Great West Engineering , Inc.

Kootenai Monitoring Well CMRWA MW#1 Construction Report

Central Montana Regional Water Authority

August 2017

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REGISTERED
PROFESSIONAL ENGINEER

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WESTERN
GROUNDWATER
SERVICES

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1. INTRODUCTION

The Central Montana Regional Water Authority (CMRWA) installed a Kootenai aquifer monitoring well, designated as CMRWA MW#1, at the U Bet Wellfield near Garneill (**Figure 1**). CMRWA is developing wells into the Madison aquifer at this location to provide a water supply to the Musselshell-Judith Regional Water System (MJRWS). The Kootenai aquifer occurs above the Madison aquifer and is utilized by numerous land owners in Judith Basin. The Kootenai monitoring well will be used to assess if a hydraulic connection exists between the two formations at the U Bet Wellfield, and also to monitor long-term water level trends in the Kootenai aquifer.

In 2015 CMRWA was awarded a grant from the State to further evaluate water resources in Judith Basin, where the U Bet Wellfield is located. One of the activities of the grant was to construct a dedicated monitoring well into the Kootenai aquifer. Unlike the many other Kootenai aquifer wells in Judith Basin, the monitoring well would not be used to supply water, and therefore would not be in regular use.[1] The monitoring well was constructed and equipped with a water level sensor in September 2016. This report is documenting the well construction and initial data.

Western Groundwater Services completed this report while working as a subconsultant to Great West Engineering, Inc. Great West Engineering is the prime consultant to CMRWA for the MJRWS project.

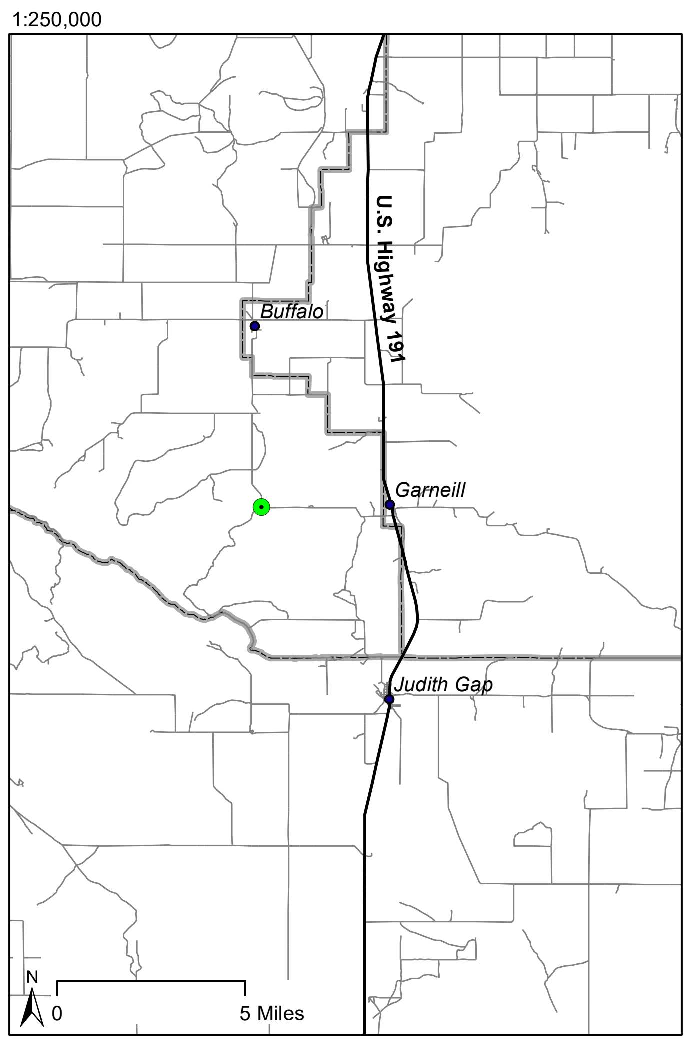


Figure 1. Location Map

1 Another activity of the grant that is underway includes monitoring of three private Kootenai wells in Judith Basin.

1.1 Report Summary

- The Kootenai monitoring well, CMRWA MW#1, was constructed to 712 feet below ground surface (ft bgs). The sandstone aquifer occurs from 610 to 712 ft, and is open to the well through a screen. This aquifer is also referred to as the Third Cat Creek.

- Static water level was at 0 ft bgs. A computer logging water level sensor has been set into the well for long-term water level monitoring.

- A 1-1/2 hp submersible pump was set into the well for sampling the groundwater. The pump is set at approximately 308 ft bgs. It can be run by a 3.5 KW generator (1PH, 240 VAC).

- The aquifer transmissivity was estimated at 147 ft^2/d, which is low but not unusual for sandstone aquifers.

- Water quality is moderately hard, has a trace of manganese, but overall a low dissolved ion concentration. Analysis of the hydrogen isotope tritium was completed, indicating the groundwater pumped from the well was at least 70 years old, since the time it entered the subsurface.

2. WELL CONSTRUCTION

2.1 Bidding

Drilling contractor services for well construction were publically bid with a bid opening on February 3, 2016. The project was awarded to the lowest bidder, Aquasource, LLC of Vaughn, MT. **Table 1** provides the bid items and actual fees paid to the contractor.

After the well was constructed and the static water level was measured, a change order was processed to install a submersible pumping system. The pumping system was not included in the initial bid because there was some likelihood the well could have been flowing artesian, and a pump would not be needed for sampling. Static water level was measured at ground level, or 0 ft bgs. The well therefore would not flow naturally and a pump was installed.

Table 1. Well Construction Contractor Fees

Item	Quantity	Units	Rate	Total
Mobilization/Demobilization	1	LS	$ 2,400	$ 2,400
12-1/4 In Drilling	40	LF	$ 80	$ 3,200
8-5/8 In Casing, set and cemented	40	LF	$ 80	$ 3,200
7-7/8 In Drilling	575	LF	$ 42	$ 24,150
4-1/2 In Casing, set and cemented	618	LF	$ 32	$ 19,776
3-7/8 In Drilling	97	LF	$ 42	$ 4,074
2 In Liner Screen	125	LF	$ 90	$ 11,250
Development	8	HR	$ 500	$ 4,000
Change No. 1 - Pumping System	1	LS	$ 11,606	$ 11,606
Change No. 1 - Pump Operation Hourly	10	HR	$ 260	$ 2,600
TOTAL				$ 86,256
LS – lump sum; LF – linear foot; HR – hours.				

2.2 As-Built Construction

Drilling equipment was mobilized to the site and surface casing was drilled, set and cemented on May 9, 2016. Drilling of the remainder of the well to the total depth of 712 ft bgs occurred from May 16th to May 22nd. Screening, development, and disinfection of the well was completed by May 27th.

A surface casing of 8-5/8 inch diameter was set and cemented into a 12-1/4 inch diameter borehole to a depth of 40 ft bgs (**Figure 2**). From below surface casing, the borehole was drilled at 7-7/8 inch diameter into the Kootenai aquifer, which occurred at 610 feet. A 4-1/2 inch diameter steel casing was set and cemented into this borehole, with a total depth of 615 ft bgs. From below this casing, the borehole was drilled at 3-7/8 inch diameter through the Kootenai aquifer, terminating at a depth of 712 ft bgs. This borehole was completed with a 2-3/8 inch diameter stainless steel wire-wrapped, rod-based screen. Well casings were centralized prior to cementing. The surface casing used two centralizers, whereas the 4-1/2 inch diameter casing used centralizers set at one per 60 feet. Development was completed by eight hours of air-lift pumping and surging. Disinfection was completed using calcium hypochlorite tablets poured into the well from surface, and the well was then capped.

Work to install the pumping system was deferred until September 2016 to coincide with other work in the area. **Table 2** lists the as-built construction for the pumping system. The completion design of the wellhead is shown on **Figure 3**. The water level sensor and pump were installed down the well below a mechanical packer. The packer holds groundwater at a depth of about 6 ft bgs to prevent freezing. In order to accommodate the packer, a 6-inch casing was welded onto the 4-inch casing from a depth of about 10 ft bgs. The power cable for the submersible pump and the communication cable for the water level sensor pass through the packer and are accessible at the surface.

To remove either the pump or water level sensor, it is necessary to remove the packer. The packer is removable from surface after loosening the riser pipe (extending from the packer to surface and used to actuate the packer) using an approximately 1-inch socket wrench. Upon re-installing the packer, it is necessary to remove water from above the packer. This can be done by bailing or air-lifting from the surface, or by running the well pump to create drawdown draining water from above the packer into the well. A 3.5 KW generator with 240VAC output is sufficient to run the well pump.

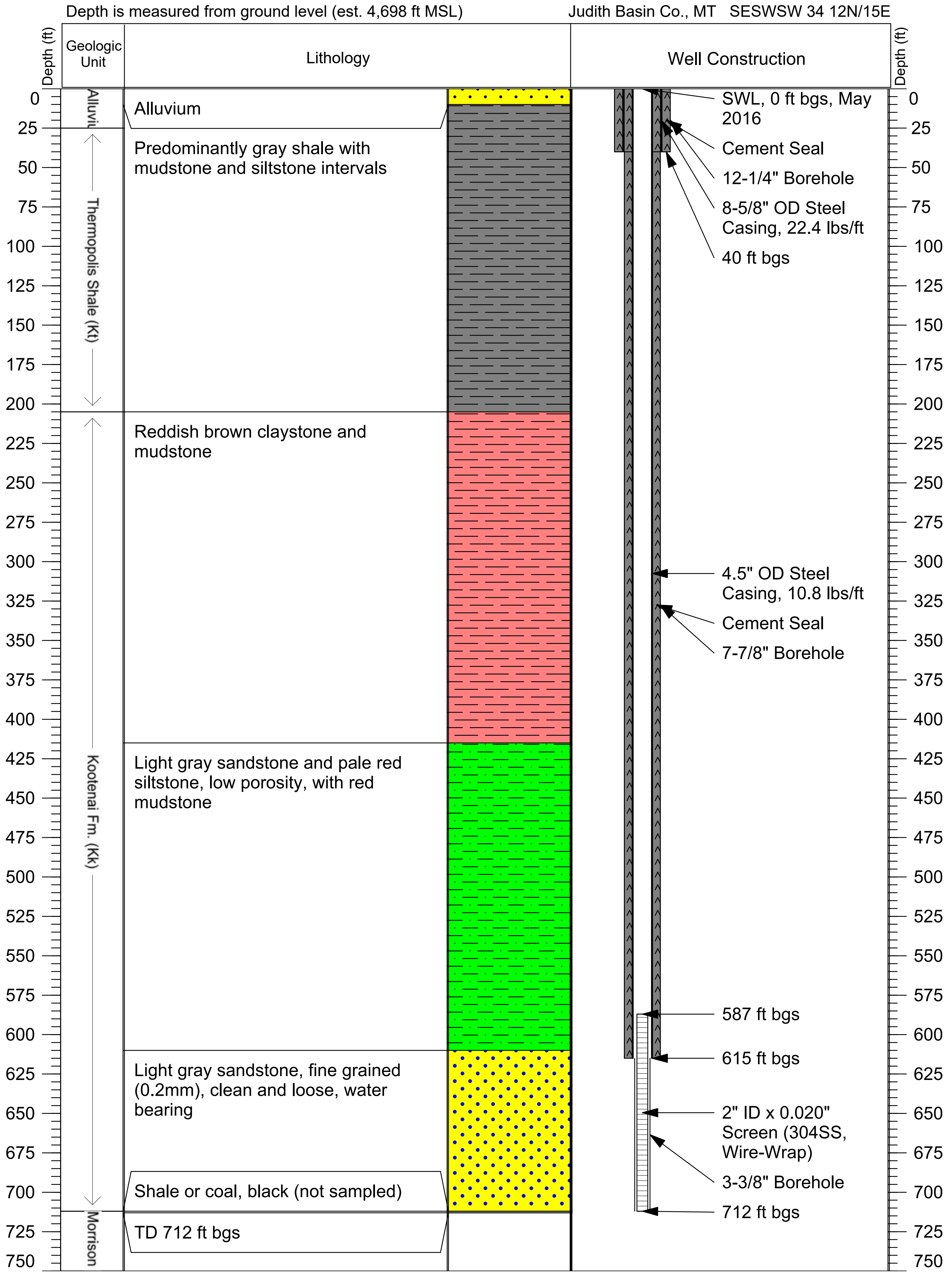


Figure 2. CMRWA MW#1 As-Built Log

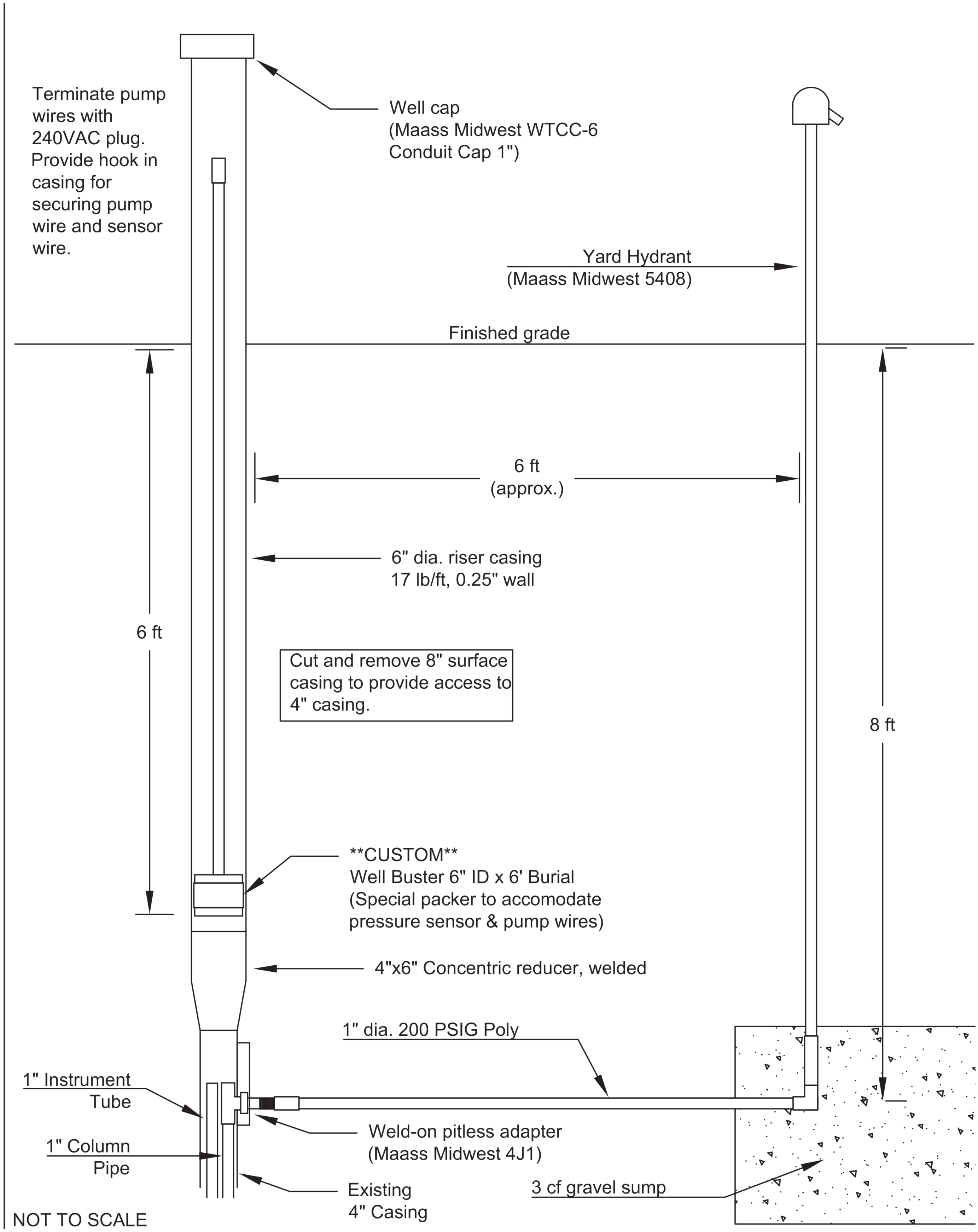


Figure 3. CMRWA MW#1 Wellhead Design

Table 2. Pumping System As-Built Information

Item	Description	
Water Level Sensor	Level Troll 500, 300 psig	In-Situ
Packer	Well Buster ™ (Custom)	Maass Midwest
Instrument Tube	Sch 80 PVC, T&C joints	287 ft
Pump Column[A]	Sch 80 PVC, T&C joints	300 ft
Pump	15SQ-290, 3-inch	Grundfos
Motor	1-1/2 HP, 3-inch, 240 VAC, 1 PH, 2-Wire	Grundfos
[A] No check valves were used.		

2.3 Borehole Geology

Samples of drilling cuttings were logged at a 30-ft interval. A detailed log of borehole samples is provided in Appendix A.

The borehole was started in unconsolidated alluvium which forms a thin cover over bedrock to a depth of about 10 ft bgs. From below alluvium, the borehole penetrated fine-grained mud rocks of the Thermopolis Shale. This formation is low permeability throughout, consisting of various beds classified as shale, claystone, mudstone, and siltstone. The Thermopolis Shale conformably overlies the Kootenai formation with a contact occurring at about 205 ft bgs. At this depth, drilling cuttings first had a red hue, which is characteristic of the Kootenai.

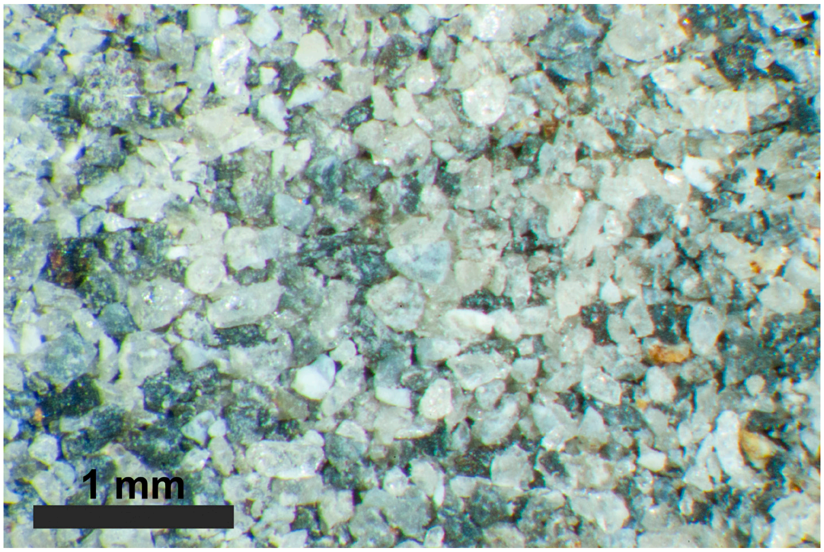
The upper part of the Kootenai formation consisted of mudstone and claystone predominantly with a reddish brown color. There are minor occurrences of limestone and sandstone in this interval. From below 425 ft bgs, the formation becomes coarser, consisting of sandstone and siltstone, but also of low permeability due to the occurrence of clay and cementation. Cementing of the formation was mostly calcium carbonate, but also included kaolin clay.

The aquifer is clearly defined by the occurrence of clean sandstone that when drilled becomes loose grains. It occurred from 610 to 712 ft bgs, and is the same aquifer known as the Third Cat Creek. The Morrison formation immediately underlies the aquifer and consists of black shale or coal—it could not be sampled, but was observed through the immediate change in mud color and reduced penetration rate.

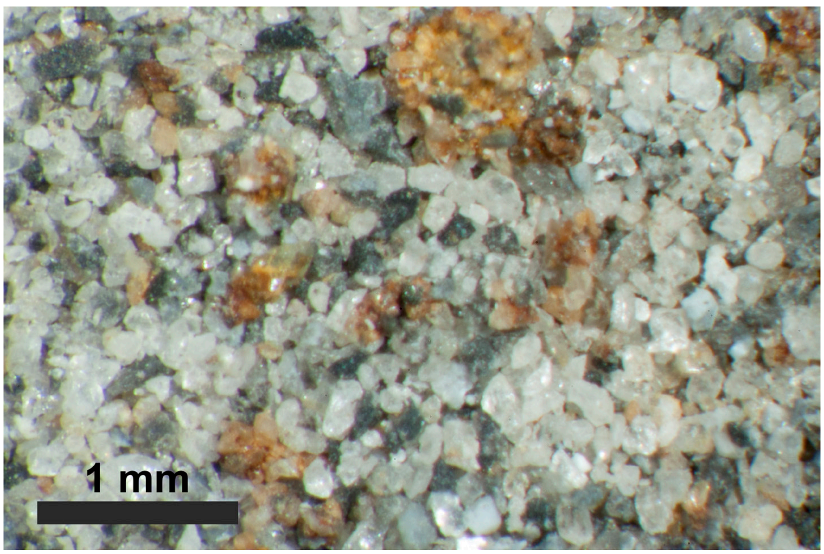
The aquifer sandstone is estimated to have a porosity of about 30%. It consists of about 70% white to light gray quartz and feldspar mineral grains, and 30% of gray to black opaque and semi-transparent grains of undetermined lithology or mineralogy (**Figure 4**). These dark grains are typically oxides, mafic rock fragments (e.g., basalt), mafic minerals (e.g., pyroxene), or in this case, possibly a dark colored form of chert (silica). There is notable iron staining of some of the material, and pyrite grains occur sparsely. The nominal grain size of the aquifer sandstone is about 0.2 millimeters, which is classified as fine sand.

Total thickness of the Kootenai formation was 507 ft. The upper 395 ft consisted of low permeability fine-grained rocks. The basal fine-grained sandstone with a thickness of 112 ft was the only water bearing zone encountered.

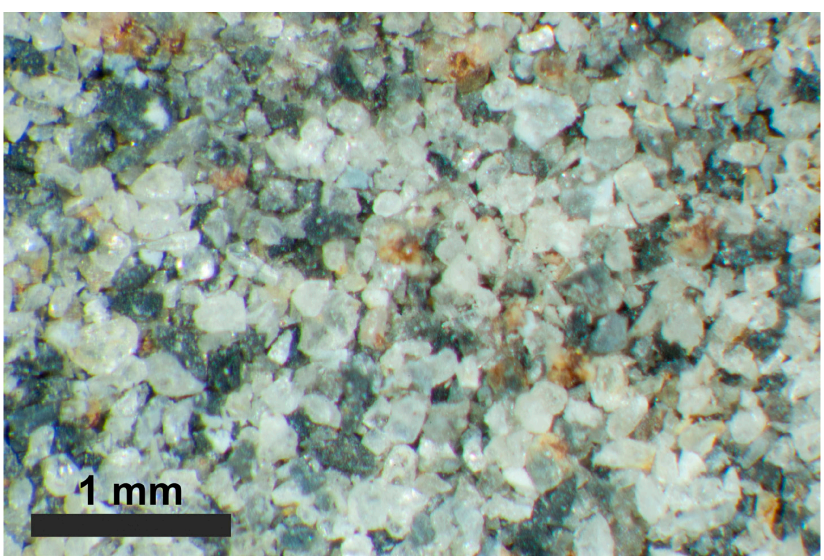
Figure 4. Aquifer Sandstone Stereomicroscope Photos (26X)



A. 640 ft



B. 670 ft



C. 700 ft

3. HYDRAULIC TESTING

A short term hydraulic test of the aquifer was completed when the well was being purged for water sampling. The test was initially started at a pumping rate of 13.2 gpm, and was then increased to 15.7 gpm (**Figure 5**). This increase of 2.5 gpm resulted in about 7-ft of additional drawdown. Total drawdown at the end of five hours of pumping was about 73 ft. Specific capacity for this pumping period was 0.2 gpm/ft (15.7 / 73).

Test data were analyzed by well hydraulic methods to determine an aquifer transmissivity of 147 ft^2/d (**Figure 6A and Figure 6B**). This transmissivity value appears to reasonably match both drawdown and recovery data. While a low value, it is not atypical of sandstone aquifers. It is possible for this value to vary by a factor of two or three in the area with no visible difference in the quality of the sandstone formation.

A model fit to the test data is most accurate for those data collected after the pumping rate was increased (**Figure 6C**). In order to fit the model to the data, the storativity was first fixed at 1E-6, and then the borehole skin factor was adjusted by reducing the effective well radius. The skin factor is about 11.25, which is exceptionally high.[2] This high skin factor value is indicating substantial plugging at the well bore, but could also be caused by aquifer anisotropy and vertical flow (i.e., partial penetration). If the well were to be used for water supply, an attempt at further development would be warranted.

Well capacity was estimated using the model and assuming that 200 ft of drawdown was available over a continuous one-year pumping period. A rate of 40 gpm was determined for the well (**Figure 6D**). If in fact the well is plugged, additional development could substantially increase this rate.

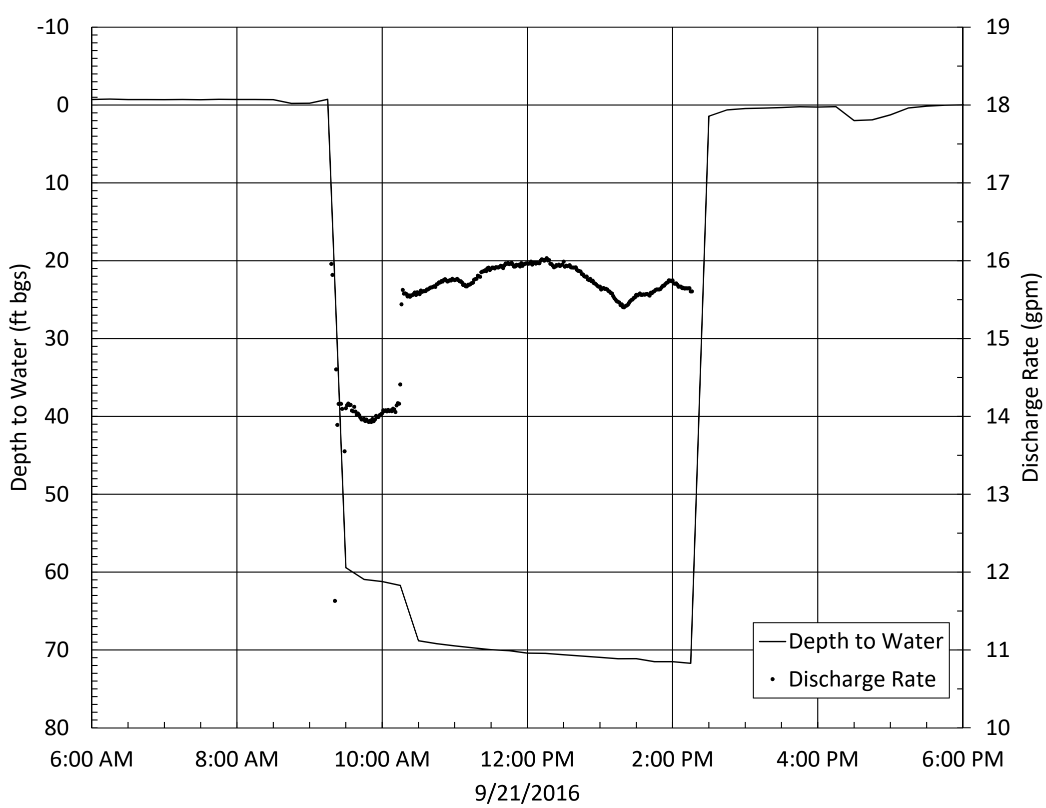


Figure 5. Pumping Test Hydrograph

2 The fixed storativity is considered a reasonable value. If it were estimated by the model, it would be reduced to unreasonably low values, while maintaining a more reasonable lower skin factor. This performance of the model is reflecting the non-uniqueness of the solution.

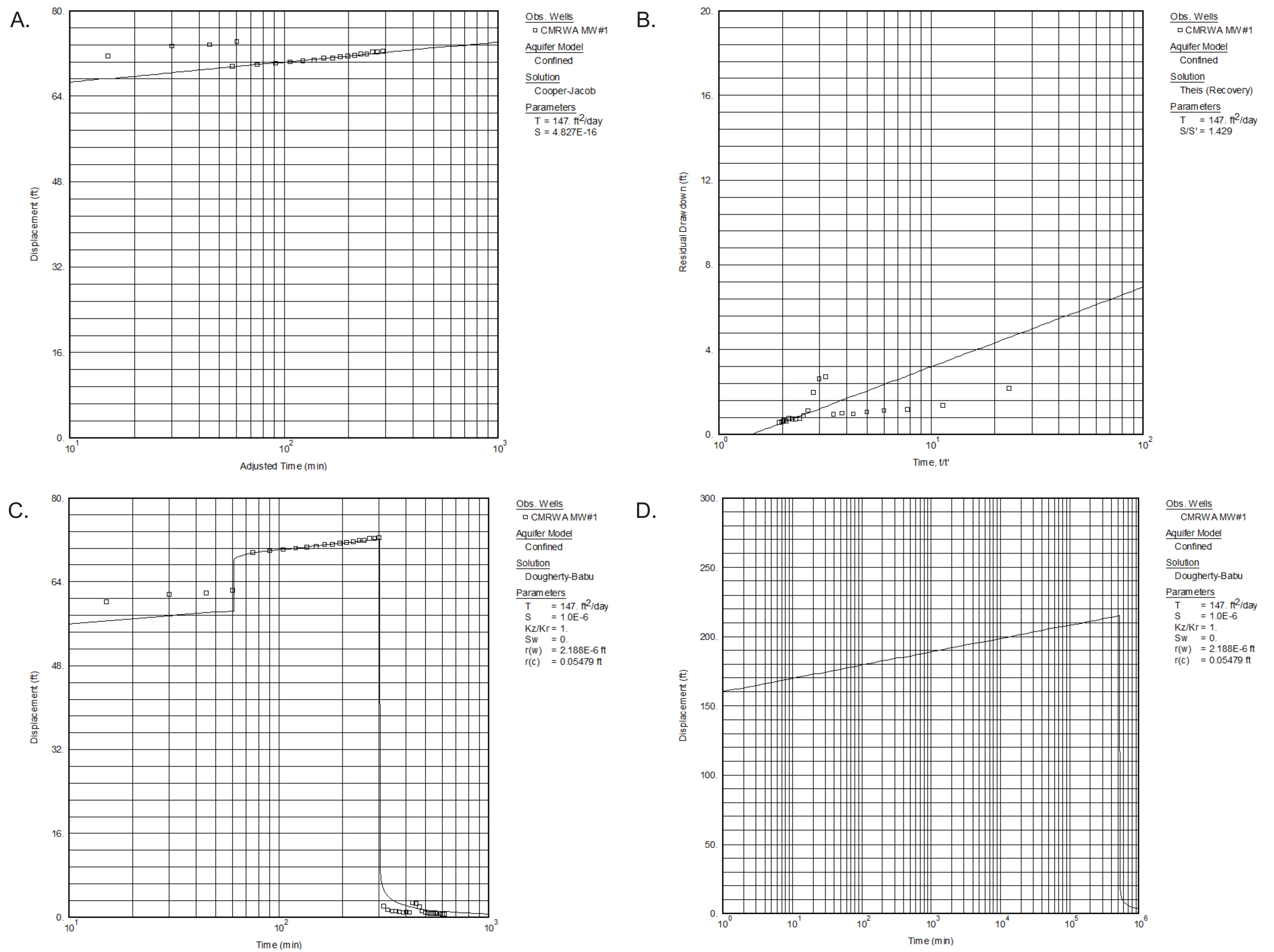


Figure 6. Hydraulic Analysis Plots

4. WATER SAMPLING

Water quality data from the CMRWA MW#1 monitoring well were collected to characterize the general chemistry of the Kootenai aquifer near to its recharge area in the Little Belt Mountains. These data were subsequently used in a study of several springs in Judith Basin. The spring study also was a grant funded project, and is reported separately.[3]

Prior to sampling the well was purged for approximately nine hours at a rate of about 15 gpm, totaling 8,100 gallons. It was estimated that possibly 1,000 gallons of drilling water had discharged into the well as water loss through the mud filter cake. This purge volume is expected to have fully removed the drilling water. The well is considered to have been producing Kootenai aquifer water at the time of sampling.

Field parameters were measured using a calibrated Horiba U-52 multi-sensor set into a pressurized flow cell. This equipment prevented the well water from contact with the atmosphere prior to measurement of field parameters. The stabilized values for field parameters are listed in **Table 3**. The Kootenai groundwater is generally reducing, which can result in dissolved iron and manganese in the water. The dissolved mineral content is low, and the pH is moderately alkaline.

Table 3. Field Parameter Measurements

Temp (C/F)	pH (std. units)	ORP (mV)	SC (µS/cm)	Turbidity (NTU)	DO (mg/L)
11.04/51.9	8.26	-267	292	5.0	0.47
Temp - temperature, ORP - oxidation reduction potential, SC - specific conductance; DO - dissolved oxygen.					

Water samples were also collected for laboratory analysis, completed by Inter-Mountain Labs, Inc. of Sheridan, WY. The lab report is provided in Appendix B. Sample bottles were filled directly from a tap in the well discharge and shipped by ground freight to the lab. Samples for metals were filtered in the field at 0.45 micrometers (µm). These results show the groundwater is hard and has a low concentration of manganese, but iron was non-detect. There was also 1 mg/L of organic carbon determined from the analysis. Both gas and diesel organic screening analyses were non-detect.

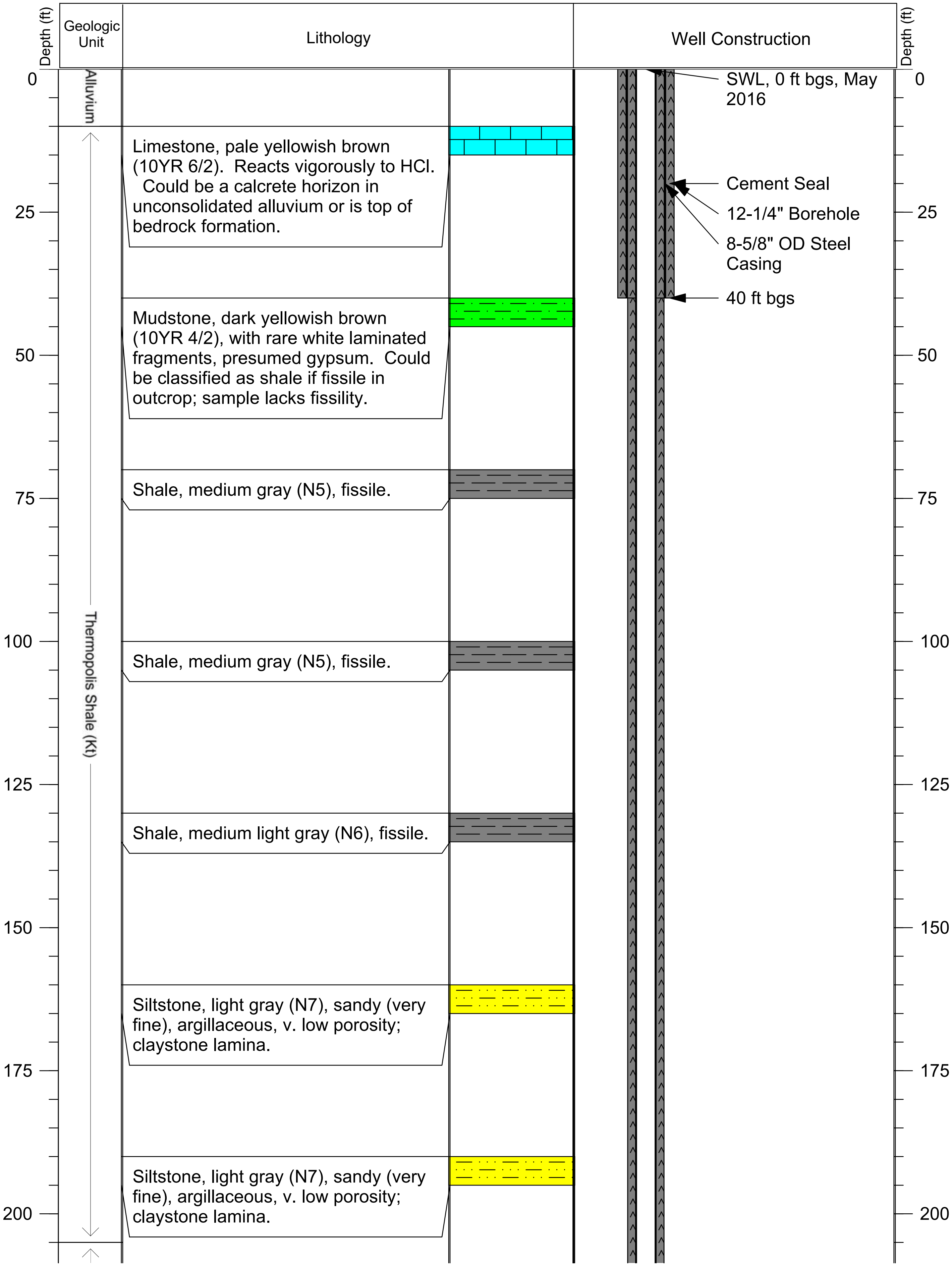
Isotope analysis was also completed on water samples at the University of Arizona Environmental Isotope Laboratory, Tucson, AZ. These samples also were filtered in the field and express shipped to the lab. Isotope results are shown in **Table 4**. These data were used in comparison to Madison groundwater and spring groundwater collected at other locations, which are discussed in the spring study report. Both carbon-13 and Sulphur-34 were found to be substantially depleted in the CMRWA MW#1 groundwater as compared to Madison groundwater. These isotopes appear to be useful in distinguishing Madison and Kootenai groundwaters from one another. The non-detect tritium result is indicating a groundwater age of greater than approximately 70 years, since the time the water first entered the subsurface.

Table 4. Isotope Analytical Results

Oxygen-18	Deuterium	Carbon-13	Sulphur-34	Tritium
-17.8	-135.6	-8.1	-3.2	< 0.5
Deuterium and tritium are isotopes of hydrogen that have two and three neutrons, respectively. Isotope measures are ratios presented as per mil (‰) relative to a standard measure, except tritium which is measured in tritium units (TU).				

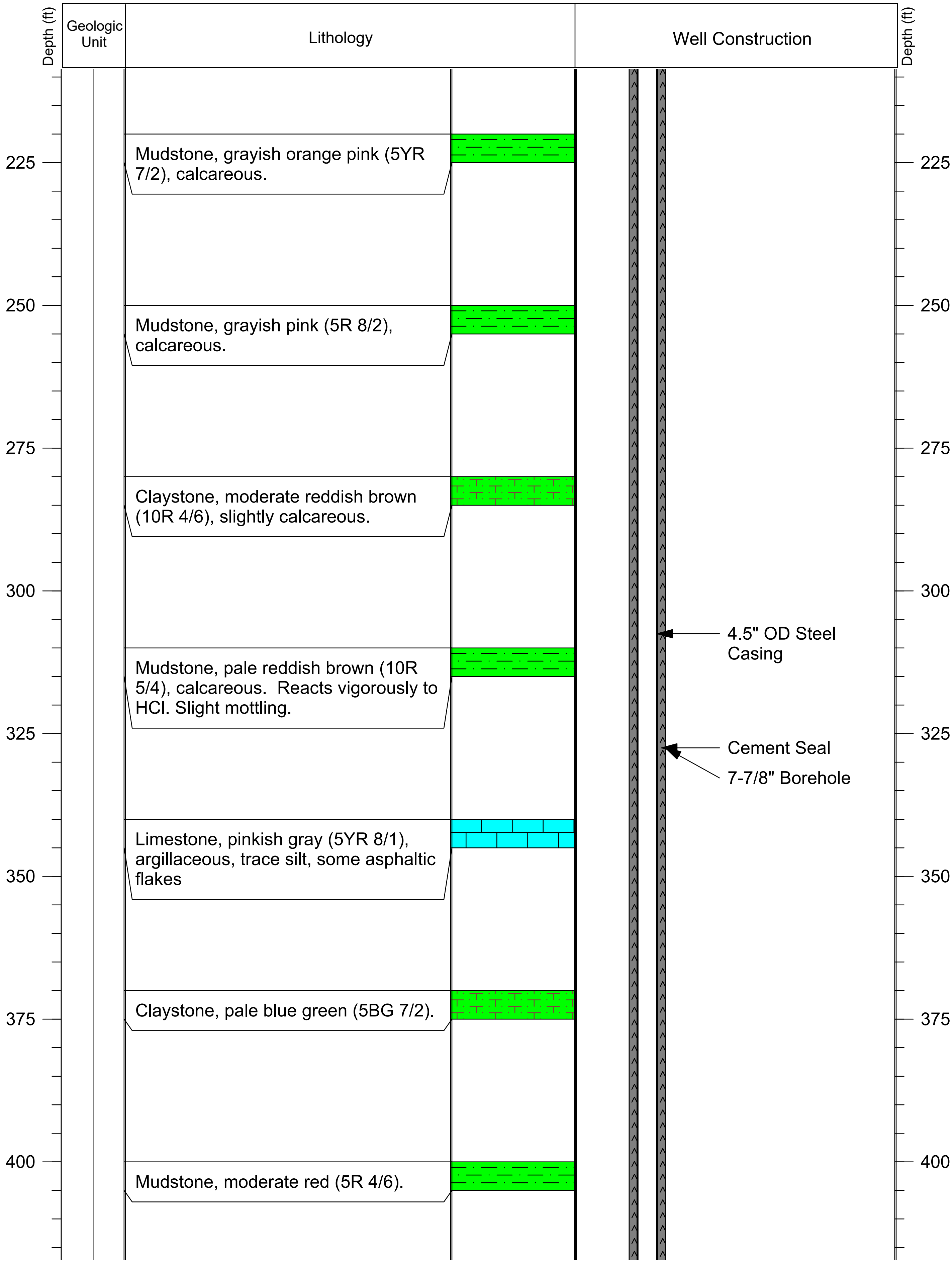
3 Judith Basin Spring Inventory Report, May 2017, available on the CMRWA website.

APPENDIX A – BOREHOLE SAMPLE LOG



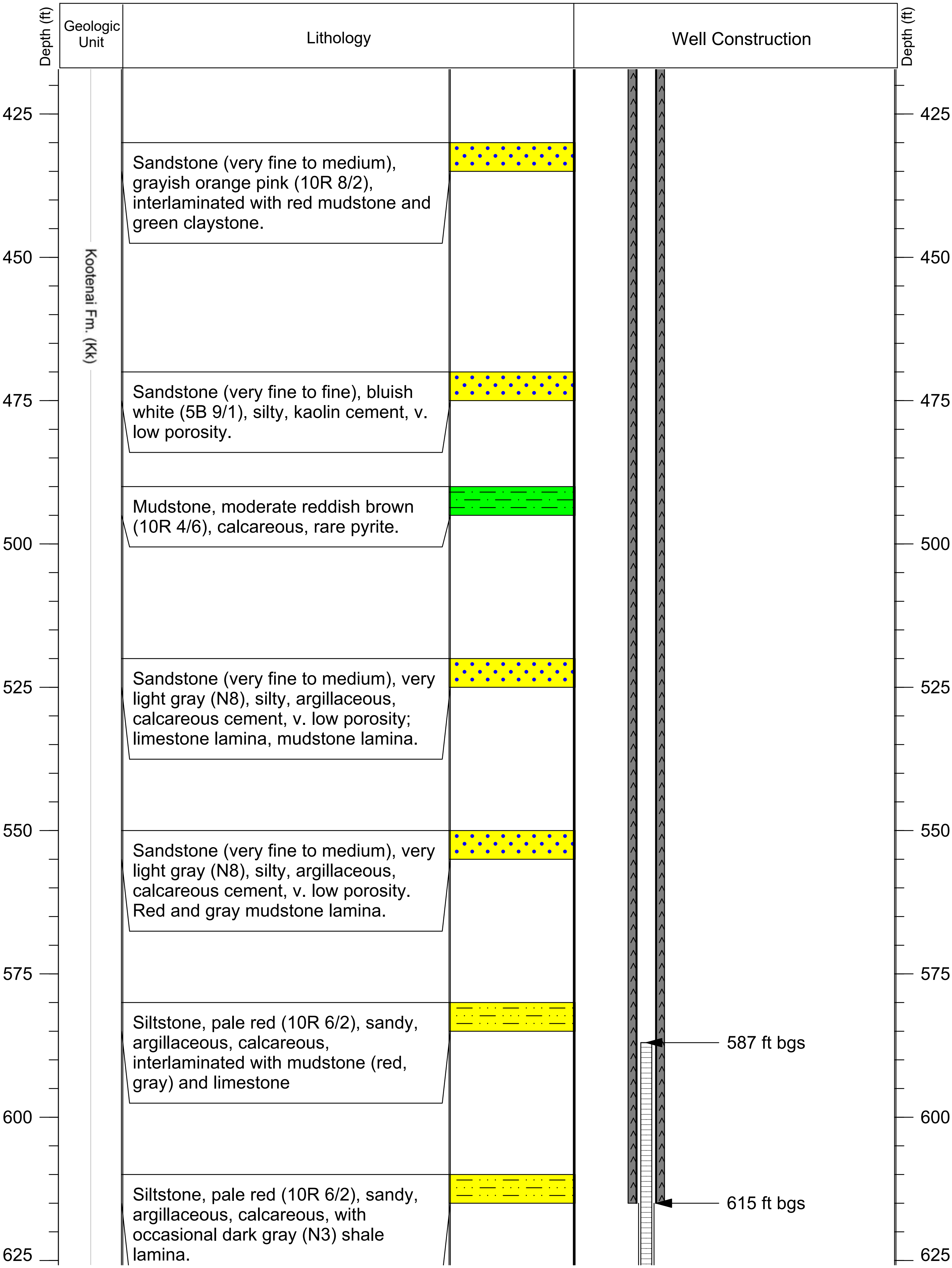
Depth (ft)
Geologic Unit
Lithology
Well Construction
Depth (ft)
0
25
50
75
100
125
150
175
200
Alluvium
Thermopolis Shale (Kt)
Limestone, pale yellowish brown (10YR 6/2). Reacts vigorously to HCl. Could be a calcrete horizon in unconsolidated alluvium or is top of bedrock formation.
Mudstone, dark yellowish brown (10YR 4/2), with rare white laminated fragments, presumed gypsum. Could be classified as shale if fissile in outcrop; sample lacks fissility.
Shale, medium gray (N5), fissile.
Shale, medium gray (N5), fissile.
Shale, medium light gray (N6), fissile.
Siltstone, light gray (N7), sandy (very fine), argillaceous, v. low porosity; claystone lamina.
Siltstone, light gray (N7), sandy (very fine), argillaceous, v. low porosity; claystone lamina.
SWL, 0 ft bgs, May 2016
Cement Seal
12-1/4" Borehole
8-5/8" OD Steel Casing
40 ft bgs

Depth is measured from ground level (est. 4,698 ft MSL) Judith Basin Co., MT SESWSW 34 12N/15E



Western Groundwater Services

Depth is measured from ground level (est. 4,698 ft MSL) Judith Basin Co., MT SESWSW 34 12N/15E



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Depth is measured from ground level (est. 4,698 ft MSL) Judith Basin Co., MT SESWSW 34 12N/15E

Depth (ft)	Geologic Unit	Lithology	Well Construction	Depth (ft)

625

Sandstone, fine (0.2 mm), light gray (N7), loose, clean, subangular to subrounded, well sorted, consisting of approximately 70% white and gray grains of quartz and feldspar and 30% gray to dark gray grains of presumed mafic rocks and minerals.

650

2" ID x 0.020" Screen (304SS, Wire-Wrap)

3-3/8" Borehole

Sandstone, fine (0.2 mm), light gray (N7), loose, clean, subangular to subrounded, well sorted, consisting of approximately 70% white and gray grains of quartz and feldspar and 30% gray to dark gray grains of presumed mafic rocks and minerals. Iron staining is common. Pyrite grains occur sparsely.

675

700

Sandstone, fine (0.2 mm), light gray (N7), loose, clean, subangular to subrounded, well sorted, consisting of approximately 70% white and gray grains of quartz and feldspar and 30% gray to dark gray grains of presumed mafic rocks and minerals. Iron staining is common.

712 ft bgs

Morrison (Jm)

725

750

Western Groundwater Services

APPENDIX B – LABORATORY ANALYSIS REPORT

Inter-Mountain Labs

Your Environmental Monitoring Partner

1673 Terra Avenue, Sheridan, Wyoming 82801 ph: (307) 672-8945

Sample Analysis Report

CLIENT: Western Groundwater Services
6595 Bear Claw Lane
Bozeman, MT 59715

Date Reported: 10/10/2016
Report ID: S1609421001

Work Order: S1609421
Collection Date: 9/21/2016 2:00:00 PM
Date Received: 9/26/2016 9:00:00 AM
Sampler: MC
Matrix: Water
COC: 169059

Project:
Lab ID: S1609421-001
Client Sample ID: CMRWA MW#1 092116 MC

Analyses	Result	RL	Qual	Units	Date Analyzed/Init	Method
General Parameters						
pH	8.4	0.1		s.u.	09/26/2016 1659 IBS	SM 4500 H B
Electrical Conductivity	307	5		µmhos/cm	09/26/2016 1659 IBS	SM 2510B
Solids, Total Dissolved (Calc)	170	10		mg/L	10/10/2016 0934 BC	SM 1030E
Alkalinity, Total (As CaCO3)	130	5		mg/L	09/26/2016 1659 IBS	SM 2320B
Hardness, Calcium/Magnesium (As CaCO3)	150	1		mg/L	10/10/2016 0934 BC	SM 2340B
Nitrogen, Nitrate (As N)	ND	0.05	H	mg/L	09/26/2016 0953 AB	EPA 300.0
Phosphorus, Orthophosphate as P	ND	0.01	H	mg/L	09/26/2016 0953 AB	EPA 300.0
Sulfide	ND	0.01		mg/L	09/26/2016 1209 KB	HACH 8131
Total Organic Carbon	1	1		mg/L	10/04/2016 1711 AB	SM 5310B
Sulfide as H2S	ND	0.01		mg/L	09/26/2016 1209 KB	HACH 8131
Anions						
Alkalinity, Bicarbonate as HCO3	156	5		mg/L	09/26/2016 1659 IBS	SM 2320B
Alkalinity, Carbonate as CO3	ND	5		mg/L	09/26/2016 1659 IBS	SM 2320B
Chloride	1	1		mg/L	09/26/2016 0953 AB	EPA 300.0
Fluoride	0.2	0.1		mg/L	09/26/2016 1659 IBS	SM 4500FC
Sulfate	29	1		mg/L	09/26/2016 0953 AB	EPA 300.0
Cations						
Calcium	48	1		mg/L	09/27/2016 1416 DG	EPA 200.7
Magnesium	7	1		mg/L	09/27/2016 1416 DG	EPA 200.7
Potassium	2	1		mg/L	09/27/2016 1416 DG	EPA 200.7
Sodium	2	1		mg/L	09/27/2016 1416 DG	EPA 200.7
Dissolved Metals						
Aluminum	0.02	0.01		mg/L	09/27/2016 1416 DG	EPA 200.7
Iron	ND	0.05		mg/L	09/27/2016 1416 DG	EPA 200.7
Manganese	0.04	0.02		mg/L	09/27/2016 1416 DG	EPA 200.7
Silicon	4.0	0.1		mg/L	09/27/2016 1416 DG	EPA 200.7
Strontium	0.38	0.02		mg/L	09/27/2016 1416 DG	EPA 200.7
8260B MBTEXN-Water (Absaraka Lab)						
GRO by 8260 (nC6-nC10)	ND	20		µg/L	10/06/2016 1138 SFK	8260B
Surr: 4-Bromofluorobenzene	91.5	87-114		%REC	10/06/2016 1138 SFK	8260B
8015C Micro Diesel Range Organics-Water (Absaraka Lab)						
Diesel Range Organics (nC10-nC32)	ND	0.5		mg/L	09/28/2016 0355 SFK	8015C
Surr: o-Terphenyl	67.5	35-103		%REC	09/28/2016 0355 SFK	8015C

These results apply only to the samples tested. **RL - Reporting Limit**

Qualifiers:

B	Analyte detected in the associated Method Blank	C	Calculated Value
E	Value above quantitation range	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	L	Analyzed by another laboratory
M	Value exceeds Monthly Ave or MCL or is less than LCL	ND	Not Detected at the Reporting Limit
O	Outside the Range of Dilutions	S	Spike Recovery outside accepted recovery limits
X	Matrix Effect		

Reviewed by: Bill Courtney

Bill Courtney, Project Manager