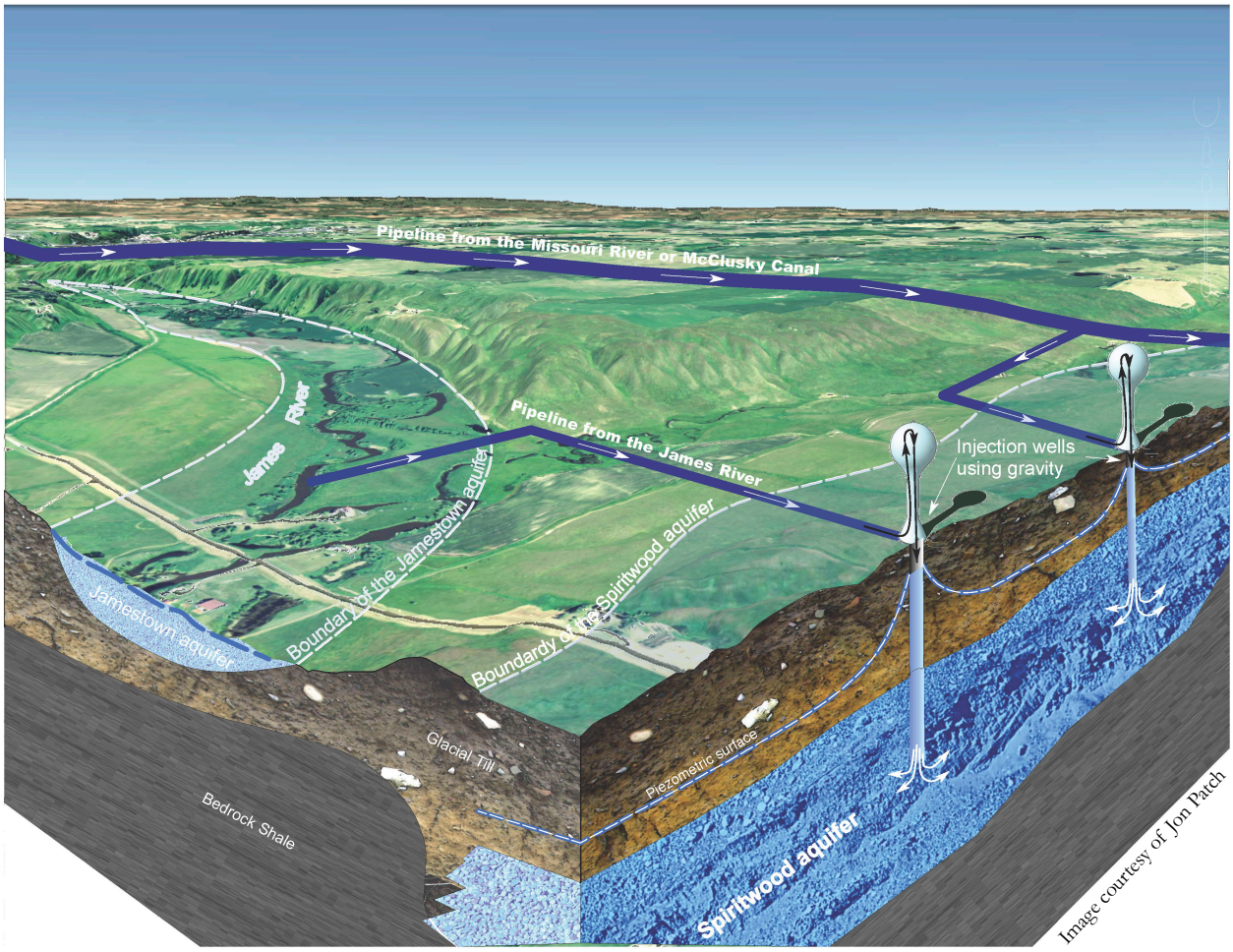
Potential Geochemical Effects of Storing James River Water in the Spiritwood Aquifer: PHREEQC Simulations of pe-pH



By:
Scott F. Korom PhD, PE, Barr Engineering

In Collaboration with:
David B. Hisz, ND State Water Commission

2018

Water Resource Investigation No. 61
North Dakota State Water Commission

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ACKNOWLEDGMENT

The work presented in this report was accomplished through the data collection efforts of many State Water Commission personal. Test hole and observation wells were installed by Terry Olson and Dan Bahm. Lithologic logs, borehole geophysical logging, sediment sample collection and organization, and well construction design were overseen by Michael Ginsbach. Water quality sampling was performed by Terry McCann.

EXECUTIVE SUMMARY

In 2017, the State Water Commission (SWC) entered into an agreement with Barr Engineering to conduct geochemical modeling, using PHREEQC, for a potential aquifer storage and recovery (ASR) pilot project in the Spiritwood Aquifer east of Jamestown, ND, using water from the James River. The purpose of this report is twofold: to summarize 1) the analytical results for twelve sediment samples collected by the SWC east of Jamestown in the Spiritwood Aquifer, and surrounding strata, and the PHREEQC chemical equilibrium results in the context of State analytical records for the James River and the Spiritwood Aquifer; and 2) to predict which parameters may exceed primary drinking water standards for James/Spiritwood ASR.

For the Spiritwood sediment samples, all of the following constituents were above reporting limits for all twelve samples: arsenic, barium, chromium, cobalt, copper, lead, nickel, radium 226, radium 228, strontium, vanadium, and zinc. The following constituents had at least one result less than its reporting limit: antimony, cadmium, gross alpha, gross beta, mercury, molybdenum, selenium, silver, thallium, and uranium. All the results for beryllium, germanium, and mercury were less than their reporting limits; however, all constituents, even those with all results below reporting limits, had at least one qualified result above zero. Therefore, all analyzed constituents were reportedly present in at least one of the Spiritwood sediment samples.

The following elements, based on PHREEQC equilibrium modeling in the context of State analytical records for the James River and Spiritwood Aquifer, were judged to have low risk of exceeding primary drinking water standards because of ASR: antimony, barium, beryllium, cadmium, chromium, copper, and fluoride. The following elements were judged to have medium risk of exceeding primary drinking water standards because of ASR: arsenic, lead, mercury, radium, selenium, and uranium. None of the elements were considered at high risk of exceeding primary drinking water standards because of ASR.

The best way to determine if ASR will cause water quality issues is to conduct a pilot field-scale research project in the Spiritwood Aquifer east of Jamestown, ND. Should the pilot project proceed, the information presented herein can be used to guide further investigations and to design the field experiments and their sampling and analysis plans.

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1 Introduction

In 2017, State Water Commission (SWC) personnel installed four observation wells and one test hole in the Spiritwood Energy Park, east of Jamestown, ND. From three sites, each a mile apart in the north-south direction, grab samples of the drill cuttings were collected every five feet from the ground surface to the bottom of each hole. Four sample intervals from each site were selected for matrix analyses to determine the elements present in the till aquitard (clay), Spiritwood Aquifer sediments (sand and gravel), and bedrock shales. Observation wells were then installed and water samples collected and analyzed for each site.

Also in 2017, the SWC entered into an agreement with Barr Engineering to conduct geochemical modeling for a potential aquifer storage and recovery (ASR) pilot project in the Spiritwood aquifer east of Jamestown using water from the James River. This report includes the results of the twelve sets of matrix analyses mentioned above, summary results of State analytical records for the James River and the Spiritwood Aquifer, and results of the geochemical modeling using PHREEQC (Parkhurst and Appelo, 1999).

PHREEQC is a USGS computer program that performs low-temperature aqueous geochemical calculations based on equilibrium chemistry. It was used to perform water quality simulations to provide insights into the water quality parameters that may exceed primary drinking water standards if James River water was stored into the Spiritwood Aquifer. The purpose of this report is twofold: 1) to summarize the sediment analytical results and the PHREEQC simulation results in the context of State analytical records for the James River and the Spiritwood Aquifer; and 2) to predict which parameters may exceed primary drinking water standards for James/Spiritwood ASR. The uncertainty of predictions made by equilibrium chemistry, because of unknown reaction rates, and because of limitations in State analytical records, make it necessary for results to be verified through field-scale pilot studies.

2 Methods

The majority of this report focuses on the PHREEQC simulations; however for context, they are compared to other analytical results as described below.

2.1 Spiritwood Aquifer Sediment Samples

Sediment samples were analyzed by Inter-Mountain Labs (IML) in Wyoming. A map and cross section showing the locations of the 12 samples are provided in Appendix A. Samples were analyzed for a suite of parameters including radionuclides, general parameters, metals (including trace elements), sulfur constituents, and carbon constituents.

2.2 James River and Spiritwood Aquifer Water Samples

State records for major water quality parameters, with the exception of orthophosphate, were compiled by Mr. David Hisz for the James River (location 13906306AB) and Spiritwood Aquifer wells in townships 136 - 142. With these data, Mr. Hisz also calculated summary statistics for minimum values, mean values, maximum values, numbers of samples, and above-detection percentages. Dissolved orthophosphate-P data for the James River at Jamestown were found in Galloway et al. (2012).

2.3 PHREEQC Simulations

Table 1 shows the maximum and minimum concentrations for major water quality parameters measured in the James River. They are the basis for the "maximum" and "minimum" James River solutions simulated by PHREEQC.

In Appendix B is a list of inorganic drinking water standards and candidate contaminants, and notes about which constituents were not able to be modeled by PHREEQC (alpha radiation, germanium, and tellurium). Table 2 shows the values for the constituents that were added to the maximum and minimum James River solutions for computer simulations. Generally, constituents with drinking water standards < 0.1 mg/L were amended at concentrations of 0.1 mg/L and other constituents were amended at their drinking water standards. Radium 226 and 228 were measured in pCi/g and the combined radium 226 and 228 primary

Table 1: Major Water Quality Parameters for the James River.

Parameter	Maximum Value (mg/L)	Minimum Value (mg/L)
Na	119	15
K	18	5.3
Mg	86.7	12
Ca	126	28.5
Mn	1.5	0
Fe	0.48	0
Nitrate	14	0.1
F	0.5	0.062
Cl	41	6
Silica	21	2.79
Bicarbonate	462	127
Sulfate	482	42
Orthophosphate-P	0.55	0

drinking water standard is in pCi/L; however, PHREEQC works with mass concentrations, so a concentration of 0.1 mg/L was also used for radium.

All simulations were done using the Lawrence Livermore National Laboratory dataset (llnl.dat). Of the eight dataset provided by the PHREEQC code, llnl.dat provides the greatest coverage of the parameters on Table 2.

Table 2: Amendment Concentrations to James River Solutions.

Parameter	Maximum Solution (mg/L)	Minimum Solution (mg/L)
Ag, silver	0.1	0.1
Al, aluminum	0.2	0.2
As, arsenic	0.1	0.1
Ba, barium	2	2
Be, beryllium	0.1	0.1
Cd, cadmium	0.1	0.1
Co, cobalt	0.1	0.1
Cr, chromium	0.1	0.1
Cu, copper	1.3	1.3
F, fluorine	No more added	No more added
Fe, iron	No more added	0.1
Hg, mercury	0.1	0.1
Mn, manganese	No more added	0.1
Mo, molybdenum	0.1	0.1
Ni, nickel	0.1	0.1
NO_3, nitrate	No more added	No more added
Pb, lead	0.1	0.1
Ra, radium	0.1	0.1
Sb, antimony	0.1	0.1
Se, selenium	0.1	0.1
SO_4, sulfate	No more added	No more added
Sr, strontium	0.1	0.1
Tl, thallium	0.1	0.1
U, uranium	0.1	0.1
V, vanadium	0.1	0.1
Zn, zinc	5.0	5.0

The maximum amended solution was simulated using five oxidation-reduction (redox) couples and five pH values (6, 7, 8, 9, 10). The redox couples were as follows:

1. O_2[O(0)] /H_2O [O(-2)]
2. NO_3 [N(5)]/N_2 [N(0)]
3. Cr(6)/Cr(3)
4. Fe(3)/Fe(2)
5. SO_4[S(6)]/HS [S(-2)]

The approximate location of each simulation is shown on the pe-pH diagram for pure water at 25^o C. (Figure 1). The five simulations for the oxygen redox couple appear above the O_2/H_2O boundary in Figure 1 because the simulations were done with water having dissolved solids and a temperature of 10^o C.

The minimum amended solution was simulated using the same five redox couples and two pH values (7 and 9).

In PHREEQC, the simulation for each solution, which was assumed to fully displace the native groundwater, was allowed to come to chemical equilibrium and the distribution of aqueous species and saturation indices (SIs) were checked to determine either the major soluble species for each parameter or the major non-silicate minerals that were supersaturated. PHREEQC calculates SIs as the logarithm of the activities of the mineral components in solution divided by the activities of the minerals components that would be in solution at equilibrium. Therefore, if SI = 0, the solution is at equilibrium. If SI < 0, the mineral is undersaturated and will tend to dissolve into solution. If SI > 0, the mineral is supersaturated and will tend to precipitate from solution.

Solution and precipitation rates vary from mineral to mineral. For example, quartz (SiO_2), is a silicate mineral that may take several years to come into equilibrium with a solution (Appelo and Postma, 2005). Therefore, I only considered non-silicate minerals that usually had only two or three components. Generally the list of minerals considered included oxides, hydroxides, carbonates, sulfates, and sulfides; some of these minerals may also take a long time to achieve chemical equilibrium.

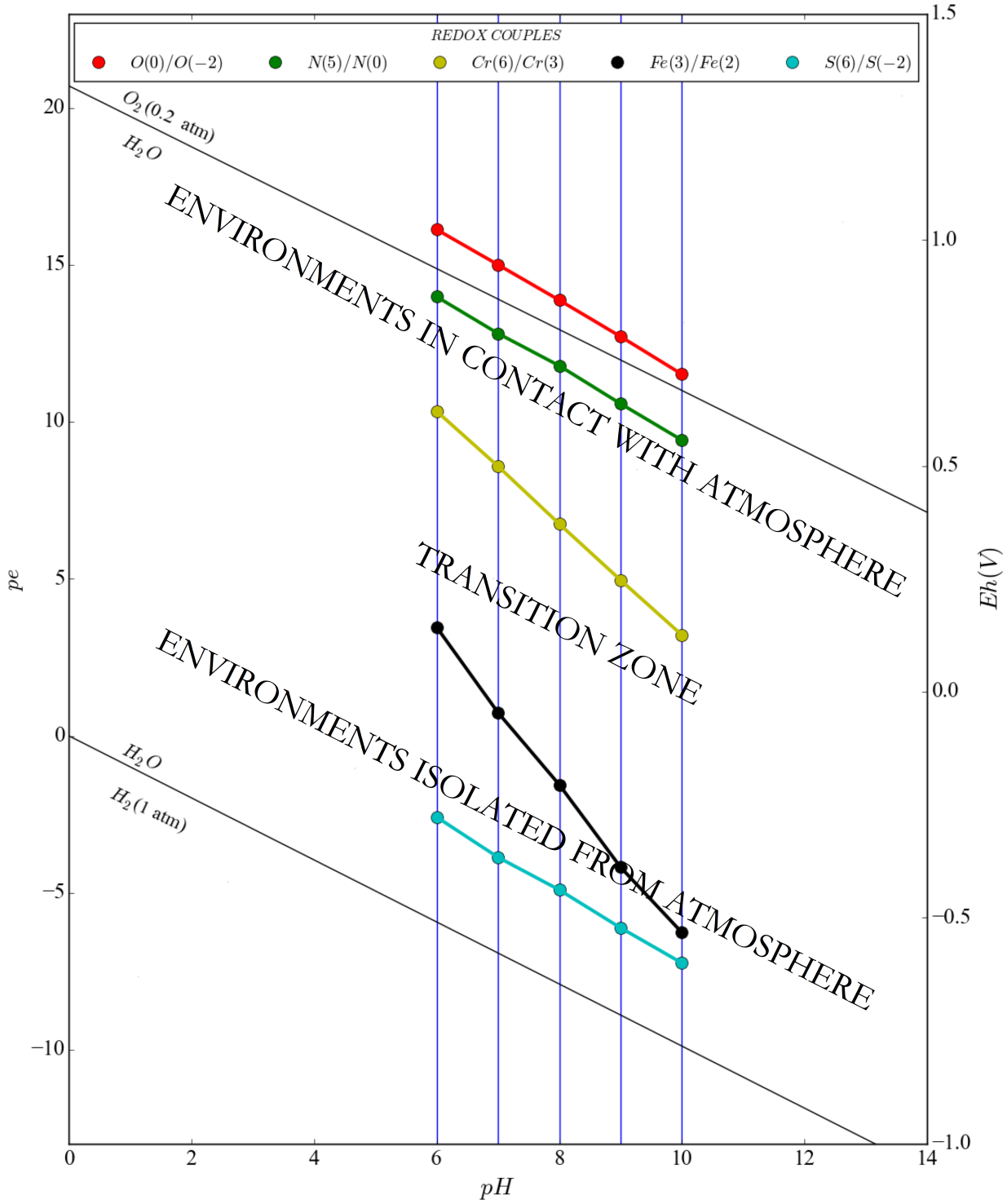

Figure 1: pe-pH Conditions Simulated in PHREEQC (adapted from Appelo and Postma, 2005).

3 Results

Below are summary results for the Spiritwood Aquifer sediment analyses, the PHREEQC simulations with the maximum amended James River solution in the context of State analytical water quality results for the James River and Spiritwood Aquifer, and the PHREEQC simulations with the minimum amended James River solutions.

3.1 Spiritwood Sediment Samples

The IML analytical results are in Appendix C. Each sample had a unique set of results; however in summary, the approximate order of concentrations from largest to smallest was calcium > total inorganic carbon > iron > magnesium > total organic carbon > aluminum > manganese > potassium > pyritic sulfur > sodium > silica. Oxides of iron, aluminum, and manganese act as sorbents for many trace elements. Total organic carbon and pyritic sulfur are reactive with oxygen and nitrate, with pyrite generally being the more reactive (Tesoriero and Puckett, 2011). Pyritic sulfur concentrations ranged from 0.03-0.23%. For reference, the in situ mesocosm site in the Elk Valley Aquifer had a concentration of 0.40% (Korom et al., 2005) and has one of the highest denitrification rates in the literature (Green et al., 2008; Korom et al., 2010). Oxidation of sulfide by oxygen and nitrate generates acid, which would be buffered by inorganic carbon (carbonate minerals) in the Spiritwood Aquifer. The approximate order of concentrations of trace elements for which all 12 results were above reporting limits was barium > strontium > zinc > vanadium > nickel > chromium > copper > cobalt > lead > arsenic. All 12 results for radium 226 and radium 228 were above the reporting limit, but results were measured in pCi/g, not in mg/Kg, so radium cannot be placed in the sequence above.

The other elements, thallium, selenium, molybdenum, antimony, cadmium, silver, mercury, uranium, gross alpha (in pCi/g), and gross beta (in pCi/g), had at least one result < its reporting limit and all the results for germanium, beryllium, and mercury were < their reporting limits. However, all constituents, even those with all results below reporting limits, had at least one qualified result above zero. Therefore, all analyzed constituents were present in at least one of the Spiritwood sediment samples.

3.2 Maximum Amended James River Solution

Results for each of the 25 conditions shown in Figure 1 are provided in Appendix D with discussion in Appendix E. PHREEQC results are compared, where possible, with State water quality records for the James River and Spiritwood wells. TI had minimal coverage by PHREEQC and is not discussed further. Results for elements with primary drinking water standards are summarized in Figure 2. Ba, Be, Cu, F, Hg, and Ra were all supersaturated for all simulations. Examples of supersaturated minerals are given in brackets. Arsenic (As) was undersaturated for all simulations. The remaining elements were supersaturated for only a portion of the simulations.

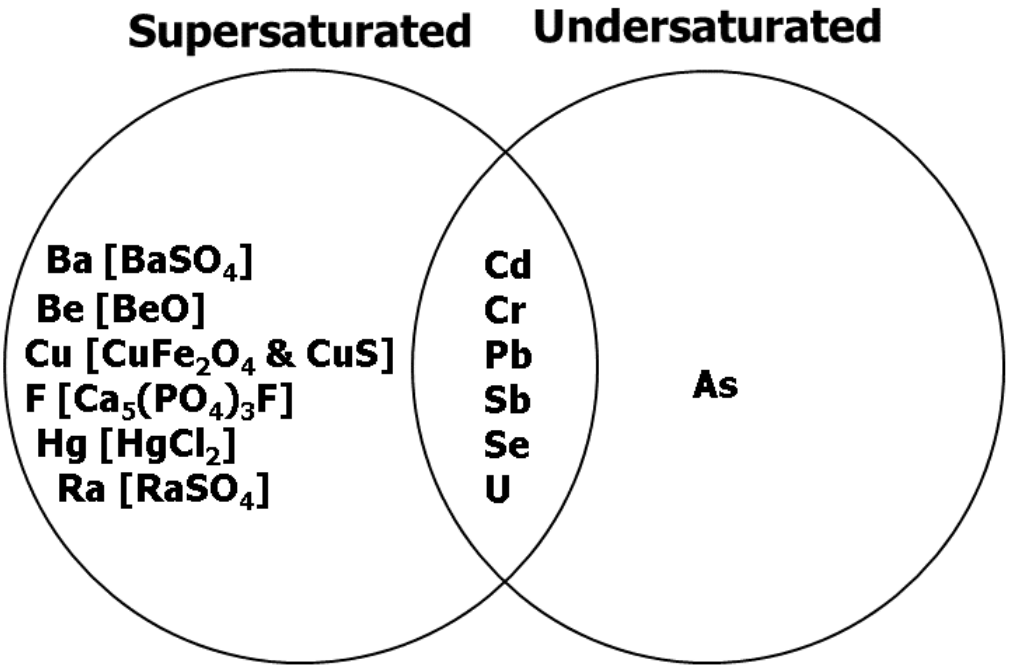

Figure 2: Saturation Conditions from PHREEQC Simulations

3.3 Minimum Amended James River Solution

The results for the simulations for pH = 7 and pH = 9 for the five redox couples are provided in Appendix F. The results were generally similar to those for the maximum amended James River solution with the following exceptions for elements having primary drinking water standards:

- Cd as Cd^{+2} was also soluble at pH = 7 for the oxygen and nitrogen couples.

- $CdCr_2O_4$ was supersaturated at pH = 7 for the chromium couple, but this result assumes that Cr is available in solution for precipitation.

- Cadmoselite [CdSe] and $CdCr_2O_4$ were supersaturated at pH = 7 for the iron couple, but this result assumes that Se and Cr, respectively, are available in solution for precipitation. Also for the iron couple, carnotite $[K_2(UO_2)_2(VO_4)_2]$ was supersaturated at pH = 7, but this result assumes that U and V are available in solution for precipitation.

- F was soluble for all simulations. The reason is that the minimum amended James River solution was modeled with orthophosphate = 0; therefore fluorapatite $[Ca_5(PO_4)_3F]$ was not supersaturated, as it was for the maximum amended James River solutions.

- Stibnite $[Sb_2S_3]$ was supersaturated at pH = 7 and pH = 9 for the sulfur couple.

In summary for similar pe and pH conditions for the minimum and maximum amended James River solutions, Cd was more soluble over a slightly wider pH range and Sb was less soluble over a slightly wider pH range in the minimum amended James River simulations. F was soluble throughout the range simulated in the minimum amended James River simulations. The total dissolved solids in the Spiritwood aquifer are higher than the James River; therefore, the maximum James River simulations are more likely to represent the conditions of a James/Spiritwood ASR project.

4 Discussion and Summary

The results indicated that some elements are soluble under oxidizing conditions, both for oxygen and nitrate. Many North Dakota outwash aquifers have sediments with detrital shale fragments. The pyritic S contents in the Spiritwood (Appendix C) are likely from shale. Upon oxidation by oxygen or nitrate, pyrite S is converted to sulfate and other trace elements may be released into solution. In the Netherlands, which also has aquifers having sediments with detrital shale fragments, the oxidation of pyrite during ASR caused increases in As, Co, Ni, and Zn. However only As concentrations reached the recovery well. Co, Ni, and Zn were believed to have coprecipitated with, or strongly absorbed to, iron oxides (Pyne, 2005, and references therein). Closer to home, the table in Appendix G shows statistically significant (α= 0.05) increases or decreases for several constituents during denitrification experiments (described by Korom et al, 2005) in several outwash aquifers in Minnesota and North Dakota. The Mann-Kendall method was used to determine significant trends. Some sites had both a control (C) test and a nitrate (N) test; the difference being that the control was amended with a solution having a similar ionic strength, but no nitrate. The results are summarized below:

- As only increased in the Larimore 2 test, but the increases were significant in both the control and nitrate tests. Therefore, the increase cannot be attributed to oxidation of pyrite by nitrate (or oxygen).

- Ba had several tests where it increased in the C and N tests, or only the C tests. The cause of the increases is unknown, but it was not caused by denitrification. However, all of the Ba concentrations remained about an order-of-magnitude less than the primary drinking water standard of 2.0 mg/L (Appendix A). In some of the N tests Ba decreased, likely because the increased sulfate caused by oxidation of pyrite led to increased precipitation of $BaSO_4$.

- Ni did not increase as a result of denitrification. Furthermore, Ni does not have a primary drinking water standard.

- Zn did not increase as a result of denitrification. Furthermore, Zn does not have a

primary drinking water standard.

- Se at the Larimore site (tests 3, 4, and 5) showed significant increases as a result of oxidation of pyrite by nitrate; however, only a single measurement was greater than the drinking water standard of 0.050 mg/L.

4.1 Summary of Results

Figure 3 summarizes the results for this investigation. Elements with green fonts are unlikely to exceed primary drinking water standards during James/Spiritwood ASR. Elements with yellow fonts probably will not exceed primary drinking water standards during James/Spiritwood ASR, but more uncertainty remains compared to the elements with green fonts. The basis for the classification for each element is given below:

- As was undersaturated for all PHREEQC simulations. Furthermore, As concentrations have exceeded the primary drinking water standard in both the James River and Spiritwood Aquifer. Oxidation of pyrite did not consistently increase As concentrations in denitrification tests. James/Spiritwood ASR is not expected to exacerbate As concentrations that are already in the James River and Spiritwood Aquifer. Therefore As is noted in yellow font in Figure 3.

- Ba was supersaturated for all PHREEQC simulations and concentrations in the James River and Spiritwood Aquifer are generally more than an order-of-magnitude less than the drinking water standard of 2.0 mg/L. Furthermore, aquifer denitrification tests showed increases of Ba were also generally more than an order-of-magnitude less than the primary drinking water standard. Therefore Ba is noted in green font in Figure 3.

- Be was supersaturated for all PHREEQC simulations. Furthermore, concentrations in the James River and Spiritwood Aquifer were consistently below reporting limits. While the primary drinking water standard of 0.004 mg/L and the reporting limits are close (<0.001 mg/L and <0.005 mg/L), it is not believed that Be will be an issue in James/Spiritwood ASR, so it is noted in green font in Figure 3.

- Cd was only soluble at pH = 6 in the PHREEQC simulations for the oxygen and nitrogen couples. Furthermore, concentrations in the James River and Spiritwood Aquifer were consistently below reporting limits. While the primary drinking water standard of 0.005 mg/L and the reporting limits are close (<0.001 mg/L and <0.005 mg/L), it is not believed that Cd will be an issue in James/Spiritwood ASR, so it is noted in green font in Figure 3.

- Cr was soluble in the PHREEQC simulations for the oxygen and nitrogen couples, which is presumably why about a fifth of the James River samples were above detection. Aquifers generally are less oxidized than rivers and the Spiritwood had no samples above detections. During James/Spiritwood ASR there may initially be Cr detections with the injection of oxidized river water; however, it is expected that concentrations will remain an order-of-magnitude below the drinking water standard of 0.1 mg/L, so Cr is noted in green font in Figure 3.

- Cu was saturated as $CuFe_2O_4$ above the sulfur couple or as covellite [CuS] at sulfate-reducing conditions (Figure 1). Over half of the James River samples were above detection and about a fifth of the Spiritwood samples; however, all samples were more than an order-of-magnitude less than the primary drinking water standard of 1.3 mg/L. Therefore, Cu is noted in green font in Figure 3.

- F was saturated as fluorapatite in the PHREEQC simulations as long as orthophosphate was in the water. James River and Spiritwood Aquifer samples usually have F concentrations; however, they are more than an order-of-magnitude less than the drinking water standard of 4.0 mg/L. Therefore, F is noted in green font in Figure 3.

- Hg was supersaturated in all PHREEQC simulations; however, concentrations were detected in most of the James River and Spiritwood Aquifer samples. James/Spiritwood ASR is not expected to exacerbate Hg concentrations that are already in the James River and Spiritwood Aquifer. Therefore Hg is noted in yellow font in Figure 3.

- Pb was supersaturated for some of the PHREEQC simulations. Pb concentrations were usually above detection for the James River and Spiritwood, but they were always less

than the primary drinking water standard of 0.015 mg/L. However, maximum concentrations were within an order-of-magnitude of the drinking water standard, so Pb is noted in yellow font in Figure 3.

- Ra was supersaturated for all of the PHREEQC simulations. However, there are no State measurements for Ra for either the James River or Spiritwood Aquifer. Therefore to be conservative, Ra is noted in yellow font in Figure 3.

- Sb was generally supersaturated for all of the PHREEQC simulations. Furthermore, concentrations in the James River and Spiritwood Aquifer were consistently below reporting limits. While the primary drinking water standard of 0.006 mg/L and the reporting limits are close (<0.001 mg/L and <0.005 mg/L), it is not believed that Sb will be an issue in James/Spiritwood ASR, so it is noted in green font in Figure 3.

- Se is soluble for the oxygen and nitrogen couples in the PHREEQC simulations. A majority of the James River and Spiritwood Aquifer samples were above detection and some samples were within an order-of-magnitude of the primary drinking water standard of 0.05 mg/L. Furthermore, Se concentrations increased for three of the Larimore denitrification tests (Appendix F). Therefore, Se is noted in yellow font in Figure 3.

- U is soluble for the oxygen, nitrogen, and chromium couples in the PHREEQC simulations. Furthermore, there are no State measurements for U for either the James River or Spiritwood Aquifer. Therefore, U is noted in yellow font in Figure 3.

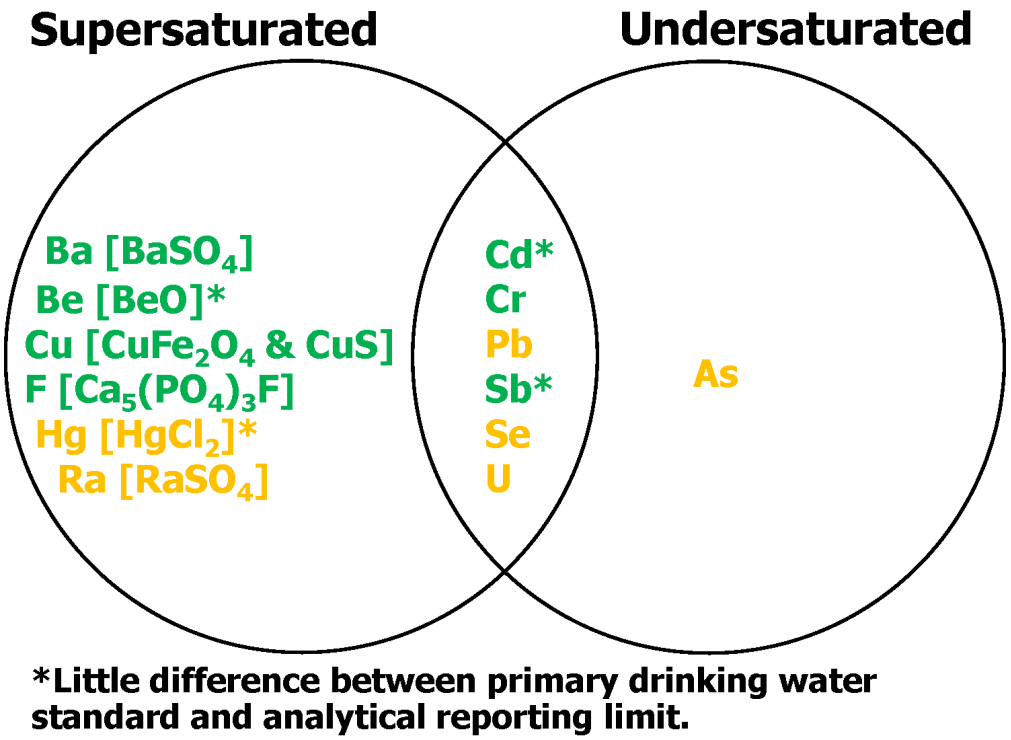

Figure 3: Risk of Exceeding Primary Drinking Water Standards (Green = Low, Yellow = Medium).

5 Further Research

This investigation into how ASR may lead to water quality problems, like all chemical equilibrium studies, has limitations. Chemical equilibrium can only reveal the saturation condition of an element in a solution. If an element is supersaturated, it will precipitate from solution; however, equilibrium chemistry indicates nothing about the rate of precipitation. Insights into kinetic issues for each element were gained by also considering State analytical data from the water sources being considered for ASR and from denitrification experiments in outwash aquifers in Minnesota and North Dakota. Based on these data, it is believed that James/Spiritwood ASR will not cause exceedances of primary drinking water standards. However, the best way to determine if ASR will cause water quality issues is to conduct a pilot field-scale research program in the Spiritwood Aquifer.

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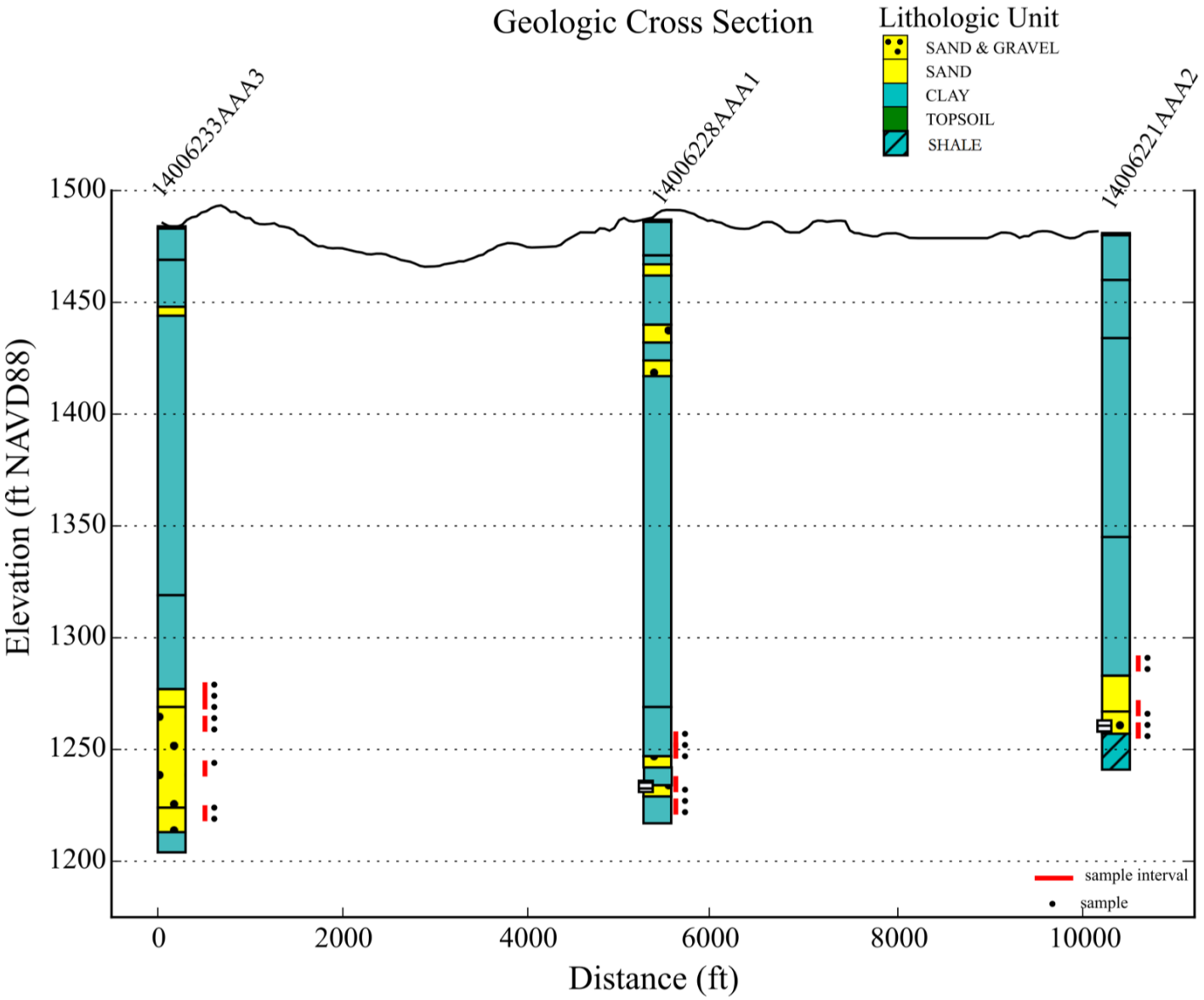
7 Appendices

7.1 Appendix A

Location map and Geologic Cross Section of Sample Sites


Spiritwood Energy Park Test Area for Observation & Test Well Locations
14006221AAA2
14006228AAA1
14006233AAA3
17
16
20
21
22
27
28
29
33
34
0
750
1500
2250
3000 feet


Geologic Cross Section
Lithologic Unit
SAND & GRAVEL
SAND
CLAY
TOPSOIL
SHALE
14006233AAA3
14006228AAA1
14006221AAA2
Elevation (ft NAVD88)
1500
1450
1400
1350
1300
1250
1200
0
2000
4000
6000
8000
10000
Distance (ft)
sample interval
sample

7.2 Appendix B

Inorganic Drinking Water Standards

Inorganic Drinking Water Standards

Primary Standards (mg/L)

- Antimony, Sb (0.006).
- Arsenic, As (0.010).
- Barium, Ba (2).
- Beryllium Be (0.004).
- Cadmium, Cd (0.005).
- Chromium, Cr (0.1).
- Copper, Cu (1.3). Also has a Secondary Standard
- Fluoride, F (4.0). Also has a Secondary Standard
- Lead, Pb (0.015 mg/L).
- Mercury, Hg (0.002).
- Nitrate-N, NO_3-N (10). Nitrate in denitrifying conditions will be reduced to nitrogen gas.
- Nitrite-N, NO_2-N (1). Nitrite in denitrifying conditions will be reduced to nitrogen gas.
- Selenium, Se (0.05).
- Thallium, Tl (0.002).

Radionuclides

- Alpha (15 pCi/L) Not modeled by PHREEQC.
- Radium, Ra 226 and 228 combined (5 pCi/L), PHREEQC does not differentiate between these two isotopes, so Ra was considered as a single element.
- Uranium, U (0.03).

Secondary Standards (mg/L)

- Aluminum, Al (0.05 to 0.2).
- Chloride, Cl (250). Not considered directly by PHREEQC simulations.
- Copper, Cu (1).
- Fluoride, F (2).
- Iron, Fe (0.3).
- Manganese, Mn (0.05).
- Silver, Ag (0.1).
- Sulfate, SO_4 (250). Sulfate is stable above sulfate-reducing conditions.
- TDS (500). Not considered directly by PHREEQC simulations.
- Zinc (5)

Contaminant Candidate List (CCL)

- Cobalt, Co (in EPA CCL 3 and CCL 4).
- Germanium, Ge (in EPA CCL 3 and CCL 4). Not in PHREEQC databases.
- Molybdenum, Mo (in EPA CCL 3 and CCL 4).
- Strontium, Sr (in EPA CCL 3).
- Tellurium, Te (in EPA CCL 3 and CCL 4). Analysis not available at IML. Furthermore, not in PHREEQC databases.
- Vanadium, V (in CCL 3 and CCL 4).

Other Constituent

- Nickel, Ni. (Listed in the Aquatic Life Criteria Table for National Recommended Water Quality Criteria. It was listed with an MCL of 0.1 mg/L on 7/17/1992, but it was remanded on 2/9/1995.)

7.3 Appendix C

Spiritwood Aquifer Sediment Analyses

Inter-Mountain Labs

Sheridan, WY and Gillette, WY

- CHAIN OF CUSTODY RECORD -

#WEB

All shaded fields must be completed.

This is a legal document; any misrepresentation may be construed as fraud.

Client Name	Project Identification	Sampler (Signature/Attestation of Authenticity)	Telephone #
North Dakota State Water Commission	ASR_Spiritwood Soil Maxtrix 2017	Micheal Ginsbach	701-328-2754

Report Address	Contact Name	Email	Phone
900 East Boulevard Ave Bismarck, ND 58505-0850	David Hisz	dhisz@nd.gov	701-328-3378

Invoice Address	Purchase Order #	Quote #
900 East Boulevard Ave Bismarck, ND 58505-0850	NDSWC_SOILS_17	1744

ITEM	LAB ID (Lab Use Only)	DATE SAMPLED	TIME SAMPLED	SAMPLE IDENTIFICATION	Matrix	# of Containers	* Metal Analysis	* Radiochemistry	* Soil Analysis	QuoteID 1744					REMARKS
1	S1710437-001	09/11/17		14006233AAA3_1	SL	1	x	x	x	x					See QuoteID: 1744
2	002	09/11/17		14006233AAA3_2	SL	1	x	x	x	x					See QuoteID: 1744
3	003	09/11/17		14006233AAA3_3	SL	1	x	x	x	x					See QuoteID: 1744
4	004	09/11/17		14006233AAA3_4	SL	1	x	x	x	x					See QuoteID: 1744
5	005	09/12/17		14006221AAA2_1	SL	1	x	x	x	x					See QuoteID: 1744
6	006	09/12/17		14006221AAA2_2	SL	1	x	x	x	x					See QuoteID: 1744
7	007	09/12/17		14006221AAA2_3	SL	1	x	x	x	x					See QuoteID: 1744
8	008	09/12/17		14006221AAA2_4	SL	1	x	x	x	x					See QuoteID: 1744
9	009	09/13/17		14006228AAA1_1	SL	1	x	x	x	x					See QuoteID: 1744
10	010	09/13/17		14006228AAA1_2	SL	1	x	x	x	x					See QuoteID: 1744
11	011	09/13/17		14006228AAA1_3	SL	1	x	x	x	x					See QuoteID: 1744
12	012	09/13/17		14006228AAA1_4	SL	1	x	x	x	x					See QuoteID: 1744
13															
14															

LAB COMMENTS	Relinquished By (Signature/Printed)	DATE	TIME	Received By (Signature/Printed)	DATE	TIME
	David Hisz	10/25/17	10:00am	Kathy Boyd	10.27.17	11:49

SHIPPING INFO

- ☒ UPS
- ☒ FedEx
- ☐ USPS
- ☐ Hand Carried
- ☐ Other

MATRIX CODES

Water	WT
Soil	SL
Solid	SD
Filter	FT
Other	OT

TURN AROUND TIMES

Check desired service

- ☐ Standard turnaround
- ☐ **RUSH - 5 Working Days**
- ☐ **URGENT - < 2 Working Days**

Rush & Urgent Surcharges will be applied

COMPLIANCE INFORMATION

Compliance Monitoring ?	Y / (N)
Program (SDWA, NPDES,...)	NA
PWSID / Permit #	
Chlorinated?	NA (Y / N)
Sample Disposal:	Lab X Client

ADDITIONAL REMARKS

Please use Quote# 1744 for analyses

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

Your Environmental Monitoring Partner

Date: 1/5/2018

CLIENT: North Dakota State Water Commission
Project: ASR_Spiritwood Soil Matrix 2017
Lab Order: S1710437

CASE NARRATIVE

Report ID: S1710437002
(Replaces S1710437001)

Samples 14006221AAA2_1, 14006221AAA2_2, 14006221AAA2_3, 14006221AAA2_4, 14006228AAA1_1, 14006228AAA1_2, 14006228AAA1_3, 14006228AAA1_4, 14006233AAA3_1, 14006233AAA3_2, 14006233AAA3_3 and 14006233AAA3_4 were received on October 27, 2017.

All samples were received and analyzed within the EPA recommended holding times, except those noted below in this case narrative. Samples were analyzed using the methods outlined in the following references:

"Standard Methods For The Examination of Water and Wastewater", approved method versions
Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, SW-846, 3rd Edition
40 CFR Parts 136 and 141
40 CFR Part 50, Appendices B, J, L, and O
Methods indicated in the Methods Update Rule published in the Federal Register Friday, May 18, 2012
ASTM approved and recognized standards

All Quality Control parameters met the acceptance criteria defined by EPA and Inter-Mountain Laboratories except as indicated in this case narrative.

Report S1710437002 replaces report S1710437001. Client requested results below the reporting limit and additional analysis.

Reviewed by:
Wade Nieuwsma, Assistant Laboratory Manager

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

Your Environmental Monitoring Partner

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-001
ClientSample ID: 14006233AAA3_1
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	8.8	pCi/g	U	10.0	SM 7110	12/29/2017 2219	MB
Gross Alpha Precision (±)	1.2	pCi/g	U		SM 7110	12/29/2017 2219	MB
Gross Beta	9.9	pCi/g	U	10.0	SM 7110	12/29/2017 2219	MB
Gross Beta Precision (±)	1.6	pCi/g	U		SM 7110	12/29/2017 2219	MB
Radium 226	0.78	pCi/g		0.200	EPA 901.1 Mod.	12/13/2017 1910	WN
Radium 226 Precision (±)	0.2	pCi/g			EPA 901.1 Mod.	12/13/2017 1910	WN
Radium 228	0.76	pCi/g		0.200	EPA 901.1 Mod.	12/13/2017 1910	WN
Radium 228 Precision (±)	0.3	pCi/g			EPA 901.1 Mod.	12/13/2017 1910	WN
General Parameters - Soil							
Percent Solids	71.6	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	126	ppm		1.00	EPA 300.0	01/12/2018 1520	AB
Fluoride	0.473	ppm		0.100	EPA 300.0	01/12/2018 1520	AB
Total Inorganic Carbon	1.50	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.355	%		0.0100	EPA600/2-78-054	11/27/2017 1147	KS
Neutralization Potential	125	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-001
ClientSample ID: 14006233AAA3_1
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	7250	mg/Kg		1.50	EPA 6010C	11/20/2017 1239	DG
Antimony	2.61	mg/Kg		1.70	EPA 6010C	11/20/2017 1239	DG
Arsenic	8.35	mg/Kg		0.600	EPA 6010C	11/20/2017 1239	DG
Barium	2200	mg/Kg		1.00	EPA 6010C	11/20/2017 1239	DG
Beryllium	0.510	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1239	DG
Cadmium	0.474	mg/Kg		0.200	EPA 6010C	11/20/2017 1239	DG
Calcium	30100	mg/Kg		5.00	EPA 6010C	11/20/2017 1239	DG
Chromium	13.9	mg/Kg		0.200	EPA 6010C	11/20/2017 1239	DG
Cobalt	7.81	mg/Kg		0.200	EPA 6010C	11/20/2017 1239	DG
Copper	12.2	mg/Kg		0.500	EPA 6010C	11/20/2017 1239	DG
Germanium	2.38	mg/Kg	U	7.00	EPA 6010C	11/20/2017 1239	DG
Iron	16000	mg/Kg		2.00	EPA 6010C	11/20/2017 1241	DG
Lead	9.39	mg/Kg		2.40	EPA 6010C	11/20/2017 1239	DG
Magnesium	8930	mg/Kg		10.0	EPA 6010C	11/20/2017 1239	DG
Manganese	538	mg/Kg		0.100	EPA 6010C	11/20/2017 1239	DG
Mercury	0.0178	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	2.18	mg/Kg		0.600	EPA 6010C	11/20/2017 1239	DG
Nickel	22.2	mg/Kg		0.200	EPA 6010C	11/20/2017 1239	DG
Potassium	2120	mg/Kg		10.0	EPA 6010C	11/20/2017 1239	DG
Selenium	0.643	mg/Kg	U	1.30	EPA 6010C	11/20/2017 1239	DG
Silicon	396	mg/Kg		4.00	EPA 6010C	11/20/2017 1239	DG
Silver	0.162	mg/Kg	U	0.400	EPA 6010C	11/20/2017 1239	DG
Sodium	2340	mg/Kg		73.0	EPA 6010C	11/20/2017 1239	DG
Strontium	82.8	mg/Kg		0.200	EPA 6010C	11/20/2017 1239	DG
Thallium	0.49	mg/Kg	U	4.30	EPA 6010C	11/20/2017 1239	DG
Uranium	0.49	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1239	DG
Vanadium	27.5	mg/Kg		0.200	EPA 6010C	11/20/2017 1239	DG
Zinc	53.5	mg/Kg		0.600	EPA 6010C	11/20/2017 1239	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-001
ClientSample ID: 14006233AAA3_1
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	0.152	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.175	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	0.0282	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	4.41	%		0.100	ASA9 29-2.2	11/27/2017 1147	KS
Total Organic Carbon	2.91	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-002
ClientSample ID: 14006233AAA3_2
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	4.1	pCi/g	U	10.0	SM 7110	12/29/2017 2219	MB
Gross Alpha Precision (±)	0.9	pCi/g	U		SM 7110	12/29/2017 2219	MB
Gross Beta	5.1	pCi/g	U	10.0	SM 7110	12/29/2017 2219	MB
Gross Beta Precision (±)	1.5	pCi/g	U		SM 7110	12/29/2017 2219	MB
Radium 226	0.43	pCi/g		0.200	EPA 901.1 Mod.	12/13/2017 2027	WN
Radium 226 Precision (±)	0.2	pCi/g			EPA 901.1 Mod.	12/13/2017 2027	WN
Radium 228	0.48	pCi/g		0.200	EPA 901.1 Mod.	12/13/2017 2027	WN
Radium 228 Precision (±)	0.2	pCi/g			EPA 901.1 Mod.	12/13/2017 2027	WN
General Parameters - Soil							
Percent Solids	77.4	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	62.9	ppm		1.00	EPA 300.0	01/12/2018 1534	AB
Fluoride	0.441	ppm		0.100	EPA 300.0	01/12/2018 1534	AB
Total Inorganic Carbon	2.30	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.165	%		0.0100	EPA600/2-78-054	11/27/2017 1152	KS
Neutralization Potential	186	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-002
ClientSample ID: 14006233AAA3_2
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	4120	mg/Kg		1.50	EPA 6010C	11/20/2017 1243	DG
Antimony	1.57	mg/Kg	U	1.70	EPA 6010C	11/20/2017 1243	DG
Arsenic	9.71	mg/Kg		0.600	EPA 6010C	11/20/2017 1243	DG
Barium	799	mg/Kg		1.00	EPA 6010C	11/20/2017 1243	DG
Beryllium	0.315	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1243	DG
Cadmium	0.620	mg/Kg		0.200	EPA 6010C	11/20/2017 1243	DG
Calcium	50900	mg/Kg		5.00	EPA 6010C	11/20/2017 1243	DG
Chromium	29.2	mg/Kg		0.200	EPA 6010C	11/20/2017 1243	DG
Cobalt	9.01	mg/Kg		0.200	EPA 6010C	11/20/2017 1243	DG
Copper	8.20	mg/Kg		0.500	EPA 6010C	11/20/2017 1243	DG
Germanium	1.85	mg/Kg	U	7.00	EPA 6010C	11/20/2017 1243	DG
Iron	21600	mg/Kg		2.00	EPA 6010C	11/20/2017 1245	DG
Lead	7.23	mg/Kg		2.40	EPA 6010C	11/20/2017 1243	DG
Magnesium	7140	mg/Kg		10.0	EPA 6010C	11/20/2017 1243	DG
Manganese	2900	mg/Kg		0.100	EPA 6010C	11/20/2017 1243	DG
Mercury	0.0144	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	2.61	mg/Kg		0.600	EPA 6010C	11/20/2017 1243	DG
Nickel	26.0	mg/Kg		0.200	EPA 6010C	11/20/2017 1243	DG
Potassium	1390	mg/Kg		10.0	EPA 6010C	11/20/2017 1243	DG
Selenium	3.17	mg/Kg		1.30	EPA 6010C	11/20/2017 1243	DG
Silicon	336	mg/Kg		4.00	EPA 6010C	11/20/2017 1243	DG
Silver	0.280	mg/Kg	U	0.400	EPA 6010C	11/20/2017 1243	DG
Sodium	1120	mg/Kg		73.0	EPA 6010C	11/20/2017 1243	DG
Strontium	74.3	mg/Kg		0.200	EPA 6010C	11/20/2017 1243	DG
Thallium	3.71	mg/Kg	U	4.30	EPA 6010C	11/20/2017 1243	DG
Uranium	1.92	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1243	DG
Vanadium	25.3	mg/Kg		0.200	EPA 6010C	11/20/2017 1243	DG
Zinc	43.4	mg/Kg		0.600	EPA 6010C	11/20/2017 1243	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-002
ClientSample ID: 14006233AAA3_2
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.149	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	0.0198	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	5.65	%		0.100	ASA9 29-2.2	11/27/2017 1152	KS
Total Organic Carbon	3.43	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-003
ClientSample ID: 14006233AAA3_3
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	3.6	pCi/g	U	10.0	SM 7110	12/29/2017 2219	MB
Gross Alpha Precision (±)	0.9	pCi/g	U		SM 7110	12/29/2017 2219	MB
Gross Beta	3.9	pCi/g	U	10.0	SM 7110	12/29/2017 2219	MB
Gross Beta Precision (±)	1.5	pCi/g	U		SM 7110	12/29/2017 2219	MB
Radium 226	0.31	pCi/g		0.200	EPA 901.1 Mod.	12/13/2017 2145	WN
Radium 226 Precision (±)	0.1	pCi/g			EPA 901.1 Mod.	12/13/2017 2145	WN
Radium 228	0.30	pCi/g		0.200	EPA 901.1 Mod.	12/13/2017 2145	WN
Radium 228 Precision (±)	0.2	pCi/g			EPA 901.1 Mod.	12/13/2017 2145	WN
General Parameters - Soil							
Percent Solids	87.3	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	37.3	ppm		1.00	EPA 300.0	01/12/2018 1548	AB
Fluoride	0.480	ppm		0.100	EPA 300.0	01/12/2018 1548	AB
Total Inorganic Carbon	3.00	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.0601	%		0.0100	EPA600/2-78-054	11/27/2017 1155	KS
Neutralization Potential	253	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-003
ClientSample ID: 14006233AAA3_3
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	2390	mg/Kg		1.50	EPA 6010C	11/20/2017 1247	DG
Antimony	2.88	mg/Kg		1.70	EPA 6010C	11/20/2017 1247	DG
Arsenic	3.94	mg/Kg		0.600	EPA 6010C	11/20/2017 1247	DG
Barium	316	mg/Kg		1.00	EPA 6010C	11/20/2017 1247	DG
Beryllium	0.166	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1247	DG
Cadmium	0.336	mg/Kg		0.200	EPA 6010C	11/20/2017 1247	DG
Calcium	69500	mg/Kg		5.00	EPA 6010C	11/20/2017 1247	DG
Chromium	11.2	mg/Kg		0.200	EPA 6010C	11/20/2017 1247	DG
Cobalt	6.27	mg/Kg		0.200	EPA 6010C	11/20/2017 1247	DG
Copper	6.14	mg/Kg		0.500	EPA 6010C	11/20/2017 1247	DG
Germanium	1.57	mg/Kg	U	7.00	EPA 6010C	11/20/2017 1247	DG
Iron	13900	mg/Kg		2.00	EPA 6010C	11/20/2017 1252	DG
Lead	4.81	mg/Kg		2.40	EPA 6010C	11/20/2017 1247	DG
Magnesium	8180	mg/Kg		10.0	EPA 6010C	11/20/2017 1247	DG
Manganese	3080	mg/Kg		0.100	EPA 6010C	11/20/2017 1247	DG
Mercury	0.00900	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	1.94	mg/Kg		0.600	EPA 6010C	11/20/2017 1247	DG
Nickel	18.2	mg/Kg		0.200	EPA 6010C	11/20/2017 1247	DG
Potassium	926	mg/Kg		10.0	EPA 6010C	11/20/2017 1247	DG
Selenium	2.59	mg/Kg		1.30	EPA 6010C	11/20/2017 1247	DG
Silicon	271	mg/Kg		4.00	EPA 6010C	11/20/2017 1247	DG
Silver	0.345	mg/Kg	U	0.400	EPA 6010C	11/20/2017 1247	DG
Sodium	534	mg/Kg		73.0	EPA 6010C	11/20/2017 1247	DG
Strontium	67.6	mg/Kg		0.200	EPA 6010C	11/20/2017 1247	DG
Thallium	4.24	mg/Kg	U	4.30	EPA 6010C	11/20/2017 1247	DG
Uranium	1.60	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1247	DG
Vanadium	15.2	mg/Kg		0.200	EPA 6010C	11/20/2017 1247	DG
Zinc	29.2	mg/Kg		0.600	EPA 6010C	11/20/2017 1247	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-003
ClientSample ID: 14006233AAA3_3
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.0610	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	4.18	%		0.100	ASA9 29-2.2	11/27/2017 1155	KS
Total Organic Carbon	1.15	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-004
ClientSample ID: 14006233AAA3_4
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	4.7	pCi/g	U	10.0	SM 7110	12/29/2017 2219	MB
Gross Alpha Precision (±)	1.0	pCi/g	U		SM 7110	12/29/2017 2219	MB
Gross Beta	6.5	pCi/g	U	10.0	SM 7110	12/29/2017 2219	MB
Gross Beta Precision (±)	1.5	pCi/g	U		SM 7110	12/29/2017 2219	MB
Radium 226	0.53	pCi/g		0.200	EPA 901.1 Mod.	12/13/2017 2303	WN
Radium 226 Precision (±)	0.1	pCi/g			EPA 901.1 Mod.	12/13/2017 2303	WN
Radium 228	0.20	pCi/g		0.200	EPA 901.1 Mod.	12/13/2017 2303	WN
Radium 228 Precision (±)	0.3	pCi/g			EPA 901.1 Mod.	12/13/2017 2303	WN
General Parameters - Soil							
Percent Solids	82.3	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	30.7	ppm		1.00	EPA 300.0	01/12/2018 1602	AB
Fluoride	0.575	ppm		0.100	EPA 300.0	01/12/2018 1602	AB
Total Inorganic Carbon	2.40	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.175	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Neutralization Potential	196	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-004
ClientSample ID: 14006233AAA3_4
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	4350	mg/Kg		1.50	EPA 6010C	11/20/2017 1256	DG
Antimony	2.04	mg/Kg		1.70	EPA 6010C	11/20/2017 1256	DG
Arsenic	6.28	mg/Kg		0.600	EPA 6010C	11/20/2017 1256	DG
Barium	167	mg/Kg		1.00	EPA 6010C	11/20/2017 1256	DG
Beryllium	0.259	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1256	DG
Cadmium	0.349	mg/Kg		0.200	EPA 6010C	11/20/2017 1256	DG
Calcium	45200	mg/Kg		5.00	EPA 6010C	11/20/2017 1256	DG
Chromium	12.2	mg/Kg		0.200	EPA 6010C	11/20/2017 1256	DG
Cobalt	6.43	mg/Kg		0.200	EPA 6010C	11/20/2017 1256	DG
Copper	7.90	mg/Kg		0.500	EPA 6010C	11/20/2017 1256	DG
Germanium	0.649	mg/Kg	U	7.00	EPA 6010C	11/21/2017 1403	DG
Iron	21500	mg/Kg		2.00	EPA 6010C	11/20/2017 1312	DG
Lead	5.58	mg/Kg		2.40	EPA 6010C	11/20/2017 1256	DG
Magnesium	8480	mg/Kg		10.0	EPA 6010C	11/20/2017 1256	DG
Manganese	2740	mg/Kg		0.100	EPA 6010C	11/20/2017 1256	DG
Mercury	0.0107	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	2.57	mg/Kg		0.600	EPA 6010C	11/20/2017 1256	DG
Nickel	16.1	mg/Kg		0.200	EPA 6010C	11/20/2017 1256	DG
Potassium	1610	mg/Kg		10.0	EPA 6010C	11/20/2017 1256	DG
Selenium	3.06	mg/Kg		1.30	EPA 6010C	11/20/2017 1256	DG
Silicon	297	mg/Kg		4.00	EPA 6010C	11/20/2017 1256	DG
Silver	0.360	mg/Kg	U	0.400	EPA 6010C	11/20/2017 1256	DG
Sodium	558	mg/Kg		73.0	EPA 6010C	11/20/2017 1256	DG
Strontium	61.9	mg/Kg		0.200	EPA 6010C	11/20/2017 1256	DG
Thallium	3.69	mg/Kg	U	4.30	EPA 6010C	11/20/2017 1256	DG
Uranium	0.55	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1256	DG
Vanadium	23.2	mg/Kg		0.200	EPA 6010C	11/20/2017 1256	DG
Zinc	38.9	mg/Kg		0.600	EPA 6010C	11/20/2017 1256	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-004
ClientSample ID: 14006233AAA3_4
COC:

WorkOrder: S1710437
CollectionDate: 9/11/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	0.0433	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.132	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	3.19	%		0.100	ASA9 29-2.2	11/27/2017 1159	KS
Total Organic Carbon	0.835	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-005
ClientSample ID: 14006221AAA2_1
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	4.3	pCi/g	U	10.0	SM 7110	12/29/2017 2219	MB
Gross Alpha Precision (±)	0.9	pCi/g	U		SM 7110	12/29/2017 2219	MB
Gross Beta	9.0	pCi/g	U	10.0	SM 7110	12/29/2017 2219	MB
Gross Beta Precision (±)	1.6	pCi/g	U		SM 7110	12/29/2017 2219	MB
Radium 226	0.56	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 020	WN
Radium 226 Precision (±)	0.1	pCi/g			EPA 901.1 Mod.	12/14/2017 020	WN
Radium 228	0.62	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 020	WN
Radium 228 Precision (±)	0.2	pCi/g			EPA 901.1 Mod.	12/14/2017 020	WN
General Parameters - Soil							
Percent Solids	76.7	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	29.7	ppm		1.00	EPA 300.0	01/12/2018 1616	AB
Fluoride	0.732	ppm		0.100	EPA 300.0	01/12/2018 1616	AB
Total Inorganic Carbon	1.00	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.154	%		0.0100	EPA600/2-78-054	11/27/2017 1203	KS
Neutralization Potential	80.8	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-005
ClientSample ID: 14006221AAA2_1
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	8360	mg/Kg		1.50	EPA 6010C	11/20/2017 1323	DG
Antimony	2.20	mg/Kg		1.70	EPA 6010C	11/20/2017 1323	DG
Arsenic	3.87	mg/Kg		0.600	EPA 6010C	11/20/2017 1323	DG
Barium	185	mg/Kg		1.00	EPA 6010C	11/20/2017 1323	DG
Beryllium	0.485	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1323	DG
Cadmium	0.303	mg/Kg		0.200	EPA 6010C	11/20/2017 1323	DG
Calcium	19000	mg/Kg		5.00	EPA 6010C	11/20/2017 1323	DG
Chromium	15.3	mg/Kg		0.200	EPA 6010C	11/20/2017 1323	DG
Cobalt	6.90	mg/Kg		0.200	EPA 6010C	11/20/2017 1323	DG
Copper	11.0	mg/Kg		0.500	EPA 6010C	11/20/2017 1323	DG
Germanium	1.17	mg/Kg	U	7.00	EPA 6010C	11/20/2017 1323	DG
Iron	17200	mg/Kg		2.00	EPA 6010C	11/20/2017 1325	DG
Lead	8.35	mg/Kg		2.40	EPA 6010C	11/20/2017 1323	DG
Magnesium	6190	mg/Kg		10.0	EPA 6010C	11/20/2017 1323	DG
Manganese	465	mg/Kg		0.100	EPA 6010C	11/20/2017 1323	DG
Mercury	0.0167	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	2.32	mg/Kg		0.600	EPA 6010C	11/20/2017 1323	DG
Nickel	16.3	mg/Kg		0.200	EPA 6010C	11/20/2017 1323	DG
Potassium	2190	mg/Kg		10.0	EPA 6010C	11/20/2017 1323	DG
Selenium	0.745	mg/Kg	U	1.30	EPA 6010C	11/20/2017 1323	DG
Silicon	343	mg/Kg		4.00	EPA 6010C	11/20/2017 1323	DG
Silver	ND	mg/Kg		0.400	EPA 6010C	11/20/2017 1323	DG
Sodium	869	mg/Kg		73.0	EPA 6010C	11/20/2017 1323	DG
Strontium	48.1	mg/Kg		0.200	EPA 6010C	11/20/2017 1323	DG
Thallium	0.30	mg/Kg	U	4.30	EPA 6010C	11/20/2017 1323	DG
Uranium	-0.59	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1323	DG
Vanadium	26.9	mg/Kg		0.200	EPA 6010C	11/20/2017 1323	DG
Zinc	50.9	mg/Kg		0.600	EPA 6010C	11/20/2017 1323	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-005
ClientSample ID: 14006221AAA2_1
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	0.0541	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.0996	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	1.37	%		0.100	ASA9 29-2.2	11/27/2017 1203	KS
Total Organic Carbon	0.403	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-006
ClientSample ID: 14006221AAA2_2
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	15.3	pCi/g		10.0	SM 7110	12/30/2017 1210	MB
Gross Alpha Precision (±)	1.5	pCi/g			SM 7110	12/30/2017 1210	MB
Gross Beta	10.5	pCi/g		10.0	SM 7110	12/30/2017 1210	MB
Gross Beta Precision (±)	1.6	pCi/g			SM 7110	12/30/2017 1210	MB
Radium 226	0.30	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 137	WN
Radium 226 Precision (±)	0.1	pCi/g			EPA 901.1 Mod.	12/14/2017 137	WN
Radium 228	0.42	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 137	WN
Radium 228 Precision (±)	0.2	pCi/g			EPA 901.1 Mod.	12/14/2017 137	WN
General Parameters - Soil							
Percent Solids	83.5	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	43.2	ppm		1.00	EPA 300.0	01/12/2018 1630	AB
Fluoride	0.692	ppm		0.100	EPA 300.0	01/12/2018 1630	AB
Total Inorganic Carbon	2.70	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.0413	%		0.0100	EPA600/2-78-054	11/27/2017 1206	KS
Neutralization Potential	224	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-006
ClientSample ID: 14006221AAA2_2
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	3690	mg/Kg		1.50	EPA 6010C	11/20/2017 1327	DG
Antimony	1.91	mg/Kg		1.70	EPA 6010C	11/20/2017 1327	DG
Arsenic	3.68	mg/Kg		0.600	EPA 6010C	11/20/2017 1327	DG
Barium	122	mg/Kg		1.00	EPA 6010C	11/20/2017 1327	DG
Beryllium	0.195	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1327	DG
Cadmium	0.315	mg/Kg		0.200	EPA 6010C	11/20/2017 1327	DG
Calcium	60700	mg/Kg		5.00	EPA 6010C	11/20/2017 1327	DG
Chromium	10.9	mg/Kg		0.200	EPA 6010C	11/20/2017 1327	DG
Cobalt	5.74	mg/Kg		0.200	EPA 6010C	11/20/2017 1327	DG
Copper	7.00	mg/Kg		0.500	EPA 6010C	11/20/2017 1327	DG
Germanium	3.00	mg/Kg	U	7.00	EPA 6010C	11/20/2017 1327	DG
Iron	15300	mg/Kg		2.00	EPA 6010C	11/20/2017 1329	DG
Lead	4.13	mg/Kg		2.40	EPA 6010C	11/20/2017 1327	DG
Magnesium	8170	mg/Kg		10.0	EPA 6010C	11/20/2017 1327	DG
Manganese	1670	mg/Kg		0.100	EPA 6010C	11/20/2017 1327	DG
Mercury	0.0011	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	2.32	mg/Kg		0.600	EPA 6010C	11/20/2017 1327	DG
Nickel	13.1	mg/Kg		0.200	EPA 6010C	11/20/2017 1327	DG
Potassium	1180	mg/Kg		10.0	EPA 6010C	11/20/2017 1327	DG
Selenium	2.43	mg/Kg		1.30	EPA 6010C	11/20/2017 1327	DG
Silicon	352	mg/Kg		4.00	EPA 6010C	11/20/2017 1327	DG
Silver	0.199	mg/Kg	U	0.400	EPA 6010C	11/20/2017 1327	DG
Sodium	495	mg/Kg		73.0	EPA 6010C	11/20/2017 1327	DG
Strontium	59.2	mg/Kg		0.200	EPA 6010C	11/20/2017 1327	DG
Thallium	2.08	mg/Kg	U	4.30	EPA 6010C	11/20/2017 1327	DG
Uranium	-1.6	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1327	DG
Vanadium	15.7	mg/Kg		0.200	EPA 6010C	11/20/2017 1327	DG
Zinc	29.5	mg/Kg		0.600	EPA 6010C	11/20/2017 1327	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-006
ClientSample ID: 14006221AAA2_2
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	0.0116	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.0296	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	2.92	%		0.100	ASA9 29-2.2	11/27/2017 1206	KS
Total Organic Carbon	0.237	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-007
ClientSample ID: 14006221AAA2_3
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	8.5	pCi/g	U	10.0	SM 7110	12/30/2017 1210	MB
Gross Alpha Precision (±)	1.2	pCi/g	U		SM 7110	12/30/2017 1210	MB
Gross Beta	12.8	pCi/g		10.0	SM 7110	12/30/2017 1210	MB
Gross Beta Precision (±)	1.6	pCi/g			SM 7110	12/30/2017 1210	MB
Radium 226	0.58	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 255	WN
Radium 226 Precision (±)	0.1	pCi/g			EPA 901.1 Mod.	12/14/2017 255	WN
Radium 228	0.47	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 255	WN
Radium 228 Precision (±)	0.2	pCi/g			EPA 901.1 Mod.	12/14/2017 255	WN
General Parameters - Soil							
Percent Solids	84.8	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	34.8	ppm		1.00	EPA 300.0	01/12/2018 1643	AB
Fluoride	0.869	ppm		0.100	EPA 300.0	01/12/2018 1643	AB
Total Inorganic Carbon	2.70	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.0418	%		0.0100	EPA600/2-78-054	11/27/2017 1210	KS
Neutralization Potential	228	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-007
ClientSample ID: 14006221AAA2_3
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	3960	mg/Kg		1.50	EPA 6010C	11/20/2017 1332	DG
Antimony	2.07	mg/Kg		1.70	EPA 6010C	11/20/2017 1332	DG
Arsenic	3.00	mg/Kg		0.600	EPA 6010C	11/20/2017 1332	DG
Barium	170	mg/Kg		1.00	EPA 6010C	11/20/2017 1332	DG
Beryllium	0.201	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1332	DG
Cadmium	0.343	mg/Kg		0.200	EPA 6010C	11/20/2017 1332	DG
Calcium	60500	mg/Kg		5.00	EPA 6010C	11/20/2017 1332	DG
Chromium	14.4	mg/Kg		0.200	EPA 6010C	11/20/2017 1332	DG
Cobalt	7.08	mg/Kg		0.200	EPA 6010C	11/20/2017 1332	DG
Copper	7.00	mg/Kg		0.500	EPA 6010C	11/20/2017 1332	DG
Germanium	1.94	mg/Kg	U	7.00	EPA 6010C	11/20/2017 1332	DG
Iron	18500	mg/Kg		2.00	EPA 6010C	11/20/2017 1334	DG
Lead	5.42	mg/Kg		2.40	EPA 6010C	11/20/2017 1332	DG
Magnesium	8580	mg/Kg		10.0	EPA 6010C	11/20/2017 1332	DG
Manganese	3070	mg/Kg		0.100	EPA 6010C	11/20/2017 1332	DG
Mercury	0.0024	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	2.40	mg/Kg		0.600	EPA 6010C	11/20/2017 1332	DG
Nickel	15.7	mg/Kg		0.200	EPA 6010C	11/20/2017 1332	DG
Potassium	1350	mg/Kg		10.0	EPA 6010C	11/20/2017 1332	DG
Selenium	3.23	mg/Kg		1.30	EPA 6010C	11/20/2017 1332	DG
Silicon	388	mg/Kg		4.00	EPA 6010C	11/20/2017 1332	DG
Silver	0.289	mg/Kg	U	0.400	EPA 6010C	11/20/2017 1332	DG
Sodium	607	mg/Kg		73.0	EPA 6010C	11/20/2017 1332	DG
Strontium	67.0	mg/Kg		0.200	EPA 6010C	11/20/2017 1332	DG
Thallium	4.07	mg/Kg	U	4.30	EPA 6010C	11/20/2017 1332	DG
Uranium	-0.52	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1332	DG
Vanadium	19.9	mg/Kg		0.200	EPA 6010C	11/20/2017 1332	DG
Zinc	35.1	mg/Kg		0.600	EPA 6010C	11/20/2017 1332	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-007
ClientSample ID: 14006221AAA2_3
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	0.0112	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.0306	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	3.01	%		0.100	ASA9 29-2.2	11/27/2017 1210	KS
Total Organic Carbon	0.279	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-008
ClientSample ID: 14006221AAA2_4
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	4.7	pCi/g	U	10.0	SM 7110	12/30/2017 1210	MB
Gross Alpha Precision (±)	0.9	pCi/g	U		SM 7110	12/30/2017 1210	MB
Gross Beta	6.2	pCi/g	U	10.0	SM 7110	12/30/2017 1210	MB
Gross Beta Precision (±)	1.4	pCi/g	U		SM 7110	12/30/2017 1210	MB
Radium 226	0.31	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 413	WN
Radium 226 Precision (±)	0.1	pCi/g			EPA 901.1 Mod.	12/14/2017 413	WN
Radium 228	0.43	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 413	WN
Radium 228 Precision (±)	0.2	pCi/g			EPA 901.1 Mod.	12/14/2017 413	WN
General Parameters - Soil							
Percent Solids	82.5	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	33.1	ppm		1.00	EPA 300.0	01/12/2018 1657	AB
Fluoride	0.666	ppm		0.100	EPA 300.0	01/12/2018 1657	AB
Total Inorganic Carbon	2.70	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.143	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Neutralization Potential	215	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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H	Holding times for preparation or analysis exceeded
L	Analyzed by another laboratory
ND	Not Detected at the Reporting Limit
S	Spike Recovery outside accepted recovery limits
X	Matrix Effect
C	Calculated Value
G	Analyzed at IML Gillette laboratory
J	Analyte detected below quantitation limits
M	Value exceeds Monthly Ave or MCL or is less than LCL
O	Outside the Range of Dilutions
U	Analysis reported under the reporting limit

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-008
ClientSample ID: 14006221AAA2_4
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	3570	mg/Kg		1.50	EPA 6010C	11/20/2017 1345	DG
Antimony	1.60	mg/Kg	U	1.70	EPA 6010C	11/20/2017 1345	DG
Arsenic	2.87	mg/Kg		0.600	EPA 6010C	11/20/2017 1345	DG
Barium	94.9	mg/Kg		1.00	EPA 6010C	11/20/2017 1345	DG
Beryllium	0.147	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1345	DG
Cadmium	0.238	mg/Kg		0.200	EPA 6010C	11/20/2017 1345	DG
Calcium	54900	mg/Kg		5.00	EPA 6010C	11/20/2017 1345	DG
Chromium	13.6	mg/Kg		0.200	EPA 6010C	11/20/2017 1345	DG
Cobalt	5.67	mg/Kg		0.200	EPA 6010C	11/20/2017 1345	DG
Copper	5.95	mg/Kg		0.500	EPA 6010C	11/20/2017 1345	DG
Germanium	1.72	mg/Kg	U	7.00	EPA 6010C	11/20/2017 1345	DG
Iron	14000	mg/Kg		2.00	EPA 6010C	11/20/2017 1347	DG
Lead	4.07	mg/Kg		2.40	EPA 6010C	11/20/2017 1345	DG
Magnesium	8520	mg/Kg		10.0	EPA 6010C	11/20/2017 1345	DG
Manganese	1550	mg/Kg		0.100	EPA 6010C	11/20/2017 1345	DG
Mercury	-0.0016	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	1.79	mg/Kg		0.600	EPA 6010C	11/20/2017 1345	DG
Nickel	13.0	mg/Kg		0.200	EPA 6010C	11/20/2017 1345	DG
Potassium	959	mg/Kg		10.0	EPA 6010C	11/20/2017 1345	DG
Selenium	1.69	mg/Kg		1.30	EPA 6010C	11/20/2017 1345	DG
Silicon	351	mg/Kg		4.00	EPA 6010C	11/20/2017 1345	DG
Silver	0.251	mg/Kg	U	0.400	EPA 6010C	11/20/2017 1345	DG
Sodium	410	mg/Kg		73.0	EPA 6010C	11/20/2017 1345	DG
Strontium	50.1	mg/Kg		0.200	EPA 6010C	11/20/2017 1345	DG
Thallium	1.85	mg/Kg	U	4.30	EPA 6010C	11/20/2017 1345	DG
Uranium	-1.4	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1345	DG
Vanadium	15.0	mg/Kg		0.200	EPA 6010C	11/20/2017 1345	DG
Zinc	26.1	mg/Kg		0.600	EPA 6010C	11/20/2017 1345	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-008
ClientSample ID: 14006221AAA2_4
COC:

WorkOrder: S1710437
CollectionDate: 9/12/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	0.0775	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.0652	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	2.67	%		0.100	ASA9 29-2.2	11/27/2017 1214	KS
Total Organic Carbon	ND	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-009
ClientSample ID: 14006228AAA1_1
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	6.3	pCi/g	U	10.0	SM 7110	12/30/2017 1210	MB
Gross Alpha Precision (±)	1.0	pCi/g	U		SM 7110	12/30/2017 1210	MB
Gross Beta	7.6	pCi/g	U	10.0	SM 7110	12/30/2017 1210	MB
Gross Beta Precision (±)	1.5	pCi/g	U		SM 7110	12/30/2017 1210	MB
Radium 226	0.49	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 530	WN
Radium 226 Precision (±)	0.2	pCi/g			EPA 901.1 Mod.	12/14/2017 530	WN
Radium 228	0.52	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 530	WN
Radium 228 Precision (±)	0.3	pCi/g			EPA 901.1 Mod.	12/14/2017 530	WN
General Parameters - Soil							
Percent Solids	70.2	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	19.3	ppm		1.00	EPA 300.0	01/12/2018 1753	AB
Fluoride	0.508	ppm		0.100	EPA 300.0	01/12/2018 1753	AB
Total Inorganic Carbon	2.10	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.258	%		0.0100	EPA600/2-78-054	11/27/2017 1218	KS
Neutralization Potential	173	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-009
ClientSample ID: 14006228AAA1_1
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	5510	mg/Kg		1.50	EPA 6010C	11/20/2017 1349	DG
Antimony	1.45	mg/Kg	U	1.70	EPA 6010C	11/20/2017 1349	DG
Arsenic	6.02	mg/Kg		0.600	EPA 6010C	11/20/2017 1349	DG
Barium	150	mg/Kg		1.00	EPA 6010C	11/20/2017 1349	DG
Beryllium	0.284	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1349	DG
Cadmium	0.336	mg/Kg		0.200	EPA 6010C	11/20/2017 1349	DG
Calcium	39600	mg/Kg		5.00	EPA 6010C	11/20/2017 1349	DG
Chromium	15.8	mg/Kg		0.200	EPA 6010C	11/20/2017 1349	DG
Cobalt	6.97	mg/Kg		0.200	EPA 6010C	11/20/2017 1349	DG
Copper	10.6	mg/Kg		0.500	EPA 6010C	11/20/2017 1349	DG
Germanium	1.29	mg/Kg	U	7.00	EPA 6010C	11/20/2017 1349	DG
Iron	16100	mg/Kg		2.00	EPA 6010C	11/20/2017 1351	DG
Lead	6.05	mg/Kg		2.40	EPA 6010C	11/20/2017 1349	DG
Magnesium	11800	mg/Kg		10.0	EPA 6010C	11/20/2017 1349	DG
Manganese	2060	mg/Kg		0.100	EPA 6010C	11/20/2017 1349	DG
Mercury	0.0153	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	3.41	mg/Kg		0.600	EPA 6010C	11/20/2017 1349	DG
Nickel	19.8	mg/Kg		0.200	EPA 6010C	11/20/2017 1349	DG
Potassium	1780	mg/Kg		10.0	EPA 6010C	11/20/2017 1349	DG
Selenium	2.33	mg/Kg		1.30	EPA 6010C	11/20/2017 1349	DG
Silicon	363	mg/Kg		4.00	EPA 6010C	11/20/2017 1349	DG
Silver	0.231	mg/Kg	U	0.400	EPA 6010C	11/20/2017 1349	DG
Sodium	554	mg/Kg		73.0	EPA 6010C	11/20/2017 1349	DG
Strontium	56.1	mg/Kg		0.200	EPA 6010C	11/20/2017 1349	DG
Thallium	2.36	mg/Kg	U	4.30	EPA 6010C	11/20/2017 1349	DG
Uranium	-1.6	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1349	DG
Vanadium	30.5	mg/Kg		0.200	EPA 6010C	11/20/2017 1349	DG
Zinc	50.7	mg/Kg		0.600	EPA 6010C	11/20/2017 1349	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-009
ClientSample ID: 14006228AAA1_1
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	0.0284	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.229	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	2.37	%		0.100	ASA9 29-2.2	11/27/2017 1218	KS
Total Organic Carbon	0.299	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-010
ClientSample ID: 14006228AAA1_2
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	8.6	pCi/g	U	10.0	SM 7110	12/30/2017 1210	MB
Gross Alpha Precision (±)	1.8	pCi/g	U		SM 7110	12/30/2017 1210	MB
Gross Beta	12.0	pCi/g		10.0	SM 7110	12/30/2017 1210	MB
Gross Beta Precision (±)	2.8	pCi/g			SM 7110	12/30/2017 1210	MB
Radium 226	0.86	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 648	WN
Radium 226 Precision (±)	0.3	pCi/g			EPA 901.1 Mod.	12/14/2017 648	WN
Radium 228	0.42	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 648	WN
Radium 228 Precision (±)	0.4	pCi/g			EPA 901.1 Mod.	12/14/2017 648	WN
General Parameters - Soil							
Percent Solids	85.4	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	26.1	ppm		1.00	EPA 300.0	01/12/2018 1806	AB
Fluoride	1.83	ppm		0.100	EPA 300.0	01/12/2018 1806	AB
Total Inorganic Carbon	3.90	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.123	%		0.0100	EPA600/2-78-054	11/27/2017 1222	KS
Neutralization Potential	327	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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H	Holding times for preparation or analysis exceeded
L	Analyzed by another laboratory
ND	Not Detected at the Reporting Limit
S	Spike Recovery outside accepted recovery limits
X	Matrix Effect
C	Calculated Value
G	Analyzed at IML Gillette laboratory
J	Analyte detected below quantitation limits
M	Value exceeds Monthly Ave or MCL or is less than LCL
O	Outside the Range of Dilutions
U	Analysis reported under the reporting limit

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-010
ClientSample ID: 14006228AAA1_2
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	2240	mg/Kg		1.50	EPA 6010C	11/20/2017 1354	DG
Antimony	2.05	mg/Kg		1.70	EPA 6010C	11/20/2017 1354	DG
Arsenic	2.98	mg/Kg		0.600	EPA 6010C	11/20/2017 1354	DG
Barium	132	mg/Kg		1.00	EPA 6010C	11/20/2017 1354	DG
Beryllium	0.103	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1354	DG
Cadmium	0.325	mg/Kg		0.200	EPA 6010C	11/20/2017 1354	DG
Calcium	48800	mg/Kg		5.00	EPA 6010C	11/20/2017 1354	DG
Chromium	10.6	mg/Kg		0.200	EPA 6010C	11/20/2017 1354	DG
Cobalt	5.64	mg/Kg		0.200	EPA 6010C	11/20/2017 1354	DG
Copper	7.48	mg/Kg		0.500	EPA 6010C	11/20/2017 1354	DG
Germanium	1.56	mg/Kg	U	7.00	EPA 6010C	11/20/2017 1354	DG
Iron	17500	mg/Kg		2.00	EPA 6010C	11/20/2017 1356	DG
Lead	8.03	mg/Kg		2.40	EPA 6010C	11/20/2017 1354	DG
Magnesium	14000	mg/Kg		10.0	EPA 6010C	11/20/2017 1354	DG
Manganese	21700	mg/Kg		0.100	EPA 6010C	11/20/2017 1356	DG
Mercury	-0.0003	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	2.61	mg/Kg		0.600	EPA 6010C	11/20/2017 1354	DG
Nickel	13.9	mg/Kg		0.200	EPA 6010C	11/20/2017 1354	DG
Potassium	2040	mg/Kg		10.0	EPA 6010C	11/20/2017 1354	DG
Selenium	15.8	mg/Kg		1.30	EPA 6010C	11/20/2017 1354	DG
Silicon	370	mg/Kg		4.00	EPA 6010C	11/20/2017 1354	DG
Silver	1.13	mg/Kg		0.400	EPA 6010C	11/20/2017 1354	DG
Sodium	673	mg/Kg		73.0	EPA 6010C	11/20/2017 1354	DG
Strontium	85.6	mg/Kg		0.200	EPA 6010C	11/20/2017 1354	DG
Thallium	18.5	mg/Kg		4.30	EPA 6010C	11/20/2017 1354	DG
Uranium	7.96	mg/Kg		2.80	EPA 6010C	11/20/2017 1354	DG
Vanadium	22.6	mg/Kg		0.200	EPA 6010C	11/20/2017 1354	DG
Zinc	45.8	mg/Kg		0.600	EPA 6010C	11/20/2017 1354	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-010
ClientSample ID: 14006228AAA1_2
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.115	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	4.14	%		0.100	ASA9 29-2.2	11/27/2017 1222	KS
Total Organic Carbon	0.208	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-011
ClientSample ID: 14006228AAA1_3
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	4.6	pCi/g	U	10.0	SM 7110	12/30/2017 1210	MB
Gross Alpha Precision (±)	0.9	pCi/g	U		SM 7110	12/30/2017 1210	MB
Gross Beta	6.2	pCi/g	U	10.0	SM 7110	12/30/2017 1210	MB
Gross Beta Precision (±)	1.4	pCi/g	U		SM 7110	12/30/2017 1210	MB
Radium 226	0.39	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 806	WN
Radium 226 Precision (±)	0.1	pCi/g			EPA 901.1 Mod.	12/14/2017 806	WN
Radium 228	0.37	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 806	WN
Radium 228 Precision (±)	0.2	pCi/g			EPA 901.1 Mod.	12/14/2017 806	WN
General Parameters - Soil							
Percent Solids	81.3	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	18.4	ppm		1.00	EPA 300.0	01/12/2018 1820	AB
Fluoride	0.913	ppm		0.100	EPA 300.0	01/12/2018 1820	AB
Total Inorganic Carbon	2.00	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.176	%		0.0100	EPA600/2-78-054	11/27/2017 1225	KS
Neutralization Potential	166	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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H	Holding times for preparation or analysis exceeded
L	Analyzed by another laboratory
ND	Not Detected at the Reporting Limit
S	Spike Recovery outside accepted recovery limits
X	Matrix Effect
C	Calculated Value
G	Analyzed at IML Gillette laboratory
J	Analyte detected below quantitation limits
M	Value exceeds Monthly Ave or MCL or is less than LCL
O	Outside the Range of Dilutions
U	Analysis reported under the reporting limit

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-011
ClientSample ID: 14006228AAA1_3
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	4320	mg/Kg		1.50	EPA 6010C	11/20/2017 1358	DG
Antimony	2.59	mg/Kg		1.70	EPA 6010C	11/20/2017 1358	DG
Arsenic	4.23	mg/Kg		0.600	EPA 6010C	11/20/2017 1358	DG
Barium	126	mg/Kg		1.00	EPA 6010C	11/20/2017 1358	DG
Beryllium	0.224	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1358	DG
Cadmium	0.350	mg/Kg		0.200	EPA 6010C	11/20/2017 1358	DG
Calcium	36900	mg/Kg		5.00	EPA 6010C	11/20/2017 1358	DG
Chromium	11.7	mg/Kg		0.200	EPA 6010C	11/20/2017 1358	DG
Cobalt	6.31	mg/Kg		0.200	EPA 6010C	11/20/2017 1358	DG
Copper	9.63	mg/Kg		0.500	EPA 6010C	11/20/2017 1358	DG
Germanium	2.59	mg/Kg	U	7.00	EPA 6010C	11/20/2017 1358	DG
Iron	13000	mg/Kg		2.00	EPA 6010C	11/20/2017 1409	DG
Lead	7.70	mg/Kg		2.40	EPA 6010C	11/20/2017 1358	DG
Magnesium	11000	mg/Kg		10.0	EPA 6010C	11/20/2017 1358	DG
Manganese	3880	mg/Kg		0.100	EPA 6010C	11/20/2017 1358	DG
Mercury	0.0139	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	1.59	mg/Kg		0.600	EPA 6010C	11/20/2017 1358	DG
Nickel	17.2	mg/Kg		0.200	EPA 6010C	11/20/2017 1358	DG
Potassium	1690	mg/Kg		10.0	EPA 6010C	11/20/2017 1358	DG
Selenium	4.29	mg/Kg		1.30	EPA 6010C	11/20/2017 1358	DG
Silicon	304	mg/Kg		4.00	EPA 6010C	11/20/2017 1358	DG
Silver	0.338	mg/Kg	U	0.400	EPA 6010C	11/20/2017 1358	DG
Sodium	727	mg/Kg		73.0	EPA 6010C	11/20/2017 1358	DG
Strontium	58.3	mg/Kg		0.200	EPA 6010C	11/20/2017 1358	DG
Thallium	5.44	mg/Kg		4.30	EPA 6010C	11/20/2017 1358	DG
Uranium	-0.89	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1358	DG
Vanadium	23.2	mg/Kg		0.200	EPA 6010C	11/20/2017 1358	DG
Zinc	46.9	mg/Kg		0.600	EPA 6010C	11/20/2017 1358	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-011
ClientSample ID: 14006228AAA1_3
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.167	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	2.60	%		0.100	ASA9 29-2.2	11/27/2017 1225	KS
Total Organic Carbon	0.600	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-012
ClientSample ID: 14006228AAA1_4
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Radionuclides - Total							
Gross Alpha	4.8	pCi/g	U	10.0	SM 7110	12/30/2017 1210	MB
Gross Alpha Precision (±)	1.0	pCi/g	U		SM 7110	12/30/2017 1210	MB
Gross Beta	5.8	pCi/g	U	10.0	SM 7110	12/30/2017 1210	MB
Gross Beta Precision (±)	1.6	pCi/g	U		SM 7110	12/30/2017 1210	MB
Radium 226	0.34	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 924	WN
Radium 226 Precision (±)	0.3	pCi/g			EPA 901.1 Mod.	12/14/2017 924	WN
Radium 228	0.44	pCi/g		0.200	EPA 901.1 Mod.	12/14/2017 924	WN
Radium 228 Precision (±)	0.6	pCi/g			EPA 901.1 Mod.	12/14/2017 924	WN
General Parameters - Soil							
Percent Solids	69.6	%		0.100	SM 2540G	10/27/2017 000	KS
Chloride	28.3	ppm		1.00	EPA 300.0	01/12/2018 1834	AB
Fluoride	0.694	ppm		0.100	EPA 300.0	01/12/2018 1834	AB
Total Inorganic Carbon	3.50	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS
Acid Potential							
Total Sulfur	0.179	%		0.0100	EPA600/2-78-054	11/27/2017 1229	KS
Neutralization Potential	287	t/1000t			EPA600/2-78-054	11/16/2017 000	CH

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-012
ClientSample ID: 14006228AAA1_4
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Metals - Total							
Aluminum	4200	mg/Kg		1.50	EPA 6010C	11/20/2017 1422	DG
Antimony	1.75	mg/Kg		1.70	EPA 6010C	11/20/2017 1422	DG
Arsenic	3.17	mg/Kg		0.600	EPA 6010C	11/20/2017 1422	DG
Barium	115	mg/Kg		1.00	EPA 6010C	11/20/2017 1422	DG
Beryllium	0.212	mg/Kg	U	0.700	EPA 6010C	11/20/2017 1422	DG
Cadmium	0.304	mg/Kg		0.200	EPA 6010C	11/20/2017 1422	DG
Calcium	58500	mg/Kg		5.00	EPA 6010C	11/20/2017 1422	DG
Chromium	10.8	mg/Kg		0.200	EPA 6010C	11/20/2017 1422	DG
Cobalt	5.40	mg/Kg		0.200	EPA 6010C	11/20/2017 1422	DG
Copper	9.66	mg/Kg		0.500	EPA 6010C	11/20/2017 1422	DG
Germanium	0.492	mg/Kg	U	7.00	EPA 6010C	11/21/2017 1411	DG
Iron	18400	mg/Kg		2.00	EPA 6010C	11/20/2017 1429	DG
Lead	7.14	mg/Kg		2.40	EPA 6010C	11/20/2017 1422	DG
Magnesium	16700	mg/Kg		10.0	EPA 6010C	11/20/2017 1422	DG
Manganese	3110	mg/Kg		0.100	EPA 6010C	11/20/2017 1422	DG
Mercury	0.0133	mg/Kg	U	0.200	7471B	11/21/2017 000	AW
Molybdenum	1.72	mg/Kg		0.600	EPA 6010C	11/20/2017 1422	DG
Nickel	15.6	mg/Kg		0.200	EPA 6010C	11/20/2017 1422	DG
Potassium	1760	mg/Kg		10.0	EPA 6010C	11/20/2017 1422	DG
Selenium	3.37	mg/Kg		1.30	EPA 6010C	11/20/2017 1422	DG
Silicon	318	mg/Kg		4.00	EPA 6010C	11/20/2017 1422	DG
Silver	0.383	mg/Kg	U	0.400	EPA 6010C	11/20/2017 1422	DG
Sodium	731	mg/Kg		73.0	EPA 6010C	11/20/2017 1422	DG
Strontium	57.5	mg/Kg		0.200	EPA 6010C	11/20/2017 1422	DG
Thallium	4.38	mg/Kg		4.30	EPA 6010C	11/20/2017 1422	DG
Uranium	-0.41	mg/Kg	U	2.80	EPA 6010C	11/20/2017 1422	DG
Vanadium	23.8	mg/Kg		0.200	EPA 6010C	11/20/2017 1422	DG
Zinc	44.6	mg/Kg		0.600	EPA 6010C	11/20/2017 1422	DG

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

Sample Analysis Report

Company: North Dakota State Water Commission
900 East Boulevard Ave
Bismark, ND 58505-0850

Date Reported 1/18/2018
Report ID S1710437002
(Replaces S1710437001)

ProjectName: ASR_Spiritwood Soil Matrix 2017
Lab ID: S1710437-012
ClientSample ID: 14006228AAA1_4
COC:

WorkOrder: S1710437
CollectionDate: 9/13/2017
DateReceived: 10/27/2017 11:49:00 AM
FieldSampler: MG
Matrix: Soil

Comments

Analyses	Result	Units	Qual	RL	Method	Date Analyzed/Init	
Sulfur							
Sulfur, Sulfate	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Pyritic	0.178	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Sulfur, Organic	ND	%		0.0100	EPA600/2-78-054	01/02/2018 000	KS
Total Organic Carbon							
Total Carbon	3.89	%		0.100	ASA9 29-2.2	11/27/2017 1229	KS
Total Organic Carbon	0.446	%		0.100	ASA9 29-3.2	01/03/2018 1632	KS

These results apply only to the samples tested.

RL - Reporting Limit

Qualifiers:

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

Reviewed by: _____
Wade Nieuwsma, Assistant Laboratory Manager

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

Your Environmental Monitoring Partner

ANALYTICAL QC SUMMARY REPORT

CLIENT: North Dakota State Water Commission
Work Order: S1710437
Project: ASR_Spiritwood Soil Matrix 2017

Date: 1/18/2018
Report ID: S1710437002 (Replaces S1710437001)

Gross Alpha in Soil Sample Type **MBLK** Units: pCi/g

MB-474 (12/29/17 22:19) RunNo: 153425 PrepDate: 12/16/17 0:00 BatchID R153425

Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Gross Alpha	ND	10					
Gross Beta	ND	10					

Gross Alpha in Soil Sample Type **LCS** Units: pCi/g

LCS-474 (12/29/17 22:19) RunNo: 153425 PrepDate: 12/16/17 0:00 BatchID R153425

Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Gross Alpha	80	10	78.6		102	77.4 - 130	
Gross Beta	150	10	122		121	80 - 131	

Gross Alpha in Soil Sample Type **MS** Units: pCi/g

S1710437-001B MS (12/29/17 22:19) RunNo: 153425 PrepDate: 12/16/17 0:00 BatchID R153425

Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Gross Alpha	90	10	78.6	ND	97.9	52.4 - 124	
Gross Beta	160	10	122	ND	122	80 - 145	

Gross Alpha in Soil Sample Type **DUP** Units: pCi/g

S1710437-002B DUP (12/29/17 22:19) RunNo: 153425 PrepDate: 12/16/17 0:00 BatchID R153425

Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Gross Alpha	ND	10	ND			20	
Gross Beta	ND	10	ND			0	

Total Mercury in Soils Sample Type **MBLK** Units: mg/Kg

MB-R152198 (11/21/17 00:00) RunNo: 152198

Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Mercury	ND	0.2					

Total Mercury in Soils Sample Type **LCS** Units: mg/Kg

LCS-R152198 (11/21/17 00:00) RunNo: 152198

Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Mercury	2.0	0.2	2		100	80 - 120	

Total Mercury in Soils Sample Type **DUP** Units: mg/Kg

S1710437-001A (11/21/17 00:00) RunNo: 152198

Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Mercury	ND	0.2	ND				

S1710437-009A (11/21/17 00:00) RunNo: 152198

Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Mercury	ND	0.2	ND				

Qualifiers:

B	Analyte detected in the associated Method Blank
E	Value above quantitation range
G	Analyzed at IML Gillette laboratory
H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits
L	Analyzed by another laboratory
ND	Not Detected at the Reporting Limit
O	Outside the Range of Dilutions
R	RPD outside accepted recovery limits
S	Spike Recovery outside accepted recovery limits
X	Matrix Effect

ANALYTICAL QC SUMMARY REPORT

CLIENT: North Dakota State Water Commission
Work Order: S1710437
Project: ASR_Spiritwood Soil Matrix 2017

Date: 1/18/2018
Report ID: S1710437002 (Replaces S1710437001)

Radium By Gamma Spectroscopy in Soil Sample Type **MBLK** Units: pCi/g

MB-14008 (12/13/17 16:34) RunNo: 152967 PrepDate: 11/15/17 0:00 BatchID 14008

Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Radium 226	ND	0.2					
Radium 228	ND	0.2					

Radium By Gamma Spectroscopy in Soil Sample Type **LCS** Units: pCi/g

LCS-14008 (12/13/17 17:52) RunNo: 152967 PrepDate: 11/15/17 0:00 BatchID 14008

Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Radium 226	33.9	0.2	37.9		89.4	70 - 130	
Radium 228	8.7	0.2	8.36		104	70 - 130	

Radium By Gamma Spectroscopy in Soil Sample Type **LCSD** Units: pCi/g

LCSD-14008 (12/14/17 23:44) RunNo: 152967 PrepDate: 11/15/17 0:00 BatchID 14008

Analyte	Result	RL	Conc	%RPD	%REC	% RPD Limits	Qual
Radium 226	34.2	0.2	33.9	0.861	90.2	20	
Radium 228	7.6	0.2	8.7	12.9	91.2	20	

Sulfur Forms Sample Type **LCS** Units: %

LCS (11/27/17 11:43) RunNo: 152302

Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Total Sulfur	0.32	0.01	0.3		107	80 - 120	

LCS-R153348 (01/02/18 00:00) RunNo: 153348

Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Sulfur, Organic	0.03	0.01	0.03		103	80 - 120	
Sulfur, Pyritic	0.15	0.01	0.14		109	80 - 120	
Sulfur, Sulfate	0.14	0.01	0.13		104	80 - 120	
Total Sulfur	0.32	0.01	0.3		106	80 - 120	

Sulfur Forms Sample Type **DUP** Units: %

S1710437-012BD (11/27/17 12:33) RunNo: 152302

Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Total Sulfur	0.21	0.01	0.18	14.8		20	

Total Organic Carbon - LECO Furnace Sample Type **LCS** Units: %

LCS (11/27/17 11:43) RunNo: 152302

Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Total Carbon	3.2	0.1	3.25		99.3	80 - 120	

Total Organic Carbon - LECO Furnace Sample Type **DUP** Units: %

S1710437-012BD (11/27/17 12:33) RunNo: 152302

Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Total Carbon	3.9	0.1	3.9	0.438		20	

Qualifiers:

B	Analyte detected in the associated Method Blank
G	Analyzed at IML Gillette laboratory
J	Analyte detected below quantitation limits
ND	Not Detected at the Reporting Limit
R	RPD outside accepted recovery limits
X	Matrix Effect
E	Value above quantitation range
H	Holding times for preparation or analysis exceeded
L	Analyzed by another laboratory
O	Outside the Range of Dilutions
S	Spike Recovery outside accepted recovery limits

ANALYTICAL QC SUMMARY REPORT

CLIENT: North Dakota State Water Commission
Work Order: S1710437
Project: ASR_Spiritwood Soil Matrix 2017

Date: 1/18/2018
Report ID: S1710437002
(Replaces S1710437001)

Total (3050) Metals by ICP - 6010C Sample Type **MBLK** Units: mg/Kg

MB-13895 (11/20/17 12:19)	RunNo: 152172	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Aluminum	ND	1.5					
Antimony	ND	1.7					
Arsenic	ND	0.6					
Barium	ND	0.08					
Beryllium	ND	0.7					
Cadmium	ND	0.2					
Chromium	ND	0.2					
Cobalt	ND	0.2					
Copper	ND	0.5					
Iron	ND	2					
Lead	ND	2.4					
Manganese	ND	0.1					
Selenium	ND	1.3					
Silver	ND	0.4					
Thallium	ND	4.3					
Uranium	ND	2.8					
Vanadium	ND	0.2					
Zinc	ND	0.6					

MB-13895 (11/20/17 12:19)	RunNo: 152264	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Germanium	ND	7.00					

MB-13895 (11/20/17 12:19)	RunNo: 153575	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Calcium	ND	5					
Magnesium	ND	10					
Potassium	ND	10					
Silicon	ND	4					
Sodium	ND	73					

MB-13895 (11/20/17 12:19)	RunNo: 153605	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Molybdenum	ND	0.6					
Nickel	ND	0.2					
Strontium	ND	0.2					

Total (3050) Metals by ICP - 6010C Sample Type **LCS** Units: mg/Kg

LCS-13895 (11/20/17 12:21)	RunNo: 152172	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Aluminum	129	1.5	125		103	80 - 120	
Antimony	49.8	1.7	50		99.5	80 - 120	
Arsenic	45.4	0.6	50		90.9	80 - 120	

Qualifiers:

B	Analyte detected in the associated Method Blank
E	Value above quantitation range
G	Analyzed at IML Gillette laboratory
H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits
L	Analyzed by another laboratory
ND	Not Detected at the Reporting Limit
O	Outside the Range of Dilutions
R	RPD outside accepted recovery limits
S	Spike Recovery outside accepted recovery limits
X	Matrix Effect

ANALYTICAL QC SUMMARY REPORT

CLIENT: North Dakota State Water Commission
Work Order: S1710437
Project: ASR_Spiritwood Soil Matrix 2017

Date: 1/18/2018
Report ID: S1710437002
(Replaces S1710437001)

Total (3050) Metals by ICP - 6010C Sample Type **LCS** Units: mg/Kg

LCS-13895 (11/20/17 12:21)	RunNo: 152172	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Barium	47.5	0.08	50		94.9	80 - 120	
Beryllium	52.7	0.7	50		105	80 - 120	
Cadmium	45.8	0.2	50		91.7	80 - 120	
Chromium	47.8	0.2	50		95.6	80 - 120	
Cobalt	47.6	0.2	50		95.2	80 - 120	
Copper	45.9	0.5	50		91.8	80 - 120	
Iron	122	2	125		98.0	80 - 120	
Lead	46.0	2.4	50		92.1	80 - 120	
Manganese	44.8	0.1	50		89.6	80 - 120	
Selenium	90.8	1.3	100		90.8	80 - 120	
Silver	23.7	0.4	25		94.7	80 - 120	
Thallium	44.5	4.3	50		89.1	80 - 120	
Uranium	48.1	2.8	50		96.1	80 - 120	
Vanadium	47.6	0.2	50		95.1	80 - 120	
Zinc	48.3	0.6	50		96.5	80 - 120	

LCS-13895 (11/20/17 12:21)	RunNo: 153605	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Spike	Ref Samp	%REC	% Rec Limits	Qual
Molybdenum	52.9	0.6	50		106	80 - 120	
Nickel	114	0.2	125		91.4	80 - 120	
Strontium	48.4	0.2	50		96.9	80 - 120	

Total (3050) Metals by ICP - 6010C Sample Type **DUP** Units: mg/Kg

S1710437-011AD (11/20/17 14:06)	RunNo: 152172	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Aluminum	4260	1.5	4320	1.18		20	
Antimony	ND	1.7	2.6			20	
Arsenic	4.0	0.6	4.2	6.19		20	
Barium	126	1	126	0.516		20	
Beryllium	ND	0.7	ND			20	
Cadmium	0.4	0.2	0.4	1.35		20	
Chromium	11.8	0.2	11.7	0.332		20	
Cobalt	6.4	0.2	6.3	1.05		20	
Copper	9.4	0.5	9.6	1.92		20	
Lead	7.4	2.4	7.7	4.55		20	
Manganese	3880	0.1	3880	0.0849		20	
Selenium	4.7	1.3	4.3	9.77		20	
Silver	ND	0.4	ND			20	
Thallium	5.7	4.3	5.4	4.64		20	
Uranium	ND	2.8	ND			20	
Vanadium	23.0	0.2	23.2	0.691		20	
Zinc	46.1	0.6	46.9	1.85		20	

Qualifiers:

B	Analyte detected in the associated Method Blank	E	Value above quantitation range
G	Analyzed at IML Gillette laboratory	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	L	Analyzed by another laboratory
ND	Not Detected at the Reporting Limit	O	Outside the Range of Dilutions
R	RPD outside accepted recovery limits	S	Spike Recovery outside accepted recovery limits
X	Matrix Effect		

ANALYTICAL QC SUMMARY REPORT

CLIENT: North Dakota State Water Commission
Work Order: S1710437
Project: ASR_Spiritwood Soil Matrix 2017

Date: 1/18/2018
Report ID: S1710437002 (Replaces S1710437001)

Total (3050) Metals by ICP - 6010C Sample Type **DUP** Units: mg/Kg

S1710437-011AD (11/20/17 14:11)	RunNo: 152172	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Iron	13000	2	13000	0.440		20	

S1710437-011AD (11/20/17 14:06)	RunNo: 152264	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Germanium	ND	7.00	ND			0	

S1710437-003AD (11/20/17 12:50)	RunNo: 153575	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Calcium	70000	5	69500	0.734		20	
Magnesium	8170	10	8180	0.0786		20	
Potassium	950	10	930	2.02		20	
Silicon	289	4	271	6.50		20	
Sodium	536	73	534	0.319		20	

S1710437-011AD (11/20/17 14:06)	RunNo: 153575	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Calcium	36800	5	36900	0.230		20	
Magnesium	10800	10	11000	1.99		20	
Potassium	1690	10	1690	0.0622		20	
Silicon	302	4	304	0.573		20	
Sodium	710	73	727	2.31		20	

S1710437-003AD (11/20/17 12:50)	RunNo: 153605	PrepDate: 11/19/17 10:05			BatchID 13895		
Analyte	Result	RL	Ref Samp	%RPD	%REC	% RPD Limits	Qual
Molybdenum	15.9	4.72	15.3	3.92		20	
Nickel	163	1.57	143	12.9		20	
Strontium	539	1.57	532	1.30		20	

Qualifiers:

B	Analyte detected in the associated Method Blank	E	Value above quantitation range
G	Analyzed at IML Gillette laboratory	H	Holding times for preparation or analysis exceeded
J	Analyte detected below quantitation limits	L	Analyzed by another laboratory
ND	Not Detected at the Reporting Limit	O	Outside the Range of Dilutions
R	RPD outside accepted recovery limits	S	Spike Recovery outside accepted recovery limits
X	Matrix Effect		

7.4 Appendix D

PHREEQC Results for Amended Maximum James River Solution

Condition: Maximum James River constituents, pe = oxygen couple, pe = 15.7, pH = 6

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69)
Al aluminum		Boehmite AlO(OH) (1.40); Diaspore AlO(OH) (1.83); Gibbsite $Al(OH)_3$ (1.31)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.51); Witherite $BaCO_3$ (1.34)
Be beryllium		Bromellite BeO (5.50)
Cd cadmium	Cd^{+2}	
Co cobalt[1]		$CoFe_2O_4$ (16.44)
Cr chromium	$HCrO_4^-$	
Cu copper		Delafossite $CuFeO_2$ (0.26); Ferrite-Cu $CuFe_2O_4$ (7.36)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (4.77)
Fe iron		Goethite FeOOH (5.29); Hematite Fe_2O_3 (11.51)
Hg mercury		Calomel Hg_2Cl_2 (0.27); Montroydite HgO (2.77)
Mn manganese		Birnessite $Mn_8O_{14}:5H_2O$ (29.95); Bixbyite Mn_2O_3 (4.65); Manganite MnO(OH) (2.90); Pyrolusite MnO_2 (6.80)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (6.94)
Pb lead	Pb^{+2}	
Ra radium		$RaSO_4$ (1.59)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (27.60); Sb_2O_5 (33.67)
Se selenium	SeO_4^{-2}	
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium[2]		Carnotite $K_2(UO_2)_2(VO_4)_2$ (0.71); Tyuyamunite $Ca(UO_2)_2(VO_4)_2$ (1.72)
V vanadium[2]		Carnotite $K_2(UO_2)_2(VO_4)_2$ (0.71); Tyuyamunite $Ca(UO_2)_2(VO_4)_2$ (1.72)
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (6.54)

[1]Minimal coverage in LLNL database.
[2]All other non-silicate U and V minerals were undersaturated.

Condition: Maximum James River constituents, pe = oxygen couple, pe = 14.7, pH = 7

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69)
Al aluminum		Boehmite AlO(OH) (2.05); Corundum Al_2O_3 (0.64); Diaspore AlO(OH) (2.48); Gibbsite $Al(OH)_3$ (1.96)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.49); Witherite $BaCO_3$ (2.77)
Be beryllium		Bromellite BeO (7.49)
Cd cadmium		Otovite $CdCO_3$ (0.02)
Co cobalt		$CoFe_2O_4$ (19.19); Spinel-Co Co_3O_4(3.89)
Cr chromium	CrO_4^{-2}	
Cu copper		Delafossite $CuFeO_2$ (1.81); Ferrite-Cu $CuFe_2O_4$ (9.35)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (9.83)
Fe iron		Goethite FeOOH (5.73); Hematite Fe_2O_3 (12.40)
Hg mercury		Calomel Hg_2Cl_2 (2.25); Montroydite HgO (4.77)
Mn manganese		Birnessite Mn_8O_{14}:$5H_2O$ (45.75); Bixbyite Mn_2O_3 (8.60); Manganite MnO(OH) (4.87); Pyrolusite MnO_2 (8.77)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (9.82)
Pb lead		Cerussite $PbCO_3$ (0.71)
Ra radium		$RaSO_4$ (1.58)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (27.60); Sb_2O_5 (33.67)
Se selenium	SeO_4^{-2}	
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^{+}	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (9.40); $ZnCO_3$:H_2O (0.10)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, oxygen couple, pe 13.7, pH = 8

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69)
Al aluminum		Boehmite AlO(OH) (2.55); Corundum Al_2O_3 (1.65); Diaspore AlO(OH) (2.98); Gibbsite $Al(OH)_3$ (2.46)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.49); Barytocalcite $BaCa(CO_3)_2$ (0.89); Witherite $BaCO_3$ (3.85)
Be beryllium		Bromellite BeO (9.48)
Cd cadmium		Otavite $CdCO_3$ (1.08)
Co cobalt		$CoFe_2O_4$ (18.89); Spinel-Co Co_3O_4 (2.57)
Cr chromium	CrO_4^{-2}	
Cu copper		Delafossite $CuFeO_2$ (2.81); Ferrite-Cu $CuFe_2O_4$ (10.43); Malachite $Cu_2CO_3(OH)_2$ (0.88); Tenorite CuO (0.61)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (13.08)
Fe iron		$Fe(OH)_3$ (0.49); Ferrite-Ca $CaFe_2O_4$ (3.03); Ferrite-Mg $MgFe_2O_4$ (3.42); Goethite FeOOH (5.81); Hematite Fe_2O_3 (12.55)
Hg mercury		Calomel Hg_2Cl_2 (4.20); Montroydite HgO (6.74)
Mn manganese		Birnessite $Mn_8O_{14}:5H_2O$ (60.62); Bixbyite Mn_2O_3 (12.31); Manganite MnO(OH) (6.73); Pyrolusite MnO_2 (10.63); Rhodochrosite $MnCO_3$ (0.73)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (11.97)
Pb lead		Cerussite $PbCO_3$ (0.77); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (0.58)
Ra radium		$RaSO_4$ (1.58)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (27.60); Sb_2O_5 (33.67)
Se selenium	SeO_4^{-2}	
Sr strontium		Strontianite $SrCO_3$ (0.45)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (11.49); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (6.66); Smithsonite $ZnCO_3$ (0.53); $ZnCO_3:H_2O$ (1.12)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = oxygen couple, pe = 12.7, pH = 9

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.68)
Al aluminum		Boehmite AlO(OH) (1.77); Corundum Al_2O_3 (0.07); Diaspore AlO(OH) (2.19); Gibbsite $Al(OH)_3$ (1.68)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.49); Barytocalcite $BaCa(CO_3)_2$ (2.75); Witherite $BaCO_3$ (4.80)
Be beryllium		Bromellite BeO (9.19)
Cd cadmium		Otavite $CdCO_3$ (1.95)
Co cobalt		$CoFe_2O_4$ (18.89)
Cr chromium	CrO_4^{-2}	
Cu copper		Brochantite $Cu_4(SO_4)(OH)_6$ (1.13); Delafossite $CuFeO_2$ (3.55); Ferrite-Cu $CuFe_2O_4$ (11.08); Malachite $Cu_2CO_3(OH)_2$ (1.49); Tenorite CuO (1.44)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (15.00)
Fe iron		$Fe(OH)_3$ (0.40); Ferrite-Ca $CaFe_2O_4$ (4.81); Ferrite-Mg $MgFe_2O_4$ (5.21); Goethite FeOOH (5.72); Hematite Fe_2O_3 (12.37)
Hg mercury		Calomel Hg_2Cl_2 (5.33); Montroydite HgO (8.77)
Mn manganese		Birnessite $Mn_8O_{14}:5H_2O$ (69.70); Bixbyite Mn_2O_3 (14.58); Manganite MnO(OH) (7.87); Pyrolusite MnO_2 (11.76); Rhodochrosite $MnCO_3$ (0.82)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (13.79)
Pb lead		Cerussite $PbCO_3$ (0.67); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (1.33); Plattnerite PbO_2 (0.55)
Ra radium		$RaSO_4$ (1.59)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (27.60); Sb_2O_5 (33.67)
Se selenium	SeO_4^{-2}	
Sr strontium		Strontianite $SrCO_3$ (1.39)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (12.75); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (11.73); Smithsonite $ZnCO_3$ (0.92); Zincite ZnO (0.88); $ZnCO_3:H_2O$ (1.51)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = oxygen couple, pe = 11.7, pH = 10

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.62)
Al aluminum		Boehmite AlO(OH) (0.77); Diaspore AlO(OH) (1.20); Gibbsite $Al(OH)_3$ (0.68)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.47); Barytocalcite $BaCa(CO_3)_2$ (3.98); Witherite $BaCO_3$ (5.48)
Be beryllium		Bromellite BeO (7.20)
Cd cadmium		Otavite $CdCO_3$ (2.04)
Co cobalt		$CoFe_2O_4$ (15.76)
Cr chromium	CrO_4^{-2}	
Cu copper		Brochantite $Cu_4(SO_4)(OH)_6$ (1.95); Delafossite $CuFeO_2$ (3.77); Ferrite-Cu $CuFe_2O_4$ (10.82); Malachite $Cu_2CO_3(OH)_2$ (1.62); Tenorite CuO (2.13)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (15.18)
Fe iron		Ferrite-Ca $CaFe_2O_4$ (5.67); Ferrite-Mg $MgFe_2O_4$ (6.15); Goethite FeOOH (5.24); Hematite Fe_2O_3 (11.41)
Hg mercury		Calomel Hg_2Cl_2 (5.50); Montroydite HgO (10.77)
Mn manganese		Birnessite $Mn_8O_{14}:5H_2O$ (63.70); Bixbyite Mn_2O_3 (13.08); Manganite MnO(OH) (7.12); Pyrolusite MnO_2 (11.01)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Bunsenite NiO (0.34); $Ni(OH)_2$ (0.09); Trevorite $NiFe_2O_4$ (14.64)
Pb lead		Cerussite $PbCO_3$ (0.34); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (1.61); Plattnerite PbO_2 (1.49)
Ra radium		$RaSO_4$ (1.62)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (27.60); Sb_2O_5 (33.66)
Se selenium	SeO_4^{-2}	
Sr strontium		Strontianite $SrCO_3$ (2.05)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (12.06); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (10.54); Zincite ZnO (1.15); $Zn(OH)_2$ (gamma) (1.30)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = nitrogen couple, pe = 14.2, pH = 6

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69)
Al aluminum		Boehmite AlO(OH) (1.40); Diaspore AlO(OH) (1.83); Gibbsite $Al(OH)_3$ (1.31)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.51); Witherite $BaCO_3$ (1.34)
Be beryllium		Bromellite BeO (5.50)
Cd cadmium	Cd^{+2}	
Co cobalt		$CoFe_2O_4$ (16.44)
Cr chromium	$HCrO_4^-$	
Cu copper		Delafossite $CuFeO_2$ (1.79); Ferrite-Cu $CuFe_2O_4$ (7.36)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (4.77)
Fe iron		Goethite FeOOH (5.29); Hematite Fe_2O_3 (11.51)
Hg mercury		Calomel Hg_2Cl_2 (3.31); Montroydite HgO (2.77)
Mn manganese		Birnessite $Mn_8O_{14}:5H_2O$ (11.69); Bixbyite Mn_2O_3 (1.60); Manganite MnO(OH) (1.38); Pyrolusite MnO_2 (3.75)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (6.94)
Pb lead	Pb^{+2}	
Ra radium		$RaSO_4$ (1.59)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (24.56); Sb_2O_5 (27.58)
Se selenium	SeO_4^{-2}	
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium[2]		Carnotite $K_2(UO_2)_2(VO_4)_2$ (0.71); Tyuyamunite $Ca(UO_2)_2(VO_4)_2$ (1.72)
V vanadium[2]		Carnotite $K_2(UO_2)_2(VO_4)_2$ (0.71); Tyuyamunite $Ca(UO_2)_2(VO_4)_2$ (1.72)
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (6.54)

[1]Minimal coverage in LLNL database.
[2]All other non-silicate U and V minerals were undersaturated.

Condition: Maximum James River constituents, pe = nitrogen couple, pe = 13.0, pH = 7

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69)
Al aluminum		Boehmite AlO(OH) (2.05); Corundum Al_2O_3 (0.64); Diaspore AlO(OH) (2.48); Gibbsite $Al(OH)_3$ (1.96)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.50); Witherite $BaCO_3$ (2.77)
Be beryllium		Bromellite BeO (7.49)
Cd cadmium		Otavite $CdCO_3$ (0.02)
Co cobalt		$CoFe_2O_4$ (19.19); Spinel-Co Co_3O_4(0.44)
Cr chromium	CrO_4^{-2}	
Cu copper		Delafossite $CuFeO_2$ (3.53); Ferrite-Cu $CuFe_2O_4$ (9.35)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (9.83)
Fe iron		Goethite FeOOH (5.73); Hematite Fe_2O_3 (12.40)
Hg mercury		Calomel Hg_2Cl_2 (5.17); Montroydite HgO (4.50)
Mn manganese		Birnessite Mn_8O_{14}:$5H_2O$ (25.08); Bixbyite Mn_2O_3 (5.15); Manganite MnO(OH) (3.15); Pyrolusite MnO_2 (5.33)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (9.82)
Pb lead		Cerussite $PbCO_3$ (0.71)
Ra radium		$RaSO_4$ (1.58)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (24.16); Sb_2O_5 (26.78)
Se selenium	SeO_4^{-2}	
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^{+}	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (9.40); $ZnCO_3$:H_2O (0.10)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = nitrogen couple, pe = 11.8, pH = 8

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69)
Al aluminum		Boehmite AlO(OH) (2.55); Corundum Al_2O_3 (1.65); Diaspore AlO(OH) (2.98); Gibbsite $Al(OH)_3$ (2.46)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.49); Barytocalcite $BaCa(CO_3)_2$ (0.89); Witherite $BaCO_3$ (3.85)
Be beryllium		Bromellite BeO (9.48)
Cd cadmium		Otavite $CdCO_3$ (1.08)
Co cobalt		$CoFe_2O_4$ (18.89)
Cr chromium	CrO_4^{-2}	
Cu copper		Ferrite-Cu $CuFe_2O_4$ (10.43); Malachite $Cu_2CO_3(OH)_2$ (0.88); Tenorite CuO (0.61)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (13.08)
Fe iron		$Fe(OH)_3$ (0.49); Ferrite-Ca $CaFe_2O_4$ (3.03); Ferrite-Mg $MgFe_2O_4$ (3.42); Goethite FeOOH (5.81); Hematite Fe_2O_3 (12.55)
Hg mercury		Calomel Hg_2Cl_2 (5.49); Montroydite HgO (5.46)
Mn manganese		Birnessite $Mn_8O_{14}:5H_2O$ (37.56); Bixbyite Mn_2O_3 (8.47); Manganite MnO(OH) (4.81); Pyrolusite MnO_2 (6.79); Rhodochrosite $MnCO_3$ (0.73)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (11.97)
Pb lead		Cerussite $PbCO_3$ (0.77); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (0.58)
Ra radium		$RaSO_4$ (1.58)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (23.76); Sb_2O_5 (25.98)
Se selenium	SeO_4^{-2}	
Sr strontium		Strontianite $SrCO_3$ (0.45)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (11.49); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (6.66); Smithsonite $ZnCO_3$ (0.53); $ZnCO_3:H_2O$ (1.12)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = nitrogen couple, pe = 10.6, pH = 9

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.68)
Al aluminum		Boehmite AlO(OH) (1.77); Corundum Al_2O_3 (0.07); Diaspore AlO(OH) (2.19); Gibbsite $Al(OH)_3$ (1.68)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.49); Barytocalcite $BaCa(CO_3)_2$ (2.75); Witherite $BaCO_3$ (4.80)
Be beryllium		Bromellite BeO (9.19)
Cd cadmium		Otavite $CdCO_3$ (1.95)
Co cobalt		$CoFe_2O_4$ (17.72)
Cr chromium	CrO_4^{-2}	
Cu copper		Brochantite $Cu_4(SO_4)(OH)_6$ (1.13); Ferrite-Cu $CuFe_2O_4$ (11.08); Malachite $Cu_2CO_3(OH)_2$ (1.49); Tenorite CuO (1.44)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (15.00)
Fe iron		$Fe(OH)_3$ (0.40); Ferrite-Ca $CaFe_2O_4$ (4.81); Ferrite-Mg $MgFe_2O_4$ (5.21); Goethite FeOOH (5.72); Hematite Fe_2O_3 (12.37)
Hg mercury		Calomel Hg_2Cl_2 (5.51); Montroydite HgO (6.27)
Mn manganese		Birnessite $Mn_8O_{14}:5H_2O$ (46.92); Bixbyite Mn_2O_3 (11.01); Manganite MnO(OH) (6.08); Pyrolusite MnO_2 (5.60); Rhodochrosite $MnCO_3$ (1.16)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (13.79)
Pb lead		Cerussite $PbCO_3$ (0.67); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (1.33)
Ra radium		$RaSO_4$ (1.59)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (23.36); Sb_2O_5 (25.18)
Se selenium	SeO_4^{-2}	
Sr strontium		Strontianite $SrCO_3$ (1.39)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (12.75); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (11.73); Smithsonite $ZnCO_3$ (0.92); Zincite ZnO (0.88)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = nitrogen couple, pe = 9.4, pH = 10

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.62)
Al aluminum		Boehmite AlO(OH) (0.77); Diaspore AlO(OH) (1.20); Gibbsite $Al(OH)_3$ (0.68)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.47); Barytocalcite $BaCa(CO_3)_2$ (3.98); Witherite $BaCO_3$ (5.48)
Be beryllium		Bromellite BeO (7.20)
Cd cadmium		Otavite $CdCO_3$ (2.04)
Co cobalt		$CoFe_2O_4$ (15.76)
Cr chromium	CrO_4^{-2}	
Cu copper		Brochantite $Cu_4(SO_4)(OH)_6$ (1.96); Ferrite-Cu $CuFe_2O_4$ (10.82); Malachite $Cu_2CO_3(OH)_2$ (1.62); Tenorite CuO (2.13)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (15.18)
Fe iron		Ferrite-Ca $CaFe_2O_4$ (5.67); Ferrite-Mg $MgFe_2O_4$ (6.15); Goethite FeOOH (5.24); Hematite Fe_2O_3 (11.41)
Hg mercury		Calomel Hg_2Cl_2 (5.52); Montroydite HgO (7.08)
Mn manganese		Birnessite $Mn_8O_{14}:5H_2O$ (55.20); Bixbyite Mn_2O_3 (13.08); Manganite MnO(OH) (7.21); Pyrolusite MnO_2 (8.79); Rhodochrosite $MnCO_3$ (1.22)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Bunsenite NiO (0.34); $Ni(OH)_2$ (0.09); Trevorite $NiFe_2O_4$ (14.64)
Pb lead		Cerussite $PbCO_3$ (0.34); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (1.61)
Ra radium		$RaSO_4$ (1.62)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (22.96); Sb_2O_5 (24.37)
Se selenium	SeO_4^{-2}	
Sr strontium		Strontianite $SrCO_3$ (2.05)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (12.06); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (10.54); Zincite ZnO (1.15); $Zn(OH)_2$ (gamma) (1.30)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = chromium couple, pe = 10.3, pH = 6

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69)
Al aluminum		Boehmite AlO(OH) (1.40); Diaspore AlO(OH) (1.83); Gibbsite $Al(OH)_3$ (1.31)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.51); Witherite $BaCO_3$ (1.34)
Be beryllium		Bromellite BeO (5.50)
Cd cadmium[1]		$CdCr_2O_4$ (6.91)
Co cobalt		$CoFe_2O_4$ (16.44)
Cr chromium		Chromite $FeCr_2O_4$ (4.39); Eskolaite Cr_2O_3 (9.27); Magnesiochromite $MgCr_2O_4$ (3.44)
Cu copper		$CuCr_2O_4$ (6.82); Ferrite-Cu $CuFe_2O_4$ (7.36)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (4.78)
Fe iron		Goethite FeOOH (5.29); Hematite Fe_2O_3 (11.51); Magnetite Fe_3O_4 (3.67)
Hg mercury		Calomel Hg_2Cl_2 (5.53)
Mn manganese[3]	Mn^{+2}	
Mo molybdenum[2]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (6.94)
Pb lead	Pb^{+2}	
Ra radium		$RaSO_4$ (1.59)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (16.79); Sb_2O_5 (12.04)
Se selenium	SeO_4^{-2}	
Sr strontium	Sr^{+2}	
Tl thallium[2]	Tl^{+}	
U uranium[3]		Carnotite $K_2(UO_2)_2(VO_4)_2$ (0.72); Tyuyamunite $Ca(UO_2)_2(VO_4)_2$ (1.72)
V vanadium[3]		Carnotite $K_2(UO_2)_2(VO_4)_2$ (0.71); Tyuyamunite $Ca(UO_2)_2(VO_4)_2$ (1.72)
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (6.54); $ZnCr_2O_4$ (16.29)

[1]All other non-silicate Cd minerals were undersaturated.
[2]Minimal coverage in LLNL database.
[3]All other non-silicate U and V minerals were undersaturated.

Condition: Maximum James River constituents, pe = chromium couple, pe = 8.4, pH = 7

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69)
Al aluminum		Boehmite AlO(OH) (2.05); Corundum Al_2O_3 (0.64); Diaspore AlO(OH) (2.48); Gibbsite $Al(OH)_3$ (1.96)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.50); Witherite $BaCO_3$ (2.77)
Be beryllium		Bromellite BeO (7.49)
Cd cadmium		$CdCr_2O_4$ (11.29); Otavite $CdCO_3$ (0.02)
Co cobalt		$CoFe_2O_4$ (19.19)
Cr chromium		Chromite $FeCr_2O_4$ (8.18); Eskolaite Cr_2O_3 (11.68); Magnesiochromite $MgCr_2O_4$ (7.84)
Cu copper		$CuCr_2O_4$ (10.32); Ferrite-Cu $CuFe_2O_4$ (9.35)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (9.83)
Fe iron		$Fe(OH)_3$ (0.41); Ferrite-Ca $CaFe_2O_4$ (0.89); Ferrite-Mg $MgFe_2O_4$ (1.27); Goethite FeOOH (5.73); Hematite Fe_2O_3 (12.40)
Hg mercury		Calomel Hg_2Cl_2 (5.51); Montroydite HgO (0.05)
Mn manganese	Mn^{+2}	
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (9.82)
Pb lead		Cerussite $PbCO_3$ (0.71)
Ra radium		$RaSO_4$ (1.58)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (14.92); Sb_2O_5 (8.30)
Se selenium	SeO_4^{-2}	
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^{+}	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (9.40); $ZnCO_3:H_2O$ (0.10); $ZnCr_2O_4$ (20.67)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = chromium couple, pe = 6.4, pH = 8

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69)
Al aluminum		Boehmite AlO(OH) (2.55); Corundum Al_2O_3 (1.65); Diaspore AlO(OH) (2.98); Gibbsite $Al(OH)_3$ (2.46)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.49); Barytocalcite $BaCa(CO_3)_2$ (0.89); Witherite $BaCO_3$ (3.85)
Be beryllium		Bromellite BeO (9.48)
Cd cadmium		Otavite $CdCO_3$ (1.08)
Co cobalt		$CoFe_2O_4$ (18.89)
Cr chromium		Chromite $FeCr_2O_4$ (10.96); Eskolaite Cr_2O_3 (13.45); Magnesiochromite $MgCr_2O_4$ (11.60)
Cu copper		Ferrite-Cu $CuFe_2O_4$ (10.43); Malachite $Cu_2CO_3(OH)_2$ (0.88); Tenorite CuO (0.61)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (13.08)
Fe iron		$Fe(OH)_3$ (0.49); Ferrite-Ca $CaFe_2O_4$ (3.03); Ferrite-Mg $MgFe_2O_4$ (3.42); Goethite FeOOH (5.81); Hematite Fe_2O_3 (12.55)
Hg mercury		Calomel Hg_2Cl_2 (5.51); Montroydite HgO (0.12)
Mn manganese		Rhodochrosite $MnCO_3$(0.73)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (11.97)
Pb lead		Cerussite $PbCO_3$ (0.77); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (0.58)
Ra radium		$RaSO_4$ (1.58)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (13.04); Sb_2O_5 (4.54)
Se selenium	SeO_4^{-2}	
Sr strontium		Strontianite $SrCO_3$ (0.45)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (11.49); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (6.66); Smithsonite $ZnCO_3$ (0.53); $ZnCO_3:H_2O$ (1.12)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = chromium couple, pe = 4.7, pH = 9

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.68)
Al aluminum		Boehmite AlO(OH) (1.77); Corundum Al_2O_3 (0.07); Diaspore AlO(OH) (2.19); Gibbsite $Al(OH)_3$ (1.68)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.49); Barytocalcite $BaCa(CO_3)_2$ (2.75); Witherite $BaCO_3$ (4.80)
Be beryllium		Bromellite BeO (9.19)
Cd cadmium		$CdCr_2O_4$ (17.56); Otavite $CdCO_3$ (1.95)
Co cobalt		$CoFe_2O_4$ (17.72)
Cr chromium		Chromite $FeCr_2O_4$ (12.24); $CuCr_2O_4$ (14.46); Eskolaite Cr_2O_3 (14.05); Magnesiochromite $MgCr_2O_4$ (14.18)
Cu copper		Brochantite $Cu_4(SO_4)(OH)_6$ (1.13); $CuCr_2O_4$ (14.46); Ferrite-Cu $CuFe_2O_4$ (11.08); Malachite $Cu_2CO_3(OH)_2$ (1.49); Tenorite CuO (1.44)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (15.00)
Fe iron		$Fe(OH)_3$ (0.40); Ferrite-Ca $CaFe_2O_4$ (4.81); Ferrite-Mg $MgFe_2O_4$ (5.21); Goethite FeOOH (5.72); Hematite Fe_2O_3 (12.37)
Hg mercury		Calomel Hg_2Cl_2 (5.51); Montroydite HgO (0.35)
Mn manganese		Rhodochrosite $MnCO_3$(1.16)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (13.79)
Pb lead		Cerussite $PbCO_3$ (0.67); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (1.33)
Ra radium		$RaSO_4$ (1.59)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (11.52); Sb_2O_5 (1.49)
Se selenium		Hg_2SeO_3 (1.18)
Sr strontium		Strontianite $SrCO_3$ (1.39)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (12.75); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (11.73); Smithsonite $ZnCO_3$ (0.92); Zincite ZnO (0.88)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = chromium couple, pe = 3.2, pH = 10

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.62)
Al aluminum		Boehmite AlO(OH) (0.77); Diaspore AlO(OH) (1.20); Gibbsite $Al(OH)_3$ (0.68)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.47); Barytocalcite $BaCa(CO_3)_2$ (3.98); Witherite $BaCO_3$ (5.48)
Be beryllium		Bromellite BeO (7.20)
Cd cadmium		$CdCr_2O_4$ (17.87); Otavite $CdCO_3$ (2.04)
Co cobalt		$CoFe_2O_4$ (15.76)
Cr chromium		Chromite $FeCr_2O_4$ (11.20); Eskolaite Cr_2O_3 (13.01); Magnesiochromite $MgCr_2O_4$ (15.03); $ZnCr_2O_4$ (25.65)
Cu copper		Brochantite $Cu_4(SO_4)(OH)_6$ (1.96); Ferrite-Cu $CuFe_2O_4$ (10.82); Malachite $Cu_2CO_3(OH)_2$ (1.62); Tenorite CuO (2.13)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (15.18)
Fe iron		Ferrite-Ca $CaFe_2O_4$ (5.67); Ferrite-Mg $MgFe_2O_4$ (6.15); Goethite FeOOH (5.24); Hematite Fe_2O_3 (11.41)
Hg mercury		Calomel Hg_2Cl_2 (5.52); Montroydite HgO (0.86)
Mn manganese		Hausmannite Mn_3O_4 (2.76); Manganite MnO(OH) (0.16); Rhodochrosite $MnCO_3$ (1.22)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Bunsenite NiO (0.34); $Ni(OH)_2$ (0.09); Trevorite $NiFe_2O_4$ (14.64)
Pb lead		Cerussite $PbCO_3$ (0.34); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (1.61)
Ra radium		$RaSO_4$ (1.62)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (10.53)
Se selenium		Hg_2SeO_3 (1.20); Naumannite Ag_2Se (0.42)
Sr strontium		Strontianite $SrCO_3$ (2.05)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (12.06); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (10.54); Zincite ZnO (1.15); $Zn(OH)_2$ (gamma) (1.30)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = iron couple, pe = 5.5, pH = 6

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69); Naumannite Ag_2Se (9.30)
Al aluminum		Boehmite AlO(OH) (1.40); Diaspore AlO(OH) (1.83); Gibbsite $Al(OH)_3$ (1.31)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.50); Witherite $BaCO_3$ (1.34)
Be beryllium		Bromellite BeO (5.50)
Cd cadmium[1]		$CdCr_2O_4$ (6.82)
Co cobalt		$CoFe_2O_4$ (15.84)
Cr chromium		Chromite $FeCr_2O_4$ (7.40); Eskolaite Cr_2O_3 (9.18); Magnesiochromite $MgCr_2O_4$ (3.35)
Cu copper		$CuCr_2O_4$ (6.72); Ferrite-Cu $CuFe_2O_4$ (3.99); Klockmannite CuSe (0.34)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (4.77)
Fe iron		Goethite FeOOH (3.61); Hematite Fe_2O_3 (8.14); Magnetite Fe_3O_4 (3.67)
Hg mercury		Calomel Hg_2Cl_2 (5.53); Tiemannite HgSe (8.99)
Mn manganese	Mn^{+2}	
Mo molybdenum[2]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (3.58)
Pb lead	Pb^{+2}	
Ra radium		$RaSO_4$ (1.59)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (7.22)
Se selenium		Klockmannite CuSe (0.34); Naumannite Ag_2Se (9.30); Tiemannite HgSe (08.99)
Sr strontium	Sr^{+2}	
Tl thallium[2]	Tl^{+}	
U uranium[3]		Carnotite $K_2(UO_2)_2(VO_4)_2$ (0.71); Tyuyamunite $Ca(UO_2)_2(VO_4)_2$ (1.72)
V vanadium[3]		Carnotite $K_2(UO_2)_2(VO_4)_2$ (0.71); Tyuyamunite $Ca(UO_2)_2(VO_4)_2$ (1.72)
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (3.17); $ZnCr_2O_4$ (16.19)

[1]All other non-silicate Cd minerals were undersaturated.
[2]Minimal coverage in LLNL database.
[3]All other non-silicate U and V minerals were undersaturated.

Condition: Maximum James River constituents, pe = iron couple, pe = 3.2, pH = 7

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69); Naumannite Ag_2Se (18.11)
Al aluminum		Boehmite AlO(OH) (2.05); Corundum Al_2O_3 (0.64); Diaspore AlO(OH) (2.48); Gibbsite $Al(OH)_3$ (1.96)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.49); Witherite $BaCO_3$ (2.77)
Be beryllium		Bromellite BeO (7.49)
Cd cadmium		$CdCr_2O_4$ (11.20); Otavite $CdCO_3$ (0.02)
Co cobalt		$CoFe_2O_4$ (15.82)
Cr chromium		Chromite $FeCr_2O_4$ (8.18); Eskolaite Cr_2O_3 (11.59); Magnesiochromite $MgCr_2O_4$ (7.74)
Cu copper		$CuCr_2O_4$ (10.23); Cuprite Cu_2O (2.63); Ferrite-Cu $CuFe_2O_4$ (5.98); Klockmannite CuSe (8.25)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (9.83)
Fe iron		$Fe(OH)_3$ (0.41); Ferrite-Ca $CaFe_2O_4$ (0.89); Ferrite-Mg $MgFe_2O_4$ (1.27); Goethite FeOOH (4.05); Hematite Fe_2O_3 (9.03)
Hg mercury		Calomel Hg_2Cl_2 (5.51); Montroydite HgO (0.05)
Mn manganese	Mn^{+2}	
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Penroseite $NiSe_2$ (0.40); Trevorite $NiFe_2O_4$ (6.46)
Pb lead		Cerussite $PbCO_3$ (0.71); Clausthalite PbSe(1.58)
Ra radium		$RaSO_4$ (1.58)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (4.55)
Se selenium		Clausthalite PbSe (1.58); Klockmannite CuSe (8.25); Krutaite $CuSe_2$ (9.83); Naumannite Ag_2Se (18.11); Penroseite $NiSe_2$ (0.40)
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^{+}	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (6.04); $ZnCO_3{:}H_2O$ (0.10); $ZnCr_2O_4$ (20.58)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = iron couple, pe = 0.4, pH = 8

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.69); Naumannite Ag_2Se (29.15)
Al aluminum		Boehmite AlO(OH) (2.55); Corundum Al_2O_3 (1.65); Diaspore AlO(OH) (2.98); Gibbsite $Al(OH)_3$ (2.46)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.49); Barytocalcite $BaCa(CO_3)_2$ (0.89); Witherite $BaCO_3$ (3.85)
Be beryllium		Bromellite BeO (9.48)
Cd cadmium		Otavite $CdCO_3$ (1.08)
Co cobalt		$CoFe_2O_4$ (15.53)
Cr chromium		Chromite $FeCr_2O_4$ (15.21); Eskolaite Cr_2O_3 (13.36); Magnesiochromite $MgCr_2O_4$ (11.51)
Cu copper		$CuCr_2O_4$ (12.74); Cuprite Cu_2O (7.69); Ferrite-Cu $CuFe_2O_4$ (6.88); Klockmannite CuSe (18.04); Malachite $Cu_2CO_3(OH)_2$ (0.50); Tenorite CuO (0.42)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (13.08)
Fe iron		$Fe(OH)_3$ (0.49); Ferrite-Ca $CaFe_2O_4$ (3.03); Ferrite-Mg $MgFe_2O_4$ (3.42); Goethite FeOOH (4.12); Hematite Fe_2O_3 (12.55); Hercynite $FeAl_2O_4$ (0.35); Magnetite Fe_3O_4 (8.09)
Hg mercury		Calomel Hg_2Cl_2 (5.51); Tiemannite HgSe (23.72)
Mn manganese		Rhodochrosite $MnCO_3$(0.73)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (8.61)
Pb lead		Cerussite $PbCO_3$ (0.77); Clausthalite PbSe(11.60); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (0.58)
Ra radium		$RaSO_4$ (1.58)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (0.99)
Se selenium		Clausthalite PbSe(11.60); Ferrolselite $FeSe_2$ (7.15); Klockmannite CuSe (18.04); Krutaite $CuSe_2$ (25.08); Naumannite Ag_2Se (29.15); Tiemannite HgSe (23.72)
Sr strontium		Strontianite $SrCO_3$ (0.45)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (8.13); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (6.66); Smithsonite $ZnCO_3$ (0.53); $ZnCO_3:H_2O$ (1.12)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = iron couple, pe = -2.3, pH = 9

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.68); Naumannite Ag_2Se (34.61)
Al aluminum		Boehmite AlO(OH) (1.77); Corundum Al_2O_3 (0.07); Diaspore AlO(OH) (2.19); Gibbsite $Al(OH)_3$ (1.68)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.49); Barytocalcite $BaCa(CO_3)_2$ (2.75); Witherite $BaCO_3$ (4.80)
Be beryllium		Bromellite BeO (9.19)
Cd cadmium		$CdCr_2O_4$ (17.46); Otavite $CdCO_3$ (1.95)
Co cobalt		$CoFe_2O_4$ (14.36); Freboldite CoSe (1.04)
Cr chromium		Chromite $FeCr_2O_4$ (12.24); $CuCr_2O_4$ (14.46); Eskolaite Cr_2O_3 (13.96); Magnesiochromite $MgCr_2O_4$ (14.18)
Cu copper		$CuCr_2O_4$ (13.11); Cuprite Cu_2O (10.55); Ferrite-Cu $CuFe_2O_4$ (6.46); Malachite $Cu_2CO_3(OH)_2$ (1.49); Tenorite CuO (0.18)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (15.00)
Fe iron		$Fe(OH)_3$ (0.40); Ferrite-Ca $CaFe_2O_4$ (1.45); Ferrite-Mg $MgFe_2O_4$ (1.85); Goethite FeOOH (4.04); Hematite Fe_2O_3 (9.00); Hercynite $FeAl_2O_4$ (0.35); Magnetite Fe_3O_4 (9.48); Siderite $FeCO_3$ (0.29)
Hg mercury		Calomel Hg_2Cl_2 (5.51); Naumannite Ag_2Se (34.61)
Mn manganese		Rhodochrosite $MnCO_3$(1.16)
Mo molybdenum[1]		$MoSe_2$ (3.71)
Ni nickel		Trevorite $NiFe_2O_4$ (10.43)
Pb lead		Cerussite $PbCO_3$ (0.67); Clausthalite PbSe (16.04); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (1.33)
Ra radium		$RaSO_4$ (1.59)
Sb antimony		$Sb(OH)_3$ (1.01)
Se selenium		Clausthalite PbSe (16.04); Freboldite CoSe (1.04); Hg_2SeO_3 (1.18); Klockmannite CuSe (21.29); Krutaite $CuSe_2$ (28.51); Naumannite Ag_2Se (34.61); Stilleite ZnSe (7.18); Wilkmanite Ni_3Se_4 (41.32)
Sr strontium		Strontianite $SrCO_3$ (1.39)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (9.38); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (11.73); Smithsonite $ZnCO_3$ (0.92); Zincite ZnO (0.88)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = iron couple, pe = -5.1, pH = 10

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.62)
Al aluminum		Boehmite AlO(OH) (0.77); Diaspore AlO(OH) (1.20); Gibbsite $Al(OH)_3$ (0.68)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.47); Barytocalcite $BaCa(CO_3)_2$ (3.98); Witherite $BaCO_3$ (5.48)
Be beryllium		Bromellite BeO (7.20)
Cd cadmium		$CdCr_2O_4$ (17.77); Otavite $CdCO_3$ (2.03)
Co cobalt		$CoFe_2O_4$ (12.40)
Cr chromium		Chromite $FeCr_2O_4$ (17.39); Eskolaite Cr_2O_3 (12.92); Magnesiochromite $MgCr_2O_4$ (14.94); $ZnCr_2O_4$ (25.65)
Cu copper		Cuprite Cu_2O (12.60); Ferrite-Cu $CuFe_2O_4$ (4.68); Tenorite CuO (2.13)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (15.18)
Fe iron		Ferrite-Ca $CaFe_2O_4$ (2.31); Ferrite-Mg $MgFe_2O_4$ (2.79); Goethite FeOOH (3.56); Hematite Fe_2O_3 (8.04) Magnetite Fe_3O_4 (9.90); Siderite $FeCO_3$ (0.39)
Hg mercury		Calomel Hg_2Cl_2 (5.52); Naumannite Ag_2Se (35.49)
Mn manganese		Hausmannite Mn_3O_4 (2.76); Manganite MnO(OH) (0.16); Rhodochrosite $MnCO_3$ (1.22)
Mo molybdenum[1]		$MoSe_2$ (3.43)
Ni nickel		Bunsenite NiO (0.34); $Ni(OH)_2$ (0.09); Trevorite $NiFe_2O_4$ (11.28); Wilkmanite Ni_3Se_4 (29.04)
Pb lead		Cerussite $PbCO_3$ (0.34); Clausthalite PbSe (16.04); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (1.61)
Ra radium		$RaSO_4$ (1.62)
Sb antimony		$Sb(OH)_3$ (1.01)
Se selenium		Clausthalite PbSe (16.04); Hg_2SeO_3 (1.20); Klockmannite CuSe (19.46); Krutaite $CuSe_2$ (21.97); Naumannite Ag_2Se (35.49); Stilleite ZnSe (6.45); Wilkmanite Ni_3Se_4 (29.04)
Sr strontium		Strontianite $SrCO_3$ (2.05)
Tl thallium[1]	Tl^+	
U uranium		$UO_{2.25}$ (1.43); Uraninite UO_2 (2.94)
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (8.69); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (10.54); Zincite ZnO (1.15); $Zn(OH)_2$ (gamma) (1.30)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = sulfur couple, pe = -2.2, pH = 6

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Acanthite Ag_2S (26.56); Chlorargyrite AgCl (0.69); Naumannite Ag_2Se (31.64)
Al aluminum		Boehmite AlO(OH) (1.41); Diaspore AlO(OH) (1.84); Gibbsite $Al(OH)_3$ (1.32)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.42)
Be beryllium		Bromellite BeO (5.50)
Cd cadmium		$CdCr_2O_4$ (6.85); CdS (11.92)
Co cobalt		Cattierite CoS_2 (12.58); CoS (1.64); Freboldite CoSe (2.04); Linnaeite Co_3S_4 (22.22)
Cr chromium		Chromite $FeCr_2O_4$ (7.63); Eskolaite Cr_2O_3 (9.19); Magnesiochromite $MgCr_2O_4$ (3.39)
Cu copper		Bornite Cu_5FeS_4 (80.45); Chalcocite (Cu_2S) (28.86); Covellite CuS (16.04); $CuCr_2O_4$ (2.39); Cuprite Cu_2O (4.60); Delafossite $CuFeO_2$ (4.64); Klockmannite CuSe (18.34); Umangite Cu_3Se_2 (48.16)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (4.91)
Fe iron		Pyrite FeS_s (10.74); Pyrrhotite FeS (0.06); Troilite FeS (0.17)
Hg mercury		Calomel Hg_2Cl_2 (5.54); Cinnabar HgS (20.79); Metacinnabar HgS (20.39); Tiemannite HgSe (23.58)
Mn manganese	Mn^{+2}	
Mo molybdenum[1]		$MoSe_2$ (21.70)
Ni nickel		Heazlewoodite Ni_3S_2 (4.37); Millerite NiS (3.87); Penroseite $NiSe_2$ (16.64); Vaesite NiS_2 (12.15)
Pb lead		Clausthalite PbSe (15.90); Galena PbS (10.83)
Ra radium		$RaSO_4$ (1.50)
Sb antimony		Stibnite Sb_2S_3 (0.79)
Se selenium		Ferroselite $FeSe_2$ (7.43); Klockmannite CuSe (18.34); Krutaite $CuSe_2$ (22.60); Naumannite Ag_2Se (31.64); Tiemannite HgSe (23.58)
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^{+}	
U uranium		$UO_{2.25}$ (0.90); $UO_{2.25}$ (beta) (0.82); Uraninite UO_2 (2.98)
V vanadium		Karelianite V_2O_3 (0.84); V_3O_5 (0.54)
Zn zinc		Sphalerite ZnS (9.14); Stilleite ZnSe (4.87); Wurtzite ZnS (6.72); $ZnCr_2O_4$ (16.24)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = sulfur couple, pe = -3.5, pH = 7

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Acanthite Ag_2S (28.36); Chlorargyrite AgCl (0.69); Naumannite Ag_2Se (32.64)
Al aluminum		Boehmite AlO(OH) (2.06); Corundum Al_2O_3 (0.67); Diaspore AlO(OH) (2.49); Gibbsite $Al(OH)_3$ (1.97)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.42)
Be beryllium		Bromellite BeO (7.50)
Cd cadmium		Cadmoselite CdSe (12.83); $CdCr_2O_4$ (11.25); CdS (13.72)
Co cobalt		Cattierite CoS_2 (12.58); $CoFe_2O_4$ (1.04); CoS (2.55); Freboldite CoSe (2.14); Linnaeite Co_3S_4 (24.28)
Cr chromium		Chromite $FeCr_2O_4$ (12.03); Eskolaite Cr_2O_3 (11.60); Magnesiochromite $MgCr_2O_4$ (7.79)
Cu copper		Bornite Cu_5FeS_4 (86.44); Chalcocite (Cu_2S) (30.66); Chalcopyrite $CuFeS_2$ (24.79); Covellite CuS (16.61); $CuCr_2O_4$ (5.57); Cuprite Cu_2O (6.60); Delafossite $CuFeO_2$ (7.42); Klockmannite CuSe (18.12); Umangite Cu_3Se_2 (48.94)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (10.00)
Fe iron		Pyrite FeS_s (10.74); Pyrrhotite FeS (1.86); Troilite FeS (1.97)
Hg mercury		Calomel Hg_2Cl_2 (5.54); Cinnabar HgS (21.37); Metacinnabar HgS (20.97); Tiemannite HgSe (23.35)
Mn manganese	Mn^{+2}	
Mo molybdenum[1]		$MoSe_2$ (18.16)
Ni nickel		Heazlewoodite Ni_3S_2 (10.42); Millerite NiS (5.67); Penroseite $NiSe_2$ (16.19); Vaesite NiS_2 (13.31)
Pb lead		Clausthalite PbSe (16.85); Galena PbS (12.59)
Ra radium		$RaSO_4$ (1.50)
Sb antimony	$HSb_2S_4^-$	
Se selenium		Ferroselite $FeSe_2$ (6.98); Klockmannite CuSe (18.12); Krutaite $CuSe_2$ (20.92); Naumannite Ag_2Se (32.64); Tiemannite HgSe (23.35); Wilkmanite Ni_3Se_4 (31.01)
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium		$UO_{2.25}$ (0.79); $UO_{2.25}$ (beta) (0.71); Uraninite UO_2 (2.98)
V vanadium		Karelianite V_2O_3 (2.85); V_3O_5 (3.33); V_4O_7 (1.85)
Zn zinc		Sphalerite ZnS (10.94); Stilleite ZnSe (5.87); Wurtzite ZnS (8.52); $ZnCr_2O_4$ (20.64)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = sulfur couple, pe = -4.6, pH = 8

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Acanthite Ag_2S (29.70); Chlorargyrite AgCl (0.69); Hercynite $FeAl_2O_4$ (0.95); Naumannite Ag_2Se (33.64)
Al aluminum		Boehmite AlO(OH) (2.57); Corundum Al_2O_3 (1.68); Diaspore AlO(OH) (3.00); Gibbsite $Al(OH)_3$ (2.48)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.41)
Be beryllium		Bromellite BeO (9.49)
Cd cadmium		Cadmoselite CdSe (15.32); $CdCr_2O_4$ (15.02); CdS (15.05)
Co cobalt		Cattierite CoS_2 (12.56); $CoFe_2O_4$ (6.09); CoS (3.28); Freboldite CoSe (2.54); Linnaeite Co_3S_4 (25.47)
Cr chromium		Chromite $FeCr_2O_4$ (15.79); Eskolaite Cr_2O_3 (13.36); Magnesiochromite $MgCr_2O_4$ (11.56)
Cu copper		Bornite Cu_5FeS_4 (90.59); Chalcocite (Cu_2S) (32.00); Chalcopyrite $CuFeS_2$ (26.28); Covellite CuS (16.78); $CuCr_2O_4$ (8.17); Cuprite Cu_2O (8.60); Delafossite $CuFeO_2$ (10.24); Klockmannite CuSe (17.95); Umangite Cu_3Se_2 (49.77)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (13.25)
Fe iron		Hematite Fe_2O_3 (0.25); Pyrite FeS_s (12.21); Pyrrhotite FeS (3.19); Troilite FeS (3.30)
Hg mercury		Calomel Hg_2Cl_2 (5.54); Cinnabar HgS (21.54); Metacinnabar HgS (21.13); Tiemannite HgSe (23.19)
Mn manganese		Alabanite MnS (0.22)
Mo molybdenum[1]		$MoSe_2$ (14.49)
Ni nickel		Heazlewoodite Ni_3S_2 (15.42); Millerite NiS (7.01); Penroseite $NiSe_2$ (15.85); Vaesite NiS_2 (13.64)
Pb lead		Clausthalite PbSe (17.53); Galena PbS (13.60)
Ra radium		$RaSO_4$ (1.50)
Sb antimony	$HSb_2S_4^-$	
Se selenium		Ferroselite $FeSe_2$ (6.64); Klockmannite CuSe (17.95); Krutaite $CuSe_2$ (19.42); Naumannite Ag_2Se (33.64); Tiemannite HgSe (23.19); Wilkmanite Ni_3Se_4 (32.67)
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium		$UO_{2.25}$ (0.70); $UO_{2.25}$ (beta) (0.63); Uraninite UO_2 (2.98)
V vanadium		Karelianite V_2O_3 (4.82); V_2O_4 (0.99); V_3O_5 (6.11); V_4O_7 (5.45)
Zn zinc		Sphalerite ZnS (12.26); Stilleite ZnSe (6.85); Wurtzite ZnS (9.84); $ZnCr_2O_4$ (24.39)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = sulfur couple, pe = -5.8, pH = 9

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Acanthite Ag_2S (30.75); Chlorargyrite AgCl (0.69); Hercynite $FeAl_2O_4$ (1.29); Naumannite Ag_2Se (34.64)
Al aluminum		Boehmite AlO(OH) (1.77); Corundum Al_2O_3 (0.08); Diaspore AlO(OH) (2.20); Gibbsite $Al(OH)_3$ (1.68)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.42)
Be beryllium		Bromellite BeO (9.20)
Cd cadmium		Cadmoselite CdSe (16.30); $CdCr_2O_4$ (17.59); CdS (16.08)
Co cobalt		Cattierite CoS_2 (9.92); $CoFe_2O_4$ (9.21); CoS (1.85); Freboldite CoSe (1.05); Linnaeite Co_3S_4 (19.96)
Cr chromium		Chromite $FeCr_2O_4$ (18.32); Eskolaite Cr_2O_3 (13.96); Magnesiochromite $MgCr_2O_4$ (14.16)
Cu copper		Bornite Cu_5FeS_4 (93.61); Chalcocite (Cu_2S) (33.05); Chalcopyrite $CuFeS_2$ (27.19); Covellite CuS (16.70); $CuCr_2O_4$ (9.63); Cuprite Cu_2O (10.60); Delafossite $CuFeO_2$ (13.04); Klockmannite CuSe (17.82); Umangite Cu_3Se_2 (50.64)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (15.25)
Fe iron		Goethite FeOOH (1.46); Hematite Fe_2O_3 (3.85); Magnetite Fe_3O_4 (5.26); Pyrite FeS_s (11.99); Pyrrhotite FeS (4.18); Troilite FeS (4.29)
Hg mercury		Calomel Hg_2Cl_2 (5.54); Cinnabar HgS (21.46); Metacinnabar HgS (21.05); Tiemannite HgSe (23.06)
Mn manganese		Alabanite MnS (1.26)
Mo molybdenum[1]		$MoSe_2$ (10.75)
Ni nickel		Heazlewoodite Ni_3S_2 (19.78); Millerite NiS (8.06); Penroseite $NiSe_2$ (15.59); Vaesite NiS_2 (13.64)
Pb lead		Clausthalite PbSe (17.63); Galena PbS (13.48)
Ra radium		$RaSO_4$ (1.50)
Sb antimony	$HSb_2S_4^-$	
Se selenium		Ferroselite $FeSe_2$ (6.31); Klockmannite CuSe (17.82); Krutaite $CuSe_2$ (18.03); Naumannite Ag_2Se (34.64); Tiemannite HgSe (23.06); Wilkmanite Ni_3Se_4 (34.40)
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium		$UO_{2.25}$ (0.64); $UO_{2.25}$ (beta) (0.56); Uraninite UO_2 (2.98)
V vanadium		Karelianite V_2O_3 (4.09); V_2O_4 (0.01); V_3O_5 (4.90); V_4O_7 (3.74)
Zn zinc		Ferrite-Zn Fe_2O_4 (4.36); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (2.44); Sphalerite ZnS (12.77); Stilleite ZnSe (7.31); Wurtzite ZnS (10.35); $ZnCr_2O_4$ (26.45)

[1]Minimal coverage in LLNL database.

Condition: Maximum James River constituents, pe = sulfur couple, pe = -6.9, pH = 10

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Acanthite Ag_2S (31.76); Chlorargyrite AgCl (0.69); Naumannite Ag_2Se (35.64)
Al aluminum		Boehmite AlO(OH) (0.77); Diaspore AlO(OH) (1.20); Gibbsite $Al(OH)_3$ (0.68); Hercynite $FeAl_2O_4$ (0.88);
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (2.42); Witherite $BaCO_3$ (1.00)
Be beryllium		Bromellite BeO (7.21)
Cd cadmium		Cadmoselite CdSe (17.07); $CdCr_2O_4$ (18.34); CdS (16.86)
Co cobalt		Cattierite CoS_2 (6.68); $CoFe_2O_4$ (11.14); Linnaeite Co_3S_4 (12.74)
Cr chromium		Chromite $FeCr_2O_4$ (18.87); Eskolaite Cr_2O_3 (12.92); Magnesiochromite $MgCr_2O_4$ (15.12)
Cu copper		Bornite Cu_5FeS_4 (96.10); Chalcocite (Cu_2S) (34.05); Chalcopyrite $CuFeS_2$ (27.67); Covellite CuS (16.58); $CuCr_2O_4$ (9.47); Cuprite Cu_2O (12.60); Delafossite $CuFeO_2$ (15.51); Umangite Cu_3Se_2 (51.51)
F fluoride		Fluorapatite $Ca_5(PO_4)_3F$ (15.92)
Fe iron		Ferrite-Ca $CaFe_2O_4$ (1.32); Ferrite-Mg $MgFe_2O_4$ (1.70); Goethite FeOOH (2.92); Hematite Fe_2O_3 (6.78); Magnetite Fe_3O_4 (9.78); Pyrite FeS_s (11.34); Pyrrhotite FeS (4.77); Troilite FeS (4.88)
Hg mercury		Calomel Hg_2Cl_2 (5.54); Cinnabar HgS (21.34); Metacinnabar HgS (20.93); Tiemannite HgSe (22.93)
Mn manganese		Alabanite MnS (1.58)
Mo molybdenum[1]		$MoSe_2$ (7.00)
Ni nickel		Bunsenite NiO (0.35); Heazlewoodite Ni_3S_2 (23.44); Millerite NiS (8.86); $Ni(OH)_2$ (0.10); Penroseite $NiSe_2$ (15.14); Trevorite $NiFe_2O_4$ (10.03); Vaesite NiS_2 (13.04)
Pb lead		Clausthalite PbSe (17.10); Galena PbS (13.23)
Ra radium		$RaSO_4$ (1.50)
Sb antimony	$HSb_2S_4^-$	
Se selenium		Ferroselite $FeSe_2$ (5.64); Klockmannite CuSe (17.69); Krutaite $CuSe_2$ (16.65 Naumannite Ag_2Se (35.64); Tiemannite HgSe (22.93); Wilkmanite Ni_3Se_4 (35.55)
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium		$UO_{2.25}$ (0.58); $UO_{2.25}$ (beta) (0.50); Uraninite UO_2 (2.98)
V vanadium		Karelianite V_2O_3 (0.64)
Zn zinc		Ferrite-Zn Fe_2O_4 (7.44); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (1.47); Sphalerite ZnS (11.94); Stilleite ZnSe (6.47); Wurtzite ZnS (9.51); Zincite ZnO (1.16); $ZnCr_2O_4$ (25.56)

[1]Minimal coverage in LLNL database.

7.5 Appendix E

Discussion of Results for Amended Maximum James River Solution

Maximum Amended James River Results

Below are summaries for the PHREEQC results for the Maximum Amended James River solutions in Appendix D compared to State analytical water quality results for the James River and Spiritwood Aquifer.

Ag - Silver

Chlorargyrite [AgCl] was supersaturated for all conditions simulated. The James River database has 19 samples that were analyzed for Ag and the Spiritwood Aquifer database has 21 samples. All results were below detection; therefore, either Ag supplies are limited in both environments or chemical equilibrium successfully predicted that Ag will not be very soluble in either the river or the aquifer. Ag has a secondary drinking water standard of 0.100 mg/L and all detection limits were either < 0.001 mg/L or < 0.005 mg/L.

Al - Aluminum

Aluminum minerals, such as boehmite [AlO(OH)] and gibbsite [$Al(OH)_3$], were supersaturated for all conditions simulated. The James River database has 19 samples that were analyzed for Al and the Spiritwood Aquifer database has 21 samples. One of the river samples and none of the aquifer samples were above detection. Either Al supplies are limited in both environments or chemical equilibrium successfully predicted that Al will not be very soluble in either the river or the aquifer. The secondary drinking water standard for Al is 0.050 mg/L to 0.200 mg/L and the detection limits in the databases are < 0.05 mg/L and < 0.250 mg/L, respectively. Therefore, comparisons of the analytical results to the standard are inconclusive.

As - Arsenic

Arsenic was soluble as $AsO3F^{-2}$ for all conditions simulated. Had stronger sulfate-reducing conditions been simulated, minerals such as arsenopyrite [FeAsS] and orpiment [As_2S_3], may have become supersaturated. In the James River, 88.6% of the 44 samples were above detection with a maximum value of 0.011 mg/L; in the Spiritwood Aquifer, 88.5% of the 87 samples were above detection with a maximum value of 0.0354 mg/L. The primary drinking water standard is 0.010 mg/L. Chemical equilibrium modeling successfully predicted that As will be soluble in both the river and the aquifer.

Ba - Barium

Barite [$BaSO_4$] was supersaturated for all conditions simulated. Had stronger sulfate-reducing conditions been simulated, BaS may have become supersaturated. The James River database has 19 samples that were analyzed for Ba and the Spiritwood Aquifer database has 21 samples. All of the measurements were above detection, with a maximum concentration of 0.108 mg/L in the river and 0.144 mg/L in the aquifer. The primary drinking water standard for Ba is 2 mg/L. Chemical equilibrium modeling unsuccessfully predicted the solubility of Ba in both the river and the aquifer.

Be - Beryllium

Bromellite [BeO] was supersaturated for all conditions simulated. The James River database has 19 samples that were analyzed for Be and the Spiritwood Aquifer database has 21 samples. None of the measurements was above detection; therefore, Be supplies are limited in both environments or chemical equilibrium successfully predicted that Be will not be mobile in either the river or the aquifer. Be has a primary drinking

water standard of 0.004 mg/L and detection limits were either $<$ 0.001 mg/L or $<$ 0.005 mg/L. Therefore, comparisons of the analytical results to the standard are somewhat inconclusive.

Cd - Cadmium

Cd was only soluble as Cd^{+2} at pH = 6 for the oxygen and nitrogen couples. Otovite [$CdCO_3$] was supersaturated for all other conditions simulated above the sulfur couple, except for the chromium and iron couples at pH = 6 where $CdCr_2O_4$ was supersaturated (If there was no Cr in the water, Cd would have been soluble.). At sulfate-reducing conditions, CdS was supersaturated. The James River database has 19 samples that were analyzed for Cd and the minimum pH was 7.0. The Spiritwood Aquifer database has 21 samples and the minimum pH = 6.5. None of the measurements was above detection. Therefore, Cd supplies are limited in both environments or chemical equilibrium successfully predicted that Cd will not be mobile in either the river or the aquifer. Cd has a primary drinking water standard of 0.005 mg/L and detection limits were either $<$ 0.001 mg/L or $<$ 0.005 mg/L, respectively. Therefore, comparisons of the analytical results to the standard are inconclusive.

Co - Cobalt

Co was supersaturated at all conditions simulated, as either $CoFe_2O_4$ above the sulfur couple or as Cattierite [CoS_2] at sulfate-reducing conditions. No Co measurements are reported in the James River or Spiritwood Aquifer databases. Co has no drinking water standard, but it is a contaminant candidate for a possible future standard.

Cr - Chromium

Cr was soluble as either $HCrO^{-4}$ or CrO^{-2} for the oxygen and nitrogen couples, but chromite [$FeCr_2O_4$] was supersaturated for all other conditions simulated. In the James River, 21.1% of the 19 samples were above detection with a maximum value of 0.0051 mg/L; none of the Spiritwood samples was above detection limits of either $<$ 0.001 mg/L or $<$ 0.005 mg/L, respectively. All 37 river samples had detectable concentrations of nitrate and almost certainly there are dissolved oxygen concentrations in the river. In the aquifer, 67.4% of the nitrate samples (n = 765) were above detection; oxygen concentrations are generally unknown. However, aquifers in North Dakota are typically less oxidized then rivers, so in this regard chemical equilibrium modeling was successful in predicting that Cr would generally be more soluble in the river than in the aquifer. Injecting James River water will cause an initial increase in pe and create conditions favorable for an increase in Cr. As the pe decreases, Cr may also decrease. A pilot field-scale study would indicate the kinetics of these reactions. The primary drinking water standard for Cr is 0.100 mg/L.

Cu - Copper

Cu was supersaturated at all conditions simulated, as either ferrite-Cu [$CuFe_2O_4$] above the sulfur couple or as covellite [CuS] at sulfate-reducing conditions. In the James River, 53.6% of the 19 samples were above detection with a maximum value of 0.00242 mg/L; in the Spiritwood Aquifer, 19.1% of the 21 samples were above detection with a maximum value of 0.0121 mg/L. The higher rate of detection of Cu in the James suggests that the aquifer environment is closer to equilibrium for Ni. The primary drinking water stand for Cu is 1.3 mg/L, which is more than 100 times greater than the maximum concentration for the Spiritwood. Therefore, it is unlikely that Cu will be a problem with James/Spiritwood ASR.

F - Fluoride

F was supersaturated as fluorapatite [$Ca_5(PO_4)_3F$] at all conditions simulated. The James River database has 61 samples that were analyzed for F and the Spiritwood Aquifer database has 770 samples. All measurements in both environments were above detections. The mean concentration was 0.17 mg/L in the river and 0.25 mg/L in the aquifer. All concentrations were below and the primary drinking water standard of 4.0 mg/L. Therefore, it is unlikely that F will be a problem with James/Spiritwood ASR. Chemical equilibrium modeling had limited ability to predict the solubility of F in both the river and the aquifer.

Fe - Iron

Fe was supersaturated at all conditions simulated, as either oxides or hydroxides above the sulfur couple, or as sulfides at sulfate-reducing conditions. In the river, 83.8% of the 62 Fe measurements were above detection; in the aquifer, 98.1% of the 773 measurements were above detection. The mean value was 0.08 mg/L in the river and 0.95 mg/L in the aquifer. The lower mean in the river suggests that Fe concentrations are precipitating out as oxides or hydroxides, as predicted by chemical equilibrium modeling. The higher mean value in the aquifer likely indicates more production of ferrous iron (Fe^{+2}), the more soluble iron species, and suggests that the redox conditions generally prevalent in the aquifer are near the iron couple and kinetics are limiting the availability of ferric iron concentrations (Fe^{+3}), or the redox conditions are between the iron and sulfur couples. The secondary drinking water standard for Fe is 0.3 mg/L. When oxygenated James River water is initially injected into the aquifer, Fe concentrations will likely be lower than the standard initially, but they will tend to increase as pe decreases. Eventually, Fe concentrations during ASR would likely exceed 0.3 mg/L. A pilot field-scale study would indicate the kinetics of these reactions.

Hg - Mercury

Calomal [Hg_2Cl_2] was supersaturated at all conditions simulated and cinnabar [HgS] was also supersaturated at sulfate-reducing conditions. In the river, 87.5% of the 24 Hg measurements were above detection with a maximum value of 0.0050 mg/L; in the aquifer, 88.2% of the 68 measurements were above detection with a maximum value of 0.0008 mg/L. The primary drinking water standard is 0.002 mg/L and detection limits are at or near this concentration. Chemical equilibrium modeling unsuccessfully predicted the solubility of Hg in both the river and the aquifer.

Mn - Manganese

Mn was insoluble oxides and hydroxides at the oxygen and nitrogen couples. Mn as Mn^{+2} was soluble at pH = 6 and pH = 7 for the chromium, iron, and sulfide couples. For pH > 7, Mn oxides were supersaturated above sulfate-reducing conditions and alabandite [MnS] was supersaturated at sulfate-reducing conditions. In the river, all of the 62 Mn measurements were above detection with a mean concentration of 0.51 mg/L; in the aquifer, all but 1 of the 759 measurements were above detection with a mean concentrations of 0.49 mg/L. Chemical equilibrium modeling unsuccessfully predicted Mn concentrations in the river and its effectiveness in the aquifer is uncertain at this level because there were multiple redox conditions represented in the analytical data. The secondary drinking water standard for Mn is 0.05 mg/L and measurements in both river and aquifer samples typically exceed this standard.

Mo - Molybdenum

Mo had minimal coverage in PHREEQC and simulations for Mo are not discussed further. All of the 25 river samples were above detection with a maximum concentration of 0.014 mg/L; 91.3% of the 80 aquifer samples were above detection with a maximum concentration of 0.050 mg/L. Mo has no drinking water standard, but it is a contaminant candidate for a possible future standard.

Ni - Nickel

Ni was supersaturated at all conditions simulated, as Trevorite [$NiFe_2O_4$] above the sulfur couple and as millerite [NiS] at sulfate-reducing conditions. In the river, 84.2% of the 19 Ni measurements were above detection with a mean value of 0.00791 mg/L; in the aquifer, 33.3% of the 21 measurements were above detection with a maximum value of 0.00578 mg/L. There is no current primary drinking water standard for Ni, but from 1992 to 1995 the standard was 0.100 mg/L. The higher rate of detection of Ni in the James suggests that the aquifer environment is closer to equilibrium for Ni.

Pb - Lead

Pb as Pb^{+2} was soluble at pH = 6 above the sulfur couple. It was supersaturated at all other conditions simulated, as cerrussite [$PbCO_3$] above the sulfur couple and as galena [PbS] at sulfate-reducing conditions. In the river, 50.0% of the 44 Pb measurements were above detection with a maximum value of 0.002 mg/L; in the aquifer, 68.5% of the 89 measurements were above detection with a maximum value of 0.00164 mg/L. The primary drinking water standard for Pb is 0.015 mg/L. Chemical equilibrium modeling had limited ability to predict the solubility of Pb in both the river and the aquifer.

Ra - Radium

$RaSO_4$ was supersaturated at all conditions simulated. There were no State measurements for Ra in either the river or aquifer.

Sb - Antimony

Sb was supersaturated as Sb(OH) above the sulfur couple. At sulfate-reducing conditions, it was supersaturated as stibnite [Sb_2S_3] at pH = 6; otherwise it was soluble as HSb_2S_4. Presumably, stibnite would become supersaturated for pH > 6 under stronger sulfate-reducing conditions. The James River database has 19 samples that were analyzed for Sb and the Spiritwood Aquifer database has 21 samples. None of the measurements was above detection; therefore, either Sb supplies are limited in both environments or chemical equilibrium successfully predicted that Sb will not be mobile in them. Sb has a secondary drinking water standard of 0.006 mg/L and detection limits were either < 0.001 mg/L or < 0.005 mg/L, respectively.

Se - Selenium

Se as SeO_4^{-2} was soluble at the oxygen and nitrogen couple and at the chromium couple for pH < 9. At the chromium couple for pH = 9 and pH = 10, Hg_2SeO_3 was supersaturated, but this assumes that Hg is available at these conditions. At the iron and sulfur couple, numerous selenides were supersaturated. In the river, 75.0% of the 44 Se measurements were above detection with a maximum value of 0.0101 mg/L; in the aquifer, 74.7% of the 91 measurements were above detection with a maximum value of 0.00234 mg/L. The primary drinking water standard for Se is 0.050 mg/L. When oxygenated James River water is initially

injected into the aquifer, Se concentrations may initially increase, but eventually they would decrease as pe decreases. A pilot field-scale study would indicate the kinetics of these reactions.

Sr - Strontium

Sr was soluble as Sr^{+2} at pH = 6 and pH = 7 for all redox couples and it was soluble as Sr^{+2} for pH values simulated for the sulfur couple. Elsewhere, strontianite [$SrCO_3$] was supersaturated. All of the Sr measurements in the river (n = 25) and in the aquifer (n = 69) were above detection, with a maximum concentration of 0.490 mg/L in the river and a maximum concentration of 0.890 mg/L in the aquifer. These results suggest that Sr concentrations may increase with ASR. Chemical equilibrium modeling was unsuccessful in predicting that Sr would not be soluble in either the river or aquifer for pH > 7. Sr has no drinking water standard, but it is a contaminant candidate for a possible future standard.

Tl - Thallium

Tl had minimal coverage in PHREEQC and simulations for Tl are not discussed further. However, the James River database has 19 samples that were analyzed for Tl and the Spiritwood Aquifer database has 21 samples. None of the measurements was above detection. However, 11 of the James River detection limits were < 0.001 mg/L and 8 were < 0.005 mg/L; for the Spiritwood, 7 were < 0.001 mg/L and 14 were < 0.005 mg/L. The primary drinking water standard for Tl is 0.002 mg/L, so more results at the lower detection limit are needed.

U - Uranium

U as $UO_2(CO_3)_3^{-4}$ was soluble for pH > 6 for the oxygen, nitrogen, and chromium couples. For these same couples with pH = 6, carnotite [$K_2(UO_2)_2(VO_4)_2$] was supersaturated; however, this assumes that V is available. For the iron couple at pH = 6, carnotite was also supersaturated and at pH = 10 uraninite [UO_2] was supersaturated. Uraninite was supersaturated for the sulfur couple. There were no State measurements for U in either the river or aquifer.

V - Vanadium

V as VO_3OH^{-2} was soluble for pH > 6 for the oxygen, nitrogen, chromium, and iron couples. Like U for these same couples with pH = 6, carnotite was supersaturated; however, this assumes that U is available. Karelianite [V_2O_3] was supersaturated for the sulfur couple. There were no State measurements for V in either the river or aquifer. V has no drinking water standard, but it is a contaminant candidate for a possible future standard.

Zn - Zinc

Ferrite-Zn [$ZnFe_2O_4$] was supersaturated at the oxygen, nitrogen, chromium, and iron couples. Sphalerite [ZnS] was saturated at sulfate-reducing conditions. In the river, 68.4% of the 19 Zn measurements were above detection with a maximum value of 0.0308 mg/L; in the aquifer, 57.1% of the 21 measurements were above detection with a maximum value of 0.0246 mg/L. Chemical equilibrium modeling had little success in predicting that Zn would generally be soluble in either environments. However, the secondary drinking water standard for Zn is 5 mg/L and none of the measurements was close to this limit.

7.6 Appendix F

PHREEQC Results for Amended Minimum James River Solution

Condition: Minimum James River constituents, pe = oxygen couple, pe = 14.7, pH = 7

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.35)
Al aluminum		Boehmite AlO(OH) (2.15); Gibbsite $Al(OH)_3$ (2.08)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (1.77); Witherite $BaCO_3$ (2.38)
Be beryllium		Bromellite BeO (7.60)
Cd cadmium	Cd^{+2}	
Co cobalt		$CoFe_2O_4$ (17.93); Spinel-Co Co_3O_4(4.18)
Cr chromium	CrO_4^{-2}	
Cu copper		Delafossite $CuFeO_2$ (1.60); Ferrite-Cu $CuFe_2O_4$ (8.46)
F fluoride	F^-	
Fe iron		Goethite FeOOH (5.06); Hematite Fe_2O_3 (11.05)
Hg mercury		Calomel Hg_2Cl_2 (0.92); Montroydite HgO (4.90)
Mn manganese		Manganite MnO(OH) (3.91); Pyrolusite MnO_2 (7.80)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (8.65)
Pb lead		Cerussite $PbCO_3$ (0.60)
Ra radium		$RaSO_4$ (0.86)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_5 (33.66)
Se selenium	SeO_4^{-2}	
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_2^{-2}$	Carnotite $K_2(UO_2)_s(VO_4)_2$ (0.01); Tyuyamunite $Ca(UO_2)_s(VO_4)_2$ (1.52)
V vanadium	VO_3OH^{-2}	Carnotite $K_2(UO_2)_s(VO_4)_2$ (0.01); Tyuyamunite $Ca(UO_2)_s(VO_4)_2$ (1.52)
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (8.25);

[1]Minimal coverage in LLNL database.

Condition: Minimum James River constituents, pe = oxygen couple, pe = 12.7, pH = 9

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.34)
Al aluminum		Boehmite AlO(OH) (1.80); Gibbsite $Al(OH)_3$ (1.71)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (1.77); Witherite $BaCO_3$ (4.44)
Be beryllium		Bromellite BeO (9.33)
Cd cadmium		Otavite $CdCO_3$ (1.74)
Co cobalt		$CoFe_2O_4$ (16.40)
Cr chromium	CrO_4^{-2}	
Cu copper		Delafossite $CuFeO_2$ (3.53); Ferrite-Cu $CuFe_2O_4$ (10.38)
F fluoride	F^-	
Fe iron		Goethite FeOOH (5.04); Hematite Fe_2O_3 (11.02)
Hg mercury		Calomel Hg_2Cl_2 (3.89); Montroydite HgO (8.38)
Mn manganese		Pyrolusite MnO_2 (10.76)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (12.62)
Pb lead		Cerussite $PbCO_3$ (0.73); Plattnerite PbO_2 (1.10)
Ra radium		$RaSO_4$ (0.86)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_5 (33.66)
Se selenium	SeO_4^{-2}	
Sr strontium		Strontianite $SrCO_3$ (0.42)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (11.51); Smithsonite $ZnCO_3$ (0.54)

[1]Minimal coverage in LLNL database.

Condition: Minimum James River constituents, pe = nitrogen couple, pe = 12.8, pH = 7

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.35)
Al aluminum		Boehmite AlO(OH) (2.17); Gibbsite $Al(OH)_3$ (2.08)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (1.77); Witherite $BaCO_3$ (2.38)
Be beryllium		Bromellite BeO (7.60)
Cd cadmium	Cd^{+2}	
Co cobalt		$CoFe_2O_4$ (17.93); Spinel-Co Co_3O_4(0.45)
Cr chromium	CrO_4^{-2}	
Cu copper		Delafossite $CuFeO_2$ (3.46); Ferrite-Cu $CuFe_2O_4$ (8.46)
F fluoride	F^-	
Fe iron		Goethite FeOOH (5.06); Hematite Fe_2O_3 (11.05)
Hg mercury		Calomel Hg_2Cl_2 (3.84); Montroydite HgO (4.49)
Mn manganese		Manganite MnO(OH) (2.04); Pyrolusite MnO_2 (4.07)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (8.65)
Pb lead		Cerussite $PbCO_3$ (0.60)
Ra radium		$RaSO_4$ (0.86)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_5 (26.20)
Se selenium	SeO_4^{-2}	
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_2^{-2}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (8.25)

[1]Minimal coverage in LLNL database.

Condition: Minimum James River constituents, pe = nitrogen couple, pe = 10.4, pH = 9

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.34)
Al aluminum		Boehmite AlO(OH) (1.80); Gibbsite $Al(OH)_3$ (1.71)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (1.77); Witherite $BaCO_3$ (4.44)
Be beryllium		Bromellite BeO (9.33)
Cd cadmium		Otavite $CdCO_3$ (1.74)
Co cobalt		$CoFe_2O_4$ (16.40)
Cr chromium	CrO_4^{-2}	
Cu copper		Delafossite $CuFeO_2$ (5.79); Ferrite-Cu $CuFe_2O_4$ (10.38); Malachite $Cu_2CO_3(OH)_2$ (2.29)
F fluoride	F^-	
Fe iron		Goethite FeOOH (5.04); Hematite Fe_2O_3 (11.02)
Hg mercury		Calomel Hg_2Cl_2 (4.05); Montroydite HgO (6.20)
Mn manganese		Manganite MnO(OH) (5.17); Pyrolusite MnO_2 (6.81)
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (12.62)
Pb lead		Cerussite $PbCO_3$ (0.73); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (2.00)
Ra radium		$RaSO_4$ (0.86)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_5 (24.60)
Se selenium	SeO_4^{-2}	
Sr strontium		Strontianite $SrCO_3$ (0.42)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (11.52); Smithsonite $ZnCO_3$ (0.54)

[1]Minimal coverage in LLNL database.

Condition: Minimum James River constituents, pe = chromium couple, pe = 8.4, pH = 7

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.35)
Al aluminum		Boehmite AlO(OH) (2.17); Gibbsite $Al(OH)_3$ (2.08)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (1.77); Witherite $BaCO_3$ (2.38)
Be beryllium		Bromellite BeO (7.60)
Cd cadmium[1]		$CdCr_2O_4$ (11.61)
Co cobalt		$CoFe_2O_4$ (17.93)
Cr chromium		Chromite $FeCr_2O_4$ (7.55); Eskolaite Cr_2O_3 (11.76); Magnesiochromite $MgCr_2O_4$ (7.25)
Cu copper		$CuCr_2O_4$ (10.87); Ferrite-Cu $CuFe_2O_4$ (8.46); Malachite $Cu_2CO_3(OH)_2$ (0.34);
F fluoride	F^-	
Fe iron		Goethite FeOOH (5.06); Hematite Fe_2O_3 (11.05)
Hg mercury		Calomel Hg_2Cl_2 (4.05); Montroydite HgO (0.15)
Mn manganese	Mn^{+2}	
Mo molybdenum[2]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (8.65)
Pb lead		Cerussite $PbCO_3$ (0.60); Crocoite $PbCrO_4$ (0.02)
Ra radium		$RaSO_4$ (0.86)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_5 (8.40)
Se selenium	SeO_4^{-2}	
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_2^{-2}$	Carnotite $K_2(UO_2)_s(VO_4)_2$ (0.01); Tyuyamunite $Ca(UO_2)_s(VO_4)_2$ (1.52)
V vanadium	VO_3OH^{-2}	Carnotite $K_2(UO_2)_s(VO_4)_2$ (0.01); Tyuyamunite $Ca(UO_2)_s(VO_4)_2$ (1.52)
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (8.25); $ZnCr_2O_4$ (20.95)

[1]All other non-silicate Cd minerals were undersaturated.
[2]Minimal coverage in LLNL database.

Condition: Minimum James River constituents, pe = chromium couple, pe = 4.7, pH = 9

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.34)
Al aluminum		Boehmite AlO(OH) (1.80); Gibbsite $Al(OH)_3$ (1.71)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (1.77); Witherite $BaCO_3$ (4.44)
Be beryllium		Bromellite BeO (9.33)
Cd cadmium		$CdCr_2O_4$ (17.87); Otavite $CdCO_3$ (1.74)
Co cobalt		$CoFe_2O_4$ (16.40)
Cr chromium		Chromite $FeCr_2O_4$ (11.55); Eskolaite Cr_2O_3 (14.08); Magnesiochromite $MgCr_2O_4$ (13.55)
Cu copper		Ferrite-Cu $CuFe_2O_4$ (10.38); Malachite $Cu_2CO_3(OH)_2$ (2.29)
F fluoride	F^-	
Fe iron		Goethite FeOOH (5.04); Hematite Fe_2O_3 (11.02)
Hg mercury		Calomel Hg_2Cl_2 (4.05); Montroydite HgO (0.46)
Mn manganese	$MnCO_3$	
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (12.62)
Pb lead		Cerussite $PbCO_3$ (0.73); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (2.00)
Ra radium		$RaSO_4$ (0.86)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (11.60)
Se selenium		Hg_2SeO_3 (1.45)
Sr strontium		Strontianite $SrCO_3$ (0.42)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (11.52); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (11.33); Smithsonite $ZnCO_3$ (0.54)

[1]Minimal coverage in LLNL database.
[2]All other non-silicate Se minerals were undersaturated.

Condition: Minimum James River constituents, pe = iron couple, pe = 3.1, pH = 7

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.35); Naumannite Ag_2Se (19.53)
Al aluminum		Boehmite AlO(OH) (2.17); Gibbsite $Al(OH)_3$ (2.08)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (1.77); Witherite $BaCO_3$ (2.38)
Be beryllium		Bromellite BeO (7.60)
Cd cadmium		Cadmoselite CdSe (0.49); $CdCr_2O_4$ (11.51)
Co cobalt		$CoFe_2O_4$ (14.53)
Cr chromium		Chromite $FeCr_2O_4$ (11.04); Eskolaite Cr_2O_3 (11.66); Magnesiochromite $MgCr_2O_4$ (7.15)
Cu copper		Cuprite Cu_2O (3.69); Ferrite-Cu $CuFe_2O_4$ (5.05); Malachite $Cu_2CO_3(OH)_2$ (0.31)
F fluoride	F^-	
Fe iron		Goethite FeOOH (3.36); Hematite Fe_2O_3 (7.65)
Hg mercury		Calomel Hg_2Cl_2 (4.05)
Mn manganese	Mn^{+2}	
Mo molybdenum[2]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (5.25)
Pb lead		Cerussite $PbCO_3$ (0.60)
Ra radium		$RaSO_4$ (0.86)
Sb antimony		$Sb(OH)_3$ (1.01); Sb_2O_4 (4.41)
Se selenium		Clausthalite PbSe (2.50); Hg_2SeO_3 (1.00); Krutaite $CuSe_2$ (11.15); Naumannite Ag_2Se (19.53); Penroseite $NiSe_2$ (1.44)
Sr strontium	Sr^{+2}	
Tl thallium[2]	Tl^+	
U uranium		Carnotite $K_2(UO_2)_s(VO_4)_2$ (0.01); Tyuyamunite $Ca(UO_2)_s(VO_4)_2$ (1.52)
V vanadium		Carnotite $K_2(UO_2)_s(VO_4)_2$ (0.01); Tyuyamunite $Ca(UO_2)_s(VO_4)_2$ (1.52)
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (4.85); $ZnCr_2O_4$ (20.85)

[1]All other non-silicate Cd minerals were undersaturated.
[2]Minimal coverage in LLNL database.

Condition: Minimum James River constituents, pe = iron couple, pe = -2.4, pH = 9

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Chlorargyrite AgCl (0.34)
Al aluminum		Boehmite AlO(OH) (1.80); Gibbsite $Al(OH)_3$ (1.71)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (1.77); Witherite $BaCO_3$ (4.45)
Be beryllium		Bromellite BeO (9.33)
Cd cadmium		$CdCr_2O_4$ (17.77); Otavite $CdCO_3$ (1.75)
Co cobalt		$CoFe_2O_4$ (13.00)
Cr chromium		Chromite $FeCr_2O_4$ (16.86); Eskolaite Cr_2O_3 (13.98); Magnesiochromite $MgCr_2O_4$ (13.46)
Cu copper		Cuprite Cu_2O (10.71); Ferrite-Cu $CuFe_2O_4$ (5.02)
F fluoride	F^-	
Fe iron		Goethite FeOOH (3.34); Hematite Fe_2O_3 (7.62)
Hg mercury		Calomel Hg_2Cl_2 (4.05)
Mn manganese	Mn^{+2}	
Mo molybdenum[1]	MoO_4^{-2}	
Ni nickel		Trevorite $NiFe_2O_4$ (9.22)
Pb lead		Cerussite $PbCO_3$ (0.73); Hydrocerussite $Pb_3(CO_3)_2(OH)_2$ (1.99)
Ra radium		$RaSO_4$ (0.86)
Sb antimony		$Sb(OH)_3$ (1.01)
Se selenium		Clausthalite PbSe (16.62); Freboldite CoSe (1.11); Krutaite $CuSe_2$ (28.26); Naumannite Ag_2Se (35.57); Penroseite $NiSe_2$ (11.54); Stilleite ZnSe (7.33)
Sr strontium		Strontianite $SrCO_3$ (0.43)
Tl thallium[1]	Tl^+	
U uranium	$UO_2(CO_3)_3^{-4}$	
V vanadium	VO_3OH^{-2}	
Zn zinc		Ferrite-Zn $ZnFe_2O_4$ (8.12); Hydrozincite $Zn_5(OH)_6(CO_3)_2$ (11.34); Smithsonite $ZnCO_3$ (0.55); Zincite ZnO (1.00)

[1]Minimal coverage in LLNL database.

Condition: Minimum James River constituents, sulfur couple, pe = -3.4, pH = 7

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Acanthite Ag_2S (28.23); Chlorargyrite AgCl (0.36)
Al aluminum		Boehmite AlO(OH) (2.18); Gibbsite $Al(OH)_3$ (2.09)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (1.69)
Be beryllium		Bromellite BeO (7.61)
Cd cadmium		CdS (12.88)
Co cobalt		Cattierite CoS_2 (11.95); $CoFe_2O_4$ (1.26); CoS (2.67)
Cr chromium		Chromite $FeCr_2O_4$ (11.59); Eskolaite Cr_2O_3 (11.60); Magnesiochromite $MgCr_2O_4$ (7.18)
Cu copper		Covellite CuS (15.64); Cuprite Cu_2O (6.72); Delafossite $CuFeO_2$ (6.99)
F fluoride	F^-	
Fe iron		Pyrite FeS_s (9.32); Pyrrhotite FeS (0.30); Troilite FeS (0.40)
Hg mercury		Calomel Hg_2Cl_2 (4.07); Cinnabar HgS (20.40)
Mn manganese	Mn^{+2}	
Mo molybdenum[1]		$MoSe_2$ (18.30)
Ni nickel		Millerite NiS (4.78); Vaesite NiS_2 (11.41)
Pb lead		Galena PbS (11.65)
Ra radium		$RaSO_4$ (0.78)
Sb antimony		Stibnite Sb_2S_3 (1.08)
Se selenium		Cadmoselite CdSe (14.58); Ferroselite $FeSe_2$ (6.58); Klockmannite CuSe (18.24); Krutaite $CuSe_2$ (21.13); Naumannite Ag_2Se (33.60); Tiemannite HgSe (23.48); Umangite Cu_3Se_2 (49.20); Wilkmanite Ni_3Se_4 (31.67)
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium		$UO_{2.25}$ (0.80); $UO_{2.25}$ (beta) (0.72); Uraninite UO_2 (2.98)
V vanadium		Karelianite V_2O_3 (2.92); V_3O_5 (3.45); V_4O_7 (2.04)
Zn zinc		Sphalerite ZnS (10.06); Wurtzite ZnS (7.63)

[1]Minimal coverage in LLNL database.

Condition: Minimum James River constituents, pe = sulfur couple, pe = -5.7, pH = 9

Element	Major Soluble Species	Major Non-Silicate Minerals (SI)
Ag silver		Acanthite Ag_2S (30.64); Chlorargyrite AgCl (0.36)
Al aluminum		Boehmite AlO(OH) (1.80); Gibbsite $Al(OH)_3$ (1.71)
As arsenic	AsO_3F^{-2}	
Ba barium		Barite $BaSO_4$ (1.70)
Be beryllium		Bromellite BeO (9.34)
Cd cadmium		CdS (15.27)
Co cobalt		Cattierite CoS_2 (7.94); $CoFe_2O_4$ (8.22); CoS (0.85)
Cr chromium		Chromite $FeCr_2O_4$ (17.81); Eskolaite Cr_2O_3 (13.99); Magnesiochromite $MgCr_2O_4$ (13.50)
Cu copper		Covellite CuS (15.75); Cuprite Cu_2O (10.72); Delafossite $CuFeO_2$ (12.59)
F fluoride	F^-	
Fe iron		Goethite FeOOH (0.95); Hematite Fe_2O_3 (2.83); Pyrite FeS_s (9.45); Pyrrhotite FeS (2.61)
Hg mercury		Calomel Hg_2Cl_2 (4.07); Cinnabar HgS (20.52)
Mn manganese	Mn^{+2}	
Mo molybdenum[1]		$MoSe_2$ (10.90)
Ni nickel		Millerite NiS (7.19); Vaesite NiS_2 (11.63)
Pb lead		Galena PbS (12.76)
Ra radium		$RaSO_4$ (0.78)
Sb antimony		Stibnite Sb_2S_3 (0.66)
Se selenium		Cadmoselite CdSe (16.55); Ferroselite $FeSe_2$ (5.88); Klockmannite CuSe (17.94); Krutaite $CuSe_2$ (18.22); Naumannite Ag_2Se (35.60); Tiemannite HgSe (23.18); Umangite Cu_3Se_2 (50.91); Wilkmanite Ni_3Se_4 (35.07)
Sr strontium	Sr^{+2}	
Tl thallium[1]	Tl^+	
U uranium		$UO_{2.25}$ (0.65); $UO_{2.25}$ (beta) (0.57); Uraninite UO_2 (2.98)
V vanadium		Karelianite V_2O_3 (4.27); V_3O_5 (5.18); V_4O_7 (4.13)
Zn zinc		Ferrite-Zn Fe_2O_4 (3.38); Sphalerite ZnS (11.77); Wurtzite ZnS (9.36)

[1]Minimal coverage in LLNL database.

7.7 Appendix G

Mann-Kendall Trend Test Results for Denitrification Tests in Aquifers

Mann-Kendall two-tailed trend test results (α = 0.05).

Tracer Test	Ag	Al	As	B	Ba	Be	Cd	Cr	Cu	Ni	Total P	Pb	Sb	Se	Tl	Zn
*Akeley-C	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
*Akeley-N	NA	NA	0	NA	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA
Hamar-1C	0	0	0	0	+	0	0	0	0	0	0	0	0	0	0	+
Hamar-1N	0	0	0	0	+	0	0	0	0	0	+	0	0	0	0	+
Hamar-2C	0	0	0	0	+	0	0	0	0	-	0	-	0	0	0	0
Hamar-2N	0	0	0	0	+	0	0	0	0	0	0	0	0	0	0	-
Karlsruhe G	0	0	0	0	0	0	0	0	+	0	+	0	0	0	0	0
Karlsruhe S1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Karlsruhe S2	0	0	0	0	-	0	0	0	-	0	0	0	0	0	0	0
Larimore-1C	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA
Larimore-1N	NA	NA	0	NA	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA
Larimore-2C	NA	NA	+	NA	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA
Larimore-2N	NA	NA	+	NA	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA
Larimore-3C	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0
Larimore-3N	0	0	0	0	-	0	0	0	0	0	0	0	+	+	0	-
Larimore-4C	0	0	0	0	0	0	0	0	0	+	0	0	0	0	0	0
Larimore-4N	0	0	0	0	-	0	0	0	0	0	0	0	0	+	0	0
Larimore-5C	0	0	0	0	0	0	0	0	0	0	0	-	0	0	0	0
Larimore-5N	0	0	0	0	-	0	0	0	0	0	0	0	0	+	0	0
Larimore-6C	0	0	?	0	0	0	0	0	0	0	0	0	0	?	0	0
Larimore-6N	0	0	?	0	0	0	0	0	0	0	0	0	0	?	0	0
*Luverne-C	NA	NA	-	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA
*Luverne-N	NA	NA	0	NA	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA
*PerhamM-N	NA	NA	0	NA	NA	NA	NA	NA	NA	+	NA	NA	NA	NA	NA	NA
*PerhamW-C	NA	NA	0	NA	NA	NA	NA	NA	NA	0	NA	NA	NA	NA	NA	NA
*PerhamW-N	NA	NA	0	NA	NA	NA	NA	NA	NA	-	NA	NA	NA	NA	NA	NA
Robinson-1C	0	0	0	-	+	0	0	0	0	0	0	0	0	0	0	+
Robinson-1N	0	0	0	0	0	0	0	0	-	-	+	0	0	0	0	+
Robinson-2C	0	0	0	0	+	0	0	0	0	0	0	-	0	0	0	-
Robinson-2N	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-

*	Site in Minnesota.
+	Increasing trend.
-	Decreasing trend.
0	No trend.
?	Lab reported that bromide caused interference with As and Se.
NA	Not analyzed.