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November 2, 2021

CERTIFIED MAIL
RETURN RECEIPT REQUESTED

Attn: Deputy Director
Division of Decommissioning, Uranium Recovery, and Waste Program
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Rockville, MD 20852-2738

Subject: Mine Unit 3 Restoration Monitoring Report, Cameco Resources, Crow Butte Operation
Source Materials License SUA-1534
Docket Number 40-8943

Dear Deputy Director:

Cameco Resources, Crow Butte Operation (CBO) is herein providing a Restoration Monitoring Report for Mine Unit 3 of the Crow Butte Operation project to the US Nuclear Regulatory Commission (NRC). The report presents the sampling data that has been collected during the stability monitoring phase of restoration for Mine Unit 3 as well as expert analysis of that data.

CBO is submitting this report as a precursor to its forthcoming ACL application. Through this process, CBO is confident it will be able to demonstrate the restoration efforts in Mine Unit 3 are protective of the surrounding USDW's, human health, and the environment.

If you have any questions, please feel free to contact me at (308) 665-2215 ext 117.

Sincerely,
CAMECO RESOURCES
CROW BUTTE OPERATION

Walter D. Nelson

Walter D. Nelson
SHEQ Coordinator

NMSS01
NMSS

Attachments: As Stated

cc: NRC – Director
CBO – File

Crow Butte Mine Unit 3 Monitoring Report

1. Introduction

1.1 This report discusses geochemical monitoring data obtained from September, 2018 to May, 2021, the latter being the latest round of sampling for which results are available as of this writing. No pumping of waters in Mine Unit 3 (MU3) has been done since before September, 2018 other than the minimal amount needed to obtain samples for laboratory analysis. Chemical testing for each sample encompassed the Guideline 8 Environmental Protection Agency (EPA) suite of tests.

1.2 Restoration for MU3 began in 1999. Seventy pore volumes of water were pumped as part of this effort, and 182,000 pounds of sodium sulfide ($Na_2S \bullet 3H_2O$) was added as a reducing agent to aid in reversing oxidation effects that occurred during mining. A summary of the water treatment steps is given in Table 1. While these restoration efforts have been beneficial, the remainder of this report will explain why further treatment efforts are not warranted and might contribute to destabilizing the aquifer geochemistry.

Phase of restoration	Pore volumes treated
Sweep	**0.7**
Ion Exchange	**41.0**
Reverse Osmosis	**25.3**
Recirculation	**3.2**
Total Pore Volumes pumped and treated	**70.2**

Table 1. A summary of water treatment steps for MU3.

2. Results and Discussion

2.1 Trending was done using the Mann-Kendall (MK) option in the EPA software package ProUCL, version 5.1.002.[1] MK was chosen because of guidance provided by Nuclear Regulatory Commission (NRC) regulators during the preparation of the Mine Unit 1 Alternate Concentration Limit (ACL) application at the Smith Ranch-Highland In-Situ Recovery (ISR) uranium mine in 2017.

2.2 The electronic files that accompany this report include the Excel workbook **Crow Butte Monitoring – Mine Unit 3.xlsx**. Also included in a separate folder are MK trend graphs for TDS, U, Ra-226, As, Mn, and V for each well for which there is enough data to infer trends. In some cases, the data set for a given analyte have so many non-detectable concentrations that no trending is possible or necessary. In those situations, no trending graph is included. Another electronic file folder provided with this report contains the laboratory data. All chemical analysis was done by Pace Analytical of Sheridan, Wyoming.

2.3 Crow Butte Monitoring – Mine Unit 3.xlsx contains worksheets for the individual wells and the composite for MU 3. There is also a worksheet entitled **TablesAndGraphs** that has the plots and graphs presented in this report and several others deemed too big for easy inclusion here.

Worksheets for the wells and MU3 Comp have the relevant data for each round of stability in cells A1:AP13. Some cells in this block have a red fill color indicating an exceedance of the restoration target value (RTV).[2] A table of the RTVs for MU3 is provided in cell addresses P79:U119 of the **TablesAndGraphs** worksheet. Note that it does not include more recent changes in the RTVs for U and As discussed later in this report. ProUCL output files showing statistical figures of merit for Mann-Kendall trending are included in cells B87:M334 of the worksheets for individual wells and the MU3 composite. No output file is included for those cases where all or most of the data consists of non-detects.

2.4 The RTV for uranium was originally 5 mg/L, but NRC regulators have stated that it must be revised downward in accordance with pre-mining baseline concentrations for this element. The worksheets show U exceedances as being anything above the pre-mining baseline average for MU3, which is a conservative interpretation since RTVs are usually higher than pre-mining averages to account for mine unit-wide variability of concentrations. The RTV for arsenic was 0.050 mg/L in the original permit and is now taken to be 0.010 mg/L to reflect changes in the EPA potable water limit for this element.

2.5 Cells A55:H66 for the individual wells and composite worksheets are a presentation of sampling dates, elapsed time since the start of stability sampling (in days since ProUCL does not work with dates), and concentrations for U, Ra-226, Total Dissolved Solids (TDS), Arsenic (As), Mn, and V. These cells are copies taken from the larger data set in A1:AP13 and are provided for easier copy-and-paste transfer into ProUCL for trend analysis and as an indication of those parameters that may be of greatest interest to regulators and restorers. For the 24 May 2021 round of sampling (the latest data as of this writing), tables ranking the concentrations of U, Ra-226, TDS, and As for the wells from maximum to minimum are provided in cell addresses P4:Z18 of the **TablesAndGraphs** worksheet along with bar graphs illustrating the same information directly below these tables.

2.6 TDS is in and of itself not a health risk at the concentrations found in MU3. It does however provide a metric for gauging whether to continue reverse osmosis (RO) treatment of groundwater. Figure 1 shows how TDS was more narrowly distributed at generally higher concentrations for the 14 wells of MU3 before mining began than now. The change in distribution strongly suggests that further RO treatment is ill-advised since decreasing TDS concentrations to significantly below those in the pre-mining aquifer may contribute to geochemical instability over long time frames.

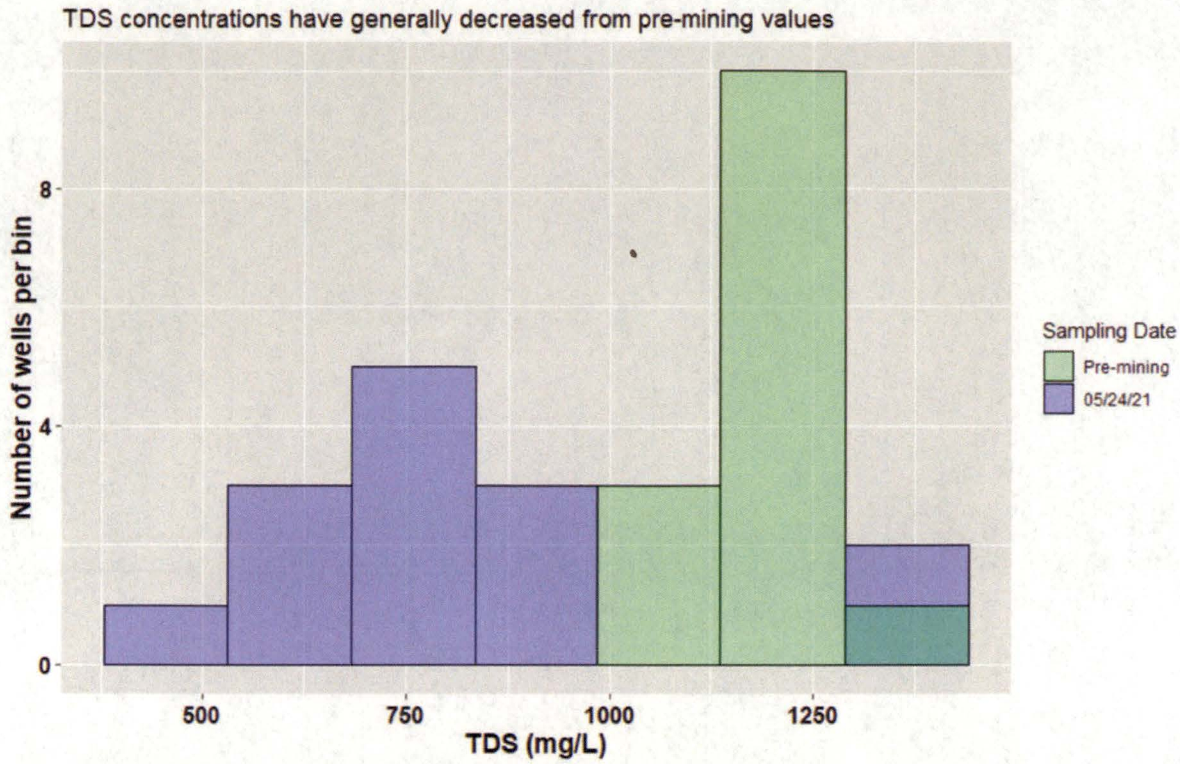

Figure 1. The two co-plotted histograms compare the distribution of TDS before mining began and as of May, 2021 for MU3. The highest concentration bin has two wells in it as of the May, 2021 sampling round and one overlapping pre-mining well, hence the darker green color for that bin.

2.7 Uranium *trends* in MU3 tend to move in concert with TDS trends (Figure 2). Ten of the 14 wells in the mine unit have U and TDS showing trends in the same direction (or no discernable direction, i.e., "stable"). However, it should be stated that higher TDS *concentrations* often do not coincide with higher U concentrations. An example of this is CM1-11, which has the second highest TDS concentration in MU3 (and a stable trend) as of the May, 2021 sampling round but among the lowest U concentrations (albeit with an increasing trend). In contrast, I288P has a TDS barely equal to 73% of the RTV and yet the highest U concentration in MU3 as of the May, 2021 sample round. The point to be made here is that further RO treatment of the waters is not an effective way to remove remaining dissolved uranium at this stage in the restoration process.

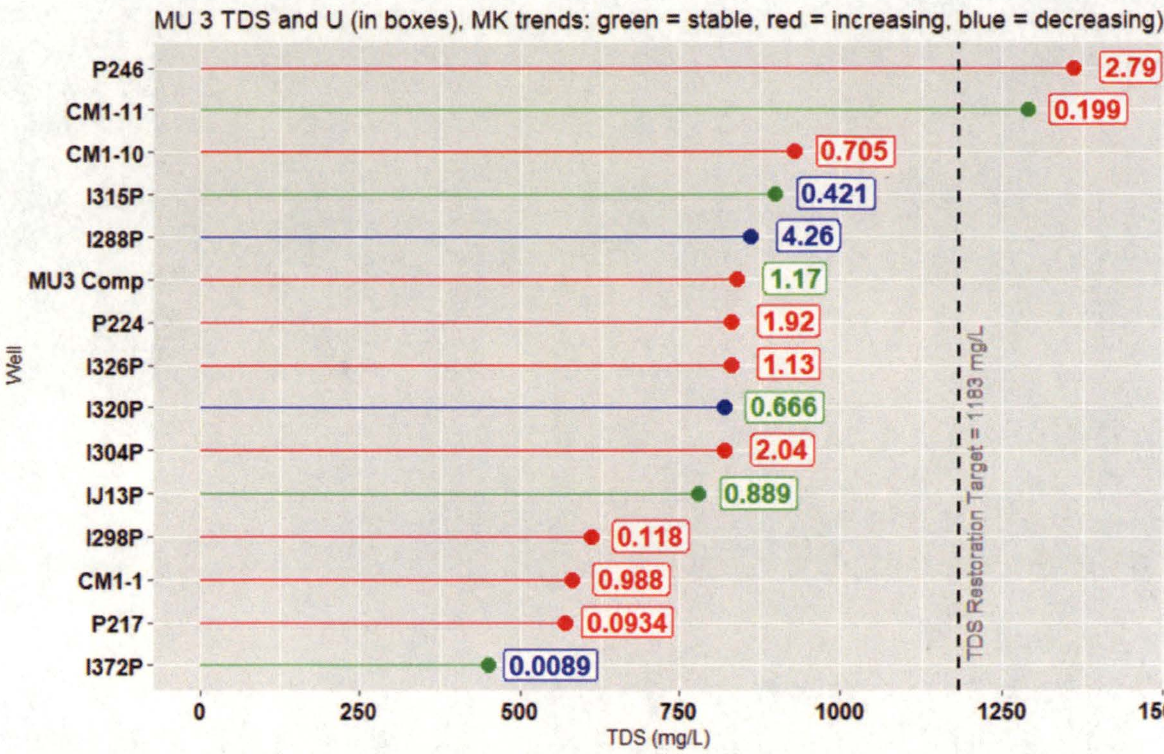

Figure 2. The graph depicts TDS and U concentrations in addition to MK trending for both parameters as of the May, 2021 sampling round.

2.8 Figure 3 is a correlation diagram for I288P, and more such diagrams for other wells are provided in the **TablesAndGraphs** worksheet of the Mine Unit 3 stability workbook (cells AB3:AJ55). Each square of the diagram shows the Pearson's correlation coefficient ("R") computed for one element of concern (EOC) versus the other for the 11 rounds of monitoring. Positive correlations occur when as one EOC rises in concentration so does its partner. Negative correlations happen when as one EOC rises that of its partner falls. Comparing correlations of dissolved concentrations over time can offer clues as to the relative mobility of EOCs through the aquifer. In addition, correlations can offer insight into the efficacy of restoration techniques.

2.9 Arsenic concentrations for MU3 are often above the RTV. Note the mild negative correlation between As and TDS for I288P (figure 3). This is probably because of the use of sodium sulfide for restoration, which is highly basic and can thus raise the pH of the groundwater enough to cause significant desorption of arsenic from the aquifer solids. Sodium sulfide was added during RO treatment and resulted in rising pH (and hence arsenic) with decreasing TDS concentrations. It is also likely that this rise in pH contributed to the desorption of uranyl carbonate complexes.[3] Both the dissolved and adsorbed uranium in the restoration zone is predominately in the form of these complexes. The upshot is that further addition of sodium sulfide at this stage of restoration is counterproductive for minimizing dissolved arsenic and uranium concentrations.

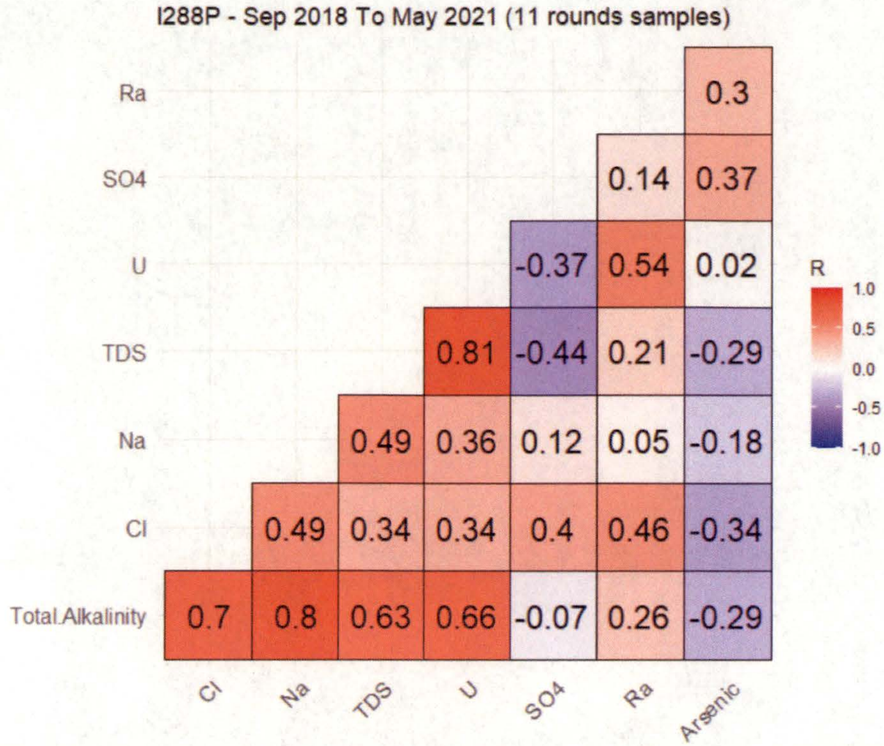

Figure 3. The correlation diagram for I288P.

2.10 Figure 4 summarizes the stability status for each of the wells (and the composite) for MU3. While stability as gauged on a well-by-well basis is imperfect, the *aggregate* stability as revealed by the mine unit composite (MU3 Comp) sampling is better. Tables and pie charts showing the mine unit totals for increasing, stable, and decreasing trends for all five elements and TDS are in cells L4:N110 of the **TablesAndGraphs** worksheet. Ra-226 and TDS are currently showing increasing trends for the composite, but both are still well below their RTVs. Figure 5 offers another perspective on the aggregate stability of MU3. While the rank order of individual well concentrations changes with each sampling round, the overall distributions of the five elements and TDS continue to look very similar over time. The three V distributions all have one high outlier point, and this is always I326P. It should be noted that V has been proposed as an amendment to uranium-contaminated groundwater in some aquifers since these two elements are the building blocks for exceptionally durable carnotite mineralization that can sequester both.[4] Thus the presence of V in the context of the mine unit should not be of environmental concern. Note also that Mn has only a secondary EPA drinking water standard that should make for little concern about it.

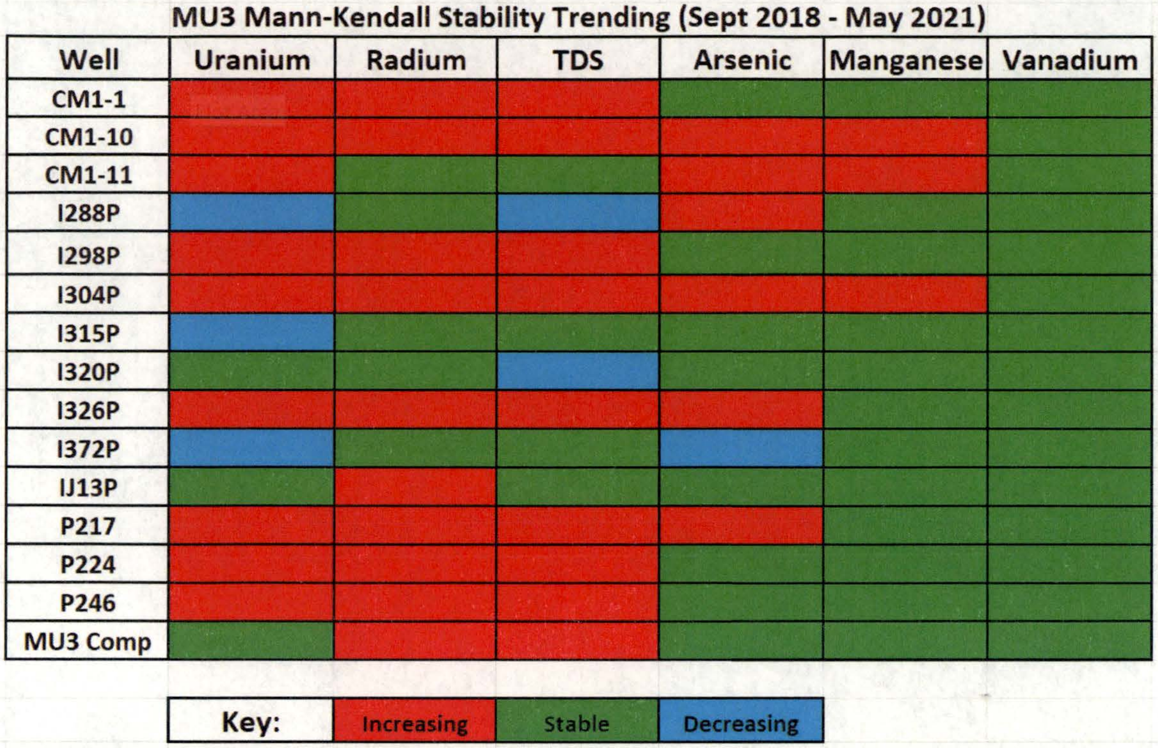

Figure 4. The matrix is based upon the 11 rounds of sampling done thus far during post-restoration monitoring. See the individual well and MU3 composite worksheets in the workbook *Crow Butte Monitoring – Mine Unit 3.xlsx* (cells B87:M334) for the ProUCL summary statistics for trending.

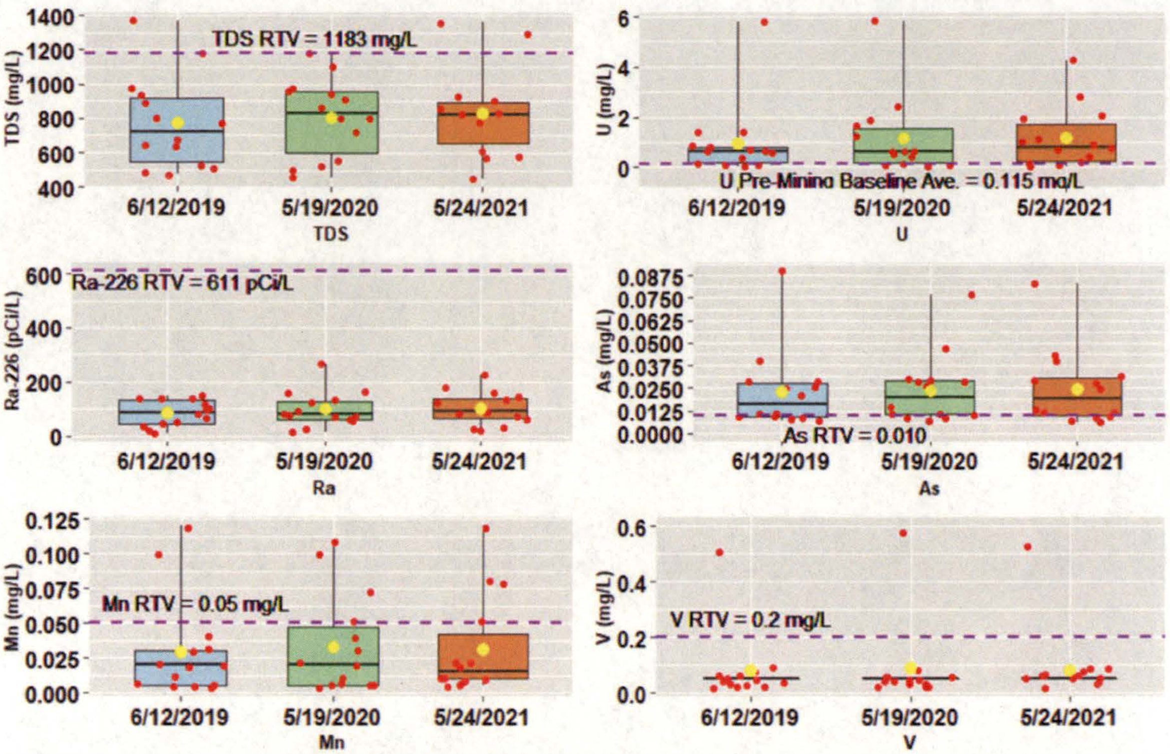

Figure 5. Box plots comparing the distributions of concentrations for the 14 wells of MU3 over a nearly two-year period from June, 2019 to May, 2021. The lower horizontal sides of the box plots mark the position of the 25th percentile of the sample distributions. In other words, 25% of the samples are expected to be below this line. The upper horizontal sides of the boxes represent the 75th percentile, and the horizontal lines at the "waist bands" of the boxes depict the positions of the median values. The yellow points mark the arithmetic means. The compression of the full V box plots (lower right-hand graph) is caused by the wide range of scale needed to accommodate the single outlier points (see discussion immediately above figure 4).

2.11 A pair of MU3 maps overlaid with TDS bubble charts can be found in the **TablesAndGraphs** worksheet. The map occupying cells AC63:AJ108 depicts the pre-mining concentrations for TDS, while another one at cells AC113:AJ160 shows the arrangement of the TDS concentrations as of the 24 May 2021 stability data set. Taken together they do not reveal any obvious changes in spatial pattern such as higher concentrations of TDS near mine unit boundaries or clusters of high TDS wells that might suggest problematic restoration.

2.12 For the purposes of this report, *synchronization* refers to instances where **different** wells have the same date of maximum or minimum concentration for the **same** ion (U, Ra, or As) or TDS. Mn and V are not included in this synchronization discussion because of a sparsity of data with detectable concentrations for them. A table entitled "Max-Min concentration dates during stability for each well" can be found at cells B4:J38 of **TableAndGraphs**. It can be used to judge the overall extent of synchronization of concentrations of EOCs. TDS and U, for example, both tended towards minimum concentrations for individual wells during the first sampling round (4 September 2018). After that date, occurrences of minimum TDS or minimum U in the mine unit for a given sampling round occur much less frequently. This may be because the TDS and U in the mine unit is re-distributing as time passes. Building on the discussion in paragraph 2.9 above, Arsenic concentrations also tended to be at minimum in September, 2018, while maxima for this species had a strong tendency towards the sampling round done on 20 August 2019. pH data (column P of the worksheets) for all the wells shows values for that parameter turning (slightly) downwards in the summer of 2019 though we do not claim the possible correlation is conclusive proof of cause-and-effect. It should be noted that in the event maximum or minimum dates occurred repeatedly for a particular well and EOC the first date of occurrence was entered into this table.

2.13 There is also no obvious evidence of widespread maximum TDS synchronization. This offers assurances that there is not a significant untreated plume of water remaining in the restoration zone.

2.14 Figure 6 shows the distribution of restoration water flow on a MU3 map with gallons of restoration treatment as contours overlaid with TDS concentrations as of the 24 May 2021 round of sampling. A larger version of this map can be found at cell addresses AC165:AJ210 of the **TablesAndGraphs** worksheet. Note that I288P has been treated more extensively than any of the other 14 monitoring wells but still has the highest U concentration among them. CM1-11, which received far less restoration gallonage, has a current U concentration of 0.199 mg/L with a TDS value similar to pre-mining baseline numbers. This map supports the contention that the management of the restoration has been reasonable and commensurate with Best Practicable Technology (BPT) standards.

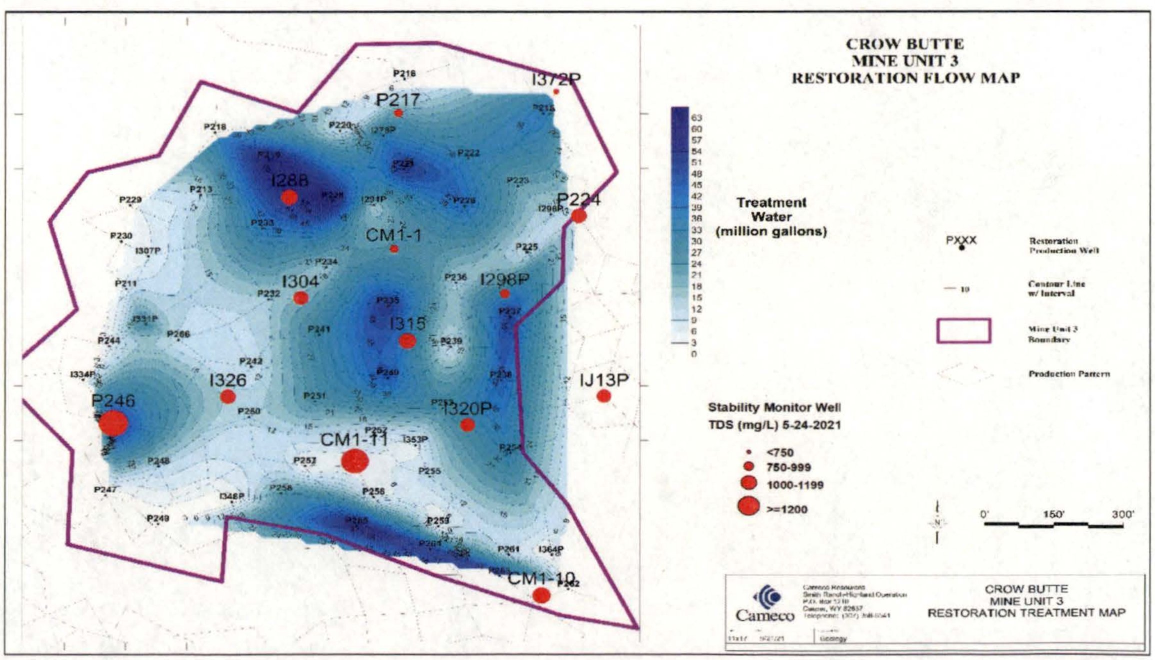

Figure 6. MU3 map with well TDS values. The contours show the volumes of water treated within the mine unit during restoration.

Conclusion

3.1 MU3 is unlikely to reach a state where every well is stable for U and As. TDS concentrations are in most cases significantly below pre-mining values, which implies that more RO treatment is likely to be a de-stabilizing influence for some or all the EOCs discussed in this report. Further addition of sodium sulfide as a restoration agent is also a probable cause of instability since it raises the pH of the aquifer waters and facilitates the desorption of uranium and arsenic species. These observations lead to the conclusion that further restoration efforts in MU3 are not justified.

3.2 We believe that U and As are the only species for which ACLs are required. Ra-226 activities are all far below the RTV for this radioisotope. TDS concentrations are not a health issue here, as discussed in this report. EPA Mn limits for potable water are, as mentioned earlier, only a secondary standard that have no significant health consequences in the context of this aquifer. V at the concentrations seen here may be helpful in precipitating uranium as discussed.

3.3 We submit this report with the aim of using it as a prelude to an ACL application for MU3, or MU3 in conjunction with one or more other mine units for which similar monitoring reports may be submitted in the future.

References:

1. To download this software go the following URL: https://www.epa.gov/land-research/proucl-software

2. Restoration Target Values were included in an appendix to the following correspondence: Ralph Knode, Vice President, Ferret Exploration Company of Nebraska, Inc., P.O. Box 169, Crawford, NE 68339 letter to Mr. Randall Wood, Director, Nebraska Department of Environmental Quality, P.O. Box 98922, Lincoln, NE 68509-8922, 19 Nov. 1992.

3. There are many references to the tendency of adsorbed uranyl carbonate species to mobilize at higher pH such as: Wazne, M.; Korfiatis, G.; Meng, X. *Environ. Sci. Tech.* **2003**, 37, 3619-3624.

4. Tokunaga, T.; Kim, Y.; Wan, J, *Environ. Sci. Tech.* **2009,** 43, 5467-5471.

ATTACHMENTS

CD of Excel and PDF files:

Crow Butte Monitoring - Mine Unit 3 Workbook

Mine Unit 3 Field pH Measurements

Mine Unit 3 Pre-mining Baseline Water Quality Data

Mine Unit 3 Average Baseline and Restoration Target Values

Mine Unit 3 Trend Graphs and Statistical Results

Mine Unit 3 Lab Reports and Chain of Custody Records 4-Sep-2018 through 24-May-2021