Annual Groundwater Monitoring Report
[40 CFR 257.90(e)]

Calendar Year 2017

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Colstrip, MT

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

Colstrip Energy Limited Partnership (CELP) owns an electric utility steam-generating unit (EGU) and an "existing CCR[1] landfill" as defined by 40 CFR 257.53. The generation facility is fired with waste coal and a portion of the CCR[2] is stored at their nearby existing CCR landfill.[3]

EPA requirements for CCR landfills are primarily contained in 40 CFR 257.50 → 107 which became effective on April 17, 2015 (80 FR 21468). This collection of requirements is commonly referred to as the CCR rule.

Among the requirements of the CCR rule includes "Groundwater Monitoring and Corrective Action" whose elements are found in 40 CFR 257.90 – 98. More specifically, §257.90(e) requires an "annual groundwater monitoring and corrective action report" be submitted annually beginning 1/31/2018. This document fulfills this annual reporting requirement. The remainder of this document provides a background discussion, summary of the sampling network, results of the water sampling and the conclusions of the sample results as they relate to the requirements of the CCR rule.

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[1] CCR = Coal Combustion Residuals

[2] A portion of the CCR produced at the plant has been sold for beneficial use from time-to-time over the past few years. This has reduced the size of the landfill that would have otherwise been created.

[3] In addition to the current active "existing" landfill there is also a closed landfill on the property. The closed landfill was last used in October 2005. That landfill has since been closed in general accordance with those permits and regulations applicable at that time. This particular (closed) landfill does not meet the definition of an "existing" or "new" landfill within the meaning of 40 CFR 257.53 and is not the subject of this report.

2.0 REGULATORY REQUIREMENTS

The CCR rule contains the following requirements/discussion as it relates to this first annual groundwater monitoring plan [40 CFR 257.90(e)].

> "(e) *Annual groundwater monitoring and corrective action report.* For existing CCR landfills … the owner or operator must prepare an annual groundwater monitoring and corrective action report. … For the preceding calendar year, the annual report must document the status of the groundwater monitoring and corrective action program for the CCR unit, summarize key actions completed, describe any problems encountered, discuss actions to resolve the problems, and project key activities for the upcoming year. … At a minimum, the annual groundwater monitoring and corrective action report must contain the following information, to the extent available:
>
> (1) A map, aerial image, or diagram showing the CCR unit and all background (or upgradient) and downgradient monitoring wells, to include the well identification numbers, that are part of the groundwater monitoring program for the CCR unit;
>
> (2) Identification of any monitoring wells that were installed or decommissioned during the preceding year, along with a narrative description of why those actions were taken;
>
> (3) In addition to all the monitoring data obtained under §§257.90 through 257.98, a summary including the number of groundwater samples that were collected for analysis for each background and downgradient well, the dates the samples were collected, and whether the sample was required by the detection monitoring or assessment monitoring programs;
>
> (4) A narrative discussion of any transition between monitoring programs …; and
>
> (5) Other information required to be included in the annual report as specified in §§257.90 through 257.98."

In accordance with the provisions of §257.90(b)(i), 91 and elsewhere, CELP has installed and is operating a "groundwater monitoring system." The system was installed and operating in December 2016. The system has been monitoring and collecting data since that time.

This report provides a summary of the results of the sampling and analysis to date which roughly covers December 2016 through December 2017. The report has been, or will be, entered into the facility's operating record and posted on the CELP CCR web site[4] as required by §§257.105(h)(1).

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[4] www.celpccr.com

3.0 AREA DESCRIPTION AND GEOLOGY

The project site is located approximately seven miles north of the town of Colstrip, Montana, in the southwest quarter of Section 29 and the northwest quarter of Section 32, Township 3 North, Range 41 East [Latitude 45.978859°, Longitude -106.663772° (WGS 84)]. The landfill serves an on-site power generation plant owned by Colstrip Energy Limited Partnership. The power plant and the landfill are operated by Rosebud Operating Services, Inc.

Conventional environmental monitoring and analyses of landfills include sampling and testing of upgradient and downgradient water from the "uppermost aquifer"[5] under the site. Water quality of the upgradient and downgradient samples is then compared to evaluate the possibility of the contaminant transport from the landfill via groundwater. For this landfill, such comparisons and definitions of upgradient, downgradient and uppermost aquifer are not feasible. In some wells, groundwater, although relatively shallow, has been encountered. In other cases, no groundwater has been found except in extremely rare circumstances.[6] Even in cases where groundwater is present, the definition of the aquifer is not self-evident. As a result, the typical boundaries of upgradient and downgradient aquifers are ill-defined. Clearly caution is needed in evaluating the water quality data since the typical comparison between up and downgradient wells is not necessarily appropriate. This has made it difficult to install monitoring wells meeting the CCR intent.

In addition, the uppermost aquifer(s) in the local hydrogeologic regime are accumulated from localized surface infiltration of direct precipitation, snowmelt, and ephemeral streams, as is the case with a surface impoundment on a neighboring property that influences a downgradient monitoring well. Based on the data, and experience in similar conditions, these waters naturally accumulate soluble components of the local geologic materials which include shale, coal, and other marine and continental sedimentary rock and their derivatives including residual clays and alluvium/colluvium. These soluble components, including sulfate, calcium, sodium and other analytes generally considered unfavorable for water quality often increase with time in contact with the various geologic materials. These conditions result in a somewhat random array of groundwater quality under the site that does not appear related to the presence of the CCR landfill. As one proceeds to analyze the data, it is necessary to be mindful that differences in constituent

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[5] The term "uppermost aquifer" is defined as "… the geological formation nearest the natural ground surface that is an aquifer, as well as lower aquifers that are hydraulically connected with this aquifer within the facility's boundary. …" (40 CFR 257.53).

[6] Well OMW-9 has produced a water sample only once in seven years while OMW-10 has never produced any water.

concentrations may or may not be due to the landfill itself, but due to the various array of groundwater quality irrespective of the landfill.

The landfill itself is made up of a series of layers of solidified boiler ash (CCR) that is in many ways similar to concrete. Excess lime (CaO or quicklime) from the combustion desulfurization process in the boiler, coupled with the resultant calcium sulfate that is also produced, renders the ash (CCR) into a mortar-like substance. This substance is converted into gypsum which is a rudimentary form of concrete. Once hydrated and hardened, surface water does not penetrate through it and thus no leachate is produced.

The geology of the area is published by the Montana Bureau of Mines and Geology in Open-File Reports MBMG-428 [Geologic map of the Lame Deer 30' x 60' quadrangle, eastern Montana, revised 2007 by Vuke, S.M., Heffern, E.L., Bergantino, R.N., and Colton, R.B. (2007)]. The site and the general Colstrip region are located within a large area of outcropping Fort Union Formation. The Fort Union Formation is Tertiary aged sediments, roughly horizontal in this area and is composed of coal, shale, and sandstone. In general, the topography is cut into the bedrock with a mantle of residual and colluvial soils on the slopes and deposits of windblown and alluvial soils in the drainages. According to the geology map (Figure GE-1) the Lebo Member of the Fort Union Formation outcrops beneath the site, near the boundary of the overlying Tongue River Member of the Fort Union Formation.

Based on a summary from Sedimentology of Coal and Coal-Bearing Sequences by R.A. Ramani and other coal resource references, the Tongue River and Lebo Members of the Fort Union Formation record a history of paludal (swamp), fluvial-deltaic, and lacustrine sedimentation. Tongue River deltas filled the basin primarily from the eastern margin as they prograded into a lake (comprising the underlying Lebo Shale Member) which occupied the basin axis. Major streams entered the Fort Union coastal plain resulting in areas of broad interdeltaic coastal plain isolated from major sediment influx. Peat accumulation began in interdeltaic and interdistributary areas. Upon delta abandonment, peat swamps overspread the abandoned lobes. The result is a somewhat discontinuous combination of thick, interdeltaic coal seams bounded by discontinuous fluvial-deltaic, lacustrine, and much thinner paludal (coal) deposits.

Exposure of site geology in the landfill base excavation revealed discontinuous layers of weathered shale, siltstone, and coal dipping gently to the northeast, roughly coincident with the surface topography (i.e., dipping generally eastward roughly five degrees) with a discontinuous mantling of sandy and clayey colluvial and alluvial deposits.

4.0 GROUNDWATER MONITORING SYSTEM DESCRIPTION

The surface hydrology is characterized as ephemeral drainage basins draining to the east. The local topography influences the locations of significant infiltration in that well-drained ridges and steep slopes generally infiltrate less than flatter drainage bottoms and ephemeral streams that accumulate surface flow. Surface materials also influence infiltration in exposures of more permeable materials infiltrating more than exposures of low permeability materials. In any case, once infiltrated, the water moves vertically and horizontally in saturated and unsaturated flow conditions in response to the relative permeability and geologic dip of the local rock, which is generally about five degrees to the east.

Groundwater at the site is presently monitored using nine groundwater monitoring wells located throughout the power generation site. This includes wells used for purposes other than the CCR rule itself. The location of these wells is shown in Figure 1.

From a historical perspective, data is available for wells OMW-1 thru OMW-6 from 1989. OMW-7 and OMW-8 were first sampled in 2002. OMW-9 was installed in 2011 and OMW-10 installed in 2016. OMW-3 and OMW-9 have been mostly dry during their lifetimes. OMW-10 never produced any water despite drilling deeper than OMW-9.

OMW-9, an intended upgradient well located just upslope of the CCR landfill, was drilled in late 2011 after a wet year (approximately 23 inches of annual precipitation compared to the typical average of 15 inches). The well was sampled and tested shortly after drilling, but has not had enough water to sample since. To better meet the ‘upgradient’ requirement of the CCR rule, an additional well (OMW-10) was constructed in 2016 just downgradient of OMW-9; but upgradient of the landfill. The well is located near the upper boundary of the active landfill. However, OMW-10 (and similarly OMW-9) has not produced water since.

Table 1 below is a summary of each, its description and status.

Figure 1: Monitoring Well Locations

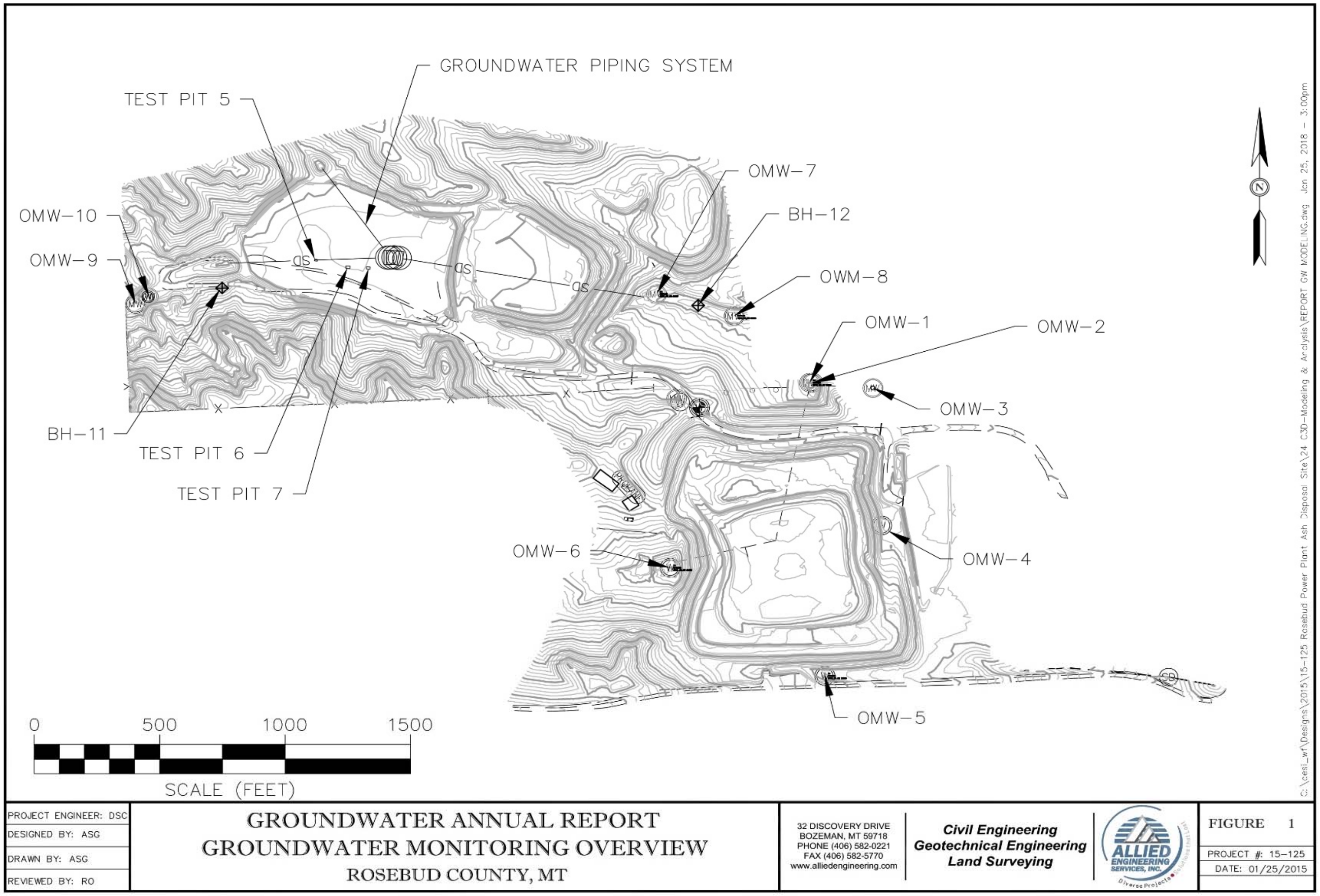

Table 1: Well Description and Status

Well	Description	Well Status
OMW-1	Down/cross-gradient in uppermost aquifer.	Downgradient CCR
OMW-2	Down/cross-gradient in a lower aquifer. Well is not in the uppermost aquifer which does not meet the requirement of CCR.	Non-CCR
OMW-3	Cross-gradient; however, the well was abandoned in 1990.	Non-CCR
OMW-4	Cross-gradient uppermost aquifer and not likely representative of the active landfill.	Non-CCR
OMW-5	Upgradient/cross-gradient in the uppermost aquifer of the closed non-CCR landfill. This well represents the upgradient well due to the lack of another representative producing well directly upgradient of the active landfill.	Upgradient CCR
OMW-6	Upgradient/cross-gradient of the active landfill. However, this well is immediately downstream of a stock-watering pond that is hydraulically connected to the pond. Based on groundwater quality data, it is not representative of the typical condition of the uppermost aquifer.	Upgradient Non-CCR
OMW-7	Downgradient in the uppermost aquifer and is considered representative for the purposes of a downgradient well as required in the CCR Rule.	Downgradient CCR
OMW-8	Downgradient in the uppermost aquifer and is considered a reasonable representation of downgradient well as required in the CCR Rule.	Downgradient CCR
OMW-9	Upgradient in the uppermost aquifer. However, the on-going monitoring of this well data is problematic because the well has been dry save the first sample in 2009 (an usually wet period prior to the sampling event). Data will be used for analysis should water collection prove successful in the future.	Upgradient CCR
OMW-10	Upgradient in the uppermost aquifer. However, like OMW-9 it has not produced measurable water.	Upgradient CCR

The analysis in the table above indicates that only four of the ten historical wells may serve a purpose under CCR. Wells 9 and 10 could be useful in analyzing the information if they were to produce water.

4.1 GROUNDWATER CHARACTERISTICS DISCUSSION

Although there are only four (producing) wells that meet the CCR criteria, it is instructive to review and analyze characteristics of the wells and hydrogeology in general. To begin, it is noted that the depths to groundwater among the wells varies, with some wells having water at 8 feet and others with water at 80 to 100 feet deep. Many of these wells are completed in bedrock that are pressurized indicating confined aquifer characteristics. The hydrologic head varies among wells that exhibit confining conditions adding to the discontinuous nature of the underlying aquifers. The shallow groundwater observed in the on-site monitoring wells can be characterized as perched or confined water tables flowing intermittently and/or ephemerally in alluvial deposits or shallow coal seams bound by low permeability bedrock or weathered bedrock (clay). The regional drinking water table, as indicated by nearby production wells, typically ranges from about 295 to 430 feet below natural ground. Regional groundwater flow direction appears to be northeasterly.

The uppermost aquifers appear to generally flow to the northeast following the geologic dip and the topography of surface drainage basins. The upper-most aquifer appears more continuous or perennial lower in the drainage basin in the vicinity of OMW-7 and OMW-8. The uppermost aquifer higher in the drainage basin near OMW-9 and OMW-10 is generally discontinuous and produces little, if any, water in the wells in most years.

For completeness, and in accordance with 40 CFR 257.93(c), Appendix A contains sample well elevations. In addition, Appendix A also provides the information regarding groundwater flow and direction.

As noted above, the uppermost aquifer is discontinuous in nature and is influenced by precipitation and site hydrology. Estimates of groundwater characteristics are derived from lithological and monitoring well data along with laboratory data for hydraulic conductivity. The saturated and unsaturated lithology in the uppermost aquifer typically varies between sandy/gravelly clay to clay. The confining layers are typically clay. A summary of groundwater characteristics is as follows:

- Saturated and unsaturated geologic units overlying the uppermost aquifer generally include alluvium/colluvium comprised of mixtures of clay, sand, and gravel. Fill material includes clayey soils as the bottom liner for the active CCR landfill.
- Groundwater gradients are relatively flat, were calculated between various wells, and average between 0.02-0.03 feet per foot.
- Groundwater flow direction is generally northeast to east and remains relatively constant over time.

- The uppermost aquifer thickness varies between wells and ranges between 3.0 feet to 15.5 feet and is seasonally thicker in the spring of each year.
- Hydraulic conductivities of soils underlying the active landfill vary between 0.047 and 0.22 feet/year.
- Porosity is estimated between 45%-55% for clayey substrate indicative of site soils.
- Based on the hydraulic conductivity, gradient, and porosity of the uppermost aquifer at the active landfill, the average linear groundwater velocities are estimated between 0.0028 and 0.013 feet/year.

5.0 GROUNDWATER MONITORING: DATA ANALYSIS

This section of the report provides a summary of the results of the monitoring data collected during the subject period (primarily calendar year 2017). This information is provided in fulfillment of 40 CFR 257.90(e)(3).[7]

5.1 DATA REPORTING

Table 2 contains a list of the monitoring wells, ID designation, sample dates and sample constituents analyzed during this reporting period. The sampling purpose (assessment or detection monitoring) is also noted in the table.

The reader will note that, for this reporting period, all sampling and analyses were conducted for "detection" monitoring.[8] However, since this was the first monitoring period for CCR, analyses were conducted for both the Detection and Assessment constituents.[9] The constituents for both programs are listed in Table 3 below.

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[7] This portion of the CCR rule states: "*In addition to all the monitoring data obtained under §§257.90 through 257.98, a summary including the number of groundwater samples that were collected for analysis for each background and downgradient well, the dates the samples were collected, and whether the sample was required by the detection monitoring or assessment monitoring programs.*"

[8] Per 40 CFR 257.94

[9] For the initial sampling period (primarily ending on 10/17/17), 40 CFR 257.94(b) required sampling for both the Appendix III (Detection) and Appendix IV (Assessment) constituents.

Table 2: Monitoring Well Sampling Matrix

Well Identification	Location (Latitude : Longitude)	Sample Dates (2017)*	Sample Purpose**	Comment
OMW-1	45.977465 : -106.659088	12/6/16, 1/5, 2/10, 3/15,4/12,5/11,6/7, 7/12, 8/9, 9/13, 10/5, and 11/9	Detection	
OMW-5	45.974031 : -106.659030	- Same as OMW-1 -	Detection	Non-CCR
OMW-6	45.975360 : -106.661386	- Same as OMW-1 -	Detection	
OMW-7	45.978560 : -106.661434	- Same as OMW-1 -	Detection	
OMW-8	45.978274 : -106.660229	- Same as OMW-1 -	Detection	
OMW-9	45.978654 : -106.669599	No samples	Detection	Dry Well
OMW-10	45.978730: -106.669400	No samples	Detection	Dry Well

* Unless otherwise indicated

** Purpose may be either “Detection” or Assessment” per 40 CFR 257.94 or 95; respectively.

Table 3: Constituents Analyzed: 2017 Reporting Period

Constituent	Program *	Constituent	Program *
Boron	Detection	Antimony	Assessment
Calcium	Detection	Arsenic	Assessment
Chloride	Detection	Barium	Assessment
Fluoride	Detection	Beryllium	Assessment
pH	Detection	Cadmium	Assessment
Sulfate	Detection	Chromium	Assessment
Total Dissolved Solids	Detection	Cobalt	Assessment
		Fluoride	Assessment
		Lead	Assessment
		Lithium	Assessment
		Mercury	Assessment
		Molybdenum	Assessment
		Selenium	Assessment
		Thallium	Assessment
		Radium 226 and 228 (combined)	Assessment

* Detection and Assessment program constituents are taken from Appendix III and IV, respectively, of 40 CFR 257. All monitoring during this initial sampling period was for purposes of Detection.

Table 4: Data Summary OMW-1 Appendix III Constituents

Date	pH	TDS	Calcium	Sulfate	Fluoride	Chloride	Boron
12/6/2016	7.4	1,530	140	625	0.5	67	0.09
1/5/2017	7.5	1,520	130	629	0.4	62	0.08
2/10/2017	7.4	1,610	126	658	0.6	67	0.07
3/15/2017	7.5	1,200	95	448	0.5	43	0.06
4/12/2017	7.5	710	80	213	0.4	19	0.08
5/11/2017	7.5	1,160	102	423	0.4	39	0.06
6/7/2017	7.6	1,420	112	534	0.4	52	0.06
7/12/2017	7.5	1,480	119	558	0.4	60	0.06
8/9/2017	7.4	1,410	125	597	0.5	60	ND
9/13/2017	7.4	1,460	112	612	0.6	63	ND
10/5/2017	7.5	1,460	118	586	0.5	60	ND
11/9/2017	7.4	1,430	115	623	0.4	64	0.09

Table 5: Data Summary for OMW-1 Appendix IV Constituents

Date	Ba	Sb	As	Be	Cd	Cr	Hg	Se	Tl	Co	Pb	Li	Mo	Radium 226 + 228
12/6/2016	0.08	ND	ND	ND	ND	ND	ND	0.108	ND	ND	0.001	0.1	ND	-2.0
1/5/2017	0.06	ND	ND	ND	ND	ND	ND	0.113	ND	ND	ND	ND	ND	1.2
2/10/2017	0.07	ND	ND	ND	ND	ND	ND	0.109	ND	ND	ND	ND	ND	1.3
3/15/2017	0.06	ND	0.002	ND	ND	ND	ND	0.071	ND	ND	0.001	ND	ND	1.7
4/12/2017	ND	ND	ND	ND	ND	ND	ND	0.032	ND	ND	ND	ND	ND	0.3
5/11/2017	ND	ND	ND	ND	ND	ND	ND	0.073	ND	ND	ND	ND	0.001	0.2
6/7/2017	0.06	ND	ND	ND	ND	ND	ND	0.091	ND	ND	ND	ND	ND	1.6
7/12/2017	0.06	ND	ND	ND	ND	ND	ND	0.100	ND	ND	ND	ND	ND	0.5
8/9/2017	0.15	ND	ND	ND	ND	0.018	ND	0.112	ND	0.005	ND	ND	ND	0.1
9/13/2017	0.07	ND	ND	ND	ND	ND	ND	0.105	ND	ND	ND	ND	ND	1.4
10/5/2017	0.07	ND	ND	ND	ND	ND	ND	0.106	ND	ND	ND	ND	ND	-0.1
11/9/2017	0.06	ND	ND	ND	ND	ND	ND	0.107	ND	ND	ND	ND	ND	0.1

Table 6: Data Summary OMW-5 Appendix III Constituents

Date	pH	TDS	Calcium	Sulfate	Fluoride	Chloride	Boron
12/06/16	7.6	4,300	43	1810	0.7	103	0.95
01/05/17	7.6	4,200	42	1880	0.6	109	0.95
02/10/17	7.6	4,370	40	2030	0.6	115	0.93
03/15/17	7.6	4,310	36	2020	0.6	105	0.93
04/12/17	7.6	3,980	42	1960	0.6	105	0.91
05/11/17	7.6	4,280	44	1970	0.7	106	0.83
06/07/17	7.6	4,400	41	1960	0.5	105	0.96
07/12/17	7.6	4,300	41	2060	0.6	116	0.98
08/09/17	7.6	4,130	36	1930	0.6	107	0.80
09/13/17	7.6	4,200	39	1940	0.6	102	0.96
10/05/17	7.6	4,000	40	1960	0.6	100	0.92
11/09/17	7.6	4,130	44	1970	0.5	107	0.94

Table 7: Data Summary OMW-5 Appendix IV Constituents

Date	Ba	Sb	As	Be	Cd	Cr	Hg	Se	Tl	Co	Pb	Li	Mo	Radium 226 + 228
12/06/16	ND	ND	ND	ND	ND	0.006	ND	ND	ND	ND	0.006	ND	ND	1.6
01/05/17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.8
02/10/17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.001	0.1	ND	3.1
03/15/17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.001	ND	ND	6.0
04/12/17	ND	ND	0.001	ND	ND	ND	ND	ND	ND	ND	0.002	ND	ND	2.3
05/11/17	ND	ND	ND	ND	ND	0.006	ND	0.002	ND	ND	0.003	ND	ND	1.3
06/07/17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1	ND	1.5
07/12/17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.1	ND	5.9
08/09/17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.3
09/13/17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.001	ND	ND	4.0
10/05/17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	1.0
11/09/17	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0.002	ND	ND	2.2

Table 8: Data Summary for OMW-7 Appendix III Constituents

Date	pH	TDS	Calcium	Sulfate	Fluoride	Chloride	Boron
12/6/2016	7.2	2620	230	1340	0.4	85	0.13
1/5/2017	7.3	2660	214	1290	0.4	80	0.14
2/10/2017	7.3	2780	215	1380	0.4	88	0.12
3/15/2017	7.3	2670	182	1380	0.4	87	0.09
4/12/2017	*7.3*	*2230*	*185*	*1160*	*0.4*	*71*	*0.12*
5/11/2017	7.3	2250	181	1190	0.4	66	0.11
6/7/2017	7.4	2370	181	1190	0.4	68	0.08
7/12/2017	7.4	2400	185	1160	0.4	72	0.09
8/9/2017	7.3	2360	177	1280	0.4	74	0.06
9/13/2017	7.4	2440	173	1300	0.4	77	0.10
10/5/2017	7.3	2,390	183	1220	0.5	72	0.08
11/9/2017	7.3	2,370	204	1290	0.4	77	0.15

Table 9: Data Summary for OMW-7 Appendix IV Constituents

Date	Ba	Sb	As	Be	Cd	Cr	Hg	Se	Tl	Co	Pb	Li	Mo	Radium 226 + 228
12/6/2016	ND	ND	ND	ND	ND	0.006	ND	0.105	ND	ND	0.012	0.1	ND	1.8
1/5/2017	ND	ND	ND	ND	ND	ND	ND	0.108	ND	ND	0.002	ND	ND	1.9
2/10/2017	0.07	0.001	ND	ND	ND	0.006	ND	0.110	ND	ND	0.01	ND	ND	2.0
3/15/2017	ND	0.002	0.002	ND	ND	0.006	ND	0.109	ND	ND	0.001	ND	ND	2.3
4/12/2017	ND	0.002	ND	ND	ND	ND	ND	0.085	ND	ND	0.004	ND	ND	0.4
5/11/2017	ND	0.002	ND	ND	ND	0.008	ND	0.074	ND	ND	0.002	ND	ND	1.1
6/7/2017	ND	0.001	ND	ND	ND	ND	ND	0.081	ND	ND	0.001	ND	ND	1.9
7/12/2017	ND	0.002	ND	ND	ND	ND	ND	0.081	ND	ND	ND	ND	ND	1.3
8/9/2017	0.05	0.003	ND	ND	ND	0.005	ND	0.091	ND	ND	0.004	ND	ND	4.0
9/13/2017	0.05	0.006	ND	ND	ND	0.011	ND	0.087	ND	ND	0.003	ND	ND	1.6
10/5/2017	ND	0.002	ND	ND	ND	ND	ND	0.089	ND	ND	0.001	ND	ND	0.1
11/9/2017	ND	0.001	ND	ND	ND	ND	ND	0.093	ND	ND	ND	ND	ND	1.6

Table 10: Data Summary for OMW-8 Appendix III Constituents

Date	pH	TDS	Calcium	Sulfate	Fluoride	Chloride	Boron
12/6/16	7.4	3090	223	1680	0.4	87	0.22
1/5/17	7.4	3050	206	1690	0.4	84	0.22
2/10/17	7.4	3180	199	1700	0.4	89	0.22
3/15/17	7.4	3070	171	1720	0.5	86	0.19
4/12/17	7.4	2840	202	1640	0.5	85	0.23
5/11/17	7.4	3040	201	1720	0.4	87	0.19
6/7/17	7.5	3060	189	1710	0.4	88	0.18
7/12/17	7.5	2860	170	1580	0.4	91	0.18
8/9/17	7.4	2970	175	1780	0.5	98	0.16
9/13/17	7.4	3020	180	1750	0.5	100	0.20
10/5/17	7.4	2,790	195	1660	0.5	95	0.16
11/9/17	7.4	2,890	200	1730	0.4	98	0.25

Table 11: Data Summary for OMW-8 Appendix IV Constituents

Date	Ba	Sb	As	Be	Cd	Cr	Hg	Se	Tl	Co	Pb	Li	Mo	Radium 226 + 228
12/6/16	0.15	ND	0.003	ND	ND	0.012	ND	0.159	ND	ND	0.012	ND	ND	1.0
1/5/17	0.07	ND	0.002	ND	ND	ND	ND	0.161	ND	ND	0.005	ND	ND	0.9
2/10/17	0.13	ND	0.003	ND	ND	ND	ND	0.158	ND	ND	0.007	0.1	ND	2.1
3/15/17	ND	ND	0.004	ND	ND	ND	ND	0.153	ND	ND	ND	ND	ND	1.3
4/12/17	0.18	ND	0.004	ND	ND	ND	ND	0.158	ND	0.006	0.012	ND	ND	0.7
5/11/17	0.10	ND	ND	ND	ND	0.005	ND	0.153	ND	ND	0.005	ND	ND	0.5
6/7/17	0.12	ND	0.003	ND	ND	0.008	ND	0.148	ND	ND	0.006	0.1	ND	0.9
7/12/17	0.06	ND	ND	ND	ND	0.006	ND	0.149	ND	ND	0.001	ND	ND	3.4
8/9/17	0.12	ND	0.005	ND	ND	0.021	ND	0.153	ND	ND	0.007	ND	ND	1.5
9/13/17	0.14	ND	0.003	ND	ND	0.027	ND	0.160	ND	ND	0.007	ND	ND	2.7
10/5/17	0.29	ND	0.009	0.001	ND	0.034	ND	0.163	ND	0.013	0.018	ND	0.001	1.2
11/9/17	0.14	ND	0.004	ND	ND	0.015	ND	0.164	ND	ND	0.007	ND	ND	0.7

5.2 DATA SUMMARY STATISTICS

Having obtained the required data for CCR purposes, the next step in this report is to summarize the collected information. The tables below provide a statistical summary of the Appendix III (Detection) constituents. For Appendix IV data, no analysis is required at this time. A brief summary and general conclusions regarding Appendix IV data was presented in the report titled "Groundwater Monitoring and Action Plan" (10/17/17) and found on the www.celpccr.com web site per 40 CFR 257.90(b) and elsewhere.

Table 12: 2017 Summary Statistics

Parameter	pH	TDS	Ca	Sulfate	Fluoride	Chloride	Boron	Cation (Ca + Na)
OMW - 1								
Count (n)	12	12	12	12	12	12	12	12
Mean	7.5	1,366	115	541	0.47	55	0.067	318
Std. Dev.	0.065	243	4.7	37	0.02	4.1	0.004	49
Skewness	0.4	-2.0	-0.7	-1.9	0.7	-1.7	0.5	-1.5
Coef. Variation	0.01	0.18	0.14	0.23	0.17	0.26	0.22	0.15
OMW - 5								
Count (n)	12	12	12	12	12	12	12	12
Mean	7.6	4,217	40.7	1,958	0.60	107	0.92	1,475
Std. Dev.	0.0	136	2.7	67	0.06	4.8	0.05	46
Skewness	1.1	-0.6	-0.7	-0.7	0.0	0.9	-1.6	-8.2
Coef. Variation	0.00	0.03	0.07	0.03	0.10	0.04	0.06	0.03
OMW - 7								
Count (n)	12	12	12	12	12	12	12	12
Mean	7.3	2,462	193	1,265	0.41	76	0.11	605
Std. Dev.	0.058	177	19	80	0.03	7.3	0.03	37
Skewness	0.06	0.55	1,03	0.06	3.46	0.38	0.04	0.03
Coef. Variation	0.01	0.07	0.10	0.06	0.07	0.10	0.26	0.06
OMW - 8								
Count (n)	12	12	12	12	12	12	12	12
Mean	7.4	2,988	193	1,697	0.44	91	0.20	776
Std. Dev.	0.04	118	16	53	0.05	5.6	0.03	32
Skewness	2.1	-0.31	0.10	-0.76	0.39	0.60	0.14	0.00
Coef. Variation	0.01	0.04	0.08	0.03	0.12	0.06	0.14	0.04

A few comments regarding the data are appropriate. The statistics and meaning of the terms count, mean and standard deviation are self-evident. The "skewness" is presented because it is one indicator to determine if the dataset has a near "normal"[10] distribution. "Skewness" indicates if the normal (bell-shaped) distribution has a degree of asymmetry.

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[10] The term "normal" refers to Gaussian distribution.

In general, a “skewness” coefficient greater than unity (absolute value) is an indication, in small sample populations such as the case here, that treating the data as a near-normal distribution might not yield fruitful results. A review of the table indicates all (absolute) values are less than 1. Therefore, that indicator leans toward a near-normal assumption.

The coefficient of variation (CV) also provides an indication as to normality of the data. It is simply the ratio of the standard deviation to the mean. A highly variable (non-normal) dataset will, of course, have a high CV. This is an indication, but not necessarily definitive, that the normal (bell-shaped) curve is too flat. An extremely low CV might indicate the opposite; i.e., the curve is too spiked.

EPA guidance documents[11] on this matter do not provide definitive guideline values. Nonetheless, the document indicates a value less than 0.5 is a positive indication of normality. The CV, however, is well-dependent for any particular constituent. This is not necessarily a ‘defect’ in the data, it is merely a mathematical indication that the data is narrowly distributed about the mean. pH, for example, has nearly no variation among and within the wells.

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[11] “Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities” EPA 530-R-09-007; March 2009.

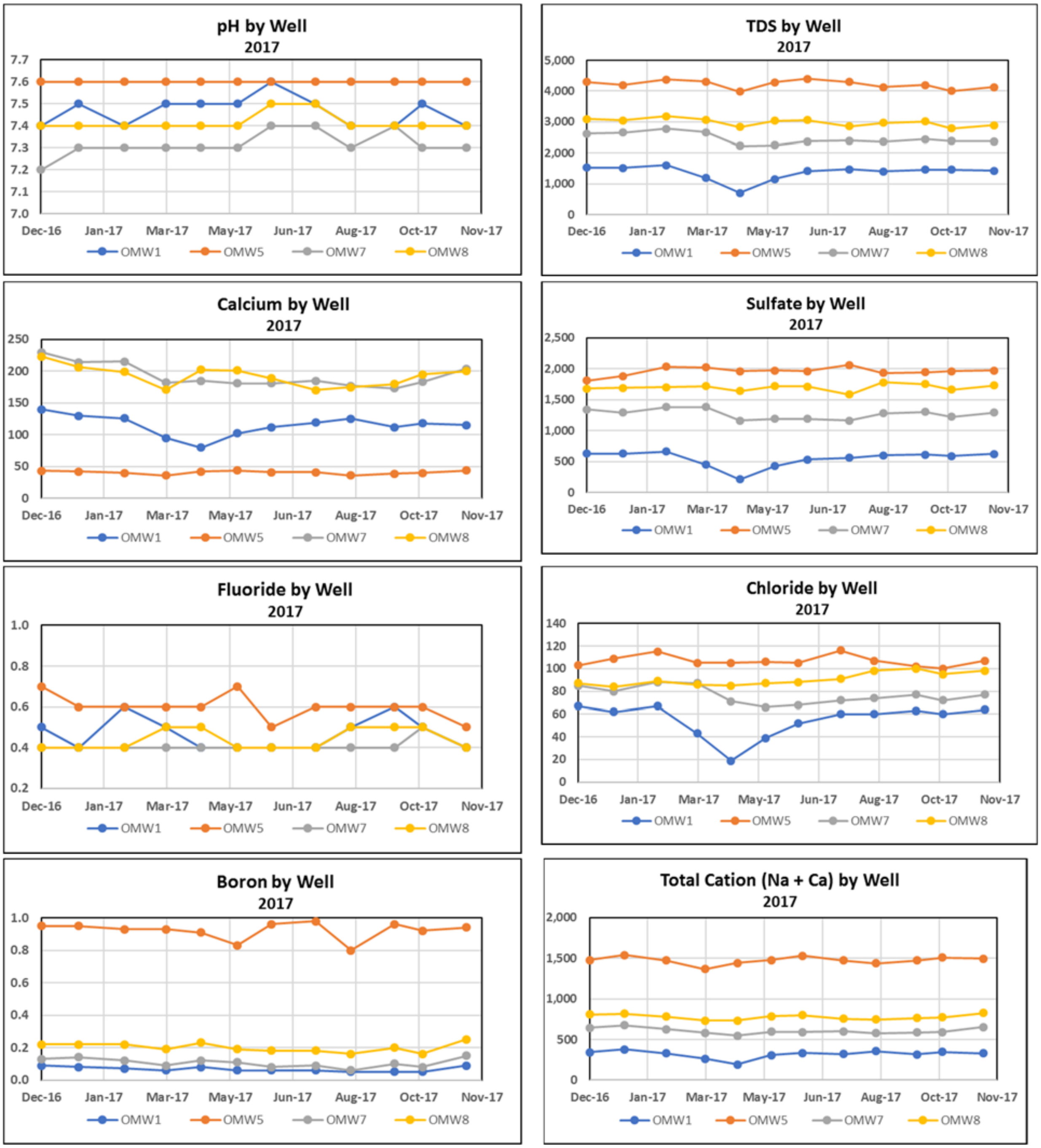
5.3 DATA ANALYSIS - GRAPHICAL

To decide if there is evidence, statistical or otherwise, of contamination, several analyses seem appropriate. One of the best ways to gain insight into the data is to review the information in a graphical manner. To that end, the 2017 data is presented in the following seven graphics. Each figure plots a single constituent by well in a time series manner.

There are a few observations worth noting in the data.

1) pH values change little regardless of the well or date. The minimal variance is confirmed with the very low standard deviations noted in the descriptive statistics tables in prior sections of this report.
2) Ranking the wells from highest constituent concentration to lowest (with the exceptions of pH and calcium) reveals the following general order: OMW-5, OMW-8, OMW-7 and then OMW-1.
3) The results of calcium alone are, for the most part, opposite that described in 2) above. The calcium data for OMW-5 is lower than the other three wells.
4) Based on the observation in 3), it was decided to combine the two most common cations (Ca and Na) to observe a pattern or difference. A ‘total cation’ graph was created and included in the list of plots below. The reasoning for combining the two cations is discussed later in this report.
5) With a few minor exceptions, none of the well data seems to undergo a significant change over the year of monthly measurements.

Figure 2: Constituent by Well



5.4 DATA ANALYSIS – STATISTICS

The CCR rule, in effect, requires a statistical analysis of the groundwater monitoring constituent data.[12] As this is the first annual report, the monitoring data to be analyzed are the Appendix III constituents (pH, TDS, Ca, $SO4^{-2}$, Fl^{-}, Cl^{-} and Boron). The statistical methods to be used for this analysis were discussed and reported in the document "Groundwater Monitoring and Action Plan" (10/17/17). This document may be found on the www.celpccr.com web site per 40 CFR 257.90(b) and elsewhere.

As a brief synopsis, the (initial) statistical methods to be employed for this project are as follows:

1) Review the data to determine if the information, by constituent within each well, may be treated as a near normal (Gaussian) distribution.
    a) Distributions meeting this criterion will be subject to parametric statistical analyses.
    b) Distributions not meeting this criterion will be subject to non-parametric statistical analyses.
2) Once the distribution is known, an 'analysis of variance' will be conducted as follows:
    a) Parametric data will (initially) use a 'single factor' or 'one-way' ANOVA test to determine differences among, and if necessary between, the means. This may be followed up with t-test analyses as necessary for single paired analysis.
    b) Non-parametric data will (initially) use the Kruskal-Wallis test. This is similar to a typical ANOVA statistic (F distribution) but the underlying data need not be normal.

5.4.1 NORMALITY TESTING

A substantial amount of analysis was conducted to determine the possibility of a normal distribution. Appendix B of this document contains the details of tests conducted in order to conclude which analysis (parametric or non-parametric) is to be used.

There are a number of statistics and tests that may be used to ascertain (near) normal status. For purposes of this study, the following were employed:

- Coefficient of Variation
- Skewness Coefficient
- Shapiro-Wilk Test

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[12] The statistical analysis is required via §257.91 and 94(e).

No single statistic or test was considered definitive. Rather the decision as to normality was based on the weight of evidence of the three methods.

The test for normality was not limited to the use of the raw data. In some cases, the data was subject to a linear transformation of the dataset to determine if perhaps a better normal distribution might emerge. (This transformed data may then be used for purposes of accepting or rejecting a particular null hypothesis within a specific statistical test.) For this CCR project a logarithmic (geometric) transformation was conducted (where needed). This ‘transformed’ data (per constituent and well) was then subjected to the same tests above to determine if the geometric transformation improved the ‘normal’ distribution null hypothesis.

Based on the analyses, none of the transformed data altered, in any meaningful way, closer to a ‘normal’ distribution. Therefore, no additional analyses (ANOVA or otherwise) were conducted with transformed data.[13]

The results of the (non-transformed) normality data sets are summarized below. The results of the individual tests are found in Appendix B.

Table 13: Normality Test Results

	Normality?							
Well	**pH**	**TDS**	**Ca**	**SO_4^{-2}**	**F^-**	**Cl^-**	**B**	**Cations (Ca + Na)**
OMW 1	Probable	Probable	Yes	Probable	Probable	Probable	Yes	Probable
OMW 5	Probable	Yes	Yes	Yes	Probable	Yes	Yes	Yes
OMW 7	Probable	Yes	Yes	Yes	No	Yes	Yes	Yes
OMW 8	No	Yes	Yes	Yes	Probable	Yes	Yes	Yes

“Yes” = All three statistical tests indicate a (near) normal distribution.
“Probable” = Two of the three tests indicate (near) normal distribution.
“No” = Either one or zero tests indicate (near) normal distribution.

It was decided to treat all the data, with a few exceptions, as a normal distribution thus invoking parametric statistical analysis. As noted in the table most of the testing provided a good indication of normality.

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[13] Since no fruitful results occurred from various transformations, raw and summary data calculations are not included in this document.

5.4.2 ANALYSIS OF VARIANCE TESTING

The CCR rule requires"

> *"A parametric analysis of variance followed by multiple comparison procedures to identify statistical significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's mean and the background mean levels for each constituent." 40 CFR 257.93(f)(1).*

This issue was discussed in previous documents. It was decided, based in part on the normality analysis above, to conduct this analysis of variance using the methods:

Parametric:
- ANOVA; and
- t-test (unpaired)

Non-Parametric:
- Kruskal-Wallis (one-way)
- Kruskal-Wallis (multiple-comparison)

ANOVA - Parametric[14]

The parametric ANOVA test was conducted followed by various t-tests. (Non-parametric analysis of variance is found later in this section.) The ANOVA test employed is a "one-way" test. This testing effectively tests the hypothesis: "*Are all of the means of each group (well) by constituent the same?".* If there is enough statistical data (at the 5% level) to deny this null hypothesis, then one can conclude that the groups (wells) in the analysis are statistically different. This is accomplished by analyzing the variance within each group (well) and among each group. If there is no statistical difference among the wells, then the variance among and within the group is consistent. The analysis calculates an "F" statistic based on an "F-distribution." The calculated F is compared against the "critical" F (a value based on the desired Type I error (5%) and sample size (number of wells and sample data).

For this analysis, the results of the calculations are contained in Appendix C. The appendix data is summarized below.

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[14] Recall that the traditional ANOVA (and "t") test is a parametric test and best suited for normally distributed data. Nonetheless, this statistical testing was conducted on all of the data in the interest of completeness since most of the well/constituent data indicated a near normal distribution. There were a few exceptions and these are addressed later in this section.

Table 14: ANOVA (between wells) Summary Results

Constituent	Calculated F Statistic	Critical F-Statistic	Statistical Difference?
pH	73	2.82	Yes
TDS	548	2.82	Yes
Calcium	295	2.82	Yes
Sulfate	621	2.82	Yes
Fluoride	26	2.82	Yes
Chloride	75	2.82	Yes
Boron	1,674	2.82	Yes
Cations (Ca + Na)	1,673	2.82	Yes

Notes:

a) Critical "F" is based on 5% Type I error and concurrent sample sizes.
b) Any absolute value of the calculated "F-Statistic" greater than the critical "F-Statistic" indicates the null hypothesis should be rejected.
c) A "Yes" does not indicate a statistically significant increase; it only indicates that the means among the same well (for the same constituent) are not equal.

The results of the ANOVA show that each constituent among all four wells is not equal (within a 95% probability window). For example, the mean fluoride concentration is not the same for all four wells. This now leads to the question of whether there is a difference (significant increase) in concentrations between upgradient (background) well OMW-5 and the other three downgradient wells. The comparison needs to be made on a constituent by constituent basis. That analysis immediately follows.

t-Test (Parametric)[15]

The (parametric) ANOVA test has indicated differences in individual constituent concentrations among the wells. The ANOVA analysis, however, is not able to distinguish exactly which wells are 'different' from each other for a given constituent. Where differences are noted, ANOVA does not yield whether the differences indicate an increase or a decrease, just a statistical difference. The t-test is able to directly compare two sets of data and ascertain the probability that they have the same mean (or come from the same population regime) and whether the difference is an increase or decrease.

There are numerous versions of the t-test including "paired," "unpaired with equal variances," "unpaired with unequal variance" and a few others. The paired t-test compares two side-by-side data points (from the same sample date and constituent, but

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[15] Ibid.

two separate wells). On average, the difference between the two paired values should be zero. A test is then applied to determine where the final difference lies on a student's "t" distribution.[16] That analysis does not seem appropriate in this case because there is not necessarily an *a priori* reason that the two paired (in time) samples will be the same.

The unpaired analysis was chosen here because it is attempting to answer the question about equal variances over a certain historical perspective. The use of "equal" or "unequal" variances was left to each t-test and based, obviously, on the similarity of the underlying variance of each sample set.

To be thorough, the t-test was applied to every possible pair of wells and constituents. The complete results of those tests are found in Appendix C along with the ANOVA results. The data is summarized in the table below.

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[16] The t-distribution is, more or less, the "normal" z-distribution, but adjusted for small(er) sample sizes.

Table 15: t-Test Summary Results

Constituent	Parameter	OMW-1 vs OMW-5		OMW-7 vs OMW-5		OMW-8 vs OMW-5	
pH	Mean	7.47	7.60	7.32	7.60	7.42	7.60
	Variance	$4.2\text{x}10^{-3}$	$8.5.\text{x}10^{-31}$	$3.3\text{x}10^{-3}$	$8.5.\text{x}10^{-31}$	$1.3\text{x}10^{-3}$	$8.5.\text{x}10^{-31}$
	Calculated “t”	-7.09		-17.0		-16.3	
	Critical “t”	2.07		2.07		2.07	
	Difference?	Yes		Yes		Yes	
TDS	Mean	1,366	4,217	2,462	4,217	2,988	4,217
	Variance	15,099	18,388	31,288	18,388	14,015	18,388
	Calculated “t”	-35.5		-27.3		-23.6	
	Critical “t”	2.07		2.07		2.07	
	Difference?	Yes		Yes		Yes	
Calcium	Mean	115	41	193	41	193	41
	Variance	264	7.2	337	7.2	157	7.2
	Calculated “t”	15.5		28.4		32.4	
	Critical “t”	2.18		2.20		2.18	
	Difference?	Yes		Yes		Yes	
Sulfate	Mean	542	1,958	1,265	1,958	1,697	1,958
	Variance	15,990	4,439	6,373	4,439	2,788	4,439
	Calculated “t”	-34.3		-23.1		-10.6	
	Critical “t”	2.11		2.07		2.07	
	Difference?	Yes		Yes		Yes	
Fluoride	Mean	0.47	0.60	0.41	0.60	0.44	0.60
	Variance	.006	.004	.001	.004	.003	.004
	Calculated “t”	-4.69		-9.93		-6.92	
	Critical “t”	2.07		2.07		2.07	
	Difference?	Yes		Yes		Yes	
Chloride	Mean	55	107	76	107	91	107
	Variance	206	23	53	23	32	23
	Calculated “t”	-11.9		-12.0		-7.5	
	Critical “t”	2.16		2.07		2.07	
	Difference?	Yes		Yes		Yes	
Boron	Mean	.067	.92	.11	.92	.20	.92
	Variance	.001	.003	.001	.003	.001	.003
	Calculated “t”	-53.1					
	Critical “t”	2.16		2.12		2.11	
	Difference?	Yes		Yes		Yes	
Total Cations (Ca + Na)	Mean	318	1,475	605	1,475	776	1,475
	Variance	2,420	2,157	1,356	2,157	1,015	2,157
	Calculated “t”	-59		-51		-43	
	Critical “t”	2.07		2.07		2.07	
	Difference?	Yes		Yes		Yes	

Notes:

a) Critical "t" is based on 5% Type I error and sample size.
b) Any absolute value of the calculated "t-Statistic" greater than the critical "t-Statistic" indicates the null hypothesis should be rejected.[17]
c) A "Yes" does not indicate a statistically significant increase; it only indicates that the means among the two wells being tested (for the given constituent) are not equal.

A review of Table 15 shows that there is enough statistical evidence to reject the hypothesis that the two means (between two wells) are not very likely from the same underlying population. The sign (±) that describes the t-statistic, however, is important. As the analysis was conducted, only a positive value "t" is an indication that there is a 'statistically significant increase" (SSI) in concentrations in the downgradient well compared to OMW-5.

ANOVA (Nonparametric)

Consistent with the normality testing results of Section 4.4.1, it was decided to conduct an additional analysis of variance using nonparametric methods for two constituents: pH and Fluoride. These two were chosen for this additional testing because the normality testing (see Table 13) indicates that these two constituents may not fit well with methods that require a normal distribution. The Kruskal-Wallis method was selected because it is able to calculate the analysis of variance; it is also capable or analyzing the multiple comparisons required by §257.93(f)(1). Additionally, the test does not require the underlying data to be normally distributed.

The analysis was conducted using the same general methodology of the parametric ANOVA and t-test described above. Appendix D contains the results of the statistical analyses using the Kruskal-Wallis test(s).[18] The table below is a brief summary of those results.

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[17] The null hypothesis is that the two means being tested are the same within a certain statistical acceptance criterion (5% Type I error).

[18] The calculations were conducted using the "Unistat" Version 10 software. Unistat is an internationally recognized statistics package. More information may be found at: Unistat Ltd, Highgate, London N6 5UQ, UK; Tel: +44 20 8964 1130; http://www.unistat.com.

Table 16: Kruskal-Wallis One-Way ANOVA Test Summary Results

Constituent	Chi-Square Statistic	Critical Chi-Square (5%)	Statistical Difference?
Fluoride	28.3	7.8	Yes
pH	39.1	7.8	Yes

Table 17: Kruskal-Wallis Multiple Comparison Test Summary Results

Well Comparison	q-statistic	Critical q-statistic (5%)	Statistical Difference?
Rank Sums			
Fluoride			
OMW-1 vs OMW-5	4.3	3.6	Yes
OMW-7 vs OMW-5	6.6	3.6	Yes
OMW-8 vs OMW-5	5.1	3.6	Yes
pH			
OMW-1 vs OMW-5	3.7	3.6	Yes
OMW-7 vs OMW-5	8.3	3.6	Yes
OMW-8 vs OMW-5	5.3	3.6	Yes
Mean Ranks			
Fluoride			
OMW-1 vs OMW-5	4.3	3.6	Yes
OMW-7 vs OMW-5	6.6	3.6	Yes
OMW-8 vs OMW-5	5.1	3.6	Yes
pH			
OMW-1 vs OMW-5	3,7	3.6	Yes
OMW-7 vs OMW-5	8.3	3.6	Yes
OMW-8 vs OMW-5	5.3	3.6	Yes
t Distribution			
Fluoride			
OMW-1 vs OMW-5	6.5	3.6	Yes
OMW-7 vs OMW-5	14.5	3.6	Yes
OMW-8 vs OMW-5	9.2	3.6	Yes
pH			
OMW-1 vs OMW-5	5.0	3.6	Yes
OMW-7 vs OMW-5	7.8	3.6	Yes
OMW-8 vs OMW-5	6.0	3.6	Yes

The results of the parametric and nonparametric ANOVA and t-tests are quite clear from an exclusive statistical point of view. These tests indicate that all constituents fail to show a statistically significant increase (SSI) for pH, TDS, sulfate, fluoride, chloride, boron and cations (Na + Ca). This observation was true for both parametric and nonparametric testing. The lone exception in the analysis is calcium. For reasons and rationale discussed later in this document, calcium concentrations, as a lone cation, in the upgradient/background well were less than those in all three downgradient wells.

A discussion of the meaning, confounding variables associated with this observation, and conclusions is found in the following sections.

5.5 STATISTICAL RESULTS SUMMARY

The mechanics of the statistical analysis having been completed via Section 4.4 above, it is now necessary to present the results in a summary form. The analyses in this, and prior, sections have been conducted for purposes of answering the following question:

> *Is there enough evidence to indicate a statistically significant increase (SSI) in any Appendix III constituent between background (or the upgradient well) and all other CCR downgradient wells which would indicate contamination?*[19]

The pure mathematical answer to that question is provided in the table below.

There is one additional statistical observation to be made prior to making a conclusion. It is as follows:

a) There are (from Table 18) a total of 24 statistical tests (or combined tests) spread over 8 constituents.
b) EPA has chosen 7 constituents for analysis.
c) Those constituents were chosen by EPA because they are believed to be an indicator of contamination.
d) If contamination were to occur, it would seem highly likely that many (or all) of the 7 constituents would yield an SSI.
e) While there is no way to estimate how many of the 7 constituents would yield an SSI, one could arbitrarily give each constituent a 50:50 (independent) probability. (If, indeed, contamination is occurring, it would seem reasonable that the probability is higher for an SSI; nonetheless, the value will be left at 50:50.)

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[19] Paraphrased from §257.94(e) and 95(a).

f) That being the case, the probability that only 1 constituent yields an SSI is roughly 5%.
g) The probability decreases by adding the cation analysis into the mix. The probability now drops to roughly 3%.

This observation suggests that the results of the CCR statistical exercise should be treated with caution. To that end, items affecting a final conclusion are found in later sections.

Table 18: Statistics Results

Well	Constituent	Significant Increase ?	Comment
OMW-1	pH	No	Data is compared to OMW5
	TDS	No	“ “
	Calcium	Yes	“ “
	Sulfate	No	“ “
	Fluoride	No	“ “
	Chloride	No	“ “
	Boron	No	“ “
	Cations (Ca + Na)	No	“ “
OMW-7	pH	No	“ “
	TDS	No	“ “
	Calcium	Yes	“ “
	Sulfate	No	“ “
	Fluoride	No	“ “ Data was not considered normal
	Chloride	No	“ “
	Boron	No	“ “
	Cations (Ca + Na)	No	“ “
OMW-8	pH	No	“ “ Data was not considered normal
	TDS	No	“ “
	Calcium	Yes	“ “
	Sulfate	No	“ “
	Fluoride	No	“ “
	Chloride	No	“ “
	Boron	No	“ “
	Cations (Ca + Na)	No	“ “

6.0 GROUNDWATER MONITORING: HYDROGEOLOGY EVALUATION

Having conducted the statistical analyses required by CCR, our attention turns to a more comprehensive, and less mathematical, review of the data. This review provides a brief discussion of data observations along with an understanding of the physical realities of the project location.

The statistical data, by itself, suggests that all three downgradient wells observe calcium levels above background or upgradient well (OMW-5) levels. While the mathematics indicate a difference; there are several confounding variables. Some of these are discussed below.

Varying geology

It is noteworthy that in this area the uppermost aquifer(s) in the local hydrogeologic regime are accumulated from localized surface infiltration of direct precipitation, snowmelt, and ephemeral streams. Based on the data, and experience in similar conditions, these waters naturally accumulate soluble components of the local geologic materials which include shale, coal, and other marine and continental sedimentary rock and their derivatives including residual clays and alluvium/colluvium. These soluble components, including calcium and sodium, often increase with time in contact with the various geologic materials. These conditions result in a somewhat random array of groundwater quality under the site that does not necessarily appear related to the presence of the CCR landfill.

OMW-5 as background

The use of OMW-5 as an upgradient or background well was discussed earlier in this document and in the 10/17/17 report.[20] The Rosebud facility has gone to extraordinary lengths in an attempt to locate an ideal upgradient well as contemplated by the CCR rule. Despite those efforts, it was decided to use OMW-5 as a combination of an upgradient and background well. It was known early on that this well, while being the best available source of information, may not be perfect. The well is located near the landfill and generally upgradient; but not in the location that was preferred.[21] As noted earlier in this and the 10/17/17 report, the data from the well, as a statistical comparison, must be reviewed with some caution. Based on the fact that the calcium data is completely out of character

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[20] This is the "Groundwater Monitoring and Action Plan" (10/17/17) required by 40 CFR 257.90(b) and found at the facility's CCR web site.

[21] Two 'ideal' locations were chosen for upgradient CCR wells. They were both drilled. However, in both cases the wells have failed to yield any water with a single one-time exception.

compared to the other six Appendix III constituents; caution should, and was, extended to this constituent.

Total Cations

While an analysis of calcium is required, it is instructive to recall its purpose and chemistry. Calcium and sodium are, in many cases, among the two most common cations in water. These two cations are very similar and tend to be interchangeable when associated with many anions (sulfate, chloride, fluoride, etc.). On its face, the low calcium in OMW-5 was quite surprising because this same well had more sulfate and TDS than the downgradient wells. This begs the question as to which cation is in this water; if not calcium.

To answer that question, the laboratory was consulted and was able to recover the sodium data from the project period. (Sodium is not required for CCR analyses since it is not one of the Appendix III or Appendix IV constituents.) The data for sodium nonetheless proved educational. The sodium concentration in OMW-5 was much higher than the other three downgradient wells. This is the exact opposite of calcium. These two observations seem to help explain why the sulfate (and to some extent TDS) concentrations in all wells were somewhat similar; but the single ion concentrations (Ca or Na; depending on the well) were opposite of each other. It seemed appropriate that, in order to take into account the unique nature of OMW-5 as a stand-in for an upgradient or background well, the best statistical analysis would be to analyze the combination (sum) of calcium and sodium.

This analysis was conducted in this document. All of the summary and statistic tables included an analysis of not only calcium, but the sum of the two cations. The reader is referred to that data and will observe that the outcome is what one would expect. The results are consistent with the other six constituent analyses. The data fails to demonstrate an SSI for the cations as a whole.

Discontinuous aquifers

The entire CCR premise is that one can establish a clear-cut set of nearby wells in which one or more wells will be upgradient of the landfill itself and the other three (or more) wells are downgradient of the landfill (and the upgradient well). The statistical analysis is then used to determine if there is a significant difference among the wells. For this area, the underlying assumption that there are ‘definitive’ up and downgradient wells is not appropriate. The data for this area shows that the uppermost aquifer is not continuous and is, to some degree, ephemeral. Additionally, the only true ‘upgradient’ well is OMW9 which has been dry following the year since it was first drilled. The data quality from that single sample showed much higher concentrations of constituents than all downgradient wells. This is apparently due to the nature of the surrounding geological materials and not, of course, due to the landfill.

7.0 CONCLUSION

This annual report has been prepared in accordance with the requirements of the CCR rule. More specifically, the report fulfills the requirements of 40 CFR 257.90(e) to complete an “annual groundwater monitoring and corrective action” report. The general purpose of the report is to provide a description and summary of the groundwater monitoring program put in place as a result of the CCR rule. Prior sections provided a summary of the monitoring well program, location of wells, data collected from those wells and other salient information.

The data from the monitoring program has undergone various statistical analyses as generally outlined in §257.93(f), (g) and (h). The results of these analyses indicate that for all Appendix III pollutants, save calcium, there is no statistically significant increase (SSI) of constituents in the downgradient wells (OMW-1, 7 and 8) compared to the upgradient well (OMW-5).

The only possible exception to this observation is calcium. However, that observation can not be accepted without putting the data into context and further discussion.

- A significant portion of the ash itself is a combination of $CaSO_4$, $CaSO_3$, etc. If one hypothesizes that OMW-7 and OMW-8 are affected by the ash and OMW-5 is not, then there should be more sulfate (and calcium) in OMW-7 and 8. However, the sulfate content in OMW-5 is the same (actually higher) than OMW-7 and 8. At the same time, the calcium concentration is less (one-fourth or less) than the other two wells. On the other hand, the sodium concentration (a very similar ion to calcium) is much higher in OMW-5 than the other wells. These observations do not support the concept that the landfill may be causing contamination. Rather the relative calcium concentration variances are more likely due to the natural background presence of sodium sulfate in the ground water, not from any leachate from the ash.
- The analysis for calcium is, in effect, an analysis of a cation which is associated with a number of possible anions. From a chemical point of view, sodium is another similar cation which is commonly found in groundwater. These two cations effectively serve the same chemical purpose as an association with anions. To help account for what appears to be natural variation in groundwater, the sum of the two cations were analyzed as a better indicator of a difference between OMW-5 and the other three downgradient wells. This analysis was included in the previous tables and figures in this report. The results indicate relative values and statistical conclusions completely consistent with all other constituent analysis.

- Since there is no traditional upgradient well in the upper-most aquifer in the active landfill drainage basin, a definitive "statistically significant increase" may not be appropriate. The general discontinuous nature of the aquifers and hydrogeology was discussed in earlier sections. As a result, elevated calcium in downgradient wells appears to be due to natural variation of the discontinuous uppermost aquifer (and geology). This could also include various operational conditions such as particulates from ash transport or minor wind erosion prior to hydrating the ash. It might also include the documented isolated erosion of the cap (but not the ash covered by the cap) on the side slope directly above OMW-7 and OMW-8. (Interestingly, that isolated erosion was subsequently repaired during the summer of 2017, not likely in time to be observed in the latter half of 2017.)

  Some additional actions, independent of CCR requirements, were also completed during calendar year 2017. Due to the lag time for transport of constituents, the results of erosional repair upslope of OMW-7 and 8 may take additional time to see a reduction of calcium levels in OMW-7 and OMW-8 (if slight erosion of the cap upslope of the wells contributed to the potential measured elevated calcium).

Based on the results of all of the analyses conducted in this document and considering the variables and caveats above, we make the following conclusions:

(1) In consideration of the observation below, there is no statistically significant increase in the Appendix III constituents in the three downgradient wells OMW-1, 7 and 8 compared to the upgradient/background well OMW-5 for the monitoring period.

(2) Although there was a mathematical increase in calcium, further investigation yielded its cause was due to the unique nature of the groundwater characteristics of the general area surrounding the project. This was confirmed by an analysis of additional cations (Na). Combining the cations (Ca and Na) yields no statistically significant increase between the upgradient/background well and the other three CCR wells.

Appendix A

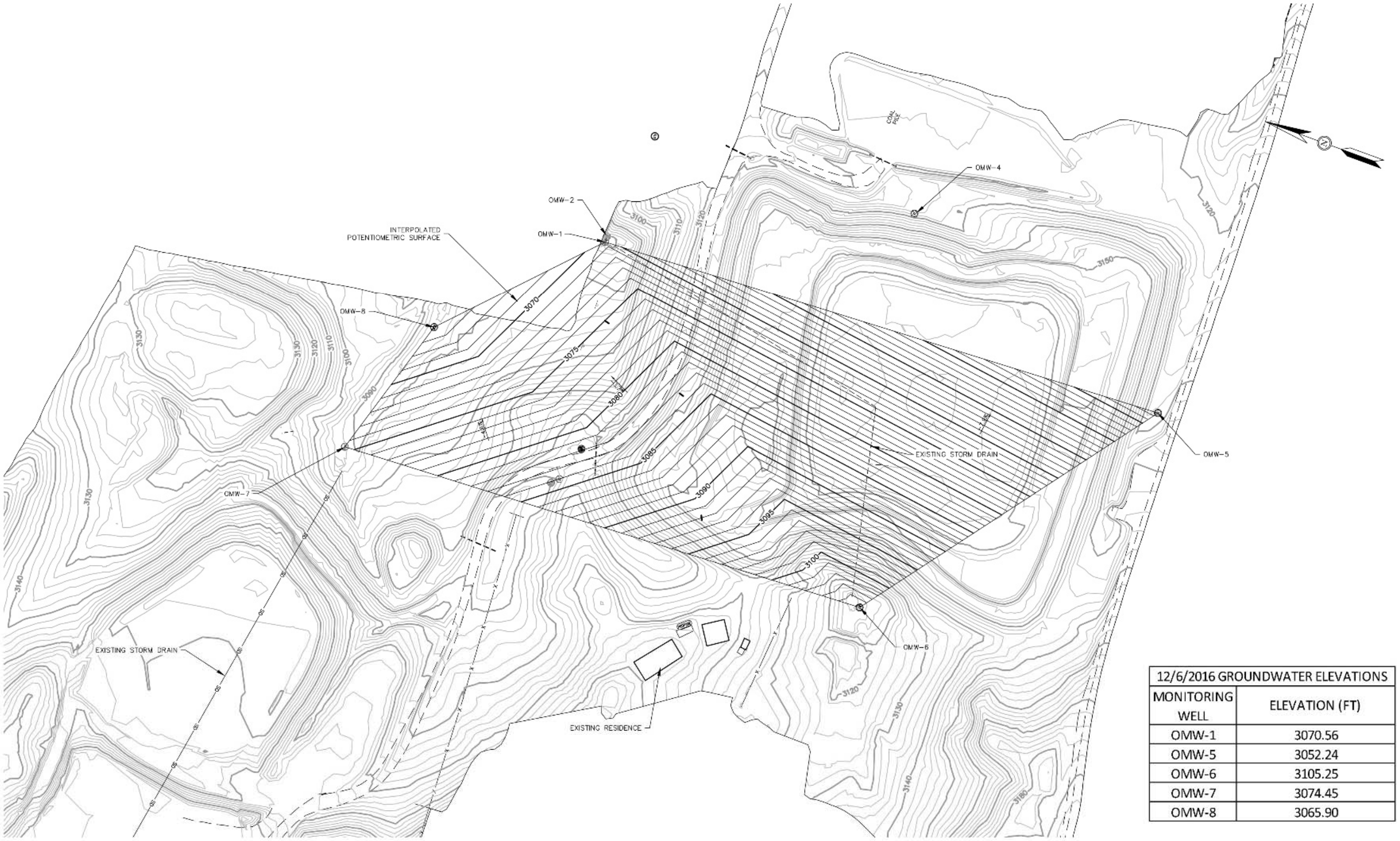
Groundwater Well:
Elevation, Flow and Direction

Calendar Year 2017

The CCR rule requires:

“Groundwater elevations must be recorded in each well …. (and) … determine the rate and direction of groundwater flow each time groundwater is sampled.” 40 CFR 257.93(c).

The figures below provide a graphical representation of the groundwater flow and rate for each sampling period. Each figure also provides the well elevation for each event.



12/6/2016 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3070.56
OMW-5	3052.24
OMW-6	3105.25
OMW-7	3074.45
OMW-8	3065.90

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

PROJECT ENGINEER: DSC
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DESIGNED BY:
REVIEWED BY: BDA

ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 12/6/2016
ROSEBUD COUNTY, MT

32 DISCOVERY DRIVE
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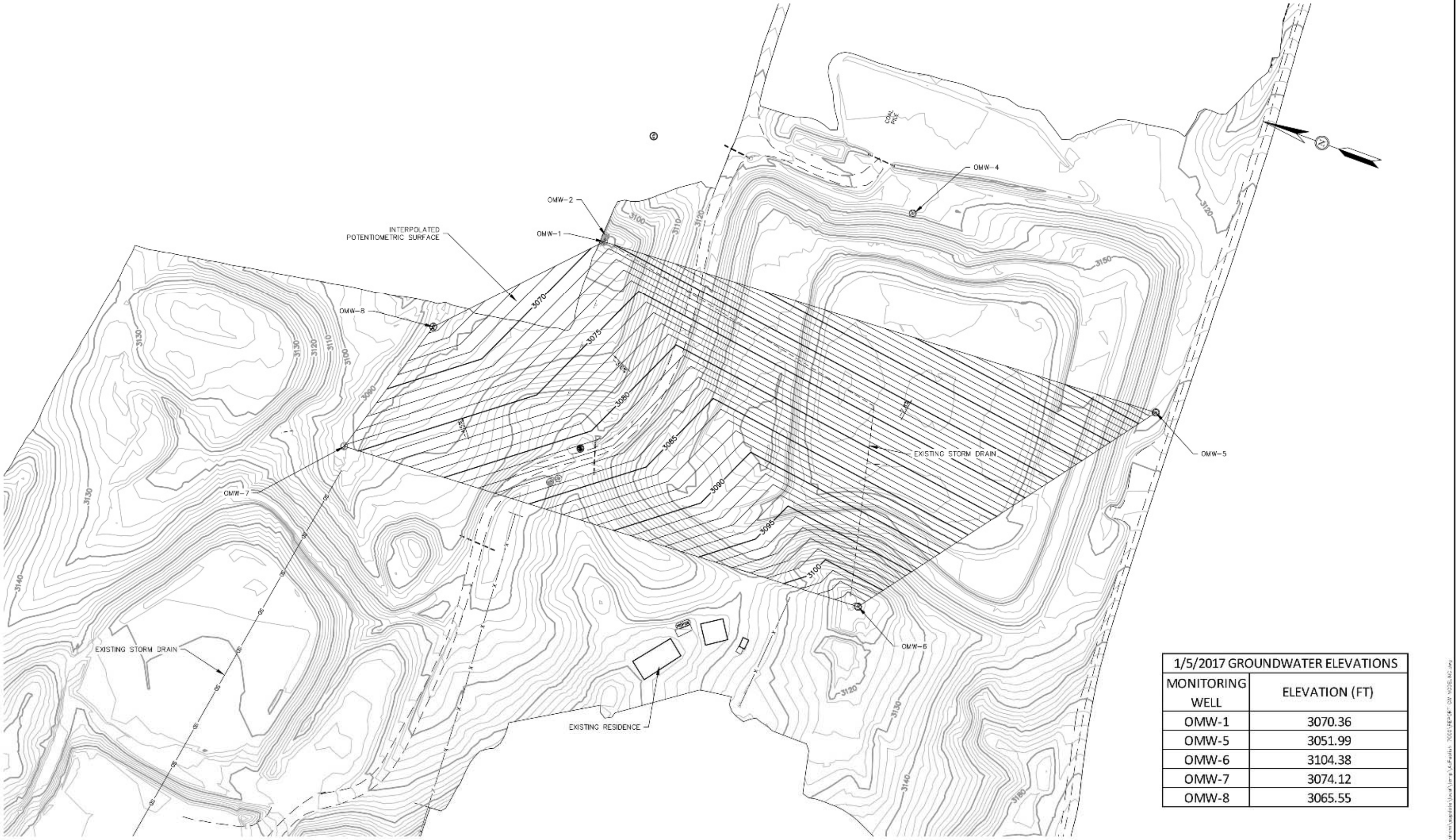
PROJECT #: 15-125
DATE: 01/16/2018
SHEET
GW-1



1/5/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3070.36
OMW-5	3051.99
OMW-6	3104.38
OMW-7	3074.12
OMW-8	3065.55

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

PROJECT ENGINEER: DSC
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ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 1/5/2017
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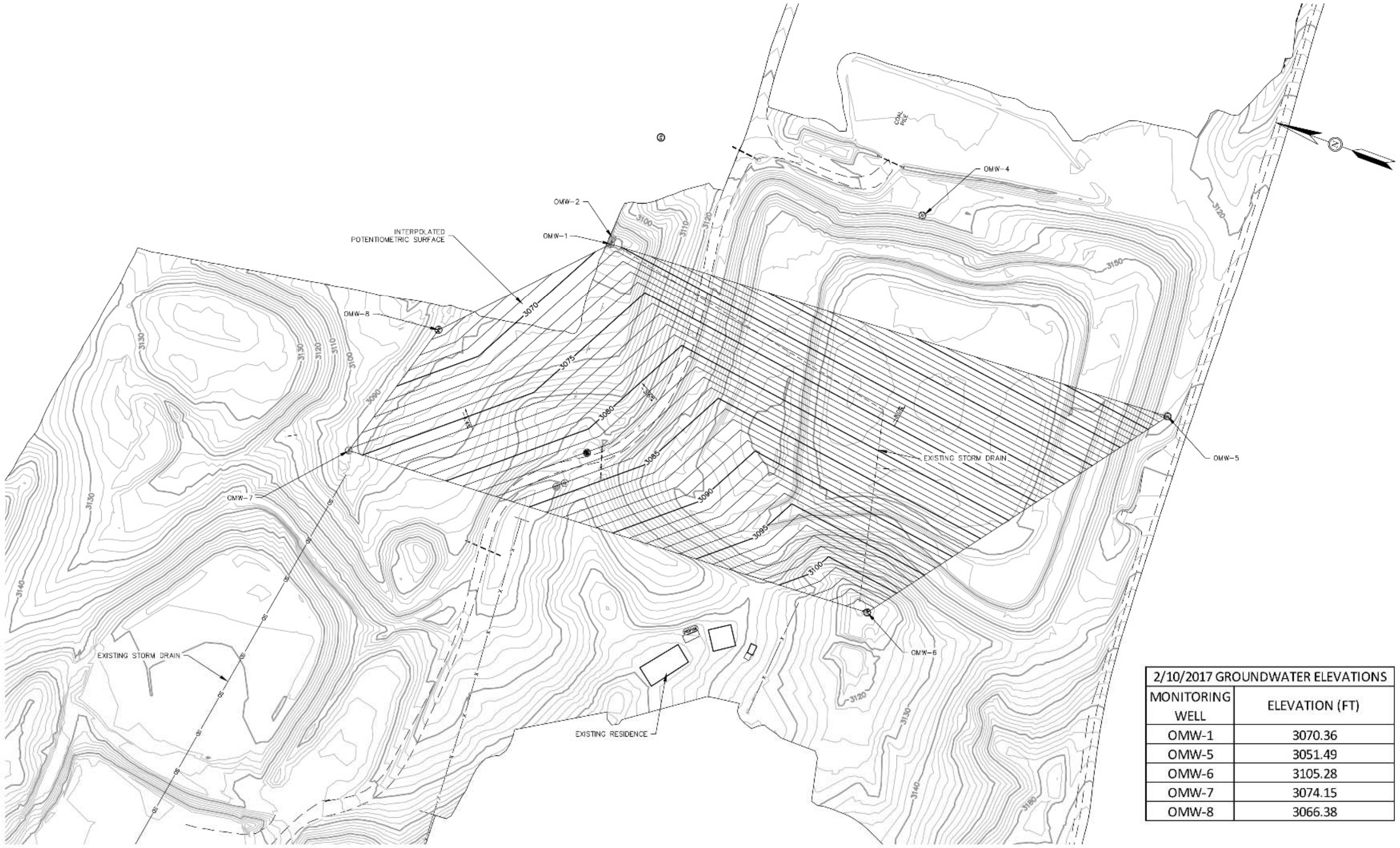

2/10/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3070.36
OMW-5	3051.49
OMW-6	3105.28
OMW-7	3074.15
OMW-8	3066.38

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

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ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 2/10/2017
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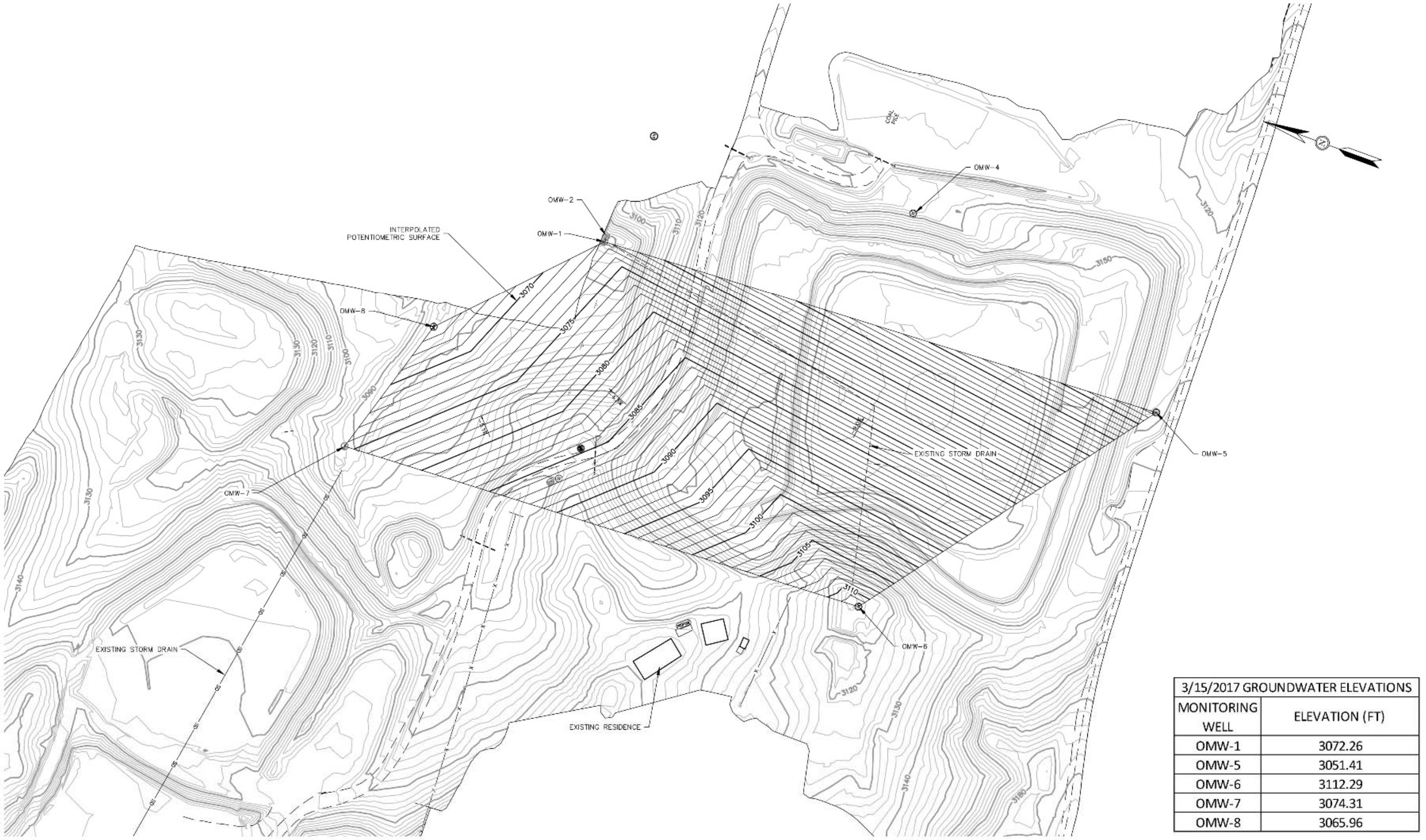

3/15/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3072.26
OMW-5	3051.41
OMW-6	3112.29
OMW-7	3074.31
OMW-8	3065.96

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

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ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 3/15/2017
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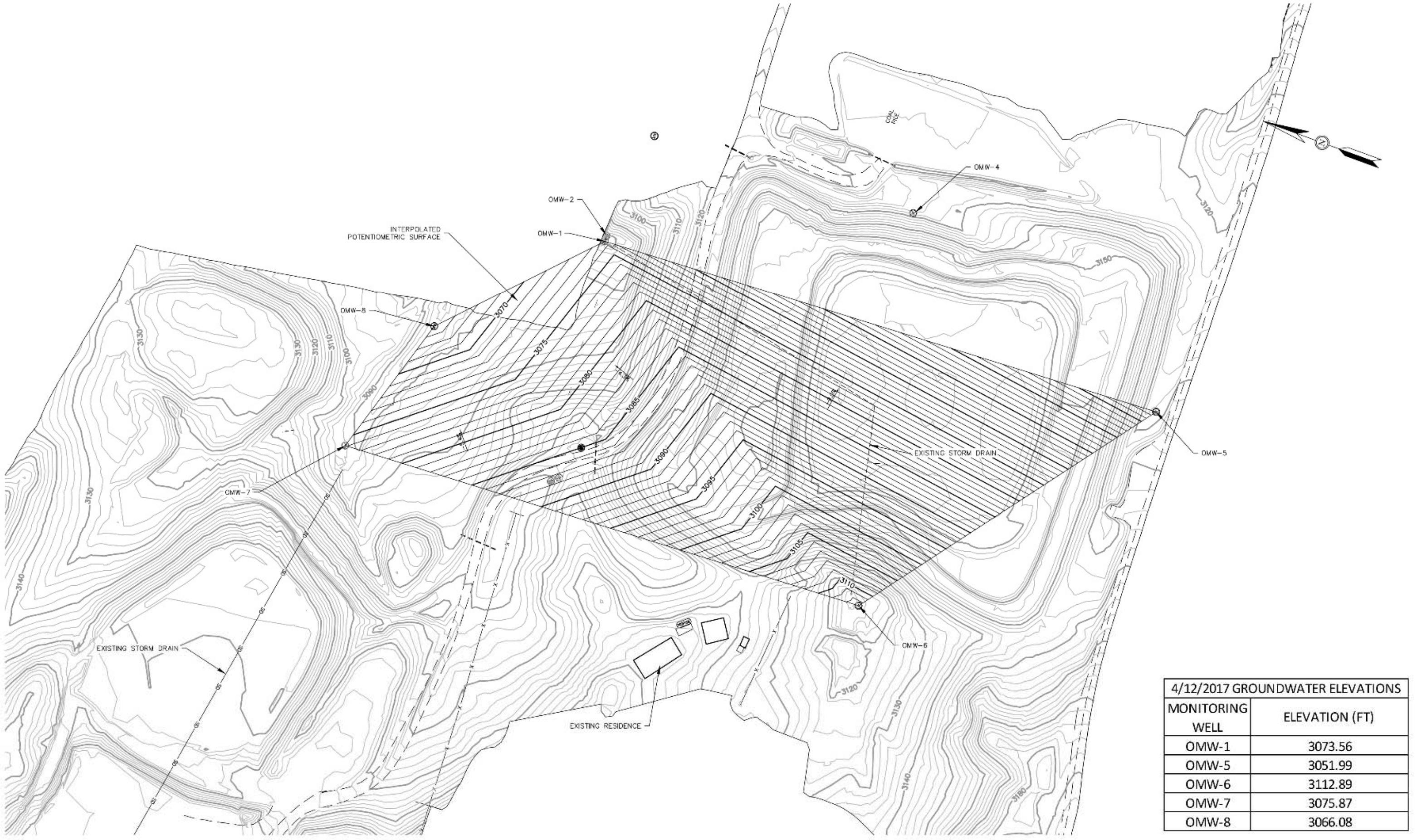

4/12/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3073.56
OMW-5	3051.99
OMW-6	3112.89
OMW-7	3075.87
OMW-8	3066.08

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

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ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 4/12/2017
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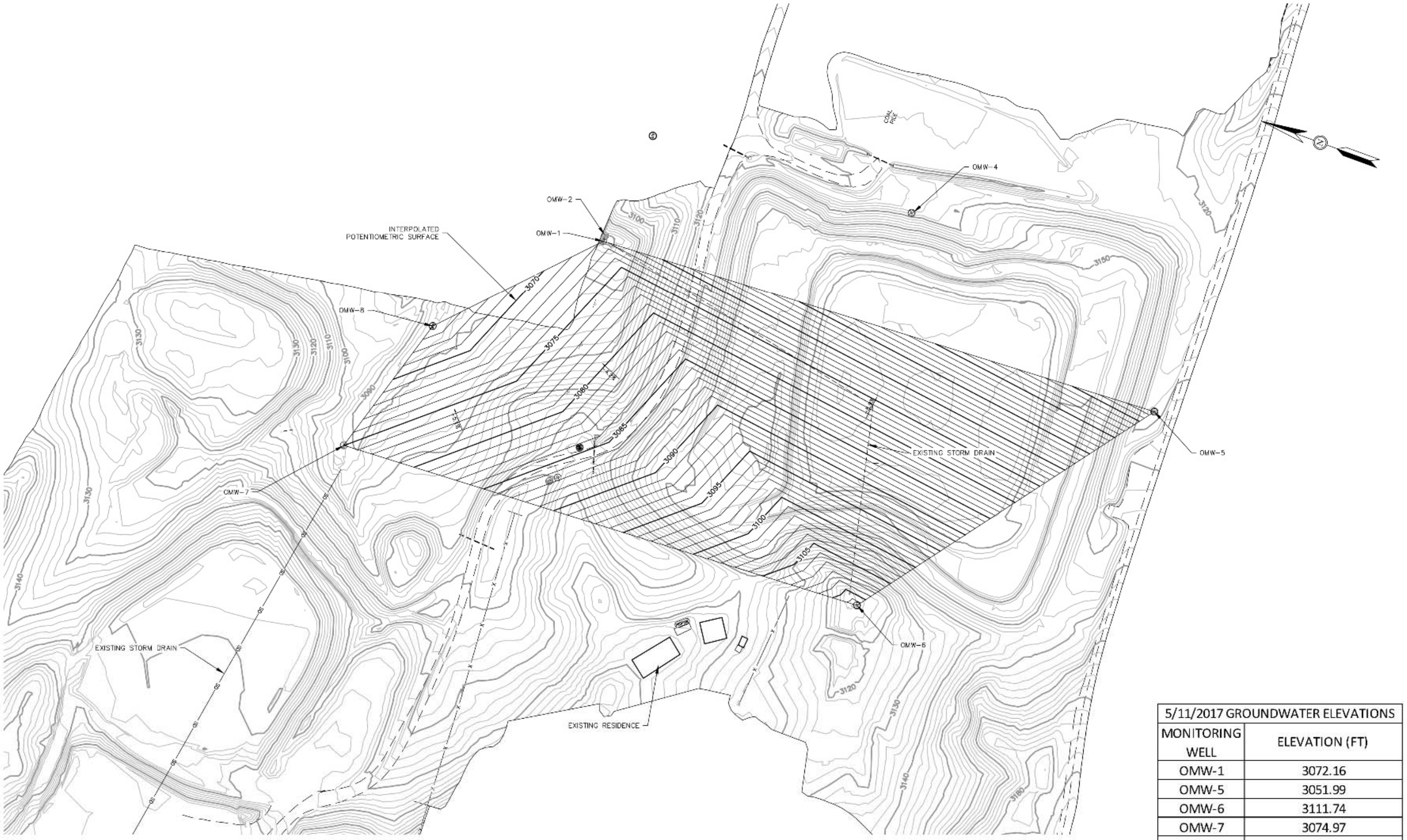

5/11/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3072.16
OMW-5	3051.99
OMW-6	3111.74
OMW-7	3074.97
OMW-8	3065.98

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

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REVIEWED BY: BDA

ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 5/11/2017
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PROJECT #: 15-125
DATE: 01/16/2018

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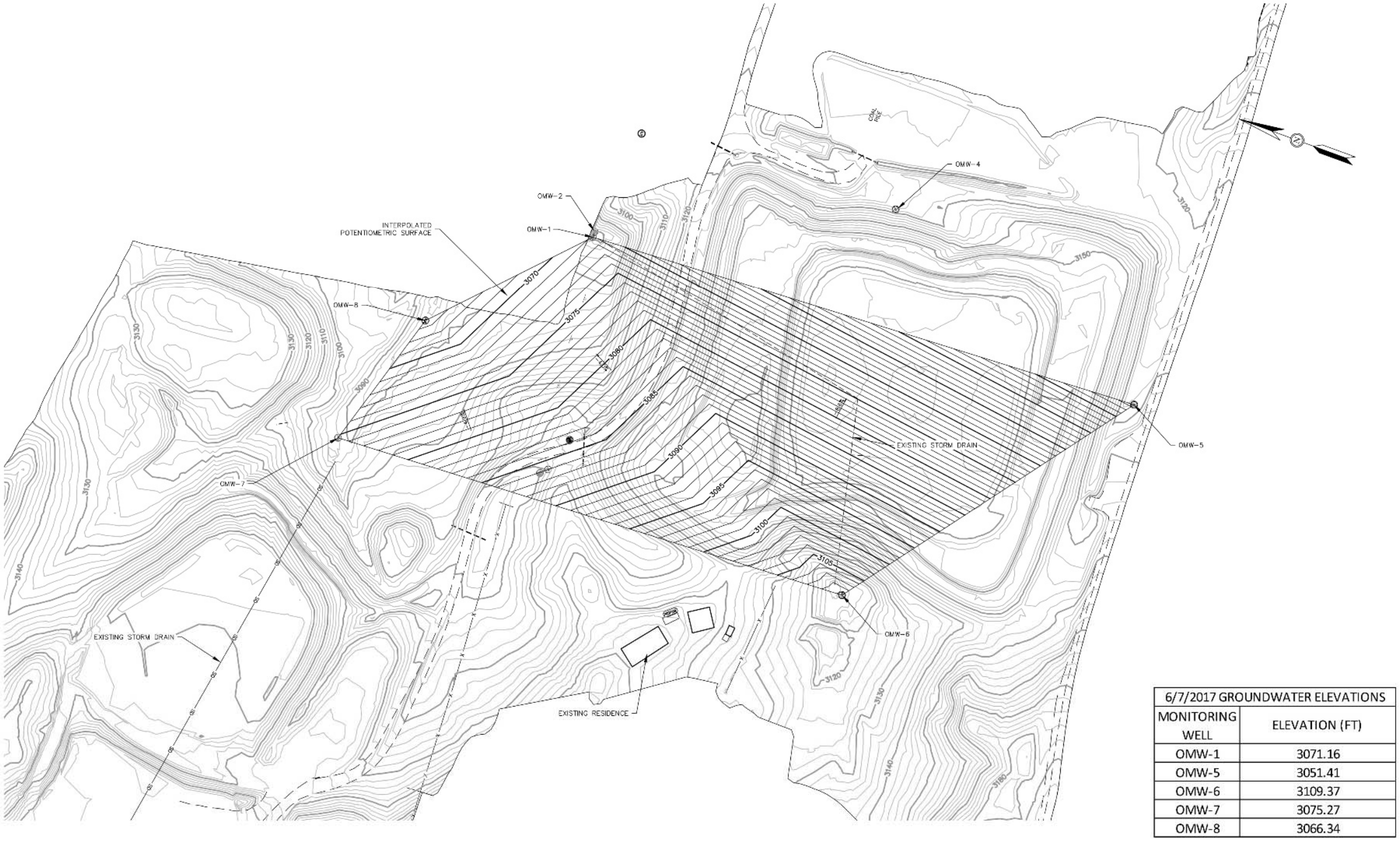

6/7/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3071.16
OMW-5	3051.41
OMW-6	3109.37
OMW-7	3075.27
OMW-8	3066.34

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0 100 200 300
SCALE (FEET)

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DESIGNED BY:
REVIEWED BY: BDA

ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 6/7/2017
ROSEBUD COUNTY, MT

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DATE: 01/16/2018

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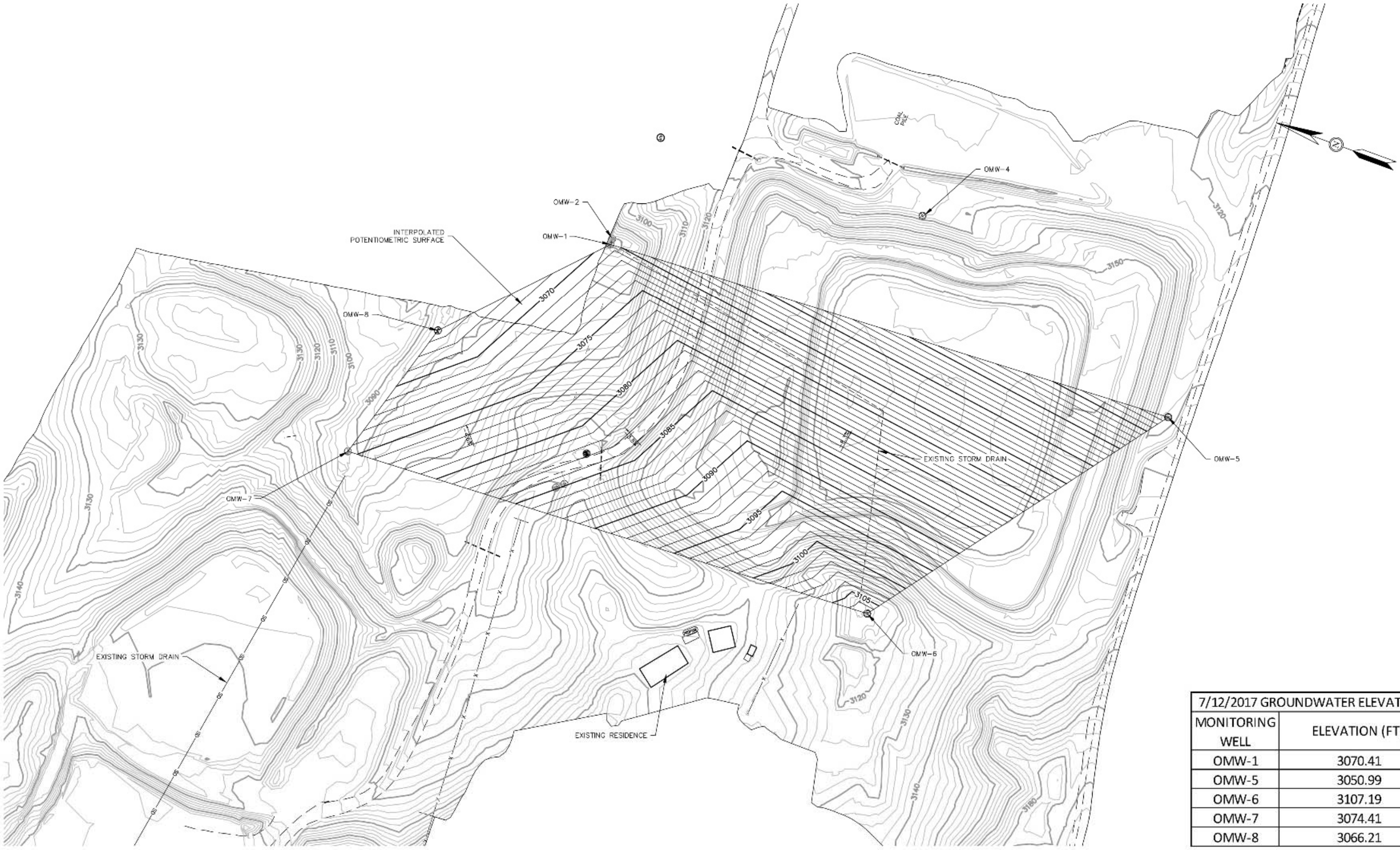

7/12/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3070.41
OMW-5	3050.99
OMW-6	3107.19
OMW-7	3074.41
OMW-8	3066.21

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

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ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 7/12/2016
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DATE: 01/16/2018

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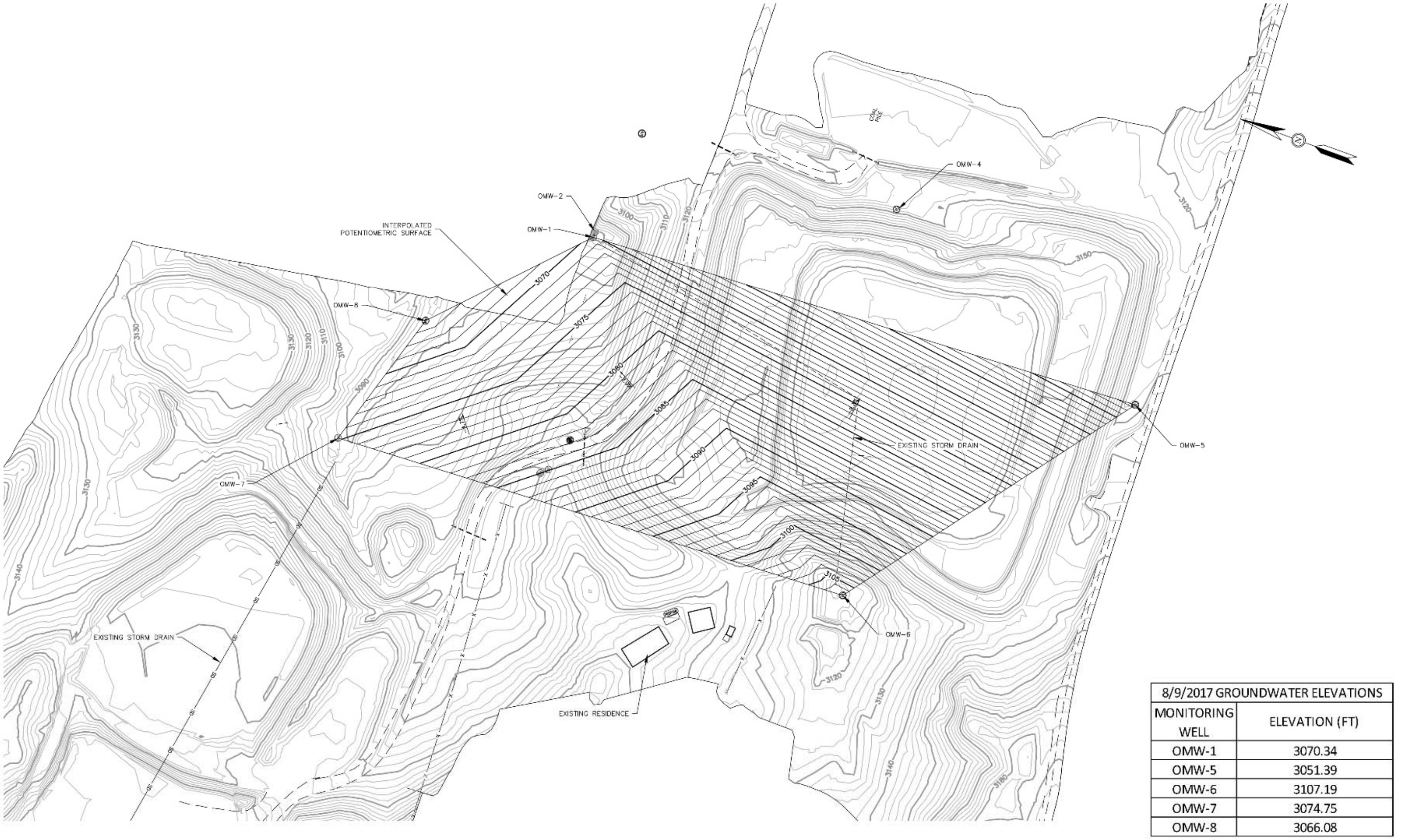

8/9/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3070.34
OMW-5	3051.39
OMW-6	3107.19
OMW-7	3074.75
OMW-8	3066.08

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

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ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 8/9/2017
ROSEBUD COUNTY, MT

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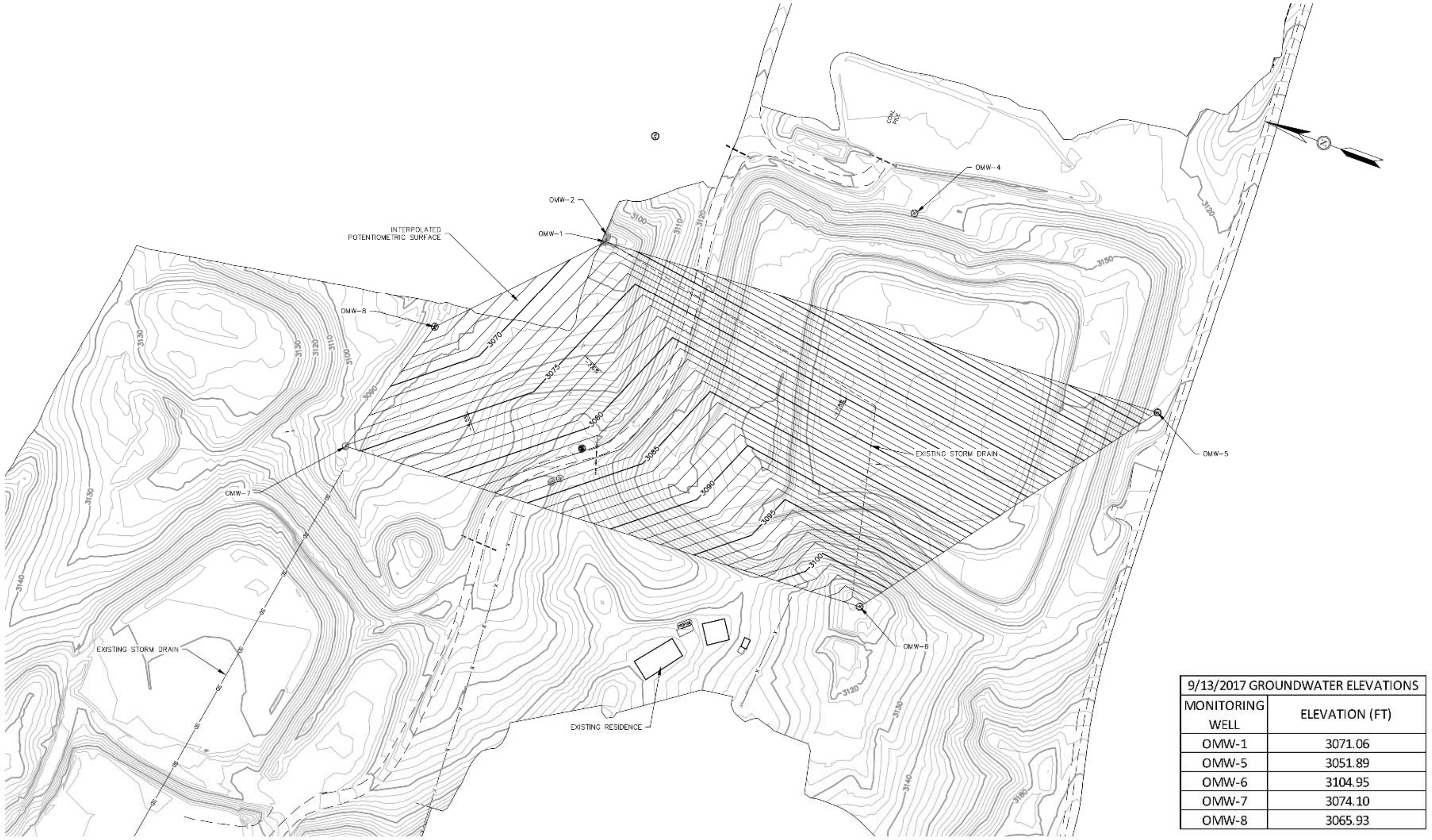

9/13/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3071.06
OMW-5	3051.89
OMW-6	3104.95
OMW-7	3074.10
OMW-8	3065.93

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SCALE (FEET)

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ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 9/13/2017
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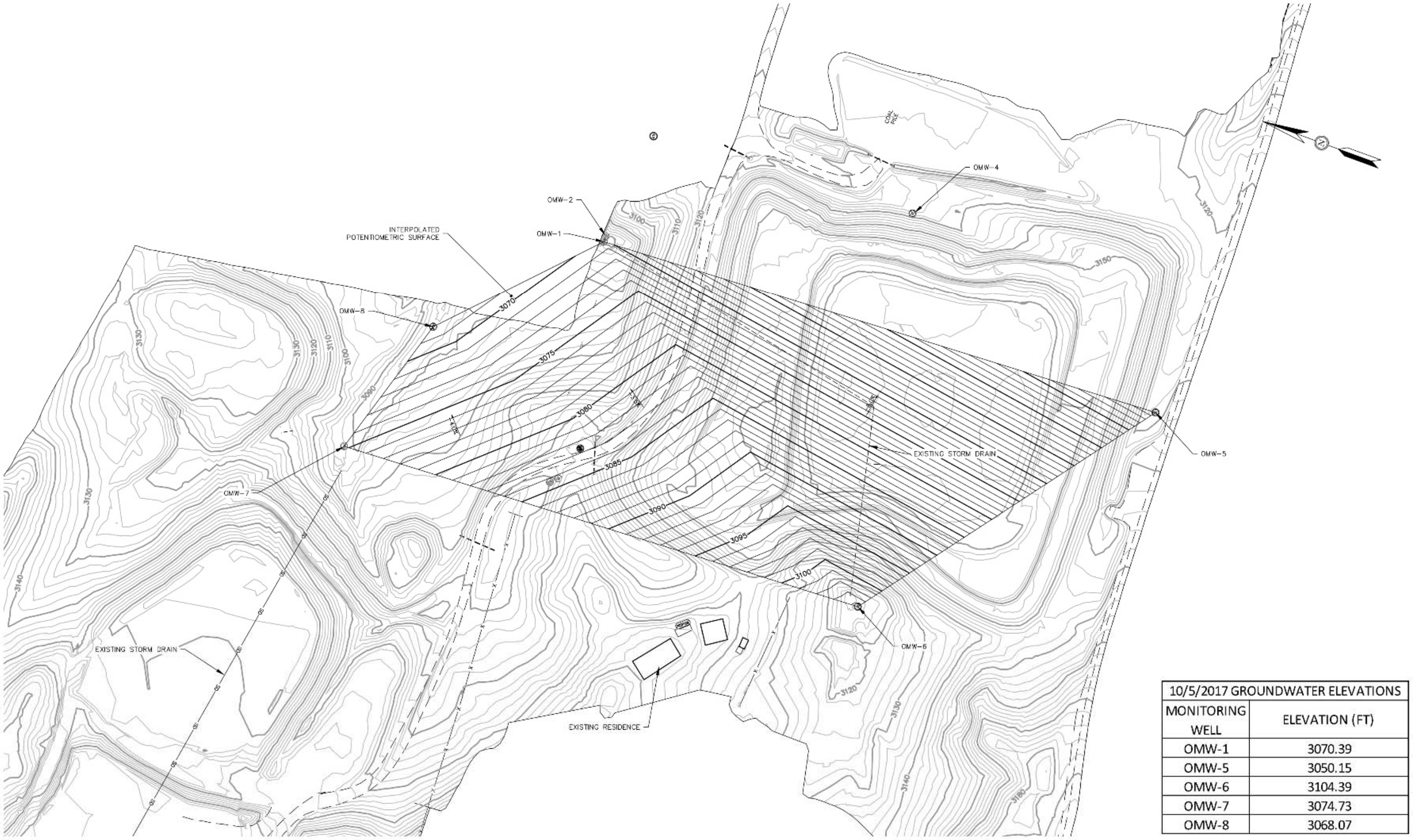

10/5/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3070.39
OMW-5	3050.15
OMW-6	3104.39
OMW-7	3074.73
OMW-8	3068.07

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

PROJECT ENGINEER: DSC
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ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 10/6/2017
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PROJECT #: 15-125
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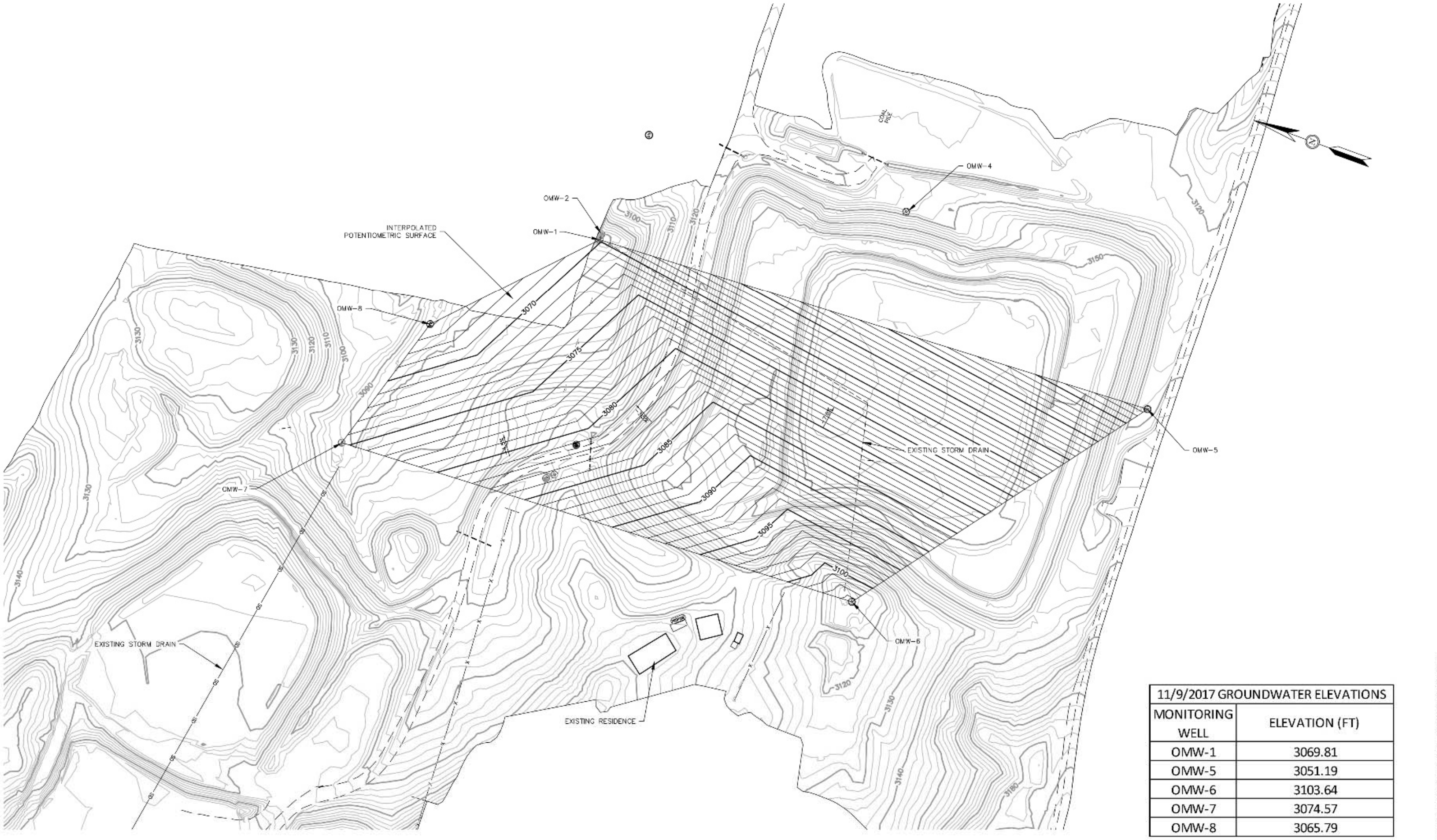

11/9/2017 GROUNDWATER ELEVATIONS	
MONITORING WELL	ELEVATION (FT)
OMW-1	3069.81
OMW-5	3051.19
OMW-6	3103.64
OMW-7	3074.57
OMW-8	3065.79

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

PROJECT ENGINEER: DSC
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DESIGNED BY:
REVIEWED BY: BDA

ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 11/9/2017
ROSEBUD COUNTY, MT

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Appendix B

Groundwater Well Data: Statistical Tests for Normality

Calendar Year 2017

A set of ‘goodness of fit’ analyses were run to determine if each constituent (on a well-by-well basis) may be treated as a normal distribution. All constituents that met this test were then analyzed for analyses of variance using the traditional ANOVA and t-tests. Those not meeting the normality test were then treated with nonparametric testing.

Since there is no single definitive test, multiple tests were employed. These include: skewness, coefficient of variation and the Shapiro-Wilk statistic. It was decided that if any particular variable (constituent by well) passed at least two of the three test statistics, the variable would then be subject to parametric methods.

The selection criteria for each test (normal vs non-normal) was as follows:

Test	Criteria	Source / Comment
Shapiro - Wilk	If the probability statistic < 0.05; then normality is assumed.	40 CFR 93(g)(2) suggests Type I errors be less than 0.05. This is also consistent with: “Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities,” EPA 530-R-09-007; March 2009.
Skewness	If absolute value of Skewness < 1.0; then normality is assumed.	This value is suggested in: “Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities,” EPA 530-R-09-007; March 2009.
Coefficient of Variation	If value of the Coefficient of Variation < 0.5; then normality is assumed.	“ “

The analysis for Skewness and Coefficient of Variation were calculated using Excel. In order to calculate the Shapiro-Wilk statistic, the statistical package “Unistat” Version 10 was employed. (Excel does not have this function or embedded in its “Data Analysis” add-in.) More information regarding the statistical package may be found at:

Unistat Ltd, Highgate, London N6 5UQ, UK
Tel: +44 20 8964 1130
http://www.unistat.com

Normality Tests

Smaller probabilities indicate non-normality.

OMW 1

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	Skewness	Coefficient of Variation	# Accepted Normality Tests
pH	12	7.47	0.07	0.78	0.006	0.38	0.01	2
TDS	12	1,366	243	0.77	0.004	-1.78	0.18	2
Calcium (Ca)	12	115	16	0.96	0.839	-0.60	0.14	3
Sulfate (SO42)	12	542	126	0.79	0.007	-1.61	0.23	2
Flouride (F)	12	0.47	0.08	0.78	0.005	0.63	0.17	2
Chloride (Cl)	12	55	14	0.80	0.009	-1.44	0.26	2
Boron (B)	12	0.07	0.01	0.87	0.066	0.43	0.22	3
Cations (Ca + Na)	12	318	49	0.837	0.025	-1.53	0.15	2

OMW 5

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	Skewness	Coefficient of Variation	# Accepted Normality Tests
pH	12	7.60	0.00	1.00	1.000	1.00	0.00	2
TDS	12	4,217	136	0.93	0.387	-0.49	0.03	3
Calcium (Ca)	12	41	2.67	0.91	0.242	-0.58	0.07	3
Sulfate (SO42)	12	1,958	67	0.93	0.424	-0.64	0.03	3
Flouride (F)	12	0.60	0.06	0.77	0.005	0.00	0.10	2
Chloride (Cl)	12	107	4.77	0.90	0.160	0.82	0.04	3
Boron (B)	12	0.92	0.05	0.81	0.012	-1.35	0.06	2
Cations (Ca + Na)	12	1475	46	0.92	0.27	-0.82	0.03	3

OMW 7

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	Skewness	Coefficient of Variation	# Accepted Normality Tests
pH	12	7.32	0.06	0.75	0.003	0.05	0.01	2
TDS	12	2,462	177	0.90	0.176	0.48	0.07	3
Calcium (Ca)	12	193	18	0.83	0.023	0.90	0.10	2
Sulfate (SO42)	12	1,265	80	0.91	0.235	0.05	0.06	3
Flouride (F)	12	0.41	0.03	0.33	0.000	3.02	0.07	1
Chloride (Cl)	12	76	7.30	0.94	0.479	0.33	0.10	3
Boron (B)	12	0.11	0.03	0.97	0.951	0.03	0.26	3
Cations (Ca + Na)	12	605	37	0.93	0.39	0.03	0.06	3

OMW 8

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	Skewness	Coefficient of Variation	# Accepted Normality Tests
pH	12	7.42	0.04	0.46	0.000	1.79	0.01	1
TDS	12	2,988	118	0.94	0.513	-0.27	0.04	3
Calcium (Ca)	12	193	16	0.94	0.474	0.08	0.08	3
Sulfate (SO42)	12	1,697	53	0.96	0.836	-0.66	0.03	3
Flouride (F)	12	0.44	0.05	0.64	0.000	0.34	0.12	2
Chloride (Cl)	12	91	5.63	0.89	0.102	0.52	0.06	3
Boron (B)	12	0.20	0.03	0.95	0.615	0.13	0.14	3
Cations (Ca + Na)	12	776	32	0.95	0.71	0.00	0.04	3

Appendix C

Analysis of Variance for Groundwater Data:

ANOVA & t-Test Results

Calendar Year 2017

The CCR rule requires:

> *"A parametric analysis of variance followed by multiple comparison procedures to identify statistical significant evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's mean and the background mean levels for each constituent." 40 CFR 257.93(f)(1).*

Regarding this 'analysis of variance,' the issue was discussed in previous documents. It was decided, based in part that the normality tests were largely successful, to conduct this testing using the two methods below:

- ANOVA; and
- t-test (unpaired)

The ANOVA test was conducted first followed by various t-tests. The ANOVA test employed is a "one-way" test to determine, on the whole, whether the means from all four wells (OMW1, 5, 7 and 8) are statistically the same. Should that test "fail" (i.e., there is not enough statistical evidence to deny the null hypothesis that all means are the same), then paired comparisons were made between the upgradient well (OMW5) and all other wells individually and by constituent.

The following pages provide the raw output from the statistical analyses themselves for each and every combination described above. Each page contains the ANOVA and t-test (among all wells) for each constituent.

pH

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	12	89.6	7.467	0.004
OMW5	12	91.2	7.600	0.000
OMW7	12	87.8	7.317	0.003
OMW8	12	89	7.417	0.002

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.5	3	0.1667	73.3333	0.0000	2.8165
Within Groups	0.1	44	0.0023			
Total	0.6	47				

t-Test: Unpaired Sample (Equal Variances)

	OMW1	*OMW5*
Mean	7.47	7.6
Variance	4.2E-03	8.61E-31
Observations	12	12
Pooled Variance	2.1E-03	
Hypothesized Mean Diffe	0	
df	22	
t Stat	-7.09	
P(T<=t) one-tail	2.1E-07	
t Critical one-tail	1.72	
P(T<=t) two-tail	4.1E-07	
t Critical two-tail	2.07	

	OMW7	*OMW5*
Mean	7.32	7.6
Variance	3.3E-03	8.61E-31
Observations	12	12
Pooled Varianc	1.7E-03	
Hypothesized M	0	
df	22	
t Stat	-17.00	
P(T<=t) one-tai	1.9E-14	
t Critical one-ta	1.72	
P(T<=t) two-tai	3.9E-14	
t Critical two-ta	2.07	

	OMW8	*OMW5*
Mean	7.42	7.6
Variance	1.5E-03	8.61E-31
Observations	12	12
Pooled Variance	7.6E-04	
Hypothesized Mea	0	
df	22	
t Stat	-16.32	
P(T<=t) one-tail	4.5E-14	
t Critical one-tail	1.72	
P(T<=t) two-tail	8.9E-14	
t Critical two-tail	2.07	

TDS

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW1	12	16,390	1,366	59,099
OMW5	12	50,600	4,217	18,388
OMW7	12	29,540	2,462	31,288
OMW8	12	35,860	2,988	14,015

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	50,480,440	3	16,826,813	548	7.529E-35	2.82
Within Groups	1,350,692	44	30,698			
Total	51,831,131	47				
Total	84,475,980	49				

t-Test: Unpaired Sample (≠ Variances)

	OMW1	OMW5
Mean	1,366	4,217
Variance	59,099	18,388
Observations	12	12
Hypothesized Mea	0	
df	17	
t Stat	-35.5	
P(T<=t) one-tail	1.102E-17	
t Critical one-tail	1.74	
P(T<=t) two-tail	2.204E-17	
t Critical two-tail	2.11	

t-Test: Unpaired Sample (= Variances)

	OMW7	OMW5
Mean	2,462	4,217
Variance	31,288	18,388
Observatic	12	12
Pooled Var	24,838	
Hypothesiz	0	
df	22	
t Stat	-27.27693	
P(T<=t) on	9.343E-19	
t Critical o	1.72	
P(T<=t) tw	1.869E-18	
t Critical tv	2.07	

	OMW8	OMW5
Mean	2,988	4,217
Variance	14,015	18,388
Observation	12	12
Pooled Varia	16,202	
Hypothesize	0	
df	22	
t Stat	-23.63818	
P(T<=t) one-	1.973E-17	
t Critical one	1.72	
P(T<=t) two-	3.946E-17	
t Critical twc	2.07	

Calcium

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	12	1,374	115	264
OMW5	12	488	41	7
OMW7	12	2,310	193	337
OMW8	12	2,311	193	257

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	191,293	3	63,764	295	3.81E-29	2.82
Within Groups	9,512	44	216			
Total	200,805	47				

t-Test: Unpaired Sample (≠ Variances)

	OMW1	*OMW5*
Mean	114.5	40.7
Variance	264.1	7.2
Observations	12	12
Hypothesized Mean Dif	0	
df	12	
t Stat	15.5	
P(T<=t) one-tail	1.31E-09	
t Critical one-tail	1.78	
P(T<=t) two-tail	2.61E-09	
t Critical two-tail	2.18	

	OMW7	*OMW5*
Mean	192.5	40.7
Variance	336.8	7.2
Observations	12	12
Hypothesized M	0	
df	11	
t Stat	28.4	
P(T<=t) one-tail	6.14E-12	
t Critical one-tai	1.80	
P(T<=t) two-tail	1.23E-11	
t Critical two-tai	2.20	

	OMW8	*OMW5*
Mean	192.6	40.7
Variance	256.6	7.2
Observatic	12	12
Hypothesi:	0	
df	12	
t Stat	32.4	
P(T<=t) on	2.36E-13	
t Critical o	1.78	
P(T<=t) tw	4.72E-13	
t Critical tv	2.18	

Sulfate

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	12	6,506	542	15,990
OMW5	12	23,490	1,958	4,439
OMW7	12	15,180	1,265	6,373
OMW8	12	20,360	1,697	2,788

ANOVA

urce of Variati	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Gro	13,777,359	3	4,592,453	621	5.21E-36	2.816466
Within Group	325,485	44	7,397			
Total	14102844.7	47				

t-Test: Unpaired Sample (≠ Variances)

	OMW1	*OMW5*
Mean	542	1,958
Variance	15,990	4,439
Observations	12	12
Hypothesized	0	
df	17	
t Stat	-34.3	
P(T<=t) one-t	1.9382E-17	
t Critical one-	1.74	
P(T<=t) two-t	3.8765E-17	
t Critical two-	2.11	

t-Test: Unpaired Sample (= Variances)

	OMW7	*OMW5*
Mean	1,265	1,958
Variance	6,373	4,439
Observation	12	12
Pooled Vari	5,406	
Hypothesize	0	
df	22	
t Stat	-23.1	
P(T<=t) one-	3.3E-17	
t Critical one	1.72	
P(T<=t) two-	6.6E-17	
t Critical tw	2.07	

	OMW8	*OMW5*
Mean	1,697	1,958
Variance	2,788	4,439
Observations	12	12
Pooled Varian	3,613	
Hypothesized M	0	
df	22	
t Stat	-10.6	
P(T<=t) one-tail	1.97E-10	
t Critical one-ta	1.72	
P(T<=t) two-tai	3.93E-10	
t Critical two-ta	2.07	

Fluoride

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	12	5.6	0.467	0.006
OMW5	12	7.2	0.600	0.004
OMW7	12	4.9	0.408	0.001
OMW8	12	5.3	0.442	0.003

ANOVA

ource of Variatio	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.254	3	0.0847	25.7	9.18E-10	2.82
Within Groups	0.145	44	0.0033			
Total	0.399167	47				

t-Test: Unpaired Sample (= Variances)

	OMW1	*OMW5*
Mean	0.467	0.600
Variance	0.006	0.004
Observations	12	12
Pooled Variance	0.0048	
Hypothesized Me	0	
df	22	
t Stat	-4.69	
P(T<=t) one-tail	5.59E-05	
t Critical one-tail	1.72	
P(T<=t) two-tail	0.000112	
t Critical two-tail	2.07	

	OMW7	*OMW5*
Mean	0.408	0.600
Variance	0.001	0.004
Observatio	12	12
Pooled Va	0.0022	
Hypothesi	0	
df	22	
t Stat	-9.93	
P(T<=t) on	6.84E-10	
t Critical o	1.72	
P(T<=t) tw	1.37E-09	
t Critical t	2.07	

	OMW8	*OMW5*
Mean	0.442	0.600
Variance	0.003	0.004
Observations	12	12
Pooled Varian	0.0031	
Hypothesized	0	
df	22	
t Stat	-6.92	
P(T<=t) one-t	3.02E-07	
t Critical one-	1.72	
P(T<=t) two-t	6.04E-07	
t Critical two-	2.07	

Chloride

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	12	656	54.7	205.5
OMW5	12	1,280	106.7	22.8
OMW7	12	917	76.4	53.4
OMW8	12	1,088	90.7	31.7

ANOVA

ource of Variatio	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17,542	3	5,847	74.64	2.7148E-17	2.82
Within Groups	3,447	44	78			
Total	20988.479	47				

t-Test: Unpaired Sample (≠ Variances)

	OMW1	*OMW5*
Mean	55	107
Variance	206	23
Observations	12	12
Hypothesized M	0	
df	13	
t Stat	-11.9	
P(T<=t) one-tail	1.13E-08	
t Critical one-tai	1.77	
P(T<=t) two-tail	2.26E-08	
t Critical two-tai	2.16	

t-Test: Unpaired Sample (= Variances)

	OMW7	*OMW5*
Mean	76	107
Variance	53	23
Observatio	12	12
Pooled Va	38.1	
Hypothesi	0	
df	22	
t Stat	-12.0	
P(T<=t) on	1.9601E-11	
t Critical o	1.72	
P(T<=t) tw	3.9202E-11	
t Critical tv	2.07	

	OMW8	*OMW5*
Mean	91	107
Variance	32	23
Observatio	12	12
Pooled Va	27.2	
Hypothesi	0	
df	22	
t Stat	-7.5	
P(T<=t) on	8.31E-08	
t Critical o	1.72	
P(T<=t) tw	1.66E-07	
t Critical tv	2.07	

Boron

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW1	12	0.800	0.067	0.0002
OMW5	12	11.060	0.922	0.0029
OMW7	12	1.270	0.106	0.0007
OMW8	12	2.400	0.200	0.0008

ANOVA

urce of Variati	SS	df	MS	F	P-value	F crit
Between Gro	5.84	3	1.95	1,674	2.4E-45	2.82
Within Group	0.051	44	0.0012			
Total	5.89	47				

t-Test: Unpaired Sample (Equal Variances)

	OMW1	OMW5
Mean	0.067	0.922
Variance	0.000	0.003
Observations	12	12
Hypothesized	0	
df	13	
t Stat	-53.1	
P(T<=t) one-t	6.9E-17	
t Critical one-	1.77	
P(T<=t) two-t	1.38E-16	
t Critical two-	2.16	

	OMW7	OMW5
Mean	0.106	0.922
Variance	0.001	0.003
Observation:	12	12
Hypothesize	0	
df	16	
t Stat	-46.9	
P(T<=t) one-	7.17E-19	
t Critical one	1.75	
P(T<=t) two-	1.43E-18	
t Critical twc	2.12	

	OMW8	OMW5
Mean	0.200	0.922
Variance	0.001	0.003
Observatic	12	12
Hypothesi:	0	
df	17	
t Stat	-41.2	
P(T<=t) on	9.04E-19	
t Critical o	1.74	
P(T<=t) tw	1.81E-18	
t Critical tv	2.11	

Total Cations (Ca + Na)

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW1	12	3817	318	2420
OMW5	12	17699	1475	2157
OMW7	12	7264	605	1356
OMW8	12	9314	776	1015

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	8713298	3	2,904,433	1,673	2.46E-45	2.82
Within Groups	76408.73	44	1,737			
Total	8789707	47				

t-Test: Unpaired Sample (Equal Variances)

	OMW1	OMW5
Mean	318	1,475
Variance	2,420	2,157
Observations	12	12
Pooled Variance	2,288	
Hypothesized Mean	0	
df	22	
t Stat	-59.2	
P(T<=t) one-tail	4.62E-26	
t Critical one-tail	1.72	
P(T<=t) two-tail	9.24E-26	
t Critical two-tail	2.07	

	OMW7	OMW5
Mean	605	1,475
Variance	1,356	2,157
Observations	12	12
Pooled Variance	1,756	
Hypothesized Me	0	
df	22	
t Stat	-50.8	
P(T<=t) one-tail	1.31E-24	
t Critical one-tail	1.72	
P(T<=t) two-tail	2.62E-24	
t Critical two-tail	2.07	

	OMW8	OMW5
Mean	776	1,475
Variance	1,015	2,157
Observations	12	12
Pooled Varianc	1,586	
Hypothesized M	0	
df	22	
t Stat	-43.0	
P(T<=t) one-tail	5.06E-23	
t Critical one-ta	1.72	
P(T<=t) two-tail	1.01E-22	
t Critical two-ta	2.07	

Appendix D

Analysis of Variance for Groundwater Data:

Kruskal-Wallis
(Nonparametric) ANOVA & t-Test Results

Calendar Year 2017

In addition to the CCR rule requirements for parametric analysis of variance described in Appendix C, the CCR rule also allows for the selection of a method that has the following attributes:

> *"An analysis of variance based on ranks followed by multiple comparison procedures to identify statistical evidence of contamination. The method must include estimation and testing of the contrasts between each compliance well's median and the background median levels for each constituent." 40 CFR 257.93(f)(2).*

The Kruskal-Wallis test appears to fulfill this requirement. The test is effectively a non-parametric alternative to the one-way F-test (ANOVA) for comparing multiple groups (wells) simultaneously. ANOVA testing's null hypothesis is that the data all comes from the same underlying population (i.e., the means are the same among all of the tested wells). In this case, however, this method looks for a difference in the average population ranks equivalent to the medians. Perhaps more importantly, the Kruskal-Wallis test does not require the underlying population be normally distributed.

A review of the pH and fluoride data (see Table 13 in the body of this report) indicate the underlying population may not be normal. This is due, most likely, to the fact that the standard deviation and variance for these two constituents are extremely low. Both pH and fluoride rarely changed more than 0.1 units during the entire 12-month sampling period (see Figure 2 graphs in the main body of this report). That is not to say that the typical ANOVA and t-test might not yield a usable result. Nonetheless, it was deemed cautionary to expand the analysis for these two constituents by conducting the Kruskal-Wallis test.

The following pages provide the raw output from the statistical analyses themselves for each and every combination of wells for pH and Fluoride. The analysis was conducted with the statistical package "Unistat" Version 10. More information regarding the statistical package may be found at:

Unistat Ltd, Highgate, London N6 5UQ, UK
Tel: +44 20 8964 1130
http://www.unistat.com

Kruskal-Wallis One-Way ANOVA

Test Results pH Analysis 2017 Data

	Cases	Rank Sum	Mean Rank
OMW1	12	323.5000	26.9583
OMW5	12	504.0000	42.0000
OMW7	12	100.5000	8.3750
OMW8	12	248.0000	20.6667
Total	48	1176.0000	24.5000

Correction for Ties = 0.0815

Chi-Square Statistic = 39.1266

Degrees of Freedom = 3

Right-Tail Probability = 0.0000

Multiple Comparisons with Rank Sums (Tukey-HSD)

Method: 95% Tukey-HSD interval.

** denotes significantly different pairs. Vertical bars show homogeneous subsets.

A pairwise test result is significant if its q stat value is greater than the table q.

Group	Cases	Rank Sum	OMW7	OMW8	OMW1	OMW5	
OMW7	12	100.5000			**	**	|
OMW8	12	248.0000				**	| |
OMW1	12	323.5000	**			**	|
OMW5	12	504.0000	**	**	**		|

Comparison	Difference	Standard Error	q Stat	Table q	Probability	Lower 95%	Upper 95%	Result
OMW5 - OMW7	403.5000	48.4974	8.3200	3.6332	0.0000	227.3011	579.6989	**
OMW1 - OMW7	223.0000	48.4974	4.5982	3.6332	0.0063	46.8011	399.1989	**
OMW8 - OMW7	147.5000	48.4974	3.0414	3.6332	0.1373	-28.6989	323.6989	
OMW5 - OMW8	256.0000	48.4974	5.2786	3.6332	0.0011	79.8011	432.1989	**
OMW1 - OMW8	75.5000	48.4974	1.5568	3.6332	0.6890	-100.6989	251.6989	
OMW5 - OMW1	180.5000	48.4974	3.7218	3.6332	0.0422	4.3011	356.6989	**

pH Analysis

Multiple Comparisons with Mean Ranks (Tukey-HSD)

Method: 95% Tukey-HSD interval.

** denotes significantly different pairs. Vertical bars show homogeneous subsets.

A pairwise test result is significant if its q stat value is greater than the table q.

Group	Cases	Mean Rank	OMW7	OMW8	OMW1	OMW5	
OMW7	12	8.3750			**	**	|
OMW8	12	20.6667				**	| |
OMW1	12	26.9583	**			**	|
OMW5	12	42.0000	**	**	**		|

Comparison	Difference	Standard Error	q Stat	Table q	Probability	Lower 95%	Upper 95%	Result
OMW5 - OMW7	33.6250	4.0415	8.3200	3.6332	0.0000	18.9418	48.3082	**
OMW1 - OMW7	18.5833	4.0415	4.5982	3.6332	0.0063	3.9001	33.2666	**
OMW8 - OMW7	12.2917	4.0415	3.0414	3.6332	0.1373	-2.3916	26.9749	
OMW5 - OMW8	21.3333	4.0415	5.2786	3.6332	0.0011	6.6501	36.0166	**
OMW1 - OMW8	6.2917	4.0415	1.5568	3.6332	0.6890	-8.3916	20.9749	
OMW5 - OMW1	15.0417	4.0415	3.7218	3.6332	0.0422	0.3584	29.7249	**

Homogeneous Subsets:

Group 1: OMW7, OMW8

Group 2: OMW8, OMW1

Group 3: OMW5

Multiple Comparisons with t Distribution

Method: 95% t interval.

** denotes significantly different pairs. Vertical bars show homogeneous subsets.

A pairwise test result is significant if its q stat value is greater than the table q.

Group	Cases	Mean	OMW7	OMW8	OMW1	OMW5	
OMW7	12	8.3750		**	**	**	|
OMW8	12	20.6667	**		**	**	|
OMW1	12	26.9583	**	**		**	|
OMW5	12	42.0000	**	**	**		|

Comparison	Difference	Standard Error	q Stat	Table q	Probability	Lower 95%	Upper 95%	Result
OMW5 - OMW7	33.6250	2.3171	14.5114	2.0154	0.0000	28.9551	38.2949	**
OMW1 - OMW7	18.5833	2.3171	8.0199	2.0154	0.0000	13.9134	23.2532	**
OMW8 - OMW7	12.2917	2.3171	5.3047	2.0154	0.0000	7.6218	16.9616	**
OMW5 - OMW8	21.3333	2.3171	9.2067	2.0154	0.0000	16.6634	26.0032	**
OMW1 - OMW8	6.2917	2.3171	2.7153	2.0154	0.0094	1.6218	10.9616	**
OMW5 - OMW1	15.0417	2.3171	6.4915	2.0154	0.0000	10.3718	19.7116	**

Kruskal-Wallis One-Way ANOVA

Test Results Fluoride Analysis 2017 Data

	Cases	Rank Sum	Mean Rank
OMW1	12	280.0000	23.3333
OMW5	12	488.0000	40.6667
OMW7	12	168.0000	14.0000
OMW8	12	240.0000	20.0000
Total	48	1176.0000	24.5000

Correction for Ties = 0.1494
Chi-Square Statistic = 28.3024
Degrees of Freedom = 3
Right-Tail Probability = 0.0000

Multiple Comparisons with Rank Sums (Tukey-HSD)

Method: 95% Tukey-HSD interval.

** denotes significantly different pairs. Vertical bars show homogeneous subsets.

A pairwise test result is significant if its q stat value is greater than the table q.

Group	Cases	Rank Sum	OMW7	OMW8	OMW1	OMW5	
OMW7	12	168.0000				**	|
OMW8	12	240.0000				**	|
OMW1	12	280.0000				**	|
OMW5	12	488.0000	**	**	**		|

Comparison	Difference	Standard Error	q Stat	Table q	Probability	Lower 95%	Upper 95%	Result
OMW5 - OMW7	320.0000	48.4974	6.5983	3.6332	0.0000	143.8011	496.1989	**
OMW1 - OMW7	112.0000	48.4974	2.3094	3.6332	0.3600	-64.1989	288.1989	
OMW8 - OMW7	72.0000	48.4974	1.4846	3.6332	0.7200	-104.1989	248.1989	
OMW5 - OMW8	248.0000	48.4974	5.1137	3.6332	0.0017	71.8011	424.1989	**
OMW1 - OMW8	40.0000	48.4974	0.8248	3.6332	0.9372	-136.1989	216.1989	
OMW5 - OMW1	208.0000	48.4974	4.2889	3.6332	0.0130	31.8011	384.1989	**

Fluoride Analysis

Multiple Comparisons with Mean Ranks (Tukey-HSD)

Method: 95% Tukey-HSD interval.

** denotes significantly different pairs. Vertical bars show homogeneous subsets.

A pairwise test result is significant if its q stat value is greater than the table q.

Group	Cases	Mean Rank	OMW7	OMW8	OMW1	OMW5	
OMW7	12	14.0000				**	|
OMW8	12	20.0000				**	|
OMW1	12	23.3333				**	|
OMW5	12	40.6667	**	**	**		|

Comparison	Difference	Standard Error	q Stat	Table q	Probability	Lower 95%	Upper 95%	Result
OMW5 - OMW7	26.6667	4.0415	6.5983	3.6332	0.0000	11.9834	41.3499	**
OMW1 - OMW7	9.3333	4.0415	2.3094	3.6332	0.3600	-5.3499	24.0166	
OMW8 - OMW7	6.0000	4.0415	1.4846	3.6332	0.7200	-8.6832	20.6832	
OMW5 - OMW8	20.6667	4.0415	5.1137	3.6332	0.0017	5.9834	35.3499	**
OMW1 - OMW8	3.3333	4.0415	0.8248	3.6332	0.9372	-11.3499	18.0166	
OMW5 - OMW1	17.3333	4.0415	4.2889	3.6332	0.0130	2.6501	32.0166	**

Homogeneous Subsets:

Group 1: OMW7, OMW8, OMW1

Group 2: OMW5

Multiple Comparisons with t Distribution

Method: 95% t interval.

** denotes significantly different pairs. Vertical bars show homogeneous subsets.

A pairwise test result is significant if its q stat value is greater than the table q.

Group	Cases	Mean	OMW7	OMW8	OMW1	OMW5	
OMW7	12	14.0000			**	**	|
OMW8	12	20.0000				**	| |
OMW1	12	23.3333	**			**	|
OMW5	12	40.6667	**	**	**		|

Comparison	Difference	Standard Error	q Stat	Table q	Probability	Lower 95%	Upper 95%	Result
OMW5 - OMW7	26.6667	3.4363	7.7603	2.0154	0.0000	19.7413	33.5921	**
OMW1 - OMW7	9.3333	3.4363	2.7161	2.0154	0.0094	2.4079	16.2587	**
OMW8 - OMW7	6.0000	3.4363	1.7461	2.0154	0.0878	-0.9254	12.9254	
OMW5 - OMW8	20.6667	3.4363	6.0142	2.0154	0.0000	13.7413	27.5921	**
OMW1 - OMW8	3.3333	3.4363	0.9700	2.0154	0.3373	-3.5921	10.2587	
OMW5 - OMW1	17.3333	3.4363	5.0442	2.0154	0.0000	10.4079	24.2587	**