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

Calendar Year 2018

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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 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 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.

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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 2018. 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 twice in eight 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 de-sulfurization 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 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 since apart from April 2018.

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

Figure 1: Monitoring Well Locations

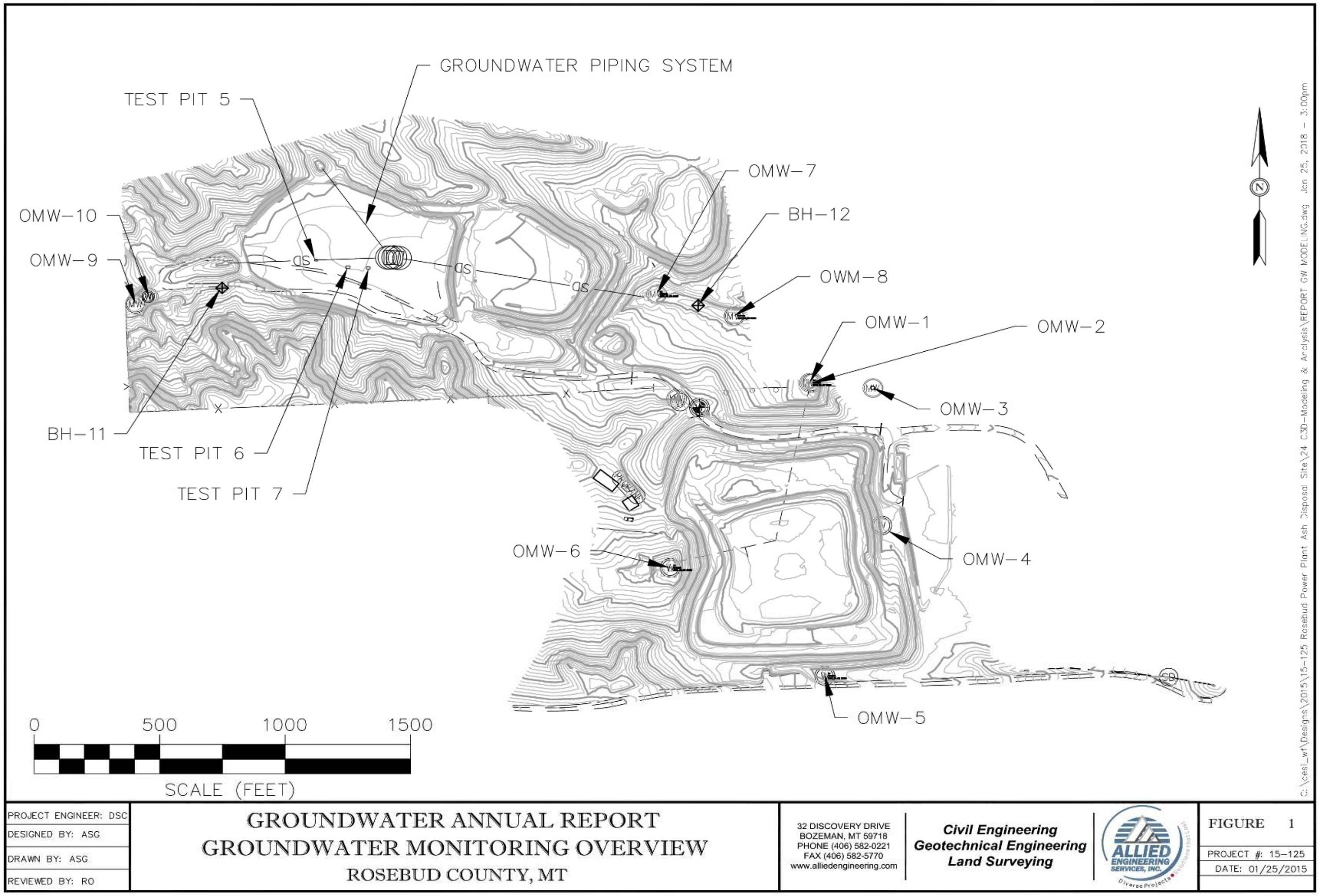

Table 1: Well Description and Status

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 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 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 2018). 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 (2018)*	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	Detection	
OMW-5	45.974031 : -106.659030	- Same as OMW-1 -	Detection	
OMW-6	45.975360 : -106.661386	No CCR Sampling	n/a	Non-CCR
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	4/20/18	n/a	Lone sample in last 7 years
OMW-10	45.978730: -106.669400	No samples	n/a	Dry Well

* Unless otherwise indicated

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

Table 3: Constituents Analyzed: 2018 Reporting Period

Constituent	Program *
Boron	Detection
Calcium	Detection
Chloride	Detection
Fluoride	Detection
pH	Detection
Sulfate	Detection
Total Dissolved Solids	Detection

* 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
6/6/2018	7.7	750	66	220	0.5	19	0.10
10/26/2018	7.5	1,210	107	415	0.4	44	0.10

Table 5: Data Summary OMW-5 Appendix III Constituents

Date	pH	TDS	Calcium	Sulfate	Fluoride	Chloride	Boron
12/06/2016	7.6	4,300	43	1,810	0.7	103	0.95
01/5/2017	7.6	4,200	42	1,880	0.6	109	0.95
02/10/2017	7.6	4,370	40	2,030	0.6	115	0.93
03/15/2017	7.6	4,310	36	2,020	0.6	105	0.93
04/12/2017	7.6	3,980	42	1,960	0.6	105	0.91
05/11/2017	7.6	4,280	44	1,970	0.7	106	0.83
06/7/2017	7.6	4,400	41	1,960	0.5	105	0.96
07/12/2017	7.6	4,300	41	2,060	0.6	116	0.98
08/9/2017	7.6	4,130	36	1,930	0.6	107	0.80
09/13/2017	7.6	4,200	39	1,940	0.6	102	0.96
10/5/2017	7.6	4,000	40	1,960	0.6	100	0.92
11/9/2017	7.6	4,130	44	1,970	0.5	107	0.94
6/06/2018	7.6	3,970	41	1,860	0.6	105	0.90
10/26/2018	7.8	4,090	39	1,670	0.6	99	0.90

Table 6: Data Summary for OMW-7 Appendix III Constituents

Date	pH	TDS	Calcium	Sulfate	Fluoride	Chloride	Boron
12/06/2016	7.2	2,620	230	1,340	0.4	85	0.13
01/5/2017	7.3	2,660	214	1,290	0.4	80	0.14
02/10/2017	7.3	2,780	215	1,380	0.4	88	0.12
03/15/2017	7.3	2,670	182	1,380	0.4	87	0.09
04/12/2017	7.3	2,230	185	1,160	0.4	71	0.12
05/11/2017	7.3	2,250	181	1,190	0.4	66	0.11
06/7/2017	7.4	2,370	181	1,190	0.4	68	0.08
07/12/2017	7.4	2,400	185	1,160	0.4	72	0.09
08/9/2017	7.3	2,360	177	1,280	0.4	74	0.06
09/13/2017	7.4	2,440	173	1,300	0.4	77	0.10
10/5/2017	7.3	2,390	183	1,220	0.5	72	0.08
11/9/2017	7.3	2,370	204	1,290	0.4	77	0.15
6/06/2018	7.5	1,800	144	939	0.4	51	0.11
10/26/2018	7.5	1,900	153	900	0.4	51	0.13

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

Date	pH	TDS	Calcium	Sulfate	Fluoride	Chloride	Boron
12/06/2016	7.4	3,090	223	1,680	0.4	87	0.22
01/5/2017	7.4	3,050	206	1,690	0.4	84	0.22
02/10/2017	7.4	3,180	199	1,700	0.4	89	0.22
03/15/2017	7.4	3,070	171	1,720	0.5	86	0.19
04/12/2017	7.4	2,840	202	1,640	0.5	85	0.23
05/11/2017	7.4	3,040	201	1,720	0.4	87	0.19
06/7/2017	7.5	3,060	189	1,710	0.4	88	0.18
07/12/2017	7.5	2,860	170	1,580	0.4	91	0.18
08/9/2017	7.4	2,970	175	1,780	0.5	98	0.16
09/13/2017	7.4	3,020	180	1,750	0.5	100	0.20
10/5/2017	7.4	2,790	195	1,660	0.5	95	0.16
11/9/2017	7.4	2,890	200	1,730	0.4	98	0.25
6/06/2018	7.5	3,110	215	1,710	0.4	86	0.18
10/26/2018	7.5	2,520	158	1,380	0.4	76	0.18

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 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 8: CCR Well Summary Statistics

Parameter	pH	TDS	Ca	Sulfate	Fluoride	Chloride	Boron	Cation (Ca + Na)
OMW – 1								
Count (n)	14	14	14	14	14	14	14	14
Mean	7.5	1,311	111	510	0.46	51	0.071	319
Std. Dev.	0.061	279	20	147	0.07	4.1	0.075	67
Skewness	0.2	-1.4	-0.9	-1.2	0.7	0.7	0.7	-1.1
Kurtosis	-0.3	1.1	0.8	0.4	-0.6	0.3	-1.4	0.6
Coef. Variation	0.01	0.21	0.18	0.29	0.16	0.16	0.32	0.21
OMW – 5								
Count (n)	14	14	14	14	14	14	14	14
Mean	7.6	4,190	41	1,930	0.60	106	0.92	1,489
Std. Dev.	0.1	144	2.5	100	0.06	4.9	0.05	61
Skewness	3.7	-0.2	-0.6	-1.4	0.0	0.9	-1.4	-0.0
Kurtosis	14	-1.9	-0.1	2.6	1.3	0.7	1.7	0.7
Coef. Variation	0.01	0.03	0.06	0.05	0.09	0.05	0.05	0.04
OMW – 7								
Count (n)	14	14	14	14	14	14	14	14
Mean	7.3	2,374	186	1,216	0.41	73	0.11	597
Std. Dev.	0.085	276	23	146	0.03	11.4	0.03	67
Skewness	0.7	-0.7	0.1	-1.2	3.7	-0.8	-0.2	0.1
Kurtosis	0.1	0.5	0.1	1.0	14	0.3	-0.7	0.0
Coef. Variation	0.01	0.12	0.13	0.12	0.07	0.16	0.24	0.11
OMW – 8								
Count (n)	14	14	14	14	14	14	14	14
Mean	7.4	2,964	192	1,675	0.44	89	0.20	778
Std. Dev.	0.05	171	19	98	0.05	6.6	0.03	46
Skewness	1.1	-1.4	-0.2	-2.4	0.7	0.0	0.4	-0.2
Kurtosis	-1.0	2.4	-0.7	6.6	-1.8	0.0	-0.6	-1.2
Coef. Variation	0.01	0.06	0.10	0.06	0.11	0.07	0.14	0.06

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 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 18 of the 28 analysis values are less than 1 (absolute). Therefore, that indicator leans toward a near-normal assumption for much of the data.

Another general ‘normal’ indicator variable 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 the tails of the curve. Nonetheless, 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 seems to be 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, 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. 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.

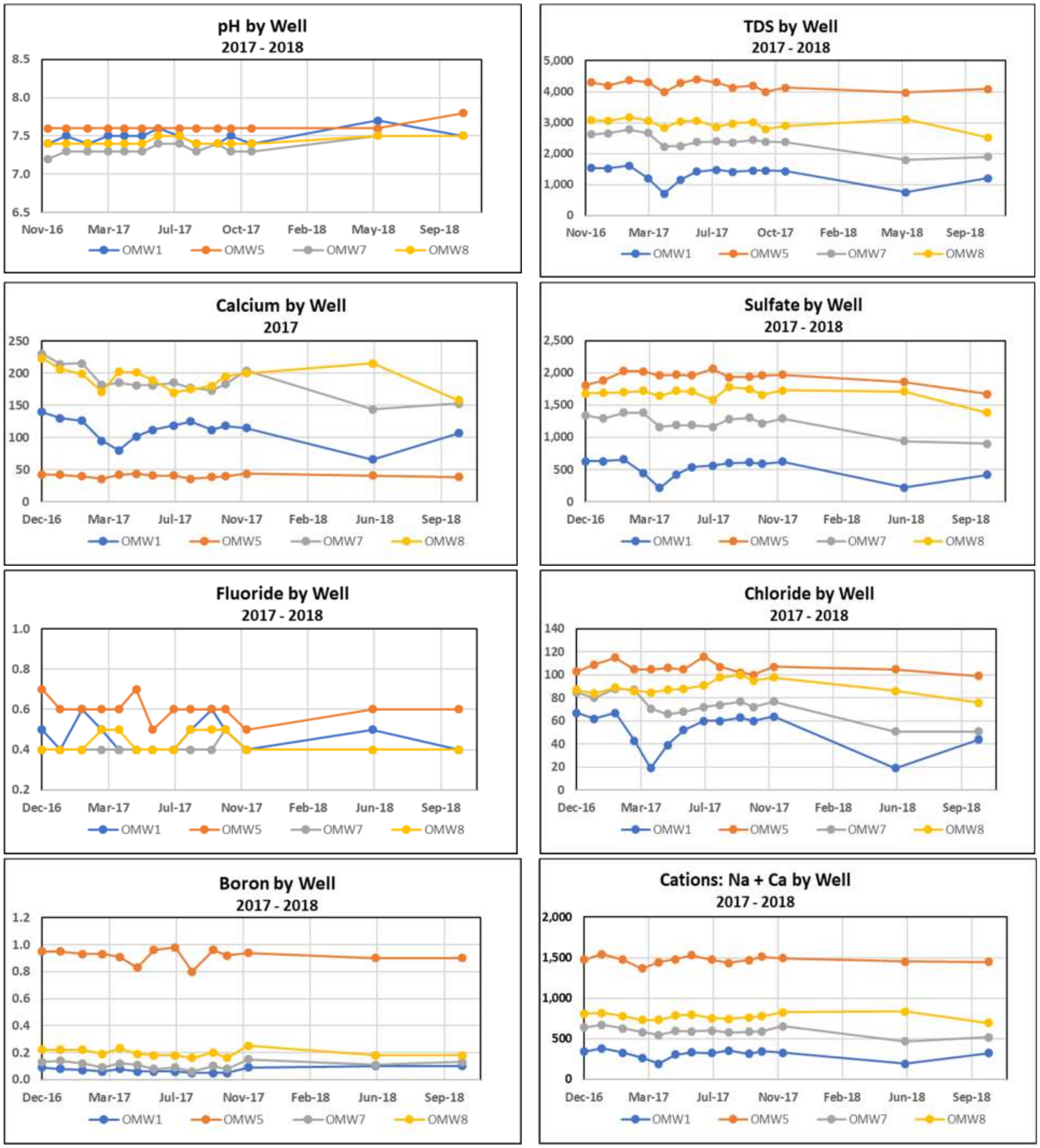
5.3 DATA ANALYSIS - GRAPHICAL

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 2017/2018 CCR data is presented in the following seven graphics. 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 year the 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, $SO4^{-2}$, Fl^{-}, Cl^{-} and Boron). The statistical methods used for this analysis was 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, 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 conclude which analysis normality. Data which exhibited near normality was analyzed using parametric tests while non-normal data was analyzed using nonparametric methods described above.

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

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
- D'Agostino-Pearson Test
- Shapiro-Wilk Test

The reason for choosing the coefficient of variation as a statistic is briefly discussed in Section 5.2 above. Additionally, it 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 that either Skewness or Kurtosis alone. 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 conducted on the raw (non-transformed) data.[15] The results of the normality data sets 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	No	Probable	Probable	Probable
OMW 5	No	Yes	Yes	Probable	Probable	Yes	No
OMW 7	Probable	Yes	Yes	Probable	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.

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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] Although not shown here, the 1st 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 thus that analysis was not repeated here.

In order to cover all eventualities, it was decided to conduct all analyses using parametric statistical analysis. To be conservative, however, an additional set of non-parametric analysis was conducted on three of the constituents due to their lower overall normality ratings. These were: pH, Sulfate and Fluoride. As it turns out, the conclusions reached for these constituents were the same regardless of the underlying parametric or non-parametric treatment.

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 (well by well: Q-Test)

ANOVA - Parametric[16]

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

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[16] 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.

"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.

Table 10: ANOVA (between wells) Summary Results

Constituent	Calculated F Statistic	Critical F-Statistic	Statistical Difference?
pH	37	2.78	Yes
TDS	396	2.78	Yes
Calcium	222	2.78	Yes
Sulfate	348	2.78	Yes
Fluoride	35	2.78	Yes
Chloride	65	2.78	Yes
Boron	2115	2.78	Yes
Cations (Ca + Na)	1491	2.78	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 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)[17]

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

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[17] Ibid.

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 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.[18] 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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[18] The t-distribution is, more or less, the “normal” z-distribution, but adjusted for small(er) sample sizes.

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	7.61	7.34	7.61	7.43	7.61
	Variance	7.5x10^{-3}	2.9.x10^{-3}	7.3x10^{-3}	2.9x10^{-3}	2.2x10^{-3}	2.9.x10^{-3}
	Calculated “t”	-4.7		10.1		9.8	
	Critical “t”	1.71		1.71		1.71	
	Difference?	Yes		Yes		Yes	
TDS	Mean	1,311	4,190	2,374	4,190	2,964	4,190
	Variance	77,776	20,708	76,195	20,708	29,209	20,708
	Calculated “t”	-34.3		-21.8		-20.6	
	Critical “t”	1.73		1.73		1.73	
	Difference?	Yes		Yes		Yes	
Calcium	Mean	111	41	186	41	192	41
	Variance	391	6.3	543	6.3	347	6.3
	Calculated “t”	13.1		23.2		30.1	
	Critical “t”	1.77		1.77		1.77	
	Difference?	Yes		Yes		Yes	
Sulfate	Mean	510	1,930	1,216	1,930	1,6665	1,930
	Variance	21,649	10,031	21,192	10,031	9,581	10,031
	Calculated “t”	-29.8		-15.1		-6.8	
	Critical “t”	1,71		1.71		1.71	
	Difference?	Yes		Yes		Yes	
Fluoride	Mean	0.46	0.60	0.41	0.60	0.44	0.60
	Variance	.006	.003	.001	.003	.002	.003
	Calculated “t”	-5.5		-11.7		-8.3	
	Critical “t”	1.71		1.71		1.71	
	Difference?	Yes		Yes		Yes	
Chloride	Mean	51	106	73	106	89	106
	Variance	268	24	130	24	43	24
	Calculated “t”	-12.0		-10.0		-7.7	
	Critical “t”	1.75		1.73		1.71	
	Difference?	Yes		Yes		Yes	
Boron	Mean	.071	.92	.11	.92	.20	.92
	Variance	.000	.003	.001	.003	.001	.003
	Calculated “t”	-59.5		-53.9		-47.5	
	Critical “t”	1.71		1.71		1.71	
	Difference?	Yes		Yes		Yes	
Total Cations (Ca + Na)	Mean	309	1,471	591	1,471	775	1,471
	Variance	3,205	1,961	2,453	1,961	1,638	1,961
	Calculated “t”	-60.8		-49.9		-43.8	
	Critical “t”	1.71		1.71		1.71	
	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.[19]
c) A “Yes” does <u>not</u> 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 (Table 9), it was decided to conduct an additional analysis of variance using nonparametric methods for three constituents: pH, Sulfate and Fluoride. These three were chosen for this additional testing because the normality testing (see Table 9) indicates that these three 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).[20] The table below is a brief summary of those results.

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

[20] 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	38	55,588	0.000	Yes
Sulfate	51	58,911	0.000	Yes
Fluoride	29	53,195	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	8	0.000	Yes
OMW-1 vs OMW-7	8	0.000	Yes
OMW-1 vs OMW-8	3	0.289	No
OMW-5 vs OMW-7	16	0.000	Yes
OMW-5 vs OMW-8	11	0.000	Yes
OMW-7 vs OMW-8	5	0.004	Yes
Sulfate			
OMW-1 vs OMW-5	43	0.000	Yes
OMW-1 vs OMW-7	21	0.000	Yes
OMW-1 vs OMW-8	35	0.000	Yes
OMW-5 vs OMW-7	21	0.000	Yes
OMW-5 vs OMW-8	8	0.000	Yes
OMW-7 vs OMW-8	14	0.000	Yes
Fluoride			
OMW-1 vs OMW-5	9	0.000	Yes
OMW-1 vs OMW-7	4	0.037	Yes
OMW-1 vs OMW-8	2	0.511	No
OMW-5 vs OMW-7	13	0.000	Yes
OMW-5 vs OMW-8	11	0.000	Yes
OMW-7 vs OMW-8	2	0.511	No

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 for all wells in the analyses fail to show a statistically significant increase (SSI) for pH, TDS, sulfate, fluoride, chloride, boron and cations (Na + Ca).[21] 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?*[22]

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 49 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.

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[21] The statistic show a near universal significant <u>difference</u>; but not a statistically significant <u>increase</u>.

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

(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 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 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	n/a
	Calcium	Yes	n/a
	Sulfate	No	No
	Fluoride	No	No
	Chloride	No	n/a
	Boron	No	n/a
	Cations (Ca + Na)	No	n/a
OMW-7	pH	No	No
	TDS	No	n/a
	Calcium	Yes	n/a
	Sulfate	No	No
	Fluoride	No	No
	Chloride	No	n/a
	Boron	No	n/a
	Cations (Ca + Na)	No	n/a
OMW-8	pH	No	No
	TDS	No	n/a
	Calcium	Yes	n/a
	Sulfate	No	No
	Fluoride	No	No
	Chloride	No	n/a
	Boron	No	n/a
	Cations (Ca + Na)	No	n/a

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.[23] 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, may not be perfect. The well is located near the landfill and generally upgradient; but not in the location that was preferred.[24] 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

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[23] 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.

[24] 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.

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 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 2017 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, 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.

This analysis was conducted in this document. All 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 2nd 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 is consistent with data and conclusions from the 1st annual report dated January 31, 2018.

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 observation cannot be accepted 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 assumptions and thus do not support a hypothesis 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 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 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 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. The general discontinuous nature of the aquifers and hydro-geology 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.

  Some additional actions, independent of CCR requirements, were also completed during calendar years 2017 and 2018. 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 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

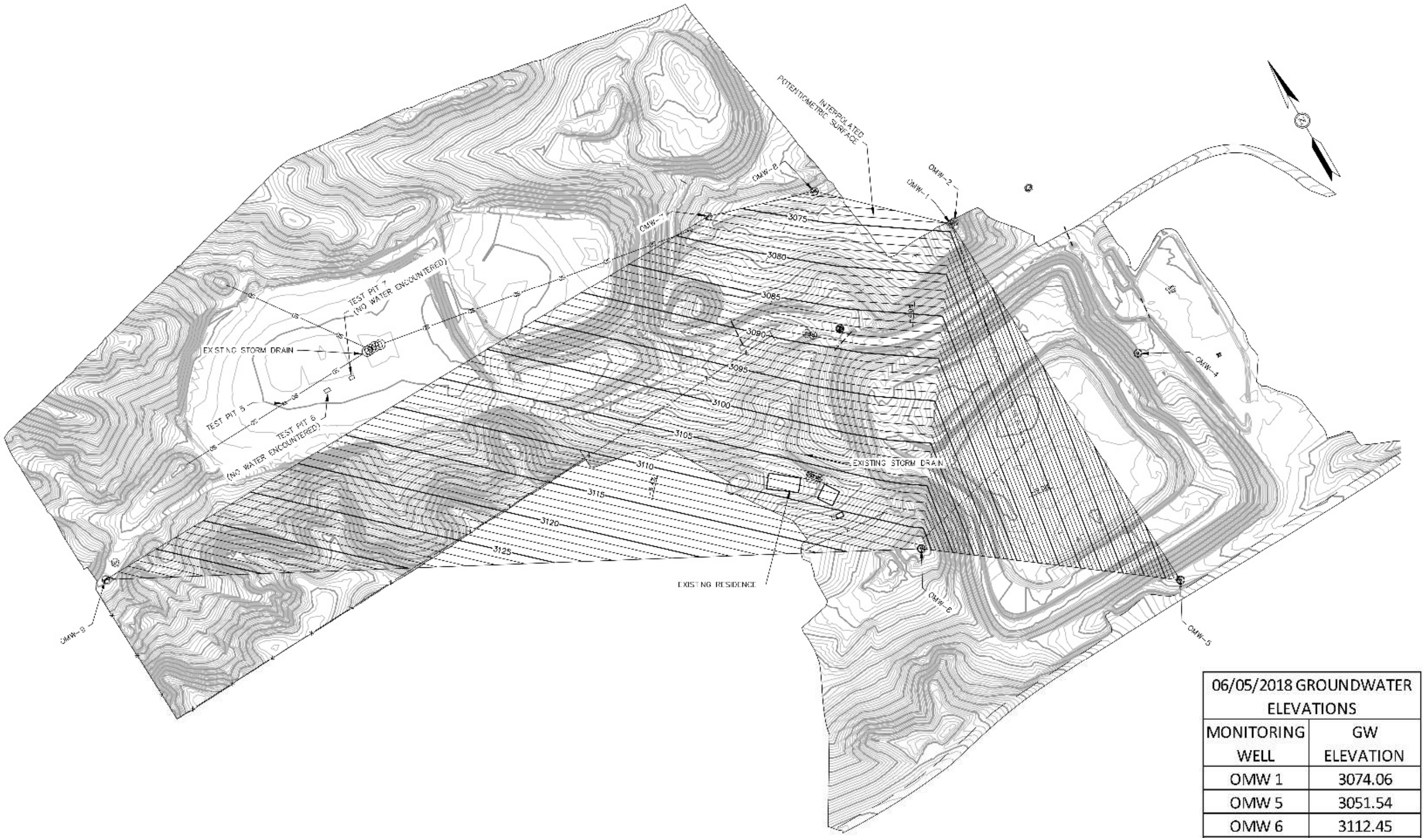
Groundwater Well: Elevation, Flow and Direction

Calendar Year 2018

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.



06/05/2018 GROUNDWATER ELEVATIONS	
MONITORING WELL	GW ELEVATION
OMW 1	3074.06
OMW 5	3051.54
OMW 6	3112.45
OMW 7	3076.64
OMW 8	3071.45
OMW 9	3140.35

NO	REVISIONS	DRAWN BY	DATE

0 150 300 450
SCALE (FEET)

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

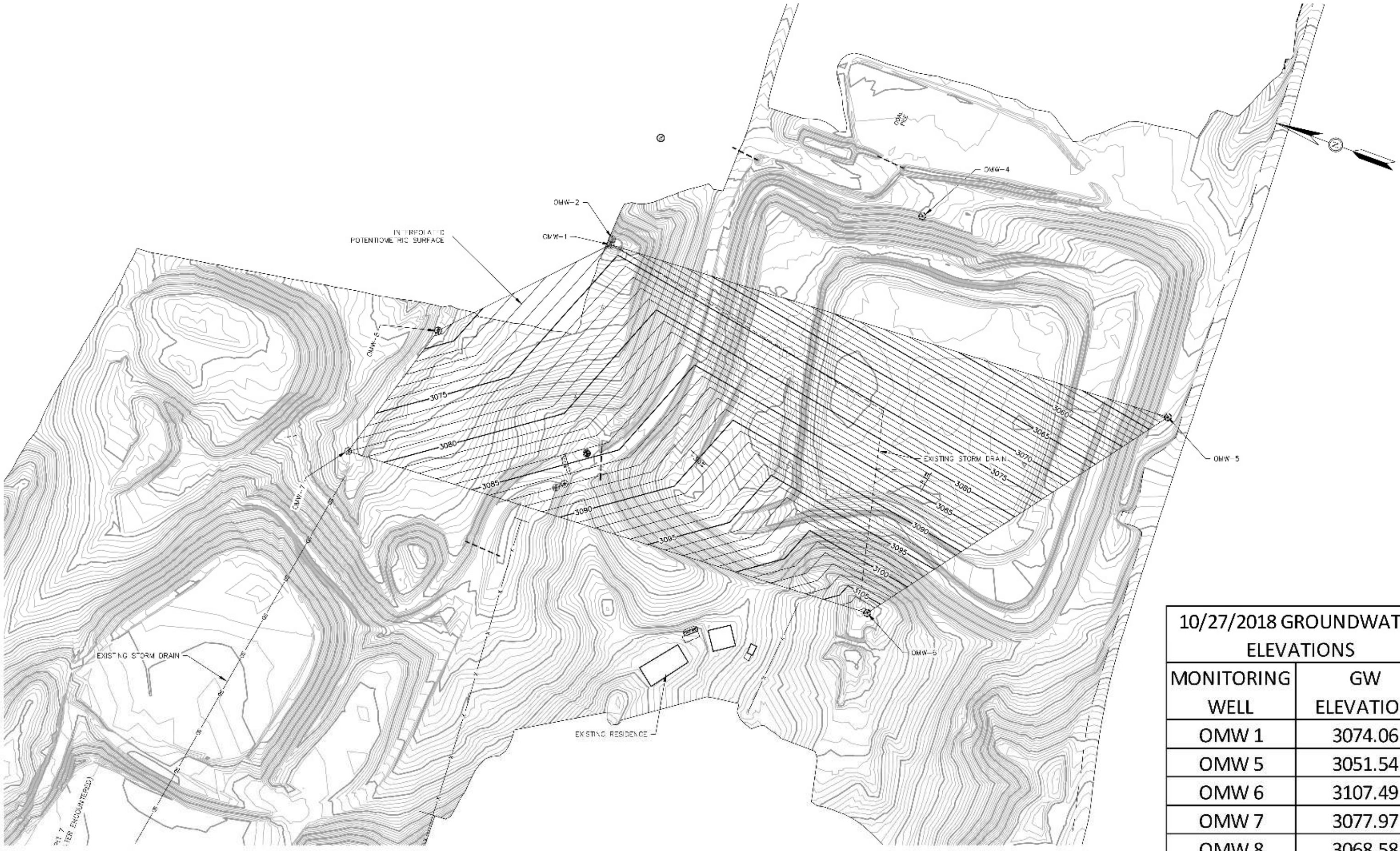
ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 06-05-18
ROSEBUD COUNTY, MT

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

Civil Engineering
Geotechnical Engineering
Land Surveying

PROJECT #: 16-125
DATE: 01/25/2019

SHEET
GW-1



10/27/2018 GROUNDWATER ELEVATIONS	
MONITORING WELL	GW ELEVATION
OMW 1	3074.06
OMW 5	3051.54
OMW 6	3107.49
OMW 7	3077.97
OMW 8	3068.58

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:10-27-18

ROSEBUD COUNTY, MT

32 DISCOVERY DRIVE
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SHEET
GW-1

Appendix B

Groundwater Well Data:
Statistical Tests for Normality

Calendar Years: 2017 & 2018

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: d’Angostino-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 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 is 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.	“ “
d’Angostino-Pearson	If the probability statistic < 0.05; then normality is assumed.	This test employs both the Kurtosis and Skewness statistic.[25] 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’Angostino-Pearson statistic, employed the Add-In Software “Real Statistics Resource Pack,” (Excel does not have this function or 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/

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

Normality Tests

Smaller probabilities indicate non-normality.

2017 / 2018

OMW 1

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	14	7.47	0.06	0.77	0.00	186	0.00	0.01	1
TDS	14	1,311	279	0.81	0.01	1.23	0.54	0.21	2
Calcium (Ca)	14	111	20	0.94	0.43	0,89	0.64	0.18	3
Sulfate (SO42)	14	510	147	0.83	0.01	10.4	0.01	0.29	1
Flouride (F)	14	0.46	0.07	0.77	0.00	1,33	0.51	0.15	2
Chloride (Cl)	14	51	16	0.83	0.01	2,15	0.29	0.32	2
Boron (B)	14	0.07	0.02	0.89	0.07	7.37	0.03	0.28	2

OMW 5

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	14	7.61	0.05	0.30	0.00	186	0.00	0.01	1
TDS	14	4,190	144	0.93	0.34	1.23	0.54	0.03	3
Calcium (Ca)	14	41	2.5	0.93	0.30	0.89	0.64	0.06	3
Sulfate (SO42)	14	1,930	100	0.89	0.07	10.4	0.01	0.05	2
Flouride (F)	14	0.60	0.06	0.73	0.00	1.330	0.51	0.09	2
Chloride (Cl)	14	106	4.9	0.91	0.15	2.5	0.29	0.05	3
Boron (B)	14	0.92	0.050	0.86	0.04	7.4	0.03	0.05	1

OMW 7

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	14	7.34	0.09	0.83	0.01	1.36	0.51	0.01	2
TDS	14	2,374	276	0.92	0.23	1.65	0.44	0.12	3
Calcium (Ca)	14	186	23	0.94	0.42	0.006	0.97	0.13	3
Sulfate (SO42)	14	1,216	146	0.87	0.04	4.59	0.10	0.12	2
Flouride (F)	14	0.41	0.03	0.30	0.00	186	0.00	0.07	1
Chloride (Cl)	14	73	11	0.91	0.18	1.62	0.44	0.16	3
Boron (B)	14	0.11	0.03	0.98	0.95	0.42	0.81	0.24	3

OMW 8

	Valid Cases	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	14	7.43	0.05	0.58	0.00	3.99	0.14	0.01	2
TDS	14	2,964	171	0.88	0.07	9.58	0.01	0.06	2
Calcium (Ca)	14	192	19	0.97	0.83	0.46	0.80	0.10	3
Sulfate (SO42)	14	1,675	98	0.75	0.00	48.2	0.00	0.06	1
Flouride (F)	14	0.44	0.05	0.62	0.00	3.800	0.15	0.11	2
Chloride (Cl)	14	89	6.6	0.93	0.35	0.00	0.99	0.07	3
Boron (B)	14	0.20	0.03	0.93	0.31	0.83	0.66	0.14	3

Appendix C

Analysis of Variance for Groundwater Data:

ANOVA & t-Test Results

Calendar Year 2017 & 2018

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	14	104.8	7.486	7.47E-03
OMW5	14	106.6	7.614	2.86E-03
OMW7	14	102.8	7.343	7.25E-03
OMW8	14	104	7.429	2.20E-03

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.545	3	0.182	36.7	6.917E-13	2.7826
Within Groups	0.257	52	0.005			
Total	0.802	55				

t-Test: Unpaired Sample (Equal Variances)

	OMW1	*OMW5*
Mean	7.49	7.61
Variance	0.00747	0.00286
Observations	14	14
Pooled Variance	0.00516484	
Hypothesized Mean Diffe	0	
df	26	
t Stat	-4.7333134	
P(T<=t) one-tail	3.40E-05	
t Critical one-tail	1.71	
P(T<=t) two-tail	6.80E-05	
t Critical two-tail	2.06	

	OMW5	*OMW7*
Mean	7.61	7.34
Variance	0.00286	0.00725
Observations	14	14
Pooled Varianc	0.0050549	
Hypothesized M	0	
df	26	
t Stat	10.1	
P(T<=t) one-tai	8.603E-11	
t Critical one-ta	1.71	
P(T<=t) two-tai	1.72E-10	
t Critical two-ta	2.06	

	OMW5	*OMW8*
Mean	7.61	7.43
Variance	0.00286	0.00220
Observations	14	14
Pooled Variance	0.002527	
Hypothesized Mea	0	
df	26	
t Stat	9.77	
P(T<=t) one-tail	1.7E-10	
t Critical one-tail	1.71	
P(T<=t) two-tail	3.41E-10	
t Critical two-tail	2.06	

TDS

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	14	18350	1310.7143	77776.37
OMW5	14	58660	4190	20707.69
OMW7	14	33240	2374.2857	76195.6
OMW8	14	41490	2963.5714	29209.34

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	60555636	3	20185212	396.0039	8.794E-36	2.7826
Within Groups	2650557.1	52	50972.253			
Total	63206193	55				
Total	84,475,980	49				

t-Test: Unpaired Sample (≠ Variances)

	OMW1	*OMW5*
Mean	1,311	4,190
Variance	77776.374	20707.692
Observations	14	14
Hypothesized Me	0	
df	19	
t Stat	-34.329367	
P(T<=t) one-tail	7.303E-19	
t Critical one-tail	1.7291328	
P(T<=t) two-tail	1.461E-18	
t Critical two-tail	2.0930241	

	OMW7	*OMW5*
Mean	2,374	4,190
Variance	76195.604	20707.69
Observati	14	14
Hypothesi	0	
df	20	
t Stat	-21.8244	
P(T<=t) on	1.014E-15	
t Critical o	1.7247182	
P(T<=t) tw	2.027E-15	
t Critical t	2.0859634	

t-Test: Unpaired Sample (= Variances)

	OMW8	*OMW5*
Mean	2,964	4,190
Variance	29209.341	20707.69
Observation	14	14
Pooled Vari	24958.516	
Hypothesize	0	
df	26	
t Stat	-20.53912	
P(T<=t) one-	6.779E-18	
t Critical on	1.7056179	
P(T<=t) two-	1.356E-17	
t Critical tw	2.0555294	

Calcium

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	14	1547	110.5	391.5
OMW5	14	568	40.6	6.3
OMW7	14	2607	186.2	543.4
OMW8	14	2684	191.7	347.0

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	214,566	3	71522.12	222.09	1.27E-29	2.78
Within Groups	16,746	52	322.0412			
Total	231,313	55				

t-Test: Unpaired Sample (≠ Variances)

	OMW1	*OMW5*
Mean	111	41
Variance	391.5	6.26
Observations	14	14
Hypothesized Mean Dif	0	
df	13	
t Stat	13.1	
P(T<=t) one-tail	3.5608E-09	
t Critical one-tail	1.7709334	
P(T<=t) two-tail	7.1215E-09	
t Critical two-tail	2.16036866	

	OMW7	*OMW5*
Mean	186	41
Variance	543.4	6.26
Observations	14	14
Hypothesized M	0	
df	13	
t Stat	23.2	
P(T<=t) one-tail	2.83E-12	
t Critical one-tai	1.770933	
P(T<=t) two-tail	5.66E-12	
t Critical two-tai	2.160369	

	OMW8	*OMW5*
Mean	192	41
Variance	347.0	6.263736
Observatic	14	14
Hypothesi	0	
df	13	
t Stat	30.1	
P(T<=t) on	1.05E-13	
t Critical o	1.770933	
P(T<=t) tw	2.09E-13	
t Critical t	2.160369	

Sulfate

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	14	7141	510	21,649
OMW5	14	27020	1,930	10,031
OMW7	14	17019	1,216	21,192
OMW8	14	23450	1,675	9,581

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	16300994.1	3	5433664.7	348.02005	2.17E-34	2.7826
Within Groups	811880.143	52	15613.08			
Total	17112874.2	55				

t-Test: Unpaired Sample (≠ Variances)

	OMW1	*OMW5*
Mean	510	1,930
Variance	21,649	10,031
Observations	14	14
Hypothesized Mea	0	
df	23	
t Stat	(29.8)	
P(T<=t) one-tail	3.3835E-20	
t Critical one-tail	1.71387153	
P(T<=t) two-tail	6.767E-20	
t Critical two-tail	2.06865761	

	OMW7	*OMW5*
Mean	1,216	1,930
Variance	21191.94	10030.77
Observation	14	14
Hypothesize	0	
df	23	
t Stat	(15.1)	
P(T<=t) one-	9.59E-14	
t Critical one	1.713872	
P(T<=t) two-	1.92E-13	
t Critical tw	2.068658	

t-Test: Unpaired Sample (= Variances)

	OMW8	*OMW5*
Mean	1,675	1,930
Variance	9580.769	10030.77
Observations	14	14
Pooled Varianc	9805.769	
Hypothesized M	0	
df	26.0	
t Stat	-6.813157	
P(T<=t) one-tail	1.56E-07	
t Critical one-ta	1.705618	
P(T<=t) two-tai	3.13E-07	
t Critical two-ta	2.055529	

Fluoride

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW1	14	6.5	0.4643	0.0055
OMW5	14	8.4	0.6000	0.0031
OMW7	14	5.7	0.4071	0.0007
OMW8	14	6.1	0.4357	0.0025

ANOVA

ource of Variatio	SS	df	MS	F	P-value	F crit
Between Groups	0.30625	3	0.102083	34.56589	1.99E-12	2.7826
Within Groups	0.153571	52	0.002953			
Total	0.459821	55				

t-Test: Unpaired Sample (= Variances)

	OMW1	OMW5
Mean	0.46	0.60
Variance	0.005549	0.003077
Observations	14	14
Pooled Variance	0.004313	
Hypothesized Me	0	
df	26	
t Stat	-5.47	
P(T<=t) one-tail	4.92E-06	
t Critical one-tail	1.705618	
P(T<=t) two-tail	9.83E-06	
t Critical two-tail	2.055529	

	OMW7	OMW5
Mean	0.41	0.60
Variance	0.000714	0.003077
Observatic	14	14
Pooled Var	0.001896	
Hypothesi	0	
df	26	
t Stat	-11.72	
P(T<=t) on	3.53E-12	
t Critical o	1.705618	
P(T<=t) tw	7.07E-12	
t Critical tv	2.055529	

	OMW8	OMW5
Mean	0.44	0.60
Variance	0.002473	0.003077
Observations	14	14
Pooled Varian	0.002775	
Hypothesized	0	
df	26	
t Stat	-8.25	
P(T<=t) one-ta	4.92E-09	
t Critical one-	1.705618	
P(T<=t) two-ta	9.85E-09	
t Critical two-	2.055529	

Chloride

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW1	14	719	51.4	268.7
OMW5	14	1484	106.0	23.5
OMW7	14	1019	72.8	130.3
OMW8	14	1250	89.3	43.0

ANOVA

ource of Variatio	SS	df	MS	F	P-value	F crit
Between Groups	22884.429	3	7628.143	65.5379	1.1213E-17	2.7826
Within Groups	6052.4286	52	116.3929			
Total	28936.857	55				

t-Test: Unpaired Sample (≠ Variances)

t-Test: Two-Sample Assuming Unequal Variances

	OMW1	OMW5
Mean	51	106
Variance	268.71	23.54
Observations	14	14
Hypothesized M	0	
df	15	
t Stat	-12.0	
P(T<=t) one-tail	2.263E-09	
t Critical one-tai	1.7530504	
P(T<=t) two-tail	4.526E-09	
t Critical two-tai	2.1314495	

	OMW7	OMW5
Mean	73	106
Variance	130.34	23.54
Observatio	14	14
Hypothesiz	0	
df	18	
t Stat	-10.0	
P(T<=t) one	4.3396E-09	
t Critical on	1.73406361	
P(T<=t) two	8.6792E-09	
t Critical tw	2.10092204	

t-Test: Unpaired Sample (= Variances)

t-Test: Two-Sample Assuming Equal Variances

	OMW8	OMW5
Mean	89	106
Variance	42.99	23.54
Observatio	14	14
Pooled Va	33.26374	
Hypothesi	0	
df	26.0	
t Stat	-7.66746	
P(T<=t) on	1.94E-08	
t Critical o	1.705618	
P(T<=t) tw	3.88E-08	
t Critical tv	2.055529	

Boron

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	14	1	0.0714	0.0003
OMW5	14	12.86	0.9186	0.0025
OMW7	14	1.51	0.1079	0.0007
OMW8	14	2.76	0.1971	0.0007

ANOVA

urce of Variati	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Gro	6.721648	3	2.240549	2115.8645	2.63E-54	2.7826
Within Group	0.055064	52	0.001059			
Total	6.776713	55				

t-Test: Unpaired Sample (Equal Variances)

t-Test: Two-Sample Assuming Equal Variances

	OMW1	*OMW5*
Mean	0.071	0.919
Variance	0.000336	0.002505
Observations	14	14
Pooled Varian	0.001421	
Hypothesized	0	
df	26	
t Stat	-59.5	
P(T<=t) one-t	1.3E-29	
t Critical one-	1.705618	
P(T<=t) two-t	2.6E-29	
t Critical two-	2.055529	

	OMW7	*OMW5*
Mean	0.108	0.919
Variance	0.000664	0.002505
Observations	14	14
Pooled Varia	0.001585	
Hypothesized	0	
df	26	
t Stat	-53.9	
P(T<=t) one-	1.65E-28	
t Critical one	1.705618	
P(T<=t) two-	3.31E-28	
t Critical two	2.055529	

	OMW8	*OMW5*
Mean	0.197	0.919
Variance	0.00073	0.002505
Observatio	14	14
Pooled Var	0.001618	
Hypothesi	0	
df	26	
t Stat	-47.5	
P(T<=t) on	4.34E-27	
t Critical o	1.705618	
P(T<=t) tw	8.68E-27	
t Critical tv	2.055529	

Total Cations (Ca + Na)

Anova: Single Factor

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
OMW1	14	4,329	309	3,205
OMW5	14	20,599	1,471	1,907
OMW7	14	8,277	591	2,453
OMW8	14	10,845	775	1,638

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	10292127	3	3430709.108	1491.090828	2.15E-50	2.7826
Within Groups	119641.9	52	2300.804917			
Total	10411769	55				

t-Test: Unpaired Sample (Equal Variances)

t-Test: Two-Sample Assuming Equal Variances

	OMW1	*OMW5*
Mean	309	1471
Variance	3205.377	1906.9904
Observations	14	14
Pooled Variance	2556.184	
Hypothesized Mean [	0	
df	26	
t Stat	-60.8	
P(T<=t) one-tail	7.26E-30	
t Critical one-tail	1.705618	
P(T<=t) two-tail	1.45E-29	
t Critical two-tail	2.055529	

t-Test: Two-Sample Assuming Equal Variances

	OMW7	*OMW5*
Mean	591	1471
Variance	2452.652	1906.99
Observations	14	14
Pooled Variance	2179.821	
Hypothesized Me	0	
df	26	
t Stat	-49.9	
P(T<=t) one-tail	1.21E-27	
t Critical one-tail	1.705618	
P(T<=t) two-tail	2.42E-27	
t Critical two-tail	2.055529	

t-Test: Two-Sample Assuming Equal Variances

	OMW8	*OMW5*
Mean	775	1471
Variance	1638.2	1906.99
Observations	14	14
Pooled Variance	1772.595	
Hypothesized M	0	
df	26	
t Stat	-43.8	
P(T<=t) one-tail	3.44E-26	
t Critical one-ta	1.705618	
P(T<=t) two-tail	6.87E-26	
t Critical two-ta	2.055529	

Appendix D

Analysis of Variance for Groundwater Data:

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

Calendar Year 2017 & 2018

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, sulfate and fluoride 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 the investigation be thorough. Nonetheless, it was deemed cautionary to expand the analysis for these three 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, sulfate and fluoride. The analysis was conducted using the "add-in" software "Real Statistics Resource Pack," (Excel does not have this function or 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	417	686.5	169.5	323	
count	14	14	14	14	56
r^2/n	12,421	33,663	2,052	7,452	55,588
H_{stat}					38.0
H_{ties}					40.7
df					3
p_{value}					0.000
α					0.05
sig					yes

TUKEY HSD/KRAMER alpha 0.05

group	*mean*	*n*	*ss*	*df*	*q-crit*
OMW1	7.47	14	0.0486		
OMW5	7.61	14	0.0371		
OMW7	7.34	14	0.0943		
OMW8	7.43	14	0.0286		
		56	0.2086	52	3.753615

Q TEST

group 1	*group 2*	*mean*	*std err*	*q-stat*	*lower*	*upper*	*p-value*
OMW1	OMW5	0.1429	0.0169	8.4	0.08	0.21	0.000
OMW1	OMW7	0.1286	0.0169	7.6	0.07	0.19	0.000
OMW1	OMW8	0.0429	0.0169	2.5	-0.02	0.11	0.289
OMW5	OMW7	0.2714	0.0169	16.0	0.21	0.33	0.000
OMW5	OMW8	0.1857	0.0169	11.0	0.12	0.25	0.000
OMW7	OMW8	0.0857	0.0169	5.1	0.02	0.15	0.004

Kruskal-Wallis Test **Sulfate**

	OMW1	OMW5	OMW7	OMW8	
median	572	1,960	1,250	1,705	
rank sum	105	683	302	506	
count	14	14	14	14	56.0
r^2/n	788	33,321	6,515	18,288	58,911
H_{stat}					50.5
H_{ties}					50.5
df					3
p_{value}					0.000
α					0.1
sig					yes

TUKEY HSD/KRAMER alpha 0.05

group	*mean*	*n*	*ss*	*df*	*q-crit*
OMW1	510	14	281,435		
OMW5	1,930	14	130,400		
OMW7	1,216	14	275,495		
OMW8	1,675	14	124,550		
		56	811880.143	52	3.753615

Q TEST

group 1	*group 2*	*mean*	*std err*	*q-stat*	*lower*	*upper*	*p-value*
OMW1	OMW5	1,420	33	43	1,295	1,545	0.000
OMW1	OMW7	706	33	21	580	831	0.000
OMW1	OMW8	1,165	33	35	1,040	1,290	0.000
OMW5	OMW7	714	33	21	589	840	0.000
OMW5	OMW8	255	33	8	130	380	0.000
OMW7	OMW8	459	33	14	334	585	0.000

Kruskal-Wallis Test **Fluoride**

	OMW1	**OMW5**	**OMW7**	**OMW8**	
median	0.45	0.60	0.40	0.40	
rank sum	382	668	231	315	
count	14	14	14	14	56
r^2/n	10,423	31,873	3,812	7,088	53,195
H_{stat}					29
H_{ties}					35
df					3
p_{value}					0.000
α					0.050
sig					yes

TUKEY HSD/KRAMER alpha 0.05

group	*mean*	*n*	*ss*	*df*	*q-crit*
OMW1	0.46	14	0.072		
OMW5	0.60	14	0.040		
OMW7	0.41	14	0.009		
OMW8	0.44	14	0.032		
		56	0.154	52	3.75

Q TEST

group 1	*group 2*	*mean*	*std err*	*q-stat*	*lower*	*upper*	*p-value*
OMW1	OMW5	0.136	0.015	9.3	0.081	0.190	0.000
OMW1	OMW7	0.057	0.015	3.9	0.003	0.112	0.037
OMW1	OMW8	0.029	0.015	2.0	-0.026	0.083	0.511
OMW5	OMW7	0.193	0.015	13.3	0.138	0.247	0.000
OMW5	OMW8	0.164	0.015	11.3	0.110	0.219	0.000
OMW7	OMW8	0.029	0.015	2.0	-0.026	0.083	0.511