Annual Groundwater Monitoring Report

[40 CFR 257.90(e)]

Calendar Year 2020

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Colstrip, MT

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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 is "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 the 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.

The ash deposited in the landfill is hydrated with water to allow the calcium sulfate and the unreacted calcium oxide in the ash to form a solid bed similar to concrete. There are no water containment ponds or sites. No water leaches from or through the solid hydrated bed into the ground water. (See pages 3-4 herein.) The groundwater monitoring is nevertheless undertaken to substantiate the lack of any impacts from the ash storage facility.

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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 2020. The report has been, or will be, entered into the facility's operating record and posted on the CELP CCR website[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 applicable. 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 creates a significant shallow groundwater mound and influences a downgradient monitoring well. Based on the data, and experience in similar conditions, infiltrated surface 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 distribution 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 concentrations may or may not be due to the landfill itself, but due to the variations of native 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 de-

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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 twice in eight years while OMW-10 has never produced any water.

sulfurization process in the boiler, coupled with the resultant calcium sulfate that is also produced, renders the ash (CCR) into a cement-like substance. This substance is hydrated during placement in the CCR landfill. Once hydrated and hardened, very little surface water penetrates through it and what little does is chemically used up hydrating the un-hydrated CCR; 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 or shallow inland sea. These deltas comprise 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 at the site is characterized as mostly ephemeral drainage basins draining to the east into East Fork Armells Creek, a perennial stream that flows generally north to join the West Fork of Armells and then north to the Yellowstone River. 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, groundwater 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. However, at the site, which is located on an east flowing ephemeral unnamed tributary of East Fork Armells Creek, the local uppermost aquifer is often perched above the regional aquifer, is discontinuous and, in some locations, is ephemeral. Similar but disconnected perched uppermost aquifers form in many named and unnamed tributaries to East Fork Armells, including Corral Creek to the south.

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 almost completely 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 apart from one sample event in April 2018.

Table 1 below provides a description and the status of each well.

Figure 1: Monitoring Well Locations

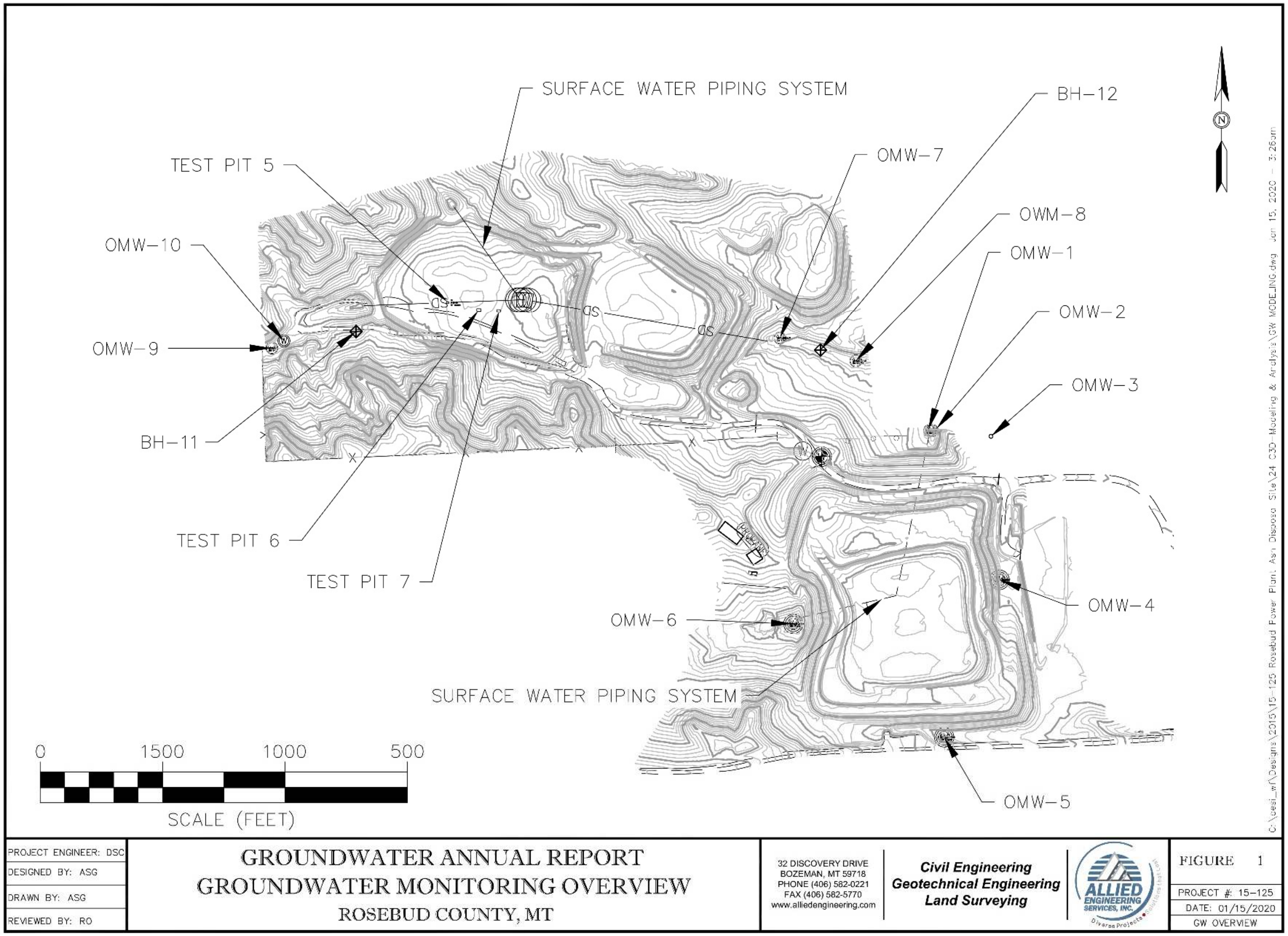

Table 1: Well Description and Status

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 elevated groundwater observed in OMW-6. Based on its elevation, proximity to stock pond and groundwater quality data, OMW-6 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 2011 (a usually wet period prior to the sampling event) and an additional single sample in the spring of 2018. Data might be suitable 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 reliable 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 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 above-described on-site 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 and 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 and perennially 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 in the discontinuous and ephemeral uppermost aquifers are variable in slope and direction. Assuming observed water in the four CCR area wells that had water represent a connected aquifer, interpretations of those surfaces on 4-25-19 and 9-17-19 are provided in Appendix A (Sheets GW-1 and GW-2). While the groundwater surfaces depicted in GW-1 and GW-2 may appear unusual, the following conditions are depicted by the calculated surface:
    - OMW-5 is located approximately 1600 feet south within the adjacent Corral Creek ephemeral drainage. The uppermost aquifer encountered at this location is about 25 feet lower than the aquifer downstream of the CCR

    landfill and is likely disconnected from the unnamed tributary in which the CCR landfill sits.
  - Flow between OM-7 and OM-8 may not be directly down gradient so actual gradients may be higher. Sheet GW-2 of Appendix A, while not necessarily typical for several reasons, indicates that the gradient is about 4.6% to the NE. These discontinuous perched aquifers in hilly terrain like this commonly have steep and variable gradients.
  - OMW-6 is located adjacent to a stock pond which creates a significant groundwater mound beneath it. Some portion of the groundwater mound likely flows toward OMW-5 (in the adjacent Corral Creek drainage) in a southeasterly direction at an estimated gradient of around 9%.
  - Groundwater from the mound at OMW-6 likely also flows northeast toward OMW-1, OMW-7, and OMW-8 at an average estimated gradient of around 4% based on Sheets GW-1 and GW-2.
- Groundwater flow direction in the vicinity of the CCR landfill is generally northeast to east and remains relatively constant over time.
- The uppermost aquifer thickness varies between wells and ranges between 1.03 feet and 47.81 feet, and is seasonally thicker in the spring of each year.
- Hydraulic conductivities of soils underlying the active landfill are estimated to vary between 2.5 and 3.8 feet/year.
- Porosity is estimated between 30%-45% for clayey substrate indicative of site soils.
- Based on the hydraulic conductivity, gradient, and effective porosity of the uppermost aquifer at the active landfill, the average linear groundwater velocities are estimated between 0.14 and 0.39 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 2020). 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] "Assessment" monitoring is required whenever a statistically significant increase over background levels has been detected during detection monitoring. Assessment monitoring was not required for this reporting period. The constituents to be monitored during detection monitoring and assessment monitoring are listed in Table 3 below.

Tables 4 through 7 list the results of groundwater monitoring of the constituents listed in Table 3 for wells OMW-1, OMW-5, OMW-7, and OMW-8, respectively, from 2016 through 2020.

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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.

Table 2: Monitoring Well Sampling Matrix

Well ID	Location (Latitude : Longitude)	Sample Dates	Sample Purpose*	Comment
OMW-1	45.977465 : -106.659088	2016: 12/6 2017: 1/5, 2/10, 3/15, 4/12, 5/11,6/7, 7/12, 8/9, 9/13, 10/5, 11/9. 2018: 6/6, 10/26 2019: 4/4, 9/17-18 (resample 10/9 OMW1 only) 2020: 5/6, 11/3	Detection	Downgradient well
OMW-5	45.974031 : -106.659030	- Same as OMW-1 -	Detection	Upgradient well
OMW-6	45.975360 : -106.661386	No CCR Sampling	n/a	Non-CCR
OMW-7	45.978560 : -106.661434	- Same as OMW-1 -	Detection	Downgradient well
OMW-8	45.978274 : -106.660229	- Same as OMW-1 -	Detection	Downgradient well
OMW-9	45.978654 : -106.669599	4/20/18	n/a	Lone sample in last 10 years
OMW-10	45.978730: -106.669400	No samples	n/a	Dry Well

* Purpose may be either "Detection" or Assessment" per 40 CFR 257.94 or 95, respectively.

Table 3: Appendix III Constituents Analyzed: 2020 Reporting Period

Constituent	Program *
Boron (B)	Detection
Calcium (Ca)	Detection
Chloride (Cl^-)	Detection
Fluoride (F^-)	Detection
pH	Detection
Sulfate (SO_4^{-2})	Detection
Total Dissolved Solids (TDS)	Detection

* These detection program constituents are taken from Appendix III of 40 CFR 257. All monitoring during this sampling period was for purposes of detection.

Table 4: Data Summary OMW-1 Appendix III Constituents Plus Sodium

Date	pH	TDS (mg/l)	Calcium (mg/l)	Sodium (mg/l)	Sulfate (mg/l)	Fluoride (mg/l)	Chloride (mg/l)	Boron (mg/l)
12/6/2016	7.4	1,530	140	263	625	0.5	67	0.09
1/5/2017	7.5	1,520	130	247	629	0.4	62	0.08
2/10/2017	7.4	1,610	126	241	658	0.6	67	0.07
3/15/2017	7.5	1,200	95	170	448	0.5	43	0.06
4/12/2017	7.5	710	80	112	213	0.4	19	0.08
5/11/2017	7.5	1,160	102	190	423	0.4	39	0.06
6/7/2017	7.6	1,420	112	217	534	0.4	52	0.06
7/12/2017	7.5	1,480	119	246	558	0.4	60	0.06
8/9/2017	7.4	1,410	125	231	597	0.5	60	ND
9/13/2017	7.4	1,460	112	215	612	0.6	63	ND
10/5/2017	7.5	1,460	118	230	586	0.5	60	ND
11/9/2017	7.4	1,430	115	215	623	0.4	64	0.09
6/6/2018	7.7	750	66	125	220	0.5	19	0.10
10/26/2018	7.5	1,210	107	214	415	0.4	44	0.10
4/26/19	7.7	683	67	132	168	0.4	15	0.09
~~9/18/19~~	~~8.2~~	~~1,760~~	~~8~~	~~664~~	~~188~~	~~1.0~~	~~9~~	~~0.94~~
10/9/19	7.4	1,230	109	178	450	0.8	50	0.10
5/6/20	7.5	652	69		105	0.3	13	0.10
11/3/20	7.4	1,440	127		528	0.5	67	0.10

Note1: The 9/18/19 sample results were declared invalid.OMW-1 was resampled on 10/9/19. The reasons were discussed in a previous report (Calendar Year 2019 – Issued January 2020).

Note 2: Sodium was included in this data summary table since sodium is used in the combined cation analysis discussed later in this report. However, sodium was inadvertently not analyzed in 2020. Future sampling will include this constituent.

Sodium was inadvertently not analyzed in 2020. Therefore, the sample size is slightly smaller than the other constituents. Future sampling will include sodium for purposes previously discussed.

Table 5: Data Summary OMW-5 Appendix III Constituents Plus Sodium

Date	pH	TDS (mg/l)	Calcium (mg/l)	Sodium (mg/l)	Sulfate (mg/l)	Fluoride (mg/l)	Chloride (mg/l)	Boron (mg/l)
12/06/2016	7.6	4,300	43	1,570	1,810	0.7	103	0.95
01/5/2017	7.6	4,200	42	1,500	1,880	0.6	109	0.95
02/10/2017	7.6	4,370	40	1,430	2,030	0.6	115	0.93
03/15/2017	7.6	4,310	36	1,330	2,020	0.6	105	0.93
04/12/2017	7.6	3,980	42	1,410	1,960	0.6	105	0.91
05/11/2017	7.6	4,280	44	1,440	1,970	0.7	106	0.83
06/7/2017	7.6	4,400	41	1,490	1,960	0.5	105	0.96
07/12/2017	7.6	4,300	41	1,500	2,060	0.6	116	0.98
08/9/2017	7.6	4,130	36	1,390	1,930	0.6	107	0.80
09/13/2017	7.6	4,200	39	1,480	1,940	0.6	102	0.96
10/5/2017	7.6	4,000	40	1,470	1,960	0.6	100	0.92
11/9/2017	7.6	4,130	44	1,450	1,970	0.5	107	0.94
6/06/2018	7.6	3,970	41	1,410	1,860	0.6	105	0.90
10/26/2018	7.8	4,090	39	1,410	1,670	0.6	99	0.90
4/26/2019	7.8	3,960	37	1,480	1,910	0.6	105	0.90
9/18/2019	7.8	4,290	41	1,410	1,950	0.6	116	0.90
5/6/2020	7.6	4,240	41		2,100	0.4	109	1.00
11/3/2020	7.6	4,330	40		1,940	0.6	111	1.01

Note: Sodium was included in this data summary table since sodium is used in the combined cation analysis discussed later in this report. However, sodium was inadvertently not analyzed in 2020. Future sampling will include this constituent.

Table 6: Data Summary OMW-7 Appendix III Constituents Plus Sodium

Date	pH	TDS (mg/l)	Calcium (mg/l)	Sodium (mg/l)	Sulfate (mg/l)	Fluoride (mg/l)	Chloride (mg/l)	Boron (mg/l)
12/06/2016	7.2	2,620	230	492	1,340	0.4	85	0.13
01/5/2017	7.3	2,660	214	457	1,290	0.4	80	0.14
02/10/2017	7.3	2,780	215	464	1,380	0.4	88	0.12
03/15/2017	7.3	2,670	182	396	1,380	0.4	87	0.09
04/12/2017	7.3	2,230	185	364	1,160	0.4	71	0.12
05/11/2017	7.3	2,250	181	391	1,190	0.4	66	0.18
06/7/2017	7.4	2,370	181	412	1,190	0.4	68	0.08
07/12/2017	7.4	2,400	185	423	1,160	0.4	72	0.09
08/9/2017	7.3	2,360	177	400	1,280	0.4	74	0.06
09/13/2017	7.4	2,440	173	391	1,300	0.4	77	0.10
10/5/2017	7.3	2,390	183	414	1,220	0.5	72	0.08
11/9/2017	7.3	2,370	204	453	1,290	0.4	77	0.15
6/06/2018	7.5	1,800	144	325	939	0.4	51	0.11
10/26/2018	7.5	1,900	153	364	900	0.4	51	0.13
4/26/2019	7.5	2,200	179	409	1,070	0.4	65	0.03
9/18/2019	7.6	1,850	142	331	875	0.4	44	0.13
5/6/2020	7.2	2,030	151		991	0.3	51	0.14
11/3/2020	7.3	1,940	152		943	0.4	49	0.16

Note: Sodium was included in this data summary table since sodium is used in the combined cation analysis discussed later in this report. However, sodium was inadvertently not analyzed in 2020. Future sampling will include this constituent.

Table 7: Data Summary OMW-8 Appendix III Constituents Plus Sodium

Date	pH	TDS (mg/l)	Calcium (mg/l)	Sodium (mg/l)	Sulfate (mg/l)	Fluoride (mg/l)	Chloride (mg/l)	Boron (mg/l)
12/06/2016	7.4	3,090	223	619	1,680	0.4	87	0.22
01/5/2017	7.4	3,050	206	610	1,690	0.4	84	0.22
02/10/2017	7.4	3,180	199	614	1,700	0.4	89	0.22
03/15/2017	7.4	3,070	171	560	1,720	0.5	86	0.19
04/12/2017	7.4	2,840	202	533	1,640	0.5	85	0.23
05/11/2017	7.4	3,040	201	588	1,720	0.4	87	0.19
06/7/2017	7.5	3,060	189	606	1,710	0.4	88	0.18
07/12/2017	7.5	2,860	170	569	1,580	0.4	91	0.18
08/9/2017	7.4	2,970	175	570	1,780	0.5	98	0.16
09/13/2017	7.4	3,020	180	565	1,750	0.5	100	0.20
10/5/2017	7.4	2,790	195	585	1,660	0.5	95	0.16
11/9/2017	7.4	2,890	200	625	1,730	0.4	98	0.25
6/06/2018	7.5	3,110	215	621	1,710	0.4	86	0.18
10/26/2018	7.5	2,520	158	537	1,380	0.4	76	0.18
4/26/2019	7.6	2,950	201	553	1,950	0.4	90	0.18
9/18/2019	7.6	3,000	212	536	1,650	0.4	95	0.18
5/6/2020	7.4	3,240	213		1,870	0.3	104	0.20
11/3/2020	7.3	3,240	216		1,750	0.4	111	0.21

Note: Sodium was included in this data summary table since sodium is used in the combined cation analysis discussed later in this report. However, sodium was inadvertently not analyzed in 2020. Future sampling will include this constituent.

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. A brief summary and general conclusions regarding Appendix IV data were presented in the report titled "Groundwater Monitoring and Action Plan" (10/17/17) and can be found on the www.celpccr.com website per 40 CFR 257.90(b).

Table 8: CCR Well Summary Statistics

Parameter	pH	TDS	Ca	Sulfate	Fluoride	Chloride	Boron	Cation (Ca + Na)[9]
OMW – 1								
Count (n)	18	18	18	18	18	18	18	16
Mean	7.5	1,242	107	466	0.47	48	0.077	319
Std. Dev.	0.081	323	23	177	0.11	19.3	0.020	67
Skewness	1.20	-0.97	-0.72	-0.93	1.45	-0.85	-0.14	-1.1`
Kurtosis	2.12	-0.54	-0.51	-0.44	3.22	-0.76	-1.68	0.56
Coef. Variation	0.011	0.26	0.21	0.38	0.24	0.40	0.25	0.21
OMW – 5								
Count (n)	18	18	18	18	18	18	18	16
Mean	7.6	4,193	40.4	1,940	0.59	107	0.93	1,489
Std. Dev.	0.077	144	2.4	97	0.068	5.00	0.053	57.8
Skewness	1.96	-0.44	-0.47	-1.14	-1.15	0.55	-0.77	0.024
Kurtosis	2.0	-1.1	-0.12	2.8	3.2	-0.2	1.1	0.8
Coef. Variation	0.010	0.034	0.06	0.050	0.115	0.047	0.057	0.039
OMW – 7								
Count (n)	18	18	18	18	18	18	18	16
Mean	7.36	2,292	180	1,161	0.40	68.2	0.11	588
Std. Dev.	0.11	295	25.1	169	0.03	13.8	0.03	70
Skewness	0.74	-0.17	0.29	-0.45	-0.00	-0.36	-0.82	-0.08
Kurtosis	-0.05	-0.87	-0.39	-1.2	8.5	-1.0	0.7	-0.10
Coef. Variation	0.015	0.13	0.14	0.15	0.086	0.20	0.31	0.12
OMW – 8								
Count (n)	18	18	18	18	18	18	18	16
Mean	7.44	2,996	196	1,684	0.42	91.7	0.20	774
Std. Dev.	0.078	174	18.4	101.4	0.055	8.32	0.025	44
Skewness	0.84	-1.065	-0.58	-1.4	0.16	0.58	0.54	0.056
Kurtosis	0.5	2.1	-0.6	4.4	0.18	0.58	-0.24	-1.1
Coef. Variation	0.01	0.06	0.09	0.06	0.13	0.09	0.13	0.06

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[9] Sodium was inadvertently not analyzed in 2020. Therefore, the sample size is slightly smaller than the other constituents. Future sampling will include sodium for purposes previously discussed.

A few comments regarding the data are appropriate. The count indicates the number of data values. The mean is the average of the data values. The standard deviation is a measure of the amount of variation in the data set. The "Skewness" is presented because it is one indicator to determine if the dataset has or nears a "normal"[10] distribution. "Skewness" indicates if the normal (bell-shaped) distribution has a degree of asymmetry. 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 that 21 of the 28 skewness values are less than 1 (absolute). Therefore, that indicator leans toward a near-normal assumption for much of the data.

Another general 'normal' indicator is Kurtosis. It is like Skewness except Kurtosis indicates large deviation (or perhaps outliers) in the data. The term is commonly discussed as a measure of how peaked (or flat) a probability distribution curve may be. However, it is more accurate to refer to it as a measure of the tails of the curve. A value of 3 is a perfectly normal distribution curve. There seems to be no consensus in the literature as to an acceptable range of Kurtosis that is a good indicator of normality. However, values between 2 and 4 seem to be the most common.

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 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] do not provide definitive guideline values for the CV. Nonetheless, the document indicates a value less than 0.5 is a positive indication of normality. A review of the data above indicates that all analyses yielded a CV less than 0.5. This particular statistic tends to indicate near-normal distributions.

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

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

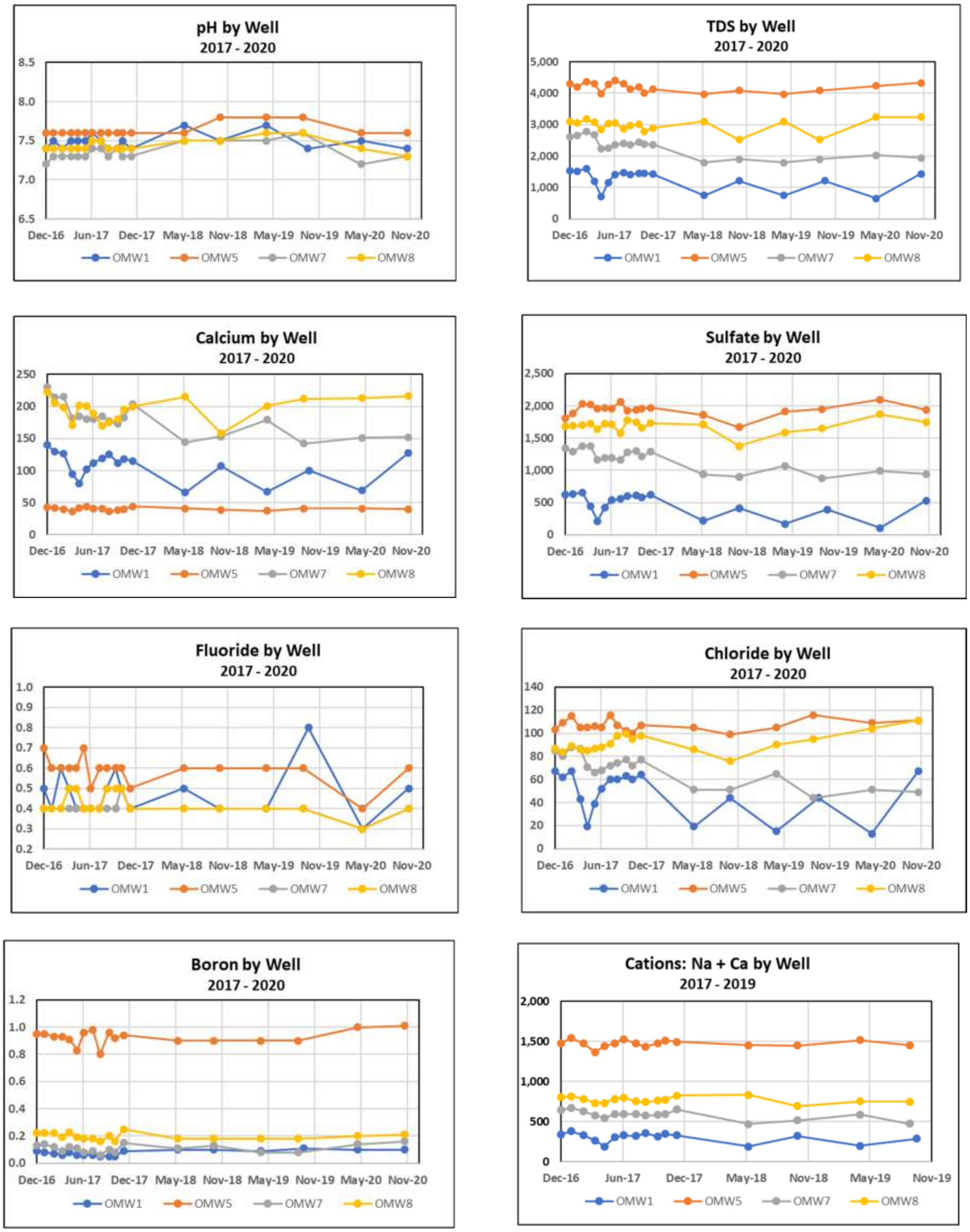
5.3 DATA ANALYSIS - GRAPHICAL

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 ↔ 2020 CCR data is presented in the following eight graphics (the cation graph covers 2017 ↔ 2019). Each figure plots a 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 yearly CCR measurement period.

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] This annual report analyzed the Appendix III constituents (pH, TDS, Ca, SO_4^{2-}, Fl^-, Cl^- and B). The statistical methods 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 website per 40 CFR 257.90(b) and elsewhere.

As a brief synopsis, the (initial) statistical methods 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. Although not required, these distributions were also subjected to parametric analysis as a matter of convenience and caution.
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 will be followed by t-test analyses as necessary for single, usually unpaired analyses.
    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. This ANOVA test will be applied in the same manner as the parametric data (one-factor ANOVA followed by well pairs on a constituent by constituent basis).

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 evaluate the assumption of normality for each of the well-constituent data sets. Data that are near normal were analyzed using parametric tests while non-normal data was analyzed using nonparametric methods described above.

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 (CV)
- D'Agostino-Pearson Test
- Shapiro-Wilk Test

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

The reason for choosing the coefficient of variation as a statistic is briefly discussed in Section 5.2 above. Additionally, the CV is a measure discussed in the statistics guideline.[13] The D'Agostino-Pearson test analyzes both the Kurtosis and Skewness of the data.[14] It uses a combination of this data to provide a better predictor of normal distributions than either Skewness or Kurtosis alone.[15] The Shapiro-Wilk test is one of the more common, semi-robust analyses to test for normality.

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 conducted on the raw (non-transformed) data.[16] The results of the normality tests are summarized below. The results of the individual tests are found in Appendix B

Table 9: Normality Test Results

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

In order to cover all eventualities, it was decided to conduct all analyses using parametric statistical analysis. To be conservative, an additional set of non-parametric analyses was conducted on four of the constituents due to their lower overall normality ratings. These were pH, sulfate, fluoride, and boron (boron is normal except for OMW1). The conclusions reached for these constituents were the same regardless of the underlying parametric or non-parametric treatment.

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[13] This is a reference to: "Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities" EPA 530-R-09-007, March 2009.

[14] A brief discussion about this test statistic (and the Shapiro-Wilk statistic) is found here: *https://www.graphpad.com/guides/prism/7/statistics/index.htm?stat_choosing_a_normality_test.htm*

[15] The October 2017 report "Rosebud Power Plant Groundwater Monitoring and Action Plan" which describes the most likely statistical tests to be applied had suggested using the Skewness statistic in combination with the CV and Shapiro-Wilk test to ascertain normality. The D'Agostino-Pearson test has since become available which uses both the skewness and kurtosis statistics as a measure of normality. Therefore, that test (D'Agostino-Pearson) replaces Skewness by itself as a more robust (one of three) test for normality.

[16] Although not shown here, the first annual report made various attempts to subject the data to various linear transformations to determine if perhaps a better normal distribution might emerge. Those efforts did not improve a normal vs. non-normal outcome and that analysis was not repeated here.

5.4.2 ANALYSIS OF VARIANCE (ANOVA) TESTING

The CCR rule requires:

> *"A parametric analysis of variance followed by multiple comparison procedures to identify statistically 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 following methods:

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

Non-Parametric:
- Kruskal-Wallis (one-way)
- Kruskal-Wallis (well by well: Q-Test)

ANOVA - Parametric[17]

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 the means of a given constituent (e.g., pH, TDS, etc.) across all wells the same?"* If there is enough statistical evidence (at the 5% level) to reject this null hypothesis, then one can conclude that the means of the constituent being analyzed across groups (wells) are statistically different. This is accomplished by analyzing the variance within each group (well-constituent) and among each group. If there is no statistical difference in the well-constituents, 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].

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

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[17] 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 the data in the interest of completeness since most of the well/constituent data had at least some indication of a near normal distribution. There were a few exceptions and these are addressed later in this section.

Table 10: ANOVA (between wells) Summary Results

Constituent	Calculated F Statistic	Critical F-Statistic	Statistical Difference?
pH	29.4	2.74	Yes
TDS	455	2.74	Yes
Calcium	249	2.74	Yes
Sulfate	384	2.74	Yes
Fluoride	23.8	2.74	Yes
Chloride	73.6	2.74	Yes
Boron	2,368	2.74	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 wells (for the same constituent) are not the same (or do not appear to come from the same population of data).

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)[18]

The (parametric) ANOVA tests indicate 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. Furthermore, 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) 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 samples taken from the same test subject, which would mean samples from the same groundwater well. 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.[19] For the purposes of this analysis, the means of various

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[18] Ibid.

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

constituents in the downgradient wells are being compared to the means of the constituents in the upgradient well. Therefore, a paired t-test is not appropriate for this analysis.

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.

Table 11: t-Test Summary Results

Constituent	Parameter	OMW-1 vs OMW-5		OMW-7 vs OMW-5		OMW-8 vs OMW-5	
pH	Mean	7.49	7.63	7.36	7.63	7.44	7.63
	Variance	0.0093	0.0059	0.012	0.0059	0.0060	0.0059
	Calculated “t”	-4.98		-8.81		-7.55	
	Critical “t”	1.69		1.69		1.69	
	Difference?	Yes		Yes		Yes	
TDS	Mean	1,242	4,193	2,292	4,193	2,996	4,193
	Variance	104,537	20,824	87,159	20,824	30,332	20,824
	Calculated “t”	-35.4*		-24.5*		-22.5	
	Critical “t”	1.711*		1.708*		1.69	
	Difference?	Yes		Yes		Yes	
Calcium	Mean	107.7	40.4	179.5	40.4	195.9	40.4
	Variance	457.2	5.55	627.7	5.55	337.5	5.55
	Calculated “t”	12.3*		23.5*		35.6*	
	Critical “t”	1.74*		1.74*		1.73*	
	Difference?	Yes		Yes		Yes	
Sulfate	Mean	466	1,940	1,161	1,940	1,684	1,940
	Variance	31,285	9,318	28,459	9,318	10,272	9,318
	Calculated “t”	-31.0*		-17.0*		-7.76	
	Critical “t”	1.71*		1.70*		1.69	
	Difference?	Yes		Yes		Yes	
Fluoride	Mean	0.47	0.59	0.40	0.59	0.42	0.59
	Variance	0.013	0.0046	0.0012	0.0046	0.0030	0.0046
	Calculated “t”	-3.76*		-10.6*		-8.12	
	Critical “t”	1.70*		1.71*		1.69	
	Difference?	Yes		Yes		Yes	
Chloride	Mean	48	107	68.2	107	91.7	107
	Variance	372	25.0	191	25.0	69.3	25.0
	Calculated “t”	-12.5*		-11.2*		-6.68*	
	Critical “t”	1.73*		1.72*		1.70*	
	Difference?	Yes		Yes		Yes	
Boron	Mean	0.077	0.93	0.11	0.93	0.196	0.93
	Variance	0.00039	0.0028	0.0012	0.0028	0.00060	0.0028
	Calculated “t”	-64.0*		-55.2*		-53.3*	
	Critical “t”	1.72*		1.70*		1.71*	
	Difference?	Yes		Yes		Yes	

Notes:

a) Critical "t" is based on 5% Type I error and sample size and is the one-tail value.
b) Any absolute value of the calculated "t-Statistic" greater than the critical "t-Statistic" indicates the null hypothesis should be rejected.[20]
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.
d) A negative calculated "t" indicates that the downgradient well constituent mean is less than the upgradient constituent mean (e.g., TDS). Similarly, a positive calculated "t" indicates the opposite.
e) "t" statistics with a "*" indicate that an unpaired two-sample with *unequal variances* t-test was conducted.
f) The number of samples analyzed in all cases is n = 18.

A review of Table 11 shows that there is enough statistical evidence to reject the hypothesis that the two means (between two wells) are not 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 concentration in the downgradient well compared to OMW-5 (the upgradient well).

ANOVA - Nonparametric

Consistent with the normality testing results (Table 9), it was decided to conduct an additional analysis of variance using nonparametric methods for four constituents: pH, sulfate, fluoride, and boron. These four were chosen for this additional testing because the normality testing indicates that these 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 of 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).[21] The table below is a brief summary of those results.

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

[21] The calculations were conducted using an "add-in" Software "Real Statistics Resource Pack" to Excel. (Excel does not have this function nor is it embedded in its "Data Analysis" add-in.) More information regarding the statistical package may be found at: *http://www.real-statistics.com/free-download/real-statistics-resource-pack/*

Table 12: Kruskal-Wallis One-Way ANOVA Test Summary Results

Constituent	H Statistic	r^2/n	p_{value}	Statistical Difference?
pH	39	113,089	0.000	Yes
Sulfate	65	124,562	0.000	Yes
Fluoride	32	110,061	0.000	Yes
Boron	62	123,179	0.000	Yes

Table 13: Kruskal-Wallis Multiple Comparison Test Summary Results

Well Comparison	q-statistic	p_{value}	Statistical Difference?
pH			
OMW-1 vs OMW-5	6.72	0.000	Yes
OMW-1 vs OMW-7	6.21	0.000	Yes
OMW-1 vs OMW-8	2.33	0.360	No
OMW-5 vs OMW-7	12.93	0.000	Yes
OMW-5 vs OMW-8	9.05	0.000	Yes
OMW-7 vs OMW-8	3.88	0.038	Yes
Sulfate			
OMW-1 vs OMW-5	18.05	0.000	Yes
OMW-1 vs OMW-7	7.27	0.000	Yes
OMW-1 vs OMW-8	12.74	0.000	Yes
OMW-5 vs OMW-7	10.78	0.000	Yes
OMW-5 vs OMW-8	5.31	0.002	Yes
OMW-7 vs OMW-8	5.47	0.001	Yes
Fluoride			
OMW-1 vs OMW-5	6.76	0.000	Yes
OMW-1 vs OMW-7	4.18	0.022	Yes
OMW-1 vs OMW-8	2.90	0.181	No
OMW-5 vs OMW-7	10.94	0.000	Yes
OMW-5 vs OMW-8	9.65	0.000	Yes
OMW-7 vs OMW-8	1.29	0.800	No
Boron			
OMW-1 vs OMW-5	102.64	0.000	Yes
OMW-1 vs OMW-7	3.86	0.039	Yes
OMW-1 vs OMW-8	14.37	0.000	Yes
OMW-5 vs OMW-7	98.77	0.000	Yes
OMW-5 vs OMW-8	88.26	0.000	Yes
OMW-7 vs OMW-8	10.51	0.000	Yes

The results of the parametric and nonparametric ANOVA and t-tests are quite clear from an exclusive statistical point of view. On a constituent-by-constituent basis these tests indicate that all wells in the analyses fail to show a statistically significant increase (SSI) for pH, TDS, sulfate, fluoride, chloride, and boron.[22] 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 5.4 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?*[23]

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 the tables above) a total of 60 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 several (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.)
f) That being the case, the probability that only 1 constituent yields an SSI is less than 2%.

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[22] The statistics show a near universal significant <u>difference,</u> but not a statistically significant <u>increase</u>.

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

g) The probability decreases by adding the cation analysis into the mix. The probability now drops to less than 1%.

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

Table 14: Statistics Results

Well	Constituent	Statistical Increase Above OMW-5 ?	
		Parametric	Non-Parametric
OMW-1	pH	No	No
	TDS	No	--
	Calcium	Yes	--
	Sulfate	No	No
	Fluoride	No	No
	Chloride	No	--
	Boron	No	No
OMW-7	pH	No	No
	TDS	No	--
	Calcium	Yes	--
	Sulfate	No	No
	Fluoride	No	No
	Chloride	No	--
	Boron	No	No
OMW-8	pH	No	No
	TDS	No	--
	Calcium	Yes	--
	Sulfate	No	No
	Fluoride	No	No
	Chloride	No	--
	Boron	No	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 aquifers 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.[24] The Rosebud facility has gone to extraordinary lengths 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, was far from ideal. The well is located near the landfill and generally upgradient; but not in the location that was preferred.[25] 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 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

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[24] 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 website.

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

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 2017 through 2019.[26] (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 help to explain why the sulfate (and to some extent TDS) concentrations in all wells were similar, but the single ion concentrations (Ca or Na, depending on the well) were opposite of each other. It seemed appropriate that, to consider 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.

That analysis was conducted in this document. All, or nearly 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, save a single sample in 2018, 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 due to the landfill.

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[26] Sodium was inadvertently not analyzed in 2020. Future sampling will include sodium for purposes previously discussed.

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. Overall, the data and results of these analyses are consistent with data and conclusions from the first three annual reports.

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 mathematical 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 statistical observation cannot be accepted as evidence of contamination for the reasons and discussion below:

- A significant portion of the ash itself is a combination of $CaSO_4$, $CaSO_3$, etc. If, in fact, OMW-7 and OMW-8 are affected by the ash and OMW-5 is not, then there must be more sulfate (and calcium) in OMW-7 and 8. This is not the case. 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 conflict with the underlying assumption (sulfates = calcium if contaminated) and thus do not support a hypothesis that the landfill may be causing contamination. Rather the calcium concentration variability between the upgradient and downgradient wells is more likely due to the natural background presence of sodium sulfate in the ground water (OMW5), not from any leachate from the ash.
- The analysis for calcium is, in effect, an analysis of a cation which is associated with several 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 was 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 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 traditional “statistically significant increase” conclusion is not appropriate for elevated calcium observed in downgradient wells. 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). The prevailing wind direction could potentially result in ash being deposited near the downgradient wells possibly influencing groundwater chemistry.

Some site disturbing actions, independent of CCR requirements, were completed during calendar years 2017, 2018, 2019, and 2020. Due to the lag time for transport of constituents, the results of a corrective erosion repair upslope of OMW-7 and 8 may take additional time before a reduction of calcium levels in OMW-7 and OMW-8 is observed (if slight erosion of the cap upslope of the wells contributed to the measured elevated calcium).

Based on the results 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 along with an inability to establish a traditional upgradient well. 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 2020

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.

05/06/2020 GROUNDWATER ELEVATIONS	
MONITORING WELL	GW ELEVATION
OMW 1	3077.76
OMW 5	3054.69
OMW 6	3109.69
OMW 7	3075.81
OMW 8	3068.16

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

PROJECT ENGINEER: DSC
DRAWN BY: ASC
DESIGNED BY:
REVIEWED BY: BDA

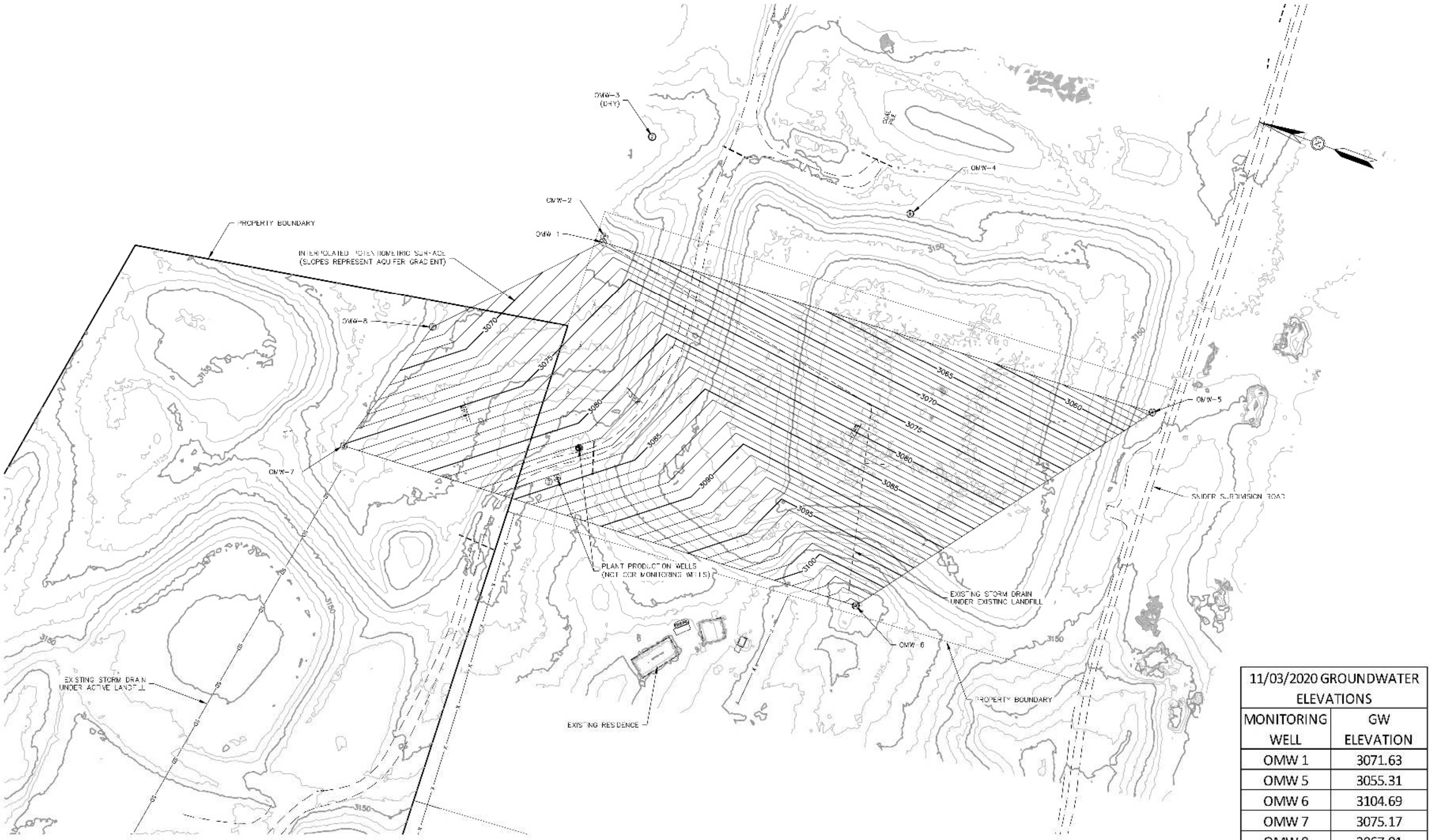
ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT:05-06-2020
ROSEBUD COUNTY, MT

32 DISCOVERY DRIVE
BOZEMAN, MT 59718
PHONE (406) 582 0221
FAX (406) 582-5770
www.alliedengineering.com

Civil Engineering
Geotechnical Engineering
Land Surveying

PROJECT #: 15-125
DATE: 01/25/2021

SHEET
GW-1



11/03/2020 GROUNDWATER ELEVATIONS	
MONITORING WELL	GW ELEVATION
OMW 1	3071.63
OMW 5	3055.31
OMW 6	3104.69
OMW 7	3075.17
OMW 8	3067.01

NO.	REVISIONS	DRAWN BY	DATE

0 100 200 300
SCALE (FEET)

PROJECT ENGINEER: DSC
DRAWN BY: ASC
DESIGNED BY:
REVIEWED BY: BCA

ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT:11-03-2020
ROSEBUD COUNTY, MT

32 DISCOVERY DRIVE
BOZEMAN, MT 59718
PHONE (406) 582-0221
FAX (406) 582-5770
www.alliedengineering.com

Civil Engineering
Geotechnical Engineering
Land Surveying

PROJECT #: 15-125
DATE: 01/25/2021

SHEET
GW-2

Appendix B

Groundwater Well Data:
Statistical Tests for Normality

Calendar Years: 2017↔ 2020

A set of 'goodness of fit' analyses was run to determine if each constituent (on a well-by-well basis) could be treated as a normal distribution. All constituents that met this test were then analyzed by analysis of variance using the traditional ANOVA and t-tests. Those not meeting the normality test were analyzed using both parametric (i.e., ANOVA and t-test) and nonparametric testing.

Since there is no single definitive test for data normality, multiple tests were employed. These include D'Agostino-Pearson statistic, 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 only 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.	This statistic is a common measure for normality. A Type I error of 0.05 was used. This value and the statistic itself are discussed and recommended 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 coefficient of variation (CV) is not considered a robust test of normality; however, the CV provides a 'quick and easy' screening test for normality according to "Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities," EPA 530-R-09-007, March 2009.
D'Agostino-Pearson	If the probability statistic > 0.05 normality is assumed.	This test employs both the Kurtosis and Skewness statistic.[27] These two statistics are, in and of themselves, a measure of normality, making this a reasonable choice for a normality test.

The analysis for the Coefficient of Variation was calculated using Excel. In order to calculate the Shapiro-Wilk and the D'Agostino-Pearson statistic, the Add-In Software "Real Statistics Resource Pack" was employed since these functions are not available in Excel or in the Excel "Data Analysis" add-in. More information regarding the statistical package may be found at:

http://www.real-statistics.com/free-download/real-statistics-resource-pack/

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[27] https://en.wikipedia.org/wiki/D%27Agostino%27s_K-squared_test

Normality Tests

Smaller probabilities indicate non-normality. **2017 ↔ 2020**

OMW 1

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	18	7.48	0.08	0.78	0.00	7.75	0.02	0.01	1
TDS	18	1,242	323	0.82	0.00	3.43	0.18	0.26	2
Calcium (Ca)	18	107	23	0.91	0.07	2.04	0.36	0.21	3
Sulfate (SO42)	18	466	177	0.86	0.01	3.07	0.22	0.38	2
Flouride (F)	18	0.47	0.11	0.83	0.00	11.34	0.00	0.24	1
Chloride (Cl)	18	48	19	0.84	0.01	3.13	0.21	0.40	2
Boron (B)	18	0.08	0.02	0.86	0.01	8.62	0.01	0.25	1

OMW 5

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	18	7.63	0.08	0.46	0.00	13.1	0.00	0.010	1
TDS	18	4,193	144	0.91	0.10	2.8	0.25	0.03	3
Calcium (Ca)	18	40	2.4	0.93	0.22	0.8	0.66	0.06	3
Sulfate (SO42)	18	1,940	97	0.91	0.10	8.5	0.01	0.05	2
Flouride (F)	18	0.59	0.07	0.72	0.00	9.3	0.01	0.11	1
Chloride (Cl)	18	107	5.0	0.93	0.17	1.1	0.57	0.05	3
Boron (B)	18	0.93	0.05	0.94	0.26	3.4	0.18	0.06	3

OMW 7

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	18	7.36	0.11	0.87	0.02	2.0	0.36	0.02	2
TDS	18	2,292	295	0.95	0.41	1.0	0.61	0.13	3
Calcium (Ca)	18	180	25	0.93	0.23	0.4	0.83	0.14	3
Sulfate (SO42)	18	1,151	169	0.91	0.09	3.0	0.23	0.15	3
Flouride (F)	18	0.40	0.03	0.48	0.00	12.3	0.00	0.09	1
Chloride (Cl)	18	68	14	0.93	0.17	1.9	0.39	0.20	3
Boron (B)	18	0.11	0.03	0.95	0.47	3.2	0.20	0.31	3

OMW 8

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	18	7.44	0.08	0.79	0.00	3.01	0.22	0.01	2
TDS	18	2,996	174	0.93	0.18	6.80	0.03	0.06	2
Calcium (Ca)	18	196	18	0.94	0.30	1.47	0.48	0.09	3
Sulfate (SO42)	18	1,684	101	0.88	0.03	12.8	0.00	0.06	1
Flouride (F)	18	0.42	0.05	0.72	0.00	0.27	0.87	0.13	2
Chloride (Cl)	18	92	8.3	0.96	0.53	1.83	0.40	0.09	3
Boron (B)	18	0.20	0.02	0.93	0.22	1.08	0.58	0.13	3

Appendix C

Analysis of Variance for Groundwater Data:

ANOVA & t-Test Results

Calendar Years 2017↔ 2020

The CCR rule requires:

> *“A parametric analysis of variance followed by multiple comparison procedures to identify statistically 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 enough statistical evidence to reject 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.

An F-test was used to compare the variances of the upgradient well constituent data to each of the downgradient wells’ constituent data to determine which unpaired t-test should be used. If the F-test result shows a probability of less than 5% that the variances are equal, then the t-test: two-sample assuming unequal variances was used. If the F-test shows that the variance of the upgradient well constituent data and the downgradient well constituent data are the same (i.e., the null hypothesis cannot be rejected), then the t-test: two-sample assuming equal variances was used.

The following pages provide the raw output from the statistical analyses themselves for each and every combination described above. Each page contains the constituent-specific ANOVA for all wells, and the t-test and F-test results for each upgradient-downgradient combination.

pH

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	18	134.8	7.488889	0.009281046
OMW5	18	137.4	7.633333	0.005882353
OMW7	18	132.4	7.355556	0.012026144
OMW8	18	133.9	7.438889	0.006045752

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.73375	3	0.244583	29.43657817	2.591E-12	2.739502
Within Groups	0.565	68	0.008309			
Total	1.29875	71				

t-Test: Two-Sample Assuming Equal Variances

	OMW1	*OMW5*
Mean	7.49	7.63
Variance	0.0093	0.0059
Observations	18	18
Pooled Variance	0.0075817	
Hypothesized Mean Dif	0	
df	34	
t Stat	-4.9766697	
P(T<=t) one-tail	9.208E-06	
t Critical one-tail	1.69092426	
P(T<=t) two-tail	1.8416E-05	
t Critical two-tail	2.03224451	

	OMW7	*OMW5*
Mean	7.36	7.63
Variance	0.0120	0.0059
Observations	18	18
Pooled Variance	0.0089542	
Hypothesized Mean Diff	0	
df	34	
t Stat	-8.806517	
P(T<=t) one-tail	1.36E-10	
t Critical one-tail	1.6909243	
P(T<=t) two-tail	2.72E-10	
t Critical two-tail	2.0322445	

	OMW8	*OMW5*
Mean	7.44	7.63
Variance	0.0060	0.0059
Observations	18	18
Pooled Variance	0.005964	
Hypothesized Mean D	0	
df	34	
t Stat	-7.553462	
P(T<=t) one-tail	4.5E-09	
t Critical one-tail	1.690924	
P(T<=t) two-tail	9.01E-09	
t Critical two-tail	2.032245	

F-Test Two-Sample for Variances

	OMW1	*OMW5*
Mean	7.49	7.63
Variance	0.0093	0.0059
Observations	18	18
df	17	17
F	1.57777778	
P(F<=f) one-tail	0.17813897	
F Critical one-tail	2.27189289	

equal variances

F-Test Two-Sample for Variances

	OMW7	*OMW5*
Mean	7.36	7.63
Variance	0.0120	0.0059
Observations	18	18
df	17	17
F	2.0444444	
P(F<=f) one-tail	0.0752256	
F Critical one-tail	2.2718929	

equal variances

F-Test Two-Sample for Variances

	OMW8	*OMW5*
Mean	7.44	7.63
Variance	0.006046	0.005882
Observations	18	18
df	17	17
F	1.027778	
P(F<=f) one-tail	0.477807	
F Critical one-tail	2.271893	

equal variances

TDS

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW1	18	22355	1242	104536.8
OMW5	18	75480	4193	20823.53
OMW7	18	41260	2292	87159.48
OMW8	18	53920	2996	30332.03

ANOVA

ource of Variatio	SS	df	MS	F	P-value	F crit
Between Groups	82946270.5	3	27648756.83	455.4013	6.212E-45	2.739502
Within Groups	4128480.5	68	60712.94853			
Total	87074751	71				

t-Test: Unpaired two-Sample (≠ Variances)

	OMW1	OMW5
Mean	1241.94444	4193.3333
Variance	104,537	20,824
Observations	18	18
Hypothesized M	0	
df	24	
t Stat	-35.3657355	
P(T<=t) one-tail	1.6128E-22	
t Critical one-tail	1.71088208	
P(T<=t) two-tail	3.2256E-22	
t Critical two-tail	2.06389856	

	OMW7	OMW5
Mean	2292.2222	4193.333
Variance	87,159	20,824
Observati	18	18
Hypothes	0	
df	25	
t Stat	-24.54517	
P(T<=t) or	2.571E-19	
t Critical c	1.7081408	
P(T<=t) tw	5.142E-19	
t Critical t	2.0595386	

t-Test: Two-Sample Assuming Equal Variances

	OMW8	OMW5
Mean	2995.5556	4193.333
Variance	30,332	20,824
Observatio	18	18
Pooled Vari	25577.778	
Hypothesiz	0	
df	34	
t Stat	-22.46809	
P(T<=t) one	2.792E-22	
t Critical on	1.6909243	
P(T<=t) two	5.585E-22	
t Critical tw	2.0322445	

F-Test Two-Sample for Variances

	OMW1	OMW5
Mean	1241.94444	4193.3333
Variance	104536.761	20823.529
Observations	18	18
df	17	17
F	5.02012696	
P(F<=f) one-tail	0.00089097	
F Critical one-tai	2.27189289	

unequal variances

F-Test Two-Sample for Variances

	OMW7	OMW5
Mean	2292.2222	4193.333
Variance	87159.477	20823.53
Observati	18	18
df	17	17
F	4.1856246	
P(F<=f) or	0.0025678	
F Critical c	2.2718929	

unequal variances

F-Test Two-Sample for Variances

	OMW8	OMW5
Mean	2995.5556	4193.333
Variance	30332.026	20823.53
Observatio	18	18
df	17	17
F	1.4566227	
P(F<=f) one	0.2230661	
F Critical or	2.2718929	

equal variances

Calcium

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW1	18	1919	106.61111	512.1339869
OMW5	18	727	40.388889	5.545751634
OMW7	18	3231	179.5	627.6764706
OMW8	18	3526	195.88889	337.5163399

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	276612.486	3	92204.162	248.7176989	1.4E-36	2.739502
Within Groups	25208.8333	68	370.71814			
Total	301821.319	71				

t-Test: Two-Sample Assuming Unequal Variances

	OMW1	OMW5
Mean	106.611111	40.3888889
Variance	512.133987	5.54575163
Observations	18	18
Hypothesized Mean D	0	
df	17	
t Stat	12.3483639	
P(T<=t) one-tail	3.2434E-10	
t Critical one-tail	1.73960673	
P(T<=t) two-tail	6.4868E-10	
t Critical two-tail	2.10981558	

	OMW7	OMW5
Mean	179.5	40.38889
Variance	627.6765	5.545752
Observations	18	18
Hypothesized Me	0	
df	17	
t Stat	23.45417	
P(T<=t) one-tail	1.09E-14	
t Critical one-tail	1.739607	
P(T<=t) two-tail	2.18E-14	
t Critical two-tail	2.109816	

	OMW8	OMW5
Mean	195.8889	40.38889
Variance	337.5163	5.545752
Observations	18	18
Hypothesized M	0	
df	18	
t Stat	35.61888	
P(T<=t) one-tail	1.91E-18	
t Critical one-tail	1.734064	
P(T<=t) two-tail	3.83E-18	
t Critical two-tail	2.100922	

F-Test Two-Sample for Variances

	OMW1	OMW5
Mean	106.611111	40.3888889
Variance	512.133987	5.54575163
Observations	18	18
df	17	17
F	92.3470831	
P(F<=f) one-tail	2.0874E-13	
F Critical one-tail	2.27189289	

unequal variances

F-Test Two-Sample for Variances

	OMW7	OMW5
Mean	179.5	40.38889
Variance	627.6765	5.545752
Observations	18	18
df	17	17
F	113.1815	
P(F<=f) one-tail	3.82E-14	
F Critical one-tail	2.271893	

unequal variances

F-Test Two-Sample for Variances

	OMW8	OMW5
Mean	195.8889	40.38889
Variance	337.5163	5.545752
Observations	18	18
df	17	17
F	60.86034	
P(F<=f) one-tail	6.64E-12	
F Critical one-tai	2.271893	

unequal variances

Sulfate

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	18	8392	466.222222	31285.35948
OMW5	18	34920	1940	9317.647059
OMW7	18	20898	1161	28458.70588
OMW8	18	30310	1683.88889	10272.22222

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	22874831.6	3	7624943.85	384.4480366	1.45772E-42	2.739502
Within Groups	1348676.89	68	19833.4837			
Total	24223508.4	71				

t-Test: Two-Sample Assuming Unequal Variances

	OMW1	*OMW5*
Mean	466.222222	1940
Variance	31285.3595	9317.64706
Observations	18	18
Hypothesized Mean	0	
df	26	
t Stat	-31.030528	
P(T<=t) one-tail	2.2507E-22	
t Critical one-tail	1.70561792	
P(T<=t) two-tail	4.5015E-22	
t Critical two-tail	2.05552944	

F-Test Two-Sample for Variances

	OMW1	*OMW5*
Mean	466.222222	1940
Variance	31285.3595	9317.64706
Observations	18	18
df	17	17
F	3.3576459	
P(F<=f) one-tail	0.00837666	
F Critical one-tail	2.27189289	

unequal variances

	OMW7	*OMW5*
Mean	1161	1940
Variance	28458.70588	9317.647
Observations	18	18
Hypothesized Mea	0	
df	27	
t Stat	-17.00449335	
P(T<=t) one-tail	2.97855E-16	
t Critical one-tail	1.703288446	
P(T<=t) two-tail	5.95711E-16	
t Critical two-tail	2.051830516	

F-Test Two-Sample for Variances

	OMW7	*OMW5*
Mean	1161	1940
Variance	28458.70588	9317.647
Observations	18	18
df	17	17
F	3.054280303	
P(F<=f) one-tail	0.013416056	
F Critical one-tail	2.271892889	

unequal variances

t-Test: Two-Sample Assuming Equal Variances

	OMW8	*OMW5*
Mean	1683.888889	1940
Variance	10272.22222	9317.647
Observations	18	18
Pooled Variance	9794.934641	
Hypothesized Mea	0	
df	34	
t Stat	-7.76334531	
P(T<=t) one-tail	2.47384E-09	
t Critical one-tail	1.690924255	
P(T<=t) two-tail	4.94768E-09	
t Critical two-tail	2.032244509	

F-Test Two-Sample for Variances

	OMW8	*OMW5*
Mean	1683.888889	1940
Variance	10272.22222	9317.647
Observations	18	18
df	17	17
F	1.102448092	
P(F<=f) one-tail	0.421484319	
F Critical one-tail	2.271892889	

equal variances

Fluoride

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW1	18	8.5	0.472222	0.012712
OMW5	18	10.6	0.588889	0.004575
OMW7	18	7.2	0.4	0.001176
OMW8	18	7.6	0.422222	0.003007

ANOVA

ource of Variatio	SS	df	MS	F	P-value	F crit
Between Grour	0.38375	3	0.127917	23.83105	1.19E-10	2.739502
Within Groups	0.365	68	0.005368			
Total	0.74875	71				

t-Test: Unpaired Sample (≠ Variances)

	OMW1	OMW5
Mean	0.472222	0.588889
Variance	0.012712	0.004575
Observations	18	18
Hypothesized M	0	
df	28	
t Stat	-3.76457	
P(T<=t) one-tail	0.000394	
t Critical one-ta	1.701131	
P(T<=t) two-tail	0.000787	
t Critical two-ta	2.048407	

	OMW7	OMW5
Mean	0.4	0.588889
Variance	0.001176	0.004575
Observati	18	18
Hypothesi	0	
df	25	
t Stat	-10.5669	
P(T<=t) on	5.21E-11	
t Critical o	1.708141	
P(T<=t) tw	1.04E-10	
t Critical t	2.059539	

t-Test: Two-Sample Assuming Equal Variances

	OMW8	OMW5
Mean	0.422222	0.588889
Variance	0.003007	0.004575
Observations	18	18
Pooled Variance	0.003791	
Hypothesized M	0	
df	34	
t Stat	-8.12085	
P(T<=t) one-tail	9.02E-10	
t Critical one-tail	1.690924	
P(T<=t) two-tail	1.8E-09	
t Critical two-tail	2.032245	

F-Test Two-Sample for Variances

	OMW1	OMW5
Mean	0.472222	0.588889
Variance	0.012712	0.004575
Observations	18	18
df	17	17
F	2.778571	
P(F<=f) one-tail	0.020976	
F Critical one-ta	2.271893	

unequal variance

F-Test Two-Sample for Variances

	OMW7	OMW5
Mean	0.4	0.588889
Variance	0.001176	0.004575
Observati	18	18
df	17	17
F	0.257143	
P(F<=f) on	0.003859	
F Critical c	0.440162	

unequal variance

F-Test Two-Sample for Variances

	OMW8	OMW5
Mean	0.422222	0.588889
Variance	0.003007	0.004575
Observations	18	18
df	17	17
F	0.657143	
P(F<=f) one-tail	0.197699	
F Critical one-tai	0.440162	

equal variance

Chloride

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW1	18	864	48	372.3529
OMW5	18	1925	106.9444	24.99673
OMW7	18	1228	68.22222	191.1242
OMW8	18	1650	91.66667	69.29412

ANOVA

urce of Variati	SS	df	MS	F	P-value	F crit
Between Grou	36326.819	3	12108.94	73.63654	2.5466E-21	2.739502
Within Groups	11182.056	68	164.442			
Total	47508.875	71				

t-Test: Unpaired Sample (≠ Variances)

	OMW1	OMW5
Mean	48	106.9444
Variance	372.35294	24.99673
Observations	18	18
Hypothesized	0	
df	19	
t Stat	-12.54564	
P(T<=t) one-tai	6.091E-11	
t Critical one-t	1.7291328	
P(T<=t) two-tai	1.218E-10	
t Critical two-t	2.0930241	

	OMW7	OMW5
Mean	68.2222222	106.9444
Variance	191.124183	24.99673
Observatio	18	18
Hypothesi	0	
df	21	
t Stat	-11.175015	
P(T<=t) on	1.3384E-10	
t Critical o	1.7207429	
P(T<=t) tw	2.6767E-10	
t Critical t	2.07961384	

	OMW8	OMW5
Mean	91.66667	106.9444444
Variance	69.29412	24.99673203
Observati	18	18
Hypothesi	0	
df	28	
t Stat	-6.67516	
P(T<=t) on	1.52E-07	
t Critical o	1.701131	
P(T<=t) tw	3.04E-07	
t Critical t	2.048407	

F-Test Two-Sample for Variances

	OMW1	OMW5
Mean	48	106.9444
Variance	372.35294	24.99673
Observations	18	18
df	17	17
F	14.896065	
P(F<=f) one-tai	4.984E-07	
F Critical one-t	2.2718929	

unequal variances

F-Test Two-Sample for Variances

	OMW7	OMW5
Mean	68.2222222	106.9444
Variance	191.124183	24.99673
Observatio	18	18
df	17	17
F	7.64596679	
P(F<=f) on	6.0215E-05	
F Critical o	2.27189289	

unequal variances

F-Test Two-Sample for Variances

	OMW8	OMW5
Mean	91.66667	106.9444444
Variance	69.29412	24.99673203
Observati	18	18
df	17	17
F	2.772127	
P(F<=f) on	0.021201	
F Critical	2.271893	

unequal variances

Boron

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW1	18	1.39	0.077222	0.0003859
OMW5	18	16.67	0.926111	0.0027781
OMW7	18	1.965	0.109167	0.0011596
OMW8	18	3.53	0.196111	0.0006016

ANOVA

ource of Variatio	SS	df	MS	F	P-value	F crit
Between Groups	8.746312	3	2.915437	2367.7501	1.09E-68	2.739502
Within Groups	0.083729	68	0.001231			
Total	8.830041	71				

t-Test: Two-Sample Assuming Unequal Variances

	OMW1	OMW5
Mean	0.077222	0.926111
Variance	0.000386	0.002778
Observations	18	18
Hypothesized Me	0	
df	22	
t Stat	-64.02731	
P(T<=t) one-tail	8.45E-27	
t Critical one-tail	1.717144	
P(T<=t) two-tail	1.69E-26	
t Critical two-tail	2.073873	

	OMW7	OMW5
Mean	0.109167	0.926111
Variance	0.00116	0.002778
Observatio	18	18
Hypothesiz	0	
df	29	
t Stat	-55.23438	
P(T<=t) one	3.08E-31	
t Critical on	1.699127	
P(T<=t) two	6.17E-31	
t Critical tw	2.04523	

	OMW8	OMW5
Mean	0.196111	0.926111
Variance	0.000602	0.002778
Observati	18	18
Hypothesi	0	
df	24	
t Stat	-53.27428	
P(T<=t) on	9.78E-27	
t Critical o	1.710882	
P(T<=t) tw	1.96E-26	
t Critical t	2.063899	

F-Test Two-Sample for Variances

	OMW1	OMW5
Mean	0.077222	0.926111
Variance	0.000386	0.002778
Observations	18	18
df	17	17
F	0.138925	
P(F<=f) one-tail	9.03E-05	
F Critical one-tail	0.440162	

unequal variance

F-Test Two-Sample for Variances

	OMW7	OMW5
Mean	0.109167	0.926111
Variance	0.00116	0.002778
Observatio	18	18
df	17	17
F	0.417392	
P(F<=f) one	0.040207	
F Critical on	0.440162	

unequal variance

F-Test Two-Sample for Variances

	OMW8	OMW5
Mean	0.196111	0.926111
Variance	0.000602	0.002778
Observati	18	18
df	17	17
F	0.216563	
P(F<=f) on	0.001462	
F Critical o	0.440162	

unequal variance

Appendix D

Analysis of Variance for Groundwater Data:

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

Calendar Years 2017↔ 2020

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 come from the same underlying population (i.e., the means are the same among all the tested wells). In this case, 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, fluoride, sulfate, and boron data (see Table 9 in the body of this report) indicate the underlying population may not be normal. That is not to say that the typical parametric ANOVA and t-test might not yield a usable result. In fact, such testing was conducted and reported in this document in order that the investigation be thorough. Nonetheless, it was deemed cautionary to expand the analysis for these four constituents by conducting a non-parametric analysis using 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, fluoride, sulfate, and boron. The analysis was conducted using the "add-in" software "Real Statistics Resource Pack," (Excel does not have this function nor is the Kruskal-Wallis test embedded in its "Data Analysis" add-in.) More information regarding the statistical package may be found at:
http://www.real-statistics.com/free-download/real-statistics-resource-pack/

Kruskal-Wallis Test pH

	OMW1	OMW5	OMW7	OMW8	
median	7.5	7.6	7.3	7.4	
rank sum	684	1,083	321	541	
count	18	18	18	18	72
r^2/n	25,992	65,161	5,707	16,230	113,089
H-stat					39
H-ties					41
df					3
p-value					5.20E-09
alpha					0.05
sig					yes

TUKEY HSD/KRAMER alpha 0.05

group	*mean*	*n*	*ss*	*df*	*q-crit*
OMW1	7.49	18	0.158		
OMW5	7.63	18	0.100		
OMW7	7.36	18	0.204		
OMW8	7.44	18	0.103		
		72	0.565	68	3.725

Q TEST

group 1	*group 2*	*mean*	*std err*	*q-stat*	*lower*	*upper*	*p-value*	*mean-crit*	*Cohen d*
OMW1	OMW5	0.144	0.021	6.72	0.064	0.224	0.000	0.080	1.585
OMW1	OMW7	0.133	0.021	6.21	0.053	0.213	0.000	0.080	1.463
OMW1	OMW8	0.050	0.021	2.33	-0.030	0.130	0.360	0.080	0.549
OMW5	OMW7	0.278	0.021	12.93	0.198	0.358	0.000	0.080	3.047
OMW5	OMW8	0.194	0.021	9.05	0.114	0.274	0.000	0.080	2.133
OMW7	OMW8	0.083	0.021	3.88	0.003	0.163	0.038	0.080	0.914

Kruskal-Wallis Test **Fluoride**

	OMW1	OMW5	OMW7	OMW8	
median	0.5	0.6	0.4	0.4	
rank sum	659	1,064	402	504	
count	18	18	18	18	72
r^2/n	24,127	62,894	8,956	14,084	110,061
H-stat					32
H-ties					38
df					3
p-value					2.73E-08
alpha					0.05
sig					yes

TUKEY HSD/KRAMER alpha 0.05

group	*mean*	*n*	*ss*	*df*	*q-crit*
OMW1	0.47	18	0.216		
OMW5	0.59	18	0.078		
OMW7	0.40	18	0.020		
OMW8	0.42	18	0.051		
		72	0.365	68	3.725

Q TEST

group 1	*group 2*	*mean*	*std err*	*q-stat*	*lower*	*upper*	*p-value*	*mean-crit*	*Cohen d*
OMW1	OMW5	0.117	0.017	6.76	0.052	0.181	0.000	0.064	1.592
OMW1	OMW7	0.072	0.017	4.18	0.008	0.137	0.022	0.064	0.986
OMW1	OMW8	0.050	0.017	2.90	-0.014	0.114	0.181	0.064	0.682
OMW5	OMW7	0.189	0.017	10.94	0.125	0.253	0.000	0.064	2.578
OMW5	OMW8	0.167	0.017	9.65	0.102	0.231	0.000	0.064	2.275
OMW7	OMW8	0.022	0.017	1.29	-0.042	0.087	0.800	0.064	0.303

Kruskal-Wallis Test **Sulfate**

	OMW1	OMW5	OMW7	OMW8	
median	531	1,960	1,190	1,705	
rank sum	171	1,129	496	832	
count	18	18	18	18	72
r^2/n	1,625	70,813	13,668	38,457	124,562
H-stat					65
H-ties					65
df					3
p-value					4.11E-14
alpha					0.05
sig					yes

TUKEY HSD/KRAMER alpha 0.05

group	*mean*	*n*	*ss*	*df*	*q-crit*
OMW1	466	18	531,851		
OMW5	2,192	18	9,994,850		
OMW7	1,161	18	483,798		
OMW8	1,684	18	174,628		
		72	11,185,127	68	3.725

Q TEST

group 1	*group 2*	*mean*	*std err*	*q-stat*	*lower*	*upper*	*p-value*	*mean-crit*	*Cohen d*
OMW1	OMW5	1,725	95.6	18.05	1,369.4	2,081.5	0.000	356.1	4.254
OMW1	OMW7	695	95.6	7.27	338.7	1,050.8	0.000	356.1	1.713
OMW1	OMW8	1,218	95.6	12.74	861.6	1,573.7	0.000	356.1	3.002
OMW5	OMW7	1,031	95.6	10.78	674.6	1,386.7	0.000	356.1	2.541
OMW5	OMW8	508	95.6	5.31	151.7	863.8	0.002	356.1	1.252
OMW7	OMW8	523	95.6	5.47	166.8	879.0	0.001	356.1	1.289

Kruskal-Wallis Test **Boron**

	OMW1	OMW5	OMW7	OMW8	
median	0.1	0.9	0.1	0.2	
rank sum	236	1,143	432	818	
count	18	18	18	18	72
r^2/n	3,081	72,581	10,344	37,174	123,179
H-stat					62
H-ties					62
df					3
p-value					1.82E-13
alpha					0.05
sig					yes

TUKEY HSD/KRAMER alpha 0.05

group	*mean*	*n*	*ss*	*df*	*q-crit*
OMW1	0.08	18	0.007		
OMW5	0.93	18	0.047		
OMW7	0.11	18	0.020		
OMW8	0.20	18	0.010		
		72	0.084	68	3.725

Q TEST

group 1	*group 2*	*mean*	*std err*	*q-stat*	*lower*	*upper*	*p-value*	*mean-crit*	*Cohen d*
OMW1	OMW5	0.849	0.008	102.64	0.818	0.880	0.000	0.031	24.192
OMW1	OMW7	0.032	0.008	3.86	0.001	0.063	0.039	0.031	0.910
OMW1	OMW8	0.119	0.008	14.37	0.088	0.150	0.000	0.031	3.388
OMW5	OMW7	0.817	0.008	98.77	0.786	0.848	0.000	0.031	23.281
OMW5	OMW8	0.730	0.008	88.26	0.699	0.761	0.000	0.031	20.804
OMW7	OMW8	0.087	0.008	10.51	0.056	0.118	0.000	0.031	2.478