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

Calendar Year 2021

**Prepared for:
Rosebud Power Plant
Colstrip, MT**

Prepared by:



Bison Engineering, Inc.
3143 E. Lyndale Avenue
Helena, MT 59601

&



Allied Engineering Services, Inc.
32 Discovery Drive
Bozeman, MT 59718

January 31, 2022

TABLE OF CONTENTS

1.0	INTRODUCTION.....	3
2.0	REGULATORY REQUIREMENTS	4
3.0	AREA DESCRIPTION AND GEOLOGY.....	5
4.0	GROUNDWATER MONITORING SYSTEM DESCRIPTION.....	6
4.1	GROUNDWATER CHARACTERISTICS DISCUSSION	8
5.0	GROUNDWATER MONITORING: DATA ANALYSIS	9
5.1	DATA REPORTING	9
5.2	DATA SUMMARY STATISTICS.....	14
5.3	DATA ANALYSIS - GRAPHICAL.....	16
5.4	DATA ANALYSIS – STATISTICS.....	18
5.4.1	NORMALITY TESTING	18
5.4.2	ANALYSIS OF VARIANCE (ANOVA) TESTING	19
5.5	STATISTICAL RESULTS SUMMARY.....	22
6.0	GROUNDWATER MONITORING: HYDROGEOLOGY EVALUATION.....	23
7.0	CONCLUSION	24

LIST OF TABLES

Table 1:	Well Description and Status.....	6
Table 2:	Appendix III Constituents Analyzed: 2021 Reporting Period.....	9
Table 3:	Data Summary OMW-1 Appendix III Constituents Plus Sodium	10
Table 4:	Data Summary OMW-5 Appendix III Constituents Plus Sodium	11
Table 5:	Data Summary OMW-7 Appendix III Constituents Plus Sodium	12
Table 6:	Data Summary OMW-8 Appendix III Constituents Plus Sodium	13
Table 7:	CCR Well Summary Statistics	14
Table 8:	Normality Test Results	18
Table 9:	ANOVA (between wells) Summary Results.....	19
Table 10:	t-Test Summary Results	20
Table 11:	Kruskal-Wallis One-Way ANOVA Test Summary Results.....	21
Table 12:	Kruskal-Wallis Multiple Comparison Test Summary Results.....	21
Table 13:	Statistics Results.....	22

LIST OF FIGURES

Figure 1:	Monitoring Well Locations.....	6
Figure 2:	Constituent by Well.....	20

LIST OF APPENDICES

APPENDIX A:	Groundwater Well: Elevation, Flow and Direction
APPENDIX B:	Groundwater Well Data: Statistical Tests for Normality
APPENDIX C:	Analysis of Variance for Groundwater Data: ANOVA & t-Test Results
APPENDIX D:	Analysis of Variance for Groundwater Data: Kruskal-Wallis (Nonparametric) ANOVA & t-Test Results

1.0 INTRODUCTION

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

EPA requirements for CCR landfills are primarily contained in 40 CFR 257.50 through 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” 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 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. The groundwater monitoring is nevertheless undertaken to substantiate the lack of any impacts from the ash storage facility.

¹ In addition to the current active “existing” landfill there is also a closed landfill on the property. The 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 the 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 operational by 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 2021. The report will be entered into the facility’s operating record and posted on the CELP CCR website² as required by §§257.105(h)(1).

² www.celpccr.com

3.0 AREA DESCRIPTION AND GEOLOGY

The regulated 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” 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.³ 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. It is necessary to be mindful that differences in constituent concentrations 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-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 should be produced.

The site and the general Colstrip region are located within a large area of outcropping Fort Union Formation⁴. 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.

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.

³ Well OMW-9 has produced a water sample only twice in eight years while OMW-10 has never produced any water.

⁴ 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)]

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.

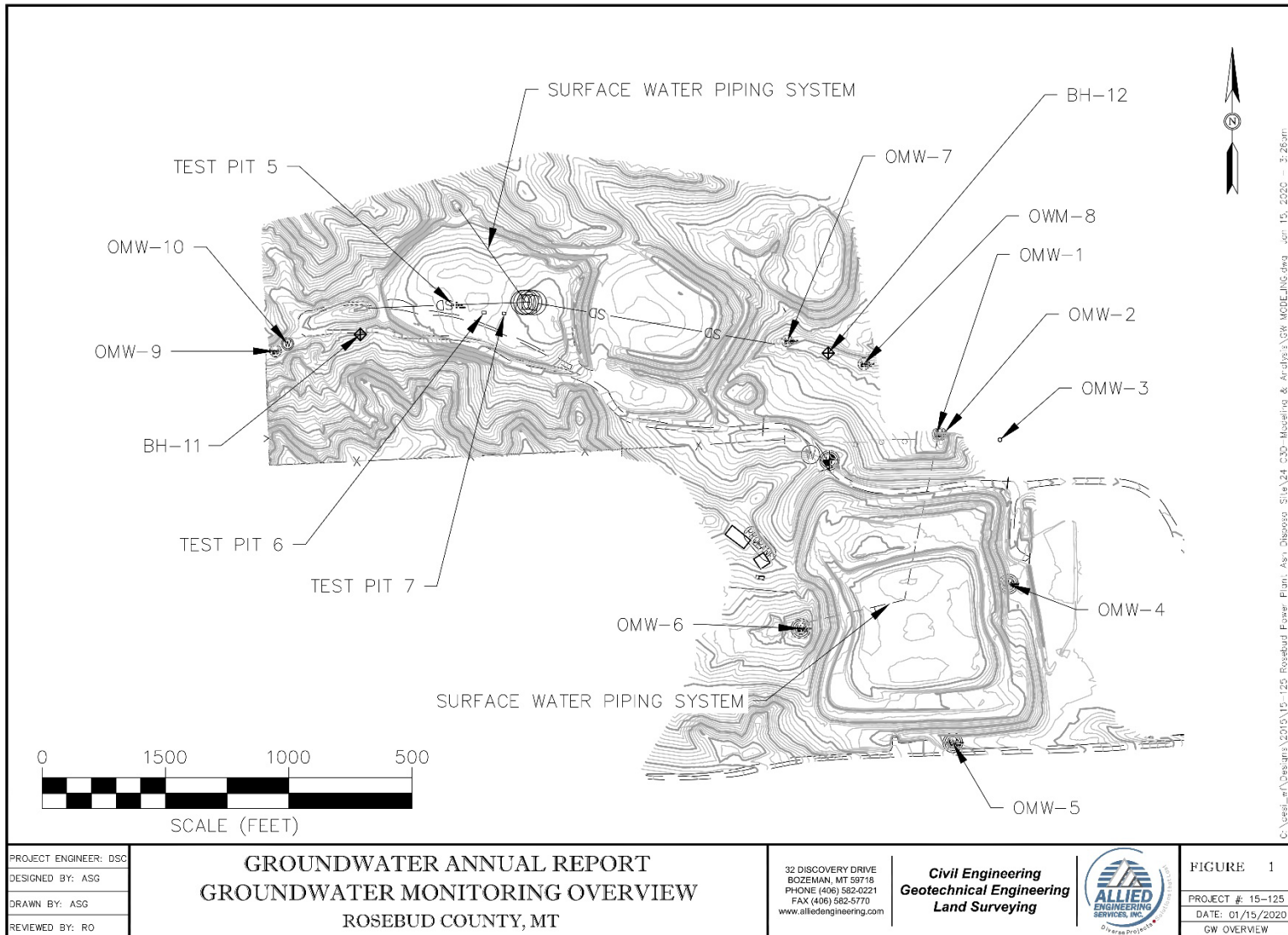
Groundwater at the site is presently monitored using nine groundwater monitoring wells located throughout the power generation site. This includes wells used for purposes other than the CCR rule itself. The location of these wells is shown in Figure 1.

Table 1 below provides a description and the status of each well. The well purpose may be either “Detection” or Assessment” per 40 CFR 257.94 or 95, respectively. 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.

Table 1: Well Description and Status

Well	Description	Well Status	Purpose
OMW-1	Down/cross-gradient in uppermost aquifer.	Downgradient CCR	Detection
OMW-2	Down/cross-gradient in a lower aquifer. This well is not in the uppermost aquifer and thus does not meet the requirement of CCR.	Non-CCR	n/a
OMW-3	Cross-gradient; however, the well was abandoned in 1990.	Non-CCR	n/a
OMW-4	Cross-gradient uppermost aquifer and not likely representative of the active landfill.	Non-CCR	n/a
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	Detection
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	n/a
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	Detection
OMW-8	Downgradient in the uppermost aquifer and is considered a reasonable representation of downgradient well as required in the CCR Rule.	Downgradient CCR	Detection
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	n/a
OMW-10	Upgradient in the uppermost aquifer. However, like OMW-9 it has not produced reliable water.	Upgradient CCR	n/a

Figure 1: Monitoring Well Locations



4.1 GROUNDWATER CHARACTERISTICS DISCUSSION

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. The depths to groundwater among the on-site wells vary, with some wells having water at 8 feet and others with water at 80 to 100 feet deep. Many of the 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 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.

Appendix A contains sample well elevations. In addition, Appendix A also provides the information regarding groundwater flow and direction.

As noted, 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 5/5/21 and 11/4/21 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 20 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 indicates that the gradient is about 3.2% to the NE. These discontinuous perched aquifers in hilly terrain like this commonly have steep and variable gradients.
- The uppermost aquifer thickness varies between wells and ranges between 1.03 feet and 47.81 feet. This aquifer 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 2021 linear groundwater velocities are estimated between 0.15 and 0.35 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 2021). This information is provided in fulfillment of 40 CFR 257.90(e)(3).

5.1 DATA REPORTING

Table 1 contains a list of the monitoring wells, ID designation, and the sampling purpose (assessment or detection monitoring). Table 2 contains the constituents analyzed during each reporting period as required in Appendix III of 40 CFR 257.

The reader will note that, for this reporting period, all sampling and analyses were conducted for “detection” monitoring. “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.

Tables 3 through 6 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 2021.

Table 2: Appendix III Constituents Analyzed: 2021 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

* 40 CFR 257.94

Table 3: 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)
12/06/2016	7.4	1,530	140	263	625	0.5	67	0.09
01/05/2017	7.5	1,520	130	247	629	0.4	62	0.08
02/10/2017	7.4	1,610	126	241	658	0.6	67	0.07
03/15/2017	7.5	1,200	95	170	448	0.5	43	0.06
04/12/2017	7.5	710	80	112	213	0.4	19	0.08
05/11/2017	7.5	1,160	102	190	423	0.4	39	0.06
06/07/2017	7.6	1,420	112	217	534	0.4	52	0.06
07/12/2017	7.5	1,480	119	246	558	0.4	60	0.06
08/09/2017	7.4	1,410	125	231	597	0.5	60	ND**
09/13/2017	7.4	1,460	112	215	612	0.6	63	ND**
10/05/2017	7.5	1,460	118	230	586	0.5	60	ND**
11/09/2017	7.4	1,430	115	215	623	0.4	64	0.09
06/06/2018	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
04/26/2019	7.7	683	67	132	168	0.4	15	0.09
10/09/2019	7.4	1,230	109	178	450	0.8	50	0.10
05/06/2020	7.5	652	69	*	105	0.3	13	0.10
11/04/2020	7.4	1,440	127	*	528	0.5	67	0.10
05/05/2021	7.5	1,460	128	220	594	0.4	69	0.08
10/06/2021	7.4	1,470	128	246	577	0.4	69	0.10

*Sodium was included and used in the combined cation analysis discussed later in this report. Sodium was not analyzed in 2020.

** Data analysis conducted as ½ of the laboratory Reporting Level (0.025 for Boron).

Table 4: 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
01/05/2017	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
06/07/2017	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
08/09/2017	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
10/05/2017	7.6	4,000	40	1,470	1,960	0.6	100	0.92
11/09/2017	7.6	4,130	44	1,450	1,970	0.5	107	0.94
06/06/2018	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
04/26/2019	7.8	3,960	37	1,480	1,910	0.6	105	0.90
09/18/2019	7.8	4,290	41	1,410	1,950	0.6	116	0.90
05/06/2020	7.6	4,240	41	*	2,100	0.4	109	1.00
11/04/2020	7.6	4,330	40	*	1,940	0.6	111	1.01
05/05/2021	8.1	4,330	39	1,420	1,960	0.6	109	0.95
09/08/2021	7.6	4,160	38	1,400	1,910	0.6	109	0.99

*Sodium was included and used in the combined cation analysis discussed later in this report. Sodium was not analyzed in 2020.

Table 5: 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
01/05/2017	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
06/07/2017	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
08/09/2017	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
10/05/2017	7.3	2,390	183	414	1,220	0.5	72	0.08
11/09/2017	7.3	2,370	204	453	1,290	0.4	77	0.15
06/06/2018	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
04/06/2019	7.5	2,200	179	409	1,070	0.4	65	0.03
09/18/2019	7.6	1,850	142	331	875	0.4	44	0.13
05/06/2020	7.2	2,030	151	*	991	0.3	51	0.14
11/04/2020	7.3	1,940	152	*	943	0.4	49	0.16
05/05/2021	7.3	2,120	160	387	1,160	0.3	60	0.11
10/06/2021	7.2	2,010	155	383	993	0.4	51	0.14

*Sodium was included and used in the combined cation analysis discussed later in this report. Sodium was not analyzed in 2020.

Table 6: 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
01/05/2017	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
06/07/2017	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
08/09/2017	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
10/05/2017	7.4	2,790	195	585	1,660	0.5	95	0.16
11/09/2017	7.4	2,890	200	625	1,730	0.4	98	0.25
06/06/2018	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
04/26/2019	7.6	2,950	201	553	1,950	0.4	90	0.18
09/18/2019	7.6	3,000	212	536	1,650	0.4	95	0.18
05/06/2020	7.4	3,240	213	*	1,870	0.3	104	0.20
11/04/2020	7.3	3,240	216	*	1,750	0.4	111	0.21
05/05/2021	7.4	3,430	211	630	2,030	0.4	124	0.21
10/06/2021	7.4	3,370	201	662	1,840	0.4	117	0.25

*Sodium was included and used in the combined cation analysis discussed later in this report. Sodium was not analyzed in 2020.

5.2 DATA SUMMARY STATISTICS

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 website.

Table 7: CCR Well Summary Statistics

	Parameter	pH	TDS	Ca	Sulfate	Fluoride	Chloride	Boron	Cation (Ca + Na)
OMW-1	Count (n) ⁵	20	20	20	20	20	20	20	18
	Mean ⁶	7.48	1,218	106.2	44.3	0.45	44.8	0.07	309
	Std. Dev. ⁷	0.09	313	22	171	0.11	19.4	0.03	65
	Skewness ⁸	1.19	-1.14	-0.88	-1.09	1.61	-0.96	-0.91	-1.01
	Kurtosis	1.09	-0.14	-0.29	-0.06	3.74	-0.50	-0.23	0.05
	Coef. Variation	0.01	0.26	0.21	0.40	0.24	0.43	0.38	0.21
OMW-5	Count (n)	20	20	20	20	20	20	20	18
	Mean	7.65	4,196	40.1	1,937	0.59	107	0.93	1,483
	Std. Dev.	0.13	140.16	2.31	91.7	0.06	4.77	0.05	55.9
	Skewness	2.66	-0.49	-0.24	-1.16	-1.25	0.42	-0.88	0.23
	Kurtosis	7.54	-1.00	-0.33	3.21	3.87	-0.13	1.18	0.85
	Coef. Variation	0.02	0.03	0.06	0.05	0.11	0.04	0.06	0.04
OMW-7	Count (n)	20	20	20	20	20	20	20	18
	Mean	7.34	2,252	175.7	1,141	0.39	65.6	0.10	580
	Std. Dev.	0.11	288	24.7	163.93	0.04	13.73	0.03	67.4
	Skewness	0.80	0.03	0.48	-0.32	-0.53	-0.14	-0.92	0.29
	Kurtosis	0.10	-0.91	-0.33	-1.19	4.99	-1.18	0.99	0.00
	Coef. Variation	0.01	0.13	0.14	0.14	0.10	0.21	0.32	0.12
OMW-8	Count (n)	20	20	20	20	20	20	20	18
	Mean	7.43	3,029	196	1,704	0.42	93.9	0.19	781
	Std. Dev.	0.07	206.7	17.7	126.9	0.05	11.92	0.03	48.3
	Skewness	1.00	-0.33	-0.73	0.00	0.29	1.08	0.29	0.01
	Kurtosis	0.93	1.13	-0.28	3.10	0.46	0.93	-0.28	-1.14
	Coef. Variation	0.01	0.07	0.09	0.07	0.13	0.13	0.13	0.06

⁵ The count indicates the number of data values.

⁶ The mean is the average of the data values.

⁷ The standard deviation is a measure of the amount of variation in the data set.

⁸ Skewness indicates if the normal (bell-shaped) distribution has a degree of asymmetry.

The “Skewness” is presented because it is one indicator to determine if the dataset has or nears a “normal” distribution. The term “normal” refers to a Gaussian distribution. In general, a “Skewness” coefficient greater than unity (absolute value) is an indication, in small sample populations such as the case here, that treating the data as a near-normal distribution might not yield fruitful results. A review of the table indicates that 24 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 documents⁹ 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.

⁹ “Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities” EPA 530-R-09-007, March 2009.

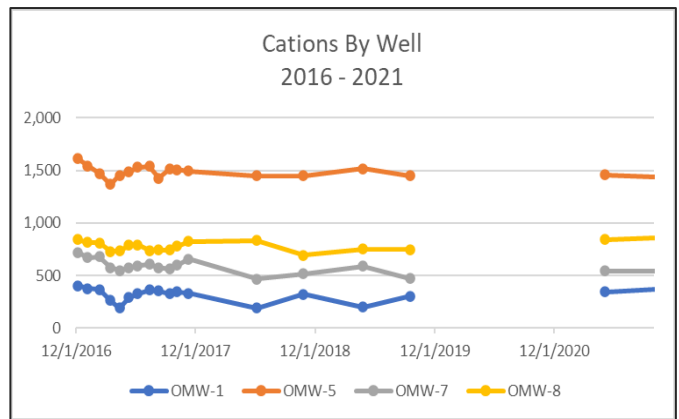
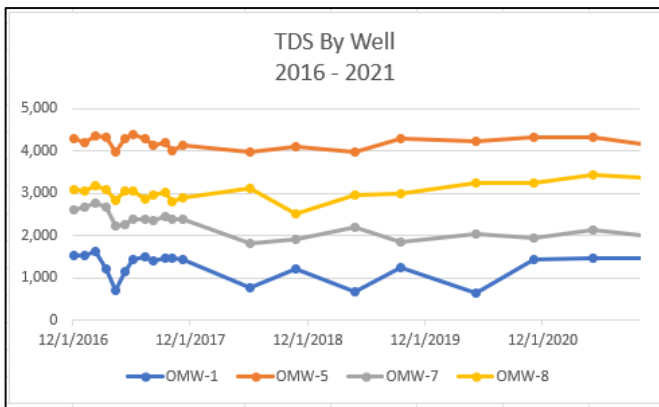
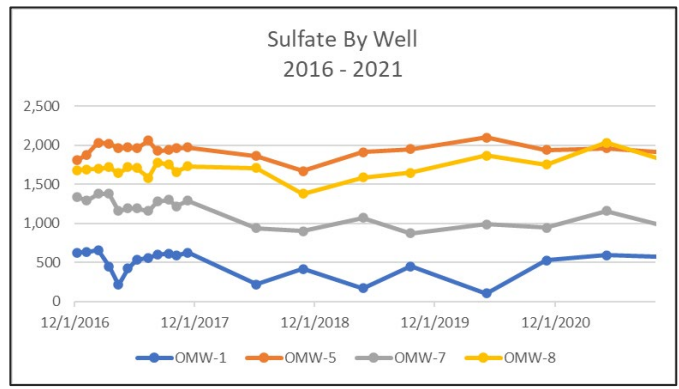
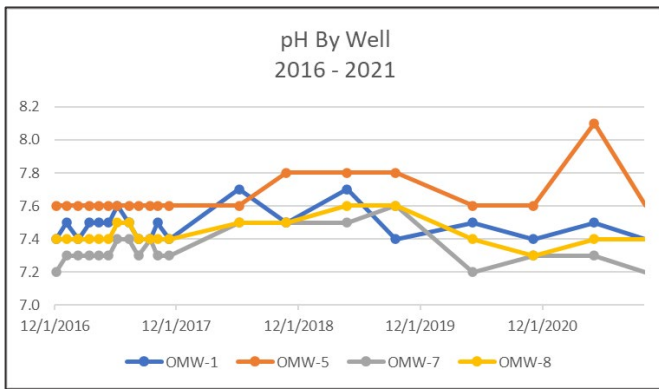
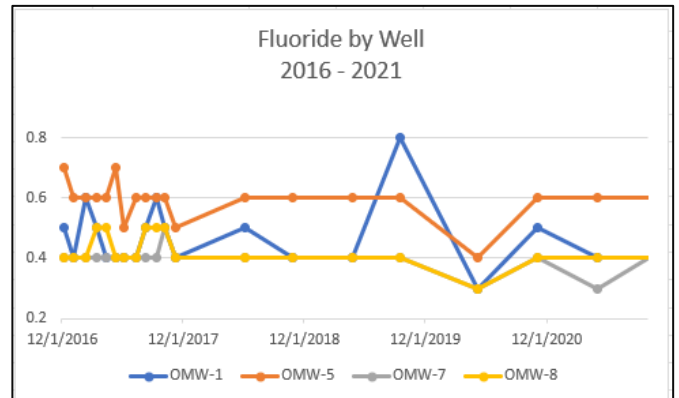
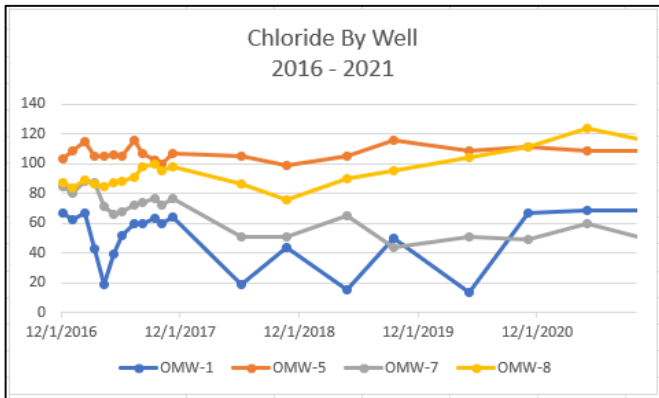
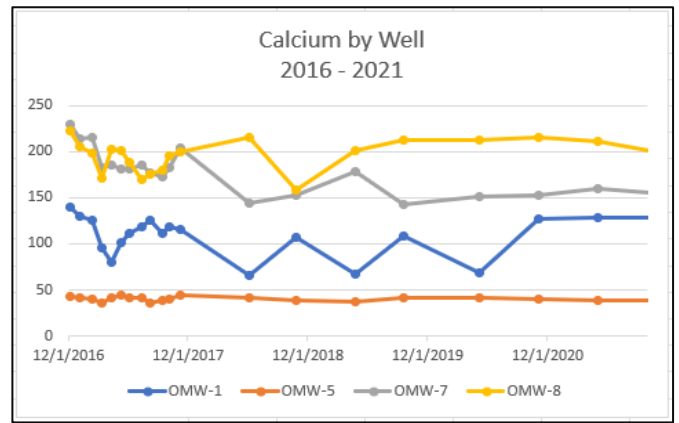
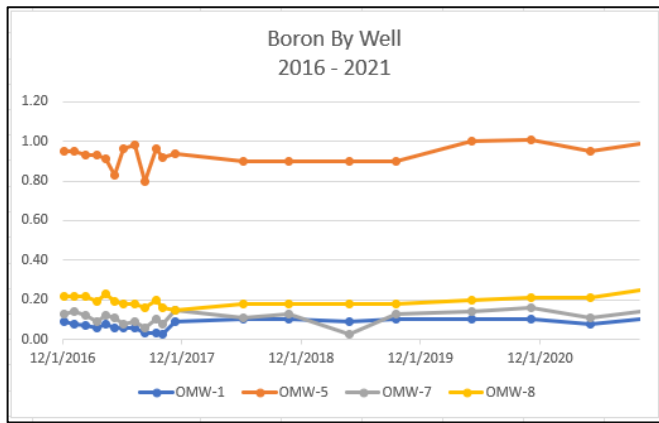
5.3 DATA ANALYSIS - GRAPHICAL

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. The 2017 through 2021 CCR data is presented in the following eight graphics. Each figure plots a constituent by well in a time series manner.

There are a few observations worth noting in the data.

- 1) Ranking the wells from highest constituent concentration to lowest (with the exception of calcium) reveals the following general order: OMW-5, OMW-8, OMW-7 and then OMW-1. The results of calcium alone are, for the most part, opposite that described above. The calcium data for OMW-5 is lower than the other three wells.
- 2) Based on the observation in 1), 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.

Figure 2: Constituent by Well



5.4.2 ANALYSIS OF VARIANCE (ANOVA) TESTING

Based on the normality analysis above to conduct the analysis of variance using Parametric analysis of ANOVA and t-test (unpaired) and non-Parametric analysis of Kruskal-Wallis (one-way) and Kruskal-Wallis (well by well: Q-Test).

ANOVA - Parametric¹¹

The parametric ANOVA test was conducted followed by various t-tests. 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.

Table 9: ANOVA (between wells) Summary Results

Constituent	Calculated F Statistic	Critical F-Statistic	Statistical Difference?
pH	31.8	2.7	Yes
TDS	503.6	2.7	Yes
Calcium	284.1	2.7	Yes
Sulfate	420.1	2.7	Yes
Fluoride	29.6	2.7	Yes
Chloride	73.7	2.7	Yes
Boron	2,580.7	2.7	Yes

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)

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

¹¹ 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.

the probability that they have the same mean (or come from the same population) and whether the difference is an increase or decrease.

The “unpaired with equal variances” and “unpaired with unequal variance” were used as the purposes of this analysis was to compare means of the constituents in the downgradient wells to the means of the constituents in the upgradient well. 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 10: t-Test Summary Results

Constituent	Parameter	OMW-1 vs OMW-5		OMW-7 vs OMW-5		OMW-8 vs OMW-5	
pH	Mean	7.5	7.7	7.3	7.7	7.4	7.7
	Variance	0.009	0.016	0.012	0.016	0.006	0.016
	Calculated “t”	-4.8		-8.2		-6.7	
	Critical “t” ¹²	1.7		1.7		1.7	
	Difference? ¹³	Yes		Yes		Yes	
TDS	Mean	1264.3	4198.5	2269.5	4198.5	3036.0	4198.5
	Variance	98,249	19,645	83,194.5	19,645	42,730.5	19,645
	Calculated “t”	-38.2*		-26.9*		-20.8*	
	Critical “t”	1.7*		1.7*		1.7*	
	Difference?	Yes		Yes		Yes	
Calcium	Mean	108.8	40.2	177.3	40.2	196.9	40.2
	Variance	501.6	5.3	608.1	5.3	314.3	5.3
	Calculated “t”	13.6*		24.8*		39.2*	
	Critical “t”	1.7*		1.7*		1.7*	
	Difference?	Yes		Yes		Yes	
Sulfate	Mean	478.2	1939.5	1152.6	1939.5	1709	1939.5
	Variance	29,347.6	8,405	26,873.4	8,405	16,114.7	8,405
	Calculated “t”	-33.6*		-18.7*		-6.6*	
	Critical “t”	1.7*		1.7*		1.7*	
	Difference?	Yes		Yes		Yes	
Fluoride	Mean	0.5	0.6	0.4	0.6	0.4	0.6
	Variance	0.0	0.0	0.0	0.0	0.0	0.0
	Calculated “t”	-4.4		-11.6		-9.2	
	Critical “t”	1.7		1.7		1.7	
	Difference?	Yes		Yes		Yes	
Chloride	Mean	50.1	107.2	67.0	107.2	94.6	107.2
	Variance	374.9	22.8	188.5	22.8	142.1	22.8
	Calculated “t”	-12.8*		-12.4*		-4.4*	
	Critical “t”	1.7*		1.7*		1.7*	
	Difference?	Yes		Yes		Yes	
Boron	Mean	0.1	0.9	0.1	0.9	0.1	0.9
	Variance	0.0	0.0	0.0	0.0	0.0	0.0
	Calculated “t”	-66.2*		-59.5*		-56.7*	
	Critical “t”	1.7*		1.7*		1.7*	
	Difference?	Yes		Yes		Yes	

* Indicate that an unpaired two-sample with *unequal variances* t-test was conducted

¹² Critical “t” is based on 5% Type I error and sample size and is the one-tail value.

¹³ “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 (or come from the same underlying population).

A review of Table 10 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 (\pm) 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, it was decided to conduct an additional analysis of variance using nonparametric methods for two constituents: pH and fluoride. These two were chosen for this additional testing because the normality testing 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). The table below is a brief summary of those results.

Table 11: Kruskal-Wallis One-Way ANOVA Test Summary Results

Constituent	H Statistic	r ² /n	Pvalue	Statistical Difference?
pH	45.7	155,917.23	0.00	Yes
Fluoride	40.0	151,195.3	0.00	Yes

Table 12: Kruskal-Wallis Multiple Comparison Test Summary Results

Constituents	Well Comparison	q-statistic	Pvalue	Statistical Difference?
pH	OMW-1 vs OMW-5	7.4	0.00	Yes
	OMW-1 vs OMW-7	6.1	0.00	Yes
	OMW-1 vs OMW-8	2.2	0.42	No
	OMW-5 vs OMW-7	13.4	0.00	Yes
	OMW-5 vs OMW-8	9.5	0.00	Yes
	OMW-7 vs OMW-8	3.9	0.00	Yes
Fluoride	OMW-1 vs OMW-5	7.9	0.00	Yes
	OMW-1 vs OMW-7	4.4	0.00	Yes
	OMW-1 vs OMW-8	2.8	0.20	No
	OMW-5 vs OMW-7	12.3	0.00	Yes
	OMW-5 vs OMW-8	10.7	0.00	Yes
	OMW-7 vs OMW-8	1.6	0.68	No

5.5 STATISTICAL RESULTS SUMMARY

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.¹⁴ 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.

There is one additional statistical observation to be made prior to making a conclusion. There are a total of 60 statistical tests spread over 8 constituents (7 of which EPA has chosen for analysis and believe to be an indicator of contamination). If contamination were to occur, it would seem highly likely that several (or all) of the 7 constituents would yield an SSI. While there is no way to estimate how many of the 7 constituents would yield an SSI, one could conservatively give each constituent a 50:50 (independent) probability as it is statistically reasonable that the probability is higher for an SSI if contamination is occurring. That being the case, the probability that only 1 constituent yields an SSI is less than 2%, and by adding cation analysis would further drop the probability to 1%. This observation suggests that the results of the CCR statistical exercise should be treated with caution.

Table 13: Statistics Results

Well	Constituent	Statistical Increase Above OMW-5	
		Parametric	Non-Parametric
OMW-1	pH	No	No
	TDS	No	--
	Calcium	Yes	--
	Sulfate	No	--
	Fluoride	No	No
	Chloride	No	--
	Boron	No	--
OMW-7	pH	No	No
	TDS	No	--
	Calcium	Yes	--
	Sulfate	No	--
	Fluoride	No	No
	Chloride	No	--
	Boron	No	--
OMW-8	pH	No	No
	TDS	No	--
	Calcium	Yes	--
	Sulfate	No	No
	Fluoride	No	No
	Chloride	No	--
	Boron	No	No

¹⁴ The statistics show a near universal significant difference, but not a statistically significant increase.

6.0 GROUNDWATER MONITORING: HYDROGEOLOGY EVALUATION

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 which 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. These soluble components (including calcium and sodium) often increase with time in contact with the various geologic materials, which result in a somewhat random array of groundwater quality that does not necessarily appear related to the presence of the CCR landfill.

OMW-5 as Background Well

The Rosebud facility has gone to extraordinary lengths to locate an ideal upgradient well. Despite those efforts, it was necessary to use OMW-5 as a combination of an upgradient and background well which was far from ideal. The well is located near the landfill and generally upgradient; but not in the location that was preferred.¹⁵

Total Cations

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.). The low calcium in OMW-5 was unexpected because it had more sulfate and TDS than the other wells. This begs the question as to which cation is in this water if not calcium.

The laboratory was able to recover the sodium data from 2017 through 2019. 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) 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 is the reason that the summary and statistic tables included an analysis of the sum of the two cations. The results are consistent with the other six constituent analyses. The data shows there isn't SSI for the cations as a whole.

Discontinuous aquifers

The entire CCR premise is that an establishment of one or more wells will be upgradient of the landfill itself and the other three (or more) wells are downgradient. The 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 except a single sample in 2018. 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.

Ground Disturbances

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).

¹⁵ OMW – 9 and 10 are the 'ideal' locations for upgradient CCR wells. However, both wells have failed to yield any water with a single one-time exception.

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, 2020 and 2021. 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).

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

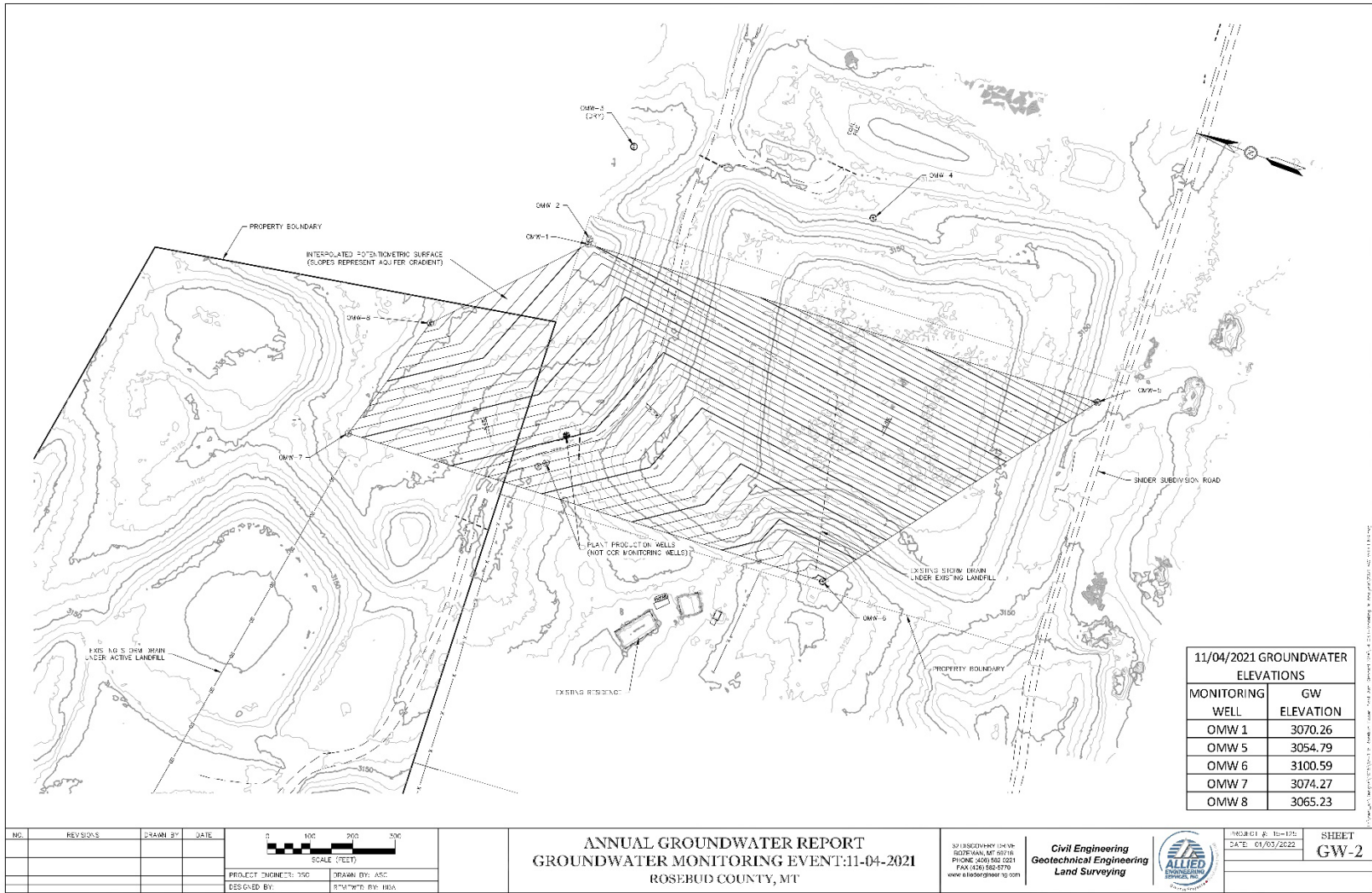
Based on the results of the analyses conducted in this document and considering the variables and caveats above, we make the following conclusions:

- (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

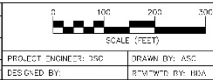
Groundwater Well: Elevation, Flow and Direction

Calendar Year 2021



11/04/2021 GROUNDWATER ELEVATIONS	
MONITORING WELL	GW ELEVATION
OMW 1	3070.26
OMW 5	3054.79
OMW 6	3100.59
OMW 7	3074.27
OMW 8	3065.23

NO.	REVISIONS	DRAWN BY	DATE



ANNUAL GROUNDWATER REPORT
GROUNDWATER MONITORING EVENT: 11-04-2021
 ROSEBUD COUNTY, MT

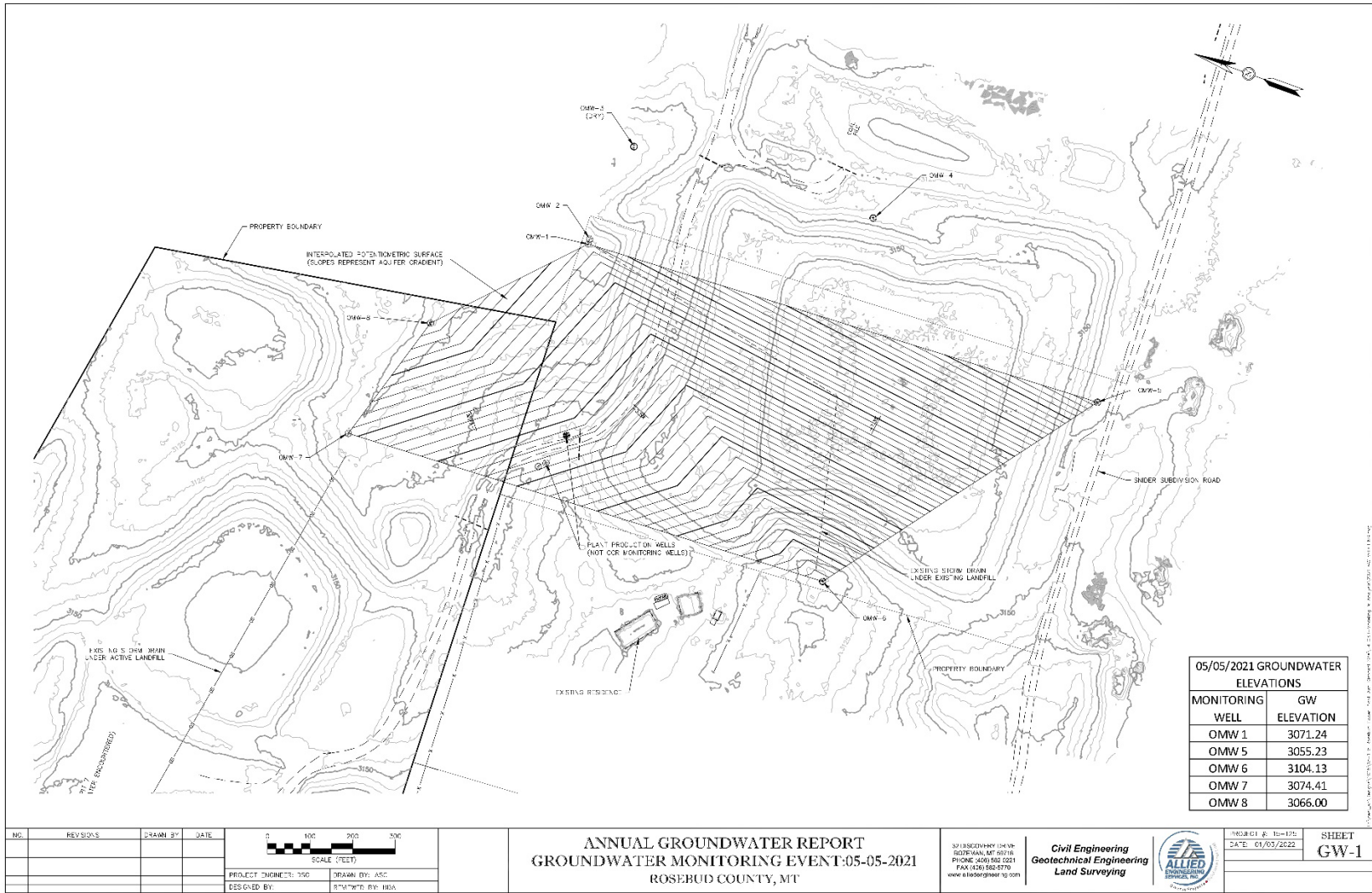
5718 SCUDWY 124 W.
 SODERAM, MT 59716
 PHONE 409-598-0221
 FAX 409-592-8770
 www.allied-engineering.com

Civil Engineering
Geotechnical Engineering
Land Surveying



DESIGN & TITLE
 DATE: 01/03/2022

SHEET
 GW-2



Appendix B

Groundwater Well Data: Statistical Tests for Normality

Calendar Years: 2016 - 2021

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) are 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. 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/>

Normality Tests

Smaller probabilities indicate non-normality.

2017 ↔ 2021

OMW 1

	Valid Cases	Missing	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	20	0	7.48	0.09	0.77	0.00	6.40	0.04	0.01	1
TDS	20	0	1,218	313	0.79	0.00	4.65	0.10	0.26	2
Calcium (Ca)	20	0	106	22.4	0.88	0.02	2.96	0.23	0.21	2
Sulfate (SO ₄) ²⁻	20	0	433	171	0.84	0.00	4.37	0.11	0.40	2
Flouride (F)	20	0	0.45	0.11	0.80	0.00	14.13	0.00	0.24	1
Chloride (Cl)	20	0	44.80	19.4	0.83	0.00	3.61	0.16	0.43	2
Boron (B)	20	0	0.07	0.03	0.84	0.00	3.12	0.21	0.38	2

OMW 5

	Valid Cases	Missing	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	20	0	7.63	0.08	0.50	0.00	27.94	0.00	0.01	1
TDS	20	0	4,193	144	0.92	0.09	2.57	0.28	0.03	3
Calcium (Ca)	20	0	40	2.4	0.96	0.45	0.28	0.87	0.06	3
Sulfate (SO ₄) ²⁻	20	0	1,940	97	0.91	0.05	9.90	0.01	0.05	2
Flouride (F)	20	0	0.59	0.07	0.69	0.00	11.69	0.00	0.11	1
Chloride (Cl)	20	0	107	5.0	0.69	0.00	11.69	0.00	0.05	1
Boron (B)	20	0	0.93	0.05	0.93	0.17	4.48	0.11	0.06	3

OMW 7

	Valid Cases	Missing	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	20	0	7.36	0.11	0.86	0.01	2.62	0.27	0.01	2
TDS	20	0	2,292	295	0.96	0.57	1.17	0.56	0.13	3
Calcium (Ca)	20	0	180	25	0.94	0.20	0.99	0.61	0.14	3
Sulfate (SO ₄) ²⁻	20	0	1,151	169	0.93	0.13	3.30	0.19	0.15	3
Flouride (F)	20	0	0.40	0.03	0.55	0.00	9.15	0.01	0.08	1
Chloride (Cl)	20	0	68	14	0.93	0.19	2.83	0.24	0.20	3
Boron (B)	20	0	0.11	0.03	0.94	0.29	4.42	0.11	0.27	3

OMW 8

	Valid Cases	Missing	Mean	Standard Deviation	Shapiro-Wilk Test	Probability	d'Agostino-Pearson Test	Probability	Coefficient of Variation	# Accepted Normality Tests
pH	20	0	7.44	0.08	0.76	0.00	4.84	0.09	0.01	2
TDS	20	0	2,996	174	0.97	0.78	1.92	0.38	0.06	3
Calcium (Ca)	20	0	196	18	0.93	0.14	2.11	0.35	0.09	3
Sulfate (SO ₄) ²⁻	20	0	1,684	101	0.92	0.10	4.91	0.09	0.06	3
Flouride (F)	20	0	0.42	0.05	0.70	0.00	0.83	0.66	0.13	2
Chloride (Cl)	20	0	92	8.3	0.91	0.05	5.39	0.07	0.09	3
Boron (B)	20	0	0.20	0.02	0.96	0.57	0.38	0.83	0.13	3

Appendix C

Analysis of Variance for Groundwater Data:

ANOVA & t-Test Results

Calendar Years 2017 through 2021

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 & t-Tests

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW-1	20	149.7	7.485	0.008710526
OMW-5	20	153.1	7.655	0.016289474
OMW-7	20	146.9	7.345	0.012078947
OMW-8	20	148.7	7.435	0.005552632

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	1.018	3	0.339333	31.83868313	1.9552E-13	2.72494
Within Groups	0.81	76	0.010658			
Total	1.828	79				

t-Test: Two-Sample Assuming Equal Variances

	OMW-1	OMW-5
Mean	7.485	7.655
Variance	0.0087	0.0163
Observations	20	20
Pooled Variance	0.0125	
Hypothesized Mea	0	
df	38	
t Stat	-4.808326	
P(T<=t) one-tail	1.206E-05	
t Critical one-tail	1.6859545	
P(T<=t) two-tail	2.412E-05	
t Critical two-tail	2.0243942	

	OMW-7	OMW-5
Mean	7.345	7.655
Variance	0.012	0.016
Observations	20	20
Pooled Variance	0.01418421	
Hypothesized Mea	0	
df	38	
t Stat	-8.2311233	
P(T<=t) one-tail	2.8405E-10	
t Critical one-tail	1.68595446	
P(T<=t) two-tail	5.681E-10	
t Critical two-tail	2.02439416	

	OMW-8	OMW-5
Mean	7.435	7.655
Variance	0.0056	0.0163
Observations	20	20
Pooled Variance	0.01092	
Hypothesized Mea	0	
df	38	
t Stat	-6.65718	
P(T<=t) one-tail	3.6E-08	
t Critical one-tail	1.68595	
P(T<=t) two-tail	7.2E-08	
t Critical two-tail	2.02439	

F-Test Two-Sample for Variances

	OMW-1	OMW-5
Mean	7.485	7.655
Variance	0.0087	0.016
Observations	20	20
df	19	19
F	0.53	
P(F<=f) one-tail	0.09	
F Critical one-tail	0.46	

	OMW-7	OMW-5
Mean	7.345	7.655
Variance	0.012	0.016
Observations	20	20
df	19	19
F	0.74	
P(F<=f) one-tail	0.26	
F Critical one-tail	0.46	

	OMW-8	OMW-5
Mean	7.435	7.655
Variance	0.0056	0.0163
Observations	20	20
df	19	19
F	0.34	
P(F<=f) one-tail	0.01	
F Critical one-tail	0.46	

TDS: ANOVA & t-Tests

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
OMW-1	20	25285	1264.25	98249.03947
OMW-5	20	83970	4198.5	19645
OMW-7	20	45390	2269.5	83194.47368
OMW-8	20	60720	3036	42730.52632

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	9.2E+07	3	30699030	503.6363096	4.9E-50	2.72494
Within Groups	4632562	76	60954.76			
Total	9.7E+07	79				

t-Test: Two-Sample Assuming Unequal Variances

	<i>OMW-1</i>	<i>OMW-5</i>
Mean	1264.25	4198.5
Variance	98249	19645
Observations	20	20
Hypothesized Mea	0	
df	26	
t Stat	-38.2178	
P(T<=t) one-tail	1.1E-24	
t Critical one-tail	1.70562	
P(T<=t) two-tail	2.2E-24	
t Critical two-tail	2.05553	

	<i>OMW-7</i>	<i>OMW-5</i>
Mean	2269.5	4198.5
Variance	83194.5	19645
Observations	20	20
Hypothesized Mea	0	
df	27	
t Stat	-26.9009	
P(T<=t) one-tail	2.5E-21	
t Critical one-tail	1.70329	
P(T<=t) two-tail	4.9E-21	
t Critical two-tail	2.05183	

	<i>OMW-8</i>	<i>OMW-5</i>
Mean	3036	4198.5
Variance	42730.5	19645
Observations	20	20
Hypothesized Mea	0	
df	33	
t Stat	-20.8162	
P(T<=t) one-tail	7.5E-21	
t Critical one-tail	1.69236	
P(T<=t) two-tail	1.5E-20	
t Critical two-tail	2.03452	

F-Test Two-Sample for Variances

	<i>OMW-1</i>	<i>OMW-5</i>
Mean	1264.25	4198.5
Variance	98249	19645
Observations	20	20
df	19	19
F	5.00122	
P(F<=f) one-tail	0.00048	
F Critical one-tail	2.16825	

	<i>OMW-7</i>	<i>OMW-5</i>
Mean	2269.5	4198.5
Variance	83194.5	19645
Observations	20	20
df	19	19
F	4.23489	
P(F<=f) one-tail	0.00142	
F Critical one-tail	2.16825	

	<i>OMW-8</i>	<i>OMW-5</i>
Mean	3036	4198.5
Variance	42730.5	19645
Observations	20	20
df	19	19
F	2.17513	
P(F<=f) one-tail	0.04933	
F Critical one-tail	2.16825	

Calcium: ANOVA & t-Tests

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW-1	20	2175	108.75	501.5657895
OMW-5	20	804	40.2	5.326315789
OMW-7	20	3546	177.3	608.1157895
OMW-8	20	3938	196.9	314.3052632

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	304520	3	101507	284.071582	3.4E-41	2.72494
Within Groups	27157	76	357.328			
Total	331677	79				

t-Test: Two-Sample Assuming Unequal Variances

	OMW-1	OMW-5
Mean	108.75	40.2
Variance	501.566	5.32632
Observations	20	20
Hypothesized Mea	0	
df	19	
t Stat	13.6165	
P(T<=t) one-tail	1.5E-11	
t Critical one-tail	1.72913	
P(T<=t) two-tail	3E-11	
t Critical two-tail	2.09302	

	OMW-7	OMW-5
Mean	177.3	40.2
Variance	608.116	5.32632
Observations	20	20
Hypothesized Mea	0	
df	19	
t Stat	24.7552	
P(T<=t) one-tail	3.2E-16	
t Critical one-tail	1.72913	
P(T<=t) two-tail	6.4E-16	
t Critical two-tail	2.09302	

	OMW-8	OMW-5
Mean	196.9	40.2
Variance	314.305	5.32632
Observations	20	20
Hypothesized Mea	0	
df	20	
t Stat	39.1976	
P(T<=t) one-tail	1.1E-20	
t Critical one-tail	1.72472	
P(T<=t) two-tail	2.2E-20	
t Critical two-tail	2.08596	

F-Test Two-Sample for Variances

	OMW-1	OMW-5
Mean	108.75	40.2
Variance	501.566	5.32632
Observations	20	20
df	19	19
F	94.1675	
P(F<=f) one-tail	7E-15	
F Critical one-tail	2.16825	

	OMW-7	OMW-5
Mean	177.3	40.2
Variance	608.116	5.32632
Observations	20	20
df	19	19
F	114.172	
P(F<=f) one-tail	1.2E-15	
F Critical one-tail	2.16825	

	OMW-8	OMW-5
Mean	196.9	40.2
Variance	314.305	5.32632
Observations	20	20
df	19	19
F	59.0099	
P(F<=f) one-tail	5.3E-13	
F Critical one-tail	2.16825	

Sulfate: ANOVA & t-Tests

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW-1	20	9563	478.15	29347.60789
OMW-5	20	38790	1939.5	8405
OMW-7	20	23051	1152.55	26873.41842
OMW-8	20	34180	1709	16114.73684

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	2.5E+07	3	8479013	420.0610993	3.3E-47	2.72494
Within Groups	1534075	76	20185.2			
Total	2.7E+07	79				

t-Test: Two-Sample Assuming Unequal Variances

	OMW-1	OMW-5
Mean	478.15	1939.5
Variance	29347.6	8405
Observations	20	20
Hypothesized Mea	0	
df	29	
t Stat	-33.6353	
P(T<=t) one-tail	4.4E-25	
t Critical one-tail	1.69913	
P(T<=t) two-tail	8.7E-25	
t Critical two-tail	2.04523	

	OMW-7	OMW-5
Mean	1152.55	1939.5
Variance	26873.4	8405
Observations	20	20
Hypothesized Mea	0	
df	30	
t Stat	-18.7373	
P(T<=t) one-tail	2.1E-18	
t Critical one-tail	1.69726	
P(T<=t) two-tail	4.1E-18	
t Critical two-tail	2.04227	

	OMW-8	OMW-5
Mean	1709	1939.5
Variance	16114.7	8405
Observations	20	20
Hypothesized Mea	0	
df	35	
t Stat	-6.58306	
P(T<=t) one-tail	6.6E-08	
t Critical one-tail	1.68957	
P(T<=t) two-tail	1.3E-07	
t Critical two-tail	2.03011	

F-Test Two-Sample for Variances

	OMW-1	OMW-5
Mean	478.15	1939.5
Variance	29347.6	8405
Observations	20	20
df	19	19
F	3.49168	
P(F<=f) one-tail	0.00453	
F Critical one-tail	2.16825	

	OMW-7	OMW-5
Mean	1152.55	1939.5
Variance	26873.4	8405
Observations	20	20
df	19	19
F	3.19731	
P(F<=f) one-tail	0.00744	
F Critical one-tail	2.16825	

	OMW-8	OMW-5
Mean	1709	1939.5
Variance	16114.7	8405
Observations	20	20
df	19	19
F	1.91728	
P(F<=f) one-tail	0.08254	
F Critical one-tail	2.16825	

Fluoride: ANOVA & t-Tests

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
OMW-1	20	9.3	0.465	0.011868421
OMW-5	20	11.8	0.59	0.004105263
OMW-7	20	7.9	0.395	0.001552632
OMW-8	20	8.4	0.42	0.002736842

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.4505	3	0.15017	29.64329004	8.5E-13	2.72494392
Within Groups	0.385	76	0.00507			
Total	0.8355	79				

t-Test: Two-Sample Assuming Equal Variances

	OMW-1	OMW-5
Mean	0.465	0.59
Variance	0.01187	0.00411
Observations	20	20
Pooled Variance	0.00799	
Hypothesized Mea	0	
df	38	
t Stat	-4.42306	
P(T<=t) one-tail	3.9E-05	
t Critical one-tail	1.68595	
P(T<=t) two-tail	7.9E-05	
t Critical two-tail	2.02439	

	OMW-7	OMW-5
Mean	0.395	0.59
Variance	0.00155	0.00410526
Observations	20	20
Pooled Variance	0.00283	
Hypothesized Mea	0	
df	38	
t Stat	-11.5937	
P(T<=t) one-tail	2.4E-14	
t Critical one-tail	1.68595	
P(T<=t) two-tail	4.8E-14	
t Critical two-tail	2.02439	

	OMW-8	OMW-5
Mean	0.42	0.59
Variance	0.00274	0.00411
Observations	20	20
Pooled Variance	0.00342	
Hypothesized Mea	0	
df	38	
t Stat	-9.19113	
P(T<=t) one-tail	1.7E-11	
t Critical one-tail	1.68595	
P(T<=t) two-tail	3.4E-11	
t Critical two-tail	2.02439	

F-Test Two-Sample for Variances

	OMW-1	OMW-5
Mean	0.465	0.59
Variance	0.01187	0.00411
Observations	20	20
df	19	19
F	2.89103	
P(F<=f) one-tail	0.01275	
F Critical one-tail	2.16825	

	OMW-7	OMW-5
Mean	0.395	0.59
Variance	0.00155	0.00410526
Observations	20	20
df	19	19
F	0.37821	
P(F<=f) one-tail	0.02005	
F Critical one-tail	0.4612	

	OMW-8	OMW-5
Mean	0.42	0.59
Variance	0.00274	0.00411
Observations	20	20
df	19	19
F	0.66667	
P(F<=f) one-tail	0.19236	
F Critical one-tail	0.4612	

Chloride: ANOVA & t-Tests

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
OMW-1	20	1002	50.1	374.9368421
OMW-5	20	2143	107.2	22.76578947
OMW-7	20	1339	66.95	188.4710526
OMW-8	20	1891	94.55	142.05

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	40254.9	3	13418	73.70434547	1.9E-22	2.72494
Within Groups	13836.3	76	182.1			
Total	54091.2	79				

t-Test: Two-Sample Assuming Unequal Variances

	<i>OMW-1</i>	<i>OMW-5</i>
Mean	50.1	107.15
Variance	374.937	22.7658
Observations	20	20
Hypothesized Mea	0	
df	21	
t Stat	-12.7936	
P(T<=t) one-tail	1.1E-11	
t Critical one-tail	1.72074	
P(T<=t) two-tail	2.2E-11	
t Critical two-tail	2.07961	

	<i>OMW-7</i>	<i>OMW-5</i>
Mean	66.95	107.15
Variance	188.471	22.7658
Observations	20	20
Hypothesized Mea	0	
df	24	
t Stat	-12.3696	
P(T<=t) one-tail	3.3E-12	
t Critical one-tail	1.71088	
P(T<=t) two-tail	6.7E-12	
t Critical two-tail	2.0639	

	<i>OMW-8</i>	<i>OMW-5</i>
Mean	94.55	107.15
Variance	142.05	22.7658
Observations	20	20
Hypothesized Mea	0	
df	25	
t Stat	-4.38921	
P(T<=t) one-tail	9.1E-05	
t Critical one-tail	1.70814	
P(T<=t) two-tail	0.00018	
t Critical two-tail	2.05954	

F-Test Two-Sample for Variances

	<i>OMW-1</i>	<i>OMW-5</i>
Mean	50.1	107.15
Variance	374.937	22.7658
Observations	20	20
df	19	19
F	16.4693	
P(F<=f) one-tail	4.8E-08	
F Critical one-tail	2.16825	

	<i>OMW-7</i>	<i>OMW-5</i>
Mean	66.95	107.15
Variance	188.471	22.7658
Observations	20	20
df	19	19
F	8.2787	
P(F<=f) one-tail	1.3E-05	
F Critical one-tail	2.16825	

	<i>OMW-8</i>	<i>OMW-5</i>
Mean	94.55	107.15
Variance	142.05	22.7658
Observations	20	20
df	19	19
F	6.23963	
P(F<=f) one-tail	0.0001	
F Critical one-tail	2.16825	

Boron: ANOVA & t-Tests

Anova: Single Factor

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
OMW-1	20	1.505	0.07525	0.000630197
OMW-5	20	18.61	0.9305	0.002710263
OMW-7	20	2.215	0.11075	0.001084934
OMW-8	20	3.89	0.1945	0.000657632

ANOVA

<i>Source of Variation</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>P-value</i>	<i>F crit</i>
Between Groups	9.83817	3	3.27939	2580.658815	2.4E-76	2.72494
Within Groups	0.09658	76	0.00127			
Total	9.93475	79				

t-Test: Two-Sample Assuming Unequal Variances

	<i>OMW-1</i>	<i>OMW-5</i>
Mean	0.07525	0.9305
Variance	0.00063	0.00271
Observations	20	20
Hypothesized Mea	0	
df	27	
t Stat	-66.1767	
P(T<=t) one-tail	1E-31	
t Critical one-tail	1.70329	
P(T<=t) two-tail	2.1E-31	
t Critical two-tail	2.05183	

	<i>OMW-7</i>	<i>OMW-5</i>
Mean	0.11075	0.9305
Variance	0.00108	0.00271
Observations	20	20
Hypothesized M	0	
df	32	
t Stat	-59.5085	
P(T<=t) one-tail	1.2E-34	
t Critical one-tai	1.69389	
P(T<=t) two-tail	2.4E-34	
t Critical two-tai	2.03693	

	<i>OMW-8</i>	<i>OMW-5</i>
Mean	0.1945	0.9305
Variance	0.00066	0.00271
Observations	20	20
Hypothesized Mean	0	
df	28	
t Stat	-56.717	
P(T<=t) one-tail	9.5E-31	
t Critical one-tail	1.70113	
P(T<=t) two-tail	1.9E-30	
t Critical two-tail	2.04841	

F-Test Two-Sample for Variances

	<i>OMW-1</i>	<i>OMW-5</i>
Mean	0.07525	0.9305
Variance	0.00063	0.00271
Observations	20	20
df	19	19
F	0.23252	
P(F<=f) one-tail	0.00129	
F Critical one-tail	0.4612	

	<i>OMW-7</i>	<i>OMW-5</i>
Mean	0.11075	0.9305
Variance	0.00108	0.00271
Observations	20	20
df	19	19
F	0.40031	
P(F<=f) one-tail	0.02638	
F Critical one-ta	0.4612	

	<i>OMW-8</i>	<i>OMW-5</i>
Mean	0.1945	0.9305
Variance	0.00066	0.00271
Observations	20	20
df	19	19
F	0.24264	
P(F<=f) one-tail	0.00168	
F Critical one-tail	0.4612	

Appendix D

Analysis of Variance for Groundwater Data:

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

Calendar Years 2017 through 2021

The Kruskal-Wallis 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 and fluoride data 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 and fluoride.

pH: Kruskal-Wallis ANOVA & Q-Test

Kruskal-Wallis Test

	OMW-1	OMW-5	OMW-7	OMW-8	
median	7.5	7.6	7.3	7.4	
rank sum	846	1346	379.5	668.5	
count	20	20	20	20	80
r ² /n	35,785.80	90,585.80	7,201.01	22,344.61	155,917.23
H-stat					45.7
H-ties					48.3
df					3
p-value					1.8335E-10
alpha					0.05
sig					yes

TUKEY HSD/KRAMER

		alpha		0.05	
group	mean	n	ss	df	q-crit
OMW-1	7.485	20	0.1655		
OMW-5	7.655	20	0.3095		
OMW-7	7.345	20	0.2295		
OMW-8	7.4	20	0.1055		
		80	0.81	76	3.72

Q TEST

group 1	group 2	mean	std err	q-stat	lower	upper	p-value	mean-crit	Cohen d
OMW-1	OMW-5	0.17	0.023085	7.364245	0.084239	0.255761	9.35E-06	0.085761	1.646695
OMW-1	OMW-7	0.14	0.023085	6.064672	0.054239	0.225761	0.0003	0.085761	1.356102
OMW-1	OMW-8	0.05	0.023085	2.165954	-0.03576	0.135761	0.423959	0.085761	0.484322
OMW-5	OMW-7	0.31	0.023085	13.42892	0.224239	0.395761	3.15E-14	0.085761	3.002797
OMW-5	OMW-8	0.22	0.023085	9.530199	0.134239	0.305761	1.62E-08	0.085761	2.131017
OMW-7	OMW-8	0.09	0.023085	3.898718	0.004239	0.175761	0.035982	0.085761	0.87178

Fluoride: Kruskal-Wallis ANOVA & Q-Test

Kruskal-Wallis Test

	OMW-1	OMW-5	OMW-7	OMW-8	
median	0.4	0.6	0.4	0.4	
rank sum	796.5	1324.5	492	627	
count	20	20	20	20	80
r ² /n	31720.61	87715.01	12103.2	19656.45	151195.3
H-stat					36.99125
H-ties					44.01988
df					3
p-value					1.49E-09
alpha					0.05
sig					yes

TUKEY HSD/KRAMER

group	mean	n	alpha 0.05		
			ss	df	q-crit
OMW-1	0.465	20	0.2255		
OMW-5	0.59	20	0.078		
OMW-7	0.395	20	0.0295		
OMW-8	0.42	20	0.052		
		80	0.385	76	3.715105

Q TEST

group 1	group 2	mean	std err	q-stat	lower	upper	p-value	mean-crit	Cohen d
OMW-1	OMW-5	0.125	0.015915	7.854191	0.065874	0.184126	2.33E-06	0.059126	1.75625
OMW-1	OMW-7	0.07	0.015915	4.398347	0.010874	0.129126	0.013735	0.059126	0.9835
OMW-1	OMW-8	0.045	0.015915	2.827509	-0.01413	0.104126	0.197321	0.059126	0.63225
OMW-5	OMW-7	0.195	0.015915	12.25254	0.135874	0.254126	3.47E-12	0.059126	2.739751
OMW-5	OMW-8	0.17	0.015915	10.6817	0.110874	0.229126	4.7E-10	0.059126	2.388501
OMW-7	OMW-8	0.025	0.015915	1.570838	-0.03413	0.084126	0.684066	0.059126	0.35125