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Technical Memorandum

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Section 1: Introduction

1.1 Background

The City of Greeley's (Greeley) water demand has increased nearly five-fold over the last 50 years. In response, Greeley evaluated several strategies to develop reliable and resilient water supplies to meet future demands. One of the approaches is aquifer storage and recovery (ASR), using the Upper Laramie aquifer underlying the Terry Ranch land parcels for groundwater supply and storage of treated surface water.

As part of the evaluation of this ASR concept, source water wells were sampled at the Terry Ranch site in 2019 and 2020 and groundwater quality was assessed in comparison with treated surface water produced by Greeley's existing Bellevue Water Treatment Plant (WTP) to determine treatment needs.

Results from groundwater sampling at Terry Ranch showed that uranium and gross alpha concentrations exceeded the respective National Primary Drinking Water Regulations (NPDWRs) maximum contaminant levels (MCLs) in select wells. Detailed results are shown below in Table 1 with MCL exceedance highlighted in blue.

Table 1. 2019 and 2020 Uranium and Gross Alpha Sampling Results

Contaminant	Units	MCL	Goal	Well	2019			2020		
					Method	MDL/RL	72-hour Composite Concentration	Method	MDL/RL	48-hour Composite Concentration
Uranium, Total	µg/L	30	Non-Detect	WWR-1	EPA 200.8	1.0 (RL)	43	EPA 200.8	0.2 (MDL)	40.6
				WWR-2			14			19.9
				WWR-3			15			28.3
				WWR-4			19			19.8
				WWR-5			12			13.6
				Flow-weighted Average	/	/	24.4	/	/	28.6
Gross Alpha	pCi/L	15	Non-Detect	WWR-1	EPA 900.0	3.0 (MDL)	27	EPA 900.0	-1000 (RL)	31
				WWR-2			5.7			16.9
				WWR-3			8.2			23.4
				WWR-4			8.8			19.4
				WWR-5			7.2			6.4
				Flow-weighted Average	/	/	14.0	/	/	22.9

µg/L = micrograms per liter
EPA = Environmental Protection Agency
MDL = method detection limit
pCi/L = picocuries per liter
RL = reporting limit,
WWR = Wingfoot Water Resources

After reviewing a series of treatment approaches (details of the review are referred to Terry Rach ASR Water Quality and Treatment Technical Memorandum, Brown and Caldwell, 2019), the treatment goals and recommended treatment methods for uranium and gross alpha are listed below in Table 2.

Table 2. Treatment Goals and Recommendations for Uranium and Gross Alpha

Contaminant	Units	Recommended Treatment	Method	Method Detection Limit (MDL)	Treatment Goal
Uranium	µg/L	Anion exchange resin	EPA 200.8	0.2	Non-detect (i.e., <0.2 µg/L)
Alpha, Gross	pCi/L	Anion exchange resin	EPA 900.0	3.0	Non-detect (i.e., <3.0 pCi/L)

1.2 Pilot Testing Objectives

Inspection activities served as an opportunity for Greeley to have their consultants evaluate Terry Ranch for potential fatal flaws that could impact the Terry Ranch Water Supply Project with regard to water quality, treatment, and environmental conditions. As part of inspection activities, a 30-day anion exchange pilot test was conducted. Water Remediation Technology's (WRT) Z-92® Uranium Treatment Process was selected for pilot testing. The main objectives of this pilot study were:

1. Demonstrate the effectiveness ("proof of concept") of the anion exchange treatment system in removing uranium and gross alpha from groundwater at Terry Ranch to below their respective detection limits.
2. Confirm the removal of gross alpha because of uranium removal. Gross alpha can be removed by uranium-specific resins depending on its composition. Gross alpha contributors can be either cationic or anionic and only the anionic emitters can be removed by anion exchange resins. Based on the available groundwater quality data, the primary cationic alpha emitter, radium 226 (Ra-226), was shown to be present in source water wells at very low concentrations, ranging from 0.1 to 0.4 pCi/L.
3. Examine the potential impact of anionic foulants on uranium and gross alpha removal. Although the selected anion exchange resin has strong selectivity for uranium, the presence other anionic constituents in water, including dissolved organic matter (often characterized by total organic carbon [TOC]), carbonate, bicarbonate, sulfate, metal complexes, etc., could potentially compete with uranium for adsorption and/or ion exchange sites, and thus negatively impacting uranium treatment performance.

Section 2: Pilot System Overview

2.1 Pilot Location

The pilot system was located at the well field at Terry Ranch. Feed water for the pilot was pumped from well exploratory borehole (EB)-2 (Figure 1), one of the two monitoring wells constructed in the exploratory boreholes. Although well WWR-1 was initially proposed as the pilot feed supply because it contains highest uranium concentration among all existing monitoring wells (Table 1), it was not selected for pilot testing because of challenges discharging the excess water which would have included either:

1. Storing and transporting the excess flow (i.e., 498 to 698 gallons per minute [gpm]) to the headworks of Greeley's wastewater treatment facility or,
2. Securing a permit from Colorado Department of Public Health and Environment (CDPHE) to discharge the excess flow via either surface or ground. This process was too uncertain and potentially lengthy.

On the other hand, wells EB-1 and EB-2 in the exploratory boreholes could be pumped at a flow rate of 20 to 25 gpm, which is more appropriate for this pilot application. Given the scheduling conflicts with the injection testing to be conducted in well EB-1, well EB-2 was selected as the final location for the pilot.

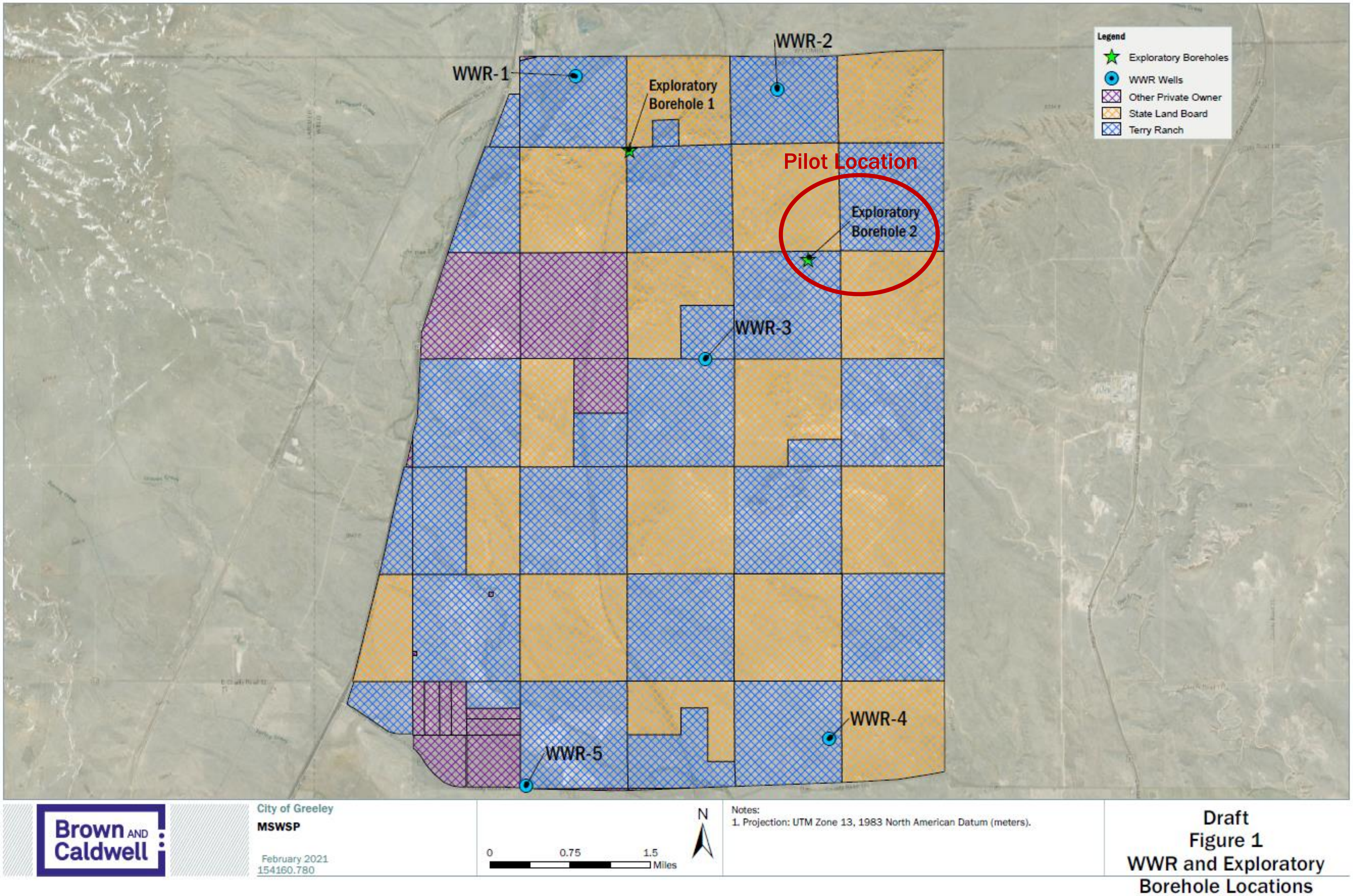

Figure 1. Terry Ranch well field and pilot location at well EB-2.

2.2 Pilot Feed Water Quality

EB-2 was first drilled, sampled, and its water quality characterized in 2020. Key sampling results are summarized below in Table 3. Findings of the pilot feed water quality include:

1. Uranium concentration in well EB-2 was 20.7 µg/L.
2. Gross alpha was in well EB-2 was 13.7 pCi/L during the original 2020 sampling, which was below the MCL of 15 pCi/L.
3. Total manganese concentration in well EB-2 was 83.1 µg/L, which exceeded the Secondary Maximum Contaminant Level (SMCL) of 50 µg/L and Greeley's manganese treatment goal of 20 µg/L.
4. Consistent with other well samples across Terry Ranch, potential foulants were not detected at concentrations that are alarming.

Table 3. Well EB-2 2020 Sampling Results

Type	Contaminant	Units	MCL	SMCL[a]	Greeley Treatment Goal	EB-2 Sampling Result	Reporting Limit
Target Contaminant	Uranium, Total	µg/L	30	-	Non-detect	20.7	0.2
	Gross Alpha	pCi/L	15	-	Non-detect	13.7	-1000
Cationic Gross Alpha Emitter	Radium 226	pCi/L	-	-	-	0.3	0.2
	Radium 228	pCi/L	-	-	-	1.1	0.3
Potential Foulant	Arsenic, Dissolved	µg/L	10	-	-	0.8	0.6
	Arsenic, Total	µg/L			-	5.3	0.6
	Bicarbonate as $CaCO_3$	mg/L	-	-	-	190.6	4
	Carbonate as $CaCO_3$	mg/L	-	-	-	<4	4
	Chloride	mg/L	-	250	-	4.8	0.01
	Fluoride	mg/L	4	2	-	0.45	0.09
	Manganese, Dissolved	µg/L	-	50	20	46.3	0.8
	Manganese, Total	µg/L				83.1	0.8
	Nitrate as N	mg/L	10	-	-	1.13	0.05
	Sulfate	mg/L	-	250	-	19.43	0.01
	Total Dissolved Solids	mg/L	-	500	-	259	5

a, SMCL: National Secondary Drinking Water Regulations secondary MCLs.
mg/L milligram(s) per liter

2.3 Pilot System Design

The WRT Z-92® uranium treatment process is designed to remove uranium from water in partially packed and fluidized resin beds. The pilot system configuration is shown below in Figure 2.

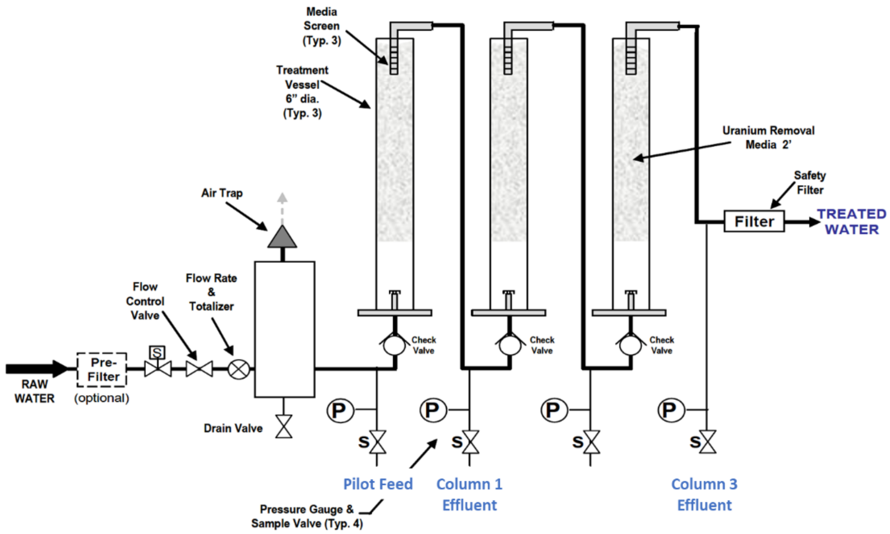

Figure 2. Uranium removal pilot system configuration

The pilot system consisted of three 6-inch internal diameter (ID) columns, each containing 3.5 feet of the Z-92® anion exchange resin. The mass of resin was approximately 22 pounds per column. Design flow rate was 1.7 gpm, resulting in an empty bed contact time (EBCT) of 3.0 minutes per column and a total system EBCT of 9 minutes. Details of the pilot system are listed in Table 4.

Table 4. Pilot System Design

Parameter	Units	Equation	Value
Column Inner Diameter, ID	inch	-	6
Cross Sectional Area, A	$inch^2$	$A = \pi \cdot (ID/2)^2$	0.2
Volumetric Flow Rate, Q	gal/min	$Q = v \cdot A$	1.7
	gal/day		2,448
Hydraulic Loading Rate, v	$(gallons/min)/ft^2$	$v = Q/A$	8.7
Bed Length per Column	feet	$L = v \cdot EBCT$	3.5
EBCT per Column	minute	$EBCT = L/v$	3.0
Resin Mass per Column	pounds	$W = V_b \cdot \rho_{Z-92}$	22

It is noteworthy that a full-scale Z-92® system typically consists of two stages in series (i.e., primary, and secondary stages) with an EBCT of 3.0 to 3.5 minutes for each stage. Due to the short duration of this testing, the primary goal was "proof of concept" to show that uranium was removed to non-detect in the first stage. The second and third stage were included as a precaution in the event uranium breakthrough occurred which was highly unlikely.

2.4 Pilot Equipment

Pilot equipment including pump, columns, valves, flow meter, pipe, and fittings were assembled and mounted in a self-contained trailer prior to the pilot study. The trailer was then transported to the Terry Ranch well field and was commissioned adjacent to well EB-2. Figures 3 and 4 show the trailer and the interior Z-92® pilot system. Pilot discharge was collected on site and was hauled offsite and disposed of at Greeley's wastewater treatment facility.

Figure 3. Self-contained trailer by WRT, containing the pilot equipment

Figure 4. 3-column anion exchange pilot system

Section 3: Pilot System Operation and Water Quality Monitoring

3.1 Pilot System Operation

Pilot feed was continuously pumped from well EB-2 for the entire duration of the pilot study from November 10, 2020 to December 10, 2020. All three columns were operated in an up-flow configuration, with the flow exiting the top of the first column entering the bottom of the second column, with the same flow path through the third column. In this flow direction, the resin bed is partially expanded at design flow rate to maximize uranium contact with the media and to allow any particulates in the water to pass through the resin bed, eliminating the need for on-site column backwash.

The Z-92® media was not exchanged over the course of pilot testing. After the completion of the pilot study, the spent media was returned to the WRT facility in Westminster, Colorado for further analysis and final disposal at a licensed facility.

Daily operation of the pilot system included checking the feed water flow rate and connections to ensure there were no leaks. An operation log was utilized during the study to record all field observations, adjustments to the pilot system, flow data, and other relevant information. The log sheets are attached in Appendix A for reference.

3.2 Water Quality Sampling and Analysis

3.2.1 Radionuclides

Sampling for radionuclides including uranium, gross alpha, gross beta, radium 226, and radium 228 in the pilot feed, column 1 effluent, and column 3 effluent (Figure 2) was conducted once during pilot system start-up and twice per week for five consecutive weeks as listed below in Table 5. The uranium and gross alpha treatment effectiveness of the primary stage was evaluated by sampling radionuclides in the column 1 effluent. Column 3 effluent was monitored to demonstrate the overall achievement of the treatment goal for uranium and gross alpha.

Table 5. Uranium, Gross Alpha, Gross Beta, Radium 226, and Radium 228 Pilot Sampling Matrix

Week	Date	Throughput (gallon)	Sample Location		
			Pilot Feed	Column 1 Effluent	Column 3 Effluent
Start-up	11/10/2020	76.5	X	X	X
1	11/11/2020	2,327.5	X	X	X
	11/13/2020	4,825.9	X	X	X
2	11/17/2020	14,725.5	X	X	X
	11/19/2020	19,475.4	X	X	X
3	11/22/2020	26,870.5	X	X	X
	11/23/2020	29,093.6	X	X	X
4	12/01/2020	48,620.3	X	X	X
	12/03/2020	53,618.2	X	X	X
5	12/08/2020	66,115.0	X	X	X
	12/10/2020	70,948.0	X	X	X

Uranium samples were analyzed by Colorado Analytical using EPA method 200.8, whereas samples for gross alpha and gross beta were analyzed by Energy Laboratories based on EPA method 90s0.0. Radium 226 and radium 228 were analyzed also by Energy Laboratories according to EPA method 903.0.

3.2.2 Other Water Quality Parameters

Since total manganese concentration in well EB-2 (83.1 µg/L, Table 3) exceeded the SMCL of 50 µg/L during the original 2020 sampling, its concentrations in the pilot feed and column 1 and 3 effluents were monitored at the same frequency as for the radionuclides (Table 5). Although dissolved manganese is not expected to be removed through anion exchange because manganese is a divalent cation, particulate manganese could potentially be removed via solid retention by the resin bed (i.e., media filtration). Manganese sampling was aimed at assessing if certain level of total manganese treatment could be achieved by removing its particulate form.

Sampling of other water quality parameters in the pilot feed and column 3 effluent, including total and dissolved metals, total and dissolved cations, total anions, TOC, UV absorbance at 254 nm, alkalinity, total dissolved solids, and hardness, etc. was performed once during pilot system start-up, a second time halfway through the pilot study in week 3, and a third time at the completion of the pilot study in week 5. Monitoring of the proposed water quality parameters was to inform any potential impact of foulants such as TOC, sulfate, metal complexes, carbonate, and bicarbonate, etc. on uranium and gross alpha removal by the Z-92® media. Detailed sampling matrix and the proposed analytical methods are summarized in the *Pilot Sampling and Analysis Plan* in Appendix B.

Section 4: Pilot Testing Results

4.1 Uranium and Gross Alpha

The uranium and gross alpha sampling results are summarized below in Table 6. Feed samples were collected immediately prior to the first column. Intermediate samples were collected after column 1 and final discharge samples were taken after column 3. Accordingly, Figures 5 and 6 show uranium and gross alpha concentrations in the pilot feed and columns 1 and 3 effluents as a function of system throughput in number of days in operation (Equation 1).

$$Number\ of\ Days\ in\ Operation = \frac{Cumulative\ Volume\ of\ Water\ Treated}{Volumetric\ Flow, Q} \qquad (Equation\ 1)$$

Figure 5 shows that uranium concentration in the pilot feed increased from 12.5 µg/L to approximately 30 µg/L over the first 6 days of pilot testing and then plateaued at an average uranium concentration of 32 µg/L for the remaining 4 weeks.

Uranium in stage 1 effluent was constantly below the reporting limit of 0.2 µg/L over the entire course of the pilot study. These data demonstrate that the Z-92® system is effective in removing uranium from groundwater at Terry Ranch to consistently meet the treatment goal of non-detect.

Gross alpha followed many of the similar trends as those noted for uranium. Gross alpha concentration in the pilot feed increased from approximately 11 pCi/L during pilot start-up and leveled off at an average of 24 pCi/L after the first week of testing.

Gross alpha was consistently below the minimal detectable concentration (MDC) in stage 1 effluent (note that MDCs are specific to each sample and varied from 2.2 to 3.2 pCi/L across all samples analyzed). The simultaneous removal of uranium and gross alpha indicates that the anionic alpha emitter, uranium, is the predominant contributor to gross alpha in the groundwater at Terry Ranch.

Table 6. Uranium and Gross Alpha Pilot Sampling Results.													
		Throughput	Days of Operation			Sample Location					Sample Location		
Week	Date	gallons	days	Radionuclide	Units	Feed	Column 1	Column 3	Radionuclide	Units	Feed	Column 1	Column 3
Start-up	11/10/2020	76.5[a]	0	Uranium, Total	µg/L	12.5	<0.2[b]	<0.2	Gross Alpha	pCi/L	11.6	<2.7[c]	<2.2
	11/10/2020	76.5[a]	0			12.9	NS[d]	NS			17.2	<2.5	<2.2
1	11/11/2020	2327.5	1			17.7	<0.2	<0.2			11	<2.4	<2.2
	11/13/2020	4825.9	2			25.8	<0.2	<0.2			19.6	<2.7	<2.9
2	11/17/2020	14725.5	6			29.7	<0.2	<0.2			26	<2.5	<3.2
	11/17/2020	14725.5	6			30.6	NS	<0.2			24.7	NS	<3.0
	11/19/2020	19475.4	8			33.1	<0.2	<0.2			22.2	<2.9	<2.8
	11/19/2020	19475.4	8			33.8	NS	<0.2			16.2	NS	<2.5
3	11/22/2020	26870.5	11			32	<0.2	<0.2			23.4	<2.5	<3.2
	11/23/2020	29093.6	12			31.3	<0.2	<0.2			20.9	<3.4	<2.7
4	12/1/2020	48620.3	20			32.2	<0.2	<0.2			24.1	<3.0	5.5
	12/3/2020	53618.2	22			31.2	<0.2	<0.2			27.8	<3.2	<2.4
5	12/8/2020	66115	27			30.3	<0.2	<0.2			24.3	<2.2	<2.8
	12/8/2020	66115	27			30	NS	<0.2			27	NS	<2.9

a. Duplicate samples were collected at select sample locations during pilot start-up and in weeks 2 and 5.
b. Uranium concentration was below its reporting limit of 0.2 µg/L using EPA method 200.8 by Colorado Analytical.
c. Gross alpha was not detected at the minimum detectable concentration (MDC) using EPA method 900.0 by Energy Laboratories. MDCs of gross alpha are specific to individual samples.
d. NS—Not sampled.

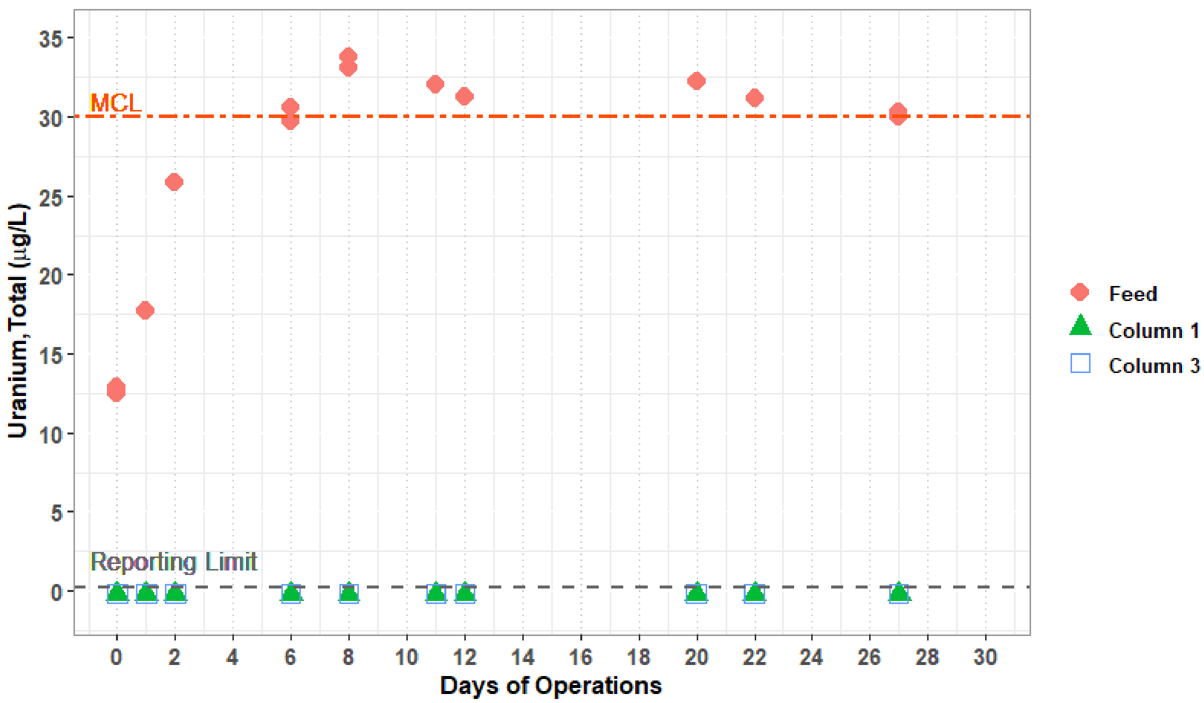

Figure 5. Uranium concentrations in pilot feed and columns 1 and 3 effluents as a function of system operation time

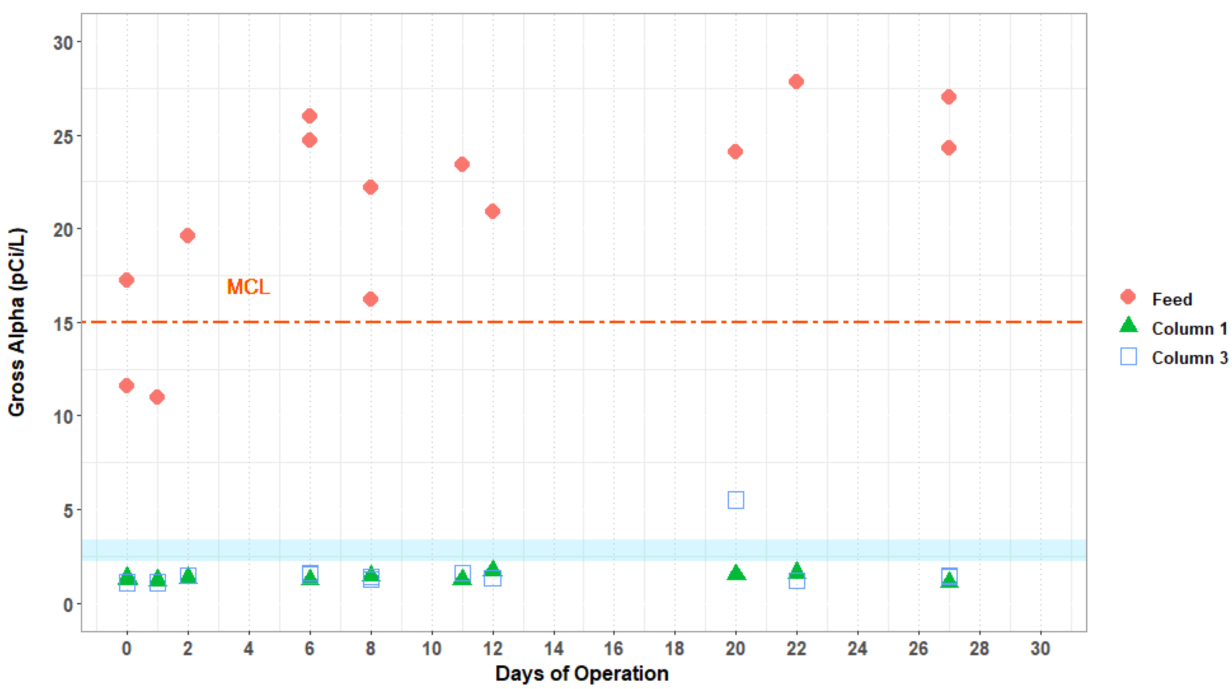

Figure 6. Gross alpha concentrations in pilot feed and columns 1 and 3 effluents as a function of system operation time

The light blue band indicates the upper and lower boundaries of minimum detectable concentrations (MDCs) of gross alpha across all samples analyzed.

4.2 Radium

The radium sampling results are summarized below in Table 7. Samples of pilot feed and columns 1 and 3 effluents were collected every week during the pilot start-up and testing. Results show that the cationic alpha emitter, Ra-226, was present in the pilot feed at low concentrations, ranging from 0.07 to 0.4 pCi/L. As anticipated, Ra-226 was not removed by the anion exchange resin and would contribute to gross alpha activity although the contribution was almost negligible.

Table 7. Radium 226, Radium 228, and Combined Radium Pilot Sampling Results

Week	Date	Ra-226 (pCi/L)			Ra-228 (pCi/L)			Combined Ra (pCi/L)		
		Feed	Column 1	Column 3	Feed	Column 1	Column 3	Feed	Column 1	Column 3
Start-up	11/10/2020	0.1	0.3	0.2	1.3	1.4	1.8	Not Sampled		
	11/10/2020	0.2	0.2	0.4	1.4	0.8	1.1	Not Sampled		
1	11/11/2020	0.08	0.2	0.2	1.1	1.5	1.9	1.2	1.7	2.1
	11/13/2020	0.07	0.2	0.07	1.4	1.5	1.3	Not Sampled		
2	11/17/2020	0.2	0.1	0.2	0.8	1.5	1.1	1	1.6	1.3
	11/17/2020	0.1	Not Sampled	0.06	1.2	Not Sampled	1.5	1.3	Not Sampled	1.5
	11/19/2020	0.1	0.2	0.1	0.7	1.3	2.0	0.8	1.5	2.1
	11/19/2020	0.1	Not Sampled	0.02	0.7	Not Sampled	1.5	0.9	Not Sampled	1.5
3	11/22/2020	0.2	0.3	0.2	1.3	1.2	1.4	1.5	1.6	1.7
	11/23/2020	0.2	0.1	0.1	1.3	1.1	1.3	1.5	1.2	1.4
4	12/1/2020	0.2	0.2	0.3	0.7	1.4	0.7	0.8	1.6	1.0
	12/3/2020	0.3	0.2	0.2	0.9	1.2	1.1	Not Sampled		
5	12/8/2020	0.4	0.1	0.2	1.2	0.7	1.3	Not Sampled		
	12/8/2020	0.1	Not Sampled	0.2	0.6	Not Sampled	0.9	Not Sampled		

4.3 Manganese

Total and dissolved manganese sampling results are listed below in Table 8. Results suggest that manganese in the pilot feed was mainly in its dissolved form and its concentration decreased with increasing well EB-2 pumping time. Due to the cationic nature of manganese, the anion exchange resin had no impact on manganese concentration as shown in Figure 7.

Table 8. Total and Dissolved Manganese Pilot Sampling Results								
		Throughput	Manganese, Dissolved			Manganese, Total		
Week	Date	gallons	Feed	Column 1	Column 3	Feed	Column 1	Column 3
Start-up	11/10/2020	76.5	29.2	29.9	30.7	30.2	30.3	30.7
	11/10/2020	76.5	27.6	27.9	28.1	27.9	28.7	28.5
1	11/11/2020	2327.5	19	18.9	19.4	19.4	19.5	20.2
	11/13/2020	4825.9	13.7	13.1	13.2	13.7	13.5	13.6
2	11/17/2020	14725.5	11	11	11.2	11.3	11	11.2
	11/19/2020	19475.4	10.6	10.5	10.7	10.7	10.7	10.9
	11/19/2020	19475.4	8.9	Not Sampled	9	Not Sampled		
3	11/22/2020	26870.5	9	9.1	9.4	9.3	9.1	9.5
	11/23/2020	29093.6	9	9.2	9.3	9	9.3	9.5
4	12/1/2020	48620.3	8	7.9	8.2	8	8	8.2
	12/3/2020	53618.2	7.8	7.7	7.8	7.8	8	7.9
5	12/8/2020	66115	7.8	7.9	8	7.8	8.1	8.1

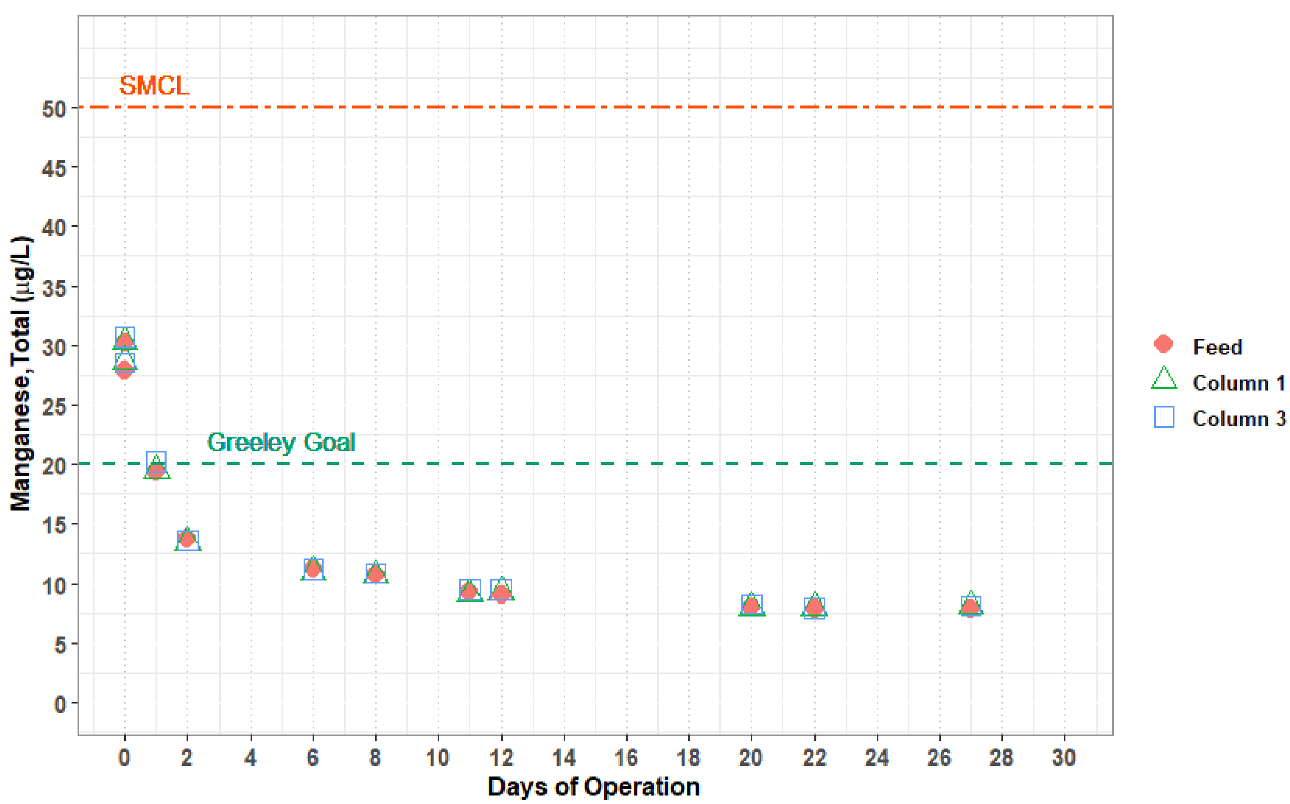

Figure 7. Total manganese concentrations in pilot feed and columns 1 and 3 effluents as a function of system operation time

4.4 Arsenic, Iron, Selenium, and Vanadium

Other metal contaminants, including arsenic, iron, selenium, and vanadium were also removed by the Z-92® media as indicated by results shown in Table 9. However, adsorption of these metal contaminants to the Z-92® media is expected to occur only during the early service period and is unlikely to continue over extended operation time. For instance, arsenic breakthrough was observed in column 3 effluent after 3 weeks of pilot system operation, indicating its breakthrough from all three resin beds.

Table 9. Arsenic, Iron, Selenium, and Vanadium Pilot Testing Results

Week		Start-up		Week 3			
Date		11/10/2020		11/22/2020		11/23/2020	
Sample Location		Feed	Column 3	Feed	Column 3	Feed	Column 3
Arsenic	µg/L	6.4/6.7[a]	0.3	2.8	0.3	2.9	1.9
Iron	µg/L	27/21[a]	<5	5	<5	5	<5
Selenium	µg/L	1.7	<0.8	1.4	<0.8	1.4	<0.8
Vanadium	µg/L	8	<1	4	<1	4	<1

a. Duplicate pilot feed samples were collected for arsenic and iron on the day of pilot start-up. Results of the duplicate samples are shown before and after the "/".

4.5 Chloride and Bicarbonate

Among other water quality parameters monitored in the pilot feed and treated effluents, changes were observed in chloride and bicarbonate concentrations across the treatment process.

As shown in Table 10, chloride concentration significantly increased from 3.4 mg/L in the pilot feed to approximately 130 mg/L in column 3 effluent during pilot start-up. This is because the mobile ions in the anion exchange resin bead are chloride ions, which is the standard delivery form for many anion exchange resins. According to WRT, most of the chloride ions would be exchanged by divalent anions in the feed water after 50 to 100 bed volumes of water processed (i.e., 255 to 510 gallons). This is evidenced by the significant decrease in bicarbonate concentration in treated water during pilot start-up. However, exchange between chloride and bicarbonate ions did not continue after pilot start-up as their concentrations in column 3 effluent approximating those in the pilot feed during sampling in week 3.

Table 10. Chloride and Bicarbonate Pilot Sampling Results.

Week		Start-up				Week 3			
Date		11/10/2020				11/22/2020		11/23/2020	
Sample Location		Feed	Column 3	Feed	Column 3	Feed	Column 3	Feed	Column 3
Chloride	mg/L	3.36	129.2	3.42	132.32	4.78	5.63	4.83	5.62
Bicarbonate	mg/L as $CaCO_3$	167.3	7.2	170	7.3	234.9	245.6	239.6	250.4

4.6 Other Water Quality Parameters

Other than the aforementioned constituents, no significant change to water quality was observed through the anion exchange treatment process. Table 11 lists the sampling results of general water quality parameters and total and dissolved metals monitored during pilot testing.

Table 11. General Water Quality and Metals Sampling Results

Category	Contaminant	Units	Start-up		Week 3			
			11/10/2020		11/22/2020		11/23/2020	
			Feed	Column 3	Feed	Column 3	Feed	Column 3
General Water Quality	Alkalinity, Total as $CaCO_3$	mg/L	167.3/170	7.2/1.3	234.9	245.6	239.6	250.4
	Bromate	ug/L	<5	<5	<5	<5	<5	<5
	Bromide	mg/L	<0.01	<0.01	0.25	0.27	0.28	0.3
	Chlorate	mg/L	Not Sampled	Not Sampled	<0.01	<0.01	<0.01	<0.01
	Chlorite	mg/L	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
	Fluoride	mg/L	0.65/0.64	0.23/0.42	0.38	0.37	0.39	0.39
	Hardness, Total as $CaCO_3$	mg/L	140.8/141.6	141.6/140.8	191.7	187.8	190.3	198.6
	Nitrate as N	mg/L	1.36/1.27	<0.05	0.52	0.72	0.45	0.74
	Nitrite as N	mg/L	Not Sampled	<0.03	<0.03	<0.03	<0.03	<0.03
	Sulfate	mg/L	17.4/16.86	0.31/0.34	14.86	0.26	14.87	0.32
	Total Dissolved Solids	mg/L	225/186	339/342	299	271	282	270
	TOC	mg/L	<0.5	0.5	<0.5	<0.5	<0.5	<0.5
	UV 254 Transmittance	%	99.4/99.7	96.7/97.9	99.6	99.7	99.5	99.8
Metals	Aluminum, Dissolved	μg/L	1	6/13	<1	<1	1	<1
	Aluminum, Total	μg/L	3	6/13	<1	<1	4	1
	Antimony, Dissolved	μg/L	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2
	Antimony, Total	μg/L	<1.2	<1.2	<1.2	<1.2	<1.2	<1.2
	Barium, Dissolved	μg/L	56.3/57.9	56.2/58.6	24.6	24.7	24.6	24.6
	Barium, Total	μg/L	58.9/56.4	58.6/56.5	24.9	24.8	24.6	24.7
	Beryllium, Dissolved	μg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Beryllium, Total	μg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Boron, Dissolved	μg/L	150/100	120/110	40	40	40	40
	Boron, Total	μg/L	160/110	120/110	40	40	40	40
	Cadmium, Dissolved	μg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Cadmium, Total	μg/L	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
	Calcium, Dissolved	mg/L	42.4/42.6	42.3/41.3	58.1	56.2	57.4	59.3
	Calcium, Total	mg/L	42.6/43.1	42.8	58.1	56.6	57.4	60.7
	Chromium, Dissolved	μg/L	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
	Chromium, Total	μg/L	<1.5	<1.5	<1.5	<1.5	<1.5	<1.5
	Cobalt, Dissolved	μg/L	0.4	0.4	<0.2	<0.2	<0.2	<0.2
	Cobalt, Total	μg/L	0.4	0.4	<0.2	<0.2	<0.2	<0.2
	Copper, Dissolved	μg/L	1.5/0.9	6.8/3.9	<0.8	<0.8	<0.8	<0.8

Table 11. General Water Quality and Metals Sampling Results								
			Start-up		Week 3			
			11/10/2020		11/22/2020		11/23/2020	
Category	Contaminant	Units	Feed	Column 3	Feed	Column 3	Feed	Column 3
	Copper, Total	µg/L	1.9/1.1	7.2/4.2	<0.8	1	<0.8	0.9
	Lead, Dissolved	µg/L	0.5/0.3	0.2/0.4	0.2	0.2	0.2	0.1
	Lead, Total	µg/L	0.7/0.4	0.3/0.4	0.2	0.2	0.2	0.1
	Lithium, Dissolved	µg/L	Not Sampled	Not Sampled	26	23	24	23
	Lithium, Total	µg/L	Not Sampled	Not Sampled	32	34	33	35
	Magnesium, Dissolved	mg/L	8.06/8.26	8.3/8.21	11.24	11.31	11.32	11.3
	Magnesium, Total	mg/L	8.35/8.27	8.42/8.29	11.33	11.31	11.42	11.43
	Mercury, Dissolved	µg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Mercury, Total	µg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Nickel, Dissolved	µg/L	2.8/1.8	2.9/3.8	1.5	1.1	0.9	0.9
	Nickel, Total	µg/L	3/2.5	3.4/3.9	1.5	1.2	0.9	0.9
	Potassium, Dissolved	mg/L	5.1	5.1/5.2	7.1	6.8	7	6.8
	Potassium, Total	mg/L	5.2	5.2	7.1	6.9	7	6.8
	Silica, Dissolved as Si	mg/L	20.3/19.8	20.2/19.4	13.2	13.6	13.6	14.1
	Silver, Dissolved	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Silver, Total	µg/L	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Sodium, Dissolved	mg/L	17	16.8/17.5	19.1	19.5	20.2	19.5
	Sodium, Total	mg/L	17.8/17.3	17.5	20	19.6	20.2	19.7
	Strontium, Dissolved	mg/L	0.57/0.584	0.593/0.59	0.743	0.768	0.769	0.784
	Strontium, Total	mg/L	0.59/0.591	0.601/0.602	0.761	0.768	0.773	0.785
	Thallium, Dissolved	µg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Thallium, Total	µg/L	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
	Zinc, Dissolved	µg/L	332/316	347/327	289	305	301	303
	Zinc, Total	µg/L	372/339	373/354	304	308	303	312

Note: Duplicate pilot feed and column 3 effluent samples were collected for select contaminants on the day of pilot start-up. Results of the duplicate samples are shown before and after the "/".

4.7 Conclusions

The anion exchange system tested consistently removed uranium and gross alpha to non-detectable levels over the entire course of the pilot study (i.e., 30 days). The removal of bicarbonate, and several metal contaminants including iron, arsenic, selenium, and vanadium was observed early in the pilot testing period and did not have any noticeable impact on uranium removal. In general, there was no significant change in water quality through the anion exchange treatment process other than the removal of uranium and gross alpha.

Attachment A: Pilot Operation Logs

Uranium Removal System

Location: Greeley, CO - Well Field

1.7 gpm

Daily Operation Log

Week Of:____________

Date	Operator	Time In	Time Out	Flow Rate Actual (gpm)	Flow Rate Adjusted (gpm)	Cumulative Totalizer Flow (gal) / Comments	Samples Taken? Yes	Samples Taken? No
Mon 11/9/20								
Tue 11/10/20	D. Jones. start	12:30		1.7	1.7	76.5	✓	
Wed 11/11/20	D Trejo	11:24	12:50	1.6	1.7	2327.5	✓	
Thu								
Fri 11/13/20	D. Trejo & D. Jones.	10:20	12:04	0.47	1.76	4825.9	✓	
Sat								
Sun								

Date	Feed Pressure	Col 1 Pressure	Col 2 Pressure	Col 3 Pressure	Discharge Pressure
Mon					
Tue 11/10/20	11.5	7.5	5.0	-0-	-0-
Wed 11/11/20	13	10	5.5	-0-	-0-
Thu					
Fri 11/13/20	11	8.5	5	0	0
Sat					
Sun					

PLEASE EMAIL THIS LOG SHEET WEEKLY TO DAVID JONES
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Notes:

Uranium Removal System

Location: Greeley, CO - Well Field

Daily Operation Log

Week Of: Nov. 16 – Nov 22

Date	Operator	Time In	Time Out	Flow Rate Actual (gpm)	Flow Rate Adjusted (gpm)	Cumulative Totalizer Flow (gal) / Comments	Samples Taken? Yes	Samples Taken? No
Mon 11/16/2020	Cole E. Gustafson	0930	0945	1.7	[illegible]	12269		✓
Tue 11/17/20	Diana Trejo	930	~~11:30~~ 11:45	1.706	none	14725.5	✓	
Wed								
Thu 11/19/20	Diana Trejo	9:50	11:50	1.71	none	19475.4	✓	
Fri 11/20/20	D. JONES	9:55		1.74	NONE	21936.0		✓
Sat								
Sun 11/22/20	D. Trejo	11:24	13:55	1.706	None	26870.5	✓	

Date	Feed Pressure	Col 1 Pressure	Col 2 Pressure	Col 3 Pressure	Discharge Pressure
Mon 11/16/2020	10.5	8.5	5.5	-0-	-0-
Tue 11/17/20	11	9	5.5	0	0
Wed					
Thu 11/19/20	10.5	8.5	5	0	0
Fri 11/20/20	11	8.5	5.5	-0-	-0-
Sat					
Sun 11/22/20	10.5	8.5	5.5	-0-	-0-

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Notes:

NO

Uranium Removal System

Location: Greeley, CO - Well Field

Daily Operation Log

Week Of: ____________

Date	Operator	Time In	Time Out	Flow Rate Actual (gpm)	Flow Rate Adjusted (gpm)	Cumulative Totalizer Flow (gal) / Comments	Samples Taken? Yes	Samples Taken? No
Mon 11/23/20	D Trejo	9:20	11:46	1.691	1.706	29093.6	✓	
Tue 11/24/20	C Gustafson	11:15	11:30	1.704	No Adjustment	31721.1		X
Wed 11/25/20	C. Gustafson	10:00	10:15	1.701	No Adjustment	34034.9		X
Thu /								
Fri 11/27/20	C Gustafson			1.696	1.711	38937.8		X
Sat								
Sun								

Date	Feed Pressure	Col 1 Pressure	Col 2 Pressure	Col 3 Pressure	Discharge Pressure
Mon 11/23/20	10.5	8.5	5.5	Ø	Ø
Tue 11/24/20	10.6	8.5	5.5	Ø	Ø
Wed 11/25/20	10.9	8.5	5.5	Ø	Ø
Thu /					
Fri 11/27/20	11.0	8.1	5.9	Ø	Ø
Sat					
Sun					

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Notes:

Uranium Removal System

Location: Greeley, CO - Well Field

Daily Operation Log

Week Of: Nov. 30th

Date	Operator	Time In	Time Out	Flow Rate Actual (gpm)	Flow Rate Adjusted (gpm)	Cumulative Totalizer Flow (gal) / Comments	Samples Taken? Yes	Samples Taken? No
Mon 11-30-20	C. Gustafson	11:45		1.71	No Adjusment	46380		X
Tue 12/1/20	D Trejo	9:35	11:06	1.76	No Adjust	48620.3	✓	
Wed 12-02-20	C. Gustafson	11:45	12:00	1.76	No Adjust	51396.2		X
Thu 12-03-20	Diana Trejo	9:00	10:38	1.79	No Adjust	53618.2	✓	
Fri 12-04-20	C. Gustafson	8:40	8:50	1.79	No Adjust	56136.5		
Sat								
Sun								

Date	Feed Pressure	Col 1 Pressure	Col 2 Pressure	Col 3 Pressure	Discharge Pressure
Mon 11-30-20	11.0	8.9	6.0	Ø	Ø
Tue 12-01-20	11.5	9.0	6.6	-0-	0 –
Wed 12-02-20	11.0	8.9	5.8	Ø	Ø
Thu 12-03-20	10.5	8.5	5.0	-0-	-0-
Fri 12-04-20	10.5	8.0	5.0	Ø	Ø
Sat					
Sun					

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4

Notes:

Uranium Removal System

Location: Greeley, CO - Well Field

Daily Operation Log

Week Of: ~~Dec 4th~~ Dec. 7th

Date	Operator	Time In	Time Out	Flow Rate Actual (gpm)	Flow Rate Adjusted (gpm)	Cumulative Totalizer Flow (gal) / Comments	Samples Taken? Yes	Samples Taken? No
Mon 12-7-20	C. Gustafson	1125	1135	1.64	1.706	63910.9		X
Tue 12/8/20	D. Trejo	9:13		1.69	1.706	66115.0	✓	
Wed 12/09/20	C. Gustafson	10:37	10:45	1.708	No Adjust	68698.8		X
Thu 12/10/20	D. Trejo	8:45	1130	1.691	1.706	70948.0	✓	
Fri								
Sat								
Sun								

Date	Feed Pressure	Col 1 Pressure	Col 2 Pressure	Col 3 Pressure	Discharge Pressure
Mon 12-7-20	10.5	8.1	5.0	Ø	Ø
Tue 12/8/20	10.5	8.5	5.5	0	0
Wed 12/9/20	10.8	8.5	5.5	Ø	Ø
Thu 12/10/20	11	9	5.5	0	0
Fri					
Sat					
Sun					

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Notes: 12/10/20 1200 Sample

12/10/20 Remove Pilot Trailer

Attachment B: Pilot Sampling Matrix

Table 1. Terry Ranch Groundwater Sampling and Analysis Plan Anticipated Samples - Pilot Treatment Project

					Organic Constituents																																	Inorganic and "Wet Chemistry" Constituents																										Microbiological Const.							Radiological Constituents														
Well Name	Field Sample Identification (proposed)	Type of Pump or Sampling System	Well Type	Sample Category	VOCs + TICs (EPA 524.2 and 8260)	Low-level 1,2,3-TCP (SRL EPA 524M-TCP)	SVOCs + UCMR2 SVOCs (EPA 525.2)	BNAs + TICs (EPA 625, 625.1)	GRO/TPH-g and ethylene glycol (SW 8015)	Acrolein and Acrylamide (EPA 8316)	DIMP (EPA 538)	Haloacetic Acids and Dalapon (EPA 552.2)	Phenols (EPA 528, 420.1)	Pesticides (EPA 1699)	Chlorinated Hydrocarbons (EPA 8121)	Methanol and Ethanol (Direct Injection SW 8015)	Fumigants (EPA 504.1)	PAH (EPA 550, 8270SIM)	OCP/PCBs (EPA 508)	PCDDs and PCDFs (EPA 8280B, 8290)	Herbicides (EPA 515.3, 515.4)	Carbamates (EPA 531.1)	Glyphosate (EPA 547)	Propylene Oxide (NIOSH Method 1612)	Endothall (EPA 548.1)	Diquat and Paraquat (EPA 549.2)	1,4-Dioxane (EPA 522)	Carboxyl Compounds (EPA 556, 8015m)	Acetanilide Degradants (EPA 535)	Nitrosamines (EPA 521)	Per- and Polyfluoroalkyl Substances (PFAS) (EPA 537)	2,3,7,8-TCDD (EPA 1613B)	Alkyl Phenols (ASTM D7065)	Diuron (EPA 532)	Organophosphorus Pesticides (EPA 614)	Hydrazine (OSHA 20M or 8315)		Total [Unfiltered] Metals (EPA 200.8, 245.1, 272.1, 272.2)	Total and Dissolved Manganese (EPA 200.8, 272.1, 272.2, 245.1)	Dissolved [Filtered] Metals (EPA 200.8, 272.1, 272.2, 245.1)	Total [Unfiltered] Cations (EPA 200.7)	Dissolved [Filtered] Cations (EPA 200.7)	Total [Unfiltered] Anions (EPA 300.0, 300.1, 326.0)	Hexavalent Chromium (EPA 218.6 or SM 3500-Cr B)	Perchlorate (EPA 314.0 or 331.0)	Color (SM 2120B)	MBAS/Foaming Agents (SM 5540C)	Odor (SM 2150 B))	Oil & Grease (EPA 1664A)	Total phosphate as PO4 + Ortho-phosphate as P (EPA 300.0, 365.1, 365.3 or SM 4500-P)	Alkalinity (SM 2320 B)	Specific Conductance (SM 2510B or EPA 120.1)	Total Sulfides, dissolved [Filtered] (SM 4500 S2 D)	TOC, DOC, and UV-254 (EPA 415.3 or SM 5310-C, 5910-B)	TDS (SM 2540C)	TSS (SM 2540D)	Hardness, Total (SM 2340B, 2340C or EPA 130.1)	Turbidity (EPA 180.1 or SM 2130B)	Asbestos TEM (EPA 100.2, TEM)	Cyanide (EPA 335.4)	pH (SM 4500 H+B)	Ammonia (SM 4500-NH3 or EPA 365.3)		Total Coliform (SM 9221B)	Fecal Coliform (SM 9221-C/E)	E. coli (SM 9221F)	Cryptosporidium and Giardia (EPA 1623 or 970-R-96-001)	Enteric Viruses (SM 9510)	Heterotophic Plate Count (SM 9215B or SM 9215D)		Gross alpha and beta (EPA 900.0 or SM 7110-B)	Uranium (EPA 907, 200.8)	Gamma Spec (EPA 901.1)	Beta and Photon Emitters (TBD by Laboratory)	Total U and Th (SW 846 6020A or EPA 200.8, 907.0)	Isotopic U and Th (HA SL 300)	Lead-210 (EPA 909.0)	Combined Radium-226 and 228 (SM 304)	Radium-226 (EPA 903.1 or SM 7500-Ra B)	Radium-228 (EPA Ra-05 or 904.0)	Thorium 230 and 232 (EPA EMSL-33, 907)	Cesium 134 and Bismuth-210 (EPA 901)	Americium, Plutonium 239, 240 and Polonium 209 (ASTM D7939 or EPA 402, Am241-D3972 and Plutonium[iso]-D3972)	Tritium (EPA 906.0 or SM 7500-3H)	Stontium-90 (EPA 905.0 or SM 7500-Sr B)
TMW-1 (EB-1)	Feed	Treatment pilot	Temp. Monitor Well	Primary																																		X	X	X	X	X	X								X			X	X		X												X		X	X						X	X	X					
TMW-1 (EB-1)	C-1	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	Discharge	Treatment pilot	Temp. Monitor Well	Primary																																		X	X	X	X	X	X								X			X	X		X												X		X	X						X	X	X					
TMW-1 (EB-1)	Feed	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	C-1	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	Discharge	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	Feed	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	Feed - FD	Treatment pilot	Temp. Monitor Well	Primary																																																																							X	X						X	X	X					
TMW-1 (EB-1)	C-1	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	Discharge	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	Discharge - FD	Treatment pilot	Temp. Monitor Well	Primary																																																																							X	X						X	X	X					
TMW-1 (EB-1)	Feed	Treatment pilot	Temp. Monitor Well	Primary																																		X	X	X	X	X	X								X			X	X		X												X		X	X						X	X	X					
TMW-1 (EB-1)	C-1	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	Discharge	Treatment pilot	Temp. Monitor Well	Primary																																		X	X	X	X	X	X								X			X	X		X												X		X	X						X	X	X					
TMW-1 (EB-1)	Feed	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	C-1	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	Discharge	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	Feed	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)	Feed - FD	Treatment pilot	Temp. Monitor Well	FD																																																																								X	X						X	X	X					
TMW-1 (EB-1)	C-1	Treatment pilot	Temp. Monitor Well	Primary																																			X																																				X	X						X	X	X					
TMW-1 (EB-1)**	Discharge	Treatment pilot	Temp. Monitor Well	Primary	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
TMW-1 (EB-1)	Discharge - FD	Treatment pilot	Temp. Monitor Well	FD																																																																									X	X						X	X	X					

in the table will be sampled twice in each week indicated, unless otherwise noted.

d method