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## **Draft Final Fate and Transport of Copper at Camp Edwards Small Arms Ranges**

Megan I. Bishop, Jay L. Clausen, Vuong Truong, Anthony J.  
Bednar, Andrew L. Bray, Summer L. Nash, Jenifer M. Nechaev,  
and Brian P. Jackson

February 2023



***Cover photo: Sierra Range on Camp Edwards, Joint Base Cape Cod***

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# **Draft Final Fate and Transport of Copper at Camp Edwards Small Arms Ranges**

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Draft report

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## Abstract

Small Arms Range (SAR) training at U.S. Department of Defense sites leads to the introduction of heavy-metal residues to the soil through the deposition of projectiles. Small arms projectiles historically consisted of a lead slug surrounded by copper (Cu)-zinc alloy jacket. Recently, the U.S. Army has shifted to training with a Cu only projectile. The literature is replete with examples of Cu's mobility in aqueous and bioavailable form. Consequently, regulators overseeing activities at some military installations are asking about the fate-and-transport potential of Cu at military SARs. To improve the fate-and-transport understanding of Cu at Camp Edwards located within Joint Base Cape Cod, a series of studies were conducted to elucidate the behavior of Cu. The studies include 1) a literature search on Cu fate-and-transport, 2) surface soil, soil profile, and lysimeter sampling at three SARs at Camp Edwards, 3) batch adsorption/desorption experiments, and 4) saturated flow through column adsorption/desorption studies. The field assessment suggests Cu has not migrated more than 2 ft (0.61 m) below the ground surface. Adsorption soil-to-water partitioning coefficients ( $K_d$ ) for batch tests increased as the concentration of copper sulfate ( $\text{CuSO}_4$ ) decreased. Desorption  $K_{ds}$  increased as the concentration of adsorbed Cu increased. Batch tests were augmented with column experiments and show that mobile Cu was rapidly adsorbed by Camp Edwards soils under site-specific conditions with minimal desorption activity. The oxidation and dissolution of Cu munitions is a slow process. Due to the fast rate of Cu sorption by SAR soils, Cu transport to groundwater at Camp Edwards SARs is unlikely.

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## **Preface**

This study was conducted for the Cold Regions Research and Engineering Laboratory under “Joint Base Cape Cod Cu Fate-and-Transport Study.” The technical monitor was Dr. Jay L. Clausen.

The work was performed by the Biogeochemical Sciences Branch of the Research and Engineering Division, US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory (ERDC-CRREL). At the time of publication, Mr. Nathan Lamie was branch chief, Dr. Caitlin Callaghan was division chief, and Mr. David Ringelberg was the technical director for ERDC-CRREL. The deputy director of ERDC-CRREL was Mr. Bryan Baker, and the director was Dr. Joseph L. Corriveau.

The commander of ERDC was COL Christian Patterson, and the director was Dr. David W. Pittman.

## Nomenclature

CEC	Cation exchange capacity
CRREL	Cold Regions Research and Engineering Laboratory
EC	Electrical conductivity
EL	Environmental Laboratory
ERDC	Engineer Research and Development Center
HPLC	High Performance Liquid Chromatography
ICP-MS	Inductively Coupled Plasma – Mass Spectrometry
ICP-OES	Inductively Coupled Plasma – Optical Emission Spectrometry
JBCC	Joint Base Cape Cod
$K_d$	Soil partitioning coefficient
MAARNG	Massachusetts Army National Guard
MEPA	Massachusetts Environmental Policy Act
MMR	Massachusetts Military Reservation
NEPA	National Environmental Policy Act
OM	Organic matter
OMMP	Operation, Maintenance and Monitoring Plan
Ppb	Parts-per-billion
Ppm	Parts-per-million
RSD	Relative standard deviation

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SAR	Small Arms Firing Range
TC	Total carbon
TDS	Total dissolved solids
TIC	Total inorganic carbon
TOC	Total organic carbon
USEPA	U.S. Environmental Protection Agency
XRD	X-Ray Diffraction
XRFS	X-Ray Fluorescence Spectroscopy

## Chemical Elements/Compounds

Ca	Calcium
Cr	Chromium
CaCO <sub>3</sub>	Calcium Carbonate
Cu	Cu
CuSO <sub>4</sub>	Cu Sulfate
DNT	Dinitrotoluene
Fe	Iron
HNO <sub>3</sub>	Nitric acid
K	Potassium
Mg	Magnesium
Mn	Manganese
Na	Sodium
Ni	Nickel
NG	Nitroglycerine
Pb	Lead
Sb	Antimony
Se	Selenium
Tl	Thallium
V	Vanadium

Zn

Zinc

# 1 Introduction

The Department of Defense has begun a transformation from lead (Pb) to copper (Cu) projectiles on small caliber weapons systems (M4, M240, and M249B). Accordingly, the Massachusetts Army National Guard (MAARNG) has transitioned to firing Cu munitions on their small arms ranges (SAR). Camp Edwards SARs were constructed to handle Cu munitions in accordance with regulatory requirements reviewed under the National Environmental Policy Act (NEPA) and the Environmental Performance Standards (EPS) documented in Chapter 47 of the Acts of 2002 to minimize environmental hazard and protect Cape Cod's groundwater supply.\*† The Operation, Maintenance and Monitoring Plan (OMMP) developed for Camp Edwards states that routine soil and groundwater monitoring for evidence of metalloid mobilization is required.‡ The OMMP indicates the following Cu action levels; soil = 10,000 mg/kg, porewater = 1,300 ug/L, and groundwater = 650 ug/L. There has not been evidence of appreciable Cu migration from routine monitoring of soil, porewater, and groundwater by MAARNG to date. The fate and transport of Cu in aqueous form is well-studied in literature which indicates a potential for transport, a finding of concern for regulators overseeing training activities using Cu munitions.

## 1.1 Cu Fate-and-Transport

Copper is a reactive, bioavailable metal that can be toxic to living organisms at high concentrations (Sharma et al. 2009). Copper introduced to the soil through anthropogenic activities has a greater affinity for the aqueous phase, Cu in its 2+ oxidative state (Rader et al. 2019; Cornu et al. 2017). Thus, Cu metal undergoes oxidation and the copper oxide (CuO) is dissolved by precipitation events. Cu<sup>2+</sup> can transform into different compartments of the environmental media when bound to ligands within the soil and porewater (Rader et al. 2019). Cu speciation is governed by

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\* Joint Base Cape Cod, *JBCC Groundwater Protection Policy: Memorandum of Agreement Between Massachusetts Air National Guard, Massachusetts Army National Guard, United States Air Force, and United States Coast Guard, 2019* (Cape Cod, Massachusetts: Joint Base Cape Cod Cape Cod, 2019).

† Massachusetts Army National Guard, *Public Comment Summary Report for the Multi-Purpose Machine Gun (MPMG) Range at the Known Distance (KD) Range Environmental Assessment (EA), 2021* (Hanscom Air Force Base, MA: Massachusetts Army National Guard, Joint Force Headquarters).

‡ *Ibid.*

geochemical processes that dictate the bioavailability and transport of the metal through the hydrologic cycle (Gnecco, Sansalone, and Lanza 2008; Rader et al. 2019).

Copper partitioning from the aqueous to solid phase can occur via adsorption of  $\text{Cu}^{2+}$  by soils (Gnecco, Sansalone, and Lanza 2008). Adsorption by cation exchange is driven by soil pH (de Bor et al. 2012; Tangtong 2014). Soil pH directly impacts cation exchange capacity (CEC) by governing the abundance of negatively charged surface sites, i.e., sorption sites (Tangtong 2014; de Bor et al. 2012). Calcium<sup>2+</sup> (Ca) ions simultaneously increase the abundance of negatively charged surfaces by replacing other cations adsorbed by soil and forming bridged bonds to other anionic species (Tangtong 2014). There is an increase in sorption sites and complex stability at high pH, thus increasing metal adsorption by soils (Tangtong 2014). Another mechanism of adsorption is covalent bonding to negatively charged functional groups present on organic matter (OM) and inorganic matter (Rader et al. 2019). Each metal has a different affinity for varying particles, which creates a competitive environment for  $\text{Cu}^{2+}$  covalent bonding in the presence of other metal cations (Bansal 2009; Perez-Novo et al. 2008). Copper is known to have a greater affinity to soils than other metal ions, such as zinc (Zn), specifically for organic substances (Perez-Novo et al. 2008). Fang, Genxing, and Lianqing 2008 found through sorption/desorption experiments that sorption of  $\text{Cu}^{2+}$  by paddy soils decreased after removing soil OM. As a result, OM content is another crucial factor in the assessment of Cu fate-and-transport (Fang, Genxing, and Lianqing 2008). Camp Edwards soils are characterized as sandy clay loam with gravel and are historically slightly acidic (pH 6.5) with a low OM content, soluble salt content, and CEC (Clausen and Korte 2009).

Aqueous  $\text{Cu}^{2+}$  can be transported to off-site locations and/or the groundwater table during rain events via percolation through the soil column under favorable pH and redox conditions (Xu et al. 2005). The rate of heavy metal transport can be influenced by additional site-specific conditions such as climate and hydrogeologic setting.

## **1.2 Camp Edwards**

Camp Edwards is situated above the Sagamore Lens Aquifer, the largest supplier to the Cape Cod Sole Source Aquifer (Clausen et al. 2004). The vadose zone spans 100 feet to the top of the groundwater table (Clausen et al. 2004). The average rainfall is 110 cm per year, 40% of rainfall reaches

groundwater, and the groundwater flow velocity is 0.3 meters per day (Clausen et al. 2004; Clausen and Korte 2009). The relative abundance and depth of Cu migration in the soil column depends on the amount of adsorbed Cu within the soil column (Sharma et al. 2009; Xu et al. 2005). Sharma et al. (2009) and Xu et al. (2005) performed column experiments to assess Cu transport and found an inverse relationship between Cu migration and depth as adsorption affects the level of Cu exposure at greater depths. The relationship between Cu transformation and environmental factors as a function of soil depth must be understood to effectively explain current Cu transport at SARs (Rader et al. 2019; Xu et al. 2005).

The use of Pb/antimony (Sb) projectiles surrounded by a Cu-Zn jacket at Camp Edwards on Joint Base Cape Cod (JBCC) in Massachusetts started in the 1930s and continued until the late 1990s (Clausen et al. 2007a). Training activity with Pb munitions was banned in 1997 by the United States Environmental Protection Agency (USEPA) due to elevated levels of Pb in SAR soils (Barker, Beal, and Clausen 2019; Clausen and Korte 2009). In effort to immobilize existing Pb in the soil, phosphate amendments were applied to the soil in 1998 (Barker, Beal, and Clausen 2019). However, Clausen et al. (2007a) showed that Pb migration at Camp Edwards was minimal in the absence of phosphates due to the slow rate of Pb corrosion and the high degree of Pb attenuation under site conditions. This extensive environmental assessment was utilized as supporting evidence in a petition submitted by the Massachusetts Military Reservation (MMR), i.e. JBCC, for the use of Pb munitions at Camp Edwards, which was later approved by the USEPA in 2009 (Barker, Beal, and Clausen 2019).

### **1.3 Objective(s)**

The objective of this project was to investigate the adsorption and desorption behavior of Cu by soils to better understand the extent of potential Cu transport in soils and surface water runoff at Camp Edwards SARs.

## 1.4 Approach

A series of technical tasks were executed to meet the objectives including; 1) literature search on Cu fate-and-transport 2) soil profiling and lysimeter sampling, 3) batch experiments, and 4) column experiments. The batch experiments provide baseline Cu adsorption and desorption equilibrium coefficients (i.e.,  $K_d$ ) to understand Cu partitioning between the solid and aqueous phase under a variety of conditions. Laboratory-based column studies were conducted to investigate the potential for Cu mobilization under Camp Edwards geochemical conditions. The column study approach was designed to investigate the extent to which Cu can be transported in soil and surface water runoff under various solid-phase Cu matrices by monitoring Cu migration as a function of soil profile depth.

## 2 Methods

### 2.1 Study Area

Sampling took place at India, Tango, and Sierra Cu-only SARs on Camp Edwards in July 2022. Sierra Range is a 300-meter modified record fire range, while both India and Tango Range are 25-meter zeroing ranges (“Small Arms Ranges” n.d.). Refer to Appendix A: Range Layouts for range design. All ranges have roughly four-to-five-meter impact berms established behind each target for Cu munition capture (Massachusetts Army National Guard 2021). Impact berms serve to prevent bullet fragmentation and contain projectiles for later metal recovery, thus limiting the potential for Cu percolation through the soil (Massachusetts Army National Guard 2021). Soil analysis by method SW6010C in October 2021 showed that the soil Cu concentration did not exceed 25 mg/kg on India, Sierra, Tango, or Lima Range. Camp Edwards soil is characterized as a sandy loam with a low OM content (Clausen and Korte 2009). Soil pH measurements at Tango Range were 5.37 in 2010 and increased to 7.6 to 8.7 after lime amendment for the remediation of Pb contaminated SAR soils (Clausen, Barker, and Booker 2017).

Each range has operational pan lysimeters two feet below the surface for routine monitoring of metalloid mobilization in soil porewater (Clausen et al. 2010b). Lysimeter layouts for Tango Range are in Appendix A: Range Layout Figures. Previous porewater measurements in 2011 indicated a pH level of 7.0 (Clausen, Barker, and Booker, 2017). Two pan lysimeters were sampled and analyzed for Cu by method SW6010C on Sierra Range. Results indicate that Cu in porewater on Sierra Range corresponded to background Cu levels. On India Range, the highest Cu porewater measurement was 270 ug/L. Groundwater Cu analysis by method SW6010C did not exceed 10 ug/L at India, Tango, and Sierra Range.

### 2.2 Soil and Lysimeter Sampling

Surface soil samples were collected in increments of 30 from six berms located in the center of each SAR described in Section 2.1 and placed into plastic sample bags. Metal hand shovels were rinsed twice with deionized water between each berm. Incremental samples were shaken to homogenize the material and analyzed at three locations for Cu, Ca, as well as a standard suite of metal analytes (Chromium (Cr), Iron (Fe), Potassium

(K), Magnesium (Mg), Manganese (Mn), Sodium (Na), Nickel (Ni), Pb, Sb, Selenium (Se), Thallium (Tl), Vanadium (V), and Zn) using the X-250 handheld X-Ray Fluorescence Spectroscopy (XRFS) analyzer (SciAps, Woburn, MA) for a duration of 120 seconds per location. Two berms at each SAR that contained the highest level of surface Cu were bored to four feet or refusal and sample across four-inch intervals using a hand auger. Tools were rinsed twice with deionized water between soil borings. In addition, clean sand was collected in bulk from a background location off Gibb's Road at JBCC to perform column and batch studies. Soil with elevated Cu levels was also collected in bulk from two locations on Berm 8 and 12 on Tango Range with elevated Cu levels determined by XRFS in the field.

All soil samples were homogenized, air-dried for 72 hours, and subsequently passed through a #10 <2 mm sieve. Core samples below the limit of XRFS detection were digested following USEPA Method 3050 for later ICP-mass spectrometry (MS) analysis of Ca, Cu, Fe, K, Mg, Na, and Pb at EL.

Water samples were collected in 500 mL Nalgene bottles from 6 functional lysimeters using a peristaltic pump. Three lysimeters were located on Sierra range on the range floor, firing point, and a background location. One lysimeter sample was collected from India range on the berm floor. A background lysimeter sample was collected from Tango range and a trip blank lysimeter sample was collected after sampling all three ranges. The sole pore-water pH was measured in-situ using a YSI meter, Model 556 MPS. Lysimeter water samples were transported to CRREL on ice.

### **2.3 Soil and Porewater Profiling**

A subset of 18 soil samples including two incremental surface samples, two core samples near two feet, and two core samples at maximum depth from each SAR were analyzed for pH, electrical conductivity (EC), cations, anions, total carbon (TC), total organic carbon (TOC) and total inorganic carbon (TIC). TC, TOC, and TIC were measured at EL. Soil pH was measured on a 1:1 soil/Milli-Q water ratio with a Fischer Scientific Accument AB200. For EC analysis, a 1:10 soil/Milli-Q water mixture was vortexed for 1 minute and filtered through a 0.45 µm syringe. Dissolved ions were measured using a 1:10 soil/Milli-Q water, ratio shaken for 24 hours, and passed through a 0.45 µm syringe filter.

Lysimeter samples from each SAR were analyzed for dissolved metals via ICP-MS. Filtered water samples were passed through a 0.45  $\mu\text{m}$  syringe filter and acidified with 1% nitric acid ( $\text{HNO}_3$ ). All ICP-MS samples were shipped to EL and stored in the refrigerator until analysis. Total dissolved solids (TDS), OC and IC concentrations were determined at EL. Lysimeter subsamples were filtered through a 0.45  $\mu\text{m}$  and measured for EC. Subsamples were then analyzed by Thermo Scientific Dionex Integrion High Performance Liquid Chromatography (HPLC) for ion concentration.

## 2.4 Batch Experiments

CRREL had originally proposed to run batch tests with and without biocide to understand the influence of biological activity on Cu adsorption/desorption by soil. However, all batch water extracts that not treated with biocide were lost in the delivery to ERDC-Environmental Laboratory (EL) for inductively coupled plasma – mass spectrometry (ICP-MS) analysis. Liquid phase Cu concentrations are necessary to calculate the equilibrium distribution coefficient ( $K_d$ ) and cannot be derived from solid phase concentrations due to the high heterogeneous nature of coarse soils. However, a significant difference in Cu  $K_d$  is not expected between batch experiments with and without biocide based on previous batch testing with NG and DNT, which found no difference (Clausen et al. 2010b). Therefore, batch experiments utilizing biocide are likely to accurately represent Cu partitioning at Camp Edwards.

CRREL had also proposed to calculate the CEC of soil samples as part of the soil chemistry profile and quantify the total extractable fraction of Cu in SAR lysimeter samples. These samples were lost in shipment as well to EL for ICP-MS analysis and are not discussed in the report. An electrolyte solution was simulated in the laboratory using Camp Edwards pan lysimeter ion concentration data collected by MAARNG in 2021. Calcium carbonate ( $\text{CaCO}_3$ ) was not found in this dataset, despite being present in rainwater in aqueous form, as it undergoes a reaction with carbonate rock to form bicarbonate (Bogan et al. 2009). Therefore, the mole ratio between cation and anion species documented in the 2021 dataset was balanced by adding  $\text{CaCO}_3$  and magnesium carbonate to the electrolyte solution to prevent potential competitive adsorption. The addition of carbonate species created increased the pH of the solution to 9. It is not likely that this affected the Cu adsorption coefficient at Camp Edwards since Camp Edward soils were previously treated with lime in 2011, which results in an

elevated pH. The batch study was amended to assess the impact of the simulated electrolyte solution on the Cu partitioning coefficient.

#### **2.4.1 Sorption Tests**

Batch sorption tests were conducted in duplicate sets using a 1:20 soil/solution ratio at room temperature. A total of 5 g of clean sand obtained from Camp Edwards was added to a 125 mL Nalgene bottle mixed with a 100 mL solution of 1% glutaraldehyde and 1) Milli-Q water, 2) Cu sulfate ( $\text{CuSO}_4$ ) solution using Milli-Q water at 10, 100, and 1000 ppm, 3) eluent from Cu contaminated JBCC soil immersed in Milli-Q water for 24 hours, 5)  $\text{CuSO}_4$  solution using Milli-Q water at 10, 100, and 1000 ppm, and 6) eluent from Cu contaminated JBCC soil immersed in Milli-Q water for 24 hours. Runs 1, 5 and 6 were repeated with electrolyte solution in place of Milli-Q water.

Batch sample containers were measured for initial pH and equilibrated for 24 hours on a rotary shaker at 150 rpm. The solution was then recovered in 50 mL centrifuge tubes and centrifuged at 3600 rpm for 15 minutes. The supernatants were then decanted into clean 125 mL Nalgene bottles, filtered through a 0.45  $\mu\text{m}$  syringe, and measured for pH. Filtered sorption supernatant from the batch sorption tests were then acidified to 1%  $\text{HNO}_3$  and refrigerated until ICP-MS analysis.

Following the sorption phase of the test the remaining soils were dried at 105°C for 24 hours (Ramamurthy, Vo, Li, and Qu 2008; Laporte-Saumure, Martel, and Mercier 2011). One set of sorption soils were sacrificed for the desorption test while the other set was ground with a mortar and pestle to increase homogenization and therefore decrease XRFS % relative standard deviation (RSD). The concentrations of Cu, Pb, Fe, Ca, K, Mg, and Na were then quantified via XRFS. Sorption soil samples that were below XRFS LOD were digested following USEPA Method 3050 for later ICP-MS analysis of Ca, Cu, Fe, K, Mg, Na, and Pb.

#### **2.4.2 Desorption Tests**

Batch desorption tests utilized the sacrificed, dried sorption material. The adsorbed soils were weighed and combined with 100 mL of either Milli-Q water or electrolyte solution to match adsorption conditions. Additionally, 5 g of contaminated JBCC soil was analyzed for initial Cu content and combined with 100 mL of Milli-Q water. Desorption solutions were

measured for pH and then placed on a rotary shaker at 150 rpm for 24 hours at room temperature. Equilibrated suspensions were centrifuged at 3600 rpm for 15 minutes in 50 mL centrifuge tubes. The supernatants were decanted into clean 125 mL Nalgene bottles, filtered through a 0.45  $\mu\text{m}$  syringe, and measured for pH. All desorption water extracts were analyzed for metal analytes Ca, Cu, Fe, K, Mg, Na, and Pb using ICP-MS.

Desorbed soil residues were dried at 105°C for 24 hours, followed by Cu analysis via XRFS. Desorption soil samples that were below XRFS LOD were digested following USEPA Method 3050 for later ICP-MS analysis of Ca, Cu, Fe, K, Mg, Na, and Pb.

### 2.4.3 Equilibrium Distribution Coefficient ( $K_d$ )

Understanding changes in Cu speciation is critical in the evaluation of Cu transport through the soil. The equilibrium distribution coefficient ( $K_d$ ) is utilized in this study as a measure of soil-to-water Cu partitioning. The adsorption and desorption  $K_d$  are defined by the following equations:

$$\text{Adsorption } K_D = \frac{S}{C_e} = \frac{C_o - C_e}{C_e} \cdot \frac{V}{m} \quad (1)$$

where:

- $K_D$  = soil-to-water partition coefficient for a given substance (L/kg)
- $S$  = mass of sorbed contaminant per mass of soil (mg/kg)
- $C_e$  = equilibrium liquid phase concentration (mg/L)
- $C_o$  = initial liquid phase concentration (mg/L)
- $V$  = volume of the liquid phase (L)
- $m$  = mass of soil (kg)

$$\text{Desorption } K_D = \frac{m \cdot S_o - V \cdot C_{e,d}}{m \cdot C_{e,d}} \quad (2)$$

where:

- $K_D$  = soil-to-water partition coefficient for a given substance (L/kg)
- $S_o$  = Cu concentration in soil after adsorption reaction (mg/kg)
- $C_{e,d}$  = equilibrium liquid phase concentration (mg/L)
- $V$  = volume of the liquid phase (L)
- $m$  = mass of soil (kg)

K<sub>as</sub> were generated for batch sorption and desorption experiments to understand Cu mobility under varying Cu matrices.

## 2.5 Column Experiments

A simulated Camp Edwards rainwater solution was created using pan lysimeter electrolyte concentration data collected by MAARNG in 2021. Four acrylic columns were packed with 500 g of clean Camp Edwards sand, tamped down, and reverse saturated using the weak electrolyte solution at a flow rate of 2.6 mL/min using a Masterflex pump for 24 hours to remove unsaturated voids. Each column was covered with parafilm to prevent drying over the weekend. After reverse saturation, Column A did not receive treatment; Cu slugs were added to the top of Column B; ( a thin, 1 cm layer of Cu contaminated soil (15 g) was applied to the top of Column C; and a thin, 1 cm layer of CuSO<sub>4</sub> (5 g) was applied to the top of Column D (Figures 1, 2, and 3). The column experiments commenced using the weak electrolyte solution at a flow rate of 2.6 mL/min once the Cu contaminated material was added to the top of the column. Leachate samples were collected over 5-minute intervals at 0.5, 1, 2, 4, 8, 22, 48, 96, 168, 336, and 672 hours into 15 mL centrifuge tubes. The leachate was acidified with 1% HNO<sub>3</sub> and refrigerated until ICP-MS analysis for Cu, Pb, Fe, Ca, K, Mg, and Na.

Figure 1. Column Design

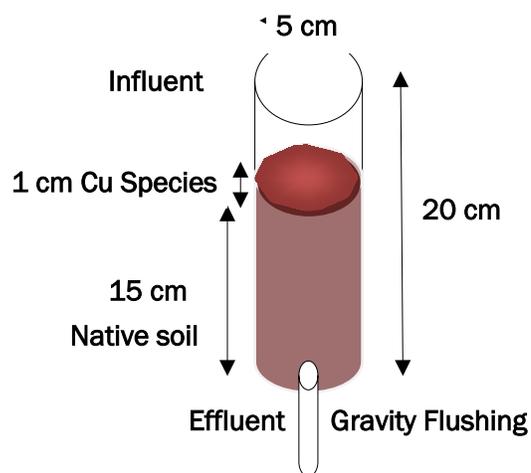


Figure 2. Column Design from left to right: Column A, B, C, and D.

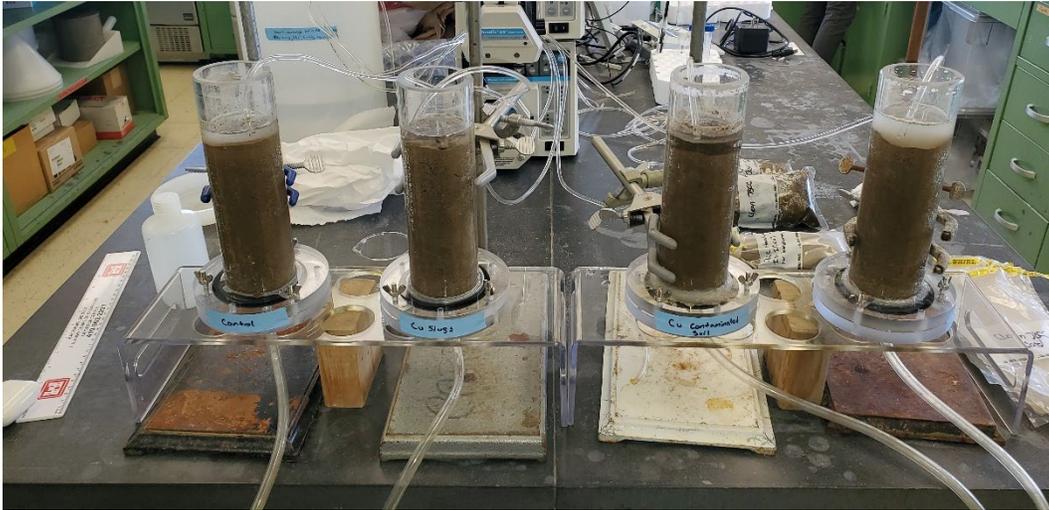


Figure 3. Zero-valent Cu applied to the top of Column B.



After 672 hours, the soil core for Column A was sliced horizontally into thirds (e.g., top, middle, bottom). Cu slugs were removed from Column B and the first 2.5 cm of soil was removed from Column C prior to core fractioning. Note that the top fraction of Column C is consequently characterized by soil from 2.5 to 5 cm depth, unlike top fractions for Column A and B. A thin layer of residual, Cu precipitate was removed from Column D

before the soil core was split into thirds. Formation of a Cu precipitate was expected at the top of the column since precipitation reactions between Cu and  $\text{CuCO}_3$  surfaces occur more frequently than adsorption reactions at large concentrations (Rodriguez-Rubio et al. 2003). The pore water was squeezed from all saturated soil sections via centrifugation and the soil was dried at  $105^\circ\text{C}$  for 24 hours. Soil samples were characterized for solid-phase Cu content as a function of soil profile depth via XRFS. Soil fractions that were below the limit of XRFS detection were digested following USEPA Method 3050 for ICP-MS analysis. The soil pH of clean Camp Edwards sand, Column A fractions, Column D fractions, and fractionated porewater were measured on a 1:1 soil/Milli-Q water ratio with a Fischer Scientific Accumant AB200 to determine the effect of the electrolyte solution on column pH.

## 3 Results

### 3.1 Soil Profiling

Soil pH of a subset of soils at SARs on Camp Edwards range from slightly to strongly acidic, with a few outliers reading circumneutral to neutral pH on Tango Range and Sierra Range at two feet below surface (Table 1). Average pH as a function of depth across SARs is slightly acidic without significant difference (Figure 4). Electrical conductivity is consistent across all ranges apart from Sierra Range at two feet below surface measuring 176  $\mu\text{s}/\text{cm}$ . Though the EC of sample S5R at a depth of two feet exceeded other samples by one to two orders of magnitude, it is still considerably low when compared to other soil types. Low EC and pH are expected in sandy soil as this soil type cannot typically retain soil nutrients due to their high porosity (Osman 2018). Total carbon values can be explained by the TOC concentrations across SARs. TOC levels are higher at the surface than at depth for all of the range soils apart from TOC measurements between 36-50 inches below the surface (Table 1).

Table 1. pH, EC, TC, OC, and IC of Camp Edwards soil subset

Range	Sample ID	Depth (in)	pH	EC <sup>1</sup> ( $\mu\text{s}/\text{cm}^3$ )	TC <sup>2</sup> (g/Kg)	TOC <sup>3</sup> (g/Kg)	TIC <sup>4</sup> (g/Kg)
India	MMR18_0in	0	6.1	20.11	13	12	ND
India	MMR19_0in	0	5.96	29.14	14	14	ND
Sierra	MMRS5R_0in	0	5.92	28.36	11	12	ND
Sierra	MMRS8R_0in	0	5.94	24.44	11	13	ND
Tango	MMRT15_0in	0	5.45	24.89	18	20	ND
Tango	MMRT17_0in	0	5.69	18.64	16	13	2.4
Tango	MMRT15_18in	18	6.4	6.78	ND	1.7	ND
Tango	MMRT15_22in	22	6.45	8.56	ND	1.2	ND
India	MMR12_24in	24	5.67	12.32	8.7	8	ND
India	MMR18_24in	24	6.39	4.31	ND	1.4	ND
Sierra	MMRS5R_24in	24	6.75	176	ND	1.8	ND
Sierra	MMRS6R_24in	24	5.64	8.59	1	1.9	ND
Tango	MMRT18_24in	24	7.4	22.81	3.8	4.5	ND
India	MMR12_32in	32	5.76	11.95	8	9.6	ND
Tango	MMRT18_32in	32	6.09	26.98	3.3	4.1	ND
Sierra	MMRS6R_36in	36	5.23	21.4	13	13	ND
India	MMR18_44in	44	5.48	15.63	11	10	1.3
Sierra	MMRS5R_50in	50	4.76	19.32	10	7.5	2.6

<sup>1</sup> electrical conductivity

<sup>2</sup> total carbon

<sup>3</sup> total organic carbon

<sup>4</sup> total inorganic carbon

Figure 4. Average pH of Camp Edwards SAR soil subset as a function of depth

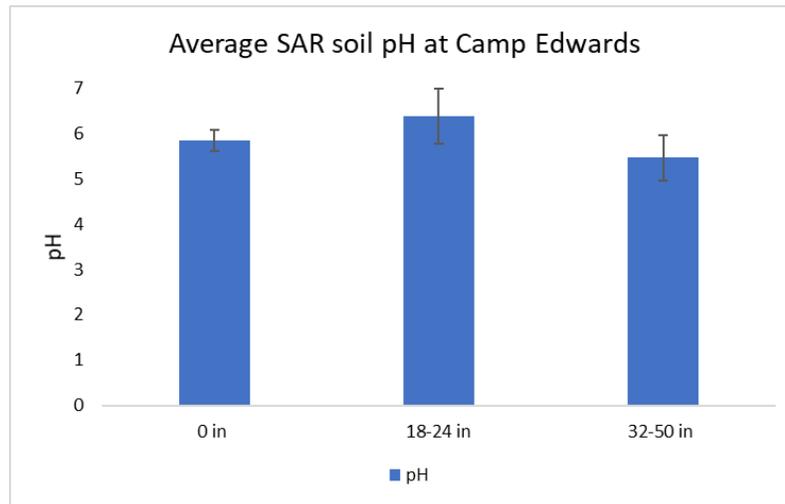


Figure 5 indicates that the SAR soil subset contains high levels of Ca, Fe, and K at the surface, which decreases with depth. Low levels of soluble cations are found across range soils (Table 2). Compared to background sand collected from the surface of an off-site location at Camp Edwards, soil on the berm surface had significantly higher levels of Ca, Fe, and K (Figure 6). Enhanced nutrient retention is likely explained by the lime amendment. Introducing calcium carbonate ( $\text{CaCO}_3$ ) to soil increases pH, leading to changes in soil processes of exchangeable ion species affecting mineral composition (Holland et al 2018). Over time,  $\text{CaCO}_3$  in soil ionizes and convert to  $\text{Ca}^{2+}$  ions and  $\text{CO}_3^{2-}$ . Total inorganic carbon, representative of  $\text{CO}_3^{2-}$ , was sporadically present in minimal concentrations in SAR soils. It is likely that  $\text{CO}_3^{2-}$  reacted with  $\text{H}^+$  to form water-soluble bicarbonate, while  $\text{Ca}^{2+}$  complexed with organic matter in the soil over time. Dinkecha and Tsegaye (2017) found that liming soils also increased the concentration of  $\text{K}^+$  but led to a reduction in micronutrients including Fe. It is important to recognize that while the SAR soils were treated with lime roughly 12 years ago, lime treatment reactions typically run to completion after 3 years (Bast, Warnche, and Christenson 2011). SAR soil pH has decreased since the initial lime application in 2011, but it is evident that liming has led to a series of changes in the mineral composition of the soil. Elevated levels of Fe, as well as Ca and K, were also found in Column D of the column experiment, discussed in Section 3.4.1. It is unclear what has caused elevated levels of Fe in SAR soils, but the presence of Cu may influence the mobility of Fe.

Table 2. Mean dissolved cation and anion concentrations (mg/kg) by IC in Camp Edwards soil subset

Range	Sample ID	Depth (in)	Concentration (mg/kg)												
			Li	Na	NH4	K	Mg	Ca	F	Cl	NO2	Br	SO4	NO3	PO4
India	MMIR18_0in	0	bd	3.89	0.81	13.40	1.41	6.39	0.53	4.08	bd	bd	3.73	11.57	0.78
India	MMRI9_0in	0	bd	8.28	2.05	25.43	3.05	10.79	0.59	9.08	bd	bd	11.65	33.41	1.26
Sierra	MMR5SR_0in	0	bd	3.70	2.47	16.09	1.99	10.75	0.62	3.17	bd	0.42	3.92	10.14	1.00
Sierra	MMRS8R_0in	0	bd	3.88	2.97	12.79	1.88	10.45	0.65	2.52	bd	0.42	3.95	5.67	1.09
Tango	MMRT15_0in	0	bd	8.05	1.07	14.86	1.87	6.76	0.34	11.88	bd	0.49	5.88	23.63	0.59
Tango	MMRT17_0in	0	bd	6.18	0.98	10.88	1.24	4.95	0.39	5.51	bd	0.52	5.34	10.91	0.67
Tango	MMRT15_18in	18	bd	1.22	0.43	2.36	0.52	4.40	0.30	1.11	0.37	bd	3.33	0.89	0.49
Tango	MMRT15_22in	22	bd	1.89	0.21	2.60	0.48	5.68	0.34	0.97	bd	bd	4.03	0.76	0.59
India	MMRI12_24in	24	bd	2.20	0.62	2.92	1.53	8.56	0.30	2.29	bd	bd	6.03	2.86	0.73
India	MMRI8_24in	24	bd	1.18	0.50	2.90	0.42	2.93	0.30	1.29	bd	bd	1.16	0.93	0.73
Sierra	MMR5SR_24in	24	bd	2.54	1.08	9.49	0.67	3.37	0.39	1.21	bd	bd	2.78	8.57	0.82
Sierra	MMRS6R_24in	24	bd	2.96	0.36	8.66	0.56	2.43	0.37	0.92	bd	bd	1.70	2.30	1.06
Tango	MMRT18_24in	24	bd	2.78	0.22	5.56	1.21	19.01	0.60	1.04	bd	bd	9.25	4.71	1.04
India	MMRI12_32in	32	bd	3.04	0.31	4.53	1.11	8.11	0.42	2.26	bd	bd	3.53	8.33	1.63
Tango	MMRT18_32in	32	bd	7.06	0.45	7.60	2.39	18.91	0.35	2.00	bd	bd	65.64	3.26	bd
Sierra	MMRS6R_36in	36	bd	4.73	2.80	15.82	2.08	8.40	0.33	1.81	0.37	bd	8.14	29.53	0.82
India	MMRI8_44in	44	0	3.61	0.34	4.21	3.29	8.82	0.68	1.45	bd	bd	5.63	6.37	31.79
Sierra	MMRS5R_50in	50	bd	6.94	2.92	11.74	2.10	4.73	bd	5.49	bd	0.38	27.68	5.44	bd

bd= Below the limit of detection

Figure 5. Average metal concentrations in Camp Edwards SAR soil subset as a function of depth

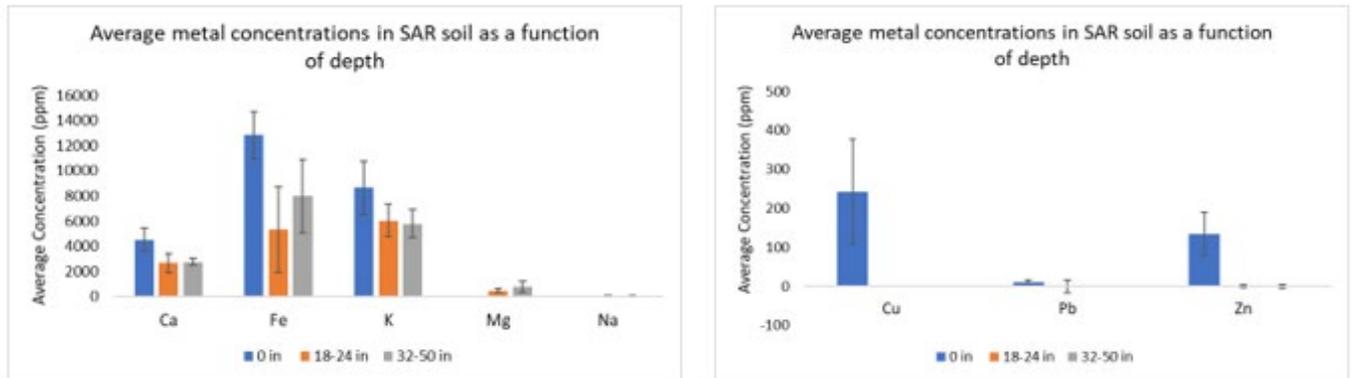


Figure 6. The difference in average XRFs metal analyte concentration between the background soil surface and SAR berm surface at Camp Edwards

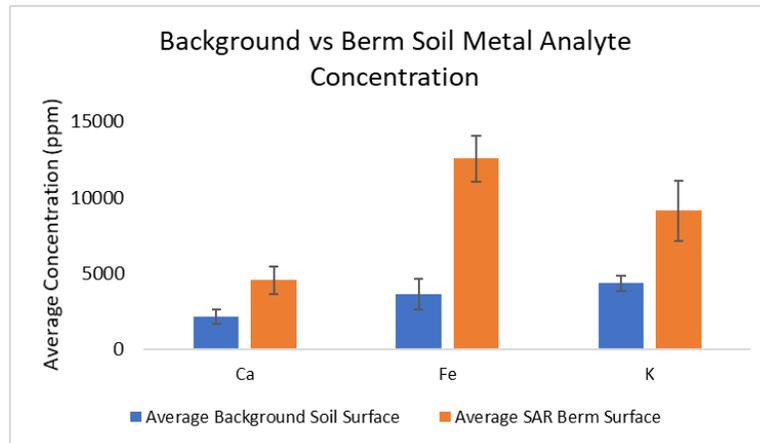
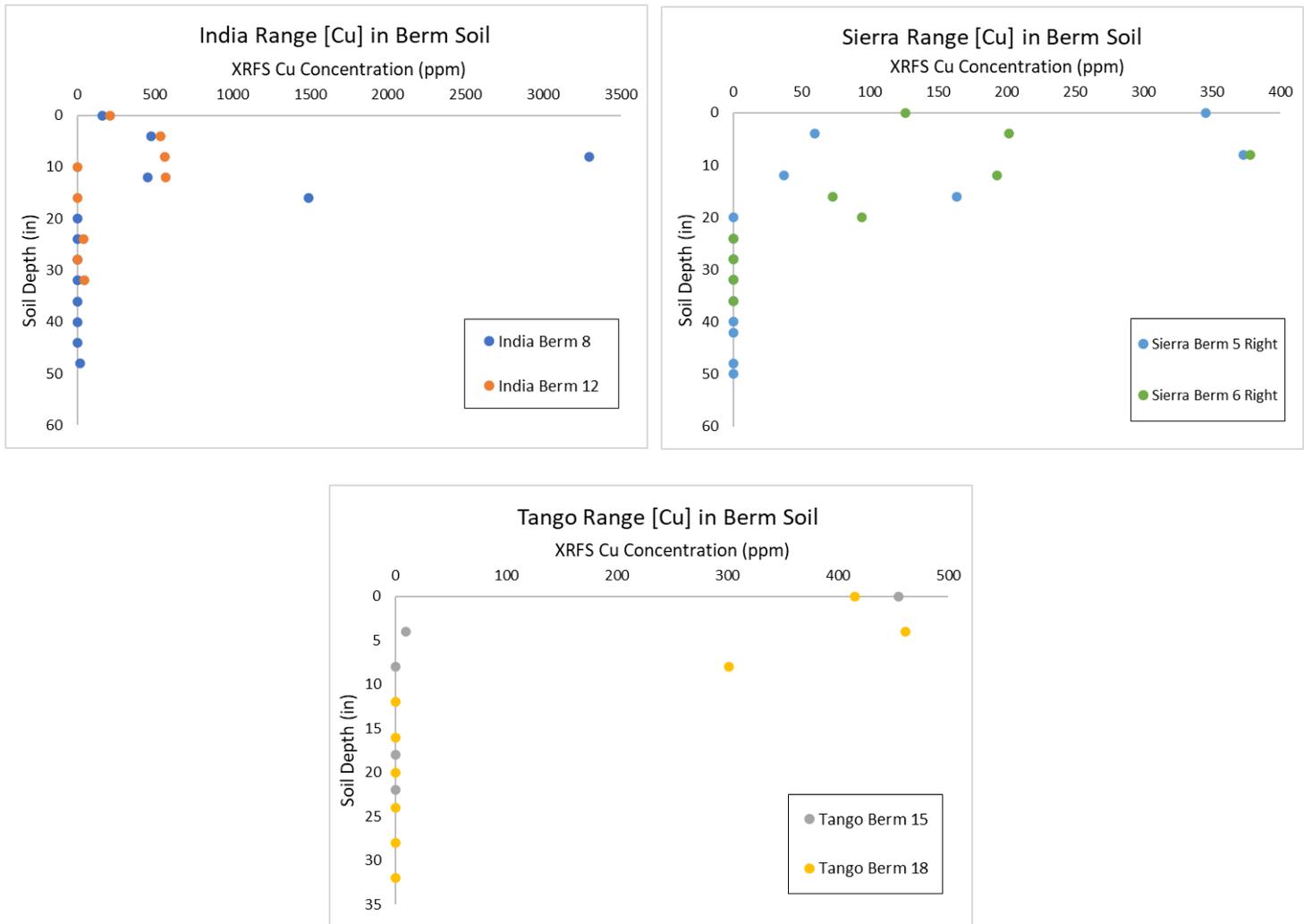


Figure 7 presents soil boring results from each SAR. On all SARs, Cu is most abundant at the surface and decreases with increasing depth to 8 inches. Cu concentrations on Sierra Range (Figure 7b) were variable from the surface to a depth of two feet but did not tend migrate further. The highest measured concentrations of Cu in berm soils were found on India Range (see Figure 7c). Berm 8 exceeded Cu XRFs measurements from other borings by an order of magnitude and was the only berm to exhibit minimal Cu migration through the soil to the maximum boring depth of 32 inches. Unlike Sierra and India Ranges, Cu on Tango Range did not migrate further than eight inches below the berm soil surface (see Figure 7a). It is important to note that Tango Range transitioned from a Pb to Cu munitions range in 2021, while Sierra and India became active in 2012 and 2013, respectively (“Small Arms Ranges” n.d.). So, Cu had less opportunity to build up in the soil and migrate at Tango Range.

It is evident that Cu accumulation and migration in the soil is a slow process under Camp Edwards geochemical conditions. The likely rate limiting step is Cu metal oxidation to Cu oxide,  $\text{Cu}^{2+}$ . The  $\text{Cu}^{2+}$  form of Cu is the species with the potential for transport.  $\text{Cu}^{2+}$  retention by adsorption, complexation, and/or precipitation in soils at Camp Edwards prevents significant Cu migration. Cu complexation and precipitation reactions were not explored in this study but may further explain the limited migration of Cu at Camp Edwards. SAR soils have increased concentrations of Ca and Fe as a result of previous liming. As previously mentioned, Rodriguez-Rubio et al. (2003) found that Cu adsorption by  $\text{CaCO}_3$  in soils occurred frequently at low levels of Cu. As Cu concentration increased, precipitation

reactions became more prominent. Analysis of SAR soil mineralogy using X-ray diffraction (XRD) to identify the abundance of both  $\text{CaCO}_3$  and Fe oxide species is needed to better infer the mechanism of Cu retention by SAR soils.

**Figure 7. Average XRFs Cu concentrations in Camp Edwards SAR soil borings as a function of soil depth**



### 3.2 Porewater Profiling

Chemical profiles for six lysimeter samples from Camp Edwards SARs are listed in Table 3. The pH of the trip blank (4.34) was 1 to 2 pH units less than other porewater samples across the ranges. Porewater pH decreased as distance increased from the impact area on Sierra Range (Table 3). The highest recorded porewater pH (6.23) was from the berm face on India

Range. The behavior of pH with respect to distance from the berm face is likely linked to the remediation effort in 2011.

The trip blank exhibited the lowest EC of 7.77 compared to other lysimeter samples, which were 1 to 2 orders of magnitude higher. Total dissolved solids were not detected in the trip blank or from the firing point on Sierra Range but were measurable in other lysimeter samples at levels from 82 to 165 mg/L. The porewater from the berm face on India Range had the highest TDS level of 165 mg/L. Organic carbon was higher in porewater from the berm face on India Range (16.7 g/kg) and the Sierra range floor (16.4 g/kg). The range floor on Sierra had elevated levels of TIC as well compared to other samples. High levels of TOC and TIC on the Sierra range floor are associated with a higher pH compared to other lysimeters. High levels of OM associated with a higher pH can lead to increased Cu sorption as OM has a strong binding affinity for Cu (Braven et al 2012; Wu, Laird, and Thompson 1999). Nonetheless, Table 4 reports negligible concentrations of dissolved Cu in all porewater samples.

**Table 3. pH, EC, TDS, OC, and IC of Camp Edwards lysimeter samples**

Sample ID	pH	EC <sup>1</sup> ( $\mu\text{s}/\text{cm}^3$ )	TDS <sup>2</sup> (g/Kg)	OC <sup>3</sup> (g/Kg)	IC <sup>4</sup> (g/Kg)
Trip Blank	4.34	7.77	ND	2.01	ND
Tango Range Background	5.82	150.2	82	4.32	1.07
Sierra Range Background	5.2	201.1	104	6.29	ND
Sierra Range Floor	6.19	146.4	72.5	16.4	13.1
Sierra Range Firing Point	5.82	74.85	ND	2.91	6.3
India Range Berm Face	6.23	147.4	165	16.7	1.3

<sup>1</sup> Electrical conductivity

<sup>2</sup> Total dissolved solids

<sup>3</sup> Organic carbon

<sup>4</sup> Inorganic carbon

ND = Not detected

Tables 4 and 5 show that mean dissolved cation species Li, Fe, NH<sub>4</sub>, K, Mg are consistently low across range lysimeters. Elevated levels of Na are present in at the background location on Sierra Range (23.41 ppm) and background lysimeter on Tango Range (13.58 ppm). Elevated levels of Ca are present in porewater on the range floor of Sierra (20.67 ppm) and on the berm face on India Range (16.24 ppm). A high dissolved Ca concentration at these two locations is likely a contributor to the slight increase in porewater pH (Table 3).

Mean dissolved anion species F, NO<sub>2</sub>, Br, and NO<sub>3</sub> are consistent across range lysimeters (Tables 4 and 5). The background location on Sierra Range contained the highest concentration of Cl at 49.14 ppm. Low levels of Cl are found at the berm face of India Range, the trip blank, and the range floor of Sierra. Elevated levels of SO<sub>4</sub> were measured from the berm face on India Range and from the background location on Tango Range. PO<sub>4</sub> was consistently low across all lysimeters, except near the berm face on India Range measuring 40.48 ppm.

**Table 4. Mean dissolved metal concentration (mg/L) by ICP-MS in Camp Edwards lysimeter samples**

Sample ID	Concentration (mg/L)						
	Ca	Fe	Mg	K	Na	Cu-63 [2]	Pb-208 [1]
Trip Blank	0.0422 J	ND	ND	0.820 B	0.284 J	0.0047 J	ND
Tango Range Background	6.87	ND	3.71	0.870 B	12.3	ND	ND
Sierra Range Background	6.62	ND	1.74	2.60 B	21.2	0.0055 J	ND
Sierra Range Floor	21.1	ND	1.86	0.273 J, B	5.11	0.0060 J	ND
Sierra Range Firing Point	2.73	0.0515 J	0.824	4.58 B	6.32	0.0023 J	ND
India Range Berm Face	15.2	0.0527 J	4.06	3.05 B	5.48	0.364	ND

ND= Not detected

J = Estimated concentration

B = Analyte is found in the associated blank and the sample.

**Table 5. Mean dissolved cation and anion concentrations (mg/kg) by IC in Camp Edwards lysimeter samples**

Sample ID	Concentration (mg/L)												
	Li	Na	NH4	K	Mg	Ca	F	Cl	NO2	Br	SO4	NO3	PO4
Trip Blank	bd	0.34	0.48	0.81	0.55	bd	bd	0.74	bd	bd	0.86	0.72	bd
Tango Range Background	bd	13.58	0.19	0.79	3.84	7.74	bd	19.20	bd	bd	26.79	6.04	bd
Sierra Range Background	bd	23.41	0.47	2.21	1.72	7.10	bd	49.14	bd	bd	4.80	3.95	0.62
Sierra Range Floor	bd	5.44	0.27	bd	1.88	20.67	bd	6.66	bd	bd	2.44	bd	bd
Sierra Range Firing Point	bd	6.68	0.21	4.01	1.06	4.17	bd	17.67	bd	bd	1.29	bd	bd
India Range Berm Face	bd	5.56	0.24	1.97	4.08	16.24	0.32	6.17	bd	0.54	15.87	3.13	40.48

bd= Below the limit of detection

### 3.3 Batch Experiments

The initial starting concentrations of Cu in the batch adsorption experiment with Milli-Q water and electrolyte solution were 3.9, 39.8, and 390 ppm (Table 6). The percent adsorption of Cu from the CuSO<sub>4</sub> Milli-Q solution ranged from 9.5 to 44.5%. More Cu adsorption was observed at the lower CuSO<sub>4</sub> concentration with Cu adsorption decreasing with increasing

CuSO<sub>4</sub> solute concentration. As concentration increases, there is less opportunity for sorption as sorption sites become limited. The Cu adsorption values of 2 to 16 L/kg are comparable or higher than observed for nitroglycerine (NG), ~ 2 L/kg and 2,4-dinitrotoluene (DNT) at 3.3 L/kg, at Camp Edwards (Clausen et al. 2010b). Despite decades since first released into the environment NG and DNT have not been observed to have migrated more than a couple feet from the ground surface at Camp Edwards (Clausen et al. 2010b). Similar to NG and DNT, Cu is not expected to be particularly mobile at Camp Edwards and should not impact groundwater given its elevated K<sub>d</sub> values. Although not measured directly in this study, Cu metal corrosion to Cu<sup>2+</sup> followed by dissolution is likely the rate limiting step in the transport of Cu at Camp Edwards. Cu is likely to migrate no more than several feet into the soil profile.

Table 6 shows that the percent adsorption of Cu from the CuSO<sub>4</sub> electrolyte solution ranged from -27.3 to 74.7%. Consistent with CuSO<sub>4</sub> Milli-Q water samples, Cu adsorption occurred most frequently in CuSO<sub>4</sub> electrolyte extracts with a CuSO<sub>4</sub> concentration of 10 ppm. At a CuSO<sub>4</sub> concentration of 100 and 1000 ppm, ICP-MS results show that adsorption of Cu by clean Camp Edwards sand was either negligible or did not occur. Yet, initial solid phase Cu concentrations in these electrolyte samples are higher than their Milli-Q sample counterparts. In addition, sample A\_BED2c had a significantly higher final Cu concentration than the initial concentration. Since this sample was created using the same stock CuSO<sub>4</sub> electrolyte solution as its duplicate and the control samples show the presence of Cu at a background level, it is possible that there was strong spectral interference. However, Cu adsorption for electrolyte samples was higher than all Milli-Q water samples of the same initial Cu concentration by roughly 10 to 30%. However, the relationship between CuSO<sub>4</sub> concentration and K<sub>d</sub> is consistent. Therefore, the simulated electrolyte solution did not interfere with the ability to utilize the results of the column experiment to explain the sorption of Cu at Camp Edwards SARs.

The amount of Cu desorbed from sand material is minimal with less than 2% of the total Cu mass (Table 7). Desorption K<sub>d</sub> values are above 40 L/kg indicating minimal desorption; similar to what was observed with NG and DNT (Clausen et al. 2010). These results indicate the majority of Cu sorbed onto soil at Camp Edwards will be retained by the soil.

Table 6. Batch Experiment Adsorption Data\*

Adsorption							
Sample ID	Description	Water Type	Initial Liquid Phase [Cu] (mg/L)	Final Liquid Phase [Cu] (mg/L)	Ads. [Cu] (ppm)	% [Cu] Ads.	Ads. Kd (L/kg)
A_BM2a	10 ppm CuSO <sub>4</sub>	Milli-Q	3.98	2.21	1.77	44.49	16.1
A_BM2b	100 ppm CuSO <sub>4</sub>	Milli-Q	39.8	30.60	9.22	23.15	6.03
A_BM2c	1000 ppm CuSO <sub>4</sub>	Milli-Q	390	353.0	37.19	9.53	2.11
A_BMD2a	10 ppm CuSO <sub>4</sub>	Milli-Q	3.98	2.29	1.69	42.48	14.8
A_BMD2b	100 ppm CuSO <sub>4</sub>	Milli-Q	39.8	31.90	7.92	19.88	4.97
A_BMD2c	1000 ppm CuSO <sub>4</sub>	Milli-Q	390	352.0	38.19	9.79	2.17
A_BE1	Control	Electrolyte	0	0.02	-0.02		-20.05
A_BE2a	10 ppm CuSO <sub>4</sub>	Electrolyte	3.98	1.01	2.98	74.72	59.13
A_BE2b	100 ppm CuSO <sub>4</sub>	Electrolyte	39.8	41.31	-1.48	-3.715	-0.72
A_BE2c	1000 ppm CuSO <sub>4</sub>	Electrolyte	390	384.29	5.01	1.287	0.26
A_BE3	Zero-valent Cu extract	Electrolyte	0.183	0.06	0.12	64.64	36.64
A_BED1	Control	Electrolyte	0	0.03	-0.03		-19.97
A_BED2a	10 ppm CuSO <sub>4</sub>	Electrolyte	3.98	1.12	2.86	71.82	50.98
A_BED2b	100 ppm CuSO <sub>4</sub>	Electrolyte	39.8	40.48	-0.59	-1.49	-0.29
A_BED2c	1000 ppm CuSO <sub>4</sub>	Electrolyte	390	496.01	-106.46	-27.33	-4.26
A_BED3	Zero-valent Cu extract	Electrolyte	0.183	0.23	-0.04	-23.13	-3.77

Table 7. Batch Experiment Desorption Data

Desorption							
Sample ID	Description	Water Type	Initial Solid Phase [Cu] (ppm)	Final Liquid Phase [Cu] (mg/L)	Des. [Cu] (ppm)	% [Cu] Des.	Des. [Cu] Kd (L/kg)
D_BMD2a	10 ppm CuSO <sub>4</sub>	Milli-Q	0.00	0.23	0.23	0.0	-21.65
D_BMD2b	100 ppm CuSO <sub>4</sub>	Milli-Q	64.90	1.04	1.04	1.6	40.99
D_BMD2c	1000 ppm CuSO <sub>4</sub>	Milli-Q	503.0	6.98	6.98	1.4	51.04
D_BED1	Control	Electrolyte	0	1.17E-04	1.17E-04	0.0	-23.7253
D_BED2a	10 ppm CuSO <sub>4</sub>	Electrolyte	82.20	9.28E-05	9.28E-05	1.13E-04	885779.1
D_BED2b	100 ppm CuSO <sub>4</sub>	Electrolyte	294.88	1.20E-04	1.20E-04	4.08E-05	2449134
D_BED2c	1000 ppm CuSO <sub>4</sub>	Electrolyte	773.60	3.41E-04	3.41E-04	4.41E-05	2265944
D_BED3	Zero-valent Cu extract	Electrolyte	0	9.12E-05	9.12E-05	4.05E-02	2448.612
D_BED5	Cu cont. JBCC soil	Electrolyte	497.86	6.56E-04	6.56E-04	1.32E-04	759146.8

\* There was some confusion in the lab regarding whether diluted or undiluted samples were used in ICP-MS analysis for samples A\_BM2c and A\_BMD2c. Reported results are undiluted samples as they fall in line with other samples and initial calculated concentrations. Correcting for a dilution for samples A\_BM2c and A\_BMD2c would result in roughly 720% adsorption.

The batch tests indicate some limited Cu mobility, which likely translates to a few feet, due to sorption reactions with the soil. Later, desorption from the soil is limited since the soil strongly retains the Cu. This is borne out by the soil profile results indicating anthropogenic derived Cu is limited to the upper 2 feet of the soil at the SARs.

### 3.4 Column Experiments

A series of calculations documented in Clausen et al. (2010b) were performed below (Equations B1 – B4) to determine the pore volume and residence time of one pore volume in each of the four columns. The soil volume (B1) was calculated using the saturated height and radius of the column. Note that the initial height of each column was 16 cm prior to reverse saturation.

$$V_{Soil} = \pi \cdot r^2 \cdot h \quad (B2)$$

where:

- $V_{Soil}$  = volume of soil in column (cm<sup>3</sup>)
- $r$  = radius of column (2.5 cm)
- $h$  = height of soil in column (15 cm saturated)

The volume of soil in each column was 294.524 cm<sup>3</sup>. Porosity was determined from the bulk density and specific gravity of the soil (B2). The specific gravity is known in sandy soils to be 2.65 g/cm<sup>3</sup>.

$$n = 1 - (\rho_b / \rho_s) \quad (B2)$$

where:

- $n$  = porosity
- $\rho_b$  = bulk density of soil (500 g soil/294.524 cm<sup>3</sup>)
- $\rho_s$  = specific gravity of soil (2.65 g/cm<sup>3</sup>)

The calculated porosity of the soil in each column was 0.3594, or 35.94%. The porosity achieved in each column resembles the maximum field value for medium sands of 35%, indicating efficient packing (Chow, 1964). The calculated soil volume and porosity was plugged into Equation B3 to find the pore volume of the column.

$$P_V = V_{Soil} \cdot n \quad (B3)$$

where:

$$\begin{aligned}
 P_V &= \text{pore volume (105.85 cm}^3\text{)} \\
 V_{\text{soil}} &= \text{volume of soil in column (294.524 cm}^3\text{)} \\
 n &= \text{porosity (0.3594)}
 \end{aligned}$$

One pore volume was equal to 105.85 cm<sup>3</sup>. All columns ran for 990.42 pore volumes (recall 672 hour run time). The residence time of one pore volume at a flow rate of 2.6 mL/min was calculated using Equation B4.

$$R_T = \frac{P_V}{Q} \quad (\text{B4})$$

where:

$$\begin{aligned}
 R_T &= \text{residence time of one pore volume (min)} \\
 P_V &= \text{pore volume (105.85 cm}^3\text{)} \\
 Q &= \text{flow rate (2.6 mL/min)}
 \end{aligned}$$

The residence time of one pore volume was to equal 40.71 minutes.

### 3.4.1 Cu Migration

Each column operated for 672 hours (990.42 pore volumes) and was designed to augment the batch test results and simulate the mechanisms by which Cu can be introduced to Camp Edwards soils. Table 7 shows that effluents from Column A, the control, contained very low concentrations of Cu (ppb) with a maximum concentration of 0.0199 ppm after 1.47 pore volumes. Seven of the 11 samples are estimated Cu concentrations as these samples measured were below the reporting limit of 0.005 ppm (Appendix B: Full Dataset). Clean Camp Edwards sand measured below the XRFs LOD, but ICP-MS analysis showed that Camp Edwards clean sand had a Cu concentration of 1.16 ppm (Table 7), which is consistent with Column A soil fractions (Figure 8). These results suggest that Cu in Column A effluent was not likely caused by cross-contamination but rather from background Cu in the packed clean sand.

It is important to note that the digestion blank that was in the run with the clean sand sample and column soil fractions reported a J flagged Cu concentration of 0.0016 ppm, as well as a J and B flagged K concentration of 0.259 ppm (Table 7). The B flag on K indicates that the analyte was found in the associated ICP-MS blank. The associated ICP-MS blank reported a MB-02 flag on K, indicating that K contamination was due to memory inferences. The complete Quality control (QC) ICP-MS dataset can be found

in Appendix B: Full Dataset. Cu in the digestion blank is not definitive (J flagged) and therefore cannot be used to rule out the presence of Cu in both the clean sand and Column A soil fractions.

Table 7. ICP-MS metal analyte concentrations (mg/L) in Column A effluents.

Sample ID	Concentration (mg/L)						
	Ca	Fe	Mg	K	Na	Cu-63 [2]	Pb-206 [1]
Column A_0.5	8.09	0.795	1.08	2.92	5.34	0.0067	0.0053
Column A_1	1.47	0.532	0.564	1.71	3.75	0.0199	0.0020 J
Column A_2	0.942	0.276	0.339	1.75	3.27	0.0059	ND
Column A_4	0.885	0.566	0.448	1.5	3.56	0.0032 J	0.0010 J
Column A_8	0.952	0.0842 J	0.424	1.15	6.94	0.0040 J	ND
Column A_21	0.616	0.114 J	0.303	0.912	8.98	0.0045 J	ND
Column A_48	0.6	0.0553 J	0.281	0.957	4.88	0.0023 J	ND
Column A_96	1.06	0.0472 J	0.483	1.12	3.01	0.0039 J	ND
Column A_168	1.29	0.0431 J	0.794	1.03	8.6	0.0026 J	ND
Column A_336	3.36	0.109 J	0.874	1.74	5.57	0.0081	ND
Column A_672	2.03	ND	0.609	0.789	5.4	0.0031 J	ND

ND= Not Detected

J = Estimated concentration

Figure 8. Cu concentrations (ppm) in column soil fractions.

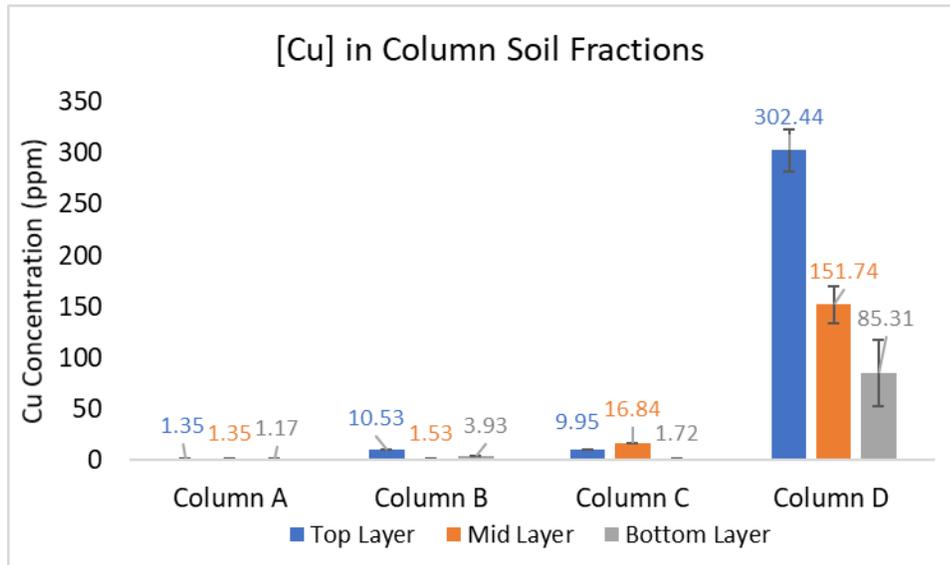


Table 8. ICP-MS Cu concentrations (mg/L) in column soil fractions.

Sample ID	Concentration (mg/L)						
	Ca	Fe	Mg	K	Na	Cu-63 [2]	Pb-206 [1]
Clean sand	81.04	6442.75	340.65	185.14	ND	1.16	3.92
Column A_top layer	249.95	2910.97	360.01	181.04	ND	1.35	2.86
Column A_mid layer	160.95	3481.88	319.79	187.24	ND	1.35	3.47
Column A_bottom layer	135.74	3122.01	297.58	168.11	ND	1.17	2.94
ColumnB_top layer	206.44	3252.94	323.21	196.01	ND	10.53	5.77
ColumnB_mid layer	162.11	3583.04	317.00	192.06	ND	1.53	3.49
ColumnB_bottom layer	132.95	3885.57	305.07	180.36	ND	3.93	3.37
ColumnC_top layer	251.35	3898.04	388.74	222.59	ND	9.95	4.16
ColumnC_mid layer	197.50	4303.44	386.69	196.46	ND	16.84	3.84
ColumnC_bottom layer	128.08	3280.13	294.69	183.27	ND	1.72	3.07
Digestion Blank 1	0.103 J	ND	ND	0.259 J, B	ND	0.0016 J	ND
Digestion Blank 2	0.104 J	ND	ND	ND	ND	ND	ND
ICP-MS Blank 1	ND	ND	ND	0.0577 MB-02	0.0499 J	ND	ND
ICP-MS Blank 2	ND	ND	ND	0.0437 J	ND	ND	ND

ND= Not Detected

J = Estimated concentration

B = Analyte is found in the associated blank and the sample.

MB-02 = The ICP-MS blank contains the analyte at a concentration above the MRL due to memory interferences

Zero-valent Cu added to the top of Column B is representative of the initial introduction of Cu metal to Camp Edwards soils. Cu was present in low levels in all soil fractions (Figure 7), with a maximum value of 10.53 ppm in the top layer. Cu concentration did not decrease consistently with increasing soil depth. As shown in Figure 7, the bottom layer contained 256% more Cu than the mid layer, which may be attributed to the inability

to maintain a constant head pressure over each column. Table 9 shows that negligible levels of Cu were found in Column B leachates across 672 hours. These results indicate that a run time of 990.42 pore volumes was not sufficient for significant Cu migration from the Cu slug placed at the top of the column. This is likely explained with dissolution being the rate limiting step. That of which did migrate was attenuated by the soil via adsorption mechanisms.

**Table 9. ICP-MS metal analyte concentrations (mg/L) in Column B effluents.**

Sample ID	Concentration (mg/L)						
	Ca	Fe	Mg	K	Na	Cu-63 [2]	Pb-206 [1]
Column B_0.5	1.96	0.0577 J	0.649	1.85	4.65	0.0028 J	ND
Column B_1	1.62	0.144 J	0.635	1.72	4.5	0.008	ND
Column B_2	0.762	0.208	0.349	1.09	3.23	0.211	0.0022 J
Column B_4	0.623	0.115 J	0.295	1.09	3.09	0.0033 J	ND
Column B_8	0.728	0.0743 J	0.386	1	7.33	0.0075	ND
Column B_21	0.534	0.319	0.316	0.889	9.04	0.0040 J	ND
Column B_48	0.452	ND	0.282	0.791	4.84	0.0023 J	ND
Column B_96	0.928	ND	0.465	1.05	2.91	0.0056	ND
Column B_168	1.19	ND	0.434	1.11	7.52	0.0029 J	ND
Column B_336	3.01	ND	0.802	1.57	5.4	0.0014 J	ND
Column B_672	1.88	ND	0.592	0.799	4.83	0.0026 J	ND

ND= Not Detected

J = Estimated concentration

A thin layer (15 g, or 1 cm) of Camp Edwards Cu contaminated soil with an XRFS concentration of 544.57 ppm was added to the top of Column C to understand the remobilization of Cu that has been adsorbed by the soil under natural conditions. Soil fraction analysis by ICP-MS revealed that Cu was present in each soil fraction, with a maximum value of 16.84 ppm in the mid layer (Figure 8). 5.23% of Cu desorbed from the contaminated soil and re-adsorbed to clean soils at greater depths within the column. Particle migration is possible but unlikely due to dense column packing explained in Section 3.4. Comparable to Column B, there was no relationship between Cu concentration and soil depth.

Table 10 shows that the highest concentration of Cu in Column C effluents by ICP-MS measured 0.211 ppm at 0.049 pore volumes and concentrations were otherwise consistently single digit parts-per-billion (ppb) levels. This level of Cu likely represents background levels in the Milli-Q water used in the experiments and not mobilized Cu. Based on the results from Columns B and C, Cu mobilization at Camp Edwards is unlikely. Column B

showed that the dissolution and migration of Cu from SAR projectiles is a slow process. Note, that the berms are established behind each target at the SARs for safety and recovery of Cu munitions after training exercises. There are few Cu slugs that remain in the soil after munition recovery that can lead to dissolution and subsequent migration of Cu. SAR soils that were contaminated by Cu containing munitions with subsequent dissolution at Camp Edwards (Column C) did not show a tendency to significantly remobilize Cu and contaminate the effluent. Thus, appreciable Cu mobilization at Camp Edwards is unlikely.

**Table 10. ICP-MS metal analyte concentrations (mg/L) in Column C effluents.**

Sample ID	Concentration (mg/L)						
	Ca	Fe	Mg	K	Na	Cu-63 [2]	Pb-206 [1]
Column C_0.5	3.08	0.114 J	0.957	2.52	5.63	0.0085	ND
Column C_1	2.08	0.387	0.773	2.01	4.73	0.313	0.0032 J
Column C_2	0.837	0.354	0.362	1.33	2.84	0.0328	0.0014 J
Column C_4	0.714	0.714	0.39	1.3	3.61	0.006	0.0013 J
Column C_8	0.833	0.0986 J	0.389	1.18	7.02	0.136	ND
Column C_21	0.469	0.117 J	0.258	0.844	8.83	0.0144	ND
Column C_48	0.435	0.0483 J	0.274	0.836	5	0.0030 J	ND
Column C_96	0.828	ND	0.429	0.971	2.89	0.007	ND
Column C_168	1.84	0.206	0.884	1.65	3.26	0.0016 J	ND
Column C_336	2.29	ND	0.608	1.43	8.37	0.0095	ND
Column C_672	1.85	0.0582 J	0.648	0.886	5.8	0.0087	ND

ND= Not Detected

J = Estimated concentration

A thin layer (5 g, or 1 cm) of  $\text{CuSO}_4$  was applied to the top of Column D to ensure sufficient Cu loading to capture the breakthrough of mobile Cu under Camp Edwards geochemical conditions. Column D represents the most conservative conditions for potential mobilization of Cu as  $\text{CuSO}_4$  is known to readily go into solution. Stoichiometry was used to find the amount of Cu in 5 g of  $\text{CuSO}_4$ ; the initial amount of Cu applied to the top of Column D was 1.99 g. As shown in Table 11 and Figure 9, the concentration of Cu in the effluent drastically increased from 155 mg/L at 0.74 pore volumes to a maximum of 680 mg/L at 1.47 pore volumes. There was a steep decline in effluent Cu concentration from 1.47 to 5.90 pore volumes, followed by a gradual decline until reaching a plateau below 1 ppm around 70.74 pore volumes (48 hours).

The Cu breakthrough curve for Column D is not a characteristic “S” shape as the influent Cu concentration was not constant; rather, the left-shifted

and steep nature of the breakthrough curve indicates that  $\text{CuSO}_4$  applied to the top of the column dissolved in the influent at a fast rate (Chowdhury, Sharifah, and Sharifuddin 2015). High influent concentrations, as well as high flow rates, correspond to faster breakthrough points and thus result in less contact time (Chowdhury, Sharifah, and Sharifuddin 2015). The influent concentration of dissolved Cu decreased as  $\text{CuSO}_4$  dissolved and migrated through the column. After the peak, a gradually decreasing influent concentration resulted in greater contact time. Soil fraction analysis via XRFS (Figure 8) shows that Cu concentration decreases with increasing soil depth, with a maximum Cu concentration of 302.44 ppm in the top layer and a minimum Cu concentration of 85.31 in the bottom layer. The results indicate the Camp Edwards soil has large capacity to sorb Cu thus limiting its mobility.

**Table 11. ICP-MS metal analyte concentrations (mg/L) in Column D effluents.\***

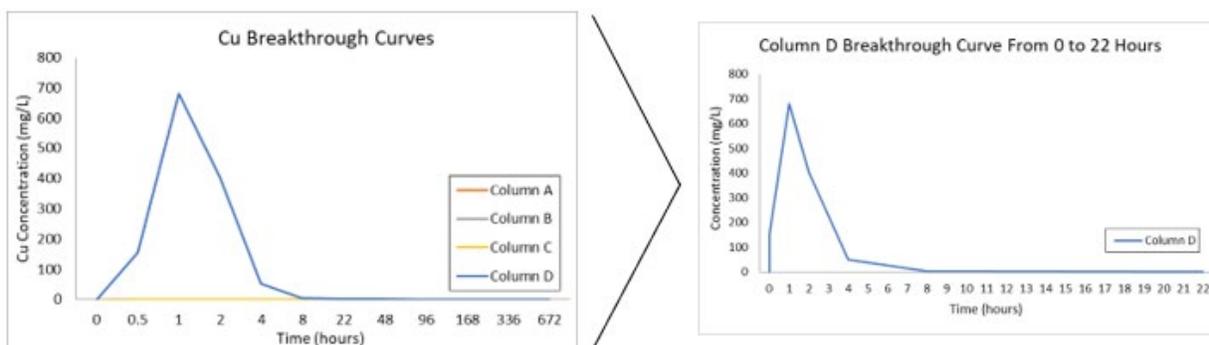
Sample ID	Concentration (mg/L)						
	Ca	Fe	Mg	K	Na	Cu-63 [2]	Pb-206 [1]
Column D_0.5	12.8	0.251	4.27	3.57	7.16	155	0.0035 J
Column D_1	2.44	0.504	0.797	1.01	0.522	680	0.007
Column D_2	1.02	0.299	0.329	2.28	1.86	404	0.0046 J
Column D_4	0.311	0.153 J	0.122 J	1.13	2.35	51.3	ND
Column D_8	0.119 J	ND	0.0668 J	0.857	6.72	4.17	ND
Column D_21	8.15	0.311	0.2	0.815	9.28	1.7	ND
Column D_48	0.189 J	ND	0.202	0.725	4.9	0.61	ND
Column D_96	0.73	ND	0.456	1.16	3.18	0.238	ND
Column D_168	1.17	ND	1	1.14	2.58	0.0555	ND
Column D_336	2.6	0.0932 J	0.721	1.53	10	0.0735	ND
Column D_672	4.37	0.28	0.827	1.84	8.23	0.0897	ND

ND= Not Detected

J = Estimated concentration

\* There was some confusion in the lab regarding whether diluted or undiluted samples were used in ICP-MS analysis for sample Column D\_1. The reported result is undiluted. Correcting for a dilution would result in an effluent Cu concentration of 13,364 mg/L. 5 grams of  $\text{CuSO}_4$  were applied to the top of the column (or 1.99 g Cu). Correcting for a 1:20 dilution would result in a peak effluent concentration of 13,364 ppm Cu as well as create outliers for all other measured analytes.

Figure 9. Cu breakthrough for Column A-D over 672 hours.



XRFS analysis of column soil fractions revealed that Column D retained higher levels of Ca, Fe, and K from the weak electrolyte influent than other columns, most notably Column A (Figure 10). Metal analytes Ca, Fe, and K average concentrations in columns A through D are organized in descending order as follows: Column D, Column B, Column C, and Column A. Recall from Section 3.1: Figure 6 that elevated levels of Ca, Fe, and K were characteristic of SAR soils contaminated with Cu, while lower levels of metal analytes were measured in soils from the background surface. These results suggest that Cu in the aqueous phase influences the levels of metal analytes Ca, Fe, and K through adsorption and/or similar mechanisms of immobilization.

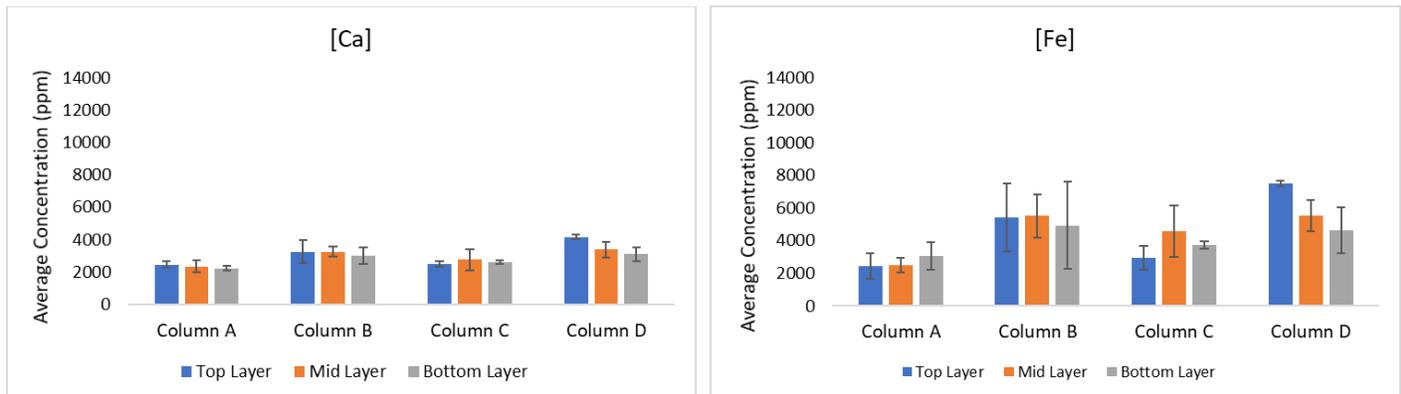
Table 12 shows the impact of influent pH on column soil pH. For reference, the pH of the influent was 9. Column A and Column D were chosen for soil pH analysis to compare a non-Cu environment to a rich Cu environment. The pH of clean JBCC sand was 5.1, whereas the pH of column A and D soils was 6.66 and 6.81 at the top of the column, respectively (Table 12). pH in both columns decreased with increasing soil depth, likely due to the initial contact between  $\text{CaCO}_3$  and the top of the column. As shown in Figure 10, the concentration of Ca decreases with increasing depth in Column D but does not show a significant change with depth in Column A.

Soil XRFS analysis shows that Column D retained more Ca, Fe, and K than Column A in each soil fraction (Figure 10). Recall that the concentration of Cu in Column B and Column C soil fractions were inconsistent with increasing depth. Metal analytes for Column B and Column C soil fractions were more variable than Column A and D, supporting the notion that mobile Cu affects the retention of other metal analytes. In a Cu rich environment (Column D), concentrations of Ca and Fe decreased with increasing

depth. K did not follow the same trend, however, the results for the bottom layer are more variable. A measurable decrease in metal analyte concentration as depth increases suggest that Cu is adsorbed by the topsoil through a series of complex reactions involving dissolved metal analytes introduced to the column. Liming applications increase soil pH and lead to increased K retention (Dinkecha and Tsegaye 2017). It is unclear why Fe concentrations were enhanced in a Cu environment. Dinkecha and Tsegaye (2017) explained that liming soils leads to a reduction in Fe concentration. However, it is evident that the presence of Cu outweighs the effect of liming on Fe abundance in soil.

The pH of available porewater was consistently between 6 and 7 in each column (Table 12). Column A had a sufficient volume of porewater in each fraction for pH analysis; here, it is evident that porewater pH decreased with increasing depth. Xu et al. (2005) investigated the effects of soil pH on Cu mobility and found that an influent pH of 5, 7, and 9 resulted in effluents with low Cu concentrations relative to leachates from influents with a pH of 1, 3, and 11. Thus, is not likely that an influent pH of 9 skewed the results of this Cu mobility study.

Figure 10. XRFs metal analyte concentrations in column soil fractions from Column A-D.



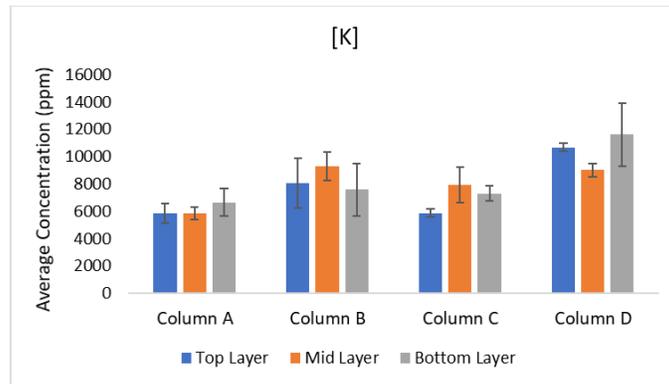


Table 12. pH of clean JBCC sand compared to the pH of column soil fractions and the associated porewater.

Column	Soil Fraction	Soil pH	Porewater pH
Clean Sand		5.1	**
Column A	Top layer	6.66	6.99
Column A	Mid layer	6.1	6.71
Column A	Bottom layer	5.85	6.53
Column B	Top layer	*	**
Column B	Mid layer	*	6.64
Column B	Bottom layer	*	6.57
Column C	0 to 2.5 in	*	**
Column C	Top layer	*	**
Column C	Mid layer	*	**
Column C	Bottom layer	*	6.38
Column D	0 to 1 in	6.81	**
Column D	Top layer	6.43	**
Column D	Mid layer	5.89	6.25
Column D	Bottom layer	5.58	6.29

\* Not analyzed

\*\* Not available

## 4 Conclusions and Recommendations

There have been numerous environmental assessments by CRREL that have been documented in the literature over the years to understand the mobilization and migration of heavy metals (lead, antimony, and tungsten) under Camp Edwards geochemical conditions. As well as studies to assess organic contaminant behavior of RDX, HMX, TNT, DNT, NG, and perchlorate.

### 4.1 Conclusions

The objective of this study was to assess the potential for Cu transport at Camp Edwards SAR as a result of using Cu projectiles. Field observations indicate the presence of Cu in the soil and soil porewater at Camp Edwards SARs. However, the soil profile data indicates that Cu above background levels is limited to the upper 2 feet of the soil profile.

Batch and column experiments indicate Cu in dissolved form is rapidly attenuated in Camp Edwards soils through sorption processes. These tests also indicate sorbed Cu is tightly bound to the soil material with minimal subsequent desorption. Column D utilizing  $\text{CuSO}_4$  indicates that the sorption processes can be overwhelmed if a high concentration of Cu is rapidly released into solution. Even then, the Camp Edwards soil has a high capacity to sorb a significant mass of Cu. However, the situation at Camp Edwards is that Cu projectiles containing zero-valent Cu are being released into the environment. In this form, the Cu must be oxidized before it becomes mobile as  $\text{Cu}^{2+}$  species. Once in the  $\text{Cu}^{2+}$  form the Cu is available for dissolution when precipitation events occur. This oxidation/dissolution step is the rate limiting mechanism in the Cu fate-and-transport process. Even then, once in solution the Cu is rapidly sorbed onto the Camp Edwards soil further limiting mobility. Finally, the sorbed Cu is only slowly released and the total mass released is only a fraction of the initial sorbed mass.

The calculated site-specific sorption values for Cu are similar or higher than values obtained for Pb, DNT, and NG. Pb, DNT, and NG. All have been used for a significant longer period of time (many decades compared to a single decade for Cu) and transport to groundwater has not been observed. Although, Cu jacketed lead projectiles have been used for many years. Routine groundwater monitoring at Camp Edwards does not

indicate the presence of anthropogenic Cu nor Pb, DNT, or NG. Given the Pb, NG, and DNT observations and the limited fate-and-transport behavior of Cu groundwater contamination of the aquifer is not expected.

## **4.2 Recommendations**

We recommend continued periodic groundwater and soil pore-water monitoring (lysimeters) for Cu. We also recommend the Camp Edwards continues their O&M policy of policing the SAR and periodically removing metal projectiles residing on the soil surface.

## References

- Bansal, O. P. 2009. "Competitive adsorption of heavy metals by soils of Aligarh district." *Int. J. Chem. Sci* 7, no. 2: 1439-1446.
- Barker, Amanda J., Samuel A. Beal, and Jay L. Clausen. 2019. *Joint Base Cape Cod Small-Arms Ranges: Lead and Antimony Batch-Reaction Study*. ERDC Hanover United States.
- Bogan, Robert AJ, Shigeru Ohde, Takeshi Arakaki, Ikuko Mori, and Cameron W. McLeod. 2009. "Changes in rainwater pH associated with increasing atmospheric carbon dioxide after the industrial revolution." *Water, air, and soil pollution* 196, no. 1: 263-271.
- Bravin, Matthieu N., Cédric Garnier, Véronique Lenoble, Frédéric Gérard, Yves Dudal, and Philippe Hinsinger. 2012. "Root-induced changes in pH and dissolved organic matter binding capacity affect copper dynamic speciation in the rhizosphere." *Geochimica et Cosmochimica Acta* 84: 256-268.
- Bast, Laura, Darryl Warncke, and Don Christenson. 2011. "Facts about Soil Acidity and Lime." *Michigan State University Extension Bulletin E-1566: facts about soil e1566.pdf (msu.edu)*
- Chow, V.T. 1964. *Handbook of Applied Hydrology*. McGraw Hill. Columbus, OH. p 13-15.
- Chowdhury, Zaira Zaman, Sharifah Bee Abd Hamid, and Sharifuddin Mohd Zain. 2015. "Evaluating design parameters for breakthrough curve analysis and kinetics of fixed bed columns for Cu (II) cations using lignocellulosic wastes." *BioResources* 10, no. 1: 732-749.
- Clausen, J.L., A. Barker, and B. Booker. 2017. Camp Edwards, MA Small Arms Range Report. Letter report prepared for MAARNG, 12 October 2017 by U.S. Army Corps of Engineers, Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory. Hanover, NH.

Clausen, Jay L., Anthony Bednar, Dennis Lambert, Ronald Bailey, Michael Kuhlbrush, Susan Taylor, and Sue Bigl. 2010a. *Phase II Tungsten Fate- and Transport Study for Camp Edwards*. ENGINEER RESEARCH AND DEVELOPMENT CENTER HANOVER NH COLD REGIONS RESEARCH AND ENGINEERING LAB.

Clausen, Jay L., and Nic Korte. 2009. "Environmental fate of tungsten from military use." *Science of the total environment* 407, no. 8: 2887-2893.

Clausen, Jay L., Nic Korte, Benjamin C. Bostick, Benjamin Rice, Matthew T. Walsh, and Andrew J. Nelson. 2007a. "Environmental assessment of lead at Camp Edwards, Massachusetts, small arms ranges."

Clausen, Jay, Joe Robb, Diane Curry, and Nic Korte. 2004. "A case study of contaminants on military ranges: Camp Edwards, Massachusetts, USA." *Environmental Pollution* 129, no. 1: 13-21.

Clausen, Jay L., Constance L. Scott, Nathan D. Mulherin, Susan R. Bigl, Gordon E. Gooch, Thomas A. Douglas, Ian T. Osgerby, and B. Palm. 2010b. "Adsorption/desorption measurements of nitroglycerin and dinitrotoluene in Camp Edwards, Massachusetts soil."

Clausen, Jay L., C. Scott, and Ian Osgerby. 2011. "Fate of nitroglycerin and dinitrotoluene in soil at small arms training ranges." *Soil and Sediment Contamination: An International Journal* 20, no. 6: 649-671.

Clausen, Jay L., Susan Taylor, Steven L. Larson, Anthony J. Bednar, Michael Ketterer, Christopher S. Griggs, Dennis J. Lambert et al. 2007b. "Fate and transport of tungsten at Camp Edwards small arms ranges."

Cornu, Jean-Yves, David Huguenot, Karine Jézéquel, Marc Lollier, and Thierry Lebeau. 2017. "Bioremediation of Cu-contaminated soils by bacteria." *World Journal of Microbiology and Biotechnology* 33, no. 2: 1-9.

de Boer, Tjalf E., Neslihan Tas, Martin Braster, Erwin JM Temminghoff, Wilfred FM Röling, and Dick Roelofs. 2012. "The influence of long-term Cu contaminated agricultural soil at different pH levels on microbial communities and springtail transcriptional regulation." *Environmental science & technology* 46, no. 1: 60-68.

- Dinkecha, Kebede, and Dereje Tsegaye. 2017. "Effects of liming on physicochemical properties and nutrient availability of acidic soils in Welmera Woreda, Central Highlands of Ethiopia." *Biochemistry and Molecular Biology* 2, no. 6: 102-109.
- Fang, W. A. N. G., P. A. N. Genxing, and L. I. Lianqing. 2009. "Effects of free iron oxyhydrates and soil organic matter on Cu sorption-desorption behavior by size fractions of aggregates from two paddy soils." *Journal of Environmental Sciences* 21, no. 5: 618-624.
- Gnecco, I., J. J. Sansalone, and L. G. Lanza. 2008. "Speciation of zinc and copper in stormwater pavement runoff from airside and landside aviation land uses." *Water, Air, and Soil Pollution* 192: 321-336.
- Holland, J. E., A. E. Bennett, A. C. Newton, P. J. White, B. M. McKenzie, T. S. George, R. J. Pakeman, J. S. Bailey, D. A. Fornara, and R. C. Hayes. 2018. "Liming impacts on soils, crops and biodiversity in the UK: A review." *Science of the Total Environment* 610: 316-332.
- Joint Base Cape Cod. 2019. *JBCC Groundwater Protection Policy: Memorandum of Agreement Between Massachusetts Air National Guard, Massachusetts Army National Guard, United States Air Force, and United States Coast Guard*. Cape Cod, Massachusetts: Joint Base Cape Cod, July. Accessed January 2023. [https://www.massnational-guard.org/ERC/publications/2019\\_07\\_10\\_JBCC\\_GWPP\\_MOA.pdf](https://www.massnational-guard.org/ERC/publications/2019_07_10_JBCC_GWPP_MOA.pdf).
- Laporte-Saumure, Mathieu, Richard Martel, and Guy Mercier. 2011. "Characterization and metal availability of Cu, lead, antimony and zinc contamination at four Canadian small arms firing ranges." *Environmental technology* 32, no. 7: 767-781.
- Massachusetts Army National Guard. 2021. *Public Comment Summary Report for the Multi-Purpose Machine Gun (MPMG) Range at the Known Distance (KD) Range Environmental Assessment (EA)*. Hanscom Air Force Base, MA: Massachusetts Army National Guard, Joint Force Headquarters, April. Accessed January 2023. [https://www.massnational-guard.org/ERC/publications/MPMG-FNSI/MAARNG\\_Final\\_MPMG\\_Comm\\_Summ\\_Report.pdf](https://www.massnational-guard.org/ERC/publications/MPMG-FNSI/MAARNG_Final_MPMG_Comm_Summ_Report.pdf).
- Massachusetts Army National Guard. 2016. 2016 Environmental Sampling and Analysis Report Juliet, Kilo, And Tango Ranges Camp Edwards Massachusetts. Massachusetts Army National Guard. 2016.

- Osman, Khan Towhid. 2018. "Sandy soils." In *Management of Soil Problems*, pp. 37-65. Springer, Cham.
- Pérez-Novo, C., M. Pateiro-Moure, F. Osorio, J. C. Nóvoa-Muñoz, E. López-Periago, and M. Arias-Estévez. 2008. "Influence of organic matter removal on competitive and noncompetitive adsorption of Cu and zinc in acid soils." *Journal of Colloid and Interface Science* 322, no. 1: 33-40.
- Rader, Kevin J., Richard F. Carbonaro, Eric D. van Hullebusch, Stijn Baken, and Katrien Delbeke. 2019. "The fate of Cu added to surface water: Field, laboratory, and modeling studies." *Environmental toxicology and chemistry* 38, no. 7: 1386-1399.
- Ramamurthy, A. S., D. Vo, X. J. Li, and J. Qu. 2008. "Surfactant-enhanced removal of Cu (II) and Zn (II) from a contaminated sandy soil." *Water, air, and soil pollution* 190, no. 1: 197-207.
- Rodriguez-Rubio, P., E. Morillo, Luis Madrid, T. Undabeytia, and C. Maqueda. 2003. "Retention of Cu by a calcareous soil and its textural fractions: influence of amendment with two agroindustrial residues." *European Journal of Soil Science* 54, no. 2: 401-409.
- Sharma, S. K., N. S. Sehkon, S. Deswal, and Siby John. 2009. "Transport and fate of Cu in soils." *International Journal of Civil and Environmental Engineering* 1, no. 1: 19-39.
- "Small Arms Ranges." n.d. Massachusetts Army National Guard Environmental and Readiness Center. Accessed December 21, 2022. [Small Arms Ranges \(massnationalguard.org\)](https://www.massnationalguard.org)
- Sodré, Fernando F., and Marco T. Grassi. 2007. "Changes in Cu speciation and geochemical fate in freshwaters following sewage discharges." *Water, Air, and Soil Pollution* 178, no. 1: 103-112.
- Tangtong, Chaiyanun. 2014. Environmental processes controlling the fate and transport of aristolochic acid in agricultural soil and Cu in contaminated lake sediment. Michigan State University.

Wu, J. I. G. A. N. G., D. A. Laird, and M. L. Thompson. 1999. *Sorption and desorption of Cu on soil clay components*. Vol. 28, no. 1. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America.

Xu, J., X. Han, S. Sun, F. Meng, and S. Dai. 2005. "Leaching Behavior of Cu (II) in a Soil Column Experiment." *Bulletin of Environmental Contamination & Toxicology* 75, no. 5.

## Appendix A: Range Layout Figures

Figure 1. India Range on Camp Edwards, JBCC



Figure 2. Tango Range on Camp Edwards, JBCC



Figure 3. Sierra Range on Camp Edwards, JBCC



Figure 4. Soil sampling (blue), lysimeter sampling (yellow), and groundwater sampling (green) locations on Tango Range (MAARNG 2016).



## Appendix C: Full Dataset

### Stoichiometric Calculations

**Batch experiments.** The adsorption  $K_d$  equation described in Section 2.4.3 requires the input of the initial concentration of Cu in solution. This value was determined for samples A\_BM2a, A\_BM2b, and A\_BM2c and their duplicates by calculating the g of Cu in 1 g of  $\text{CuSO}_4$ . To find how many g of Cu are in 1 gram of  $\text{CuSO}_4$ , first the g of  $\text{CuSO}_4$  was multiplied by the molar mass of  $\text{CuSO}_4$  to convert g to moles.  $\text{CuSO}_4$  in moles was then multiplied by the mole ratio of Cu to  $\text{CuSO}_4$  to account for both the cation and anion species. This mole ratio was then multiplied by the molar mass of Cu to convert moles to g, thus find the g of Cu in 1 g of  $\text{CuSO}_4$ . Refer to C-1 below:

$$1 \text{ g CuSO}_4 \cdot \frac{1 \text{ mol CuSO}_4}{159.609 \text{ g CuSO}_4} \cdot \frac{1 \text{ mol Cu}}{1 \text{ mol CuSO}_4} \cdot \frac{63.549 \text{ g Cu}}{1 \text{ mol Cu}} = 0.398 \text{ g Cu} \quad \text{(C-1)}$$

The mass of Cu in 1 g of  $\text{CuSO}_4$  was fed into equation C-2 to find the concentration of Cu in a 1000 ppm  $\text{CuSO}_4$  solution.

$$\frac{398 \text{ mg Cu}}{1 \text{ L solution}} = 398 \text{ ppm Cu} \quad \text{(C-2)}$$

A 1000 ppm  $\text{CuSO}_4$  stock solution was created to perform a 10-fold serial dilution. Recall that sample A\_BM2a, A\_BM2b, and A\_BM2c had an initial  $\text{CuSO}_4$  concentration of 10 ppm, 100 ppm, and 1000 ppm, respectively. Therefore, the initial concentration of Cu in A\_BM2a and A\_BM2b was 3.98 ppm and 39.8 ppm, respectively. Sample A\_BM2c had an initial concentration of 390 ppm because 98 mL stock solution was mixed with 2 mL of 50% glutaraldehyde to form a 1% glutaraldehyde solution.

### Column experiments.

A weak electrolyte solution was created as the influent for the column experiments to simulate rainwater at JBCC. Porewater data from a background location on Sierra Range, collected by the MAARNG in 2021, was utilized for this simulation. Porewater electrolyte concentrations at the background location on Sierra Range for Ca, Mg, K, Na, chloride, sulfate, and phosphates are listed in Table C-1.

Table C-1. Pan lysimeter porewater data collected by MAARNG in 2021 at a background location on Sierra Range.

Electrolyte	Porewater Concentration (mg/L)
Calcium	3
Chloride	0.011
Magnesium	0.7
Phosphates	0.000057
Potassium	1.1
Sodium	9.3
Sulfate	0.0071

Potassium chloride, calcium carbonate, magnesium carbonate, and sodium sulfide were selected to reach target cation concentrations in Table C-x. The unit conversions detailed in Equation C-1 were applied to each cation to determine the mass of compound required to simulate JBCC rainwater. For example, the porewater concentration of Ca (3 mg/L) was multiplied by the inverse of the molar mass to convert mg/L to molar concentration. Then, the molar concentration was multiplied by the mole ratio of Ca to calcium chloride. This value was multiplied by the molar mass of calcium chloride to find the mass of calcium chloride required to make a 3 ppm solution of Ca. Equation C-1 was also utilized to find the respective mass of chloride in a 3 ppm solution of Ca.

### XRFS Results

Table C-1. XRFS data for soil samples collected on Sierra Range at Camp Edwards.

Range	Sample ID	Depth (in)	Concentration (ppm)					
			Ca	Cu	Fe	K	Pb	Zn
Sierra	MMRS4R_30INC	0	4650.65 +/- 443.56	<LOD	12340.75 +/- 2550.93	9537.03 +/- 480.40	7 +/- 0.79	<LOD
Sierra	JBCCS5R_30INC	0	5143.31 +/- 208.12	345.7 +/- 235.56	11931.33 +/- 345.16	10851.41 +/- 374.19	<LOD	138.13 +/- 10.87
Sierra	MMRS6R_30INC	0	5674.15 +/- 112.57	126.03 +/- 8.28	11338.29 +/- 220.49	10760.36 +/- 335.12	6.98 +/- 4.30	104.03 +/- 8.31
Sierra	MMRS7R_30INC	0	4458.28 +/- 216.71	66.05 +/- 22.80	12635.62 +/- 1176.42	9567.43 +/- 534.12	<LOD	56.28 +/- 13.92
Sierra	MMRS8R_30INC	0	3411.54 +/- 170.77	188.29 +/- 32.42	11428.55 +/- 864.53	5343.92 +/- 165.09	9.29 +/- 3.73	135.91 +/- 1.53
Sierra	JBCCS5R_4in	4	6187.78 +/- 217.27	59.35 +/- 10.81	12823.02 +/- 1224.49	10459.06 +/- 223.29	<LOD	52.79 +/- 1.10
Sierra	MMRS5R_8in	8	5343.71 +/- 233.72	372.73 +/- 48.24	12121.13 +/- 15.14	5879.06 +/- 219.71	11.51 +/- 1.21	150.4 +/- 4.79
Sierra	MMRS5R_12in	12	4602.1 +/- 147.86	37 +/- 7.89	10850.11 +/- 278.83	5214.53 +/- 159.58	10.66 +/- 3.42	25.57 +/- 3.80
Sierra	MMRS5R_16in	16	3315.1 +/- 82.53	163.17 +/- 12.41	8207.86 +/- 2926.90	5228.12 +/- 357.33	<LOD	11.53 +/- 14.56
Sierra	MMRS5R_20in*	20	2217.03	<LOD	2202.11	4754.04	<LOD	<LOD
Sierra	MMRS5R_24in*	24	3218.59	<LOD	2919.09	5381.00	<LOD	<LOD
Sierra	MMRS5R_28in*	28	2411.66	<LOD	8606.14	4970.32	<LOD	<LOD
Sierra	MMRS5R_32in*	32	2717.44	<LOD	2143.62	5623.73	<LOD	<LOD
Sierra	MMRS5R_36in*	36	2549.99	<LOD	3722.24	4715.64	<LOD	<LOD
Sierra	MMRS5R_40in*	40	2613.35	<LOD	4983.72	6273.86	<LOD	<LOD
Sierra	MMRS5R_42in*	42	2249.29	<LOD	4227.82	4684.34	<LOD	<LOD
Sierra	MMRS5R_48in*	48	2395.33	<LOD	10985.74	5212.18	<LOD	<LOD
Sierra	MMRS5R_50in*	50	2328.06	<LOD	11739.44	5538.19	<LOD	<LOD
Sierra	MMRS6R_4in	4	3709.43 +/- 110.41	201.46 +/- 26.66	9728.6 +/- 407.58	5502.88 +/- 29.78	<LOD	157.73 +/- 1.31
Sierra	MMRS6R_8in	8	3926.97 +/- 153.79	377.66 +/- 32.42	10506.95 +/- 111.59	5068.62 +/- 206.66	16.36 +/- 13.45	202.31 +/- 4.80
Sierra	MMRS6R_12in	12	3514.75 +/- 56.87	193.12 +/- 23.70	9495.29 +/- 304.27	5435.52 +/- 128.02	<LOD	86.59 +/- 2.72
Sierra	MMRS6R_16in	16	3073.73 +/- 22.13	72.91 +/- 20.60	11284.34 +/- 1169.88	5335.08 +/- 98.59	29.62 +/- 4.50	25.47 +/- 8.00
Sierra	MMRS6R_20in	20	3629.06 +/- 146.62	93.73 +/- 27.42	10654.58 +/- 711.29	6118.99 +/- 338.89	8.21 +/- 4.35	41.24 +/- 0.92
Sierra	MMRS6R_24in*	24	2370.96	<LOD	5531.59	5644.77	<LOD	<LOD
Sierra	MMRS6R_28in*	28	2411.66	<LOD	8606.14	4970.32	<LOD	<LOD
Sierra	MMRS6R_32in*	32	2052.00	<LOD	10861.59	4420.43	<LOD	<LOD
Sierra	MMRS6R_36in*	36	2690.36	<LOD	7362.43	4779.33	<LOD	<LOD

<LOD = below XRFS detection limit

Table C-2. XRFS data for soil samples collected on Tango Range at Camp Edwards.

Range	Sample ID	Depth (in)	Concentration (ppm)					
			Ca	Cu	Fe	K	Pb	Zn
Tango	MMRT15_30INC	0	3874.42 +/- 101.66	300.74 +/- 201.21	13555.14 +/- 419.44	9671.74 +/- 629.71	10.41 +/- 2.89	109.95 +/- 44.72
Tango	JBCCT16_30INC	0	3842.06 +/- 157.61	301.12 +/- 97.91	12418.37 +/- 250.79	9803.43 +/- 404.16	10.24 +/- 3.26	105.86 +/- 22.26
Tango	JBCCT17_30INC	0	4154.92 +/- 105.24	217.85 +/- 62.99	14566.53 +/- 1893.54	10075.16 +/- 659.52	11.17 +/- 3.09	135.19 +/- 23.49
Tango	MMRT18_30INC	0	3974.12 +/- 106.63	217.09 +/- 24.80	13074.38 +/- 977.50	9428.92 +/- 351.35	10.65 +/- 4.28	124.53 +/- 15.11
Tango	MMRT19_30INC	0	3915.65 +/- 141.38	163.32 +/- 25.17	13764.27 +/- 651.74	9711.3 +/- 356.44	10.52 +/- 1.57	99.96 +/- 6.82
Tango	MMRT18_0in	0	3301.96	415.52	11496.93	5812.69	13.28	192.04
Tango	MMRT15_0in	0	3732.32	455.07	15292.87	6948.89	9.99	232.09
Tango	MMRT18_4in	4	3482.79 +/- 61.19	460.99 +/- 63.35	12049.13 +/- 993.09	8136.77 +/- 360.61	8.85 +/- 1.71	138.58 +/- 8.31
Tango	JBCCT18_8in	8	4110 +/- 328.82	301.2 +/- 99.82	12777.86 +/- 1369.99	10396.78 +/- 634.19	8.06 +/- 5.13	134.49 +/- 32.64
Tango	MMRT18_12in	12	2471.25 +/- 218.75	<LOD	4350.51 +/- 48.83	6922.93 +/- 927.22	<LOD	<LOD
Tango	MMRT18_16in*	16	2072.64	<LOD	4010.20	6305.06	<LOD	<LOD
Tango	MMRT18_20in*	20	1743.30	<LOD	2699.94	3821.12	<LOD	<LOD
Tango	MMRT18_24in*	24	3911.77	<LOD	6750.46	6025.02	<LOD	<LOD
Tango	MMRT18_28in*	28	3248.17	<LOD	6584.44	6871.83	<LOD	<LOD
Tango	MMRT18_32in*	32	3052.53	<LOD	6550.69	7454.55	<LOD	<LOD
Tango	JBCCT15_4in	4	3902.41 +/- 324.29	8.98 +/- 2.50	14238.57 +/- 1576.59	10398.8 +/- 539.16	10.81 +/- 4.92	33.03 +/- 9.21
Tango	MMRT15_8in*	8	2787.80	<LOD	3134.61	4938.57	<LOD	<LOD
Tango	MMRT15_18in*	18	1893.59	<LOD	2998.25	5368.51	<LOD	<LOD
Tango	MMRT15_22in*	22	1955.84	<LOD	1932.15	6510.90	<LOD	<LOD

<LOD = below XRFS detection limit, \* = one replication

Table C-3. XRFs data for soil samples collected on India Range at Camp Edwards.

Range	Sample ID	Depth (in)	Concentration (ppm)					
			Ca	Cu	Fe	K	Pb	Zn
India	MMRI8_30INC	0	4923.01 +/- 114.97	160.96 +/- 101.58	10545.19 +/- 307.07	8799.68 +/- 881.71	9.93 +/- 2.48	73.59 +/- 25.71
India	MMRI9_30INC	0	5806.22 +/- 736.49	91.15 +/- 38.88	13313.25 +/- 1742.63	9958.17 +/- 613.47	<LOD	92.91 +/- 25.58
India	MMRI10_30INC	0	5887.62 +/- 112.43	137.87 +/- 71.24	16107.77 +/- 2465.13	9971.04 +/- 404.78	11.92 +/- 5.12	95.21 +/- 15.69
India	MMRI11_30INC	0	5459.88 +/- 1016.75	41.5 +/- 32.42	13112.24 +/- 2579.09	9959.4 +/- 817.78	12.14 +/- 3.85	57.29 +/- 15.92
India	MMRI12_30INC	0	4948.71 +/- 527.42	211.75 +/- 149.76	11533.96 +/- 786.91	9337.33 +/- 516.48	7.04 +/- 2.43	69.45 +/- 29.75
India	MMRI8_4in	4	3713.22 +/- 53.13	476.12 +/- 35.13	9737.17 +/- 841.94	8249.97 +/- 272.75	<LOD	150.93 +/- 3.64
India	MMRI8_8in	8	4428.75 +/- 238.27	3299.99 +/- 4514.54	11298.96 +/- 1075.19	9834.44 +/- 142.01	18.46 +/- 5.94	420.45 +/- 296.89
India	MMRI8_12in	12	4295.88 +/- 88.26	453.74 +/- 149.13	12426.05 +/- 1831.78	9601.05 +/- 256.63	45.11 +/- 4.45	191.39 +/- 36.15
India	MMRI8_16in	16	4450.07 +/- 354.27	1492.53 +/- 174.66	10596.25 +/- 267.17	8521.95 +/- 72.15	10.49 +/- 1.24	265.55 +/- 6.21
India	MMRI8_20in	20	3834.61	<LOD	4737.14	7179.79	<LOD	<LOD
India	MMRI8_24in*	24	3100.41	<LOD	5216.48	8672.98	<LOD	<LOD
India	MMRI8_28in*	28	3266.64	<LOD	3598.23	9131.44	<LOD	<LOD
India	MMRI8_32in*	32	2755.69	<LOD	4111.87	9240.67	<LOD	<LOD
India	MMRI8_36in*	36	2539.04	<LOD	5305.70	6335.43	<LOD	<LOD
India	MMRI8_40in*	40	2379.42	<LOD	4198.17	5587.71	<LOD	<LOD
India	MMRI8_44in*	44	2971.73	<LOD	4263.29	6227.31	<LOD	<LOD
India	MMRI8_48in	48	2567.16 +/- 173.52	20.32 +/- 5.45	7889.77 +/- 1061.85	7014.45 +/- 557.65	337.65 +/- 10.25	<LOD
India	JBCC112_4in	4	4610.62 +/- 259.88	537.07 +/- 206.34	13699.36 +/- 3049.14	11135.2 +/- 1043.18	12.24 +/- 6.17	149.34 +/- 28.25
India	JBCC112_8in	8	4276.79 +/- 286.14	561.34 +/- 103.99	11146.83 +/- 5369.41	9626.81 +/- 780.06	21.74 +/- 8.46	127.44 +/- 30
India	JBCC112_12in	12	3991.69 +/- 158.28	568.77 +/- 82.75	11813.57 +/- 5438.24	9022.63 +/- 178.23	<LOD	137.85 +/- 19.46
India	MMRI12_16in*	16	2901.09	<LOD	12907.53	4732.99	29.38	12.04 +/- 1.86
India	MMRI12_20in*	20	3073	<LOD	4187.31	5433.68	<LOD	<LOD
India	MMRI12_24in	24	2212.61 +/- 44.32	39.52 +/- 11.29	4184.99 +/- 298.13	4757.11 +/- 96.17	31.24 +/- 103.88	<LOD
India	MMRI12_28in*	28	2256.65	<LOD	4462.02	3966.79	176.19	<LOD
India	MMRI12_32in	32	2683.52 +/- 39.91	45.25 +/- 21.95	6415.04 +/- 1064.53	4966.55 +/- 510.03	22.63 +/- 3.29	<LOD

<LOD = below XRFs detection limit, \* = one replication

Table C-4. XRFs data for column soils.

Sample ID	Concentration (ppm)					
	Ca	Cu	Fe	K	Pb	Zn
JBCC clean sand	2143.22 +/- 459.72	<LOD	3651.48 +/- 1002.14	4344.45 +/- 520.52	<LOD	<LOD
JBCC contaminated sand (<1 cm depth - Column C)	4142.60 +/- 293.33	544.57 +/- 1.90	9973.43 +/- 1136.15	9197.72 +/- 322.12	15.46 +/- 8.53	227.52 +/- 12.88
Column A_top layer	2451.23 +/- 189.34	<LOD	2439.19 +/- 783.53	5857.15 +/- 713.50	<LOD	<LOD
Column A_mid layer	2330.92 +/- 368.48	<LOD	2476.60 +/- 449.88	5841.23 +/- 464.35	<LOD	<LOD
Column A_bottom layer	2213.85 +/- 139.12	<LOD	3039.79 +/- 839.27	6641.90 +/- 990.59	<LOD	<LOD
Column B_top layer	3242.22 +/- 704.77	<LOD	5407.52 +/- 2080.70	8034.98 +/- 1815.94	<LOD	<LOD
Column B_mid layer	3252.52 +/- 299.28	<LOD	5512.02 +/- 1334.63	9274.90 +/- 1026.18	<LOD	<LOD
Column B_bottom layer	3016.04 +/- 508.51	<LOD	4939.17 +/- 2692.40	7585.40 +/- 1913.98	<LOD	<LOD
Column C_<2.5cm	2769.86 +/- 199.09	23.43 +/- 6.80	3062.73 +/- 1177.59	7205.31 +/- 1647.71	<LOD	<LOD
Column C_top layer	2501.61 +/- 157.14	<LOD	2931.77 +/- 725.82	5867.46 +/- 269.37	<LOD	<LOD
Column C_mid layer	2750.80 +/- 646.86	<LOD	4580.07 +/- 1565.50	7920.14 +/- 1269.77	<LOD	<LOD
Column C_bottom layer	2600.38 +/- 118.50	<LOD	3724.59 +/- 236.69	7289.91 +/- 541.00	<LOD	<LOD
ColumnD_<1cm	3363.32 +/- 677.24	118.03 +/- 38.66	4007.43 +/- 1718.14	7905.08 +/- 1488.31	<LOD	<LOD
ColumnD_top layer	4161.00 +/- 152.99	302.44 +/- 20.68	7475.99 +/- 169.19	10679.20 +/- 292.02	<LOD	<LOD
ColumnD_mid layer	3378.85 +/- 467.86	151.74 +/- 17.61	5529.10 +/- 941.82	8999.48 +/- 499.93	<LOD	<LOD
ColumnD_>bottom layer	3102.43 +/- 436.43	85.31 +/- 32.57	4639.19 +/- 1394.56	11599.63 +/- 2312.08	<LOD	<LOD

<LOD = below XRFs detection limit

### ICP-MS Results

Table C-5a. ICP-MS metal concentrations in column effluents.

LabName	LABSAMPID	SAMPLENAME	Concentration (mg/L)							
			Ca	Fe	Mg	Mn	K	Na	Cu-63 [2]	Pb-206 [1]
ERDC-EL-EP-C	22I2101-01	Column A_0.5	8.09	0.795	1.08		2.92	5.34	0.0067	0.0053
ERDC-EL-EP-C	22I2101-02	Column A_1	1.47	0.532	0.564		1.71	3.75	0.0199	0.0020 J
ERDC-EL-EP-C	22I2101-03	Column A_2	0.942	0.276	0.339		1.75	3.27	0.0059	ND
ERDC-EL-EP-C	22I2101-04	Column A_4	0.885	0.566	0.448		1.50	3.56	0.0032 J	0.0010 J
ERDC-EL-EP-C	22I2101-05	Column A_8	0.952	0.0842 J	0.424		1.15	6.94	0.0040 J	ND
ERDC-EL-EP-C	22I2101-06	Column A_21	0.616	0.114 J	0.303		0.912	8.98	0.0045 J	ND
ERDC-EL-EP-C	22I2101-07	Column A_48	0.600	0.0553 J	0.281		0.957	4.88	0.0023 J	ND
ERDC-EL-EP-C	22I2101-08	Column A_96	1.06	0.0472 J	0.483		1.12	3.01	0.0039 J	ND
ERDC-EL-EP-C	22I2101-09	Column A_168	1.29	0.0431 J	0.794		1.03	8.60	0.0026 J	ND
ERDC-EL-EP-C	22I2101-10	Column A_336	3.36	0.109 J	0.874		1.74	5.57	0.0081	ND
ERDC-EL-EP-C	22I2101-11	Column A_672	2.03	ND	0.609		0.789	5.40	0.0031 J	ND
ERDC-EL-EP-C	22I2101-12	Column B_0.5	1.96	0.0577 J	0.649		1.85	4.65	0.0028 J	ND
ERDC-EL-EP-C	22I2101-13	Column B_1	1.62	0.144 J	0.635		1.72	4.50	0.0080	ND
ERDC-EL-EP-C	22I2101-14	Column B_2	0.762	0.208	0.349		1.09	3.23	0.211	0.0022 J
ERDC-EL-EP-C	22I2101-15	Column B_4	0.623	0.115 J	0.295		1.09	3.09	0.0033 J	ND
ERDC-EL-EP-C	22I2101-16	Column B_8	0.728	0.0743 J	0.386		1.00	7.33	0.0075	ND
ERDC-EL-EP-C	22I2101-17	Column B_21	0.534	0.319	0.316		0.889	9.04	0.0040 J	ND
ERDC-EL-EP-C	22I2101-18	Column B_48	0.452	ND	0.282		0.791	4.84	0.0023 J	ND
ERDC-EL-EP-C	22I2101-19	Column B_96	0.928	ND	0.465		1.05	2.91	0.0056	ND
ERDC-EL-EP-C	22I2101-20	Column B_168	1.19	ND	0.434		1.11	7.52	0.0029 J	ND
ERDC-EL-EP-C	22I2101-21	Column B_336	3.01	ND	0.802		1.57	5.40	0.0014 J	ND
ERDC-EL-EP-C	22I2101-22	Column B_672	1.88	ND	0.592		0.799	4.83	0.0026 J	ND
ERDC-EL-EP-C	22I2101-23	Column C_0.5	3.08	0.114 J	0.957		2.52	5.63	0.0085	ND
ERDC-EL-EP-C	22I2101-24	Column C_1	2.08	0.387	0.773		2.01	4.73	0.313	0.0032 J
ERDC-EL-EP-C	22I2101-25	Column C_2	0.837	0.354	0.362		1.33	2.84	0.0328	0.0014 J
ERDC-EL-EP-C	22I2101-26	Column C_4	0.714	0.714	0.390		1.30	3.61	0.0060	0.0013 J
ERDC-EL-EP-C	22I2101-27	Column C_8	0.833	0.0986 J	0.389		1.18	7.02	0.136	ND
ERDC-EL-EP-C	22I2101-28	Column C_21	0.469	0.117 J	0.258		0.844	8.83	0.0144	ND
ERDC-EL-EP-C	22I2101-29	Column C_48	0.435	0.0483 J	0.274		0.836	5.00	0.0030 J	ND
ERDC-EL-EP-C	22I2101-30	Column C_96	0.828	ND	0.429		0.971	2.89	0.0070	ND
ERDC-EL-EP-C	22I2101-31	Column C_168	1.84	0.206	0.884		1.65	3.26	0.0016 J	ND
ERDC-EL-EP-C	22I2101-32	Column C_336	2.29	ND	0.608		1.43	8.37	0.0095	ND
ERDC-EL-EP-C	22I2101-33	Column C_672	1.85	0.0582 J	0.648		0.886	5.80	0.0087	ND
ERDC-EL-EP-C	22I2101-34	Column D_0.5	12.8	0.251	4.27		3.57	7.16	155	0.0035 J
ERDC-EL-EP-C	22I2101-35	Column D_1	2.44	0.504	0.797		1.01	0.522	680	0.0070
ERDC-EL-EP-C	22I2101-36	Column D_2	1.02	0.299	0.329		2.28	1.86	404	0.0046 J
ERDC-EL-EP-C	22I2101-37	Column D_4	0.311	0.153 J	0.122 J		1.13	2.35	51.3	ND
ERDC-EL-EP-C	22I2101-38	Column D_8	0.119 J	ND	0.0668 J		0.857	6.72	4.17	ND
ERDC-EL-EP-C	22I2101-39	Column D_21	8.15	0.311	0.200		0.815	9.28	1.70	ND
ERDC-EL-EP-C	22I2101-40	Column D_48	0.189 J	ND	0.202		0.725	4.90	0.610	ND
ERDC-EL-EP-C	22I2101-41	Column D_96	0.730	ND	0.456		1.16	3.18	0.238	ND
ERDC-EL-EP-C	22I2101-42	Column D_168	1.17	ND	1.00		1.14	2.58	0.0555	ND
ERDC-EL-EP-C	22I2101-43	Column D_336	2.60	0.0932 J	0.721	ND	1.53	10.0	0.0735	ND
ERDC-EL-EP-C	22I2101-44	Column D_672	4.37	0.280	0.827	ND	1.84	8.23	0.0897	ND

ND = not detected, J = estimated concentration

Table C-5b. ICP-MS QC data for column effluents.

LBSAMPID	QCTYPE	MATRIX	METHODNAME	ANALYTE	CASNUMBER	SURROGATE	TIC	RESULT	DL	RL	UNITS	RPTOMDL	BASIS	DILUTION	SOURCEID	SOURCECERES	SPIKELEVEL	RECOVERY	RPD	UPPERCL	LOWERCL	RPDCL	ANOTE	
B22J114-BLK1	Blank	Water	EPA 6010	Calcium	7440-70-2	FALSE	FALSE	ND	0.0040	0.0200	mg/L	TRUE	NA	1									U	
B22J114-BLK1	Blank	Water	EPA 6010	Iron	7439-89-6	FALSE	FALSE	ND	0.0040	0.0200	mg/L	TRUE	NA	1										U
B22J114-BLK1	Blank	Water	EPA 6010	Magnesium	7439-95-4	FALSE	FALSE	ND	0.0040	0.0200	mg/L	TRUE	NA	1										U
B22J114-BLK1	Blank	Water	EPA 6010	Potassium	7440-09-7	FALSE	FALSE	ND	0.0200	0.0500	mg/L	TRUE	NA	1										U
B22J114-BLK1	Blank	Water	EPA 6010	Sodium	7440-23-5	FALSE	FALSE	ND	0.0200	0.0500	mg/L	TRUE	NA	1										U
B22J114-BLK2	Blank	Water	EPA 6010	Calcium	7440-70-2	FALSE	FALSE	ND	0.0040	0.0200	mg/L	TRUE	NA	1										U
B22J114-BLK2	Blank	Water	EPA 6010	Iron	7439-89-6	FALSE	FALSE	ND	0.0040	0.0200	mg/L	TRUE	NA	1										U
B22J114-BLK2	Blank	Water	EPA 6010	Magnesium	7439-95-4	FALSE	FALSE	ND	0.0040	0.0200	mg/L	TRUE	NA	1										U
B22J114-BLK2	Blank	Water	EPA 6010	Potassium	7440-09-7	FALSE	FALSE	ND	0.0200	0.0500	mg/L	TRUE	NA	1										U
B22J114-BLK2	Blank	Water	EPA 6010	Sodium	7440-23-5	FALSE	FALSE	ND	0.0200	0.0500	mg/L	TRUE	NA	1										U
B22J114-BS1	LCS	Water	EPA 6010	Calcium	7440-70-2	FALSE	FALSE	47.3	0.0040	0.0200	mg/L	TRUE	NA	1			50.00	94.7		120	80			
B22J114-BS1	LCS	Water	EPA 6010	Iron	7439-89-6	FALSE	FALSE	48.7	0.0040	0.0200	mg/L	TRUE	NA	1			50.00	97.5		120	80			
B22J114-BS1	LCS	Water	EPA 6010	Magnesium	7439-95-4	FALSE	FALSE	46.7	0.0040	0.0200	mg/L	TRUE	NA	1			50.00	93.4		120	80			
B22J114-BS1	LCS	Water	EPA 6010	Potassium	7440-09-7	FALSE	FALSE	45.6	0.0200	0.0500	mg/L	TRUE	NA	1			50.00	91.1		120	80			
B22J114-BS1	LCS	Water	EPA 6010	Sodium	7440-23-5	FALSE	FALSE	44.8	0.0200	0.0500	mg/L	TRUE	NA	1			50.00	89.6		120	80			
B22J114-BS2	LCS	Water	EPA 6010	Calcium	7440-70-2	FALSE	FALSE	47.2	0.0040	0.0200	mg/L	TRUE	NA	1			50.00	94.5		120	80			
B22J114-BS2	LCS	Water	EPA 6010	Iron	7439-89-6	FALSE	FALSE	48.6	0.0040	0.0200	mg/L	TRUE	NA	1			50.00	97.3		120	80			
B22J114-BS2	LCS	Water	EPA 6010	Magnesium	7439-95-4	FALSE	FALSE	46.8	0.0040	0.0200	mg/L	TRUE	NA	1			50.00	93.7		120	80			
B22J114-BS2	LCS	Water	EPA 6010	Potassium	7440-09-7	FALSE	FALSE	46.2	0.0200	0.0500	mg/L	TRUE	NA	1			50.00	92.3		120	80			
B22J114-BS2	LCS	Water	EPA 6010	Sodium	7440-23-5	FALSE	FALSE	45.2	0.0200	0.0500	mg/L	TRUE	NA	1			50.00	90.5		120	80			
B22J114-DUP1	Duplicate	Water	EPA 6010	Calcium	7440-70-2	FALSE	FALSE	1.47	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-0	1.47			0.0167				20	
B22J114-DUP1	Duplicate	Water	EPA 6010	Iron	7439-89-6	FALSE	FALSE	0.536	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-0	0.532			0.668				20	
B22J114-DUP1	Duplicate	Water	EPA 6010	Magnesium	7439-95-4	FALSE	FALSE	0.578	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-0	0.564			2.50				20	
B22J114-DUP1	Duplicate	Water	EPA 6010	Potassium	7440-09-7	FALSE	FALSE	1.67	0.200	0.500	mg/L	TRUE	NA	10	22I2101-0	1.71			2.30				20	
B22J114-DUP1	Duplicate	Water	EPA 6010	Sodium	7440-23-5	FALSE	FALSE	3.54	0.200	0.500	mg/L	TRUE	NA	10	22I2101-0	3.75			5.91				20	
B22J114-DUP2	Duplicate	Water	EPA 6010	Calcium	7440-70-2	FALSE	FALSE	2.64	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-4	2.60			1.58				20	
B22J114-DUP2	Duplicate	Water	EPA 6010	Iron	7439-89-6	FALSE	FALSE	0.0938	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-4	0.0932			0.642				20	J
B22J114-DUP2	Duplicate	Water	EPA 6010	Magnesium	7439-95-4	FALSE	FALSE	0.718	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-4	0.721			0.405				20	
B22J114-DUP2	Duplicate	Water	EPA 6010	Potassium	7440-09-7	FALSE	FALSE	1.44	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-4	1.53			5.96				20	
B22J114-DUP2	Duplicate	Water	EPA 6010	Sodium	7440-23-5	FALSE	FALSE	10.0	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-4	10.0			0.0829				20	
B22J114-MS1	Matrix Spike	Water	EPA 6010	Calcium	7440-70-2	FALSE	FALSE	480	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-0	1.47	500.0	95.6		120	80			
B22J114-MS1	Matrix Spike	Water	EPA 6010	Iron	7439-89-6	FALSE	FALSE	494	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-0	0.532	500.0	98.7		120	80			
B22J114-MS1	Matrix Spike	Water	EPA 6010	Magnesium	7439-95-4	FALSE	FALSE	477	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-0	0.564	500.0	95.2		120	80			
B22J114-MS1	Matrix Spike	Water	EPA 6010	Potassium	7440-09-7	FALSE	FALSE	481	0.200	0.500	mg/L	TRUE	NA	10	22I2101-0	1.71	500.0	95.8		120	80			
B22J114-MS1	Matrix Spike	Water	EPA 6010	Sodium	7440-23-5	FALSE	FALSE	478	0.200	0.500	mg/L	TRUE	NA	10	22I2101-0	3.75	500.0	94.9		120	80			
B22J114-MS2	Matrix Spike	Water	EPA 6010	Calcium	7440-70-2	FALSE	FALSE	477	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-4	2.60	500.0	94.8		120	80			
B22J114-MS2	Matrix Spike	Water	EPA 6010	Iron	7439-89-6	FALSE	FALSE	490	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-4	0.0932	500.0	98.0		120	80			
B22J114-MS2	Matrix Spike	Water	EPA 6010	Magnesium	7439-95-4	FALSE	FALSE	472	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-4	0.721	500.0	94.2		120	80			
B22J114-MS2	Matrix Spike	Water	EPA 6010	Potassium	7440-09-7	FALSE	FALSE	473	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-4	1.53	500.0	94.2		120	80			
B22J114-MS2	Matrix Spike	Water	EPA 6010	Sodium	7440-23-5	FALSE	FALSE	481	0.0400	0.200	mg/L	TRUE	NA	10	22I2101-4	10.0	500.0	94.1		120	80			
B22K043-BLK1	Blank	Water	EPA 6020	Copper-65 [2]	7440-50-8	FALSE	FALSE	ND	0.0002	0.0010	mg/L	TRUE	NA	1									U	
B22K043-BLK1	Blank	Water	EPA 6020	Lead-206 [1]	7439-92-1	FALSE	FALSE	ND	0.0002	0.0010	mg/L	TRUE	NA	1										U
B22K043-BLK2	Blank	Water	EPA 6020	Copper-65 [2]	7440-50-8	FALSE	FALSE	ND	0.0002	0.0010	mg/L	TRUE	NA	1										U
B22K043-BLK2	Blank	Water	EPA 6020	Lead-206 [1]	7439-92-1	FALSE	FALSE	ND	0.0002	0.0010	mg/L	TRUE	NA	1										U
B22K043-BS1	LCS	Water	EPA 6020	Copper-65 [2]	7440-50-8	FALSE	FALSE	0.0534	0.0002	0.0010	mg/L	TRUE	NA	1			0.05000	107		120	80			
B22K043-BS1	LCS	Water	EPA 6020	Lead-206 [1]	7439-92-1	FALSE	FALSE	0.0477	0.0002	0.0010	mg/L	TRUE	NA	1			0.05000	95.4		120	80			
B22K043-BS2	LCS	Water	EPA 6020	Copper-65 [2]	7440-50-8	FALSE	FALSE	0.0500	0.0002	0.0010	mg/L	TRUE	NA	1			0.05000	100		120	80			
B22K043-BS2	LCS	Water	EPA 6020	Lead-206 [1]	7439-92-1	FALSE	FALSE	0.0484	0.0002	0.0010	mg/L	TRUE	NA	1			0.05000	96.9		120	80			
B22K043-DUP1	Duplicate	Water	EPA 6020	Copper-65 [2]	7440-50-8	FALSE	FALSE	0.0894	0.0010	0.0050	mg/L	TRUE	NA	5	22I2101-4	0.0897			0.422				20	
B22K043-DUP1	Duplicate	Water	EPA 6020	Lead-206 [1]	7439-92-1	FALSE	FALSE	ND	0.0010	0.0050	mg/L	TRUE	NA	5	22I2101-4	ND							20	U
B22K043-DUP2	Duplicate	Water	EPA 6020	Copper-65 [2]	7440-50-8	FALSE	FALSE	0.0665	0.0010	0.0050	mg/L	TRUE	NA	5	22I2101-4	0.0735			10.0				20	
B22K043-DUP2	Duplicate	Water	EPA 6020	Lead-206 [1]	7439-92-1	FALSE	FALSE	ND	0.0010	0.0050	mg/L	TRUE	NA	5	22I2101-4	ND							20	U
B22K043-MS1	Matrix Spike	Water	EPA 6020	Copper-65 [2]	7440-50-8	FALSE	FALSE	0.653	0.0020	0.0100	mg/L	TRUE	NA	10	22I2101-4	0.0897	0.5000	113		120	80			
B22K043-MS1	Matrix Spike	Water	EPA 6020	Lead-206 [1]	7439-92-1	FALSE	FALSE	0.477	0.0020	0.0100	mg/L	TRUE	NA	10	22I2101-4	ND	0.5000	95.4		120	80			
B22K043-MS2	Matrix Spike	Water	EPA 6020	Copper-65 [2]	7440-50-8	FALSE	FALSE	0.599	0.0020	0.0100	mg/L	TRUE	NA	10	22I2101-4	0.0735	0.5000	105		120	80			
B22K043-MS2	Matrix Spike	Water	EPA 6020	Lead-206 [1]	7439-92-1	FALSE	FALSE	0.468	0.0020	0.0100	mg/L	TRUE	NA	10	22I2101-4	ND</								

Table C-6a. ICP-MS metal concentrations in batch water extracts using Milli-Q water.

LabName	LABSAMPID	SAMPLENAME	Concentration (mg/L)						
			Ca	Fe	Mg	K	Na	Cu-63 [2]	Pb-206 [1]
ERDC-EL-EP-C	22I2102-17	A_BM2a	0.281	0.0423 J	0.102 J	4.61	8.40	2.21	ND
ERDC-EL-EP-C	22I2102-18	A_BM2b	0.357	0.0699 J	0.114 J	1.01	8.36	30.6	0.0024 J
ERDC-EL-EP-C	22I2102-19	A_BM2c	0.350	0.215	0.132 J	0.995	8.33	353	0.0127
ERDC-EL-EP-C	22I2102-20	A_BMD2a	0.203	ND	0.0595 J	0.698	7.26	2.29	ND
ERDC-EL-EP-C	22I2102-21	A_BMD2b	0.380	0.0738 J	0.0912 J	0.797	7.86	31.9	ND
ERDC-EL-EP-C	22I2102-22	A_BMD2c	0.328	0.205	0.118 J	0.910	8.06	352	0.0123
ERDC-EL-EP-C	22I2102-24	A_BMD3	0.790	0.129 J	0.187 J	3.66	8.15	0.0683	ND
ERDC-EL-EP-C	22I2102-39	D_BMD2a	ND	0.127 J	ND	0.563	7.81	0.231	ND
ERDC-EL-EP-C	22I2102-40	D_BMD2b	ND	0.167 J	ND	0.436 J	7.43	1.04	ND
ERDC-EL-EP-C	22I2102-41	D_BMD2c	ND	0.187 J	ND	0.448 J	7.29	6.98	ND
ERDC-EL-EP-C	22I2102-42	D_BMD3	0.101 J	0.0700 J	ND	0.560	7.68	0.0105	ND

ND = not detected, J = estimated concentration

Table C-6b. ICP-MS QC data for batch water extracts using Milli-Q water.

LabName	LABSAMPID	QCTYPE	MATRIX	METHODNAME	ANALYTE	RESULT	DL	RL	UNITS	RPTOMDL	SOURCEID	SOURCECERES	SPIKELEVEL	RECOVERY	RPD	UPPERCL	LOWERCL	RPDCL	ANOTE
ERDC-EL-EP-C	B22K089-BLK1	Blank	Water	EPA 6020	Copper-65 [2]	ND	0.0002	0.0010	mg/L	TRUE									U
ERDC-EL-EP-C	B22K089-BLK1	Blank	Water	EPA 6020	Lead-206 [1]	ND	0.0002	0.0010	mg/L	TRUE									U
ERDC-EL-EP-C	B22K089-BS1	LCS	Water	EPA 6020	Copper-65 [2]	0.0448	0.0002	0.0010	mg/L	TRUE			0.05000	89.6		120	80		
ERDC-EL-EP-C	B22K089-BS1	LCS	Water	EPA 6020	Lead-206 [1]	0.0482	0.0002	0.0010	mg/L	TRUE			0.05000	96.4		120	80		
ERDC-EL-EP-C	B22K089-DUP1	Duplicate	Water	EPA 6020	Copper-65 [2]	0.0102	0.0020	0.0100	mg/L	TRUE	22I2102-42	0.0105			2.89			20	
ERDC-EL-EP-C	B22K089-DUP1	Duplicate	Water	EPA 6020	Lead-206 [1]	ND	0.0020	0.0100	mg/L	TRUE	22I2102-42	ND						20	U
ERDC-EL-EP-C	B22K089-MS1	Matrix Spike	Water	EPA 6020	Copper-65 [2]	0.477	0.0020	0.0100	mg/L	TRUE	22I2102-42	0.0105	0.5000	93.2		120	80		
ERDC-EL-EP-C	B22K089-MS1	Matrix Spike	Water	EPA 6020	Lead-206 [1]	0.475	0.0020	0.0100	mg/L	TRUE	22I2102-42	ND	0.5000	95.0		120	80		
ERDC-EL-EP-C	B22L119-BLK1	Blank	Water	EPA 6010	Calcium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L119-BLK1	Blank	Water	EPA 6010	Iron	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L119-BLK1	Blank	Water	EPA 6010	Magnesium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L119-BLK1	Blank	Water	EPA 6010	Potassium	0.0337	0.0200	0.0500	mg/L	TRUE									J
ERDC-EL-EP-C	B22L119-BLK1	Blank	Water	EPA 6010	Sodium	ND	0.0200	0.0500	mg/L	TRUE									U
ERDC-EL-EP-C	B22L119-BS1	LCS	Water	EPA 6010	Calcium	48.5	0.0040	0.0200	mg/L	TRUE			50.00	96.9		120	80		
ERDC-EL-EP-C	B22L119-BS1	LCS	Water	EPA 6010	Iron	47.5	0.0040	0.0200	mg/L	TRUE			50.00	94.9		120	80		
ERDC-EL-EP-C	B22L119-BS1	LCS	Water	EPA 6010	Magnesium	48.1	0.0040	0.0200	mg/L	TRUE			50.00	96.1		120	80		
ERDC-EL-EP-C	B22L119-BS1	LCS	Water	EPA 6010	Potassium	47.9	0.0200	0.0500	mg/L	TRUE			50.00	95.8		120	80		
ERDC-EL-EP-C	B22L119-BS1	LCS	Water	EPA 6010	Sodium	46.4	0.0200	0.0500	mg/L	TRUE			50.00	92.8		120	80		

U = not detected

Table C-7b. ICP-MS metal concentrations in batch water extracts using the electrolyte solution.

LabName	SAMPLENAME	Concentration (mg/L)							
		Ca	Fe	Mg	K	Mn	Cu	Zn	Pb
Dartmouth College	A_BE1	1.157	0.005	0.672	1.635	0.014	0.022	0.008	0.029
Dartmouth College	A_BED1	1.355	0.004	0.665	1.573	0.013	0.031	0.009	0.000
Dartmouth College	A_BE2a	2.076	0.019	0.734	1.185	0.030	1.010	0.056	0.000
Dartmouth College	A_BE2b	2.603	0.087	0.822	1.348	0.045	41.314	0.105	0.001
Dartmouth College	A_BE2c	2.351	0.249	0.653	1.232	0.046	384.288	0.127	0.007
Dartmouth College	A_BED2a	2.156	0.016	0.718	1.226	0.026	1.123	0.047	0.000
Dartmouth College	A_BED2b	2.703	0.087	0.815	1.351	0.045	40.482	0.105	0.002
Dartmouth College	A_BED2c	2.237	0.277	0.615	1.202	0.043	496.011	0.127	0.022
Dartmouth College	A_BE3	1.508	0.017	0.512	1.953	0.022	0.065	0.090	0.000
Dartmouth College	A_BED3	1.681	0.020	0.535	2.062	0.024	0.225	0.092	0.001
Dartmouth College	D_BED1	2.725	0.003	0.680	1.485	0.006	0.062	0.007	0.000
Dartmouth College	D_BED2a	2.766	0.012	0.681	1.454	0.012	0.379	0.033	0.000
Dartmouth College	D_BED2b	2.502	0.013	0.614	1.368	0.010	2.204	0.027	0.000
Dartmouth College	D_BED2c	2.644	0.012	0.634	1.381	0.008	9.951	0.031	0.000
Dartmouth College	D_BED3	2.734	0.004	0.660	1.483	0.008	0.032	0.018	0.000
Dartmouth College	D_BED5	4.674	0.025	1.151	2.528	0.054	0.342	0.540	0.001
Dartmouth College	A_BED3 intial [Cu] concentration	1.701	0.046	0.457	1.755	0.009	0.183	0.118	0.001

Table C-7b. ICP-MS QC data for batch water extracts using the electrolyte solution.

QC			Ca	Fe	Mg	K	Mn	Cu	Zn	Pb
Calibration check	ICV	% recovery	96%	97%	97%	97%	95%	100%	99%	102%
Calibration check	ICV	% recovery	91%	101%	103%	101%	99%	103%	99%	105%
Calibration check	ICV	% recovery	90%	98%	98%	96%	96%	92%	96%	103%
Calibration check	ICV	% recovery	87%	94%	93%	92%	92%	106%	100%	100%
Calibration check	ICV	% recovery	90%	100%	102%	100%	99%	104%	96%	106%
Calibration check	ICV	% recovery	112%	109%	103%	96%	107%		101%	105%
Calibration check	ICV	% recovery	108%	108%	98%	90%	105%		101%	113%
laboratory control solution	USGS 251	% recovery	114%	103%	98%	93%	99%	111%	105%	103%
laboratory control solution	USGS 252	% recovery	108%	100%	93%	89%	97%	110%	104%	104%
laboratory control solution	USGS 253	% recovery	106%	101%	93%	90%	98%	108%	103%	101%
laboratory control solution	USGS 254	% recovery	111%	100%	90%	89%	97%	109%	105%	102%
laboratory control solution	USGS 255	% recovery	114%	103%	99%	92%	100%	107%	101%	105%
laboratory control solution	USGS 256	% recovery	95%	96%	97%	93%	95%		93%	103%
laboratory control solution	USGS 257	% recovery	91%	96%	103%	97%	94%		95%	115%
analysis duplicate	Cold Regions 002 dup	% difference	15%	12%	2%	11%	1%	5%	11%	14%
analysis spike	Cold Regions 002 spk	% recovery	174%	102%	102%	95%	99%	106%	101%	106%

Table C-8a. ICP-MS metal concentrations in SAR soil subsample and batch soil acid digestates.

LabName	LABSAMPID	SAMPLENAME	Concentration (mg/L)						
			Ca	Fe	Mg	K	Na	Cu-63 [2]	Pb-206 [1]
ERDC-EL-EP-C	22I2103-01	T15 8 in digestate	177.6199	2309.0593	207.8811	239.4580 B	41.9709	1.1447	1.3486
ERDC-EL-EP-C	22I2103-02	T15 18 in digestate	145.5345	3108.2014	287.9504	265.0807 B	21.8302 J	1.8296	1.6633
ERDC-EL-EP-C	22I2103-03	T15 22 in digestate	211.8593	4494.2958	330.1302	393.8937	56.4615	1.5838	1.7484
ERDC-EL-EP-C	22I2103-04	T18 12 in digestate	352.2542	5340.9627	679.5700	500.8451	52.2666	2.8160	2.4627
ERDC-EL-EP-C	22I2103-05	T18 16 in digestate	279.8826	4283.0525	448.4483	439.9670	47.0712 J	2.0143	1.8977
ERDC-EL-EP-C	22I2103-06	T18 20 in digestate	150.5639	2938.0870	256.1677	267.6691	22.2709 J	1.9971	1.8402
ERDC-EL-EP-C	22I2103-07	T18 24 in digestate	594.6540	5394.7991	642.6759	449.5666	32.2871 J	4.7204	8.7257
ERDC-EL-EP-C	22I2103-08	T18 28 in digestate	550.0238	5531.4302	672.7134	477.2418	31.6082 J	4.3565	8.4219
ERDC-EL-EP-C	22I2103-09	T18 32 in digestate	398.4966	6139.2747	705.9660	462.2156	34.8937 J	4.1670	8.4352
ERDC-EL-EP-C	22I2103-10	I12 16 in digestate	985.8693	12453.0861	1276.4413	723.3168	95.1623	26.1515	42.8594
ERDC-EL-EP-C	22I2103-11	I12 20 in digestate	514.8983	6885.8653	560.1189	393.6248	85.6108	6.9373	9.9383
ERDC-EL-EP-C	22I2103-12	I12 28 in digestate	342.8564	3573.1420	233.3902	200.3438	71.8759	4.5232	5.6592
ERDC-EL-EP-C	22I2103-13	I8 20 in digestate	399.2988	5842.6006	464.5792	421.0589	94.0039	14.6881	2.6765
ERDC-EL-EP-C	22I2103-14	I8 24 in digestate	243.6800	4374.0057	404.7740	305.8745	79.8333	3.1301	1.8047
ERDC-EL-EP-C	22I2103-15	I8 28 in digestate	333.4250	4581.9720	470.7793	398.4323	84.5096	3.3972	1.5728
ERDC-EL-EP-C	22I2103-16	I8 32 in digestate	243.4532	4504.9237	369.3413	354.7757	77.4056	3.3085	3.2877
ERDC-EL-EP-C	22I2103-17	I8 36 in digestate	319.9473	3507.1148	254.3171	210.2218	69.0143	3.0867	7.1988
ERDC-EL-EP-C	22I2103-18	I8 40 in digestate	318.8047	3397.7872	269.5158	204.4964	72.6749	2.2442	5.1281
ERDC-EL-EP-C	22I2103-19	I8 44 in digestate	531.7689	4185.6026	305.3517	234.7261	76.6495	6.8652	6.6263
ERDC-EL-EP-C	22I2103-20	S5R 20 in digestate	484.4832	7401.8273	636.6607	538.3147	95.3438	14.0790	2.5673
ERDC-EL-EP-C	22I2103-21	S5R 24 in digestate	380.3644	5726.3653	475.4555	413.8030	93.9417	17.7643	2.6019
ERDC-EL-EP-C	22I2103-22	S5R 28 in digestate	265.8172	4703.7179	441.2980	407.0325	77.5646	4.9010	1.5783
ERDC-EL-EP-C	22I2103-23	S5R 32 in digestate	276.6905	3638.3716	416.1251	374.7305	93.2469	5.2833	1.6449
ERDC-EL-EP-C	22I2103-24	S5R 36 in digestate	281.4524	4092.9164	395.8891	351.5578	86.4977	4.0723	1.5568
ERDC-EL-EP-C	22I2103-25	S5R 40 in digestate	193.3857	4242.0094	352.4611	294.2374	74.8590	5.0946	1.6635
ERDC-EL-EP-C	22I2103-26	S5R 42 in digestate	258.3910	4441.4198	418.1991	335.1819	46.1783 J	3.7046	1.6603
ERDC-EL-EP-C	22I2103-27	S5R 48 in digestate	268.3874	12113.9852	1462.0327	661.0476	52.5287	4.6576	7.8323
ERDC-EL-EP-C	22I2103-28	S5R 50 in digestate	219.8927	13276.5381	1348.3984	619.2260	51.7578 J	4.0348	8.8891
ERDC-EL-EP-C	22I2103-29	S6R 24 in digestate	363.2741	5412.8882	606.4919	412.9527	42.5372 J	6.9032	5.0920
ERDC-EL-EP-C	22I2103-30	S6R 28 in digestate	351.8555	9864.5197	933.0453	573.8595	85.5553	6.8591	7.7806
ERDC-EL-EP-C	22I2103-31	S6R 32 in digestate	263.2290	13161.4493	579.9264	386.6176	43.7001 J	5.2337	11.5163
ERDC-EL-EP-C	22I2103-32	S6R 36 in digestate	464.5416	7752.6147	675.7901	401.9874	40.8140 J	29.7389	18.9713
ERDC-EL-EP-C	22I2103-33	S6R 32 in #2 digestate	266.5257	10824.4158	546.3266	344.1347	29.8182 J	4.6668	11.7435
ERDC-EL-EP-C	22I2103-34	S6R 32 in #3 digestate	251.5051	10616.8139	528.7792	344.2734	43.4980 J	5.3496	10.8230
ERDC-EL-EP-C	22I2103-35	S6R 32 in MS digestate	321.7053	11002.9498	625.5963	442.2138	91.5865	104.7900	64.2363
ERDC-EL-EP-C	22I2103-36	S6R 32 in MSD digestate	353.0032	11801.5872	668.4085	454.3089	90.7573	108.6164	72.2717
ERDC-EL-EP-C	22I2103-37	T18 28 in #2 digestate	520.5315	5581.6030	713.9017	512.1696	30.5211 J	4.1705	8.3410
ERDC-EL-EP-C	22I2103-38	T18 28 in #3 digestate	532.3901	5118.7414	670.8731	455.4551	29.1327 J	4.0006	7.8679
ERDC-EL-EP-C	22I2103-39	T18 28 in MS digestate	696.6195	6146.0321	835.7358	577.2287	85.8576	110.0472	65.1978
ERDC-EL-EP-C	22I2103-40	T18 28 in MSD digestate	661.7145	6015.5860	784.1005	570.4435	84.8405	110.9772	66.2752
ERDC-EL-EP-C	22I2103-41	Core Sampling LCS 1	0.611	0.566	0.468	0.632	0.569	1.24	0.512
ERDC-EL-EP-C	22I2103-42	Core Sampling LCS 2	0.591	0.561	0.471	0.588	0.561	1.31	0.523
ERDC-EL-EP-C	22I2103-43	Core Sampling Blank 1	0.112 J	ND	ND	ND	ND	ND	ND
ERDC-EL-EP-C	22I2103-44	Core Sampling Blank 2	0.0876	ND	ND	ND	ND	ND	ND
ERDC-EL-EP-C	22I2103-45	A1 digestate	121.842	3035.735	277.759	160.047	ND	1.477	2.860
ERDC-EL-EP-C	22I2103-46	DF1 digestate	138.773	2281.349	206.057	115.644	ND	1.125	1.945
ERDC-EL-EP-C	22I2103-47	AM1 digestate	82.098	2313.946	228.225	117.282	ND	1.162	2.229
ERDC-EL-EP-C	22I2103-48	DFM1 digestate	61.770	2010.157	157.043	99.461	ND	0.911	1.822
ERDC-EL-EP-C	22I2103-49	AM2a digestate	86.733	6450.459	334.468	184.892	ND	38.848	3.656
ERDC-EL-EP-C	22I2103-50	DFM2a digestate	77.152	2640.211	275.322	165.398	ND	18.903	2.825

ND = not detected, B = metal analyte detected in both the run blank and the sample, J = estimated concentration

Table C-8b. ICP-MS QC data for SAR soil subsample and batch soil acid digestates.

LabName	LABSAMPID	QCTYPE	MATRIX	METHODNAME	ANALYTE	RESULT	DL	RL	UNITS	RPTMDL	SOURCEID	SOURCERES	SPIKELEVEL	RECOVERY	RPD	UPPERCL	LOWERCL	RPDCL	ANOTE
ERDC-EL-EP-C	B22115-DUP1	Duplicate	Water	EPA 6010	Calcium	3.67	0.0400	0.200	mg/L	TRUE	2212103-21	3.64			0.943			20	
ERDC-EL-EP-C	B22115-DUP1	Duplicate	Water	EPA 6010	Iron	55.9	0.0400	0.200	mg/L	TRUE	2212103-21	54.8			1.85			20	
ERDC-EL-EP-C	B22115-DUP1	Duplicate	Water	EPA 6010	Magnesium	4.54	0.0400	0.200	mg/L	TRUE	2212103-21	4.55			0.8205			20	
ERDC-EL-EP-C	B22115-DUP1	Duplicate	Water	EPA 6010	Potassium	3.90	0.200	0.500	mg/L	TRUE	2212103-21	3.96			1.73			20	
ERDC-EL-EP-C	B22115-DUP1	Duplicate	Water	EPA 6010	Sodium	0.836	0.200	0.500	mg/L	TRUE	2212103-21	0.899			7.33			20	
ERDC-EL-EP-C	B22115-DUP2	Duplicate	Water	EPA 6010	Calcium	0.747	0.0400	0.200	mg/L	TRUE	2212103-50	0.751			0.485			20	
ERDC-EL-EP-C	B22115-DUP2	Duplicate	Water	EPA 6010	Iron	26.0	0.0400	0.200	mg/L	TRUE	2212103-50	25.7			0.934			20	
ERDC-EL-EP-C	B22115-DUP2	Duplicate	Water	EPA 6010	Magnesium	2.71	0.0400	0.200	mg/L	TRUE	2212103-50	2.68			1.17			20	
ERDC-EL-EP-C	B22115-DUP2	Duplicate	Water	EPA 6010	Potassium	1.60	0.200	0.500	mg/L	TRUE	2212103-50	1.61			0.991			20	
ERDC-EL-EP-C	B22115-DUP2	Duplicate	Water	EPA 6010	Sodium	ND	0.200	0.500	mg/L	TRUE	2212103-50	ND						20	U
ERDC-EL-EP-C	B22115-MS1	Matrix Spike	Water	EPA 6010	Calcium	526	0.0400	0.200	mg/L	TRUE	2212103-21	3.64	500.0	104		120	80		
ERDC-EL-EP-C	B22115-MS1	Matrix Spike	Water	EPA 6010	Iron	587	0.0400	0.200	mg/L	TRUE	2212103-21	54.8	500.0	106		120	80		
ERDC-EL-EP-C	B22115-MS1	Matrix Spike	Water	EPA 6010	Magnesium	514	0.0400	0.200	mg/L	TRUE	2212103-21	4.55	500.0	102		120	80		
ERDC-EL-EP-C	B22115-MS1	Matrix Spike	Water	EPA 6010	Potassium	503	0.200	0.500	mg/L	TRUE	2212103-21	3.96	500.0	99.8		120	80		
ERDC-EL-EP-C	B22115-MS1	Matrix Spike	Water	EPA 6010	Sodium	483	0.200	0.500	mg/L	TRUE	2212103-21	0.899	500.0	96.5		120	80		
ERDC-EL-EP-C	B22115-MS2	Matrix Spike	Water	EPA 6010	Calcium	520	0.0400	0.200	mg/L	TRUE	2212103-50	0.751	500.0	104		120	80		
ERDC-EL-EP-C	B22115-MS2	Matrix Spike	Water	EPA 6010	Iron	556	0.0400	0.200	mg/L	TRUE	2212103-50	25.7	500.0	106		120	80		
ERDC-EL-EP-C	B22115-MS2	Matrix Spike	Water	EPA 6010	Magnesium	506	0.0400	0.200	mg/L	TRUE	2212103-50	2.68	500.0	101		120	80		
ERDC-EL-EP-C	B22115-MS2	Matrix Spike	Water	EPA 6010	Potassium	481	0.200	0.500	mg/L	TRUE	2212103-50	1.61	500.0	95.8		120	80		
ERDC-EL-EP-C	B22115-MS2	Matrix Spike	Water	EPA 6010	Sodium	467	0.200	0.500	mg/L	TRUE	2212103-50	ND	500.0	93.4		120	80		
ERDC-EL-EP-C	B22K078-BLK1	Blank	Water	EPA 6020	Copper-63 [2]	ND	0.0002	0.0010	mg/L	TRUE									U
ERDC-EL-EP-C	B22K078-BLK1	Blank	Water	EPA 6020	Lead-206 [1]	ND	0.0002	0.0010	mg/L	TRUE									U
ERDC-EL-EP-C	B22K078-BLK2	Blank	Water	EPA 6020	Copper-63 [2]	ND	0.0002	0.0010	mg/L	TRUE									U
ERDC-EL-EP-C	B22K078-BLK2	Blank	Water	EPA 6020	Lead-206 [1]	ND	0.0002	0.0010	mg/L	TRUE									U
ERDC-EL-EP-C	B22K078-BS1	LCS	Water	EPA 6020	Copper-63 [2]	0.0517	0.0002	0.0010	mg/L	TRUE			0.05000	103		120	80		
ERDC-EL-EP-C	B22K078-BS1	LCS	Water	EPA 6020	Lead-206 [1]	0.0472	0.0002	0.0010	mg/L	TRUE			0.05000	94.4		120	80		
ERDC-EL-EP-C	B22K078-BS2	LCS	Water	EPA 6020	Copper-63 [2]	0.0525	0.0002	0.0010	mg/L	TRUE			0.05000	105		120	80		
ERDC-EL-EP-C	B22K078-BS2	LCS	Water	EPA 6020	Lead-206 [1]	0.0480	0.0002	0.0010	mg/L	TRUE			0.05000	96.0		120	80		
ERDC-EL-EP-C	B22K078-BLK1	Duplicate	Water	EPA 6020	Copper-63 [2]	0.0159	0.0010	0.0050	mg/L	TRUE	2212103-01	0.0174			9.37			20	
ERDC-EL-EP-C	B22K078-DUP1	Duplicate	Water	EPA 6020	Lead-206 [1]	0.0206	0.0010	0.0050	mg/L	TRUE	2212103-01	0.0205			0.730			20	
ERDC-EL-EP-C	B22K078-DUP2	Duplicate	Water	EPA 6020	Copper-63 [2]	0.184	0.0010	0.0050	mg/L	TRUE	2212103-50	0.184			0.0848			20	
ERDC-EL-EP-C	B22K078-DUP2	Duplicate	Water	EPA 6020	Lead-206 [1]	0.0269	0.0010	0.0050	mg/L	TRUE	2212103-50	0.0275			2.15			20	
ERDC-EL-EP-C	B22K078-MS1	Matrix Spike	Water	EPA 6020	Copper-63 [2]	0.532	0.0020	0.0100	mg/L	TRUE	2212103-01	0.0174	0.5000	103		120	80		
ERDC-EL-EP-C	B22K078-MS1	Matrix Spike	Water	EPA 6020	Lead-206 [1]	0.498	0.0020	0.0100	mg/L	TRUE	2212103-01	0.0205	0.5000	95.6		120	80		
ERDC-EL-EP-C	B22K078-MS2	Matrix Spike	Water	EPA 6020	Copper-63 [2]	0.703	0.0020	0.0100	mg/L	TRUE	2212103-50	0.184	0.5000	104		120	80		
ERDC-EL-EP-C	B22K078-MS2	Matrix Spike	Water	EPA 6020	Lead-206 [1]	0.514	0.0020	0.0100	mg/L	TRUE	2212103-50	0.0275	0.5000	97.3		120	80		
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Calcium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Iron	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Magnesium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Potassium	0.0577	0.0200	0.0500	mg/L	TRUE									MB-02
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Sodium	0.0499	0.0200	0.0500	mg/L	TRUE									J
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Calcium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Iron	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Magnesium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Potassium	0.0437	0.0200	0.0500	mg/L	TRUE									J
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Sodium	ND	0.0200	0.0500	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Calcium	47.4	0.0040	0.0200	mg/L	TRUE			50.00	94.8		120	80		
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Iron	48.9	0.0040	0.0200	mg/L	TRUE			50.00	97.9		120	80		
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Magnesium	47.1	0.0040	0.0200	mg/L	TRUE			50.00	94.2		120	80		
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Potassium	46.6	0.0200	0.0500	mg/L	TRUE			50.00	93.3		120	80		B
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Sodium	46.2	0.0200	0.0500	mg/L	TRUE			50.00	92.3		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Calcium	47.6	0.0040	0.0200	mg/L	TRUE			50.00	95.2		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Iron	49.2	0.0040	0.0200	mg/L	TRUE			50.00	98.5		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Magnesium	47.4	0.0040	0.0200	mg/L	TRUE			50.00	94.8		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Potassium	47.3	0.0200	0.0500	mg/L	TRUE			50.00	94.5		120	80		B
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Sodium	46.9	0.0200	0.0500	mg/L	TRUE			50.00	93.8		120	80		
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Calcium	0.638	0.0400	0.200	mg/L	TRUE	2212104-01	0.666			4.27			20	
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Iron	41.8	0.0400	0.200	mg/L	TRUE	2212104-01	41.2			1.41			20	
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Magnesium	4.75	0.0400	0.200	mg/L	TRUE	2212104-01	4.80			0.966			20	
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Potassium	1.99	0.200	0.500	mg/L	TRUE	2212104-01	5.26			90.3			20	RPD-06, B
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Sodium	0.611	0.200	0.500	mg/L	TRUE	2212104-01	3.68			143			20	RPD-06
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Calcium	0.0760	0.0400	0.200	mg/L	TRUE	2212104-34	0.104			30.9			20	RPD-01, J
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Iron	ND	0.0400	0.200	mg/L	TRUE	2212104-34	ND						20	U
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Magnesium	0.0486	0.0400	0.200	mg/L	TRUE	2212104-34	ND						20	J
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Potassium	ND	0.200	0.500	mg/L	TRUE	2212104-34	ND						20	U
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Sodium	ND	0.200	0.500	mg/L										

Table C-9a. ICP-MS metal concentrations in batch and column soil acid digestates.

LabName	LABSAMPID	SAMPLENAME	Concentration (mg/L)						
			Ca	Fe	Mg	K	Na	Cu-63 [2]	Pb-206 [1]
ERDC-EL-EP-C	22I2104-01	ABM2a digestate	69.0827	4273.5853	497.8934	545.6082 B	381.7183	22.6127	2.6969
ERDC-EL-EP-C	22I2104-02	DFBM2a digestate	45.5300	1792.3593	152.4536	156.5739 B	50.1655 J	15.3484	1.8645
ERDC-EL-EP-C	22I2104-03	ABM3 digestate	67.9452	2463.0120	254.7943	170.9245 B	27.1781 J	2.8027	2.5479
ERDC-EL-EP-C	22I2104-04	DFBM3 digestate	69.9090	2650.2815	249.3769	169.0337 B	23.3726 J	2.3686	2.6085
ERDC-EL-EP-C	22I2104-05	AM3 digestate	64.7151	2800.4758	275.8521	187.7473 B	ND	2.6117	2.5173
ERDC-EL-EP-C	22I2104-06	DFM3 digestate	145.3991	2735.1295	222.6741	143.3655 B	ND	2.1047	2.2064
ERDC-EL-EP-C	22I2104-07	A3 digestate	139.3372	3199.5956	340.6021	170.3011 B	ND	3.9530	3.2925
ERDC-EL-EP-C	22I2104-08	DF3 digestate	244.8827	2778.8866	229.9768	190.5826 B	ND	2.7150	2.6085
ERDC-EL-EP-C	22I2104-09	DFM4 digestate	58.2231	2732.4942	220.7015	156.5929 B	ND	2.4172	6.9048
ERDC-EL-EP-C	22I2104-10	AM4 digestate	77.5169	2750.6010	229.2167	159.4098 B	ND	2.6672	7.4183
ERDC-EL-EP-C	22I2104-11	DF4 digestate	340.5419	2811.8141	252.0219	161.4190 B	ND	1.8121	4.4156
ERDC-EL-EP-C	22I2104-12	A4 digestate	113.6597	4004.6453	312.2986	178.45632 B	ND	2.8149	7.5738
ERDC-EL-EP-C	22I2104-13	ColumnA_U digestate	249.9523	2910.9676	360.0137	181.0354 B	ND	1.3475	2.8595
ERDC-EL-EP-C	22I2104-14	ColumnA_M digestate	160.9451	3481.8849	319.7864	187.2434 B	ND	1.3465	3.4714
ERDC-EL-EP-C	22I2104-15	ColumnA_L digestate	135.7397	3122.0142	297.5833	168.1085 B	ND	1.1695	2.9445
ERDC-EL-EP-C	22I2104-16	ColumnB_U digestate	206.4365	3252.9391	323.2087	196.0104 B	ND	10.5303	5.7656
ERDC-EL-EP-C	22I2104-17	ColumnB_M digestate	162.1145	3583.0392	317.0009	192.0592 B	ND	1.5282	3.4901
ERDC-EL-EP-C	22I2104-18	ColumnB_L digestate	132.9544	3885.5654	305.0736	180.3644 B	ND	3.9268	3.3702
ERDC-EL-EP-C	22I2104-19	ColumnC_U digestate	251.3487	3898.0353	388.7385	222.5927 B	ND	9.9474	4.1643
ERDC-EL-EP-C	22I2104-20	ColumnC_M digestate	197.5007	4303.4367	386.6856	196.4612 B	ND	16.8395	3.8357
ERDC-EL-EP-C	22I2104-21	ColumnC_L digestate	128.0811	3280.1257	294.6907	183.2705 B	ND	1.7182	3.0719
ERDC-EL-EP-C	22I2104-22	Clean Sand digestate	81.0368	6442.7459	340.6509	185.1364 B	ND	1.1637	3.9249
ERDC-EL-EP-C	22I2104-23	AM2a #2 digestate	75.3932	2432.0389	217.8261	142.7501 B	ND	22.7343	2.2629
ERDC-EL-EP-C	22I2104-24	AM2a #3 Digestate	97.3480	3563.2662	322.4397	176.6230 B	ND	34.4004	3.2039
ERDC-EL-EP-C	22I2104-25	AM2a MS digestate	125.3921	3517.3557	372.9885	231.6567 B	61.3146	127.5174	54.7262
ERDC-EL-EP-C	22I2104-26	AM2a MSD digestate	148.9890	3053.2258	342.0452	194.1054 B	63.2679	124.8570	54.9790
ERDC-EL-EP-C	22I2104-27	DF3 #2 digestate	149.2024	2065.8800	171.1133	99.1205 B	ND	1.7737	1.8676
ERDC-EL-EP-C	22I2104-28	DF3 #3 digestate	167.5614	1675.6143	197.2559	112.4146 B	ND	1.7605	1.5271
ERDC-EL-EP-C	22I2104-29	DF3 MS digestate	249.0634	2635.9206	386.0482	172.2688 B	63.0961	93.5025	53.7562
ERDC-EL-EP-C	22I2104-30	DF3 MSD digestate	219.6617	1660.3538	196.9736	142.3160 B	148.5037	98.6931	55.2764
ERDC-EL-EP-C	22I2104-31	Batch/Column LCS 1	0.5680	0.545	0.477	0.583 B	0.478 J	0.8820	0.491
ERDC-EL-EP-C	22I2104-32	Batch/Column LCS 2	0.5730	0.548	0.471	0.716 B	0.5270	0.9250	0.507
ERDC-EL-EP-C	22I2104-33	Batch/Column Blank 1	0.103 J	ND	ND	0.259 J, B	ND	0.0016 J	ND
ERDC-EL-EP-C	22I2104-34	Batch/Column Blank 2	0.104 J	ND	ND	ND	ND	ND	ND

ND = not detected, B = metal analyte detected in both the run blank and the sample, J = estimated concentration

Table C-9b. ICP-MS QC data for in batch and column soil acid digestates.

LabName	LABSAMPID	QCTYPE	MATRIX	METHODNAME	ANALYTE	RESULT	DL	RL	UNITS	RPTOMDL	SOURCEID	SOURCERES	SPIKELEVEL	RECOVERY	RPD	UPPERCL	LOWERCL	RPDCL	ANOTE
ERDC-EL-EP-C	B22K079-BLK1	Blank	Water	EPA 6020	Copper-63 [1]	ND	0.0002	0.0010	mg/L	TRUE									U
ERDC-EL-EP-C	B22K079-BLK1	Blank	Water	EPA 6020	Lead-206 [1]	ND	0.0002	0.0010	mg/L	TRUE									U
ERDC-EL-EP-C	B22K079-BLK2	Blank	Water	EPA 6020	Copper-63 [1]	ND	0.0002	0.0010	mg/L	TRUE									U
ERDC-EL-EP-C	B22K079-BLK2	Blank	Water	EPA 6020	Lead-206 [1]	ND	0.0002	0.0010	mg/L	TRUE									U
ERDC-EL-EP-C	B22K079-BS1	LCS	Water	EPA 6020	Copper-63 [1]	0.0502	0.0002	0.0010	mg/L	TRUE			0.05000	100		120	80		
ERDC-EL-EP-C	B22K079-BS1	LCS	Water	EPA 6020	Lead-206 [1]	0.0472	0.0002	0.0010	mg/L	TRUE			0.05000	94.4		120	80		
ERDC-EL-EP-C	B22K079-BS2	LCS	Water	EPA 6020	Copper-63 [1]	0.0495	0.0002	0.0010	mg/L	TRUE			0.05000	99.1		120	80		
ERDC-EL-EP-C	B22K079-BS2	LCS	Water	EPA 6020	Lead-206 [1]	0.0480	0.0002	0.0010	mg/L	TRUE			0.05000	96.0		120	80		
ERDC-EL-EP-C	B22K079-DUP1	Duplicate	Water	EPA 6020	Copper-63 [1]	0.210	0.0010	0.0050	mg/L	TRUE	22I2104-01	0.218			3.65			20	
ERDC-EL-EP-C	B22K079-DUP1	Duplicate	Water	EPA 6020	Lead-206 [1]	0.0272	0.0010	0.0050	mg/L	TRUE	22I2104-01	0.0260			4.26			20	
ERDC-EL-EP-C	B22K079-DUP2	Duplicate	Water	EPA 6020	Copper-63 [1]	ND	0.0010	0.0050	mg/L	TRUE	22I2104-34	ND						20	U
ERDC-EL-EP-C	B22K079-DUP2	Duplicate	Water	EPA 6020	Lead-206 [1]	ND	0.0010	0.0050	mg/L	TRUE	22I2104-34	ND						20	U
ERDC-EL-EP-C	B22K079-MS1	Matrix Spike	Water	EPA 6020	Copper-63 [1]	0.651	0.0020	0.0100	mg/L	TRUE	22I2104-01	0.218	0.5000	86.6		120	80		
ERDC-EL-EP-C	B22K079-MS1	Matrix Spike	Water	EPA 6020	Lead-206 [1]	0.485	0.0020	0.0100	mg/L	TRUE	22I2104-01	0.0260	0.5000	91.9		120	80		
ERDC-EL-EP-C	B22K079-MS2	Matrix Spike	Water	EPA 6020	Copper-63 [1]	0.431	0.0020	0.0100	mg/L	TRUE	22I2104-34	ND	0.5000	86.1		120	80		
ERDC-EL-EP-C	B22K079-MS2	Matrix Spike	Water	EPA 6020	Lead-206 [1]	0.489	0.0020	0.0100	mg/L	TRUE	22I2104-34	ND	0.5000	97.8		120	80		
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Calcium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Iron	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Magnesium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Potassium	0.0577	0.0200	0.0500	mg/L	TRUE									MB-02
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Sodium	0.0499	0.0200	0.0500	mg/L	TRUE									J
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Calcium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Iron	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Magnesium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Potassium	0.0437	0.0200	0.0500	mg/L	TRUE									J
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Sodium	ND	0.0200	0.0500	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Calcium	47.4	0.0040	0.0200	mg/L	TRUE			50.00	94.8		120	80		
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Iron	48.9	0.0040	0.0200	mg/L	TRUE			50.00	97.9		120	80		
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Magnesium	47.1	0.0040	0.0200	mg/L	TRUE			50.00	94.2		120	80		
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Potassium	46.6	0.0200	0.0500	mg/L	TRUE			50.00	93.3		120	80		B
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Sodium	46.2	0.0200	0.0500	mg/L	TRUE			50.00	92.3		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Calcium	47.6	0.0040	0.0200	mg/L	TRUE			50.00	95.2		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Iron	49.2	0.0040	0.0200	mg/L	TRUE			50.00	98.5		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Magnesium	47.4	0.0040	0.0200	mg/L	TRUE			50.00	94.8		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Potassium	47.3	0.0200	0.0500	mg/L	TRUE			50.00	94.5		120	80		B
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Sodium	46.9	0.0200	0.0500	mg/L	TRUE			50.00	93.8		120	80		
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Calcium	0.638	0.0400	0.200	mg/L	TRUE	22I2104-01	0.666			4.27			20	
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Iron	41.8	0.0400	0.200	mg/L	TRUE	22I2104-01	41.2			1.41			20	
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Magnesium	4.75	0.0400	0.200	mg/L	TRUE	22I2104-01	4.80			0.966			20	
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Potassium	1.99	0.200	0.500	mg/L	TRUE	22I2104-01	5.26			90.3			20	RPD-06, B
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Sodium	0.611	0.200	0.500	mg/L	TRUE	22I2104-01	3.68			143			20	RPD-06
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Calcium	0.0760	0.0400	0.200	mg/L	TRUE	22I2104-34	0.104			30.9			20	RPD-01, J
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Iron	ND	0.0400	0.200	mg/L	TRUE	22I2104-34	ND						20	U
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Magnesium	0.0486	0.0400	0.200	mg/L	TRUE	22I2104-34	ND						20	J
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Potassium	ND	0.200	0.500	mg/L	TRUE	22I2104-34	ND						20	U
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Sodium	ND	0.200	0.500	mg/L	TRUE	22I2104-34	ND						20	U
ERDC-EL-EP-C	B22L053-MS1	Matrix Spike	Water	EPA 6010	Calcium	898	0.0400	0.200	mg/L	TRUE	22I2104-01	0.666	1000	89.7		120	80		
ERDC-EL-EP-C	B22L053-MS1	Matrix Spike	Water	EPA 6010	Iron	947	0.0400	0.200	mg/L	TRUE	22I2104-01	41.2	1000	90.5		120	80		
ERDC-EL-EP-C	B22L053-MS1	Matrix Spike	Water	EPA 6010	Magnesium	915	0.0400	0.200	mg/L	TRUE	22I2104-01	4.80	1000	91.1		120	80		
ERDC-EL-EP-C	B22L053-MS1	Matrix Spike	Water	EPA 6010	Potassium	883	0.200	0.500	mg/L	TRUE	22I2104-01	5.26	1000	87.8		120	80		B
ERDC-EL-EP-C	B22L053-MS1	Matrix Spike	Water	EPA 6010	Sodium	910	0.200	0.500	mg/L	TRUE	22I2104-01	3.68	1000	90.6		120	80		
ERDC-EL-EP-C	B22L053-MS2	Matrix Spike	Water	EPA 6010	Calcium	474	0.0400	0.200	mg/L	TRUE	22I2104-34	0.104	500.0	94.7		120	80		
ERDC-EL-EP-C	B22L053-MS2	Matrix Spike	Water	EPA 6010	Iron	489	0.0400	0.200	mg/L	TRUE	22I2104-34	ND	500.0	97.8		120	80		
ERDC-EL-EP-C	B22L053-MS2	Matrix Spike	Water	EPA 6010	Magnesium	473	0.0400	0.200	mg/L	TRUE	22I2104-34	ND	500.0	94.6		120	80		
ERDC-EL-EP-C	B22L053-MS2	Matrix Spike	Water	EPA 6010	Potassium	468	0.200	0.500	mg/L	TRUE	22I2104-34	ND	500.0	93.5		120	80		B
ERDC-EL-EP-C	B22L053-MS2	Matrix Spike	Water	EPA 6010	Sodium	460	0.200	0.500	mg/L	TRUE	22I2104-34	ND	500.0	91.9		120	80		

U = not detected, B = metal analyte detected in both the run blank and the sample, J = estimated concentration  
 MB-02 = analyte contamination is caused by memory inferences  
 RPD -01 = RPD not evaluated because sample concentration is under reporting limit, RPD-06 = RPD values between duplicate samples or spikes over acceptance limit

Table C-10a. ICP-MS metal concentrations in lysimeter samples.

LabName	LABSAMPID	SAMPLENAME	Concentration (mg/L)						
			Ca	Fe	Mg	K	Na	Cu-63 [2]	Pb-206 [1]
ERDC-EL-EP-C	22K1504-01	DF_S. Range FP	2.73	0.0515 J	0.824	4.58 B	6.32	0.0023 J	ND
ERDC-EL-EP-C	22K1504-02	DF_India BF	15.2	0.0527 J	4.06	3.05 B	5.48	0.364	ND
ERDC-EL-EP-C	22K1504-03	DF_S. Range Backg	6.62	ND	1.74	2.60 B	21.2	0.0055 J	ND
ERDC-EL-EP-C	22K1504-04	DF_S. Range RF	21.1	ND	1.86	0.273 J, B	5.11	0.0060 J	ND
ERDC-EL-EP-C	22K1504-05	DF_Trip Blank	0.0422 J	ND	ND	0.820 B	0.284 J	0.0047 J	ND
ERDC-EL-EP-C	22K1504-06	DF_T. Range Backg	6.87	ND	3.71	0.870 B	12.3	ND	ND

ND = not detected, B = metal analyte detected in both the run blank and the sample, J = estimated concentration

Table C-10b. ICP-MS QC data for lysimeter samples.

LabName	LABSAMPID	QCTYPE	MATRIX	METHOD	ANALYTE	RESULT	DL	RL	UNITS	RPTOMDL	SOURCEID	SOURCERES	SPIKELEVEL	RECOVERY	RPD	UPPERCL	LOWERCL	RPDCL	ANOTE
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Calcium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Iron	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Magnesium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Potassium	0.0577	0.0200	0.0500	mg/L	TRUE									MB-02
ERDC-EL-EP-C	B22L053-BLK1	Blank	Water	EPA 6010	Sodium	0.0499	0.0200	0.0500	mg/L	TRUE									J
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Calcium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Iron	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Magnesium	ND	0.0040	0.0200	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Potassium	0.0437	0.0200	0.0500	mg/L	TRUE									J
ERDC-EL-EP-C	B22L053-BLK2	Blank	Water	EPA 6010	Sodium	ND	0.0200	0.0500	mg/L	TRUE									U
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Calcium	47.4	0.0040	0.0200	mg/L	TRUE			50.00	94.8		120	80		
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Iron	48.9	0.0040	0.0200	mg/L	TRUE			50.00	97.9		120	80		
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Magnesium	47.1	0.0040	0.0200	mg/L	TRUE			50.00	94.2		120	80		
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Potassium	46.6	0.0200	0.0500	mg/L	TRUE			50.00	93.3		120	80		B
ERDC-EL-EP-C	B22L053-BS1	LCS	Water	EPA 6010	Sodium	46.2	0.0200	0.0500	mg/L	TRUE			50.00	92.3		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Calcium	47.6	0.0040	0.0200	mg/L	TRUE			50.00	95.2		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Iron	49.2	0.0040	0.0200	mg/L	TRUE			50.00	98.5		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Magnesium	47.4	0.0040	0.0200	mg/L	TRUE			50.00	94.8		120	80		
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Potassium	47.3	0.0200	0.0500	mg/L	TRUE			50.00	94.5		120	80		B
ERDC-EL-EP-C	B22L053-BS2	LCS	Water	EPA 6010	Sodium	46.9	0.0200	0.0500	mg/L	TRUE			50.00	93.8		120	80		
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Calcium	0.638	0.0400	0.200	mg/L	TRUE	22I2104-01	0.666			4.27			20	
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Iron	41.8	0.0400	0.200	mg/L	TRUE	22I2104-01	41.2			1.41			20	
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Magnesium	4.75	0.0400	0.200	mg/L	TRUE	22I2104-01	4.80			0.966			20	
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Potassium	1.99	0.200	0.500	mg/L	TRUE	22I2104-01	5.26			90.3			20	RPD-06, B
ERDC-EL-EP-C	B22L053-DUP1	Duplicate	Water	EPA 6010	Sodium	0.611	0.200	0.500	mg/L	TRUE	22I2104-01	3.68			143			20	RPD-06
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Calcium	0.0760	0.0400	0.200	mg/L	TRUE	22I2104-34	0.104			30.9			20	RPD-01, J
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Iron	ND	0.0400	0.200	mg/L	TRUE	22I2104-34	ND						20	U
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Magnesium	0.0486	0.0400	0.200	mg/L	TRUE	22I2104-34	ND						20	J
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Potassium	ND	0.200	0.500	mg/L	TRUE	22I2104-34	ND						20	U
ERDC-EL-EP-C	B22L053-DUP2	Duplicate	Water	EPA 6010	Sodium	ND	0.200	0.500	mg/L	TRUE	22I2104-34	ND						20	U
ERDC-EL-EP-C	B22L053-MS1	Matrix Spike	Water	EPA 6010	Calcium	898	0.0400	0.200	mg/L	TRUE	22I2104-01	0.666	1000	89.7		120	80		
ERDC-EL-EP-C	B22L053-MS1	Matrix Spike	Water	EPA 6010	Iron	947	0.0400	0.200	mg/L	TRUE	22I2104-01	41.2	1000	90.5		120	80		
ERDC-EL-EP-C	B22L053-MS1	Matrix Spike	Water	EPA 6010	Magnesium	915	0.0400	0.200	mg/L	TRUE	22I2104-01	4.80	1000	91.1		120	80		
ERDC-EL-EP-C	B22L053-MS1	Matrix Spike	Water	EPA 6010	Potassium	883	0.200	0.500	mg/L	TRUE	22I2104-01	5.26	1000	87.8		120	80		B
ERDC-EL-EP-C	B22L053-MS1	Matrix Spike	Water	EPA 6010	Sodium	910	0.200	0.500	mg/L	TRUE	22I2104-01	3.68	1000	90.6		120	80		
ERDC-EL-EP-C	B22L053-MS2	Matrix Spike	Water	EPA 6010	Calcium	474	0.0400	0.200	mg/L	TRUE	22I2104-34	0.104	500.0	94.7		120	80		
ERDC-EL-EP-C	B22L053-MS2	Matrix Spike	Water	EPA 6010	Iron	489	0.0400	0.200	mg/L	TRUE	22I2104-34	ND	500.0	97.8		120	80		
ERDC-EL-EP-C	B22L053-MS2	Matrix Spike	Water	EPA 6010	Magnesium	473	0.0400	0.200	mg/L	TRUE	22I2104-34	ND	500.0	94.6		120	80		
ERDC-EL-EP-C	B22L053-MS2	Matrix Spike	Water	EPA 6010	Potassium	468	0.200	0.500	mg/L	TRUE	22I2104-34	ND	500.0	93.5		120	80		B
ERDC-EL-EP-C	B22L053-MS2	Matrix Spike	Water	EPA 6010	Sodium	460	0.200	0.500	mg/L	TRUE	22I2104-34	ND	500.0	91.9		120	80		

U = not detected, B = metal analyte detected in both the run blank and the sample, J = estimated concentration  
 MB-02 = analyte contamination is caused by memory inferences  
 RPD -01 = RPD not evaluated because sample concentration is under reporting limit, RPD-06 = RPD values between duplicate samples or spikes over acceptance limit