

Reconnaissance Soil Geochemistry at the Riverton Uranium Mill Tailings Remedial Action Site, Fremont County, Wyoming

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Reconnaissance Soil Geochemistry at the Riverton Uranium Mill Tailings Remedial Action Site, Fremont County, Wyoming

By David B. Smith and Michael J. Sweat

Abstract

Soil samples were collected and chemically analyzed from the Riverton Uranium Mill Tailings Remedial Action Site, which lies within the Wind River Indian Reservation in Fremont County, Wyoming. Nineteen soil samples from a depth of 0 to 5 centimeters were collected in August 2011 from the site. The samples were sieved to less than 2 millimeters and analyzed for 44 major and trace elements following a near-total multi-acid extraction. Soil pH was also determined. The geochemical data were compared to a background dataset consisting of 160 soil samples previously collected from the same depth throughout the State of Wyoming as part of another ongoing study by the U.S. Geological Survey. Risk from potentially toxic elements in soil from the site to biologic receptors and humans was estimated by comparing the concentration of these elements with soil screening values established by the U.S. Environmental Protection Agency. All 19 samples exceeded the carcinogenic human health screening level for arsenic in residential soils of 0.39 milligrams per kilogram (mg/kg), which represents a one-inone-million cancer risk (median arsenic concentration in the study area is 2.7 mg/kg). All 19 samples also exceeded the lead and vanadium screening levels for birds. Eighteen of the 19 samples exceeded the manganese screening level for plants, 13 of the 19 samples exceeded the antimony screening level for mammals, and 10 of 19 samples exceeded the zinc screening level for birds. However, these exceedances are also found in soils at most locations in the Wyoming Statewide soil database, and elevated concentrations alone are not necessarily cause for alarm. Uranium and thorium, two other elements of environmental concern, are elevated in soils at the site as compared to the Wyoming dataset, but no human or ecological soil screening levels have been established for these elements.

Introduction

The effects of soil composition on human and ecological health is well documented (see, for example, Anastasia and Kender, 1973; Rehab and Wallace, 1978; Kaplan and others, 1990; Ainsworth and others, 1991; Angle and Chaney, 1991; Lamersdorf and others, 1991; Jiang and Singh, 1994; Spurgeon and others, 1994; Lehoczky and others, 1996; Oliver, 1997; Abrahams, 2002; Plumlee and Ziegler, 2003; Pierzynski and others, 2005). Soil can be a pathway for potentially toxic elements of natural or anthropogenic origin to enter the human or animal body through ingestion, inhalation, or dermal absorption and to enter plants by absorption through root tissues. Low concentrations of nutrients or elevated concentrations of toxic elements in soil may control the vegetation species that can grow in the soil (Gough and others, 1989; Oze and others, 2004).

On August 11, 2011, 19 soil samples were collected from the Riverton Uranium Mill Tailings Remedial Action (UMTRA) Site about 4 kilometers southwest of Riverton, Wyoming (fig. 1). The Riverton UMTRA Site is located on the Wind River Indian Reservation (Eastern Shoshone and Northern Arapahoe Tribes) and covers an area of approximately 10.4 square kilometers. The land is currently owned by Chemtrade Refinery Services (U.S. Department of Energy, 2011). The mill was constructed in 1958 and closed in 1963. During this period of operation, the mill processed approximately 800,000 metric tons of uranium and vanadium ore (U.S. Department of Energy, 1995, 2011). Solid waste material was transferred to a tailings pile covering about 29 hectares. Between 1988 and 1990, the mill tailings and contaminated soils were removed from the site. However, the Eastern Shoshone and Northern Arapahoe Tribes continue to have concerns about groundwater and soil contamination at the site.

The purpose of this investigation was to determine the geochemical variation for 44 chemical elements in soils of the UMTRA site and to compare these soil concentrations with available ecological and human health soil screening levels established by the U.S. Environmental Protection Agency. To put the concentrations observed at the UMTRA site into a more regional context, the site-specific geochemical variation was compared to the variation observed for the entire State of Wyoming as determined from samples collected at 160 sites throughout the State in 2008 as part of the North American Soil Geochemical Landscapes Project (Smith and others, 2011, 2012).



Figure 1. Location of 19 soil samples collected from the Riverton Uranium Mill Tailings Remedial Action Site, Fremont County, Wyoming.

Sample Collection

Nineteen samples were collected from sites selected to provide relatively even coverage throughout the UMTRA site. The site was mapped using land-ownership coverages in ArcGIS, and the Chemtrade property (former mill-tailings site) was excluded to determine the surface area available for sampling. A pixilated randomized selection process was then run to determine sampling locations. Land ownership was determined for five sites in each pixel and access requested for the first site in each pixel. If access was denied or not available (not able to contact owner), then the next site owner was contacted. This process continued until access was obtained or until all sites for a pixel were exhausted. For this sampling effort, access was obtained from the first or second property owner in all cases.

At each site, a sample was collected from a depth of 0–5 centimeters (cm). This particular sample medium was selected because this near-surface material is the part of the soil with which humans and most animals come into contact most often. Geochemical information for this layer is critical for evaluation of a soil pathway through which potentially toxic elements may enter the bodies of both humans and animals. It also is considered to be the portion of the soil most likely to indicate the influence of uranium milling at the site.

Sample Preparation and Analytical Methods

Samples were air dried at ambient temperature, disaggregated, and sieved through a 2millimeter (mm) stainless steel screen. Material less than 2 mm in size was crushed to less than 150 micrometers (μ m) in a ceramic mill and thoroughly mixed to ensure homogeneity. Prepared samples were sent to a U.S. Geological Survey (USGS) contract geochemical laboratory for major and trace element analysis.

Concentrations of the elements aluminum (Al), calcium (Ca), iron (Fe), potassium (K), magnesium (Mg), sodium (Na), sulfur (S), titanium (Ti), silver (Ag), barium (Ba), beryllium (Be), bismuth (Bi), cadmium (Cd), cerium (Ce), cobalt (Co), chromium (Cr), cesium (Cs), copper (Cu), gallium (Ga), indium (In), lanthanum (La), lithium (Li), manganese (Mn), molybdenum (Mo), niobium (Nb), nickel (Ni), phosphorus (P), lead (Pb), rubidium (Rb), antimony (Sb), scandium (Sc), tin (Sn), strontium (Sr), tellurium (Te), thorium (Th), thallium (Tl), uranium (U), vanadium (V), tungsten (W), yttrium (Y), and zinc (Zn) were determined by inductively coupled plasma–atomic emission spectrometry (ICP–AES) by a method similar to Briggs (2002) and inductively coupled plasma–mass spectrometry (ICP–MS) by a method similar to Briggs and Meier (2002). A sample of 0.25 grams (g) was decomposed using a mixture of hydrochloric, nitric, perchloric, and hydrofluoric acids at a temperature between 125 and 150 degrees Celsius (°C).

The four-acid digestion results in an effectively total dissolution of most mineral constituents in soil. However, it does not fully dissolve some of the more refractory or resistant minerals. Examples of such incomplete dissolution include Ba in barite, Cr in chromite, Ti in rutile, Sn in cassiterite, Al in corundum, and rare earth elements in monazite (Briggs, 2002). An aliquot of the digested sample was aspirated into the ICP–AES instrument and the ICP–MS instrument and the concentrations of the optimal elements were determined. The ICP–AES method is best for the major elements, sulfur, and elements with relatively high concentrations not requiring a low detection limit. The ICP–MS method is optimal for trace elements requiring lower limits of determination near or below their crustal abundance and elements not determined by ICP–AES. The lower limits of determination (LLD) are listed in table 1.

Table 1. Elements determined by ICP-MS and ICP-AES.

[LLD, lower limit of determination; ICP-MS, inductively coupled plasma-mass spectrometry; ICP-AES,	
inductively coupled plasma-atomic emission spectrometry; %, percent; mg/kg, milligrams per kilogram]	

Element	Analytical method	LLD
Aluminum	ICP-AES	0.01%
Calcium	ICP-AES	0.01%
Iron	ICP-AES	0.01%
Potassium	ICP-AES	0.01%
Magnesium	ICP-AES	0.01%
Sodium	ICP-AES	0.01%
Phosphorus	ICP-AES	50 mg/kg
Titanium	ICP-AES	0.01%
Silver	ICP-MS	1 mg/kg
Barium	ICP-AES	5 mg/kg
Beryllium	ICP-MS	0.1 mg/kg
Bismuth	ICP-MS	0.04 mg/kg
Cadmium	ICP-MS	0.1 mg/kg
Cerium	ICP-MS	0.05 mg/kg
Cobalt	ICP-MS	0.1 mg/kg
Chromium	ICP-AES	1 mg/kg
Cesium	ICP-MS	5 mg/kg
Copper	ICP-AES	0.5 mg/kg
Gallium	ICP-MS	0.05 mg/kg
Indium	ICP-MS	0.02 mg/kg
Lanthanum	ICP-MS	0.5 mg/kg
Lithium	ICP-AES	1 mg/kg
Manganese	ICP-AES	5 mg/kg
Molybdenum	ICP-MS	0.05 mg/kg
Niobium	ICP-MS	0.1 mg/kg
Nickel	ICP-AES	0.5 mg/kg
Lead	ICP-MS	0.5 mg/kg
Rubidium	ICP-MS	0.2 mg/kg
Sulfur	ICP-AES	0.01%
Antimony	ICP-MS	0.05 mg/kg
Scandium	ICP-MS	0.1 mg/kg
Tin	ICP-MS	0.1 mg/kg
Strontium	ICP-AES	0.5 mg/kg
Tellurium	ICP-MS	0.1 mg/kg
Thallium	ICP-MS	0.1 mg/kg
Thorium	ICP-MS	0.2 mg/kg
Uranium	ICP-MS	0.1 mg/kg
Vanadium	ICP-AES	1 mg/kg
Tungsten	ICP-MS	0.1 mg/kg
Yttrium	ICP-MS	0.1 mg/kg
Zinc	ICP-AES	1 mg/kg

Mercury (Hg) was determined by treating 0.1 g of sample with a mixture of nitric and hydrochloric acids and heating at 110 °C for 30 minutes. Once cooled, solutions of sulfuric acid, potassium permanganate, and potassium persulfate were added followed by sodium chloride-hydroxylamine sulfate. The final solution was reduced by stannous chloride and analyzed by atomic absorption spectrometry (AAS). This method is a modification of that published by the U.S. Environmental Protection Agency (1994). The LLD is 0.02 milligrams per kilogram (mg/kg).

Selenium (Se) was determined by heating 0.25 g of sample at 175 °C with a combination of nitric, hydrofluoric and perchloric acids. After the solution was cooled, hydrochloric and nitric acids were added, then the solution was heated and cooled again. The sample was diluted and analyzed using hydride-generation AAS in a method similar to Hageman and Brown (2002). The LLD is 0.2 mg/kg. For analysis of arsenic (As), the sample was fused in a mixture of sodium peroxide and sodium hydroxide at 750 °C. The fused mixture was then dissolved in hydrochloric acid and analyzed by hydride-generation atomic absorption spectrometry in a method similar to Hageman and Brown (2002). The LLD is 0.6 mg/kg.

Splits of the material less than 2 mm in size were provided to the Colorado State University Soil, Water, and Plant Testing Laboratory for determination of soil pH on a saturated soil paste using the methods described by Richards (1954).

Quality Assurance and Quality Control

Quality assurance (QA) is mainly the concern of the analytical laboratory. The various components of the QA plan include standard operating procedures, instrument logs, training records, data acceptance and rejection criteria, and laboratory audits. Unlike the unquantifiable QA element, the quality control (QC) element measures, by an analytical method, the accuracy and precision of the data produced. The accuracy and precision are established through the analysis of reference materials (RMs) and sample replicates, respectively. The 19 samples from the Riverton UMTRA Site were processed along with thousands of soil samples collected as part of the North American Soil Geochemical Landscapes Project (Smith and others, 2011, 2012) and were subject to the same QA/QC protocols used in that project as described below.

The samples taken through the analytical process in the USGS contract laboratories received QC checks on three separate levels. The first-level QC assessment was made by the USGS contract laboratory. In the next level, quality was assessed by the USGS QC officer, followed by a third-level assessment by the USGS principal investigator for the Riverton UMTRA Site soil geochemistry study.

The USGS contract laboratory is accredited to the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) 17025 standard, which includes both QA and QC protocols. The QC is monitored by analyzing a RM with every batch of 48 samples. The RM most often used is a syenite rock standard (SY-3) developed by the Canadian Centre for Mineral and Energy Technology (Govindaraju, 1989). Shewhart Control Charts (Taylor, 1987) are generated for the RM analyses and reviewed with every report as part of the internal quality audits.

The accuracy for elements determined by ICP–MS and ICP–AES was considered acceptable if recovery was within the range of 85–115 percent at five times the LLD. The accuracy for Hg and Se was considered acceptable if recovery was within 80–120 percent at five times the LLD.

At the second tier, the USGS QC officer assessed precision and accuracy on the basis of five RMs that were inserted between every batch of 50 samples. The soil RMs used in this study were SRM 2709 and SoNE-1. SRM 2709, a soil from the San Joaquin Valley of central California, is a certified RM available from the National Institute of Standards and Technology and is used to assess both accuracy and precision (National Institute of Standards and Technology, 2003). The acceptance criteria for accuracy are the same as those used by the contract laboratory.

SoNE-1 is a USGS in-house, noncertified soil RM prepared specifically for the North American Soil Geochemical Landscapes Project. It was collected from the Sharpsburg Soil Series (Natural Resources Conservation Service, 2008) in Lancaster County, Nebraska, and is used in this study to assess only precision. The precision for elements determined by ICP–MS and ICP–AES, and for total carbon (C) and carbonate C was considered acceptable if the calculated relative standard deviation (RSD) of duplicate samples is no greater than 15 percent. The precision for Hg, As, and Se was considered acceptable if the calculated RSD of duplicate samples was no greater than 20 percent.

The USGS principal investigator for the Riverton UMTRA Site soil geochemistry study initiated the final QC tier, which included two blind SoNE-1 RMs inserted in each batch of 18 samples. In general, one RM was inserted into the first half of the batch and one RM into the second half. The acceptance criteria for accuracy and precision are those stated in the previous paragraph.

The Colorado State University Soil, Water, and Plant Testing Laboratory maintains its own rigorous QC program for soil pH determinations including periodic calibration of the pH electrode with standard solutions.

Estimation of Risk

In this report, risk to biologic receptors and humans from potentially toxic elements in soil within the Riverton UMTRA Site is estimated by comparing the concentration of these elements with soil screening values established by the U.S. Environmental Protection Agency (USEPA).

Ecological Soil Screening Levels

Ecological Soil Screening Levels (Eco-SSLs) are "concentrations of contaminants in soil that are protective of ecological receptors that commonly come into contact with and (or) consume biota that live in or on the soil" (U.S. Environmental Protection Agency, 2003). USEPA has established Eco-SSLs for many of the soil contaminants that are frequently of ecological concern for plants and animals at hazardous waste sites. These contaminants include the following 15 trace elements that occur naturally in soil: Ag, As, Ba, Be, Cd, Cr, Co, Cu, Mn, Ni, Pb, Sb, Se, V, and Zn (U.S. Environmental Protection Agency, 2006, 2005b, 2005c, 2005d, 2005e, 2008a, 2005f, 2007a, 2007b, 2007c, 2005g, 2005a, 2007d, 2005h, 2007e, respectively). Eco-SSLs have been derived separately for four groups of biological receptors: plants, soil invertebrates, birds, and mammals (table 2). Complete details on how the Eco-SSLs were derived are given in U.S. Environmental Protection Agency (2003). Eco-SSLs are considered to be protective of terrestrial ecosystems and are intended to be applied at the screening stage of an ecological risk assessment. For the current investigation, the values are used to identify those trace elements of potential concern in soils of the Riverton UMTRA Site.

As seen in table 2, Eco-SSL for Cr have been established for Cr(III) and Cr(VI). The chemical analysis performed on the Riverton UMTRA Site samples in this study resulted in total Cr concentrations and did not yield separate concentration values for the two oxidation states. For this reason, Cr will not be considered further in this report.

 Table 2.
 Ecological soil screening levels (Eco-SSLs) as established by the U.S. Environmental Protection Agency.

[Ag, silver; As, arsenic; Ba, barium; Be, beryllium; Cd, cadmium; Co, cobalt; Cr(III), trivalent chromium; Cr(VI), hexavalent chromium; Cu, copper; Mn, manganese; Ni, nickel; Pb, lead; Sb, antimony; Se, selenium; V, vanadium; Zn, zinc; NA, not available; mg/kg, milligrams per kilogram]

Flomont	Eco-SSL Plants (ma/ka)	Eco-SSL Soil invertebrates (mg/kg)	Eco-SSL Birds (ma/ka)	Eco-SSL Mammals (ma/ka)	
Liemeni	1 unis (mg/kg)	Sou invertebrutes (mg/kg)	Dirus (mg/kg)		
Ag"	560	NA	4.2	14	
As ^b	18	NA	43	46	
Ba ^c	NA	330	NA	2000	
Be ^d	NA	40	NA	21	
Cd ^e	32	140	0.77	0.36	
Co ^f	13	NA	120	230	
Cr(III) ^g	NA	NA	26	34	
Cr(VI) ^g	NA	NA	NA	130	
Cu^h	70	80	28	49	
Mn ⁱ	220	450	4300	4000	
Ni ^j	38	280	210	130	
Pb^k	120	1700	11	56	
\mathbf{Sb}^{1}	NA	78	NA	0.27	
Se ^m	0.52	4.1	1.2	0.63	
V^n	NA	NA	7.8	280	
Zn ^o	160	120	46	79	

^a U.S. Environmental Protection Agency (2006); ^b U.S. Environmental Protection Agency (2005b); ^c U.S. Environmental Protection Agency (2005c); ^d U.S. Environmental Protection Agency (2005d); ^e U.S. Environmental Protection Agency (2005d); ^e U.S. Environmental Protection Agency (2008a); ^h U.S. Environmental Protection Agency (2007a); ⁱ U.S. Environmental Protection Agency (2007b); ^j U.S. Environmental Protection Agency (2007c); ^k U.S. Environmental Protection Agency (2005g); ¹ U.S. Environmental Protection Agency (2007c); ^k U.S. Environmental Protection Agency (2005g); ¹ U.S. Environmental Protection Agency (2005a); ^m U.S. Environmental Protection Agency (2007c); ^k U.S. Environmental Protection Agency (2007d); ⁿ U.S. Environmental Protection Agency (2005a); ^m U.S. Environmental Protection Agency (2007d); ⁿ U.S. Environmental Protection Agency (2005b); ^o U.S. Environmental Protection Agency (2007c); ^k U.S. Environmental Protection Agency (2007d); ⁿ U.S. Environmental Protection Agency (2005b); ^o U.S. Environmental Protection Agency (2007c); ^k U.S. Environmental Protection Agency (2007d); ⁿ U.S. Environmental Protection Agency (2007d); ⁿ U.S. Environmental Protection Agency (2007d); ⁿ U.S. Environmental Protection Agency (2007b); ^o U.S. Environmental Protection Agency (2007c); ^k U.S. Environmental Protection Agency (2007b); ^o U.S. Environmental Protection Agency (2007c); ^k U.S. Environmental Protection Agency (2007c

Human Health Soil Screening Levels

EPA has developed regional screening levels based on human health risk for both residential and industrial soils (U.S. Environmental Protection Agency, 2011) as shown in tables 3 and 4, respectively. A detailed discussion of the human health soil screening level concept is found in U.S. Environmental Protection Agency (1991; 1996a, b; 2002; 2008b). For some elements, two screening levels have been established, each of which corresponds to fixed levels of risk. One of the screening levels represents a one-in-one million (10^{-6}) cancer risk

(carcinogenic screening level), and the other represents a noncarcinogenic hazard quotient (HQ) of 1. The HQ is defined as the estimated (maximum) concentration of a specific toxic element divided by a screening benchmark regarded as a threshold of toxicity (generally a No-Adverse Effects Level) (U.S. Environmental Protection Agency, 2008b). If the HQ is greater than 1, then harmful effects are likely due to the element in question. If the HQ is less than 1, then harmful effects are not likely. Generally for residential soils, if a substance causes both carcinogenic and noncarcinogenic effects, the 10^{-6} carcinogenic risk will result in a more stringent screening level.

 Table 3.
 Human health soil screening levels for industrial soils (U.S. Environmental Protection Agency, 2011).

[Ag, silver; As, arsenic; Ba, barium; Be, beryllium; Cd, cadmium; Co, cobalt; Cu, copper; Mn, manganese; Ni, nickel; Pb, lead; Sb, antimony; Se, selenium; U, uranium; V, vanadium; Zn, zinc; mg/kg, milligrams per kilogram; NA, not available]

Element	Human health screening level carcinogenic (mg/kg)	Human health screening level noncarcinogenic (mg/kg)
Ag	NA	390
As	0.39	22
Ba	NA	15,000
Be	1,400	160
Cd	1,800	70
Co	370	23
Cu	NA	3,100
Mn	NA	1,800
Ni	1,300	1,500
Pb	NA	400
Sb	NA	31
Se	NA	390
U	NA	230
V	NA	390
Zn	NA	23,000

Estimation of Background

For most investigations of soil geochemistry at potentially hazardous sites, an estimation of the background concentrations of elements in soil is made by collecting a very limited number of samples outside the boundaries of the site. Given that true geochemical background for a given element is not just one concentration value but rather a distribution of concentration values (Matschullat and others, 2000; Reimann and Filzmoser, 2000; Reimann and Garrett, 2005; Reimann and others, 2005); this approach is considered by the authors to be wholly inadequate. For this investigation, a dataset of 160 samples of soils from depths of 0 to 5 cm collected throughout the entire State of Wyoming by the North American Soil Geochemical Landscapes Project (Smith and others, 2011, 2012) was used to determine the regional-scale geochemical background variation to provide context within which to consider the data from the Riverton UMTRA Site.

Results

Table 5 presents a statistical summary for 41 elements in 0- to 5-cm soils from the Riverton UMTRA Site. The elements Ag, Cs, and Te are not included in this table because most concentration values are below the LLD. A complete listing of the geochemical data (44 elements and soil pH) is shown in appendix 1. Box-and-whisker plots allow a visual representation of the data distribution for each of the elements showing at least one exceedance of the Eco-SSLs or the human health soil screening levels (fig. 2). Figure 2 also provides a comparison of the UMTRA data with the 160-sample Statewide dataset. Given the history of uranium milling at the site, U and Th are elements of potential environmental concern, and their box-and-whisker plots are shown in figure 3. There are no established EcoSSLs for either element. The noncarcinogenic human health screening level (residential soils) for U is 230 mg/kg and for industrial soils is 3,100 mg/kg, both far exceeding any concentrations found at the Riverton UMTRA Site.

 Table 4.
 Human health soil screening levels for industrial soils (U.S. Environmental Protection Agency, 2011).

Element	Human health screening level carcinogenic (mg/kg)	Human health screening level noncarcinogenic (mg/kg)
Ag	NA	5,100
As	1.6	260
Ba	NA	190,000
Be	6,900	2,000
Cd	9,300	800
Co	1,900	300
Cu	NA	41,000
Mn	NA	23,000
Ni	64,000	20,000
Pb	NA	800
Sb	NA	410
Se	NA	5,100
U	NA	3,100
V	NA	5,200
Zn	NA	310,000

[Ag, silver; As, arsenic; Ba, barium; Be, beryllium; Cd, cadmium; Co, cobalt; Cu, copper; Mn, manganese; Ni, nickel; Pb, lead; Sb, antimony; Se, selenium; U, uranium; V, vanadium; Zn, zinc; mg/kg, milligrams per kilogram; NA, not available]

Table 5. Statistical summary for 41 elements in 0–5 cm soils from the Riverton UMTRA Site.

[Al, aluminum; Ca, calcium; Fe, iron; K, potassium; Mg, magnesium; Na, sodium; S, sulfur; Ti, titanium; As, arsenic; Ba, barium; Be, beryllium; Bi, bismuth; Cd, cadmium; Ce, cerium; Co, cobalt; Cr, chromium; Cu, copper; Ga, gallium; Hg, mercury; In, indium; La, lanthanum; Li, lithium; Mn, manganese; Mo, molybdenum; Nb, niobium; Ni, nickel; P, phosphorus; Pb, lead; Rb, rubidium; Sb, antimony; Sc, scandium; Se, selenium; Sn, tin; Sr, strontium; Th, thorium; Tl, thallium; U, uranium; V, vanadium; W, tungsten; Y, yttrium; and Zn, zinc; n = 19; UMTRA, Uranium Mill Tailings Remedial Action; MAD, median absolute deviation; %, percent; mg/kg, milligrams per kilogram; <, less than]

Element	Units	Minimum	Median	Maximum	MAD
Al	%	3.57	5.73	10.0	0.62
Ca	%	1.30	2.15	7.39	0.89
Fe	%	0.72	1.95	3.36	0.22
Κ	%	1.36	1.97	3.54	0.21
Mg	%	0.22	0.98	1.88	0.25
Na	%	0.84	1.51	2.65	0.24
S	%	0.01	0.03	0.3	0.01
Ti	%	0.07	0.21	0.36	0.03
As	mg/kg	1.5	2.7	7.3	1.2
Ba	mg/kg	551	870	1,780	208
Be	mg/kg	0.8	1.2	2.2	0.1
Bi	mg/kg	0.05	0.12	0.23	0.03
Cd	mg/kg	<0.1 ^a	0.2	0.3	0.1
Ce	mg/kg	30	67.8	136	20.2
Co	mg/kg	2.5	7.8	14.7	1.3
Cr	mg/kg	7	50	104	9
Cu	mg/kg	4.1	10.6	20.3	2.1
Ga	mg/kg	9.01	13.5	25.2	1.5
Hg	mg/kg	0.01	0.01	0.06	0.00
In	mg/kg	<0.02 ^b	0.03	0.04	0.00
La	mg/kg	16	38.4	77.2	11.9
Li	mg/kg	7	15	29	4
Mn	mg/kg	208	410	1,410	71
Мо	mg/kg	0.21	0.56	3.36	0.15
Nb	mg/kg	3	7	11.9	0.7
Ni	mg/kg	4.7	21.2	40.3	3.0
Р	mg/kg	320	750	1,350	148
Pb	mg/kg	12.5	22.3	35.7	5.5
Rb	mg/kg	48.3	63.2	111	9.8
Sb	mg/kg	0.14	0.32	0.59	0.09

Table 5. Statistical summary for 41 elements in 0–5 cm soils from the Riverton UMTRA Site.—Continued

[Al, aluminum; Ca, calcium; Fe, iron; K, potassium; Mg, magnesium; Na, sodium; S, sulfur; Ti, titanium; As, arsenic; Ba, barium; Be, beryllium; Bi, bismuth; Cd, cadmium; Ce, cerium; Co, cobalt; Cr, chromium; Cu, copper; Ga, gallium; Hg, mercury; In, indium; La, lanthanum; Li, lithium; Mn, manganese; Mo, molybdenum; Nb, niobium; Ni, nickel; P, phosphorus; Pb, lead; Rb, rubidium; Sb, antimony; Sc, scandium; Se, selenium; Sn, tin; Sr, strontium; Th, thorium; Tl, thallium; U, uranium; V, vanadium; W, tungsten; Y, yttrium; and Zn, zinc; n = 19; UMTRA, Uranium Mill Tailings Remedial Action; MAD, median absolute deviation; %, percent; mg/kg, milligrams per kilogram; <, less than]

Element	Units	Minimum	Median	Maximum	MAD
Sc	mg/kg	2	6.1	10.8	0.6
Se	mg/kg	<0.2 ^c	0.2	2.5	0.1
Sn	mg/kg	0.9	1	2	0.1
Sr	mg/kg	216	332	647	105
Th	mg/kg	4.6	15.3	31.9	6.8
Tl	mg/kg	0.3	0.4	0.6	0
U	mg/kg	1.2	2.6	11.3	0.6
V	mg/kg	16	49	82	6
W	mg/kg	0.1	0.6	0.9	0.1
Y	mg/kg	7	12.6	21.4	1.2
Zn	mg/kg	16	47	74	6

^a One sample had a Cd concentration of <0.1 mg/kg. This value was replaced by 0.05 mg/kg for calculation of the MAD.

^b One sample had an In concentration of <0.02 mg/kg. This value was replaced by 0.01 mg/kg for calculation of the MAD.

^c Eight samples had Se concentrations of <0.2 mg/kg. These values were replaced by 0.1 mg/kg for calculation of the MAD.

Figure 2 (following six pages). Box-and-whisker plots showing the variation of (*A*) As (arsenic), (*B*) Ba (barium), (*C*) Cd (cadmium), (D) Co (cobalt), (*E*) Cu (copper), (F) Mn (manganese), (*G*) Ni (nickel), (H) Pb (lead), (I) Sb (antimony), (J) Se (selenium), (K) V (vanadium), and (L) Zn (zinc) in soils from the Riverton Uranium Mill Tailings Remedial Action (UMTRA) Site, Fremont County, Wyoming, and in soils from the 160-sample Statewide dataset. The outer limits of the lower and upper whiskers on the plots represent the 10th and 90th percentiles, respectively. The "X" between the two box-and-whisker plots in each figure represents the median for six soil samples from the Wyoming Statewide dataset that are located within the Wind River drainage. Eco-SSL, ecological soil screening level; mg/kg, milligrams per kilogram.

















Figure 3. Box-and-whisker plots showing the variation of (*A*) U (uranium) and (*B*) Th (thorium) in soils from the Riverton Uranium Mill Tailings Remedial Action (UMTRA) Site, Fremont County, Wyoming, and in soils from the 160-sample Statewide dataset. The outer limits of the lower and upper whiskers on the plots represent the 10th and 90th percentiles, respectively. The "X" between the two box-and-whisker plots in each figure represents the median for six soil samples from the Wyoming Statewide dataset that are located within the Wind River drainage. mg/kg, milligrams per kilogram.

Discussion

Within the UMTRA site, all 19 samples exceed (1) the carcinogenic human health screening level for As in residential soils (0.39 mg/kg) and (2) the Pb and V Eco-SSLs (ecological soil screening level) for birds (11 and 7.8 mg/kg, respectively). Eighteen of the 19 samples exceed the Mn Eco-SSL for plants (220 mg/kg), 13 of the 19 samples exceed the Sb Eco-SSL for mammals (0.27 mg/kg), and 10 of 19 samples exceed the Zn Eco-SSL for birds (46 mg/kg). However, to provide perspective, these exceedances are found in soils at most locations in the 160-sample Wyoming Statewide soil database. Therefore, elevated concentrations alone are not necessarily cause for alarm.

Elements of most environmental concern to the tribes are U, V, Ni, Zn, and Th. Elements Ni, Zn, U, and Th are enriched in soils at the site compared to the Wyoming Statewide soil database (figures 2G, 2L, 3A, and 3B, respectively). The former mill site processed both U and V (U.S. Department of Energy, 2011), so it might be expected that both elements would be enriched at the site with respect to the Wyoming Statewide soils dataset; however V is depleted compared to the Wyoming soil dataset (fig. 2K).

Of interest to the tribes is how these elements in the soils are transported and incorporated into vegetation, biota, and water. The principal surface uses are growing hay, grazing, and subsistence gardening. The Little Wind River runs along the south institutional-control boundary of the UMTRA site and is used for recreation and subsistence purposes. Previous investigations by the Wind River Environmental Quality Commission have found U concentrations in sediments of an oxbow lake as high as 9.23 mg/kg (Shakespeare and Goggles, 2010), similar to the highest soil concentrations found in this study. Concentrations of As, Ni, and V in oxbow lake sediments also were similar to soil concentrations found in this study. This could imply that either eolian transport and (or) surface runoff are the principal transport mechanisms for moving soils toward the Little Wind River. If the former is a principal transport mechanism, then long-term exposure to dust and airborne particulates possibly could present human health concerns.

Perhaps of greater interest to the tribes is the subsurface mobilization and transport of these elements through groundwater. A recently completed retrospective analysis of groundwater quality at the UMTRA site (Anthony Ranalli, written commun.) indicates that subsurface mobilization is not a primary consideration in groundwater, although these elements are present in groundwater at detectable concentrations.

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