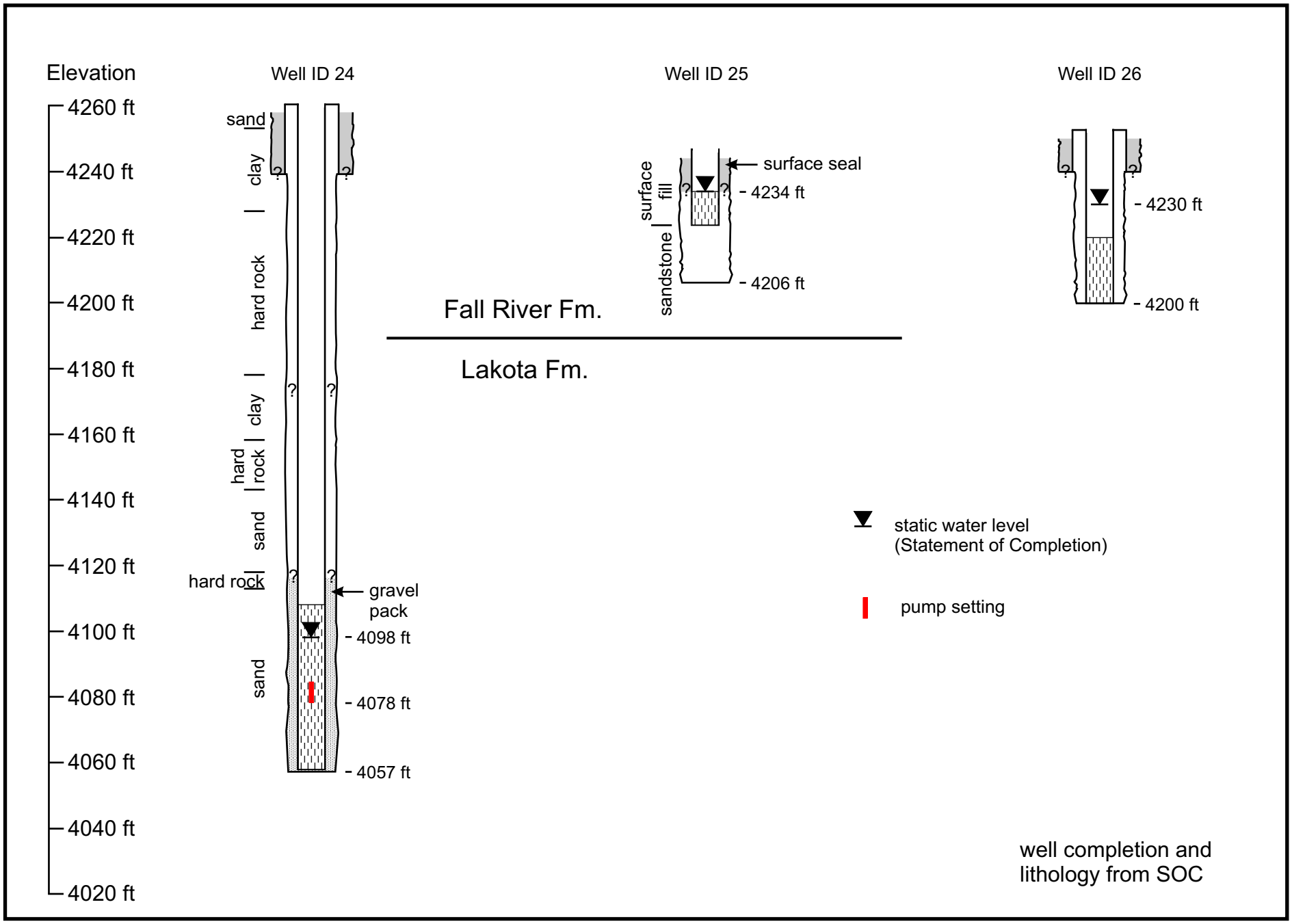
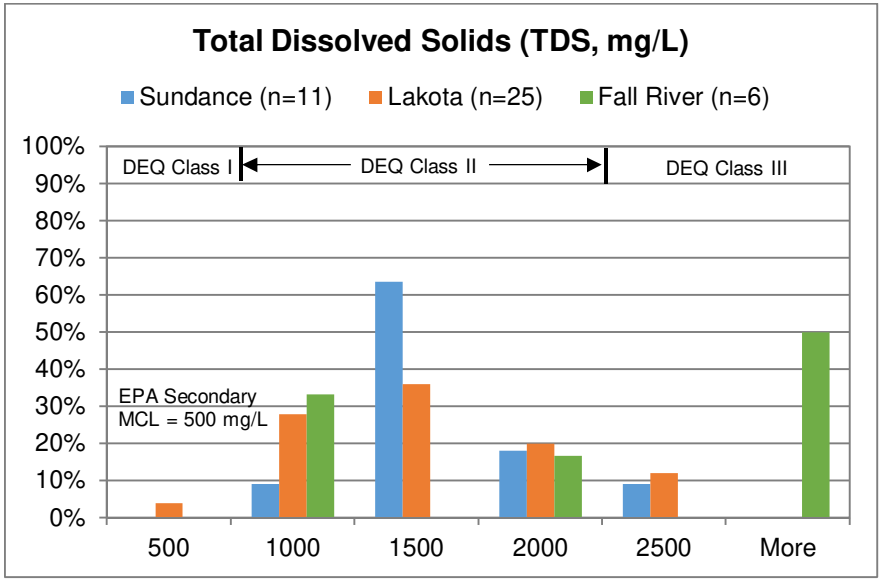
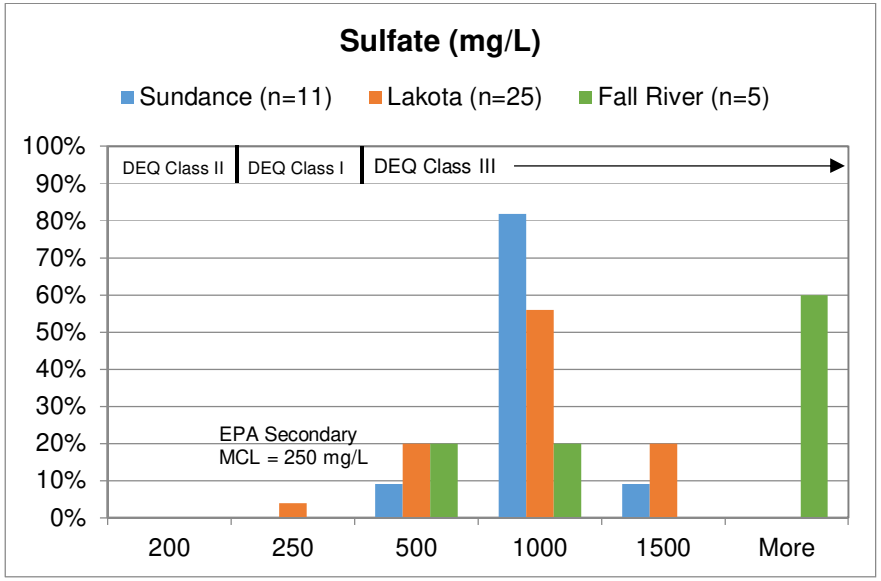
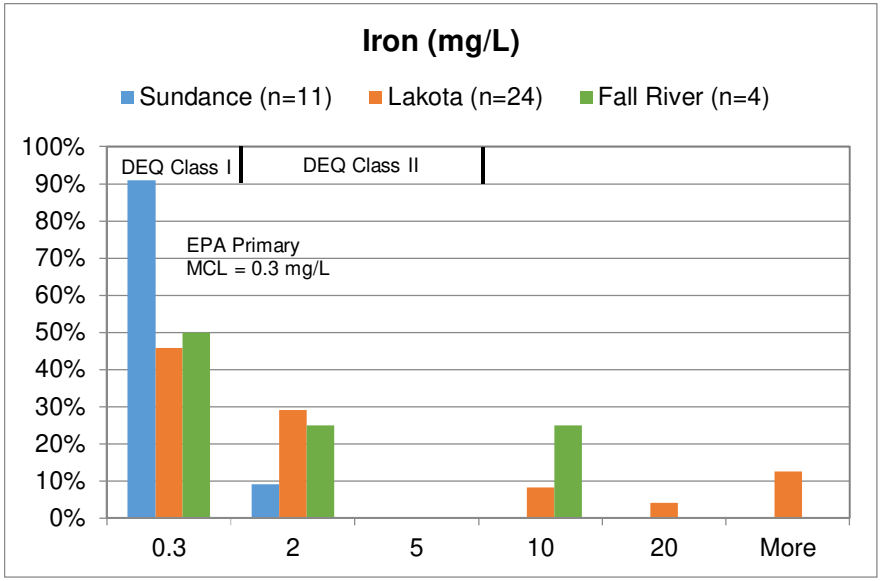
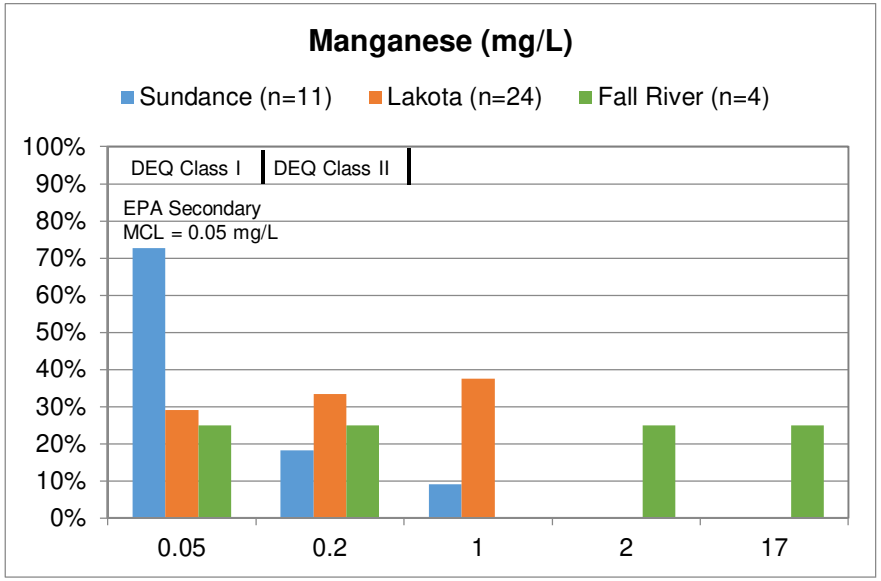


Figure 14 - Well IDs 24, 25, and 26









Concentration categories are ranges, e.g. 36% of the TDS values for the Lakota Formation are >1000 and ≤1500 mg/L.

Figure 15 - Fall River, Lakota, and Sundance Formation Water Quality Summary

Iron deposits at Well ID 84 seep - 7/19/2018

Iron deposits at Well ID 62 seep - 7/19/2018

Figure 16 - Iron-rich Groundwater

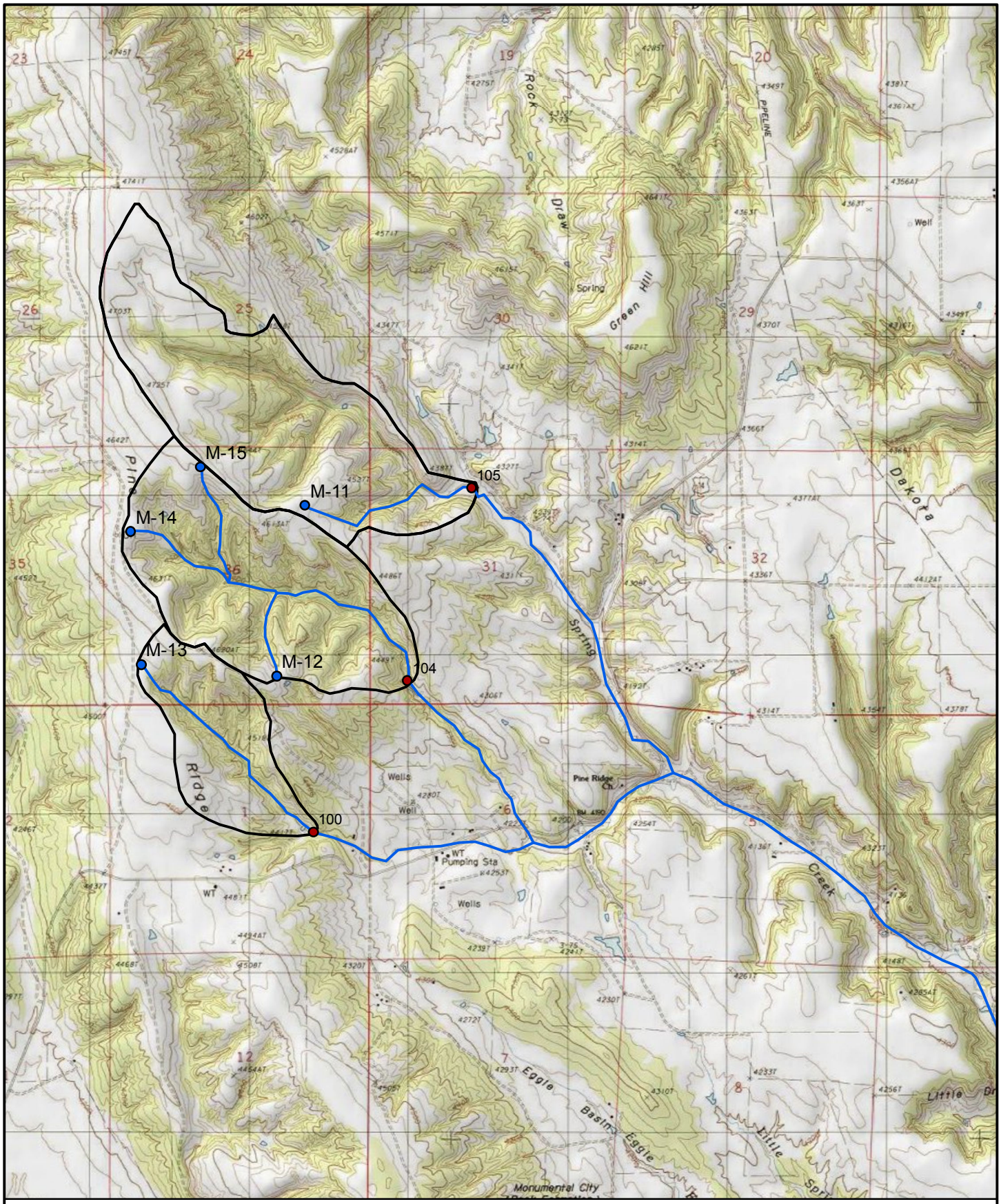
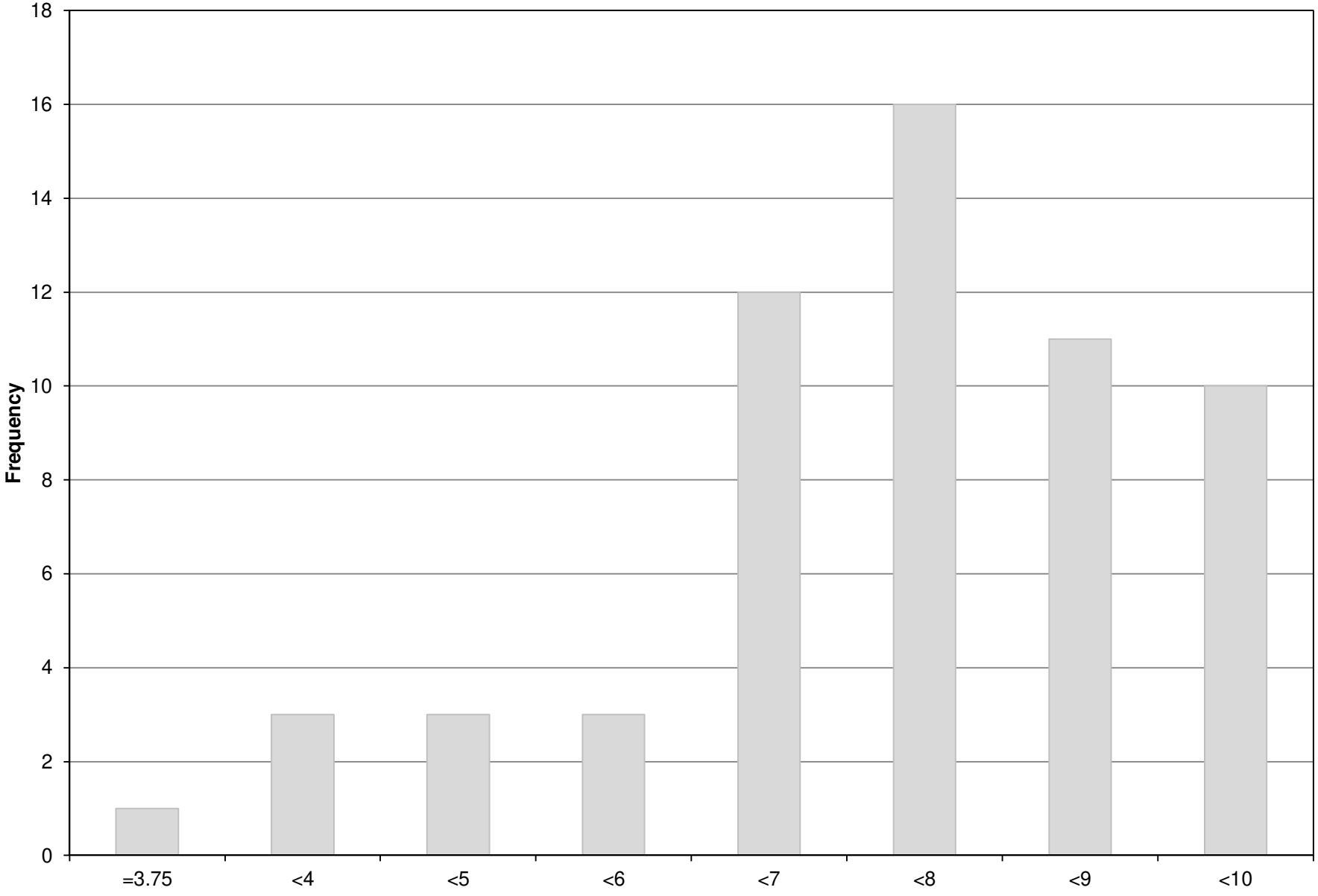
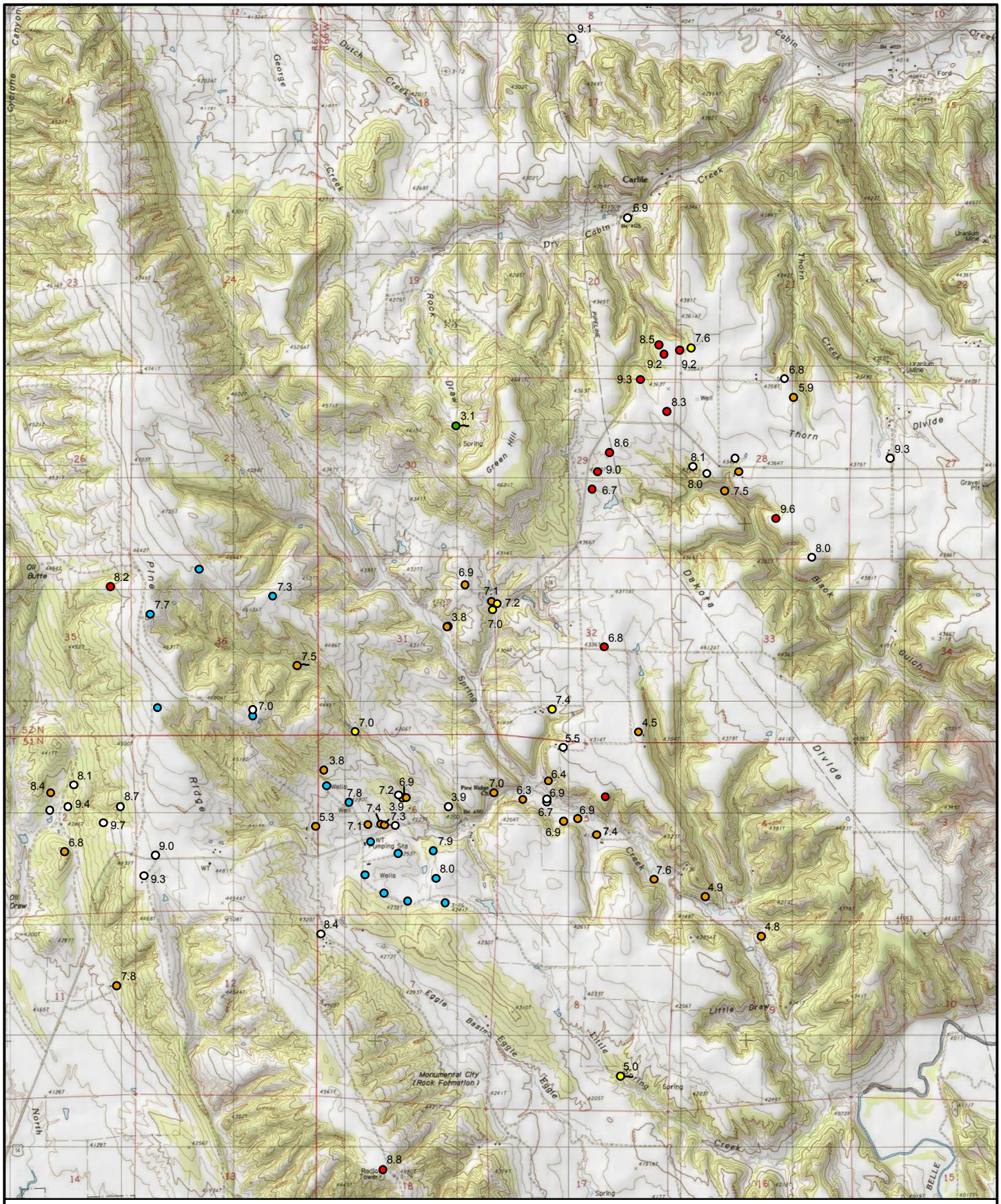


Figure 17 - Gillette Madison Wellfield Runoff Estimation Points

Figure 18 - Gillette Madison Wellfield Study Area Domestic Well pH Distribution (n = 59)

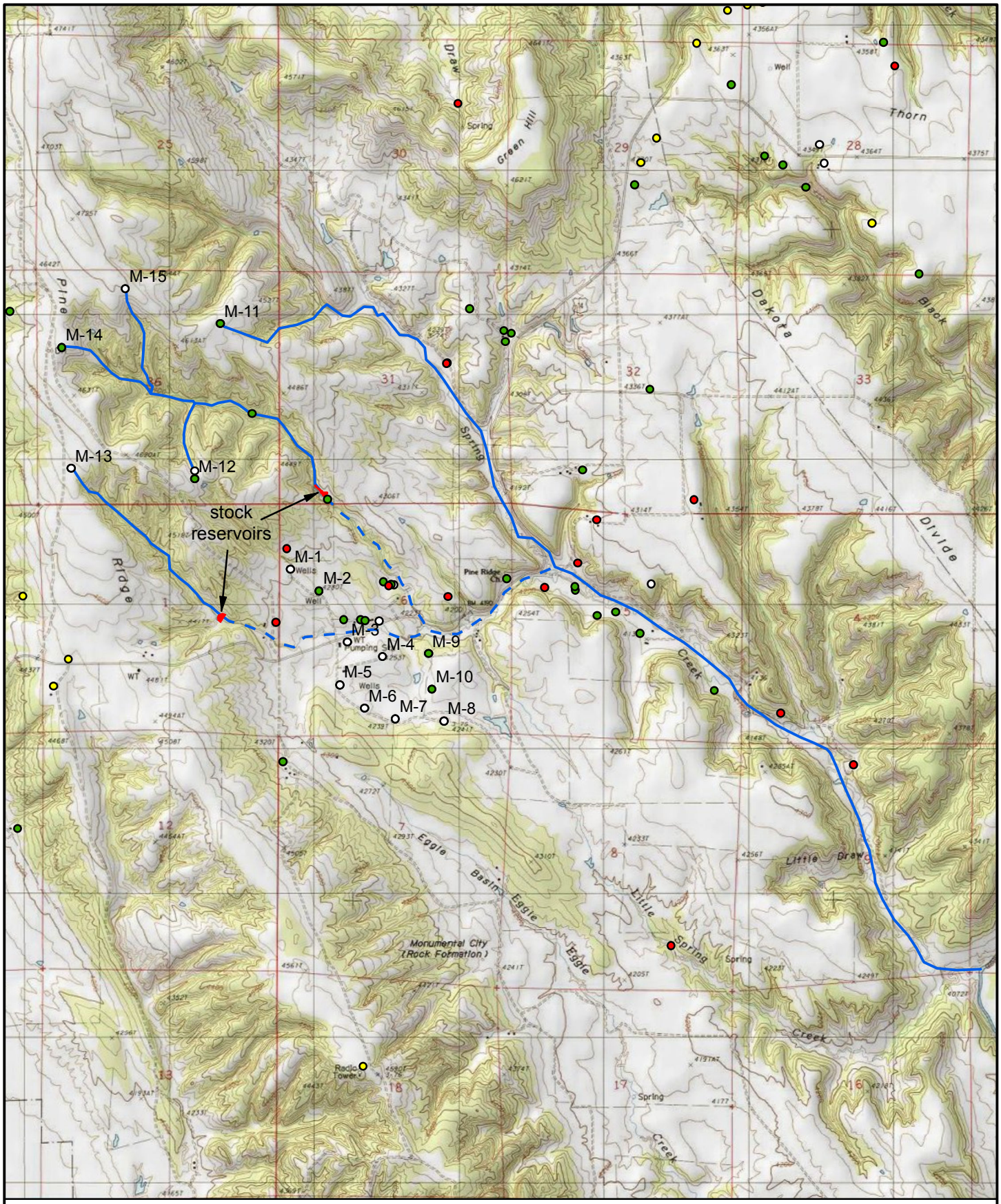




Formation

- Skull Creek Shale
- Fall River
- Lakota
- Sundance
- Madison
- unknown

Figure 19 - Study Area pH Distribution



Field pH

- > 8.5
- 6.5 - 8.5
- < 6.5
- no data

channel receiving drilling and test discharge

channel below stock reservoirs

City of Gillette Wells (M-1 - M-15)

Figure 20 - Gillette Madison Wellfield Drainages

Fractured rock in channel below M-12

Exposed bedrock above Well ID 84

Seep area at Well ID 74

Fractured rock in channel below M-15

Figure 21 - Potential Recharge Features
M-12, 14, 15 Drainage; 7/19/2018

Fractured rock in channel

Exposed bedrock above ID 84

Location ID 74

Reservoir at ID 84

Figure 22 - Streamflow below M-14; 10/10/2016

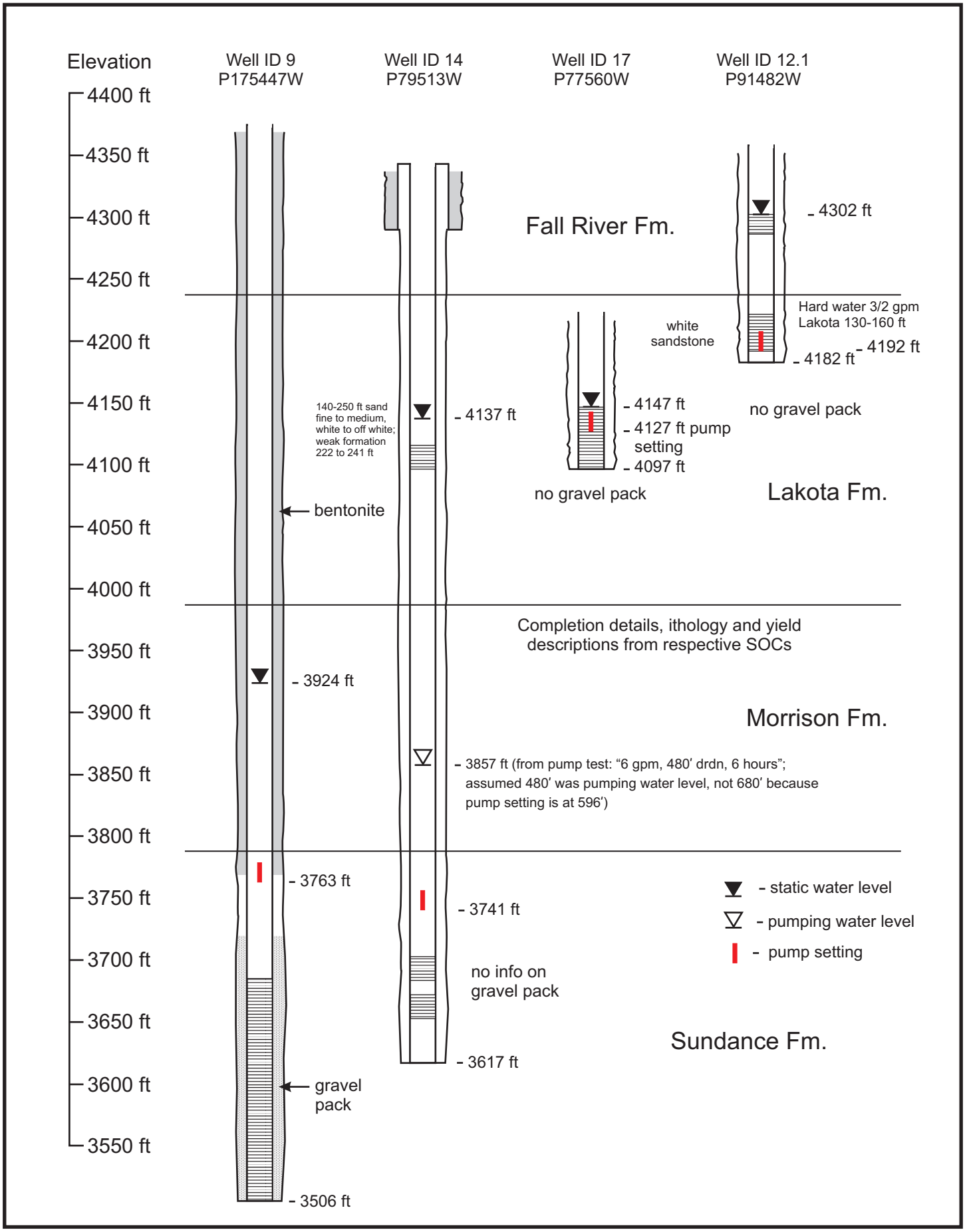
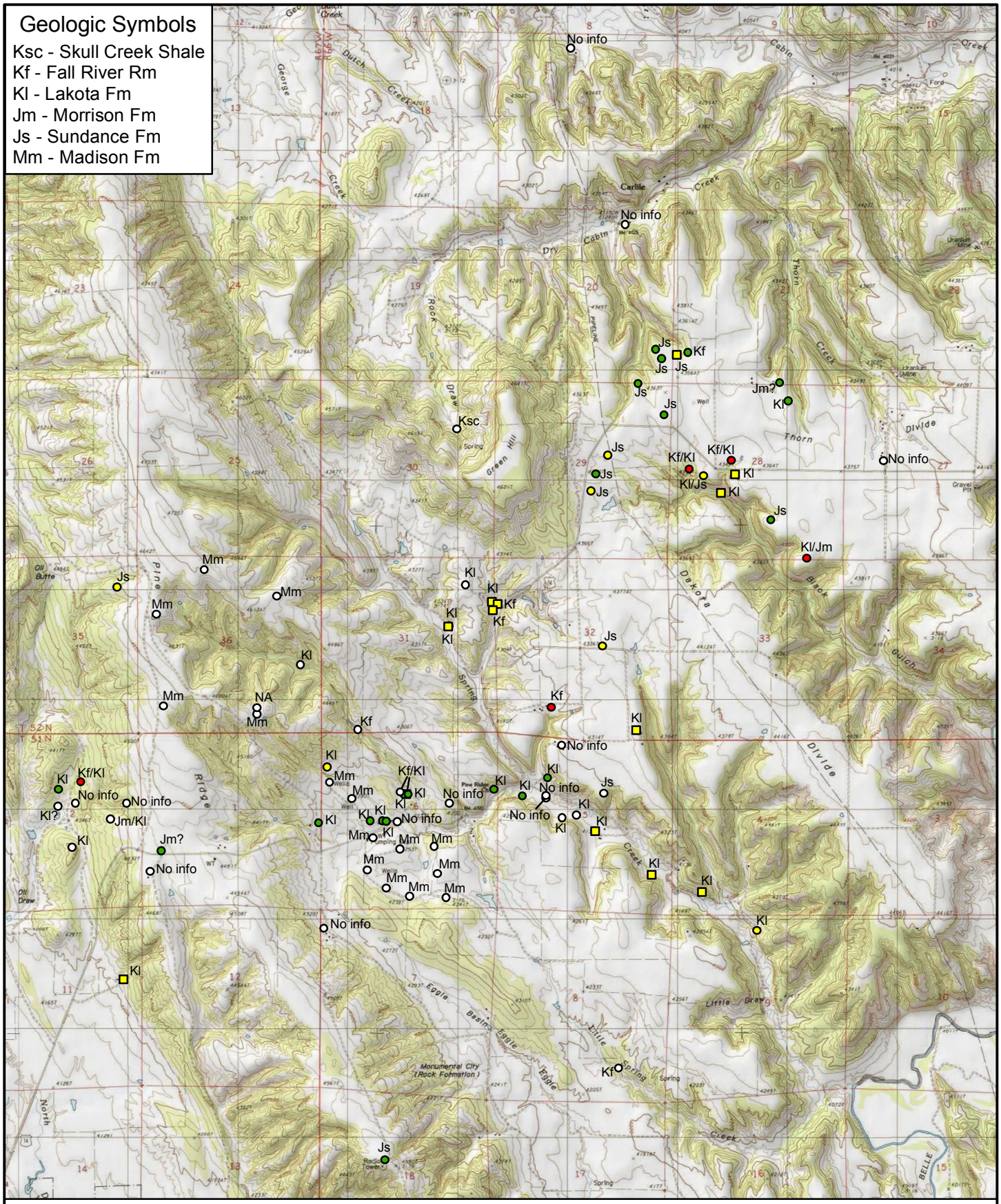


Figure 23 - Well IDs 9, 12.1, 14, and 17



- Screen Top <=10 ft below SWL; multi-zone completion
- Screen Top >10 ft below SWL; multi-zone completion
- Screen Top <=10 ft below SWL; single-zone completion
- Screen Top >10 ft below SWL; single-zone completion
- other reference points

(All information from SOC)

Figure 24 - Study Area Well Completions

TABLES

Table 1 - Gillette Madison Wellfield Project Data Points

ID	Permit	Facility Name[2]	Installation Date	Depth to Water (ft)	Well Depth (ft)	Water Level Elevation (ft)	Source Formation	Fall 2017 DEQ Samples[1] TDS (mg/L)	Sulfate (mg/L)	pH	Iron (mg/L)	Manganese (mg/L)
1	Unknown	Unknown	No info	No info	No info	No info	No info	**1500**	**832**	**9.09**	0.241	0.014
2	Unknown	Unknown	No info	No info	No info	No info	No info	**1090**	**406**	6.94	0.03	0.019
3	P103869W	VIREN #1	2011	410	695	3949	Js	**1450**	**775**	8.49	<0.02	0.026
4	P176508W	STEVENS #1	2006	560	640	3792	Js	**1140**	**583**	**9.19**	<0.02	<0.001
5	P153470W	HANSON #1	2003	40	110	4311	Kf	**979**	**400**	7.6	0.03	**0.137**
6	P192717W	MCKENZIE NO. 1	2010	410	690	3951	Js	**1120**	**581**	**9.2**	<0.02	0.011
7	P102271W	RYAN #1	1996	370	700	3993	Js	**1140**	**613**	**9.29**	<0.02	0.001
8	P190417W	ANDERSON/JACKSON 1	2009	430	760	3935	Js	**903**	**436**	**9.58**	<0.05	0.01
9	P175447W	MEADOWLARK WELL #1	2007	445	863	3924	Js	**1350**	**779**	8.34	0.14	**0.056**
10	P173019W	ROWDY NO. 1	2006	400	825	3967	Js	**1630**	**943**	**8.58**	<0.05	0.012
11	Unpermitted	"Dewey Ranch #2"	No info	No info	No info	No info	No info	**1150**	**560**	**9.31**	<0.05	0.007
12	P91343W	DOC #1	1993	45	135	4281	Kf/Kl	**1170**	**426**	**8.13**	<0.02	0.015
12.1	P91482W	DOC #2	1993	50	170	4302	Kf/Kl					
13	P5762P	DEEDER NO. 1	1934	260	270	4093	Kl					
14	P79513W	THOLE #2	1989	200	720	4137	Kl/Js	**1020**	**563**	7.95	**4.77**	**0.519**
15	P201020W	CRANSTON #1	2014	380	705	3980	Js	**1290**	**656**	**8.99**	<0.02	0.009
16	P173017W	TIA #1	2007	375	825	3975	Js	**1740**	**927**	6.74	**1.683**	**0.936**
17	P77560W	NEIMAN ENTERPRISE #1	1988	70	120	4147	Kl	**1580**	**764**	7.45	0.1	0.006
18	P128570W	K. & R. DENNIS #1	2001	190	300	4173	Kl	**774**	**496**	**5.93**	**0.859**	**0.629**
19	P99737W	ANDERSON #1	1995	120	310	4253	Kl/Jm	**1210**	**625**	7.98	0.098	0.011
M-15	P204036W	M-15	2017	852	2915	3850	Mm					
21	P169736W	WILLIAMS NO 8 SHED	2005	240	320	4084	Kl	428	228	6.87	**5.99**	**0.12**
22	P193417W	R RANCH II	2010	570	745	4023	Js	**1440**	**740**	8.24	0.06	**0.123**
M-11	P206730W	M-11	2013	727	2801	3846	Mm	**817**	**390**	7.25	**0.39**	0.008
24	P35815W	SHOP WELL 6	1977	160	201	4098	Kl	**695**	**380**	7.07	**0.41**	**0.241**
25	P3581W	WILLIAMS #3	1969	10	38	4234	Kf	**4120**	**2640**	7.16	<0.05	0.002
26	P3634P	WILLIAMS #2	1967	20	50	4230	Kf	**2860**	**1720**	7.02		
M-14	P204035W	M-14	2016	792	2915	3852	Mm	**797**	**399**	7.69		
28	P143356W	WILLIAMS #5	2002	40	190	4197	Kl					
28.1	P143356W relocate	WILLIAMS #5	2016	120	180	4115	Kl	**1260**	**903**	**3.75**	**24.193**	**0.745**
M-13	P204034W	M-13	2016	724	2796	3859	Mm					
M-12	P206731W	M-12	2012	689	2891	3842	Mm	**760**	**324**	6.96	**4.2**	0.1
31	P208333W	ENL ERLAND NO. 1	2017	90	160	4207	Kf	**1520**	**806**	7.44	**0.36**	**1.36**
32	P46170W	WATER WELL #1	1979	260	290	4088	Kl	**927**	**587**	**4.5**	**40.4**	**0.153**
33	P101253W	AURAND #2	No info	No info	No info	No info	No info	**643**	**405**	**5.52**	**17.5**	**0.121**
34	P54046W	WILLIAMS #1	1980	210	266	4114	Kl	**2200**	**1260**	**3.76**		
36	P206170W	WOLF #1	2017	100	280	4207	Kf/Kl	**1690**	**650**	8.1	<0.05	0.01
37	P177462W	OLVER #1	2007	150	600	4122	Kl	**1770**	**834**	8.37	<0.05	0.018
38	P85375W	ROCKING-27	No info	No info	No info	No info	No info	**714**	48	**9.43**	<0.05	0.002
39	P174356W	AARS #3	2006	220	380	4162	Jm/Kl	**668**	7	**9.69**	<0.05	0.004
40	Unknown	Unknown	No info	No info	No info	No info	No info	**1690**	**918**	**8.65**	<0.05	0.003
41	P85246W	KETTERLING #1	1987	320	340	3996	Kl	**2320**	**1480**	6.8	**5.651**	**0.22**
42	P70507W	B K #1	1987	290	421	4168	Jm?	**906**	**332**	**9.04**	<0.05	0.001
43	Unknown	Unknown	No info	No info	No info	No info	No info	**758**	**653**	**9.28**	<0.05	<0.001
44	P52843W	MCKILLIP #1	1980	230	280	4065	Kl	**1300**	**1100**	**5.34**	**10.254**	**0.649**
45	P133080W	ERLAND #5	2001	51	102	4185	Kf/Kl	**1340**	**592**	6.89	<0.05	0.011
45.1	P207609W	CRANSTON HOUSE	2017	120	220	4119	Kl	**1770**	**1170**	**3.9**	**29.319**	**0.701**
46	P33805W	PINE RIDGE COMMUNITY CHURCH #1	1977	130	190	4062	Kl	**1310**	**691**	7.01	0.04	0.004
47	P28851W	ERLAND NO. 4	1975	40	120	4193	Kl					
47.1	P207610W	MECINT CRANSTON #1	2017	No info	No info	No info	No info	**989**	**660**	**3.91**	**21.32**	**0.465**

ID	Permit	Facility Name[2]	Installation Date	Depth to Water (ft)	Well Depth (ft)	Water Level Elevation (ft)	Source Formation	Fall 2017 DEQ Samples[1] TDS (mg/L)	Sulfate (mg/L)	pH	Iron (mg/L)	Manganese (mg/L)
48	P114433W	GRIFFITH #1	1999	90	140	4168	Kl	**1080**	**523**	7.06	**1.131**	**0.148**
49	P114770W	MARK #1	2000	60	120	4182	Kl	**943**	**418**	7.38	0.269	**0.151**
50	P114771W	THELMA #1	1999	70	120	4163	Kl	**929**	**450**	7.26	**0.374**	**0.094**
51	Unknown	"Griffith well"	No info	10	No info	4215	No info					
52	P182675W	25 SPRING CREEK	1992	72	200	4114	Kl	**1320**	**756**	**6.39**	**0.355**	**0.094**
53	Unknown	Unknown	approx. 1980	244	approx. 400	4056	Js					
54	P137994W	SPRING CREEK - HAPONSTALL # 1	2002	65	140	4109	Kl	**1250**	**781**	**6.25**	0.092	**0.227**
55	P204215W	TAYLOR #1	2015	40	135	4108	Kl	**1580**	**814**	6.94	<0.05	0.001
56	P194216W	MCDONALD #1	1993	30	120	4132	Kl	**1640**	**849**	6.9	<0.05	<0.001
57	P38110W	ROBIDOUX #1	1977	50	80	4093	Kl	**1470**	**779**	7.38	<0.05	<0.001
58	P97333W	KATHY #1	1994	40	120	4081	Kl	**1230**	**653**	7.59	<0.05	<0.001
59	P203713W	WHITE #1	2015	55	123	4077	Kl	**932**	**603**	**4.91**	**0.74**	**0.332**
60	Unknown	"Old house well"	No info	No info	No info	No info	No info	**1660**	**960**	8.35	**0.88**	**0.078**
61	P59915W	NORMA #1	1982	175	215	4051	Kl	**2380**	**1340**	7.76	**1.039**	**0.056**
62	P201975W	TIGGER #2	NA	0	Spring	4156	Kf	**3120**	**1690**	**5.03**	**6.12**	**16.9**
63	P191804W	TIGGER #1	2010	585	680	4014	Js	**2180**	**1230**	**8.82**	<0.02	<0.001
M-1	P56867W	M-1	1981	447	2767	3857	Mm					
M-2	P56868W	M-2	1981	428	2614	3852	Mm	**579**	**264**	7.8	0.19	0.02
M-3	P56869W	M-3	1981	405	3001	3830	Mm					
M-4	P56870W	M-4	1981	403	2525	3852	Mm					
M-9	P172433W	M-9	1998	404	2523	3833	Mm	**581**	**262**	7.94	0.03	<0.01
M-5	P56871W	M-5	1981	395	3005	3860	Mm					
M-10	P172432W	M-10	1998	402	2524	3830	Mm	**601**	**261**	8.03	0.04	<0.01
M-6	P56872W	M-6	1981	395	3005	3851	Mm					
M-7	P56873W	M-7	1986	387	3006	3849	Mm					
M-8	P56874W	M-8	1986	391	3008	3849	Mm					
74	Natural Spring	"State Section Spring"	NA	0	Spring	4347	Kl	**967**	**415**	7.47	0.063	**0.055**
75	Abandoned Borehole	TH-2	2012	NA	1692	NA	NA					
76	P208312W	RLC #1	2018	400	800	3908	Js			6.8		
77	Natural Spring	"Green Hill Spring"	NA	0	Spring	4379	Ksc	**6600**	**4550**	**3.12**	**10.374**	**54.6**
78	Unpermitted	Unknown	No info	57	>180	4194	Kl?					
79	Unpermitted	"backup well"	2002	No info	102	No info	Kf/Kl	**1130**	**541**	7.15	<0.05	**0.122**
80	P208254W	ARNOLD ALTAFFER #3	No info	No info	No info	No info	No info	**1670**	**907**	6.67	<0.05	**0.081**
81	Stream sample		NA	0	Creek	4152	No info	**2010**	**1020**	6.91	<0.05	**0.105**
82	P204707W	RCWW 1	2016	40	114	4071	Kl	**1050**	**686**	**4.79**	0.121	**0.489**
83	P198336W	SHARON-KEN	2009	280	350	4066	Jm?	**1330**	**612**	6.75	**1.483**	**0.255**
84	Seep	"reservoir seep"	NA	0	Seep	4288	Kf	**693**		7.02		

[1]IDs 45, 74, 76, 77, and 79-84 were sampled in 2018. See Tables 6 through 10 for complete analyses.
[2]Quotes indicate unofficial name given for purposes of identification in this report.
Notes: Jm = Morrison Formation, Js = Sundance Formation, Kf = Fall River Formation, Kl = Lakota Formation, Ksc = Skull Creek Shale, Mm = Madison Formation
pH values are field measurements where available, otherwise lab data.
NA = Not Applicable
Bold = exceeds EPA drinking water standard
IDs M-11 through M-15: City of Gillette well data obtained from City of Gillette files; SEO Statements of Completion for M-11 and M-12 have been reversed.
ID 42: this is the well location for sample #35 in Tables 6 through 10.
ID 51: Depth to water is a visual estimate on July 20, 2018.
ID 53: Installation date and well depth estimated by owner; depth to water measured on July 20, 2018.
ID 78: Depth to water and well depth measured on July 20, 2018.
ID 79: Installation date reported by owner; well depth and depth to water measured on July 20, 2018.
ID 84: TDS estimated from conductivity measurement, July 20, 2018.

TABLE 2 - STATIC WATER LEVELS (SWL) IN GILLETTE MADISON WELLFIELD STUDY AREA

Well ID	Date	SWL (Feet Below Ground Surface)
45	2001	51 (original)
	7/2017	96
	7/2018	66.2
45.1	8/2017	120 (original)
	7/2018	133.2
28	2002	40 (original)
	7/2018	26.8
53	est. 1980	<385 (original)
	7/2018	244*
54	2002	65 (original)
	7/2018	65.4*
28.1	2016	120 (original)
	7/2018	120.1*

* - depth estimated with a sonic depth meter

TABLE 3 – GILLETTE MADISON WELL-FIELD TIMELINE

Date	Gillette Madison Wellfields	Area Domestic Wells
pre-1981	no activity	10 wells: 1934-1980 (inc well ID #47 - 1975)
1980 - 1981	Completion of Gillette Madison Wells M-1 through M-8; 1981 – 1996 average annual wellfield production: 1,377 gpm, 724 Mg (HDR, 2009)	5 wells
1980-1995		9 wells
1996	Completion of Gillette Madison Wells M-9 and M-10; 1997 – 2007 average annual full wellfield production: 2,302 gpm; 1,211 Mg (HDR, 2009)	
1997-2010		20 wells (inc. wells ID#45/ #79 - 2001/02)
2011		1 well
Oct - Dec	Construction of M-12	
2012		
Jan - Oct.	Completion of M-12	
Oct	M-12 Drilling discharge: 10/2 to 10/5 - 1.4 Mg, avg 510 gpm, max 800 gpm M-12 Test discharge: 10/21- 0.2 Mg, avg 570 gpm, max 650 gpm	
Nov/Dec	M-12 Stimulation: 11/13 M-12 Test discharge: 11/30 to 12/3 - 1.2 Mg, avg 1086 gpm, max 1500 gpm Test discharge: 12/3 to 12/5 - 4.3 Mg, avg 1500 gpm, max 1500 gpm	
Sept - Dec	Construction of M-11	
2013		
Jan - Mar	Completion of M-11	
February	M-11 Drilling discharge: 2/21 to 2/26 - 3.2 Mg, avg 470 gpm, max 1075 gpm	

TABLE 3 (cont.) – GILLETTE MADISON WELL-FIELD TIMELINE

Date	Gillette Madison Wellfields	Area Domestic Wells
March	M-11Test discharge: 3/10 to 3/11 - 0.9 Mg, avg 820 gpm, max 950 gpm M-11 Stimulation: 3/26	
April	M-11 Test discharge: 4/13 to 4/14 - 0.9 Mg, avg 1280 gpm, max 1605 gpm M-12 Test discharge: 4/13 - 5.3 Mg, avg 1400 gpm, max 1500 gpm	
May	M-11 Test discharge: 5/10 to 5/14 - 7.8 Mg, avg 1600 gpm, max 1600 gpm	
2014		
2015	Dec - start construction of M-13	
2016	Finish construction of M-13	
April	M-13 Drilling discharge: 4/1 to 4/6 - 2.2 Mg, avg 400 gpm, max 800 gpm	
May	M-13 Test discharge: 5/15 to 5/17 - 1.8 Mg, avg 900 gpm, max 1440 gpm (discharge to field irrigation)	
June	M-13 Stimulation: 6/2 to 6/8 M-13 Test discharge: 6/11 - 0.4 Mg, avg 400 gpm	
Aug-Oct	Construction of M-14	
Oct	M-14 Drilling discharge: 10/7 to 10/12 - 1.1 Mg, avg 400 gpm, max 800 gpm M-14 Drilling discharge: 10/31 - 0.3 Mg, avg 400 gpm	
Nov.	M-14 Test discharge: 11/17 - 0.5 Mg, avg 715 gpm, max 880 gpm. (no stimulation to date)	
Nov/Dec	Begin construction M-15	
2017	Complete construction of M-15	#28.5 cattle 1st refused water

May	M-15 Drilling discharge: 5/3 - 0.7 Mg, avg 400 gpm Test discharge: 5/18 - 0.8 Mg, avg 1010 gpm, max 1400 gpm	

TABLE 3 (cont.) – GILLETTE MADISON WELL-FIELD TIMELINE

Date	Gillette Madison Wellfields	Area Domestic Wells
June	M-15 Stimulation: 6/1 M-15 Test discharge: 6/17 to 6/18 - 0.6 Mg , avg 400 gpm, max 500 gpm	
June / July	M-14 Minnelusa discharge: 6/30 to 7/9 - 1.4 Mg; avg 200 gpm M-14 Madison discharge: 7/18 - 0.1 Mg; avg 400 gpm	7/13: well ID #45 and ID#79 reported "dry"; replacement wells #45.1 and #47.1 completed (found low pH)
Oct / Nov	M-14 Madison discharge: 10/1 - 1.2 Mg; avg 800 gpm	1st round DEQ sampling
2018		
Jan		Well ID#76 replacement well completed
July		2nd round DEQ sampling

Table 4 - Peak Streamflow Estimates

Gillette Madison Wellfield study area

	Estimation Point 100	Estimation Point 104	Estimation Point 105
Peak flow rate estimates:			
Flow with 1.5-yr recurrence interval	9.8 cfs	14.5 cfs	15.8 cfs
Peak City well discharge comparison	M-13: 2.0 cfs (5/2016)	M-12: 3.1 cfs (5/2013)	M-11: 2.8 cfs (4/2013)
Peak event volume estimates:			
Event volume with 2-yr. recurrence interval	5.6 ac-ft (1.8 Mg)	6.8 ac-ft (2.2 Mg)	5.3 ac-ft (1.7 Mg)
Event volume with 5-yr. recurrence interval	10.0 ac-ft (3.2 Mg)	13.1 ac-ft (4.2 Mg)	10.7 ac-ft (3.4 Mg)
Event volume with 10-yr. recurrence interval	13.2 ac-ft (4.3 Mg)	17.9 ac-ft (5.8 Mg)	15.0 ac-ft (4.9 Mg)
Peak City well discharge comparison	M-13: 6.8 ac-ft (2.2 Mg) (4/2016)	M-12: 13.2 ac-ft (4.3 Mg) (12/2012)	M-11: 16.3 ac-ft (5.3 Mg) (4/2013)
cfs = cubic feet per second; ac-ft = acre-feet; Mg = million gallons			

TABLE 5 - LABORATORY ANALYTICAL METHODS

ANALYTES	ANALYTICAL METHOD
WDEQ WATER QUALITY LAB	
Bicarbonates	SM2320-B-1997
Carbonates	SM2320-B-1997
Chlorides	EPA300.0 R2.1
Sulfates	EPA300.0 R2.1
Calcium Total	EPA 200.7
Magnesium Total	EPA 200.7
Potassium Total	EPA 200.7
Sodium Total	EPA 200.7
Aluminum Dissolved	EPA 200.8
Aluminum Total	EPA 200.8
Arsenic Dissolved	EPA 200.8
Arsenic Total	EPA 200.8
Barium Dissolved	EPA 200.8
Barium Total	EPA 200.8
Beryllium Dissolved	EPA 200.8
Beryllium Total	EPA 200.8
Boron Dissolved	EPA 200.8
Boron Total	EPA 200.8
Cadmium Dissolved	EPA 200.8
Cadmium Total	EPA 200.8
Chromium Dissolved	EPA 200.8
Chromium Total	EPA 200.8
Cobalt Dissolved	EPA 200.8
Cobalt Total	EPA 200.8
Copper Dissolved	EPA 200.8

TABLE 5 (cont.) - LABORATORY ANALYTICAL METHODS

ANALYTES	ANALYTICAL METHOD
WDEQ WATER QUALITY LAB	
Copper Total	EPA 200.8
Iron Dissolved	EPA 200.7/200.8
Iron Total	EPA 200.7/200.8
Lead Dissolved	EPA 200.8
Lead Total	EPA 200.8
Manganese Dissolved	EPA 200.8
Manganese Total	EPA 200.8
Nickel Dissolved	EPA 200.8
Nickel Total	EPA 200.8
Selenium Dissolved	EPA 200.8
Selenium Total	EPA 200.8
Silver Dissolved	EPA 200.8
Silver Total	EPA 200.8
Strontium Dissolved	EPA 200.8
Strontium Total	EPA 200.8
Vanadium Dissolved	EPA 200.8
Vanadium Total	EPA 200.8
Zinc Dissolved	EPA 200.8
Zinc Total	EPA 200.8
Ammonia (as Nitrogen)	SM4500-NH3 F2011
Nitrate-Nitrite (as Nitrogen)	SM4500-NO3 F2011
Alkalinity	SM 2320-B-2011
Fluoride	SM4500-F-C
pH	SM4500H+ B-2011

TABLE 5 (cont.) - LABORATORY ANALYTICAL METHODS

ANALYTES	ANALYTICAL METHOD
ENERGY LABS	
pH	A4500-H B
Solids, Total Dissolved TDS @ 180 C	A2540 C
Cyanide	Kelada-01
Bromide	EPA 300.0
Sulfide	A4500-S D
Mercury	E245.1
Gross Alpha minus Rn & U	E900.1
Radium 226	E903.0
Radium 226 + Radium 228	A7500-RA
Strontium 90	E905.0
Radium 228	RA-05
Bacteria, Iron Related	IRB-BART
Bacteria, Total Coliform	A9223 B
Bacteria, E. Coli Coliform	A9223 B

TABLE 6 - FIELD PARAMETER READINGS
2017 and 2018 SAMPLING EVENTS

WQRR Chapter 8, Table 1 Domestic Use Standard				6.5 - 8.5	N/A	N/A	N/A	N/A	N/A	N/A	500
MAP ID	**SAMPLE ID**	**SAMPLE DATE (mm/dd/yy)**	**SAMPLE TIME (Military Time)**	**pH, field (SU)**	**DO (mg/L)**	**ORP (mV)**	**Temp (°C)**	**EC (µS/cm2)**	**Turbidity (NTU)**	**Ferrous Iron (mg/L)**	**TDS (mg/L)**
47.1	Data from Owner	80417	--	**3.97***	NA	NA	NA	NA	NA	NA	841*
	1-102517-0926	102517	926	**3.91**	10.5	137	9.97	1.09	0	>3	**614**
	071918-1100	71918	1100	**4.2**	1.86	191	13.58	1.08	0	>3	NM
25	2-102517-1055	102517	1055	7.16	22.42	10	10.94	4.54	0	0.8	NM
45.1	Data from Owner	80417	NR	**3.96***	NA	NA	NA	NA	NA	NA	NA
	Data from Owner	80717	1400	**4.54***	NA	NA	NA	NA	NA	NA	NA
	1-102517-1056	102517	1056	**3.9**	0	223	10.39	2.16	0	>3	**1380**
	071918-0930	71918	930	**4.61**	1.23	144	11.5	2.18	9.7	>3	NM
48	1-102517-1300	102517	1300	7.06	0	-65	10.52	0.986	0	>3	**633**
34	Data from Owner	100517	1110	**3.85***	NA	NA	NA	NA	NA	NA	NA
	2-102517-1352	102517	1352	**3.76**	0	364	12.07	2.78	0	>3	NM
	071918-1335	71918	1335	**3.61**	2.43	302	14.27	2.76	0	2.69	NM
50	1-102517-1500	102517	1500	7.26	0	-42	10.58	0.861	0	0.29	**551**
28.1	Data from Owner	7252016	1200	**4.04***	NA	NA	NA	NA	NA	NA	NA
	Data from Owner	100517	1025	**3.71***	NA	NA	NA	NA	NA	NA	NA
	2-102517-1512	102517	1512	**3.75**	0	246	11.04	1.23	0	>3	NM
	071818-1130	71818	1100	**3.54**	1.63	289	12.3	1.3	0	>3	NM
49	1-102517-1555	102517	1555	7.38	0	-43	10.42	0.866	0	0.14	**554**
26	2-102517-1627	102517	1627	7.02	0	161	12.41	3.12	0	0.27	NM
61	1-102617-0855	102617	855	7.76	1.19	-29	9.95	2.02	0	>3	**1290**
21	2-102617-1032	102617	1032	6.87	0	71	9.64	0.605	0.3	0.14	NM
41	1-102617-1105	102617	1105	6.8	0	-37	11.44	2	0	>3	**1320**
24	2-102617-1145	102617	1145	7.07	0	108	7.4	0.833	19.8	0.14	NM
37	1-102617-1225	102617	1225	8.37	0	-155	13.24	1.99	20.1	0	**1270**
14	Data from Owner	51189	--	6.65*	NA	NA	NA	NA	NA	NA	6.65
	2-102617-1329	102617	1329	7.95	0	-42	10.21	1.32	39.6	>3	NM
36	1-102617-1345	102617	1345	8.1	15.91	109	NM	2	23.5	NS	**1280**
11	2-102617-1535	102617	1535	**9.31**	0	14	9.31	1.51	30.4	0.03	NM
58	2-102717-0920	102717	920	7.59	0	263	8.15	1.47	28.6	NS	NM
35	1-102717-0930	102717	930	**9.04**	0	-3	11.51	0.995	1	0	NM
57	2-102717-1048	102717	1048	7.38	0	204	8.11	1.77	1.1	0.05	NM
43	1-102717-1120	102717	1120	**9.28**	3.31	-264	12.27	0.845	0	0	**541**
56	1-103117-1015	103117	1015	6.9	7	173	8.5	1.43	0	0	NM
55	1-103117-1150	103117	1150	6.94	3.04	158	8.63	1.4	0	0.03	NM
52	Data from Owner	40594	NR	6.5*	NA	NA	NA	NA	NA	NA	825*
	Data from Owner	52296	NR	6.5*	NA	NA	NA	NA	NA	NA	1051*
	Data from Owner	42007	NR	**6.1***	NA	NA	NA	NA	NA	NA	NA
	Data from Owner	20713	NR	**6.13***	NA	NA	NA	NA	NA	NA	NA
	1-103117-1440	103117	1440	**6.39**	2.4	124	9.46	1.18	0	0.31	NM
	071618-1600	71618	1600	6.58	2.17	77	12.29	NA	3.5	0.89	NM
1	1-11117-0948	110117	948	**9.09**	3.3	-31	10.5	2.12	1.5	0.13	NM
44	1-11117-1206	110117	1206	**5.34**	1.98	96	10.38	1.7	2.6	>3	NM
	071818-1550	71818	1550	**4.72**	1.53	202	13.78	1.84	2.3	>3	NM
10	1-11117-1440	110117	1440	**8.58**	1.41	-55	12.41	2.14	1.6	0	NM
40	1-11217-0900	110217	900	**8.65**	5.35	124	12.41	2.35	0	0	NM
38	1-11217-1030	110217	1030	**9.43**	1.8	-30	13.43	0.858	0	0	NM
39	1-11217-1245	110217	1245	**9.69**	0.35	-30	12.58	0.771	0	0.39	NM
54	1-11217-1445	110217	1445	**6.25**	1.43	170	9.09	1.18	0	0.05	NM
	071818-0900	71818	900	**5.85**	1.24	231	11.08	NM	0	0.07	NM
16	1-11317-0855	110317	855	6.74	2.04	32	10.21	1.95	13	>3	NM
19	1-11617-1150	110617	1150	7.98	2.16	15	9.19	1.45	2.9	0.1	NM

8	1-11617-1325	110617	1325	**9.58**	2.23	39	11.68	1.05	0	0.12	NM
18	1-11617-1450	110617	1450	**5.93**	5.8	179	9.24	0.827	24.7	0.54	NM
	071618-0920	71618	920	**5.4**	12.15	182	14.25	1.04	NM	0.87	NM
60	1-11717-0900	110717	900	8.35	4.33	-142	13.2	2.09	17	1.06	NM
63	1-11717-0950	110717	950	**8.82**	5.73	19	6.23	2.77	0	0.09	NM
62	1-11717-1130	110717	1130	**5.03**	31.9	2.96	3.61	4.15	31.9	>3	NM
	071818-1300	71818	1300	**4.04**	3.02	381	24.19	2.37	NM	>3	NM
9	Data from Owner	51007	1930	8.17*	NA	NA	NA	NA	NA	NA	NM
	1-11717-1330	110717	1330	8.34	1.2	-35	12.43	1.66	0	0.09	NM
12.2	1-11717-1457	110717	1457	8.13	2.67	58	9.81	0.24	0	0	NM
15	1-11817-0900	110817	900	**8.99**	1.78	116	13.33	1.6	3.4	0	NM
6	1-11817-1029	110817	1029	**9.2**	0.89	20	13.32	1.19	0	0	NM
4	1-11817-1125	110817	1125	**9.19**	NM	NM	NM	NM	NM	0	NM
3	1-11817-1302	110817	1302	8.49	1.87	107	12.43	1.76	0	0	NM
5	1-11817-1425	110817	1425	7.6	2.87	128	9.5	0.944	1.3	0	NM
31	1-11917-0906	110917	906	7.44	2.99	44	8.62	1.44	6.3	0.41	NM
46	1-111517-0945	111517	937	7.01	1.05	225	9.45	1.38	7.6	0.03	NM
	071618-1455	71618	1455	6.86	2.96	110	12.94	NA	-30.5	NS	NM
7	1-111517-1230	111517	1213	**9.29**	2.62	134	12.75	1.71	10.9	0.19	NM
22	1-111517-1515	111517	1500	8.24	7.23	-36	12.1	2.14	13.9	0.06	NM
59	1-111617-0915	111617	915	**4.91**	1.65	267	10.58	1	18.5	0.92	NM
	071718-0920	71718	920	**4.64**	6.58	264	11.62	1.1	6	1.21	NM
32	1-111617-1115	111617	1115	**4.5**	1.49	212	10.55	0.964	6.9	>3	NM
	071618-1110	71618	1110	**4.23**	1.49	285	12.9	1.55	0	>3	NM
2	1-111617-1310	111617	1310	6.94	3.04	81	10.86	1.17	5.7	0.04	NM
13	1-111617-1435	111617	1435	NM	NM	NM	NM	NM	NM	NS	NM
17	1-111617-1554	111617	1554	7.45	5.58	111	9.27	1.81	7.5	0.13	NM
33	1-113017-1445	113017	1445	NM	NM	NM	NM	NM	NM	NS	NM
	071618-1340	71618	1340	**5.66**	2.99	117	12.73	0.67	9.1	>3	NM
82	Data from Owner	012616	--	6.8*	NA	NA	NA	NA	NA	NA	900*
	071718-1225	71718	1225	**4.79**	3.35	230	11.85	124	1.5	NS	NM
83	071818-1710	71818	1710	6.75	NM	NM	NM	NM	NM	NS	NM
45	Data from Owner	81000	NR	7.4*	NA	NA	NA	NA	NA	NA	NA
	Data from Owner	42309	NR	7.5*	NA	NA	NA	NA	NA	NA	NA
	Data from Owner	90116	NR	6.63*	NA	NA	NA	NA	NA	NA	NA
	NT-071918-1015	71918	1015	6.89	NM	NM	NM	NM	NM	NS	NM
79	NT-071918-0920	71918	920	7.23	NM	NM	NM	NM	NM	NS	NM
	072018-0930	72018	930	7.15	1.44	87	11.88	NA	0	NS	NM
80	072018-0805	72018	805	6.67	1.49	118	9.79	NA	0	0.25	NM
74	SW-1-071918	71918	1240	7.47	NM	NM	NM	NM	NM	NS	NM
84	Not Sampled	71918	--	7.02	NM	NM	NM	NM	NM	NS	NM
81	SW-2	72018	735	6.91	8.68	115	13.85	NA	0	NS	1.54
77	Spring-1	72018	945	**3.12**	NM	NM	NM	NM	NM	NS	NM

Notes:

N/A = Not Applicable

NA = Not Analyzed

NM = Not measured or not recorded

NS = Not Sampled

* = Data provided by well owner

Font Colors and Bolding = exceeds corresponding standards

(**RED** - lower than 6.5 s.u. (pH) or >500 mg/L for TDS) (**BLUE** - Higher than 8.5 s.u. for pH)

TABLE 7 - MAJOR CATIONS, MAJOR ANIONS, TOTAL DISSOLVED SOLIDS
2017 and 2018 SAMPLING EVENTS

Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					500	N/A	N/A	N/A	N/A	250	N/A	N/A	N/A	10	250	4	N/A
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					5000	N/A	N/A	N/A	N/A	3000	N/A	N/A	N/A	10	2000	N/A	N/A
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10	N/A	N/A	N/A
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					500	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	250	4	N/A
EPA Health Advisory (EPA HA)					N/A	30-60 mg/L Taste Threshold	N/A	N/A	N/A	250 mg/L Taste Threshold 500 mg/L Health-based Value	N/A	N/A	N/A	N/A	N/A	N/A	N/A
						CATIONS				ANIONS							
MAP ID	SAMPLE ID	SAMPLE DATE (mm/dd/yy)	SAMPLE TIME (Military Time)	PERMITTED USE	TDS (mg/L)	Sodium Total (mg/L)	Calcium Total (mg/L)	Magnesium Total (mg/L)	Potassium Total (mg/L)	Sulfate (mg/L)	Alkalinity (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Nitrate-Nitrite as Nitrogen (mg/L)	Chloride (mg/L)	Flouride (mg/L)	Bromide Dissolved (mg/L)
47.1	1-102517-0926	102517	926	DOM	989 (J)	89	58	21	8	660	<10	<10	<10	N/A	13	0.2	<0.1
	071918-1100	71918	1100		943 (D)	93	74	21	8	638	<10	<10	<10	N/A	13	0.3	NA
25	2-102517-1055	102517	1055	STK	4120 (J)	414	459	293	78	2640	440 (J)	440 (J)	<10 (J)	0.98	49	0.8	<0.1
45.1	1-102517-1056	102517	1056	DOM STK	1770 (J)	310 (J)	67	29	12	1170	<10	<10	<10	N/A	13 (J)	0.2	<0.1
	071918-0930	71918	930		1790 (D)	302	117	29	14	1170	<10	<10	<10	N/A	26	0.5	NA
48	1-102517-1300	102517	1300	DOM	1080 (J)	306 (J)	46 (J)	18	6	523	280	280	<10	N/A	26	0.3	<0.1
34	2-102517-1352	102517	1352	STK	2200 (J)	489 (J)	60	27	16	1260	<10	<10	<10	N/A	27	0.2	<0.1
	071918-1335	71918	1335		2220 (D)	491	57	25	16	1450	<10	<10	<10	N/A	26	0.3	NA
50	1-102517-1500	102517	1500	DOM	929 (J)	281 (J)	38	14	6	450	272	272	<10	N/A	14	0.3	<0.1
28.1	2-102517-1512	102517	1512	STK	1260 (J)	45	56	24	8	903	<10	<10	<10	N/A	12	0.2	<0.1
	071818-1100	71818	1100		1310 (D)	48	55	24	7	913	<10	<10	<10	N/A	11	0.2	NA
49	1-102517-1555	102517	1555	DOM	943 (J)	263 (J)	53	19	6	418	309	309	<10	N/A	19	0.4	<0.1
26	2-102517-1627	102517	1627	DOM	2860 (J)	244 (J)	350 (J)	220 (J)	20	1720	295	295	<10	4.58	43	0.5	<0.1
61	1-102617-0855	102617	855	DOM STK	2380 (J)	517 (J)	151 (J)	69	15	1340	344	344	<10	N/A	35	0.3	<0.1
21	2-102617-1032	102617	1032	STK	428 (J)	41	65	9	5	228	74	74	<10	N/A	6	0.4	<0.1
41	1-102617-1105	102617	1105	DOM	2320 (J)	705 (J)	27	11	8	1480	85	85	<10	N/A	28	0.3	<0.1
24	2-102617-1145	102617	1145	DOM STK	695 (J)	70	66	32	7	380	80	80	<10	N/A	9	0.5	<0.1
37	1-102617-1225	102617	1225	DOM	1770 (J)	633 (J)	9	3	5	834	438 (J)	438 (J)	<10 (J)	0.086	37	1.2	0.1
14	2-102617-1329	102617	1329	DOM STK	1020 (J)	149 (J)	120 (J)	33	9	563	161	161	<10	N/A	13	0.9	<0.1
36	1-102617-1345	102617	1345	DOM	1690 (J)	662 (J)	13	4	8	650	693 (J)	693 (J)	<10 (J)	<0.05	37	1.9	0.1
11	2-102617-1535	102617	1535	DOM	1150 (J)	346 (J)	19	2	4	560	227	170	57	<0.05	14	0.7	<0.1
58	2-102717-0920	102717	920	DOM	1230 (J)	50	217 (J)	52	8	653	196	196	<10	1.24	29	0.5	<0.1
35	1-102717-0930	102717	930	DOM	906 (J)	344 (J)	2	<1	2	332	359 (J)	241 (J)	117 (J)	<0.05	16	1.3	<0.1
57	2-102717-1048	102717	1048	DOM STK	1470 (J)	94	236 (J)	75	9	779	242	242	<10	0.27	34 (J)	0.5	<0.1
43	1-102717-1120	102717	1120	DOM STK	758 (J)	50 (J)	217 (J)	52	8	653	196 (J)	196 (J)	<10 (J)	1.24	29	0.5	<0.1
56	1-103117-1015	103117	1015	DOM	1640 (J)	108 (J)	282 (J)	69	6	849	248	248	<10	1.96	39	0.5	<0.1
55	1-103117-1150	103117	1150	DOM STK	1580 (J)	102 (J)	255 (J)	76	8	814	244	244	<10	0.076	45	0.6	<0.1
52	1-103117-1440	103117	1440	DOM	1320 (J)	92 (J)	228 (J)	45 (J)	6	756	152	152	<10	0.73	25	0.5	<0.1
	071618-1600	71618	1600		1370 (D)	92	237	47	5	758	167	167	<10	0.27	27	0.5	NA
1	1-11117-0948	110117	948	STK	1500 (J)	510 (J)	10	4	5	832	181	181	<10	<0.05	26	0.8	0.1
44	1-11117-1206	110117	1206	STK	1300 (J)	356 (J)	25	12	7	1100	<10	<10	<10	N/A	12	0.6	<0.1
	071818-1550	71818	1550		1290 (D)	362	26	12	7	865	<10	<10	<10	M/A	13	0.8	NA
10	1-11117-1440	110117	1440	DOM	1630 (J)	524 (J)	19	8	4	943	189	189	<10	<0.05	27	0.6	<0.1
40	1-11217-0900	110217	900	DOM	1690 (J)	580 (J)	6	2	4	918	330	330	<10	0.41	11	2.3	<0.1
38	1-11217-1030	110217	1030	DOM	714 (J)	293 (J)	2	<1	2	48	561 (J)	454 (J)	107 (J)	<0.05	19	4.2	0.2
39	1-11217-1245	110217	1245	DOM	668 (J)	72 (J)	227	59	6	781	78 (J)	78 (J)	<10 (J)	<0.05	33	0.2	0.1
54	1-11217-1445	110217	1445	DOM	1250 (J)	72	227 (J)	59	6	781	78	78	<10	<0.05	33	0.2	<0.1

TABLE 7 - MAJOR CATIONS, MAJOR ANIONS, TOTAL DISSOLVED SOLIDS
2017 and 2018 SAMPLING EVENTS

Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					500	N/A	N/A	N/A	N/A	250	N/A	N/A	N/A	10	250	4	N/A
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					5000	N/A	N/A	N/A	N/A	3000	N/A	N/A	N/A	10	2000	N/A	N/A
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10	N/A	N/A	N/A
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					500	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	250	4	N/A
EPA Health Advisory (EPA HA)					N/A	30-60 mg/L Taste Threshold	N/A	N/A	N/A	250 mg/L Taste Threshold 500 mg/L Health-based Value	N/A	N/A	N/A	N/A	N/A	N/A	N/A
						CATIONS				ANIONS							
MAP ID	SAMPLE ID	SAMPLE DATE (mm/dd/yy)	SAMPLE TIME (Military Time)	PERMITTED USE	TDS (mg/L)	Sodium Total (mg/L)	Calcium Total (mg/L)	Magnesium Total (mg/L)	Potassium Total (mg/L)	Sulfate (mg/L)	Alkalinity (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Nitrate-Nitrite as Nitrogen (mg/L)	Chloride (mg/L)	Flouride (mg/L)	Bromide Dissolved (mg/L)
54	071818-0900	71818	900	DOM	1300 (D)	81	199	57	5	779	76	76	<10	<0.05	34	0.3	NA
16	1-11317-0855	110317	855	STK	1740 (J)	250 (J)	181 (J)	61	13	927	174	174	<10	N/A	12 (J)	0.2	<0.1
19	1-11617-1150	110617	1150	DOM	1210 (J)	359	6	3	1	625	192	106	86	<0.05	26	0.5	<0.1
8	1-11617-1325	110617	1325	DOM	903 (J)	285	4	2	1	436	220	158	62	<0.05	12	0.8	<0.1
18	1-11617-1450	110617	1450	DOM STK	774 (J)	88	77	26	9	496	<10	<10	<10	N/A	11	0.4	<0.1
	071618-0920	71618	920		792 (D)	96	80	27	13	522	<10	<10	<10	N/A	12	0.2	NA
60	1-11717-0900	110717	900	STK	1660 (J)	409	59	33	4	960	182	182	<10	N/A	35	1.1	0.1
63	1-11717-0950	110717	950	DOM STK	2180 (J)	684	15	6	3	1230	239	197	41	0.66	29	1.9	0.1
62	1-11717-1130	110717	1130	STK (SPRING)	3120 (J)	131	348	164	7	1690	<10	<10	<10	N/A	26	1.8	<0.1
	071818-1300	71818	1300		2260 (D)	99	295	122	9	1470	<10	<10	<10	N/A	26	1.4	NA
9	1-11717-1330	110717	1330	DOM	1350 (J)	433	31	8	3	779	206	206	<10	<0.05	25	0.7	<0.1
12.2	1-11717-1457	110717	1457	DOM	1170 (J)	332	45	12	5	426	469 (J)	469 (J)	<10 (J)	<0.05 (UJ)	27	0.5	<0.1
15	1-11817-0900	110817	900	DOM	1290 (J)	413	10	4	2	656	226	182	43	<0.05	26	1.5	<0.1
6	1-11817-1029	110817	1029	DOM	1120 (J)	335	7	3	2	581	196	196	<10	<0.05	27	0.8	0.1
4	1-11817-1125	110817	1125	DOM	1140 (J)	322	6	3	2	583	188	188	<10	0.36	27	0.6	<0.1
3	1-11817-1302	110817	1302	DOM	1450 (J)	361	37	16	2	775	212	212	<10	<0.05	39	0.7	0.1
5	1-11817-1425	110817	1425	DOM	979 (J)	101	127	38	5	400	357	357	<10	0.1	16	0.6	<0.1
31	1-11917-0906	110917	906	STK	1520 (J)	41	322	23	3	806	196	196	<10	0.05	32	0.5	<0.1
46	1-111517-0945	111517	937	DOM STK	1310 (J)	92	215	60	5	691	227	227	<10	<0.05	33	0.6	<0.1
	071618-1455	71618	1455		1360 (D)	85	232	59	6	705	233	233	<10	0.11	43	0.5	NA
7	1-111517-1230	111517	1213	DOM	1140 (J)	360	7	3	2	613	191	159	32	<0.05	14	0.6	0.1
22	1-111517-1515	111517	1500	DOM	1440 (J)	426	60	10	3	740	267	267	<10	<0.05	30	1.6	<0.1
59	1-111617-0915	111617	915	DOM STK	932 (J)	109	103	29	3	603	<10	<10	<10	N/A	14	0.5	<0.1
	071718-0920	71718	920		898 (D)	106	74	26	5	591	<10	<10	<10	N/A	15	0.6	NA
32	1-111617-1115	111617	1115	DOM	927 (J)	83	88	22	3	587	<10	<10	<10	N/A	12	0.9	<0.1
	071618-1110	71618	1110		897 (D)	85	88	22	4	597	<10	<10	<10	N/A	14	0.7	NA
2	1-111617-1310	111617	1310	DOM STK	1090 (J)	48	151	44	4	406	329	329	<10	2.18	48	0.7	<0.1
13	1-111617-1435	111617	1435	STK	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
17	1-111617-1554	111617	1554	DOM	1580 (J)	161	210	72	7	764	238	238	<10	<0.05	58	0.6	<0.1
33	1-113017-1445	113017	1445	DOM	643 (J)	90	59	18	4	405	14	14	<10	N/A	4 (J)	2.2	<0.1
	071618-1340	71618	1340		466 (D)	97	28	8	4	304	17	17	<10	N/A	7	1.4	NA
82	071718-1225	71718	1225	DOM	1050 (D)	84	131	33	8	686	<10	<10	<10	0.12	12	0.7	NA
83	071818-1710	71818	1710	DOM	1330 (D)	191	178	40	<1	612	402	402	<10	N/A	13	0.7	NA

TABLE 7 - MAJOR CATIONS, MAJOR ANIONS, TOTAL DISSOLVED SOLIDS
2017 and 2018 SAMPLING EVENTS

Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					500	N/A	N/A	N/A	N/A	250	N/A	N/A	N/A	10	250	4	N/A
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					5000	N/A	N/A	N/A	N/A	3000	N/A	N/A	N/A	10	2000	N/A	N/A
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	10	N/A	N/A	N/A
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					500	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	250	4	N/A
EPA Health Advisory (EPA HA)					N/A	30-60 mg/L Taste Threshold	N/A	N/A	N/A	250 mg/L Taste Threshold 500 mg/L Health-based Value	N/A	N/A	N/A	N/A	N/A	N/A	N/A
						CATIONS				ANIONS							
MAP ID	SAMPLE ID	SAMPLE DATE (mm/dd/yy)	SAMPLE TIME (Military Time)	PERMITTED USE	TDS (mg/L)	Sodium Total (mg/L)	Calcium Total (mg/L)	Magnesium Total (mg/L)	Potassium Total (mg/L)	Sulfate (mg/L)	Alkalinity (mg/L)	Bicarbonate (mg/L)	Carbonate (mg/L)	Nitrate-Nitrite as Nitrogen (mg/L)	Chloride (mg/L)	Flouride (mg/L)	Bromide Dissolved (mg/L)
45	NT-071918-1015	71918	1015	DOM STK	**1340 (D)**	**223**	162	43	11	**592**	373	373	<10	N/A	31	0.4	NA
79	NT-071918-0920	71918	920	DOM STK	**1130 (D)**	**313**	61	17	8	**531**	321	321	<10	N/A	16	0.3	NA
	072018-0930	72018	930	DOM STK	**1130 (D)**	**350**	36	13	8	**541**	295	295	<10	N/A	15	0.3	NA
80	072018-0805	72018	805	DOM	**1670 (D)**	**105**	278	79	8	**907**	274	274	<10	0.074	38	0.6	NA
74	SW-1-071918	71918	1240	N/A	967 (D)	214	58	24	20	415	261	261	<10	N/A	26	1	NA
84	Not Sampled	71918	--	N/A	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
81	SW-2	72018	735	N/A	2010 (D)	127	332	96	10	1020	335	335	<10	N/A	56	0.6	NA
77	Spring-1	72018	945	N/A	6600 (D)	473	457	498	37	4550	<10	<10	<10	N/A	55	0.8	NA

Notes:

J = The result is an estimated quantity. The associated numerical value is the approximate concentration of the analyte in the sample.

D = Results were obtained from a diltued sample

< # = The analyte was analyzed for, but was not detected above the level of the reported sample quantitation limit.

N/A = Not Applicable

NM - Not measured or not recorded

NA = Not Analyzed

Font Colors and Bolding = exceeds corresponding standards

TABLE 8 - GENERAL CHEMISTRY PARAMETERS AND BACTERIA
2017 and 2018 SAMPLING EVENTS

Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					6.5-8.5	0.2	N/A	0.5	N/A	N/A	N/A	N/A	N/A
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					6.5-8.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	0.2	N/A	N/A	N/A	N/A	Absent	N/A	Absent
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					6.5-8.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EPA Health Advisory (EPA HA)					N/A	N/A	N/A	30 mg/L Taste Threshold	N/A	N/A	N/A	N/A	N/A
MAP ID	**SAMPLE ID**	**SAMPLE DATE (mm/dd/yy)**	**SAMPLE TIME (Military Time)**	**PERMITTED USE**	**pH, lab (SU)**	**Cyanide Total (mg/L)**	**Sulfide (mg/L)**	**Ammonia as Nitrogen (mg/L)**	**Deuterium (2H)**	**Oxygen-18 (18O)**	**E-Coli (per 100ml)**	**Iron Related Bacteria (CFU/ml)**	**Total Coliform (per 100ml)**
47.1	1-102517-0926	102517	926	DOM	4.15 (J)	<0.005	<0.04	0.5	-138.35	-18.33	Absent	< 1.0 (J)	Absent
	071918-1100	71918	1100		4.44 (H)	NA	<0.04	0.46	NA	NA	NA	NA	NA
25	2-102517-1055	102517	1055	STK	7.23 (J)	<0.005	<0.04	<0.05	-106.81	-12.72	Absent	9000	Present
45.1	1-102517-1056	102517	1056	DOM STK	4.15 (J)	<0.005	<0.04	0.8	-139.16	-18.19	Absent	< 1.0	Absent
	071918-0930	71918	930		4.47 (H)	NA	<0.04	0.74	NA	NA	NA	NA	NA
48	1-102517-1300	102517	1300	DOM	7.13 (J)	<0.005	<0.04	0.5	-131.83	-16.84	Absent	< 1.0	Absent
34	2-102517-1352	102517	1352	STK	3.92 (J)	<0.005	<0.04	1.1	-139.9	-18.42	Absent	< 1.0	Absent
	071918-1335	71918	1335		3.96 (H)	NA	<0.04	1.19	NA	NA	NA	NA	NA
50	1-102517-1500	102517	1500	DOM	7.23 (J)	<0.005	<0.04	0.6	-133.11	-17.15	Absent	2200	Absent
28.1	2-102517-1512	102517	1512	STK	3.75 (J)	<0.005	<0.04	0.2	-140.66	-18.57	Absent	< 1.0	Absent
	071818-1100	71818	1100		3.71 (H)	NA	<0.04	0.22	NA	NA	NA	NA	NA
49	1-102517-1555	102517	1555	DOM	7.2 (J)	<0.005	<0.04	0.4	-135.81	-17.71	Absent	500	Absent
26	2-102517-1627	102517	1627	DOM	7.08 (J)	<0.005	<0.04	<0.05	-100.44	-11.59	Absent	500	Absent
61	1-102617-0855	102617	855	DOM STK	6.95 (J)	<0.005	<0.04	0.7	-144.23	-18.73	Absent	9000 (J)	Absent
21	2-102617-1032	102617	1032	STK	6.35 (J)	<0.005	<0.04	0.2	-140.69	-18.4	Absent	2200 (J)	Absent
41	1-102617-1105	102617	1105	DOM	6.54 (J)	<0.005	<0.04	1	-146.33	-19.29	Absent	< 1.0 (J)	Absent
24	2-102617-1145	102617	1145	DOM STK	6.47 (J)	<0.005	<0.04	<0.05	-139.29	-18.12	Absent	2200 (J)	Present
37	1-102617-1225	102617	1225	DOM	8.33 (J)	<0.005	<0.04	0.4	-147.23	-19.34	Absent	35000 (J)	Absent
14	2-102617-1329	102617	1329	DOM STK	6.89 (J)	<0.005	0.25	0.06	-136.17	-17.72	Absent	9000 (J)	Absent
36	1-102617-1345	102617	1345	DOM	8.06 (J)	<0.005	<0.04	0.5	-147.08	-18.96	Absent	35000 (J)	Present
11	2-102617-1535	102617	1535	DOM	8.68 (J)	<0.005	<0.04	0.3	-154.31	-19.99	Absent	< 1.0 (J)	Absent
58	2-102717-0920	102717	920	DOM	6.79 (J)	<0.005	<0.04	<0.05	-128.53	-16.5	Absent	9000	Present
35	1-102717-0930	102717	930	DOM	8.85 (J)	<0.005	<0.04	0.2	-144.18	-18.71	Absent	< 1.0	Absent
57	2-102717-1048	102717	1048	DOM STK	7.08 (J)	<0.005	<0.04	<0.05	-122.54	-15.58	Absent	< 1.0	Absent

TABLE 8 - GENERAL CHEMISTRY PARAMETERS AND BACTERIA
2017 and 2018 SAMPLING EVENTS

Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					6.5-8.5	0.2	N/A	0.5	N/A	N/A	N/A	N/A	N/A
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					6.5-8.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	0.2	N/A	N/A	N/A	N/A	Absent	N/A	Absent
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					6.5-8.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EPA Health Advisory (EPA HA)					N/A	N/A	N/A	30 mg/L Taste Threshold	N/A	N/A	N/A	N/A	N/A
MAP ID	**SAMPLE ID**	**SAMPLE DATE (mm/dd/yy)**	**SAMPLE TIME (Military Time)**	**PERMITTED USE**	**pH, lab (SU)**	**Cyanide Total (mg/L)**	**Sulfide (mg/L)**	**Ammonia as Nitrogen (mg/L)**	**Deuterium (2H)**	**Oxygen-18 (18O)**	**E-Coli (per 100ml)**	**Iron Related Bacteria (CFU/ml)**	**Total Coliform (per 100ml)**
43	1-102717-1120	102717	1120	DOM STK	8.99 (J)	<0.005	0.41	<0.05	-144.15	-18.83	Absent	9000	Absent
56	1-103117-1015	103117	1015	DOM	6.9 (J)	<0.005	<0.04	<0.05	-128.91	-16.43	Absent	2200	Absent
55	1-103117-1150	103117	1150	DOM STK	6.99 (J)	<0.005	<0.04	<0.05	-123.95	-16.23	Absent	9000	Absent
52	1-103117-1440	103117	1440	DOM	6.47 (J)	<0.005	<0.04	<0.05	-134.78	-17.56	Absent	25	Absent
	071618-1600	71618	1600		6.47 (H)	NA	<0.04	0.076	NA	NA	NA	NA	NA
1	1-11117-0948	110117	948	STK	8.6 (J)	<0.005	<0.04	0.4	-151.83	-20.44	Absent	9000	Present
44	1-11117-1206	110117	1206	STK	5.08 (J)	<0.005	<0.04	0.7	-137.54	-18.4	Absent	150	Absent
	071818-1550	71818	1550		5.09 (H)	NA	<0.04	0.63	NA	NA	NA	NA	NA
10	1-11117-1440	110117	1440	DOM	8.48 (J)	<0.005	<0.04	0.5	-152.57	-20.41	Absent	35000	Absent
40	1-11217-0900	110217	900	DOM	6.72 (J)	<0.005	<0.04	0.09	-144.53	-19.03	Absent	9000 (J)	Present (J)
38	1-11217-1030	110217	1030	DOM	8.69 (J)	<0.005	0.73	0.2	-149.9	-19.42	Absent	9000	Present
39	1-11217-1245	110217	1245	DOM	8.53 (J)	<0.005	0.22	<0.05	-145.25	-19.11	Absent	9000	Absent
54	1-11217-1445	110217	1445	DOM	5.96 (J)	<0.005	<0.04	<0.05	-128.24	-16.38	Absent	2200	Absent
	071818-0900	71818	900		5.91 (H)	NA	<0.04	<0.05	NA	NA	NA	NA	NA
16	1-11317-0855	110317	855	STK	6.57 (J)	<0.005	<0.04	0.4	-132.7	-16.92	Absent	2200 (J)	Absent
19	1-11617-1150	110617	1150	DOM	8.85 (J)	<0.005	1.07	0.3	NA	NA	Absent	< 1.0	Absent
8	1-11617-1325	110617	1325	DOM	8.76 (J)	<0.005	<0.04	0.3	-144.34	-18.55	Absent	9000	Absent
18	1-11617-1450	110617	1450	DOM STK	5.22 (J)	<0.005	<0.04	0.08	NA	NA	Absent	< 1.0	Absent
	071618-0920	71618	920		5.21 (H)	NA	<0.04	0.11	NA	NA	NA	NA	NA
60	1-11717-0900	110717	900	STK	8.05 (J)	<0.005	<0.04	0.5	-145.74	-18.75	Absent	35000	Present
63	1-11717-0950	110717	950	DOM STK	8.49 (J)	<0.005	<0.04	<0.05	-145.92	-19.89	Absent	9000	Present
62	1-11717-1130	110717	1130	STK (SPRING)	4.41 (J)	<0.005	<0.04	5.2	-132.01	17.15	Absent	< 1.0	Present
	071818-1300	71818	1300		3.97 (H)	NA	<0.04	2.46	NA	NA	NA	NA	NA
9	1-11717-1330	110717	1330	DOM	8.07 (J)	<0.005	<0.04	0.3	-146.41	-19.74	Absent	< 1.0	Present

TABLE 8 - GENERAL CHEMISTRY PARAMETERS AND BACTERIA
2017 and 2018 SAMPLING EVENTS

Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					6.5-8.5	0.2	N/A	0.5	N/A	N/A	N/A	N/A	N/A
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					6.5-8.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	0.2	N/A	N/A	N/A	N/A	Absent	N/A	Absent
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					6.5-8.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EPA Health Advisory (EPA HA)					N/A	N/A	N/A	30 mg/L Taste Threshold	N/A	N/A	N/A	N/A	N/A
MAP ID	**SAMPLE ID**	**SAMPLE DATE (mm/dd/yy)**	**SAMPLE TIME (Military Time)**	**PERMITTED USE**	**pH, lab (SU)**	**Cyanide Total (mg/L)**	**Sulfide (mg/L)**	**Ammonia as Nitrogen (mg/L)**	**Deuterium (2H)**	**Oxygen-18 (18O)**	**E-Coli (per 100ml)**	**Iron Related Bacteria (CFU/ml)**	**Total Coliform (per 100ml)**
12.2	1-11717-1457	110717	1457	DOM	7.54 (J)	<0.005	<0.04	0.08 (J)	-145.17	-18.65	Absent	9000	**Present**
15	1-11817-0900	110817	900	DOM	**8.56 (J)**	<0.005	<0.04	0.3	-153.02	-19.71	Absent	35000	Absent
6	1-11817-1029	110817	1029	DOM	**8.56 (J)**	<0.005	<0.04	0.3	-152.77	-19.79	Absent	9000	Absent
4	1-11817-1125	110817	1125	DOM	8.37 (J)	<0.005	<0.04	<0.05	-153.53	-20.12	Absent	9000	Absent
3	1-11817-1302	110817	1302	DOM	7.96 (J)	<0.005	<0.04	0.3	-148.33	-19.18	Absent	< 1.0	Absent
5	1-11817-1425	110817	1425	DOM	7.16 (J)	<0.005	<0.04	0.08	-141.9	-17.72	Absent	150	Absent
31	1-11917-0906	110917	906	STK	7.07 (J)	<0.005	<0.04	0.2	-133.68	-16.88	Absent	9000	Absent
46	1-111517-0945	111517	937	DOM STK	6.72 (J)	<0.005	<0.04	<0.05	-132	-17.2	Absent	9000	Absent
	071618-1455	71618	1455		6.81 (H)	NA	<0.04	<0.05	NA	NA	NA	NA	NA
7	1-111517-1230	111517	1213	DOM	**8.57 (J)**	<0.005	<0.04	0.32	-153.09	-20.52	Absent	9000	Absent
22	1-111517-1515	111517	1500	DOM	7.73 (J)	<0.005	<0.04	**0.52**	-147.43	-19.52	Absent	2200	Absent
59	1-111617-0915	111617	915	DOM STK	**4.63 (J)**	<0.005	<0.04	0.095	-134.99	-17.15	Absent	< 1.0	Absent
	071718-0920	71718	920		**4.47 (H)**	NA	<0.04	0.082	NA	NA	NA	NA	NA
32	1-111617-1115	111617	1115	DOM	**4.45 (J)**	<0.005	<0.04	0.23	-141.92	-18.04	Absent	< 1.0	Absent
	071618-1110	71618	1110		**4.36 (H)**	NA	<0.04	0.24	NA	NA	NA	NA	NA
2	1-111617-1310	111617	1310	DOM STK	6.68 (J)	<0.005	<0.04	<0.05	-126.39	-16.27	Absent	2200	Absent
13	1-111617-1435	111617	1435	STK	NA	NA	NA	NA	NA	NA	NA	9000	NA
17	1-111617-1554	111617	1554	DOM	6.89 (J)	<0.005	<0.04	<0.05	-123.05	-15.53	Absent	500	**Present**
33	1-113017-1445	113017	1445	DOM	**5.52 (J)**	<0.005	<0.04	0.23	NA	NA	Absent	500	Absent
	071618-1340	71618	1340		**5.56 (H)**	NA	<0.04	0.18	NA	NA	NA	NA	NA
	071718-1225			DOM	**6.8**								
82		71718	1225		**4.58 (H)**	<0.005	<0.04	<0.05	-139.67	-18.26	Absent	<1.0	Absent
83	071818-1710	71818	1710	DOM	7.06 (H)	<0.005	0.19	0.12	-142.95	-18.49	Absent	35000	**Present**
45	NT-071918-1015	71918	1015	DOM STK	7.05 (H)	NA	<0.04	NA	NA	NA	NA	35000	NA
79	NT-071918-0920	71918	920	DOM STK	7.47 (H)	NA	<0.04	NA	NA	NA	NA	9000	NA

TABLE 8 - GENERAL CHEMISTRY PARAMETERS AND BACTERIA
2017 and 2018 SAMPLING EVENTS

Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					**6.5-8.5**	**0.2**	**N/A**	**0.5**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					**6.5-8.5**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					**N/A**	**0.2**	**N/A**	**N/A**	**N/A**	**N/A**	**Absent**	**N/A**	**Absent**
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					**6.5-8.5**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
EPA Health Advisory (EPA HA)					**N/A**	**N/A**	**N/A**	**30 mg/L Taste Threshold**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
MAP ID	**SAMPLE ID**	**SAMPLE DATE (mm/dd/yy)**	**SAMPLE TIME (Military Time)**	**PERMITTED USE**	**pH, lab (SU)**	**Cyanide Total (mg/L)**	**Sulfide (mg/L)**	**Ammonia as Nitrogen (mg/L)**	**Deuterium (2H)**	**Oxygen-18 (18O)**	**E-Coli (per 100ml)**	**Iron Related Bacteria (CFU/ml)**	**Total Coliform (per 100ml)**
79	072018-0930	72018	930	DOM STK	7.54 (H)	<0.005	<0.04	**0.59**	-138.9	-17.78	Absent	9000	**Present**
80	072018-0805	72018	805	DOM	6.96 (H)	<0.005	<0.04	<0.05	-122.96	-15.51	Absent	35000	**Present**
74	SW-1-071918	71918	1240	N/A	7.55 (H)	NA	<0.04	NA	-110.01	-13.77	NA	9000	NA
84	Not Sampled	71918	--	N/A	NS	NS	NS	NS	NS	NS	NS	NS	NS
81	SW-2	72018	735	N/A	7.56 (H)	NA	<0.04	NA	-121.9	-15.24	NA	9000	NA
77	Spring-1	72018	945	N/A	**3.38 (H)**	NA	<0.04	NA	-92.19	-10.62	NA	<1.0	NA

Notes:

J = The result is an estimated quantity. The associated numerical value is the approximate concentration of the analyte in the sample.

H = The result was analyzed outside of analytical hold time, the result is an estimated concentration.

< # = The analyte was analyzed for, but was not detected above the level of the reported sample quantitation limit.

N/A = Not Applicable

NA = Not Analyzed

Font Colors and Bolding = exceeds corresponding standards

TABLE 9 - TRACE METALS
2017 and 2018 SAMPLING EVENTS

MAP ID	SAMPLE ID	SAMPLE DATE (mm/dd/yy)	SAMPLE TIME (Military Time)	PERMITTED USE	Aluminum Dissolved (mg/L)	Aluminum Total (mg/L)	Arsenic Dissolved (mg/L)	Arsenic Total (mg/L)	Barium Dissolved (mg/L)	Barium Total (mg/L)	Beryllium Dissolved (mg/L)	Beryllium Total (mg/L)	Boron Dissolved (mg/L)	Boron Total (mg/L)	Cadmium Dissolved (mg/L)	Cadmium Total (mg/L)	Chromium Dissolved (mg/L)	Chromium Total (mg/L)	Cobalt Dissolved (mg/L)	Cobalt Total (mg/L)	Copper Dissolved (mg/L)	Copper Total (mg/L)	Iron Dissolved (mg/L)	Iron Total (mg/L)	Lead Dissolved (mg/L)	Lead Total (mg/L)
Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					N/A	N/A	0.05	0.05	2	2	N/A	N/A	0.75	0.75	0.005	0.005	0.1	0.1	N/A	N/A	1	1	0.3	0.3	0.015	0.015
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					5	5	0.2	0.2	N/A	N/A	N/A	N/A	5	5	0.05	0.05	0.05	0.05	1	1	0.5	0.5	N/A	N/A	0.1	0.1
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	N/A	0.10	0.10	2	2	0.004	0.004	N/A	N/A	0.005	0.005	0.1	0.1	N/A	N/A	1.3	1.3	N/A	N/A	N/A	N/A
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					0.05 - 0.2	0.05 - 0.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3	0.3	0.015	0.015
EPA Health Advisory (EPA HA)					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
47.1	1-102517-0926	102517	926	DOM	39.7 (J)	40.8 (J)	<0.001	<0.001	<0.01	<0.01	0.006	<0.001	0.104	<0.01	<0.0001	<0.0001	<0.005	<0.005	0.039	<0.005	<0.005	<0.005	21.32 (J)	22.094 (J)	0.003	<0.001
	071918-1100	71918	1100		29.6	32.2	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	20.027	20.72	NA	NA
25	2-102517-1055	102517	1055	STK	<0.05	<0.05	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.075	0.922 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05	0.7 (J)	<0.001	<0.001
45.1	1-102517-1056	102517	1056	DOM STK	50.9 (J)	50.6 (J)	<0.001	<0.001	<0.01	<0.01	0.005	<0.001	0.134	0.156	<0.0001	<0.0001	<0.005	<0.005	0.011	<0.005	<0.005	<0.005	29.319 (J)	30.074 (J)	<0.001	<0.001
	071918-0930	71918	930		83	48.6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	87.948	32.049	NA	NA
48	1-102517-1300	102517	1300	DOM	<0.05	<0.05	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.164	0.189	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	1.131 (J)	1.234 (J)	<0.001	<0.001
34	2-102517-1352	102517	1352	STK	NA	30.8 (J)	NA	<0.001	NA	<0.01	NA	<0.001	NA	0.169	NA	0.0153	NA	<0.005	NA	0.304	NA	<0.005	NA	62.08 (J)	NA	<0.001
	071918-1335	71918	1335		33	31.9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	72.701	67.319	NA	NA
50	1-102517-1500	102517	1500	DOM	<0.05	<0.05	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.163 (J)	0.171 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.374 (J)	0.417 (J)	<0.001	<0.001
28.1	2-102517-1512	102517	1512	STK	94.9 (J)	92.4 (J)	0.006	<0.001	<0.01	<0.01	0.006	<0.001	0.078	0.112	0.0015	<0.0001	0.067	0.077	0.175	0.19	0.005	0.07	24.193 (J)	24.132 (J)	0.003	<0.001
	071818-1100	71818	1100		104	106	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	25.259	25.414	NA	NA
49	1-102517-1555	102517	1555	DOM	<0.05	<0.05	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.173	0.23 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.269	0.311 (J)	<0.001	<0.001
26	2-102517-1627	102517	1627	DOM	NA	<0.05	NA	<0.001	NA	0.017	NA	<0.001	NA	0.375 (J)	NA	<0.0001	NA	<0.005	NA	<0.005	NA	0.024	NA	0.139	NA	<0.001
61	1-102617-0855	102617	855	DOM STK	<0.05	<0.05	<0.001	<0.001	0.015	0.017	<0.001	<0.001	0.163	0.166	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	0.007	0.021	1.039 (J)	1.077 (J)	<0.001	0.002
21	2-102617-1032	102617	1032	STK	<0.05	2.73 (J)	<0.001	<0.001	<0.01	<0.01	<0.001	0.001	0.055	0.074	0.0001	0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	5.99	5.473 (J)	<0.001	<0.001
41	1-102617-1105	102617	1105	DOM	<0.05	<0.05	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.107	0.115	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	5.651 (J)	5.552 (J)	<0.001	<0.001
24	2-102617-1145	102617	1145	DOM STK	<0.05	0.119	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.152	0.182	<0.0001	<0.0001	<0.005	<0.005	0.007	0.006	<0.005	<0.005	0.41	0.928 (J)	<0.001	<0.001
37	1-102617-1225	102617	1225	DOM	<0.05	<0.05	<0.001	<0.001	<0.01	0.01	<0.001	<0.001	0.265 (J)	0.309 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	0.046	<0.05	0.108	<0.001	0.003
14	2-102617-1329	102617	1329	DOM STK	<0.05	<0.05	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.07	0.084	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	4.77	9.081 (J)	<0.001	<0.001
36	1-102617-1345	102617	1345	DOM	<0.05	1.27	<0.001	<0.001	0.067	0.081	<0.001	<0.001	0.321 (J)	0.336 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	0.01	<0.05	0.401	<0.001	<0.001
11	2-102617-1535	102617	1535	DOM	<0.05	<0.05	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.249 (J)	0.227 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05	<0.05	<0.001	<0.001
58	2-102717-0920	102717	920	DOM	<0.05	<0.05	<0.001	<0.001	0.018	0.018	<0.001	<0.001	0.092	0.108	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	0.005	<0.05	<0.05	<0.001	<0.001
35	1-102717-0930	102717	930	DOM	<0.05	<0.05	<0.001	<0.001	0.023	0.024	<0.001	<0.001	0.168	0.193	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05	<0.05	<0.001	<0.001
57	2-102717-1048	102717	1048	DOM STK	<0.05	<0.05	<0.001	<0.001	0.019	0.02	<0.001	<0.001	0.106	0.138	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	0.006	<0.05	<0.05	<0.001	<0.001
43	1-102717-1120	102717	1120	DOM STK	<0.05	<0.05	<0.001	<0.001	0.018	0.018	<0.001	<0.001	0.092	0.108	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	0.005	<0.05	<0.05	<0.001	<0.001
56	1-103117-1015	103117	1015	DOM	<0.05	<0.05	<0.001	<0.001	0.011	0.011	<0.001	<0.001	0.148	0.197	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	0.036	0.023	<0.05	<0.05	<0.001	<0.001
55	1-103117-1150	103117	1150	DOM STK	<0.05	<0.05	<0.001	<0.001	0.012	0.012	<0.001	<0.001	0.128	0.143	0.0004	0.0004	<0.005	<0.005	<0.005	<0.005	0.009	0.006	<0.05	0.053	<0.001	<0.001
52	1-103117-1440	103117	1440	DOM	0.226	2.91 (J)	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.085	0.092	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	0.04	0.03	0.355 (J)	1.011 (J)	<0.001	0.002
	071618-1600	71618	1600		0.069	1.02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.85	1.567	NA	NA

TABLE 9 - TRACE METALS
2017 and 2018 SAMPLING EVENTS

MAP ID	SAMPLE ID	SAMPLE DATE (mm/dd/yy)	SAMPLE TIME (Military Time)	PERMITTED USE	Aluminum Dissolved (mg/L)	Aluminum Total (mg/L)	Arsenic Dissolved (mg/L)	Arsenic Total (mg/L)	Barium Dissolved (mg/L)	Barium Total (mg/L)	Beryllium Dissolved (mg/L)	Beryllium Total (mg/L)	Boron Dissolved (mg/L)	Boron Total (mg/L)	Cadmium Dissolved (mg/L)	Cadmium Total (mg/L)	Chromium Dissolved (mg/L)	Chromium Total (mg/L)	Cobalt Dissolved (mg/L)	Cobalt Total (mg/L)	Copper Dissolved (mg/L)	Copper Total (mg/L)	Iron Dissolved (mg/L)	Iron Total (mg/L)	Lead Dissolved (mg/L)	Lead Total (mg/L)
Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					N/A	N/A	0.05	0.05	2	2	N/A	N/A	0.75	0.75	0.005	0.005	0.1	0.1	N/A	N/A	1	1	0.3	0.3	0.015	0.015
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					5	5	0.2	0.2	N/A	N/A	N/A	N/A	5	5	0.05	0.05	0.05	0.05	1	1	0.5	0.5	N/A	N/A	0.1	0.1
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	N/A	0.10	0.10	2	2	0.004	0.004	N/A	N/A	0.005	0.005	0.1	0.1	N/A	N/A	1.3	1.3	N/A	N/A	N/A	N/A
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					0.05 - 0.2	0.05 - 0.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3	0.3	0.015	0.015
EPA Health Advisory (EPA HA)					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1	1-11117-0948	110117	948	STK	<0.05	<0.05	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.346 (J)	0.37 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.241	0.51 (J)	<0.001	<0.001
44	1-11117-1206	110117	1206	STK	1.43 (J)	1.52 (J)	<0.001	<0.001	<0.01	<0.01	0.002	0.002	0.119	0.133	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	0.017	10.254 (J)	9.807 (J)	<0.001	<0.001
	071818-1550	71818	1550		1.4	1.69	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10.021	10.784	NA	NA
10	1-11117-1440	110117	1440	DOM	<0.05	<0.05	0.002	0.002	0.01	<0.01	<0.001	<0.001	0.344 (J)	0.275 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05	0.06	<0.001	<0.001
40	1-11217-0900	110217	900	DOM	<0.05	<0.05	<0.001	<0.001	0.01	0.01	<0.001	<0.001	0.557 (J)	0.575 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05	<0.05	<0.001	<0.001
38	1-11217-1030	110217	1030	DOM	<0.05	<0.05	<0.001	<0.001	0.028	0.026	<0.001	<0.001	0.388 (J)	0.365 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05	<0.05	<0.001	<0.001
39	1-11217-1245	110217	1245	DOM	0.335	0.921	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.114 (J)	0.125 (J)	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.092	0.245	<0.001	<0.001
54	1-11217-1445	110217	1445	DOM	0.335 (J)	0.921 (J)	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	0.114	0.125	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.092	0.245	<0.001	<0.001
	071818-0900	71818	900		0.21	0.401	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.085	0.11	NA	NA
16	1-11317-0855	110317	855	STK	<0.05	0.106	<0.001	0.001	<0.01	<0.01	<0.001	<0.001	0.169	0.191	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	1.683 (J)	5.284	<0.001	<0.001
19	1-11617-1150	110617	1150	DOM	<0.05	0.176 (J)	<0.001	<0.001	<0.01	<0.01	<0.001 (UJ)	<0.001 (UJ)	0.17	0.183	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.098	0.743 (J)	<0.001	<0.001
8	1-11617-1325	110617	1325	DOM	<0.05	<0.05	<0.001	<0.001	0.011	0.01	<0.001 (UJ)	<0.001 (UJ)	0.169	0.165	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.05	<0.05	<0.001	<0.001
18	1-11617-1450	110617	1450	DOM STK	0.091	0.124	<0.001	<0.001	<0.01	<0.01	<0.001 (UJ)	<0.001 (UJ)	0.106	0.12	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	0.081	0.052	0.859 (J)	3.42 (J)	0.002	0.002
	071618-0920	71618	920		<0.050	0.067	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.875	6.008	NA	NA
60	1-11717-0900	110717	900	STK	<0.03	<0.03	<0.001	<0.001	<0.05	0.013	<0.001	<0.001	0.38	0.34	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.88	2.66	<0.001	<0.001
63	1-11717-0950	110717	950	DOM STK	<0.03	<0.03	<0.001	<0.001	<0.05	0.012	<0.001	<0.001	0.70	0.74	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.02	<0.02	<0.001	<0.001
62	1-11717-1130	110717	1130	STK (SPRING)	60.7	44.7	0.002	0.001	<0.05	<0.05	0.015	0.012	0.6	0.61	0.002	0.001	<0.005	<0.005	0.428	0.396	0.018	0.028	6.12	17.4	<0.001	<0.001
	071818-1300	71818	1300		28.2	29.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.414	7.946	NA	NA
9	1-11717-1330	110717	1330	DOM	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.29	0.32	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.14	0.16	<0.001	<0.001
12.2	1-11717-1457	110717	1457	DOM	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.11	0.12	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.02	<0.02	<0.001	<0.001
15	1-11817-0900	110817	900	DOM	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.35	0.37	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	0.007	<0.02	0.02	<0.001	<0.001
6	1-11817-1029	110817	1029	DOM	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.19	0.18	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.02	<0.02	<0.001	<0.001
4	1-11817-1125	110817	1125	DOM	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.17	0.16	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	0.009	0.008	<0.02	<0.02	<0.001	<0.001
3	1-11817-1302	110817	1302	DOM	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.24	0.22	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	0.012	0.011	<0.02	<0.02	<0.001	<0.001
5	1-11817-1425	110817	1425	DOM	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.15	0.14	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	0.009	0.013	0.03	0.34	<0.001	<0.001
31	1-11917-0906	110917	906	STK	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.06	0.06	<0.001	<0.001	<0.005	<0.005	0.005	0.005	<0.005	<0.005	0.36	0.5	<0.001	<0.001

TABLE 9 - TRACE METALS
2017 and 2018 SAMPLING EVENTS

MAP ID	SAMPLE ID	SAMPLE DATE (mm/dd/yy)	SAMPLE TIME (Military Time)	PERMITTED USE	Aluminum Dissolved (mg/L)	Aluminum Total (mg/L)	Arsenic Dissolved (mg/L)	Arsenic Total (mg/L)	Barium Dissolved (mg/L)	Barium Total (mg/L)	Beryllium Dissolved (mg/L)	Beryllium Total (mg/L)	Boron Dissolved (mg/L)	Boron Total (mg/L)	Cadmium Dissolved (mg/L)	Cadmium Total (mg/L)	Chromium Dissolved (mg/L)	Chromium Total (mg/L)	Cobalt Dissolved (mg/L)	Cobalt Total (mg/L)	Copper Dissolved (mg/L)	Copper Total (mg/L)	Iron Dissolved (mg/L)	Iron Total (mg/L)	Lead Dissolved (mg/L)	Lead Total (mg/L)
Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					N/A	N/A	0.05	0.05	2	2	N/A	N/A	0.75	0.75	0.005	0.005	0.1	0.1	N/A	N/A	1	1	0.3	0.3	0.015	0.015
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					5	5	0.2	0.2	N/A	N/A	N/A	N/A	5	5	0.05	0.05	0.05	0.05	1	1	0.5	0.5	N/A	N/A	0.1	0.1
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	N/A	0.10	0.10	2	2	0.004	0.004	N/A	N/A	0.005	0.005	0.1	0.1	N/A	N/A	1.3	1.3	N/A	N/A	N/A	N/A
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					0.05 - 0.2	0.05 - 0.2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.3	0.3	0.015	0.015
EPA Health Advisory (EPA HA)					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
46	1-111517-0945	111517	937	DOM STK	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.11	0.12	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	0.043	<0.005	0.04	**0.31**	<0.001	<0.001
	071618-1455	71618	1455		<0.050	**267**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**0.378**	**8.601**	NA	NA
7	1-111517-1230	111517	1213	DOM	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.16	0.17	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.02	0.02	<0.001	<0.001
22	1-111517-1515	111517	1500	DOM	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.43	0.48	<0.001	<0.001	<0.005	<0.005	0.011	0.011	<0.005	<0.005	0.06	**0.49**	<0.001	<0.001
59	1-111617-0915	111617	915	DOM STK	**11.8**	**14.4**	<0.001	<0.001	<0.05	<0.05	0.002	0.002	0.09	0.09	<0.001	<0.001	<0.005	<0.005	0.019	0.02	<0.005	<0.005	**0.74**	**1.06**	<0.001	<0.001
	071718-0920	71718	920		**18.9**	**19**	<0.001	<0.001	<0.010	<0.010	0.003	<0.001	0.108	<0.01	0.0002	<0.0001	<0.005	<0.005	0.021	<0.005	<0.005	<0.005	**1.226**	**1.34**	<0.001	<0.001
32	1-111617-1115	111617	1115	DOM	**13.5**	**14.1**	0.002	0.002	<0.05	<0.05	0.003	0.003	0.07	0.07	<0.001	<0.001	<0.005	<0.005	0.045	0.046	<0.005	<0.005	**40.4**	**40.4**	<0.001	<0.001
	071618-1110	71618	1110		**11.4**	**120**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**26.115**	**27.096**	NA	NA
2	1-111617-1310	111617	1310	DOM STK	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.26	0.25	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.03	0.03	<0.001	<0.001
13	1-111617-1435	111617	1435	STK	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
17	1-111617-1554	111617	1554	DOM	<0.03	<0.03	<0.001	<0.001	<0.05	<0.05	<0.001	<0.001	0.13	0.12	<0.001	<0.001	<0.005	<0.005	0.006	0.006	<0.005	<0.005	0.1	0.27	<0.001	<0.001
33	1-113017-1445	113017	1445	DOM	**1.26**	**1.44**	<0.001	<0.001	<0.05	<0.05	**0.005**	**0.005**	0.09	0.09	<0.001	<0.001	<0.005	<0.005	<0.005	<0.005	0.008	<0.005	**17.5**	**18.1**	<0.001	<0.001
	071618-1340	71618	1340		**0.535**	**0.591**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	**5.111**	**5.246**	NA	NA
82	071718-1225	71718	1225	DOM	**15.4**	**22.2**	<0.001	<0.001	<0.012	<0.012	0.003	0.003	0.11	0.103	0.0008	0.0008	<0.005	<0.005	0.031	0.033	0.008	0.021	0.121	0.297	0.003	0.003
83	071818-1710	71818	1710	DOM	<0.05	**0.282**	0.001	0.077	0.016	0.042	<0.001	0.002	0.145	0.177	<0.0001	<0.0001	<0.005	0.006	<0.005	<0.005	<0.005	0.038	**1.483**	**139.038**	<0.001	0.004
45	NT-071918-1015	71918	1015	DOM STK	<0.05	**1.32**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.05	**4.747**	NA	NA
79	NT-071918-0920	71918	920	DOM STK	<0.05	**0.152**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.05	**0.707**	NA	NA
	072018-0930	72018	930	DOM STK	<0.05	**0.184**	<0.001	<0.001	<0.01	0.011	<0.001	<0.001	0.176	0.165	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.5	**0.601**	<0.001	<0.001
80	072018-0805	72018	805	DOM	<0.05	<0.05	<0.001	<0.001	0.017	0.016	<0.001	<0.001	0.174	0.169	<0.0001	<0.0001	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.5	<0.5	<0.001	<0.001
74	SW-1-071918	71918	1240	N/A	<0.05	0.209	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0.063	1.097	NA	NA
84	Not Sampled	71918	--	N/A	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
81	SW-2	72018	735	N/A	<0.05	<0.05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	<0.05	0.168	NA	NA
77	Spring-1	72018	945	N/A	72.7	72.8	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	10.374	10.697	NA	NA

Notes:

J = The result is an estimated quantity. The associated numerical value is the approximate concentration of the analyte in the sample.

< # = The analyte was analyzed for, but was not detected above the level of the reported sample quantitation limit.

N/A = Not Applicable

NA = Not Analyzed

Font Colors and Bolding = exceeds corresponding standards

TABLE 9 - TRACE METALS
2017 and 2018 SAMPLING EVENTS

MAP ID	SAMPLE ID	SAMPLE DATE (mm/dd/yy)	SAMPLE TIME (Military Time)	PERMITTED USE	Lithium Dissolved (mg/L)	Lithium Total (mg/L)	Manganese Dissolved (mg/L)	Manganese Total (mg/L)	Mercury Dissolved (mg/L)	Mercury Total (mg/L)	Nickel Dissolved (mg/L)	Nickel Total (mg/L)	Selenium Dissolved (mg/L)	Selenium Total (mg/L)	Silver Dissolved (mg/L)	Silver Total (mg/L)	Strontium Dissolved (mg/L)	Strontium Total (mg/L)	Vanadium Dissolved (mg/L)	Vanadium Total (mg/L)	Zinc Dissolved (mg/L)	Zinc Total (mg/L)
Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					N/A	N/A	0.05	0.05	0.002	0.002	N/A	N/A	0.05	0.05	0.1	0.1	N/A	N/A	N/A	N/A	5	5
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					N/A	N/A	N/A	N/A	0.00005	0.00005	N/A	N/A	0.05	0.05	N/A	N/A	N/A	N/A	0.1	0.1	25	25
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	N/A	N/A	N/A	0.002	0.002	N/A	N/A	0.05	0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					N/A	N/A	0.05	0.05	N/A	N/A	N/A	N/A	N/A	N/A	0.1	0.1	N/A	N/A	N/A	N/A	5	5
EPA Health Advisory (EPA HA)					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
47.1	1-102517-0926	102517	926	DOM	0.2	0.3	0.465 (J)	0.457 (J)	<0.00005	<0.00005	0.089	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.492 (J)	0.496 (J)	0.013	<0.005	0.154	0.155
	071918-1100	71918	1100		NA	NA	0.42	0.463	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
25	2-102517-1055	102517	1055	STK	NA	0.3	0.002	0.082	NA	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	1.85 (J)	4.55 (J)	<0.005	<0.005	<0.005	0.015
45.1	1-102517-1056	102517	1056	DOM STK	0.4	0.4	0.701 (J)	0.723 (J)	<0.00005	<0.00005	0.072	<0.01	<0.001	<0.001	<0.0001	<0.0001	1.05 (J)	1.12 (J)	0.015	<0.005	0.141	0.151
	071918-0930	71918	930		NA	NA	0.72	0.781	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
48	1-102517-1300	102517	1300	DOM	<0.1	<0.1	0.148	0.157	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.308 (J)	0.631 (J)	<0.005	<0.005	0.027	<0.005
34	2-102517-1352	102517	1352	STK	NA	0.3	NA	0.705	NA	<0.00005	NA	0.173	NA	<0.001	NA	<0.0001	NA	1.31	NA	<0.005	NA	0.144
	071918-1335	71918	1335		NA	NA	0.707	0.759	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
50	1-102517-1500	102517	1500	DOM	<0.1	<0.1	0.094	0.101	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.634 (J)	0.683 (J)	<0.005	<0.005	<0.005	<0.005
28.1	2-102517-1512	102517	1512	STK	NA	0.2	0.745 (J)	0.709 (J)	NA	<0.00005	0.24	0.247	<0.001	<0.001	<0.0001	<0.0001	0.498 (J)	0.49 (J)	0.014	<0.005	0.478 (J)	0.509 (J)
	071818-1100	71818	1100		NA	NA	0.747	0.808	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
49	1-102517-1555	102517	1555	DOM	<0.1	<0.1	0.151	0.16	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.561 (J)	0.554 (J)	<0.005	<0.005	<0.005	<0.005
26	2-102517-1627	102517	1627	DOM	NA	0.1	NA	0.005	NA	<0.00005	NA	<0.01	NA	<0.001	NA	<0.0001	NA	3.03 (J)	NA	<0.005	NA	0.015
61	1-102617-0855	102617	855	DOM STK	0.2	0.2	0.056	0.06	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	3.69 (J)	3.19 (J)	<0.005	<0.005	0.504 (J)	0.375 (J)
21	2-102617-1032	102617	1032	STK	<0.1	<0.1	0.12	0.116	<0.00005	<0.00005	0.014	0.015	<0.001	<0.001	<0.0001	<0.0001	0.118	0.108	<0.005	<0.005	0.104	0.102
41	1-102617-1105	102617	1105	DOM	0.2	0.2	0.22	0.21	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.872 (J)	0.852 (J)	<0.005	<0.005	0.112	0.12
24	2-102617-1145	102617	1145	DOM STK	0.1	0.1	0.241	0.228	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.797 (J)	0.763 (J)	<0.005	<0.005	0.037	0.035
37	1-102617-1225	102617	1225	DOM	<0.1	<0.1	0.018	0.018	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.441 (J)	0.435 (J)	<0.005	<0.005	<0.005	0.079
14	2-102617-1329	102617	1329	DOM STK	<0.1	<0.1	0.519 (J)	0.499 (J)	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.424 (J)	0.399 (J)	<0.005	<0.005	<0.005	<0.005
36	1-102617-1345	102617	1345	DOM	<0.1	<0.1	0.01	0.015	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.767 (J)	0.787 (J)	<0.005	<0.005	0.023	0.016
11	2-102617-1535	102617	1535	DOM	<0.1	<0.1	0.007	0.005	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.925 (J)	0.651 (J)	<0.005	<0.005	0.067	0.05
58	2-102717-0920	102717	920	DOM	<0.1	<0.1	<0.001	<0.001	<0.00005	<0.00005	<0.01	<0.01	0.01	0.009	<0.0001	<0.0001	0.853 (J)	0.82 (J)	<0.005	<0.005	0.057	0.054
35	1-102717-0930	102717	930	DOM	<0.1	<0.1	0.001	0.001	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.13	0.125	<0.005	<0.005	<0.005	<0.005
57	2-102717-1048	102717	1048	DOM STK	<0.1	<0.1	<0.001	<0.001	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.984 (J)	0.937 (J)	<0.005	<0.005	0.015	0.013
43	1-102717-1120	102717	1120	DOM STK	<0.1	<0.1	<0.001	<0.001	<0.00005	<0.00005	<0.01	<0.01	0.01	0.009	<0.0001	<0.0001	0.853 (J)	0.82 (J)	<0.005	<0.005	0.057	0.054
56	1-103117-1015	103117	1015	DOM	<0.1	<0.1	<0.001	<0.001	<0.00005	<0.00005	<0.01	<0.01	0.002	0.002	<0.0001	<0.0001	1.17 (J)	1.23 (J)	<0.005	<0.005	0.018	0.01
55	1-103117-1150	103117	1150	DOM STK	<0.1	<0.1	0.001	0.001	<0.00005	<0.00005	<0.01	<0.01	0.001	0.001	<0.0001	<0.0001	1.24 (J)	1.31 (J)	<0.005	<0.005	0.021	0.026
52	1-103117-1440	103117	1440	DOM	<0.1	<0.1	0.094	0.095	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.741 (J)	0.786 (J)	<0.005	<0.005	0.067	0.039
	071618-1600	71618	1600		NA	NA	0.078	0.085	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 9 - TRACE METALS
2017 and 2018 SAMPLING EVENTS

MAP ID	SAMPLE ID	SAMPLE DATE (mm/dd/yy)	SAMPLE TIME (Military Time)	PERMITTED USE	Lithium Dissolved (mg/L)	Lithium Total (mg/L)	Manganese Dissolved (mg/L)	Manganese Total (mg/L)	Mercury Dissolved (mg/L)	Mercury Total (mg/L)	Nickel Dissolved (mg/L)	Nickel Total (mg/L)	Selenium Dissolved (mg/L)	Selenium Total (mg/L)	Silver Dissolved (mg/L)	Silver Total (mg/L)	Strontium Dissolved (mg/L)	Strontium Total (mg/L)	Vanadium Dissolved (mg/L)	Vanadium Total (mg/L)	Zinc Dissolved (mg/L)	Zinc Total (mg/L)
Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					N/A	N/A	0.05	0.05	0.002	0.002	N/A	N/A	0.05	0.05	0.1	0.1	N/A	N/A	N/A	N/A	5	5
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					N/A	N/A	N/A	N/A	0.00005	0.00005	N/A	N/A	0.05	0.05	N/A	N/A	N/A	N/A	0.1	0.1	25	25
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	N/A	N/A	N/A	0.002	0.002	N/A	N/A	0.05	0.05	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					N/A	N/A	0.05	0.05	N/A	N/A	N/A	N/A	N/A	N/A	0.1	0.1	N/A	N/A	N/A	N/A	5	5
EPA Health Advisory (EPA HA)					N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1	1-11117-0948	110117	948	STK	<0.1	<0.1	0.014	0.014	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.463 (J)	0.483 (J)	<0.005	<0.005	<0.005	<0.005
44	1-11117-1206	110117	1206	STK	0.2	0.2	0.649 (J)	0.636 (J)	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.177	0.18	<0.005	<0.005	0.026	0.03
	~~071818-1550~~	~~71818~~	~~1550~~		NA	NA	0.601	0.677	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	1-11117-1440	110117	1440	DOM	<0.1	0.1	0.012	0.01	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.951 (J)	0.815 (J)	<0.005	<0.005	<0.005	<0.005
40	1-11217-0900	110217	900	DOM	<0.1	0.1	0.003	0.004	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.475 (J)	0.489 (J)	<0.005	<0.005	<0.005	<0.005
38	1-11217-1030	110217	1030	DOM	<0.1	<0.1	0.002	0.002	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.085	0.084	<0.005	<0.005	<0.005	<0.005
39	1-11217-1245	110217	1245	DOM	<0.1	<0.1	**0.227**	**0.226**	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	1.02	1.04	<0.005	<0.005	0.017	0.011
54	1-11217-1445	110217	1445	DOM	<0.1	<0.1	**0.227**	**0.226**	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	1.02 (J)	1.04 (J)	<0.005	<0.005	0.017	0.011
	071818-0900	71818	900		NA	NA	**0.203**	**0.211**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
16	1-11317-0855	110317	855	STK	<0.1	<0.1	0.936	0.948 (J)	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	1.2 (J)	1.24 (J)	<0.005	<0.005	<0.005	<0.005
19	1-11617-1150	110617	1150	DOM	<0.1	<0.1	0.011	0.009	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.301 (J)	0.256 (J)	<0.005	<0.005	<0.005	0.047
8	1-11617-1325	110617	1325	DOM	<0.1	<0.1	0.01	0.009	<0.00005	<0.00005	<0.01	<0.01	<0.001	<0.001	<0.0001	<0.0001	0.204	0.186	<0.005	<0.005	<0.005	<0.005
18	1-11617-1450	110617	1450	DOM STK	0.2 (J)	0.2	**0.629 (J)**	**0.562 (J)**	<0.00005	<0.00005	0.013	0.012	<0.001	<0.001	<0.0001	<0.0001	1.12 (J)	1.04 (J)	<0.005	<0.005	0.03	0.02
	071618-0920	71618	920		NA	NA	**0.593**	**0.612**	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
60	1-11717-0900	110717	900	STK	0.1	0.2 (J)	0.078	0.109	<0.00005	<0.00005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.0001	0.87	1.06	<0.01	<0.005	0.06	0.24 (J)
63	1-11717-0950	110717	950	DOM STK	0.1	0.1	<0.001	0.001	<0.00005	<0.00005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.0001	0.63	0.63	<0.01	<0.005	<0.01	<0.005
62	1-11717-1130	110717	1130	STK (SPRING)	0.4	0.4	16.9	14.9	<0.00005	<0.00005	0.443 (J)	0.406	0.001	<0.001	<0.001	<0.001	1.09	1.03	<0.01	<0.01	0.52	0.47
	071818-1300	71818	1300		NA	NA	8.72	9.58	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	1-11717-1330	110717	1330	DOM	0.1	0.1	**0.056**	**0.057**	<0.00005	<0.00005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	0.9	0.89	<0.01	<0.01	<0.01	0.03
12.2	1-11717-1457	110717	1457	DOM	<0.1	<0.1	0.015	0.017	<0.00005	<0.00005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	0.41	0.43	<0.01	<0.01	<0.01	<0.01
15	1-11817-0900	110817	900	DOM	<0.1	<0.1	0.009	0.01	<0.00005	<0.00005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	0.36	0.38	<0.01	<0.01	0.01	0.01
6	1-11817-1029	110817	1029	DOM	<0.1	<0.1	0.011	0.011	<0.00005	<0.00005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	0.41	0.43	<0.01	<0.01	<0.01	<0.01
4	1-11817-1125	110817	1125	DOM	<0.1	<0.1	<0.001	0.001	<0.00005	<0.00005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	0.37	0.4	<0.01	<0.01	0.03	0.01
3	1-11817-1302	110817	1302	DOM	<0.1	<0.1	0.026	0.028	<0.00005	<0.00005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	2.11	2.12	<0.01	<0.01	0.02	0.02
5	1-11817-1425	110817	1425	DOM	<0.1	<0.1	**0.137**	**0.144**	<0.00005	<0.00005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	1.05	1.03	<0.01	<0.01	0.08	0.12
31	1-11917-0906	110917	906	STK	<0.1	<0.1	1.36	1.29	<0.00005	<0.00005	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	0.79	0.8	<0.01	<0.01	<0.01	<0.01

TABLE 10 - RADIONUCLIDES
2017 and 2018 SAMPLING EVENTS

Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					N/A	N/A	15	5	N/A	8
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					N/A	N/A	15	5	N/A	8
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	N/A	N/A	5	N/A	N/A
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					N/A	N/A	N/A	N/A	N/A	N/A
EPA Health Advisory (EPA HA)					N/A	N/A	N/A	N/A	N/A	N/A
MAP ID	**SAMPLE ID**	**SAMPLE DATE (mm/dd/yy)**	**SAMPLE TIME (Military Time)**	**PERMITTED USE**	**Gross Alpha minus Rn & U (pCi/L)**	**Rad 226 (pCi/L)**	**Gross Alpha minus Rn & U + Ra 226, calc (pCi/L)**	**Rad 226+228 (pCi/L)**	**Rad 228 (pCi/L)**	**Strontium 90 (pCi/L)**
47.1	1-102517-0926	102517	926	DOM	2.7 (J)	1.5	4.2	2	0.51 (U)	-0.4 (U)
	071918-1100	71918	1100		NA	NA	NA	NA	NA	NA
25	2-102517-1055	102517	1055	STK	0.4 (U)	0.09 (U)	0.5	1.1 (U)	0.96 (U)	5.8
45.1	1-102517-1056	102517	1056	DOM STK	3.2 (J)	2.1	5.3	2.3	0.26 (U)	-0.2 (U)
	071918-0930	71918	930		NA	NA	NA	NA	NA	NA
48	1-102517-1300	102517	1300	DOM	0.7 (J)	0.6	1.3	1.3 (U)	0.76 (U)	0.8 (U)
34	2-102517-1352	102517	1352	STK	16	13.8	**29.8**	**14.3**	0.44 (U)	0.9 (U)
	071918-1335	71918	1335		NA	NA	NA	NA	NA	NA
50	1-102517-1500	102517	1500	DOM	0.9 (J)	0.5	1.4	1.6 (U)	1 (U)	1 (U)
28.1	2-102517-1512	102517	1512	STK	4.5	2.6	7.1	3	0.38 (U)	0.9 (U)
	071818-1100	71818	1100		NA	NA	NA	NA	NA	NA
49	1-102517-1555	102517	1555	DOM	0.6 (J)	0.5	1.1	0.6 (U)	0.06 (U)	-0.9 (U)
26	2-102517-1627	102517	1627	DOM	0.5	0.3	0.8	1 (U)	0.69 (U)	-0.3 (U)
61	1-102617-0855	102617	855	DOM STK	1.6 (J)	0.7 (J)	2.3	0.6 (U)	-0.06 (U)	-0.4 (U)
21	2-102617-1032	102617	1032	STK	1.6	1.1	2.7	1.1 (U)	-0.02 (U)	-0.5 (U)
41	1-102617-1105	102617	1105	DOM	1.4 (J)	1.2 (J)	2.6	1.6	0.36 (U)	-1.4 (U)
24	2-102617-1145	102617	1145	DOM STK	1.6	1	2.6	1.7 (U)	0.67 (U)	0.8 (U)
37	1-102617-1225	102617	1225	DOM	0.7 (J)	0.3 (J)	1	0.5 (U)	0.24 (U)	0.7 (U)
14	2-102617-1329	102617	1329	DOM STK	1.7	1.2	2.9	2.1 (U)	0.88 (U)	-1.3 (U)
36	1-102617-1345	102617	1345	DOM	1.3 (J)	0.2 (J)	1.5	0.5 (U)	0.32 (U)	0.7 (U)
11	2-102617-1535	102617	1535	DOM	0.5 (U)	0.2 (U)	0.7	0.7 (U)	0.48 (U)	3.3 (U)
58	2-102717-0920	102717	920	DOM	1	0.6	1.6	2.2	1.6	-1.2 (U)
35	1-102717-0930	102717	930	DOM	0.4 (U)	0.1 (U)	0.5	1.1 (U)	0.95 (U)	2.9
57	2-102717-1048	102717	1048	DOM STK	1.2	1	2.2	3.9	2.9	2.2 (U)
43	1-102717-1120	102717	1120	DOM STK	0.6	0.2	0.8	4	3.8	0.9 (U)
56	1-103117-1015	103117	1015	DOM	5.2	1.7	6.9	**6.2**	4.5	3.8
55	1-103117-1150	103117	1150	DOM STK	1.5	0.7	2.2	0.5 (U)	-0.2 (U)	0.3 (U)
52	1-103117-1440	103117	1440	DOM	3.4	1.6	5	2.5	0.83 (U)	3.3 (U)
	071618-1600	71618	1600		NA	NA	NA	NA	NA	NA
1	1-11117-0948	110117	948	STK	0.4 (U)	0.3	0.7	1.4 (U)	1.1 (U)	1.2 (U)
44	1-11117-1206	110117	1206	STK	4.2	3.2	7.4	**6.9**	3.7	0.4 (U)
	071818-1550	71818	1550		NA	NA	NA	NA	NA	NA

TABLE 10 - RADIONUCLIDES
2017 and 2018 SAMPLING EVENTS

Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					N/A	N/A	15	5	N/A	8
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					N/A	N/A	15	5	N/A	8
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					N/A	N/A	N/A	5	N/A	N/A
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					N/A	N/A	N/A	N/A	N/A	N/A
EPA Health Advisory (EPA HA)					N/A	N/A	N/A	N/A	N/A	N/A
MAP ID	**SAMPLE ID**	**SAMPLE DATE (mm/dd/yy)**	**SAMPLE TIME (Military Time)**	**PERMITTED USE**	**Gross Alpha minus Rn & U (pCi/L)**	**Rad 226 (pCi/L)**	**Gross Alpha minus Rn & U + Ra 226, calc (pCi/L)**	**Rad 226+228 (pCi/L)**	**Rad 228 (pCi/L)**	**Strontium 90 (pCi/L)**
10	1-11117-1440	110117	1440	DOM	0.8	0.3	1.1	1.7	1.4 (U)	0.5 (U)
40	1-11217-0900	110217	900	DOM	0.8	0.3	1.1	1.1 (U)	0.79 (U)	1.4 (U)
38	1-11217-1030	110217	1030	DOM	0.8	0.2	1	1.2 (U)	1 (U)	1.3 (U)
39	1-11217-1245	110217	1245	DOM	0.2 (U)	0.2 (U)	0.4	1.2 (U)	0.97 (U)	0.4 (U)
54	1-11217-1445	110217	1445	DOM	2.8	1.2	4	3.1	1.9	-1.6 (U)
	071818-0900	71818	900		NA	NA	NA	NA	NA	NA
16	1-11317-0855	110317	855	STK	2.5	2	4.5	4	2	2.2 (U)
19	1-11617-1150	110617	1150	DOM	0.4 (U)	0.3	0.7	0.7 (U)	0.36 (U)	0.5 (U)
8	1-11617-1325	110617	1325	DOM	0.6	0.4	1	1.3 (U)	0.91 (U)	1 (U)
18	1-11617-1450	110617	1450	DOM STK	2.2	2	4.2	2.8	0.79 (U)	1.7 (U)
	071618-0920	71618	920		NA	NA	NA	NA	NA	NA
60	1-11717-0900	110717	900	STK	1.9	0.4	2.3	1.1 (U)	0.68 (U)	1.4 (U)
63	1-11717-0950	110717	950	DOM STK	0.3 (U)	0.3	0.6	0.07 (U)	-0.2 (U)	2.2 (U)
62	1-11717-1130	110717	1130	STK (SPRING)	1	0.4	1.4	0.9 (U)	0.5 (U)	1.8 (U)
	071818-1300	71818	1300		NA	NA	NA	NA	NA	NA
9	1-11717-1330	110717	1330	DOM	0.3 (U)	0.2 (U)	0.5	0.9 (U)	0.67 (U)	2 (U)
12.2	1-11717-1457	110717	1457	DOM	0.2 (U)	0.3	0.5	0.7 (U)	0.4 (U)	1.2 (U)
15	1-11817-0900	110817	900	DOM	0.7	0.07 (U)	0.8	-1 (U)	-1 (U)	1.4 (U)
6	1-11817-1029	110817	1029	DOM	1	0.3	1.3	-1 (U)	-2 (U)	-3 (U)
4	1-11817-1125	110817	1125	DOM	0.6 (U)	0.2	0.8	-0.3 (U)	-0.4 (U)	0.7 (U)
3	1-11817-1302	110817	1302	DOM	0.8	0.2	1	-0.2 (U)	-0.4 (U)	0.5 (U)
5	1-11817-1425	110817	1425	DOM	1.5	1	2.5	1.4 (U)	0.42 (U)	0.9 (U)
31	1-11917-0906	110917	906	STK	1	0.7	1.7	-0.5 (U)	-1 (U)	0.5 (U)
46	1-111517-0945	111517	937	DOM STK	1.2	-0.003 (U)	1.2	0.6 (U)	0.57 (U)	0.8 (U)
	071618-1455	71618	1455		NA	NA	NA	NA	NA	NA
7	1-111517-1230	111517	1213	DOM	0.5 (U)	0.2	0.7	0.6 (U)	0.41 (U)	0.5 (U)
22	1-111517-1515	111517	1500	DOM	1.4	0.4	1.8	1.5 (U)	1.1 (U)	-0.2 (U)
59	1-111617-0915	111617	915	DOM STK	1.5	1.4	2.9	3.1	1.6 (U)	0 (U)
	071718-0920	71718	920		NA	NA	NA	NA	NA	NA

TABLE 10 - RADIONUCLIDES
2017 and 2018 SAMPLING EVENTS

Wyoming Rules and Regulation Chapter 8, Table 1- Domestic					**N/A**	**N/A**	**15**	**5**	**N/A**	**8**
Wyoming Rules and Regulation Chapter 8, Table 1- Livestock					**N/A**	**N/A**	**15**	**5**	**N/A**	**8**
EPA National Primary Drinking Water Regulations / Maximum Contaminant Levels (EPA MCL)					**N/A**	**N/A**	**N/A**	**5**	**N/A**	**N/A**
EPA National Secondary Drinking Water Regulations / Secondary Maxiumum Contaminant Level (EPA SMCL)					**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
EPA Health Advisory (EPA HA)					**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
MAP ID	**SAMPLE ID**	**SAMPLE DATE (mm/dd/yy)**	**SAMPLE TIME (Military Time)**	**PERMITTED USE**	**Gross Alpha minus Rn & U (pCi/L)**	**Rad 226 (pCi/L)**	**Gross Alpha minus Rn & U + Ra 226, calc (pCi/L)**	**Rad 226+228 (pCi/L)**	**Rad 228 (pCi/L)**	**Strontium 90 (pCi/L)**
32	1-111617-1115	111617	1115	DOM	7.9	6.1	14	**9.9**	3.8	2 (U)
	071618-1110	71618	1110		NA	NA	NA	NA	NA	NA
2	1-111617-1310	111617	1310	DOM STK	0.4 (U)	0.4	0.8	0.3 (U)	-0.09 (U)	0.4 (U)
13	1-111617-1435	111617	1435	STK	NA	NA	NA	NA	NA	NA
17	1-111617-1554	111617	1554	DOM	0.9	0.6	1.5	2.7	2.1	0.3 (U)
33	1-113017-1445	113017	1445	DOM	2	2.6	4.6	3.3	0.72 (U)	-0.2 (U)
	071618-1340	71618	1340		NA	NA	NA	NA	NA	NA
82	071718-1225	71718	1225	DOM	2	1.1	3.1	3.5	2.4	2.9
83	071818-1710	71818	1710	DOM	14	9.3	**25.3**	**12.9**	3.7	4.8
45	NT-071918-1015	71918	1015	DOM STK	NS	NS	NS	NS	NS	NS
79	NT-071918-0920	71918	920	DOM STK	NS	NS	NS	NS	NS	NS
	072018-0930	72018	930	DOM STK	0.7	0.6	0.13	1.5 (U)	0.9 (U)	2.0 (U)
80	072018-0805	72018	805	DOM	0.7	0.3	1	1.8 (U)	1.5 (U)	1.2 (U)
74	SW-1-071918	71918	1240	N/A	NS	NS	NS	NS	NS	NS
84	Not Sampled	71918	--	N/A	NS	NS	NS	NS	NS	NS
81	SW-2	72018	735	N/A	NS	NS	NS	NS	NS	NS
77	Spring-1	72018	945	N/A	NS	NS	NS	NS	NS	NS

Notes:

J = The result is an estimated quantity. The associated numerical value is the approximate concentration of the analyte in the sample.

(U) = The analyte was analyzed for, but was not detected above the level of the reported sample quantitation limit.

N/A = Not Applicable

NA = Not Analyzed

NS = Not Sampled

TABLE 11 - DUPLICATE SAMPLE RELATIVE PERCENT DIFFERENCE
Gillette Madison Well-field Project

Well Name	Sample Date	Parameter Name	Sample Value	Units	Qualifier	Duplicate Field RPD (%)
2-102717-1048 Field Dup	10/27/2017	Bacteria, E-Coli Coliform	Absent	per 100ml		
2-102717-1048	10/27/2017	Bacteria, E-Coli Coliform	Absent	per 100ml		
2-102717-1048 Field Dup	10/27/2017	Bacteria, Iron Related	9000	CFU/ml		200.00
2-102717-1048	10/27/2017	Bacteria, Iron Related	< 1.0	CFU/ml		
2-102717-1048 Field Dup	10/27/2017	Bacteria, Total Coliform	Absent	per 100ml		
2-102717-1048	10/27/2017	Bacteria, Total Coliform	Absent	per 100ml		
2-102717-1048 Field Dup	10/27/2017	Bromide, Dissolved	<0.1	mg/L		
2-102717-1048	10/27/2017	Bromide, Dissolved	<0.1	mg/L		
2-102717-1048 Field Dup	10/27/2017	Bromide, meq, Dissolved	0.0009	meq/L		11.76
2-102717-1048	10/27/2017	Bromide, meq, Dissolved	0.0008	meq/L		
2-102717-1048 Field Dup	10/27/2017	Cyanide, Total	<0.005	mg/L		
2-102717-1048	10/27/2017	Cyanide, Total	<0.005	mg/L		
2-102717-1048 Field Dup	10/27/2017	Gross Alpha minus Rn & U	1.4	pCi/L		15.38
2-102717-1048	10/27/2017	Gross Alpha minus Rn & U	1.2	pCi/L		
2-102717-1048 Field Dup	10/27/2017	Lithium, Dissolved	<0.1	mg/L		
2-102717-1048	10/27/2017	Lithium, Dissolved	<0.1	mg/L		
2-102717-1048 Field Dup	10/27/2017	Lithium, Total Recoverable	<0.1	mg/L		
2-102717-1048	10/27/2017	Lithium, Total Recoverable	<0.1	mg/L		
2-102717-1048 Field Dup	10/27/2017	Mercury	<0.00005	mg/L		
2-102717-1048 Field Dup	10/27/2017	Mercury	<0.00005	mg/L		
2-102717-1048	10/27/2017	Mercury	<0.00005	mg/L		
2-102717-1048	10/27/2017	Mercury	<0.00005	mg/L		
2-102717-1048 Field Dup	10/27/2017	pH	7.08	s.u.	J	
2-102717-1048	10/27/2017	pH	7.08	s.u.	J	
2-102717-1048 Field Dup	10/27/2017	Radium 226	0.8	pCi/L		22.22
2-102717-1048	10/27/2017	Radium 226	1	pCi/L		
2-102717-1048 Field Dup	10/27/2017	Radium 226 + Radium 228	2.4	pCi/L		47.62
2-102717-1048	10/27/2017	Radium 226 + Radium 228	3.9	pCi/L		
2-102717-1048 Field Dup	10/27/2017	Radium 228	1.6	pCi/L		57.78
2-102717-1048	10/27/2017	Radium 228	2.9	pCi/L		
2-102717-1048 Field Dup	10/27/2017	Solids, Total Dissolved TDS @ 180 C	1450	mg/L		1.37
2-102717-1048	10/27/2017	Solids, Total Dissolved TDS @ 180 C	1470	mg/L		
2-102717-1048 Field Dup	10/27/2017	Strontium 90	1.5	pCi/L	U	37.84
2-102717-1048	10/27/2017	Strontium 90	2.2	pCi/L	U	
2-102717-1048 Field Dup	10/27/2017	Sulfide	<0.04	mg/L		

TABLE 11 - DUPLICATE SAMPLE RELATIVE PERCENT DIFFERENCE
Gillette Madison Well-field Project

Well Name	Sample Date	Parameter Name	Sample Value	Units	Qualifier	Duplicate Field RPD (%)
2-102717-1048	10/27/2017	Sulfide	<0.04	mg/L		
1-11917-0906	11/9/2017	Bacteria, E-Coli Coliform	Absent	per 100ml		
1-11917-0906-DUP	11/9/2017	Bacteria, E-Coli Coliform	Absent	per 100ml		
1-11917-0906	11/9/2017	Bacteria, Iron Related	9000	CFU/ml		
1-11917-0906-DUP	11/9/2017	Bacteria, Iron Related	9000	CFU/ml		
1-11917-0906	11/9/2017	Bacteria, Total Coliform	Absent	per 100ml		
1-11917-0906-DUP	11/9/2017	Bacteria, Total Coliform	Absent	per 100ml		
1-11917-0906	11/9/2017	Bromide, Dissolved	<0.1	mg/L		
1-11917-0906-DUP	11/9/2017	Bromide, Dissolved	<0.1	mg/L		
1-11917-0906	11/9/2017	Cyanide, Total	<0.005	mg/L		
1-11917-0906-DUP	11/9/2017	Cyanide, Total	<0.005	mg/L		
1-11917-0906	11/9/2017	Gross Alpha minus Rn & U	1.0	pCi/L		18.18
1-11917-0906-DUP	11/9/2017	Gross Alpha minus Rn & U	1.2	pCi/L		
1-11917-0906	11/9/2017	Lithium, Dissolved	<0.1	mg/L		
1-11917-0906-DUP	11/9/2017	Lithium, Dissolved	<0.1	mg/L		
1-11917-0906	11/9/2017	Lithium, Total Recoverable	<0.1	mg/L		
1-11917-0906-DUP	11/9/2017	Lithium, Total Recoverable	<0.1	mg/L		
1-11917-0906	11/9/2017	Mercury	<0.00005	mg/L		
1-11917-0906	11/9/2017	Mercury	<0.00005	mg/L		
1-11917-0906-DUP	11/9/2017	Mercury	<0.00005	mg/L		
1-11917-0906-DUP	11/9/2017	Mercury	<0.00005	mg/L		
1-11917-0906	11/9/2017	pH	7.07	s.u.	J	0.57
1-11917-0906-DUP	11/9/2017	pH	7.03	s.u.	J	
1-11917-0906	11/9/2017	Radium 226	0.7	pCi/L		
1-11917-0906-DUP	11/9/2017	Radium 226	0.7	pCi/L		
1-11917-0906	11/9/2017	Radium 226 + Radium 228	-0.5	pCi/L		1200.00
1-11917-0906-DUP	11/9/2017	Radium 226 + Radium 228	0.7	pCi/L		
1-11917-0906	11/9/2017	Radium 228	-1	pCi/L		212.37
1-11917-0906-DUP	11/9/2017	Radium 228	0.03	pCi/L		
1-11917-0906	11/9/2017	Solids, Total Dissolved TDS @ 180 C	1520	mg/L		0.00
1-11917-0906-DUP	11/9/2017	Solids, Total Dissolved TDS @ 180 C	1520	mg/L		
1-11917-0906	11/9/2017	Strontium 90	0.5	pCi/L	U	200.00
1-11917-0906-DUP	11/9/2017	Strontium 90	0	pCi/L	U	
1-11917-0906	11/9/2017	Sulfide	<0.04	mg/L		
1-11917-0906-DUP	11/9/2017	Sulfide	<0.04	mg/L		

TABLE 11 - DUPLICATE SAMPLE RELATIVE PERCENT DIFFERENCE
Gillette Madison Well-field Project

Well Name	Sample Date	Parameter Name	Sample Value	Units	Qualifier	Duplicate Field RPD (%)
1-11917-0906	11/9/2017	Aluminum, Dissolved	<0.03	mg/L		
1-11917-0906-DUP	11/9/2017	Aluminum, Dissolved	<0.03	mg/L		
1-11917-0906	11/9/2017	Aluminum, Total Recoverable	<0.03	mg/L		
1-11917-0906-DUP	11/9/2017	Aluminum, Total Recoverable	<0.03	mg/L		
1-11917-0906	11/9/2017	Arsenic, Dissolved	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Arsenic, Dissolved	<0.001	mg/L		
1-11917-0906	11/9/2017	Arsenic, Total Recoverable	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Arsenic, Total Recoverable	<0.001	mg/L		
1-11917-0906	11/9/2017	Barium, Dissolved	<0.05	mg/L		
1-11917-0906-DUP	11/9/2017	Barium, Dissolved	<0.05	mg/L		
1-11917-0906	11/9/2017	Barium, Total Recoverable	<0.05	mg/L		
1-11917-0906-DUP	11/9/2017	Barium, Total Recoverable	<0.05	mg/L		
1-11917-0906	11/9/2017	Beryllium, Dissolved	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Beryllium, Dissolved	<0.001	mg/L		
1-11917-0906	11/9/2017	Beryllium, Total Recoverable	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Beryllium, Total Recoverable	<0.001	mg/L		
1-11917-0906	11/9/2017	Boron, Dissolved	0.06	mg/L		0.00
1-11917-0906-DUP	11/9/2017	Boron, Dissolved	0.06	mg/L		
1-11917-0906	11/9/2017	Boron, Total Recoverable	0.06	mg/L		15.38
1-11917-0906-DUP	11/9/2017	Boron, Total Recoverable	0.07	mg/L		
1-11917-0906	11/9/2017	Cadmium, Dissolved	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Cadmium, Dissolved	<0.001	mg/L		
1-11917-0906	11/9/2017	Cadmium, Total Recoverable	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Cadmium, Total Recoverable	<0.001	mg/L		
1-11917-0906	11/9/2017	Calcium, meq, Total Recoverable	16.1	meq/L		4.85
1-11917-0906-DUP	11/9/2017	Calcium, meq, Total Recoverable	16.9	meq/L		
1-11917-0906	11/9/2017	Calcium, Total Recoverable	322	mg/L		5.14
1-11917-0906-DUP	11/9/2017	Calcium, Total Recoverable	339	mg/L		
1-11917-0906	11/9/2017	Chromium, Dissolved	<0.005	mg/L		
1-11917-0906-DUP	11/9/2017	Chromium, Dissolved	<0.005	mg/L		
1-11917-0906	11/9/2017	Chromium, Total Recoverable	<0.005	mg/L		
1-11917-0906-DUP	11/9/2017	Chromium, Total Recoverable	<0.005	mg/L		
1-11917-0906	11/9/2017	Cobalt, Dissolved	0.005	mg/L		18.18
1-11917-0906-DUP	11/9/2017	Cobalt, Dissolved	0.006	mg/L		
1-11917-0906	11/9/2017	Cobalt, Total Recoverable	0.005	mg/L		18.18

TABLE 11 - DUPLICATE SAMPLE RELATIVE PERCENT DIFFERENCE
Gillette Madison Well-field Project

Well Name	Sample Date	Parameter Name	Sample Value	Units	Qualifier	Duplicate Field RPD (%)
1-11917-0906-DUP	11/9/2017	Cobalt, Total Recoverable	0.006	mg/L		
1-11917-0906	11/9/2017	Copper, Dissolved	<0.005	mg/L		
1-11917-0906-DUP	11/9/2017	Copper, Dissolved	<0.005	mg/L		
1-11917-0906	11/9/2017	Copper, Total Recoverable	<0.005	mg/L		
1-11917-0906-DUP	11/9/2017	Copper, Total Recoverable	<0.005	mg/L		
1-11917-0906	11/9/2017	Iron, Dissolved	0.36	mg/L		5.41
1-11917-0906-DUP	11/9/2017	Iron, Dissolved	0.38	mg/L		
1-11917-0906	11/9/2017	Iron, Total Recoverable	0.5	mg/L		12.77
1-11917-0906-DUP	11/9/2017	Iron, Total Recoverable	0.44	mg/L		
1-11917-0906	11/9/2017	Lead, Dissolved	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Lead, Dissolved	<0.001	mg/L		
1-11917-0906	11/9/2017	Lead, Total Recoverable	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Lead, Total Recoverable	<0.001	mg/L		
1-11917-0906	11/9/2017	Magnesium, meq, Total Recoverable	1.86	meq/L		1.07
1-11917-0906-DUP	11/9/2017	Magnesium, meq, Total Recoverable	1.88	meq/L		
1-11917-0906	11/9/2017	Magnesium, Total Recoverable	23	mg/L		0.00
1-11917-0906-DUP	11/9/2017	Magnesium, Total Recoverable	23	mg/L		
1-11917-0906	11/9/2017	Manganese, Dissolved	1.36	mg/L		0.74
1-11917-0906-DUP	11/9/2017	Manganese, Dissolved	1.35	mg/L		
1-11917-0906	11/9/2017	Manganese, Total Recoverable	1.29	mg/L		0.00
1-11917-0906-DUP	11/9/2017	Manganese, Total Recoverable	1.29	mg/L		
1-11917-0906	11/9/2017	Nickel, Dissolved	<0.005	mg/L		
1-11917-0906-DUP	11/9/2017	Nickel, Dissolved	<0.005	mg/L		
1-11917-0906	11/9/2017	Nickel, Total Recoverable	<0.005	mg/L		
1-11917-0906-DUP	11/9/2017	Nickel, Total Recoverable	<0.005	mg/L		
1-11917-0906	11/9/2017	Potassium, meq, Total Recoverable	0.09	meq/L		
1-11917-0906-DUP	11/9/2017	Potassium, meq, Total Recoverable	0.09	meq/L		
1-11917-0906	11/9/2017	Potassium, Total Recoverable	3	mg/L		
1-11917-0906-DUP	11/9/2017	Potassium, Total Recoverable	3	mg/L		
1-11917-0906	11/9/2017	Selenium, Dissolved	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Selenium, Dissolved	<0.001	mg/L		
1-11917-0906	11/9/2017	Selenium, Total Recoverable	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Selenium, Total Recoverable	<0.001	mg/L		
1-11917-0906	11/9/2017	Silver, Dissolved	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Silver, Dissolved	<0.001	mg/L		

TABLE 11 - DUPLICATE SAMPLE RELATIVE PERCENT DIFFERENCE
Gillette Madison Well-field Project

Well Name	Sample Date	Parameter Name	Sample Value	Units	Qualifier	Duplicate Field RPD (%)
1-11917-0906	11/9/2017	Silver, Total Recoverable	<0.001	mg/L		
1-11917-0906-DUP	11/9/2017	Silver, Total Recoverable	<0.001	mg/L		
1-11917-0906	11/9/2017	Sodium, meq, Total Recoverable	1.79	meq/L		0.56
1-11917-0906-DUP	11/9/2017	Sodium, meq, Total Recoverable	1.8	meq/L		
1-11917-0906	11/9/2017	Sodium, Total Recoverable	41	mg/L		0.00
1-11917-0906-DUP	11/9/2017	Sodium, Total Recoverable	41	mg/L		
1-11917-0906	11/9/2017	Strontium, Dissolved	0.79	mg/L		1.27
1-11917-0906-DUP	11/9/2017	Strontium, Dissolved	0.78	mg/L		
1-11917-0906	11/9/2017	Strontium, Total Recoverable	0.8	mg/L		6.45
1-11917-0906-DUP	11/9/2017	Strontium, Total Recoverable	0.75	mg/L		
1-11917-0906	11/9/2017	Vanadium, Dissolved	<0.01	mg/L		
1-11917-0906-DUP	11/9/2017	Vanadium, Dissolved	<0.01	mg/L		
1-11917-0906	11/9/2017	Vanadium, Total Recoverable	<0.01	mg/L		
1-11917-0906-DUP	11/9/2017	Vanadium, Total Recoverable	<0.01	mg/L		
1-11917-0906	11/9/2017	Zinc, Dissolved	<0.01	mg/L		
1-11917-0906-DUP	11/9/2017	Zinc, Dissolved	<0.01	mg/L		
1-11917-0906	11/9/2017	Zinc, Total Recoverable	<0.01	mg/L		
1-11917-0906-DUP	11/9/2017	Zinc, Total Recoverable	<0.01	mg/L		
1-111617-1310	11/16/2017	Alkalinity	329	mg/L		0.00
1-111617-DUP	11/16/2017	Alkalinity	329	mg/L		
1-111617-1310	11/16/2017	Aluminum Dissolved	<0.03	mg/L		
1-111617-DUP	11/16/2017	Aluminum Dissolved	<0.03	mg/L		
1-111617-1310	11/16/2017	Aluminum Total	<0.03	mg/L		
1-111617-DUP	11/16/2017	Aluminum Total	<0.03	mg/L		
1-111617-1310	11/16/2017	Ammonia (as Nitrogen)	<0.05	mg/L		
1-111617-DUP	11/16/2017	Ammonia (as Nitrogen)	<0.05	mg/L		
1-111617-1310	11/16/2017	Arsenic Dissolved	<0.001	mg/L		
1-111617-DUP	11/16/2017	Arsenic Dissolved	<0.001	mg/L		
1-111617-1310	11/16/2017	Arsenic Total	<0.001	mg/L		
1-111617-DUP	11/16/2017	Arsenic Total	<0.001	mg/L		
1-111617-1310	11/16/2017	Bacteria, E-Coli Coliform	Absent	per 100ml		
1-111617-DUP	11/16/2017	Bacteria, E-Coli Coliform	Absent	per 100ml		
1-111617-1310	11/16/2017	Bacteria, Iron Related	2200	CFU/ml		125.93
1-111617-DUP	11/16/2017	Bacteria, Iron Related	500	CFU/ml		
1-111617-1310	11/16/2017	Bacteria, Total Coliform	Absent	per 100ml		

TABLE 11 - DUPLICATE SAMPLE RELATIVE PERCENT DIFFERENCE
Gillette Madison Well-field Project

Well Name	Sample Date	Parameter Name	Sample Value	Units	Qualifier	Duplicate Field RPD (%)
1-111617-DUP	11/16/2017	Bacteria, Total Coliform	Absent	per 100ml		
1-111617-1310	11/16/2017	Barium Dissolved	<0.05	mg/L		
1-111617-DUP	11/16/2017	Barium Dissolved	<0.05	mg/L		
1-111617-1310	11/16/2017	Barium Total	<0.05	mg/L		
1-111617-DUP	11/16/2017	Barium Total	<0.05	mg/L		
1-111617-1310	11/16/2017	Beryllium Dissolved	<0.001	mg/L		
1-111617-DUP	11/16/2017	Beryllium Dissolved	<0.001	mg/L		
1-111617-1310	11/16/2017	Beryllium Total	<0.001	mg/L		
1-111617-DUP	11/16/2017	Beryllium Total	<0.001	mg/L		
1-111617-1310	11/16/2017	Bicarbonates	329	mg/L		
1-111617-DUP	11/16/2017	Bicarbonates	329	mg/L		
1-111617-1310	11/16/2017	Boron Dissolved	0.26	mg/L		26.09
1-111617-DUP	11/16/2017	Boron Dissolved	0.2	mg/L		
1-111617-1310	11/16/2017	Boron Total	0.25	mg/L		8.33
1-111617-DUP	11/16/2017	Boron Total	0.23	mg/L		
1-111617-1310	11/16/2017	Bromide Dissolved	<0.1	mg/L		
1-111617-DUP	11/16/2017	Bromide Dissolved	<0.1	mg/L		
1-111617-1310	11/16/2017	Bromide, meq, Dissolved	0.001	meq/L		
1-111617-DUP	11/16/2017	Bromide, meq, Dissolved	0.001	meq/L		
1-111617-1310	11/16/2017	Cadmium Dissolved	<0.001	mg/L		
1-111617-DUP	11/16/2017	Cadmium Dissolved	<0.001	mg/L		
1-111617-1310	11/16/2017	Cadmium Total	<0.001	mg/L		
1-111617-DUP	11/16/2017	Cadmium Total	<0.001	mg/L		
1-111617-1310	11/16/2017	Calcium Total	151	mg/L		24.93
1-111617-DUP	11/16/2017	Calcium Total	194	mg/L		
1-111617-1310	11/16/2017	Calcium, meq, Total	7.51	meq/L		25.15
1-111617-DUP	11/16/2017	Calcium, meq, Total	9.67	meq/L		
1-111617-1310	11/16/2017	Carbonates	<10	mg/L		
1-111617-DUP	11/16/2017	Carbonates	<10	mg/L		
1-111617-1310	11/16/2017	Chlorides	48	mg/L		0.00
1-111617-DUP	11/16/2017	Chlorides	48	mg/L		
1-111617-1310	11/16/2017	Chromium Dissolved	<0.005	mg/L		
1-111617-DUP	11/16/2017	Chromium Dissolved	<0.005	mg/L		
1-111617-1310	11/16/2017	Chromium Total	<0.005	mg/L		
1-111617-DUP	11/16/2017	Chromium Total	<0.005	mg/L		

TABLE 11 - DUPLICATE SAMPLE RELATIVE PERCENT DIFFERENCE
Gillette Madison Well-field Project

Well Name	Sample Date	Parameter Name	Sample Value	Units	Qualifier	Duplicate Field RPD (%)
1-111617-1310	11/16/2017	Cobalt Dissolved	<0.005	mg/L		
1-111617-DUP	11/16/2017	Cobalt Dissolved	<0.005	mg/L		
1-111617-1310	11/16/2017	Cobalt Total	<0.005	mg/L		
1-111617-DUP	11/16/2017	Cobalt Total	<0.005	mg/L		
1-111617-1310	11/16/2017	Copper Dissolved	<0.005	mg/L		
1-111617-DUP	11/16/2017	Copper Dissolved	<0.005	mg/L		
1-111617-1310	11/16/2017	Copper Total	<0.005	mg/L		
1-111617-DUP	11/16/2017	Copper Total	<0.005	mg/L		
1-111617-1310	11/16/2017	Cyanide, Total	<0.005	mg/L		
1-111617-DUP	11/16/2017	Cyanide, Total	<0.005	mg/L		
1-111617-1310	11/16/2017	Deuterium (2H)	-16.27			0.18
1-111617-DUP	11/16/2017	Deuterium (2H)	-16.3			
1-111617-1310	11/16/2017	Flouride	0.7	mg/L		13.33
1-111617-DUP	11/16/2017	Flouride	0.8	mg/L		
1-111617-1310	11/16/2017	Gross Alpha minus Rn & U	0.4	pCi/L	U	28.57
1-111617-DUP	11/16/2017	Gross Alpha minus Rn & U	0.3	pCi/L	U	
1-111617-1310	11/16/2017	Iron Dissolved	0.03	mg/L		40.00
1-111617-DUP	11/16/2017	Iron Dissolved	0.02	mg/L		
1-111617-1310	11/16/2017	Iron Total	0.03	mg/L		
1-111617-DUP	11/16/2017	Iron Total	0.03	mg/L		
1-111617-1310	11/16/2017	Lead Dissolved	<0.001	mg/L		
1-111617-DUP	11/16/2017	Lead Dissolved	<0.001	mg/L		
1-111617-1310	11/16/2017	Lead Total	<0.001	mg/L		
1-111617-DUP	11/16/2017	Lead Total	<0.001	mg/L		
1-111617-1310	11/16/2017	Lithium Dissolved	<0.1	mg/L		
1-111617-DUP	11/16/2017	Lithium Dissolved	<0.1	mg/L		
1-111617-1310	11/16/2017	Lithium Total	<0.1	mg/L		
1-111617-DUP	11/16/2017	Lithium Total	<0.1	mg/L		
1-111617-1310	11/16/2017	Magnesium Total	44	mg/L		24.00
1-111617-DUP	11/16/2017	Magnesium Total	56	mg/L		
1-111617-1310	11/16/2017	Magnesium, meq, Total Recoverable	3.63	meq/L		23.36
1-111617-DUP	11/16/2017	Magnesium, meq, Total Recoverable	4.59	meq/L		
1-111617-1310	11/16/2017	Manganese Dissolved	0.019	mg/L		5.41
1-111617-DUP	11/16/2017	Manganese Dissolved	0.018	mg/L		
1-111617-1310	11/16/2017	Manganese Total	0.018	mg/L		0.00

TABLE 11 - DUPLICATE SAMPLE RELATIVE PERCENT DIFFERENCE
Gillette Madison Well-field Project

Well Name	Sample Date	Parameter Name	Sample Value	Units	Qualifier	Duplicate Field RPD (%)
1-111617-DUP	11/16/2017	Manganese Total	0.018	mg/L		
1-111617-1310	11/16/2017	Mercury	<0.00005	mg/L		
1-111617-1310	11/16/2017	Mercury	<0.00005	mg/L		
1-111617-DUP	11/16/2017	Mercury	<0.00005	mg/L		
1-111617-DUP	11/16/2017	Mercury	<0.00005	mg/L		
1-111617-1310	11/16/2017	Nickel Dissolved	<0.005	mg/L		
1-111617-DUP	11/16/2017	Nickel Dissolved	<0.005	mg/L		
1-111617-1310	11/16/2017	Nickel Total	<0.005	mg/L		
1-111617-DUP	11/16/2017	Nickel Total	<0.005	mg/L		
1-111617-1310	11/16/2017	Nitrate-Nitrite (as Nitrogen)	2.18	mg/L		0.00
1-111617-DUP	11/16/2017	Nitrate-Nitrite (as Nitrogen)	2.18	mg/L		
1-111617-1310	11/16/2017	Oxygen-18 (18O)	-126.39			0.64
1-111617-DUP	11/16/2017	Oxygen-18 (18O)	-125.58			
1-111617-1310	11/16/2017	pH	6.68	s.u.	J	0.30
1-111617-DUP	11/16/2017	pH	6.66	s.u.	J	
1-111617-1310	11/16/2017	Potassium Total	4	mg/L		40.00
1-111617-DUP	11/16/2017	Potassium Total	6	mg/L		
1-111617-1310	11/16/2017	Potassium, meq, Total Recoverable	0.11	meq/L		30.77
1-111617-DUP	11/16/2017	Potassium, meq, Total Recoverable	0.15	meq/L		
1-111617-1310	11/16/2017	Radium 226	0.4	pCi/L		210.26
1-111617-DUP	11/16/2017	Radium 226	-0.01	pCi/L		
1-111617-1310	11/16/2017	Radium 226 + Radium 228	0.3	pCi/L		187.10
1-111617-DUP	11/16/2017	Radium 226 + Radium 228	0.01	pCi/L		
1-111617-1310	11/16/2017	Radium 228	-0.09	pCi/L		314.29
1-111617-DUP	11/16/2017	Radium 228	0.02	pCi/L		
1-111617-1310	11/16/2017	Selenium Dissolved	0.001	mg/L		
1-111617-DUP	11/16/2017	Selenium Dissolved	0.001	mg/L		
1-111617-1310	11/16/2017	Selenium Total	0.001	mg/L		
1-111617-DUP	11/16/2017	Selenium Total	0.001	mg/L		
1-111617-1310	11/16/2017	Silver Dissolved	<0.001	mg/L		
1-111617-DUP	11/16/2017	Silver Dissolved	<0.001	mg/L		
1-111617-1310	11/16/2017	Silver Total	<0.001	mg/L		
1-111617-DUP	11/16/2017	Silver Total	<0.001	mg/L		
1-111617-1310	11/16/2017	Sodium Total	48	mg/L		31.58
1-111617-DUP	11/16/2017	Sodium Total	66	mg/L		

TABLE 11 - DUPLICATE SAMPLE RELATIVE PERCENT DIFFERENCE
Gillette Madison Well-field Project

Well Name	Sample Date	Parameter Name	Sample Value	Units	Qualifier	Duplicate Field RPD (%)
1-111617-1310	11/16/2017	Sodium, meq, Total Recoverable	2.08	meq/L		31.24
1-111617-DUP	11/16/2017	Sodium, meq, Total Recoverable	2.85	meq/L		
1-111617-1310	11/16/2017	Solids, Total Dissolved TDS @ 180 C	1090	mg/L		0.00
1-111617-DUP	11/16/2017	Solids, Total Dissolved TDS @ 180 C	1090	mg/L		
1-111617-1310	11/16/2017	Strontium 90	0.4	pCi/L		85.71
1-111617-DUP	11/16/2017	Strontium 90	1	pCi/L		
1-111617-1310	11/16/2017	Strontium Dissolved	0.84	mg/L		0.00
1-111617-DUP	11/16/2017	Strontium Dissolved	0.84	mg/L		
1-111617-1310	11/16/2017	Strontium Total	0.8	mg/L		1.24
1-111617-DUP	11/16/2017	Strontium Total	0.81	mg/L		
1-111617-1310	11/16/2017	Sulfates	406	mg/L		0.49
1-111617-DUP	11/16/2017	Sulfates	404	mg/L		
1-111617-1310	11/16/2017	Sulfide	<0.04	mg/L		
1-111617-DUP	11/16/2017	Sulfide	<0.04	mg/L		
1-111617-1310	11/16/2017	Vanadium Dissolved	<0.01	mg/L		
1-111617-DUP	11/16/2017	Vanadium Dissolved	<0.01	mg/L		
1-111617-1310	11/16/2017	Vanadium Total	<0.01	mg/L		
1-111617-DUP	11/16/2017	Vanadium Total	<0.01	mg/L		
1-111617-1310	11/16/2017	Zinc Dissolved	<0.01	mg/L		
1-111617-DUP	11/16/2017	Zinc Dissolved	<0.01	mg/L		
1-111617-1310	11/16/2017	Zinc Total	<0.01	mg/L		
1-111617-DUP	11/16/2017	Zinc Total	<0.01	mg/L		
1-110917-0906	11/9/2017	Deuterium (2H)	-16.88			2.46
1-110917-0906	11/9/2017	Deuterium (2H)	-17.3			
1-110917-0906	11/9/2017	Oxygen-18 (18O)	-133.68			1.73
1-110917-0906	11/9/2017	Oxygen-18 (18O)	-136.01			
2-102717-1048	43035	Deuterium (2H)	-15.58			2.21
2-102717-1048-DUP	43035	Deuterium (2H)	-15.24			

Red Font Indicates Samples with RPDs Outside of Quality Control Limits (30%)
J = The sample was analyzed past the recommended holding time; therefore the result is estimated.
U = Not detected at minimum detectable concentration; therefore, the result is estimated.

TABLE 12 - MISSED SAMPLES
Gillette Madison Well-field Project

Sample ID	SDG	Analysis	Reason for Missed Sample or Analysis
071918-0920	2018-07-20-003	Ammonia (as Nitrogen)	Listed on the chain of custody but sample was not properly preserved; and therefore, was not analyzed by the laboratory.
071918-0920	2018-07-20-003	Nitrate-Nitrite (as Nitrogen)	Listed on the chain of custody but sample was not properly preserved; and therefore, was not analyzed by the laboratory.
071918-1015	2018-07-20-003	Ammonia (as Nitrogen)	Listed on the chain of custody but sample was not properly preserved; and therefore, was not analyzed by the laboratory.
071918-1015	2018-07-20-003	Nitrate-Nitrite (as Nitrogen)	Listed on the chain of custody but sample was not properly preserved; and therefore, was not analyzed by the laboratory.
1-11617-1325	2017-11-09-001	Dissolved metals	Filter was not operational
1-11717-0900	2017-11-09-001	Dissolved metals	Filter was not operational
1-11717-0950	2017-11-09-001	Dissolved metals	Filter was not operational
SPRING-1	2018-07-20-003	Ammonia (as Nitrogen)	Listed on the chain of custody but sample was not properly preserved; and therefore, was not analyzed by the laboratory.
SPRING-1	2018-07-20-003	Nitrate-Nitrite (as Nitrogen)	Listed on the chain of custody but sample was not properly preserved; and therefore, was not analyzed by the laboratory.
SW-1-071918	2018-07-20-003	Ammonia (as Nitrogen)	Listed on the chain of custody but sample was not properly preserved; and therefore, was not analyzed by the laboratory.
SW-1-071918	2018-07-20-003	Nitrate-Nitrite (as Nitrogen)	Listed on the chain of custody but sample was not properly preserved; and therefore, was not analyzed by the laboratory.
SW-2	2018-07-20-003	Ammonia (as Nitrogen)	Listed on the chain of custody but sample was not properly preserved; and therefore, was not analyzed by the laboratory.
SW-2	2018-07-20-003	Nitrate-Nitrite (as Nitrogen)	Listed on the chain of custody but sample was not properly preserved; and therefore, was not analyzed by the laboratory.

TABLE 13 – pH OF COMMON SUBSTANCES

pH Value	Example Solution in this pH
pH = 0	Battery Acid
pH = 1	Stomach Acid
pH = 2	Lemon juice, vinegar
pH = 3	Grapefruit/orange juice, soda
pH = 4	Tomato juice, beer
pH = 5	Pepto Bismol, black coffee
pH = 6	Saliva, milk
pH = 7	Neutral
pH = 8	Sea water, eggs
pH= 9	Baking soda, toothpaste
pH = 10	Great Salt Lake, Milk of Magnesia
pH = 11	Ammonia solution
pH = 12	Soapy water
pH = 13	Bleach, oven cleaners
pH = 14	Liquid drain cleaner

TABLE 14 – SUMMARY OR DOMESTIC WELL CHEMISTRY

Gillette Madison Wellfield Study

	average for wells with pH > 6.5 s.u.	average for wells with pH < 6.5 s.u.
chloride (Mol %)	2.7	1.9
iron (Mol %)	ND	1.8
Iron (mg/L)	ND	22.86
sulfate (Mol %)	26.5	41.4
Sulfate (mg/L)	22.86	887.4

s.u.: Standard units

ND: Not detected greater than the sample quantitation limit

TABLE 15- WATER QUALITY COMPARISON:

FALL RIVER, LAKOTA AND MADISON FORMATIONS

	TDS (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	Cl (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)
Fall River	2215	321	148	186	33	260	1451
Lakota	1324	122	37	220	25	156	773
Madison	689	145	58	13	43	220	390

mg/L : milligrams per liter

APPENDICIES

(ON CD)

APPENDIX A
WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY
WYOMING POLLUTION DISCHARGE ELIMINATION SYSTEMS PERMITS

APPENDIX B
PRIVATE LANDOWNER COMMENTS ON WATER QUALITY/WELL PERFORMANCE

APPENDIX C
ANALYTICAL LABORATORY REPORTS

APPENDIX D
DATA VALIDATION REPORTS

APPENDIX E
TABLE OF QUALIFIED AND REJECTED DATA

APPENDIX F
DISCHARGE ESTIMATES

APPENDIX G
WATER TREATMENT OPTIONS

APPENDIX G. WATER TREATMENT OPTIONS

This appendix reviews specific domestic-well water quality concerns identified in the study area and suggests potential treatment options.

G.1 TREATMENT FOR ELEVATED pH

Acidulation involves the addition of acid to water to decrease pH. Either a strong acid (hydrochloric, sulfuric) or weak acid (white vinegar) can be used depending on the magnitude of the pH decrease required and the buffering capacity of the water (the resistance to pH change because of the presence of certain minerals). A metering pump typically injects acid from a storage tank into the piping at point of entry into the residential water system. Acidulation is the most direct and inexpensive method to decrease pH. The potential drawbacks are the safety issue of handling acid (especially a strong acid) and damage to the water system that could be caused by overtreatment. A system using a metering pump would have automatic pH monitoring installed to prevent overtreatment. Although not preferred from a safety standpoint, hydrochloric acid is freeze-resistant compared to the other acids.

G.2 NEUTRALIZING FILTER

Water that has a low pH (acidic) can be treated using a neutralizing filter containing calcite or ground limestone (calcium carbonate), or magnesia (magnesium oxide) to raise the pH. Neutralizing filters must be backwashed periodically since they also serve as mechanical filters that remove solid particles from the water. They also require periodic replacement of the neutralizing material. Water with a neutralizing filter should be tested for water hardness since the filter material will add calcium or magnesium to the water. For high capacity wells, a chemical feed pump can be used to feed a solution of soda ash (sodium carbonate) into the water supply. Soda ash can raise the pH level of water to over 8. If the water contains high levels of iron, or requires disinfection, a chemical feed pump is preferred since hypochlorite bleach and soda ash may be mixed into a single solution and fed through the pump.

G.3 CHLORINATION (TREATMENT FOR BACTERIA)

Chlorination (also called disinfection) involves the addition of chlorine gas or a chlorine containing compound to destroy bacteria in water. One method of chlorination is short-term (one-day) treatment of a well with a relatively high dose of a chlorine compound such as bleach, a process known as shock treatment. If the shock treatment cannot adequately disinfect the well, then a point-of -entry chlorination system can be installed. For residential water systems, bleach is typically the disinfectant compound of choice because of greater safety compared to the use of chlorine gas. A residential point- of-entry chlorination system typically has a bleach storage tank, and bleach is injected into the water as it is pumped from the well. Where freeze protection for the bleach storage tank is an issue, chlorine gas can be injected from a cylinder into the water line. Chlorination is a proven technology and the equipment and operating costs are relatively inexpensive. Elevated water pH decreases chlorination efficiency. Thus, local groundwater may

need acidulation for effective chlorination. Feed water with an elevated soluble ferrous iron content would need iron removal before or filtering after chlorination, as the chlorine chemicals will oxidize the ferrous iron to insoluble ferric chloride which would foul the water system.

G.4 FILTRATION (TREATMENT FOR TURBIDITY, INSOLUBLE IRON)

Filtration is a simple and relatively inexpensive technology for removal of particulate matter that contributes to water turbidity. Filtration will also remove non-soluble (ferric) iron. In residential applications, filtration involves passing water through a cartridge or bag inside a filter housing, where the filter material traps or blocks the particulate matter. The filter is replaced once loaded with particulate matter to the point that water flow is restricted.

G.5 GREENSAND ADSORPTION (TREATMENT FOR IRON AND MANGANESE)

Greensand is a material with the unique capability to oxidize dissolved iron and manganese to their insoluble (solid) forms. The solid iron and manganese are then filtered (adsorbed) by the greensand. Treatment proceeds until the solid iron and manganese loading on the greensand restricts continued water flow, at which point the greensand vessel is backwashed similar to the process for a conventional residential water softener. Greensand adsorption is effective and relatively inexpensive. The major drawback is the hazard of the potassium permanganate (strong oxidizer chemical) used to backwash and regenerate the greensand.

G.6 ION EXCHANGE (TREATMENT FOR TDS, ANIONS, CATIONS, METALS, RADIONUCLIDES)

Ion Exchange (IX) vessels contain resins manufactured to adsorb specific constituents. As water flows through an IX vessel, components on the surface of the resin switch (exchange) with the target constituents in the water. The conventional residential water softener is an example of an IX treatment in which the calcium and magnesium hardness minerals in the water exchange with sodium ions on the resin. When the sodium ions on the resin are depleted, the resin is backwashed with a salt (sodium) solution to regenerate the resin for another cycle of use. IX resins can be effective for numerous water constituents and many resins are regenerated with a salt solution that is inexpensive and safe to handle. However, some resins, including those for sodium and chloride treatment, require regeneration using a strong acid or caustic solution.

G.7 OZONATION (TREATMENT FOR BACTERIA)

Ozonation is an alternative to chlorination for water disinfection. In this technology, an ozone generator converts oxygen in the air to oxidizing ozone molecules and the ozone is injected into the water. Ozonation efficiency is relatively insensitive to water pH, so local groundwater ozonation has the advantage of not requiring feed water acidulation as necessary for chlorination. However, ozone equipment is costly and ozone generation has a relatively high power requirement.

TABLE G-1 – POTENTIAL WATER TREATMENT OPTIONS

Water Quality Constituent	Acidulation	Chlorination	Neutralizing Filter	Greensand Adsorption	Ion Exchange	Ozonation	Reverse Osmosis
High pH	X						
Low pH			X				
TDS					X		X
Sulfate					X		X
Sodium					X		X
Iron and Manganese				X	X		X
Nitrate					X		X
Bacteria		X				X	
Radionuclides					X		X
Trace Metals					X		X