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Assessment of Nonpoint Source Chemical Loading Potential to Watersheds Containing Uranium Waste Dumps Associated with Uranium Exploration and Mining, San Rafael Swell, Utah

Prepared in cooperation with the Bureau of Land Management

Scientific Investigations Report 2008–5110

U.S. Department of the Interior
U.S. Geological Survey

Cover photo: Looking out of an abandoned uranium mine near Tomsich Butte along Muddy Creek approximately 30 miles northwest of Hanksville, Utah. Source: Brent Jorgensen, USGS, 2006.

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Conversion Factors, Datums, and Abbreviated Water-Quality Units

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	247.1	square mile (mi^2)
	Volume	
liter (L)	33.82	ounce, fluid (gal/min)
liter (L)	61.02	cubic inch (in^3)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32.

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Altitude, as used in this report, refers to distance above the vertical datum. Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is reported in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25°C). Concentrations of chemical constituents in water are reported either in milligrams per liter (mg/L), or micrograms per liter (µg/L).

Abbreviations and Acronyms

(Clarification or additional information given in parentheses)

AML	abandoned mine lands
GIS	geographic information system
HDPE	high density polyethylene
ICP-MS	inductively coupled plasma-mass spectrometry
ID	identification number
SCIMAP	Sensitive Catchment Integrated Mapping and Analysis Project
SED	sediment
SRS	San Rafael Swell

Organizations

BLM	Bureau of Land Management
NWQL	National Water Quality Laboratory (USGS)
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Units of measurement

C	Celsius
cm	centimeter
ft	foot (feet)
in.	inch
g	gram
L	liter
mi	mile
mi^2	square mile
mL	milliliter (10^{-3} liter)
mm	millimeter (10^{-3} meter)
µg/L	microgram per liter (10^{-6} grams per liter)

Chemical Elements

Ag	Silver
As	Arsenic
Ba	Barium
Be	Beryllium
Cd	Cadmium
Cr	Chromium
Cu	Copper
Fe	Iron
Hg	Mercury
Mn	Manganese
Mo	Molybdenum
Ni	Nickel
Pb	Lead
Sb	Antimony
Se	Selenium
U	Uranium
V	Vanadium
Zn	Zinc

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Abstract

During July and August of 2006, 117 solid-phase samples were collected from abandoned uranium waste dumps, geologic background sites, and adjacent streambeds in the San Rafael Swell, in southeastern Utah. The objective of this sampling program was to assess the nonpoint source chemical loading potential to ephemeral and perennial watersheds from uranium waste dumps on Bureau of Land Management property. Uranium waste dump samples were collected using solid-phase sampling protocols. After collection, solid-phase samples were homogenized and extracted in the laboratory using a field leaching procedure. Filtered (0.45 micron) water samples were obtained from the field leaching procedure and were analyzed for Ag, As, Ba, Be, Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se, U, V, and Zn at the Inductively Coupled Plasma-Mass Spectrometry Metals Analysis Laboratory at the University of Utah, Salt Lake City, Utah and for Hg at the U.S. Geological Survey National Water Quality Laboratory, Denver, Colorado.

For the initial ranking of chemical loading potential of suspect uranium waste dumps, leachate analyses were compared with existing aquatic life and drinking-water-quality standards and the ratio of samples that exceeded standards to the total number of samples was determined for each element having a water-quality standard for aquatic life and drinking-water.

Approximately 56 percent (48/85) of the leachate samples extracted from uranium waste dumps had one or more chemical constituents that exceeded aquatic life and drinking-water-quality standards. Most of the uranium waste dump sites with elevated trace-element concentrations in leachates were along Reds Canyon Road between Tomsich Butte and Family Butte. Twelve of the uranium waste dump sites with elevated trace-element concentrations in leachates contained three or more constituents that exceeded drinking-water-quality standards. Eighteen of the uranium waste dump sites had three or more constituents that exceeded trace-element concentrations for aquatic life water-quality standards. The proximity of the uranium waste dumps in the Tomsich Butte area near Muddy Creek, coupled with the elevated concentration of trace elements, increases the offsite impact potential to water resources. Future assessment and remediation priority of these areas may be done by using GIS-based risk-mapping techniques, such as Sensitive Catchment Integrated Mapping and Analysis Project.

Introduction

The San Rafael Swell, located in southeastern Utah in Wayne and Emery Counties, covers approximately 2,000 mi^2 of mainly Bureau of Land Management (BLM) lands and is located in the Colorado Plateau physiographic province (fig. 1). The San Rafael Swell is a large asymmetrical anticline with altitudes ranging from 4,000 to 7,000 ft above sea level. The uplift has created the steeply dipping layers of the San Rafael Reef that borders the eastern edge of the uplift with altitudes ranging from 4,000 to 6,000 ft, whereas the western boundary is less dramatic but higher in altitude (6,000 to 7,000 ft). Exposed rocks from the uplift range in age from the Permian Coconino Formation through the Jurassic Entrada Sandstone. The San Rafael River and Muddy Creek are perennial streams that flow through the San Rafael Swell, but most of the land is covered by ephemeral drainages that only contribute runoff during rainfall and snowmelt events. The San Rafael River flows to the southeast through the northern section of the San Rafael Swell, to its confluence with the Green River south of Green River, Utah. Muddy Creek flows through the southern section of the San Rafael Swell to its confluence with the Fremont River, where together they form the Dirty Devil River near Hanksville, Utah.

Climate in the San Rafael area varies with altitude. The higher altitudes (6,000 to 7,000 ft), located in the central and western sections of the San Rafael Swell, generally have mild summers and cold winters. Lower altitudes (4,000 to 5,000 ft), on the eastern side of the San Rafael Reef, are

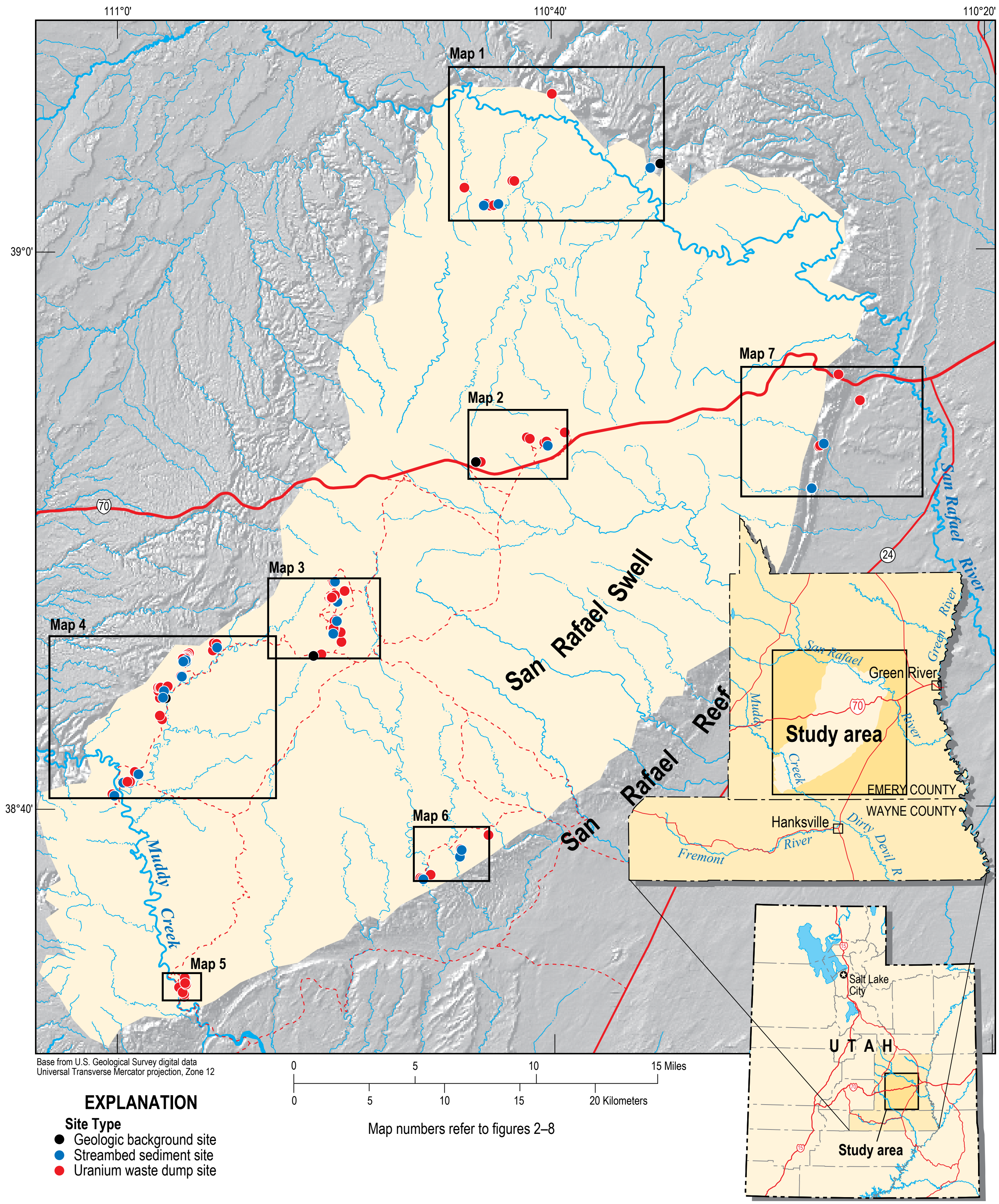


Figure 1. San Rafael Swell, Utah abandoned mine lands study area and index map showing sampled uranium waste dump, streambed sediment, and geologic background sites.

characterized by mild winters and hot summers. Most of the precipitation falls as rain from convective thunderstorms that typically occur between August and October. This arid region receives approximately 6 to 8 in. of precipitation in the lower elevations and approximately 8 to 10 in. of precipitation in the higher elevations (Natural Resources Conservation Service, 1998).

Several areas in southern Utah experienced an increase in uranium mining and exploration in the 1950s. Most of the ores were extracted from the Triassic-age Chinle Formation, which is overlain by the Moenkopi Formation which is underlain by the Permian-age Kaibab Formation. Currently, thousands of abandoned uranium waste dumps exist throughout the state of Utah, with many of the properties located on lands managed by the BLM. Approximately 190 uranium waste dump sites and adits have been inventoried by the BLM throughout the San Rafael Swell (Terry Snyder, Bureau of Land Management, written commun. 2006) (table 1). These abandoned uranium waste dumps present unique characteristics that make it difficult to quantify nonpoint source pollution contributions to specific watersheds. These characteristics include: (1) locations that are primarily in watersheds with ephemeral streams; (2) radioactive sands and fine particulates that are radioactive for hundreds of thousands of years; (3) intense rainfall and snowmelt events that can mobilize and transport mine waste with associated radioactive material and trace elements long distances during relatively short periods; and (4) remote locations that do not allow for cost effective water and suspended-sediment sampling during storm and snowmelt runoff events.

Sample collection from uranium waste dump sites during July and August of 2006 was completed by the U.S. Geological Survey (USGS) in cooperation with the BLM. The objective of this project was to assess the nonpoint source chemical loading potential from uranium waste dump sites to ephemeral and perennial watersheds and then to use this loading potential to set remediation priorities. The specific objective of this report is to present results of chemical analysis of leachates from the 85 uranium waste dump, 8 geologic background and 24 streambed soil samples collected from BLM properties within the San Rafael Swell study area (fig. 1). Initial ranking of the chemical loading potential of each sample was done by comparing the leachate composition with existing U.S. Environmental Protection Agency (USEPA) water-quality standards.

Methodology

Solid-Phase Sample Collection

One hundred seventeen samples (85 uranium waste dump sites, 24 streambed sites, and 8 geologic background sites) were collected in July and August 2006 using a modified version of the solid-phase sampling methods outlined in Smith and others (2000) and Hageman and Briggs (2000). The general locations of uranium waste dump, geologic background, and streambed sites that were sampled are shown on figure 1, and more detailed maps of the sampled sites are shown in figures 2, 3, 4, 5, 6, 7, and 8. Because of the steep nature of the uranium waste dumps, sampling generally took place from the safest and most accessible location. A few of the BLM inventoried sites that were unsafe to access were not sampled. Geologic background samples were collected in the same geologic layer adjacent to sampled uranium waste dump sites. Approximately one geologic background sample was collected for every 10 uranium waste dump samples. Streambed samples were collected from ephemeral stream channels downstream from sampled uranium waste dump sites.

Samples from uranium waste dump and geologic background sites consisted of 30 scoops of soil collected from up to 15 cm in depth using a plastic trowel. Scoops of soil were compiled into 5-gallon plastic buckets and sealed with lids and labeled. Streambed samples were collected along ephemeral stream channels using a plastic trowel that consisted of 10 scoops from up to 15 cm in depth. Each scoop sample location was chosen at random within a 10- to 30-m channel transect in the dry stream channel below a sampled uranium waste dump site. Scoops of soil were compiled into 1-gallon plastic zip-lock bags and labeled.

Uranium waste dump sites and geologic background sites were labeled SRS (San Rafael Swell) and then numbered in sequential order from when the samples were collected. SRS sample IDs that were assigned to the abandoned uranium mines by the USGS have been paired with the site IDs assigned by the BLM and can be viewed in table 1. Streambed samples were labeled SRS-SED (San Rafael Swell-Sediment) and then numbered in the order in which they were collected relative to the other streambed samples.

All sampling equipment was thoroughly cleaned in the field between each sampling location. An all plastic multi-purpose sprayer was used to thoroughly wash all plastic trowels, collection buckets, and lids. Each item was rinsed three times with deionized water, wiped with a clean towel, and allowed to air dry before use at the next site.

Field Leachate Extraction Procedure

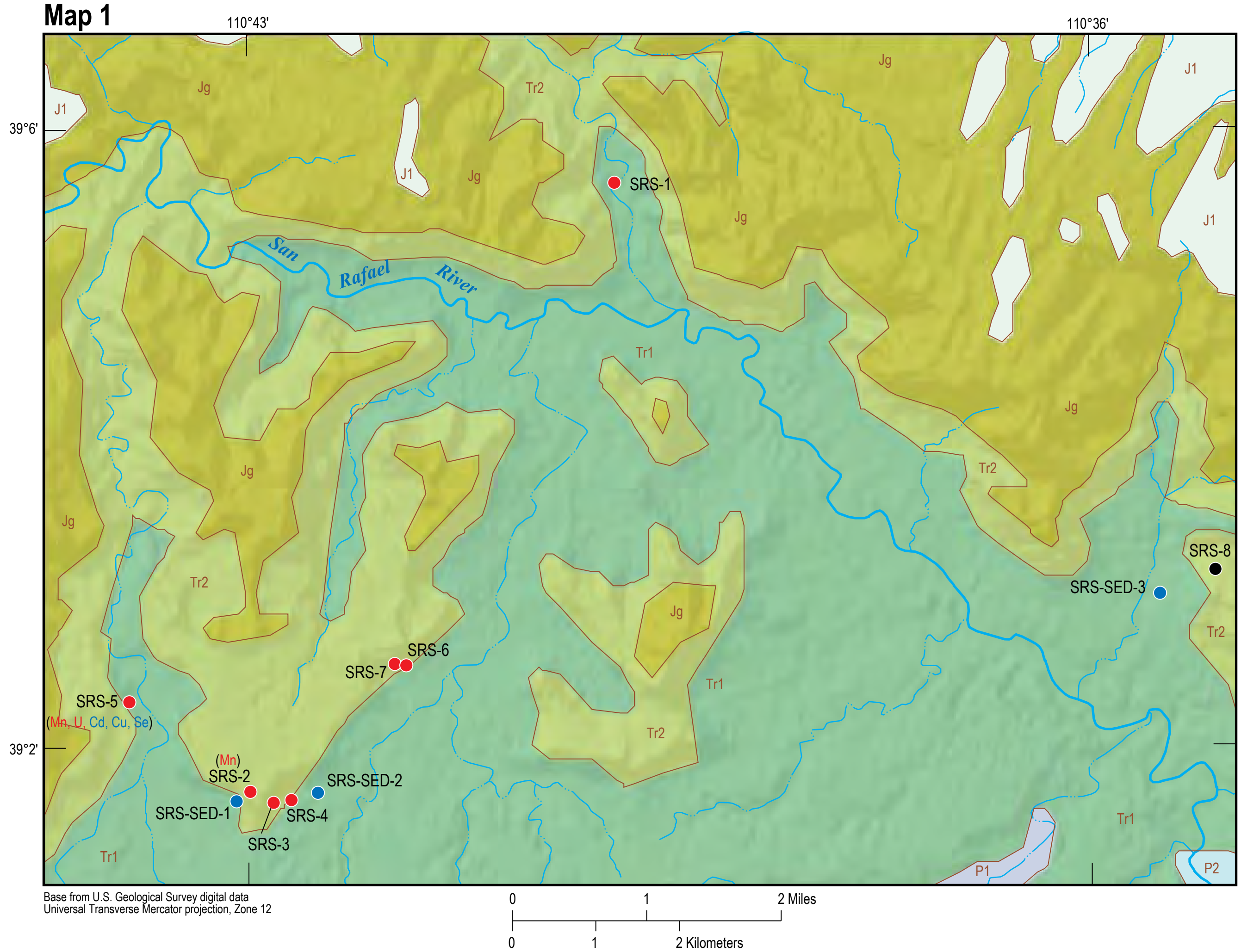
After collection of solid-phase samples, water samples were extracted in the laboratory using a field leaching procedure. Solid-phase samples were thoroughly mixed using a plastic trowel and approximately 800 g of sediment were measured out using a pan balance and transferred to a 1-L glass beaker and allowed to air dry. Extremely wet samples were placed into a 1-L glass beaker, covered with aluminum foil and placed in an oven at 200°C and allowed to dry for a minimum of 2 hours. The dried sample was then sieved through 2-mm stainless-steel mesh.

Table 1. U.S. Geological Survey site identification and associated Bureau of Land Management Tag Numbers for abandoned uranium mines, San Rafael Swell, Utah.

[USGS Site ID, U.S. Geological Survey Site Identification; BLM, Bureau of Land Management; SRS, San Rafael Swell]

USGS Site ID	BLM Tag Number	USGS Site ID	BLM Tag Number
SRS-1	4201110HO001 through 4201110HO002	SRS-48	4251118HO001
SRS-2	4211105HO001	SRS-50	40905HO007 through 40905HO008
SRS-3	4211105IO001	SRS-51	424905HO020 through 424905HO021
SRS-4	4211105HO003 through 421105HO008	SRS-52	424905HO019
SRS-5	4201131HO001 through 4201131HO002	SRS-53	424905HO018
SRS-6	4201133HO002, 4201133HO004	SRS-54	424905HO016
SRS-7	4201133HO001, 4201133HP001	SRS-55	424905HO011 through 424905HO015
SRS-9	4221123HP001	SRS-56	424905HO009
SRS-10	4221121HO002	SRS-57	4240905HO022
SRS-11	4221122HP001	SRS-58	4240905HO023
SRS-12	4221122HO002	SRS-59	4260909HP001
SRS-13	4221122HO001	SRS-60	420909HO005
SRS-17	4221407HO001	SRS-61	4260909HO007
SRS-18	4221334HO001	SRS-62	4260909HO003 through 4260909HO004
SRS-19	4221323IO001	SRS-63	4260909HO002
SRS-20	4221301HO001	SRS-65	4260908HO001
SRS-21	4221335HO001	SRS-68	4260909HO001
SRS-22	4221335IO001	SRS-69	4260916HO001
SRS-23	4251108HO001	SRS-70	4240918HO002
SRS-24	4241006HO001	SRS-71	4240918HO001
SRS-26	4231032HP001	SRS-72	4240907HO009 through 4240907HO011
SRS-27	423103HO003 through 423103HO005	SRS-75	4240907HO003 through 4240907HO005, and 4240907HP002
SRS-28	4231031HO001 through 4231031HO002	SRS-76	4240907HO008
SRS-30	4231032HO001	SRS-77	4240907HO001
SRS-31	4231030HO002 through 4231030HO003, and 4231030HP003	SRS-78	4240907HP001, 4240907HO002
SRS-32	4231030HO004	SRS-79	4230933HO002
SRS-33	4231019HP001	SRS-80	4230933HO001
SRS-35	4231019HO002	SRS-81	4230932HO003
SRS-34	4231019HO003 through 4231019HO004	SRS-83	420904HO001
SRS-36	4231019HO001	SRS-84	4240835HO001 through 4240835HO004
SRS-38	4231019HO005	SRS-85	4240835HO005 through 4240835HO009
SRS-39	4231030HP001, 4231030HO001	SRS-87	4240835IO001
SRS-40	4231020HO001	SRS-88	4240835HO001
SRS-41	4231020HO002	SRS-89	4240836HO001 through 4240836HO002
SRS-42	4231019HP010	SRS-90	4240836HO003 through 4240836HO004
SRS-43	4251024HO006, 4251024HP002	SRS-91	4240825HO007
SRS-44	4251024HO003 through 4251024HO004, and 4251024HP001	SRS-92	4240825HO006
SRS-45	4251024HO001 through 4251024HO002	SRS-93	4240825HO005
SRS-46	4251024HO007 through 4251024HO008	SRS-94	4240835HO010
SRS-47	425118HO002 through 425118HO004		

Map 1



EXPLANATION

Geologic Units

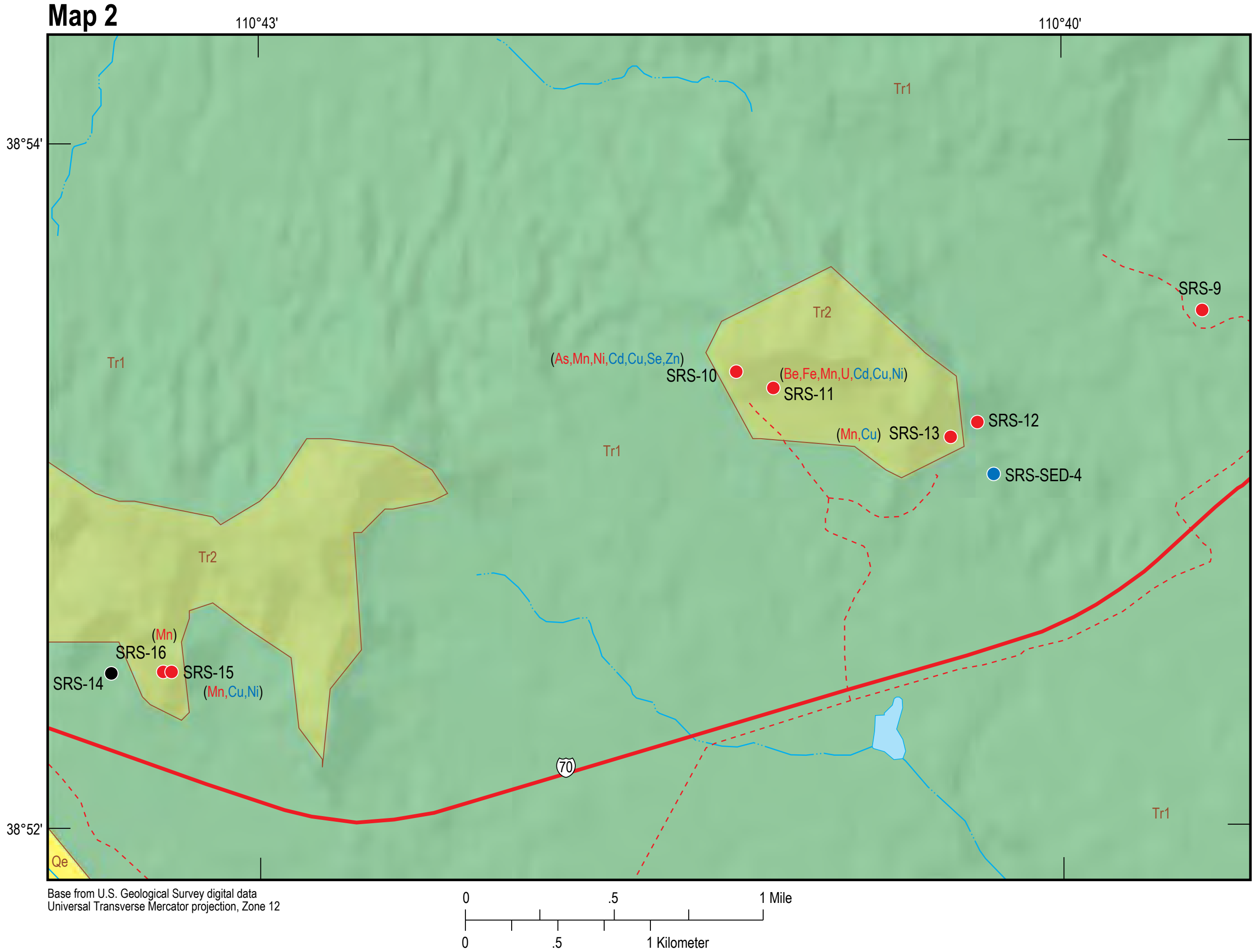
- J1 Jurassic, Bluff Sandstone, Summerville Formation, Curtis Formation, Entrada Sandstone, Carmel Formation, Arapien Shale
- Jg Jurassic, Glen Canyon Group-Navajo Sandstone, Kayenta Formation, Wingate Sandstone
- Tr2 Triassic, Chinle Shale, Shinarump Member
- Tr1 Triassic, Moenkopi Formation
- P1 Permian, White Rim Sandstone, De Chelly Sandstone, Organ Rock Shale, Cedar Mesa Sandstone, Halgaito Formation, Elephant Canyon Formation
- P2 Permian, Kaibab Limestone

Sample site

- SRS-5 Site ID, refer to table 4 for site information
- (Mn, U, Cd, Cu, Se) Constituents listing for those that exceed water-quality standards, see table 5. Red text indicates drinking-water standards, blue text indicates aquatic life standards
- ● Geologic background site
- ● Streambed sediment site
- ● Uranium waste dump site

Figure 2. Location of uranium waste dump, streambed sediment, and geologic background sites and constituents that exceeded drinking-water and aquatic life water-quality standards in Map 1 where solid-phase material was collected.

Map 2



EXPLANATION

Geologic Units

- Qe — Quaternary, surficial deposits-older alluvium and colluvium
- Tr2 — Chinle Shale, Shinarump Member
- Tr1 — Triassic, Moenkopi Formation

Sample site

- SRS-15 — Site ID, refer to table 4 for site information
- (Mn,Cu,Ni) — Constituents listing for those that exceed water-quality standards, see table 5. Red text indicates drinking-water standards, blue text indicates aquatic life standards
- ● Geologic background site
- ● Streambed sediment site
- ● Uranium waste dump site

Figure 3. Location of uranium waste dump, streambed sediment, and geologic background sites and constituents that exceeded drinking-water and aquatic life water-quality standards in Map 2 where solid-phase material was collected.

Map 3

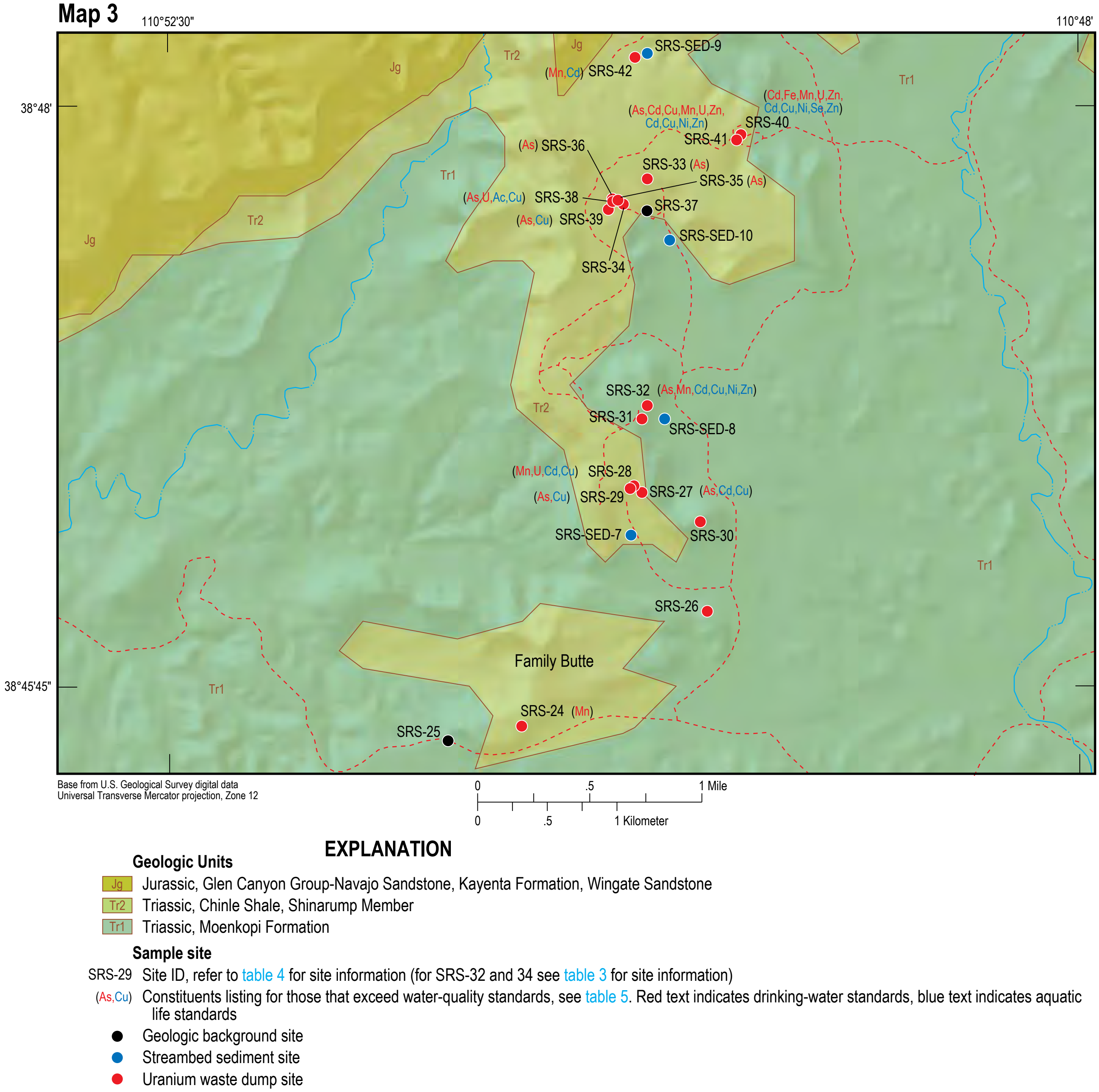


Figure 4. Location of uranium waste dump, streambed sediment, and geologic background sites and constituents that exceeded drinking-water and aquatic life water-quality standards in Map 3 where solid-phase material was collected.

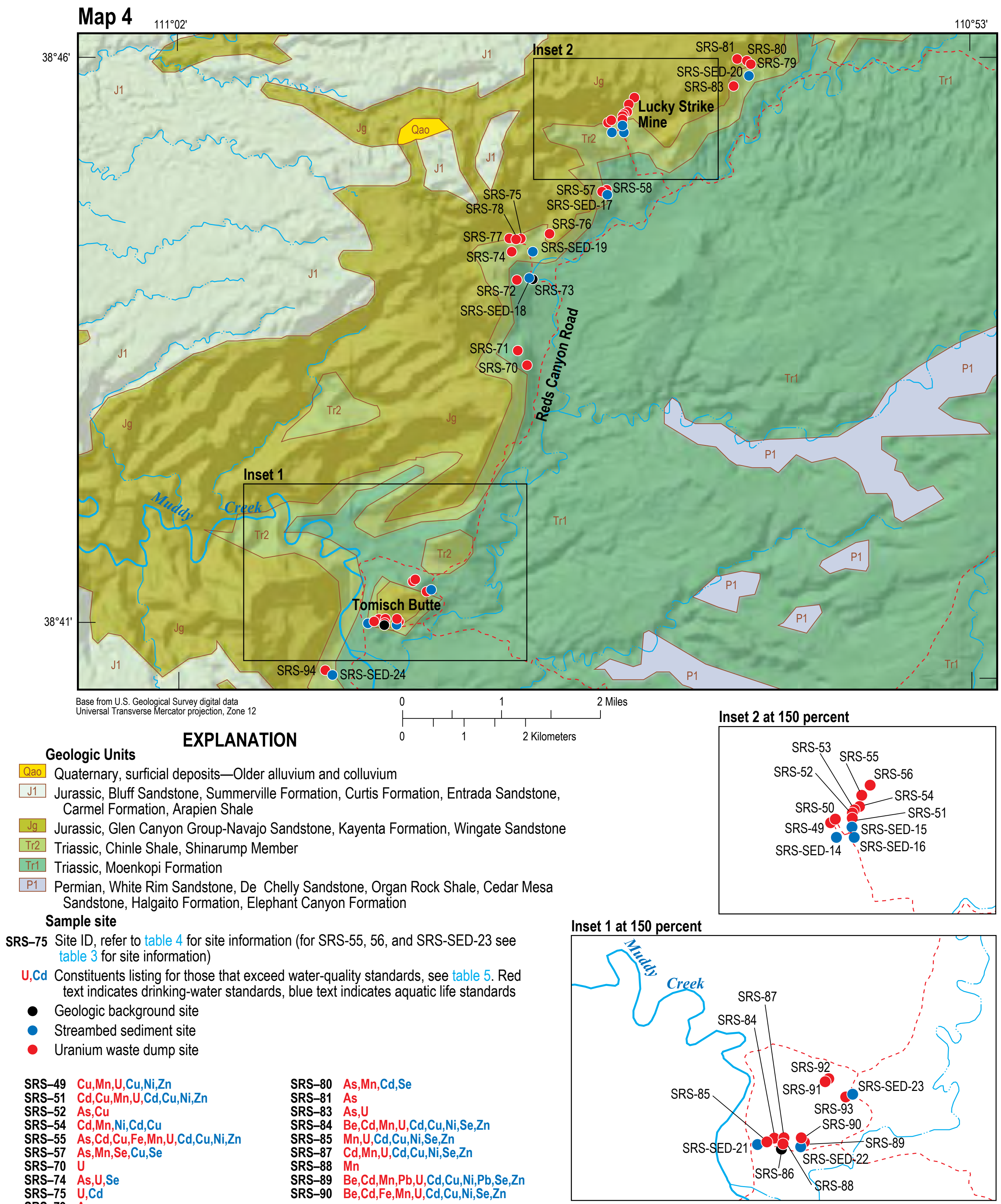


Figure 5. Location of uranium waste dump, streambed sediment, and geologic background sites and constituents that exceeded drinking-water and aquatic life water-quality standards in Map 4 where solid-phase material was collected.

Map 5

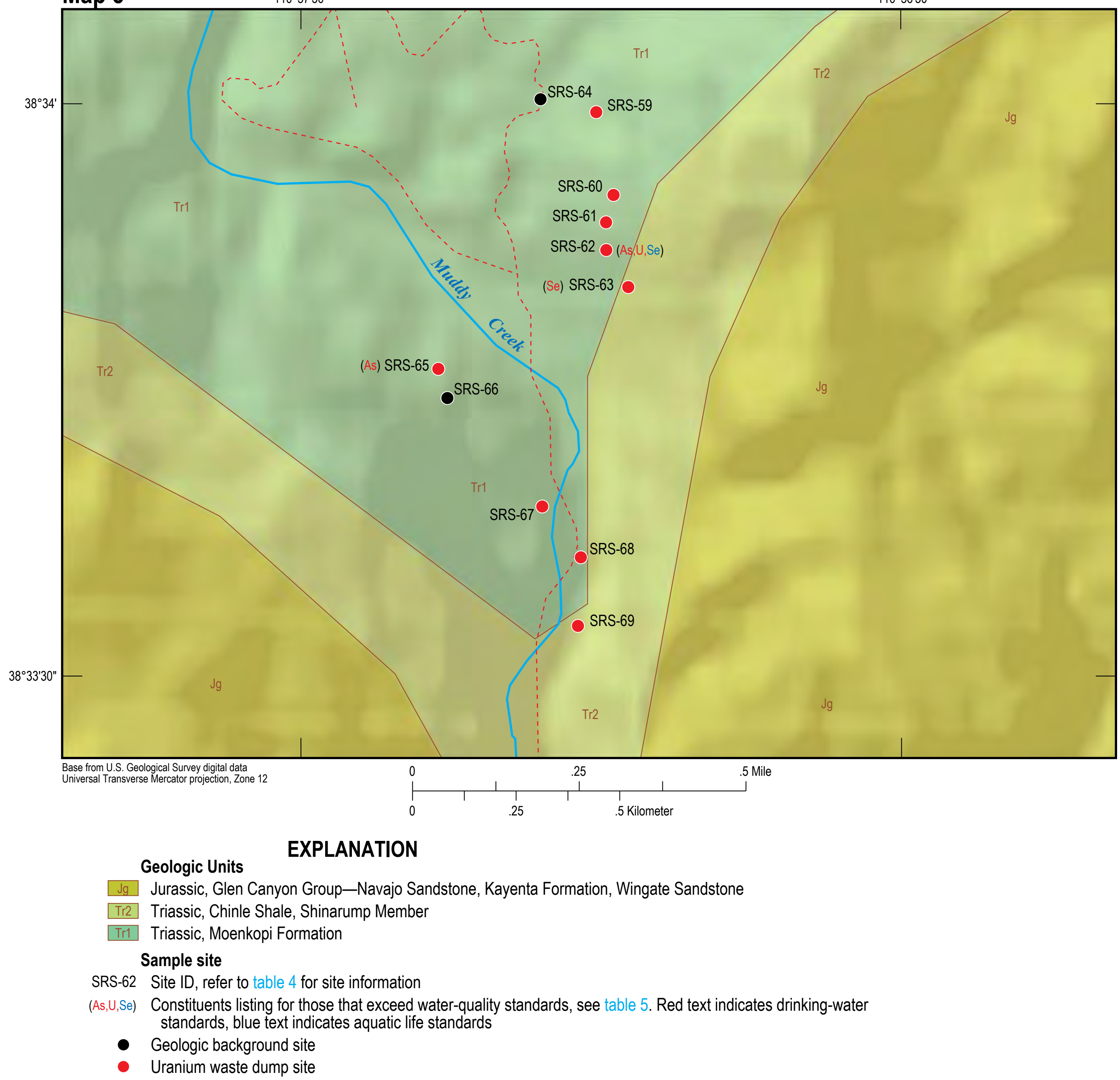
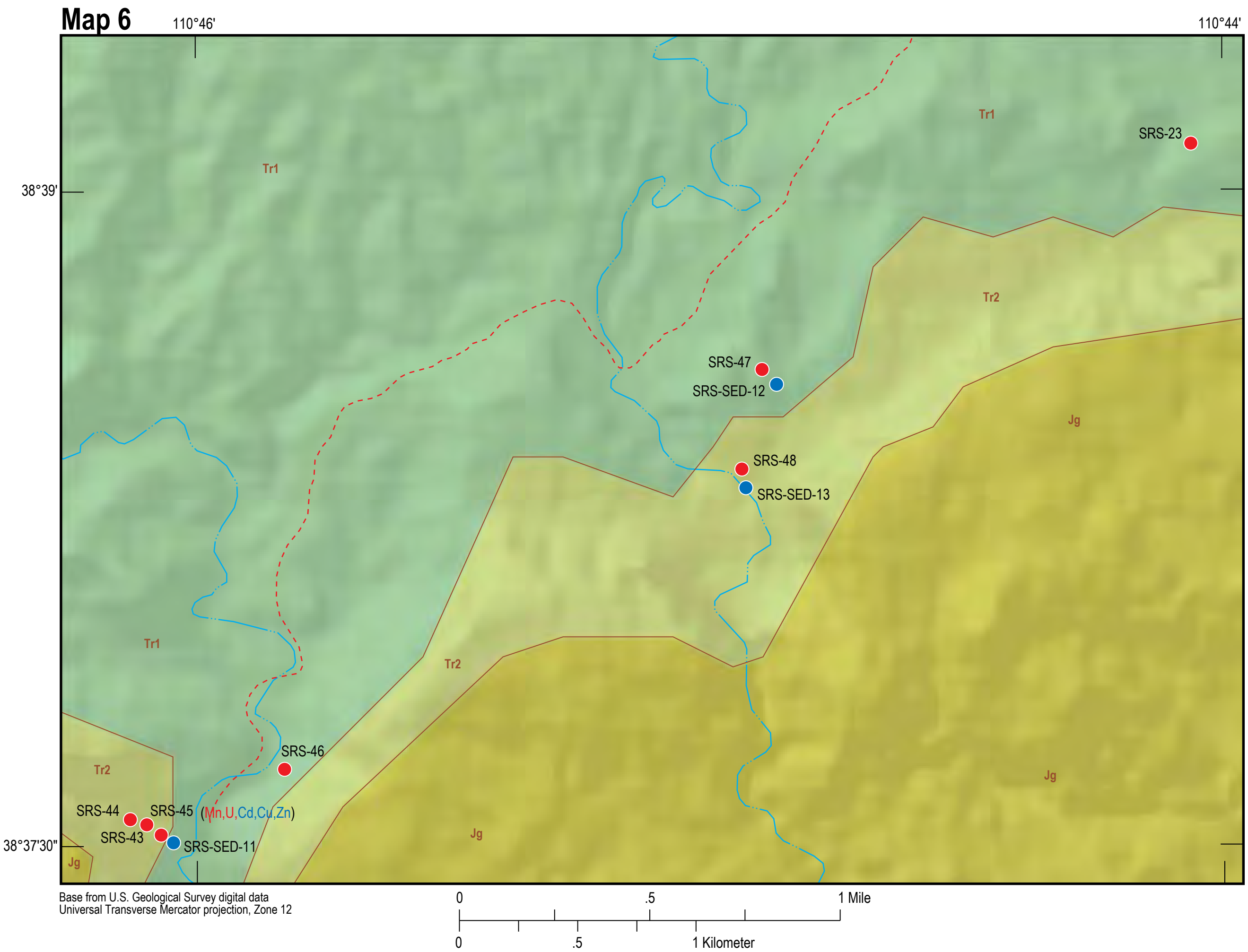


Figure 6. Location of uranium waste dump and geologic background sites and constituents that exceeded drinking-water and aquatic life water-quality standards in Map 5 where solid-phase material was collected.



EXPLANATION

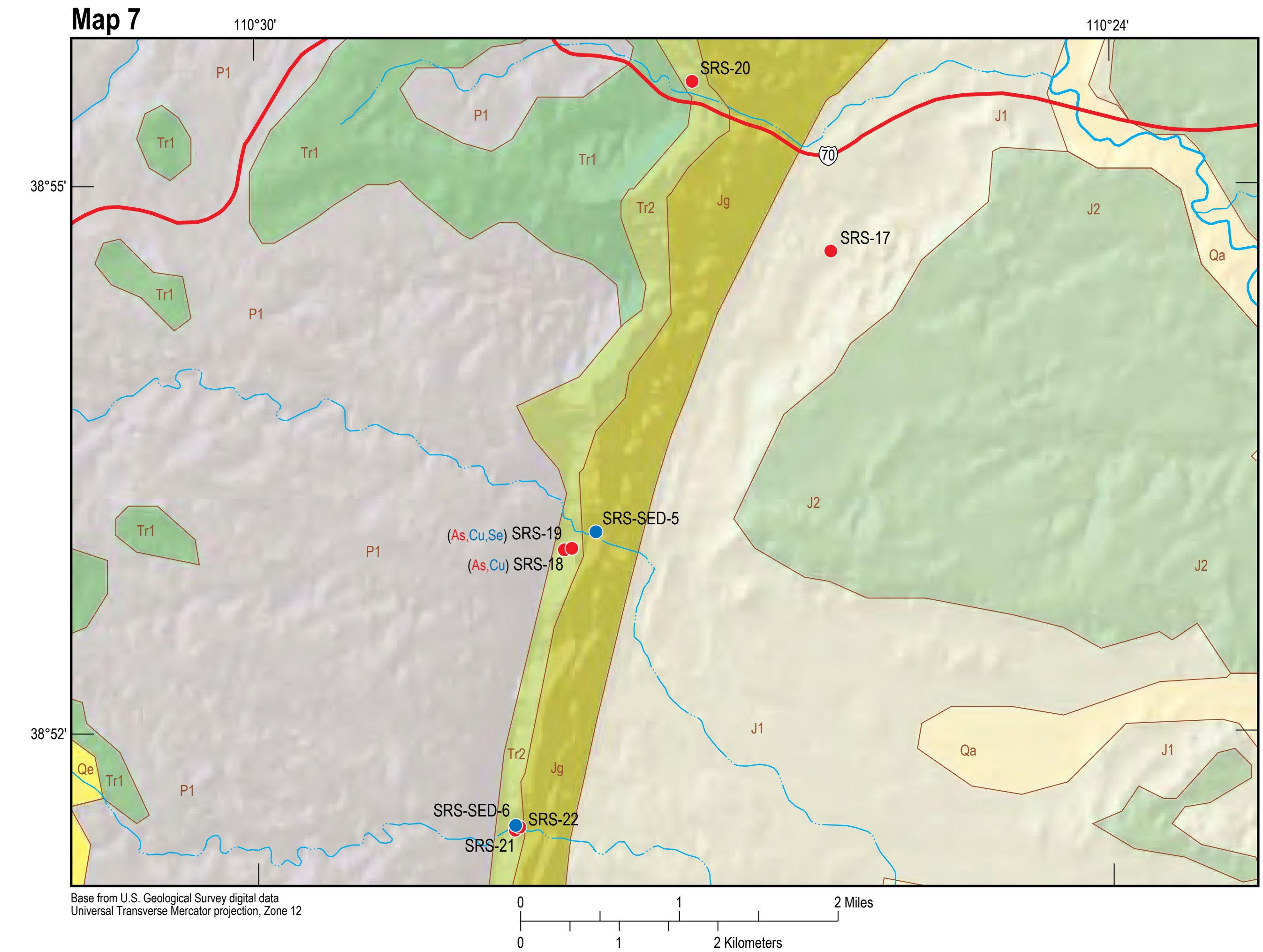
Geologic Units

- Jg — Jurassic, Glen Canyon Group—Navajo Sandstone, Kayenta Formation, Wingate Sandstone
- Tr2 — Triassic, Chinle Shale, Shinarump Member
- Tr1 — Triassic, Moenkopi Formation

Sample site

- SRS-45 — Site ID, refer to table 4 for site information (for SRS-23 see table 3 for site information)
- (Mn,U,Cd,Cu,Zn) — Constituents listing for those that exceed water-quality standards, see table 5. Red text indicates drinking-water standards, blue text indicates aquatic life standards
- ● Geologic background site
- ● Streambed sediment site
- ● Uranium waste dump site

Figure 7. Location of uranium waste dump and streambed sediment sites and constituents that exceeded drinking-water and aquatic life water-quality standards in Map 6 where solid-phase material was collected.



EXPLANATION

Geologic Units

- Qa — Quaternary, surficial deposits—Eolian deposits
- Qe — Quaternary, surficial deposits-older alluvium and colluvium
- J1 — Jurassic, Bluff Sandstone, Summerville Formation, Curtis Formation, Entrada Sandstone, Carmel Formation, Arapien Shale
- J2 — Jurassic, Morrison Formation, Brushy Basin Marble,Salt Wash Marble
- Jg — Jurassic, Glen Canyon Group-Navajo Sandstone, Kayenta Formation, Wingate Sandstone
- Tr2 — Chinle Shale, Shinarump Member
- Tr1 — Triassic, Moenkopi Formation
- P1 — Permian, White Rim Sandstone, De Chelly Sandstone, Organ Rock Shale, Cedar Mesa Sandstone, Halgaito Formation, Elephant Canyon Formation

Sample site

- SRS-18 — Site ID, refer to table 4 for site information (for SRS-21 see table 3 for site information)
- (As,Cu) — Constituents listing for those that exceed water-quality standards, see table 5. Red text indicates drinking-water standards, blue text indicates aquatic life standards
- ● Streambed sediment site
- ● Uranium waste dump site

Figure 8. Location of uranium waste dump and streambed sediment sites and constituents that exceeded drinking-water and aquatic life water-quality standards in Map 7 where solid-phase material was collected.

Fifty grams of sieved sample were added with 1,000 g of deionized water creating a 1:20 solid-to-liquid weight ratio. The sediment and water slurry was then mixed in a precleaned 1.5-L wide-mouth high density polyethylene (HDPE) Nalgene bottle and agitated for 5 minutes on a shaker table operating at 170 oscillations per minute. After shaking, the samples were allowed to settle for 1 hour prior to filtration.

Water was filtered through a 0.45 micron high-capacity Versapor membrane capsule filter (GeoTech dispos-a-filter) using precleaned tubing and a peristaltic pump. For each leachate sample, the filtered water sample was collected in one 250-mL acid-rinsed glass bottle and one 125-mL acid-rinsed HDPE bottle. After filtration, water samples were preserved by acidification to a pH less than 2. The samples collected in 250-mL glass bottles were preserved with 2 mL of hydrochloric acid and then sent to the USGS National Water Quality Laboratory (NWQL) for Hg analysis. The samples collected in 125-mL HDPE bottles were preserved with 1-mL Ultrex-grade nitric acid and sent to the Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) Metals Analysis Laboratory at the University of Utah for trace-element analysis (Ag, Al, As, Ba, Be, Cd, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se, U, V, and Zn). The remaining unfiltered aliquot of water was then decanted and used to measure specific conductance and pH.

Bottles and tubing used for sample extraction were cleaned according to the USGS inorganic constituents cleaning procedures outlined in Wilde (2004). Process blank and replicate samples were processed after every 10 environmental samples. All process blank samples were labeled as AML99

Table 2. Chemical analysis of process blank samples for trace-element concentrations.

[Samples were analyzed at the Inductively Coupled Plasma-Mass Spectrometry Metals Analysis Laboratory at the University of Utah and mercury samples were µg/L, micrograms per liter; AML, Abandoned Mine Lands; <, less than lower reporting limit; E, estimated value]

Site ID	Date	Time (MDT)	Antimony dissolved (µg/L as Sb)	Arsenic dissolved (µg/L as As)	Barium dissolved (µg/L as Ba)	Beryllium dissolved (µg/L as Be)	Cadmium dissolved (µg/L as Cd)	Chromium dissolved (µg/L as Cr)	Copper dissolved (µg/L as Cu)	Iron dissolved (µg/L as Fe)
AML99	10/11/2006	1135	<0.20	<0.20	<0.20	<0.06	<0.040	<2.0	<0.40	<6.0
AML99	10/13/2006	1030	<.20	<.20	<.20	<.06	<.040	<2.0	<.40	<6.0
AML99	10/16/2006	1610	<.20	<.20	<.20	<.06	<.040	<2.0	<.40	<6.0
AML99	10/25/2006	1020	<.20	<.20	<.20	<.06	<.040	<2.0	<.40	<6.0
AML99	10/18/2006	1400	<.20	<.20	<.20	<.06	<.040	<2.0	<.40	<6.0
AML99	10/30/2006	1050	<.20	<.20	<.20	<.06	<.040	<2.0	<.40	<6.0

[1] Values exceed lower reporting limit; Lower reporting limit: Sb, 0.20;As, 0.20; Ba, 0.20; Be, 0.06; Cd, 0.04 Cr, 2.0; Cu, 0.40; Fe, 6.0; Pb, 0.08; Mn, 0.20;

Table 3. Chemical analysis of replicate leachate samples for trace-element concentrations from uranium waste dump samples, San Rafael

[Samples were analyzed at the Inductively Coupled Plasma-Mass Spectrometry Metals Analysis Laboratory at the University of Utah and mercury samples were dd.mm.ss.s, degrees.minutes.seconds; ft, feet; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; SRS, San Rafael Swell;

Site ID	Date	Time (MDT)	Latitude (dd.mm.ss.s)	Longitude (dd.mm.ss.s)	Elevation (ft)	pH (standard units)	Specific Conductance (µS/cm)	Antimony dissolved (µg/L as Sb)	Arsenic dissolved (µg/L as As)	Barium dissolved (µg/L as Ba)	Beryllium dissolved (µg/L as Be)
SRS-SED-23	10/11/2006	1120	38 41 18.1	110 59 07.7	5,340	7.1	344	<0.20	0.25	3.7	<0.06
SRS-SED-23	10/11/2006	1130	38 41 18.1	110 59 07.7	5,340	7.2	148	<.20	.27	3.9	<.06
SRS-21	10/16/2006	1600	38 51 28.5	110 28 12.9	4,600	5.9	474	<.20	.46	6.7	<.06
SRS-21	10/16/2006	1605	38 51 28.5	110 28 12.9	4,600	6.0	406	<.20	.51	7.1	<.06
SRS-23	10/26/2006	1225	38 39 06.5	110 43 06.5	5,680	8.0	629	<.20	4.2	6.4	<.06
SRS-23	10/26/2006	1230	38 39 06.5	110 43 06.5	5,680	8.0	1,035	<.20	4.1	5.9	<.06
SRS-32	10/30/2006	1435	38 46 50.6	110 50 07.3	7,080	6.3	705	<.20	11	1.8	.15
SRS-32	10/30/2006	1440	38 46 50.6	110 50 07.3	7,080	6.5	701	<.20	11	1.5	.14
SRS-34	10/13/2006	1035	38 47 38.0	110 50 14.8	7,080	8.1	191	<.20	[1] 73	[1] 11	[1] <.06
SRS-34	10/13/2006	1040	38 47 38.0	110 50 14.8	7,080	7.9	164	<.20	101	21	.22
SRS-55	10/17/2006	1445	38 45 35.7	110 56 53.4	6,180	4.6	734	<.20	[1] 16	[1] 12	0.5
SRS-55	10/17/2006	1450	38 45 35.7	110 56 53.4	6,180	4.6	758	<.20	7.0	6.2	.46
SRS-56	10/25/2006	1005	38 45 39.5	110 56 49.6	6,060	4.6	1,239	<.20	2.0	1.1	1.6
SRS-56	10/25/2006	1015	38 45 39.5	110 56 49.6	6,060	4.6	1,123	<.20	1.9	1.1	1.6

[1] Replicate samples exceeding plus or minus 20 percent; Lower reporting limit: Sb, 0.20;As, 0.20; Ba, 0.20; Be, 0.06; Cd, 0.04 Cr, 2.0; Cu, 0.40; Fe, 6.0; Pb,

and given an individual time and date for each sample. AML refers to the abandoned mine lands study and 99 is an arbitrary number assigned to each blank sample. Blanks and replicates were analyzed at the ICP-MS Metals Analysis Laboratory at the University of Utah and the USGS NWQL. Process blank samples followed the same procedures as leachate samples in the laboratory, but were analyzed without any sediment in the 1.5-L Nalgene bottles.

Results of chemical analyses for the six process blank samples are presented in table 2. Most of the results for the process blank samples contained trace-element concentrations below the lower reporting limit; however, concentrations for Mn, Ni, U, and Zn exceeded lower reporting limits. Concentrations of Mn ranged in concentrations between 0.35 µg/L to 0.98 µg/L, with a median concentration of 0.70 µg/L. Concentrations of Ni ranged in concentrations between less than 0.06 µg/L to 0.20 µg/L, and had a median concentration of 0.13 µg/L. Concentrations of Zn ranged in concentrations between less that 0.6 µg/L to 1.49 µg/L, and had a median concentration of 0.82 µg/L. All U concentrations with the exception of one blank sample, which had a concentration of 0.4 µg/L were below the lower reporting limit.

Results of chemical analyses for the seven replicate samples are presented in table 3. Although most of the results for the replicate analyses were within plus or minus 20 percent, a few constituents in selected San Rafael Swell sites varied by more than plus or minus 2 percent: SRS-21 (Cu, Hg); SRS-23 (Cd, Hg, Ni); SRS-34 (As, Ba, Be, Cd, Cu, Fe, Mn, Ni, Pb, Se, U, V, Zn); SRS-55 (As, Ba, Fe, Hg, Pb, Zn), and SRS-56 (Hg) (table 3).

analyzed at the U.S. Geological Survey National Water Quality Laboratory, Denver, Colorado. Site ID, site identification; MDT, Mountain Daylight Time;

Lead dissolved (µg/L as Pb)	Manganese dissolved (µg/L as Mn)	Mercury dissolved (µg/L as Hg)	Molybdenum dissolved (µg/L as Mo)	Nickel dissolved (µg/L as Ni)	Selenium dissolved (µg/L as Se)	Silver dissolved (µg/L as Ag)	Uranium dissolved (µg/L as U)	Vanadium dissolved (µg/L as V)	Zinc dissolved (µg/L as Zn)
<0.08	[1] 0.35	<0.010	<4.0	<0.06	<0.40	<0.20	<0.04	<2.0	<0.60
<.08	[1] .95	<.010	<4.0	[1] .20	<.40	<.20	[1] .40	<2.0	[1] 1.5
<.08	[1] .98	<.010	<4.0	[1] .13	<.40	<.20	<.04	<2.0	[1] .82
<.08	[1] .49	E.009	<4.0	[1] .10	<.40	<.20	<.04	<2.0	<.60
<.08	[1] .6	.011	<4.0	[1] .20	<.40	<.20	<.04	<2.0	[1] .82
<.08	[1] .8	<.010	<4.0	[1] .12	<.40	<.20	<.04	<2.0	[1] .82

Hg, 0.010; Mo, 4.0; Ni, 0.06; Se, 0.40; Ag, 0.20; U, 0.04; V, 2.0; Zn, 0.60]

Swell, Utah.

analyzed at the U.S. Geological Survey National Water Quality Laboratory, Denver, Colorado. Site ID, site identification; MDT, Mountain Daylight Time; SED, sediment; <, less than lower reporting limit; E, estimated value]

Cadmium dissolved (µg/L as Cd)	Chromium dissolved (µg/L as Cr)	Copper dissolved (µg/L as Cu)	Iron dissolved (µg/L as Fe)	Lead dissolved (µg/L as Pb)	Manganese dissolved (µg/L as Mn)	Mercury dissolved (µg/L as Hg)	Molybdenum dissolved (µg/L as Mo)	Nickel dissolved (µg/L as Ni)	Selenium dissolved (µg/L as Se)	Silver dissolved (µg/L as Ag)	Uranium dissolved (µg/L as U)	Vanadium dissolved (µg/L as V)	Zinc dissolved (µg/L as Zn)
<0.040	<2.0	<0.40	22	<0.08	3.7	<0.010	<4.0	0.31	<0.40	<0.20	0.19	<2.0	<0.60
<.040	<2.0	<.40	18	<.08	3.8	<.010	<4.0	.27	<.40	<.20	.17	<2.0	<.60
.723	<2.0	[1] 2.1	<6.0	<.08	19	[1] <.010	<4.0	3.8	<.40	<.20	11	<2.0	56
.678	<2.0	2.9	<6.0	<.08	17	E.006	<4.0	3.6	<.40	<.20	12	<2.0	61
[1] .139	<2.0	2.0	<6.0	<.08	2.4	E.007	<4.0	[1] .61	<.40	<.20	15	<2.0	.84
.098	<2.0	1.6	<6.0	<.08	1.7	.012	<4.0	.47	<.40	<.20	13	<2.0	.95
1.6	<2.0	1,054	<6.0	<.08	165	<.010	<4.0	240	1.3	<.20	15	<2.0	703
1.6	<2.0	937	<6.0	<.08	171	<.010	<4.0	250	1.2	<.20	13	<2.0	699
[1] <.018	<2.0	[1] 27	[1] 77	[1] 1.7	[1] 4.2	E.008	<4.0	[1] 1.5	[1] .56	<.20	[1] 22	[1] 8.5	[1] 8.4
.073	<2.0	115	314	8.3	16	E.009	<4.0	7.2	1.6	<.20	53	[1] 2.4	34
18	<2.0	3,981	[1] 566	[1] 6.4	233	[1] .017	4.3	331	3.1	<.20	211	2.1	2,937
18	<2.0	3,863	178	.91	237	E.010	<4.0	353	3.0	<.20	175	<2.0	3,020
14	<2.0	77	39	.32	1,142	.011	<4.0	332	5.3	<.20	10	<2.0	1,397
12	<2.0	79	36	.26	1,002	.016	<4.0	286	5.2	<.20	10	<2.0	1,275

0.08; Mn, 0.20; Hg, 0.010; Mo, 4.0; Ni, 0.06; Se, 0.40; Ag, 0.20; U, 0.04; V, 2.0; Zn, 0.60]

Results

Trace-element concentrations in the leachate samples (table 4) (located at back of report) were compared with aquatic life (U.S. Environmental Protection Agency, 2007b) and drinking-water-quality standards (U.S. Environmental Protection Agency, 2007a) (table 5). For constituents without an aquatic life or drinking-water-quality standard, no comparison was made. To quantify constituents that exceeded an aquatic life or drinking-water-quality standard, a ratio of the number of uranium waste dump sites exceeding a particular standard to the total number of uranium waste dump sites sampled was determined for each constituent. The ratio of uranium waste dump sites that exceeded drinking-water-quality standards is: As 23/85, Be 4/85, Cd 10/85, Cu 5/85, Fe 4/85, Mn 28/85, Pb 1/85, Se 2/85, U 21/85, and Zn 2/85. The ratio of uranium waste dump sites that exceeded aquatic life water-quality standards is: As 1/85, Cd 31/85, Cu 30/85, Ni 17/85, Pb 4/85, Se 17/85, and Zn 16/85.

Water-quality standards and trace-element concentrations for leachate samples are graphically presented using box plots in figure 9. None of the constituents had median values that exceeded both the aquatic life and drinking-water-quality standards. However, mean values for As, Mn, and U exceeded drinking-water-quality standards. Approximately 25 percent of the uranium waste dump leachate samples exceeded drinking-water-quality standards. Mean values for Cd, Cu, Ni, and Zn exceeded aquatic life water-quality standards. Approximately 35 percent of uranium waste dump leachate samples exceeded aquatic life water-quality standards for Cu and Cd.

Sites where concentrations of trace metals exceeded aquatic life and drinking-water-quality standards are displayed using bar graphs in figures 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, and 20. Aquatic life and drinking-water-quality standards are shown for As (fig. 10); Be (fig. 11); Cd (fig. 12); Cu (fig. 13); Fe (fig. 14); Mn (fig. 16); Ni (fig. 17); Pb (fig. 15); Se (fig. 18); U (fig. 19); and Zn (fig. 20).

Several sample sites had one or more constituents that exceeded water-quality standards. Approximately 56 percent (48/85) of the uranium waste dump samples exceeded aquatic life and drinking-water-quality standards for one or more constituents analyzed. The location of sample sites, site type, constituents that exceeded one or both water-quality standards, surrounding geology, and stream hydrology are shown in detail for each map area 1 through 7 (figs. 2, 3, 4, 5, 6, 7, 8). Most of the sites that exceeded standards were located in two primary locations. Approximately 73 percent (35/48) of the contaminated sites were located along Reds Canyon Road, between Lucky Strike Mine and Tomsich Butte (21/48 sites) and approximately 1 mi north of Family Butte (14/48 sites).

Sites SRS-11, SRS-40, SRS-41, SRS-49, SRS-50, SRS-51, SRS-55, SRS-57, SRS-84, SRS-87, SRS-89, and SRS-90 contained three or more constituents that exceeded drinking-water-quality standards. Sites SRS-40, SRS-89, and SRS-90 had five constituents that exceeded drinking-water-quality standards, and sites SRS-41 and SRS-55 had six constituents that exceeded drinking-water-quality standards. Sites SRS-5, SRS-10, SRS-11, SRS-32, SRS-40, SRS-41, SRS-45, SRS-49, SRS-50, SRS-51, SRS-54, SRS-55, SRS-56, SRS-84, SRS-85, SRS-87, SRS-89, and SRS-90 contained three or more constituents that exceeded aquatic life water-quality standards. Sites SRS-10, SRS-40, SRS-55, SRS-56, SRS-84, SRS-85, SRS-87, and SRS-90 had five constituents that exceeded aquatic life water-quality standards, whereas site SRS-89 had six constituents that exceeded aquatic life water-quality standards.

Nearly all sites that exceeded standards were uranium waste dump sites. However, geologic background site SRS-86 exceeded aquatic water-quality standards for Se, and sediment site SRS-SED-16 exceeded aquatic water-quality standards for Cu. No other geologic background or streambed sites exceeded standards. Most uranium waste dump sites are located in or near ephemeral streams that would likely minimize their contaminant contribution to perennial streams. Uranium waste dump sites located near Tomsich Butte mine workings were less than 0.25 mi from the perennial Muddy Creek (fig. 5). Sites SRS-84, SRS-85, SRS-87, SRS-88, SRS-89, and SRS-90, located on the southern side of Tomsich

Table 5. U.S. Environmental Protection Agency drinking-water-quality standards[1] and aquatic life water-quality standards[2].

[µg/L, micrograms per liter; na, not applicable]

Element	Drinking Water Standard Concentration (µg/L)	Aquatic Life Water Standard Concentration (µg/L)
Antimony (Sb)	6	n/a
Arsenic (As)	10	150
Barium (Ba)	2,000	n/a
Beryllium (Be)	4	n/a
Cadmium (Cd)	5	[3]0.25
Chromium (Cr)	100	n/a
Copper (Cu)	1,300	[3]9
Iron (Fe)	300	n/a
Lead (Pb)	15	[3]2.5
Manganese (Mn)	50	n/a
Mercury (Hg)	2	0.77
Molybdenum (Mo)	n/a	n/a
Nickel (Ni)	n/a	[3]52
Selenium (Se)	50	5
Silver (Ag)	100	n/a
Uranium (U)	30	n/a
Vanadium (V)	n/a	n/a
Zinc (Zn)	5,000	[3]120

[1]Drinking-water-quality standards (U.S. Environmental Protection Agency, 2007a)

[2]Aquatic life water-quality standards (U.S. Environmental Protection Agency, 2007b)

[3]Aquatic life standard is based on a hardness value of 100 µg/L

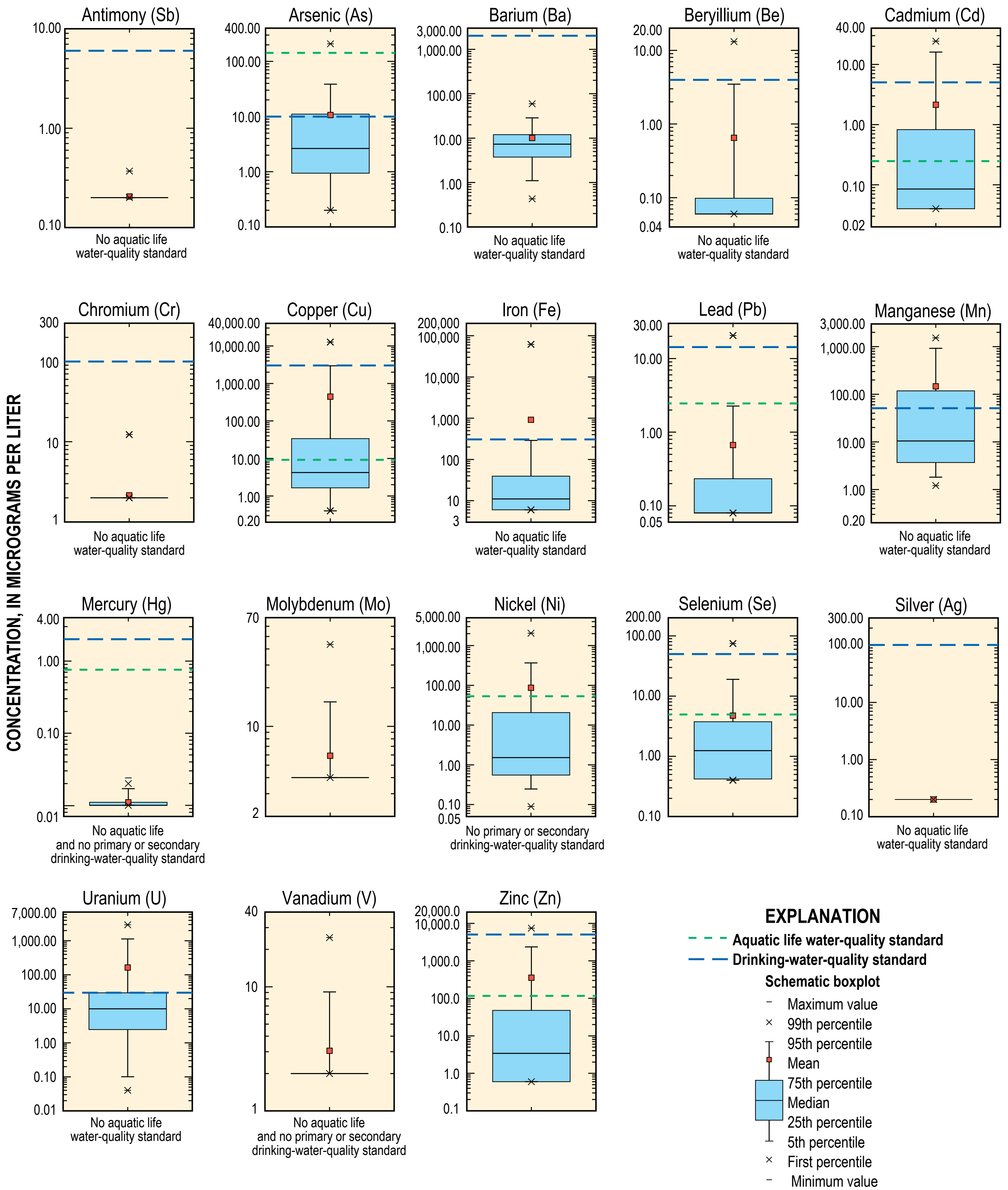


Figure 9. Box plots showing concentrations of dissolved trace elements in leachate extractions from the 85 uranium waste dump samples collected from the San Rafael Swell, Utah.

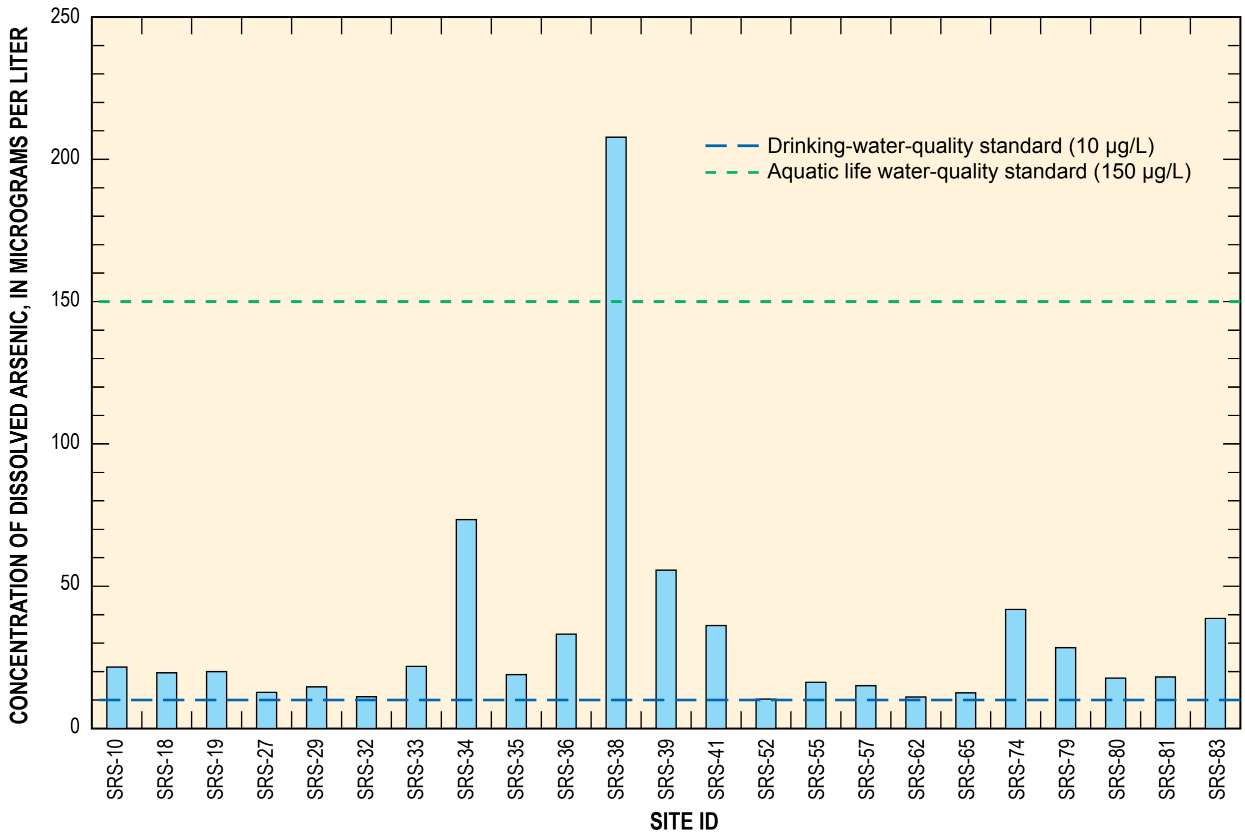


Figure 10. Concentrations of dissolved arsenic in uranium waste dump leachate samples that exceeded aquatic life and drinking-water-quality standards.

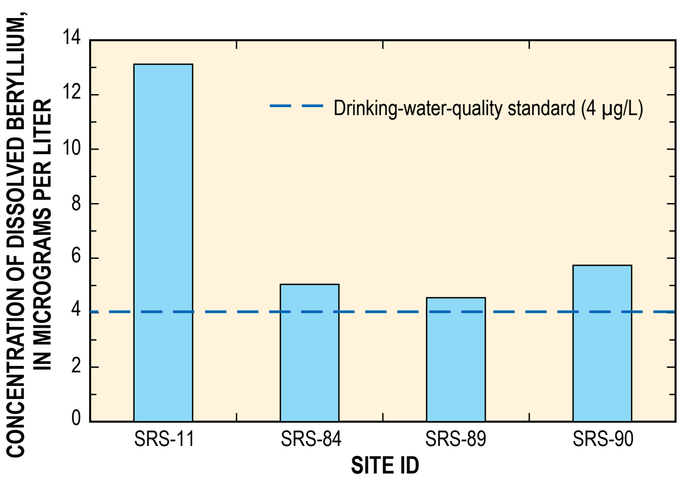


Figure 11. Concentrations of dissolved beryllium in uranium waste dump leachate samples that exceeded drinking-water-quality standards.

Butte, all contained constituents that exceeded water-quality standards for both drinking water and aquatic life. Samples from SRS-84, SRS-85, SRS-88, SRS-89, and SRS-90 contained the largest concentrations of dissolved U, with concentrations that ranged from 1,135 µg/L (SRS-88) to 2,970 µg/L (SRS-90) (fig. 5). The proximity (approximately 0.25 mi) of these uranium waste dumps to Muddy Creek, coupled with the elevated concentrations of selected trace elements, increases their potential impact to offsite water resources.

Future Work

Many uranium waste dumps in the San Rafael Swell contain elevated concentrations of trace elements as indicated from results of leachate analyses. Future assessment of the nonpoint source chemical loading potential to streams and remediation priority of these areas may be assessed using GIS-based risk-mapping techniques, such as Sensitive Catchment Integrated Mapping and Analysis Project (SCIMAP) (Reaney and others, 2006). SCIMAP uses the physical attributes of each watershed to assist in the ranking of remediation priorities. These attributes include: slope area by class (0–10 percent,10–20 percent, etc.); aspect area by class (SE, S, SW, etc.); outcrop area by geologic formation; total surface area

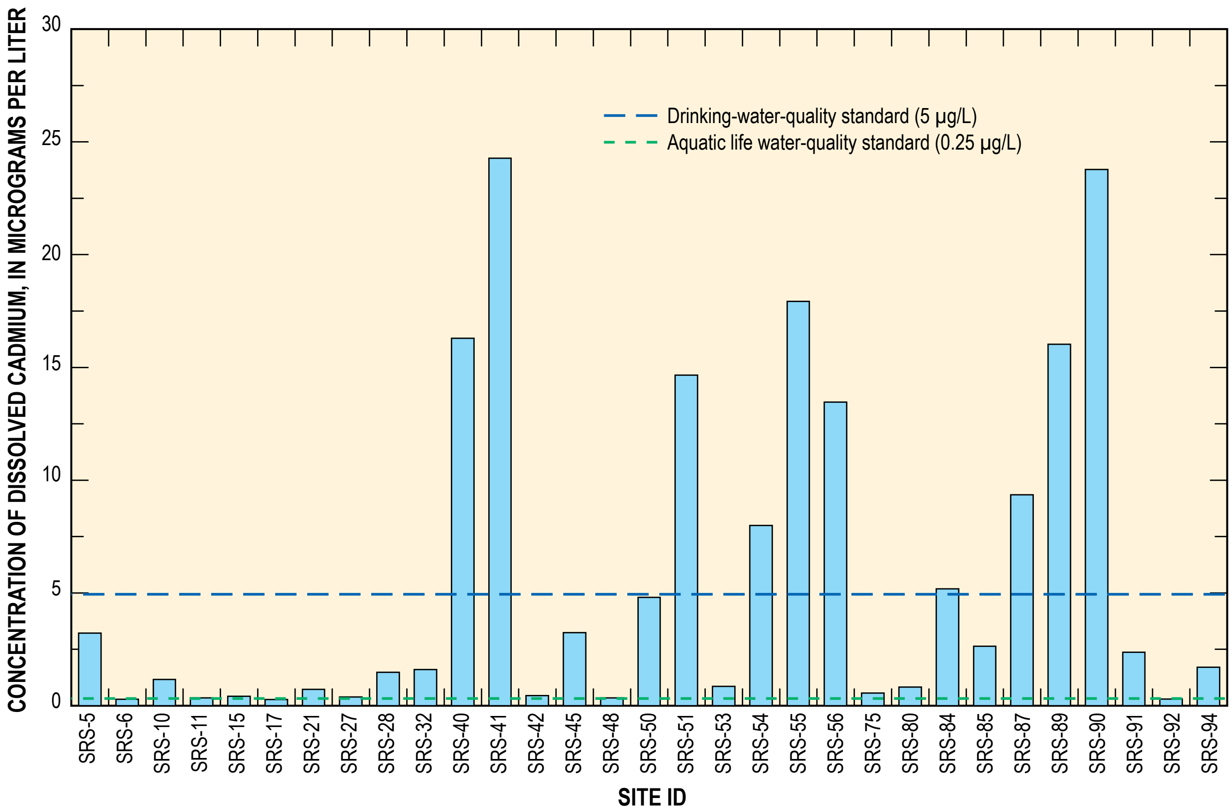


Figure 12. Concentrations of dissolved cadmium in uranium waste dump leachate samples that exceeded aquatic life and drinking-water-quality standards.

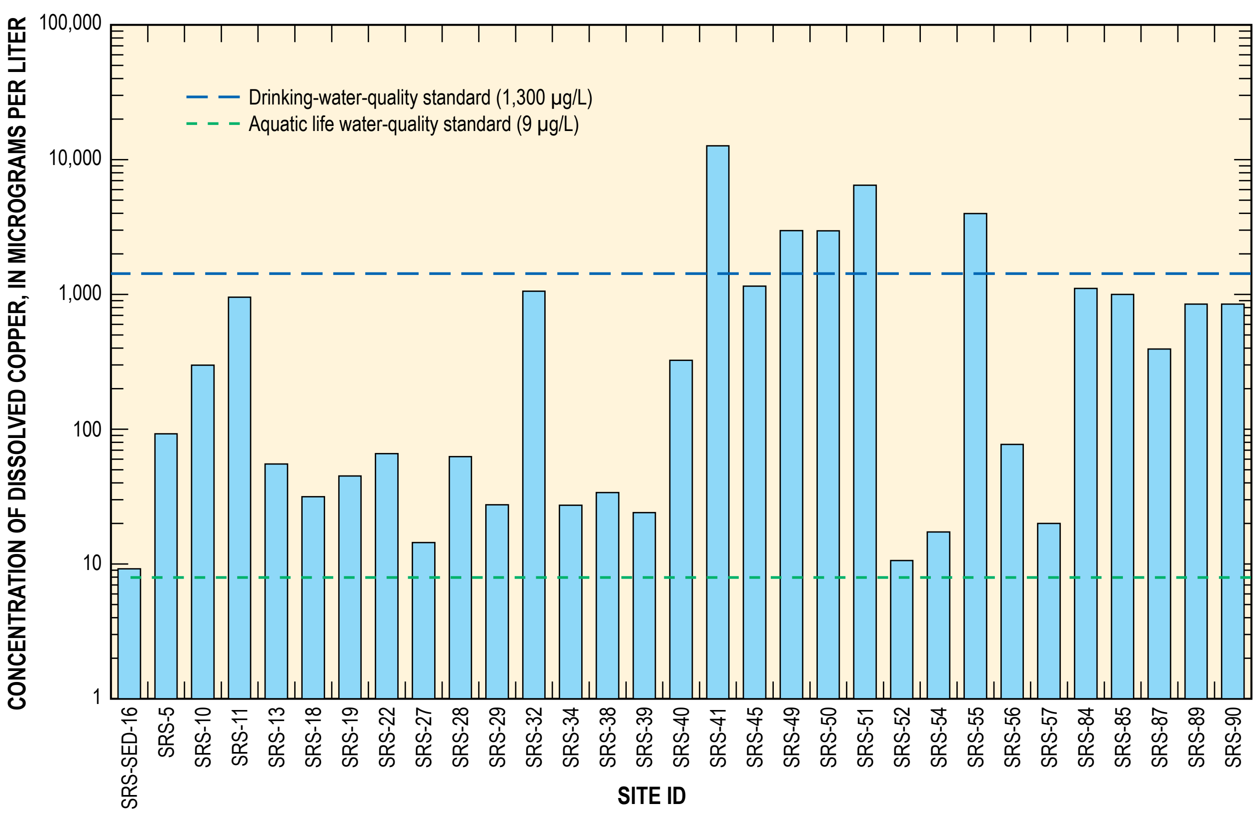


Figure 13. Concentrations of dissolved copper in uranium waste dump leachate samples that exceeded aquatic life and drinking-water-quality standards.

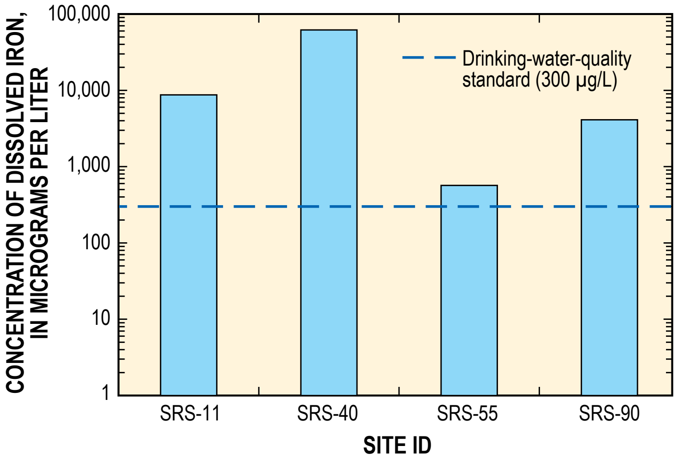


Figure 14. Concentrations of dissolved iron in uranium waste dump leachate samples that exceeded drinking-water-quality standards.

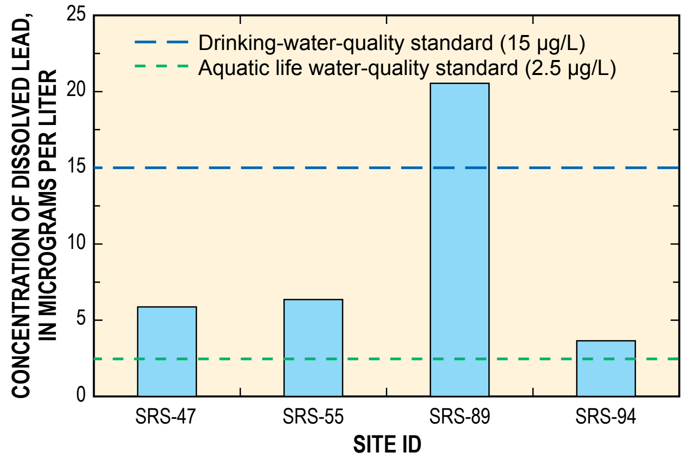


Figure 15. Concentrations of dissolved lead in uranium waste dump leachate samples that exceeded aquatic life and drinking-water-quality standards.

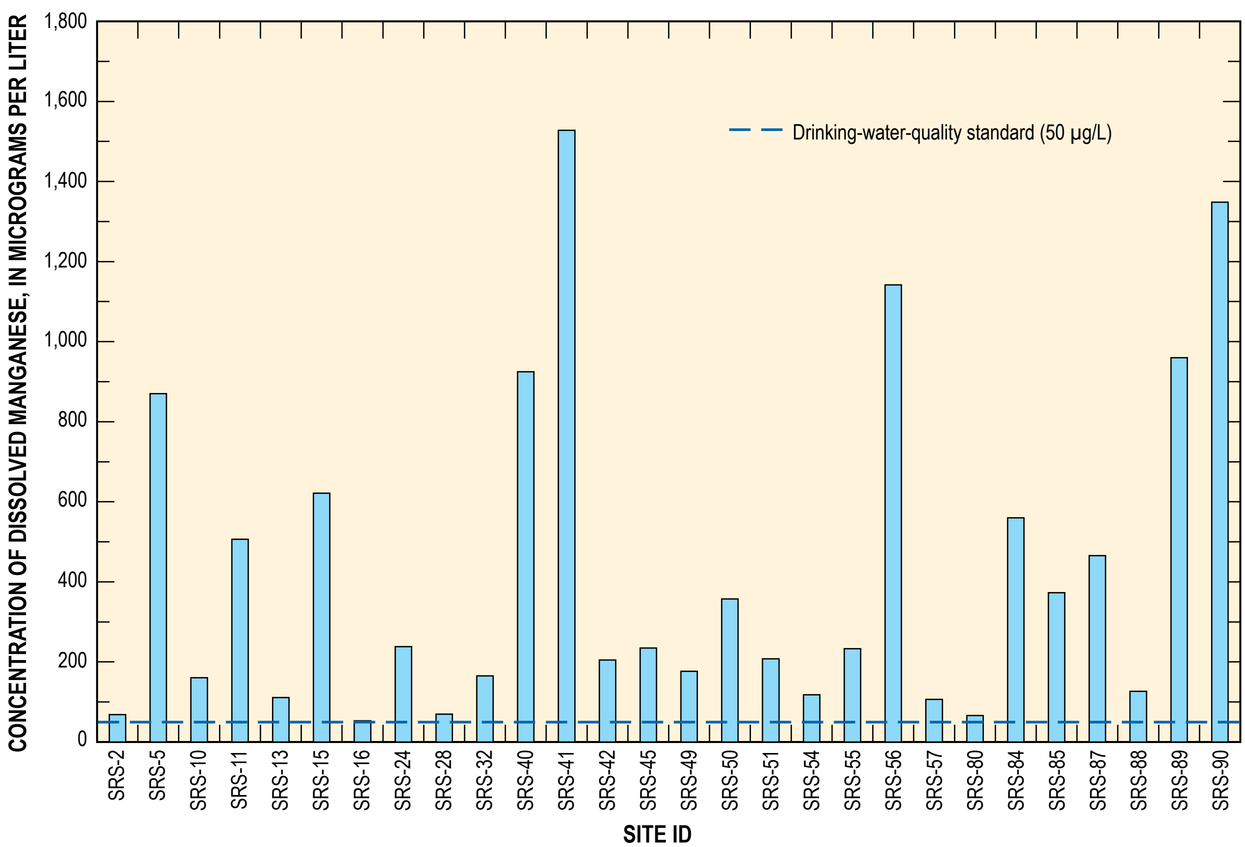


Figure 16. Concentrations of dissolved manganese in uranium waste dump leachate samples that exceeded drinking-water-quality standards.

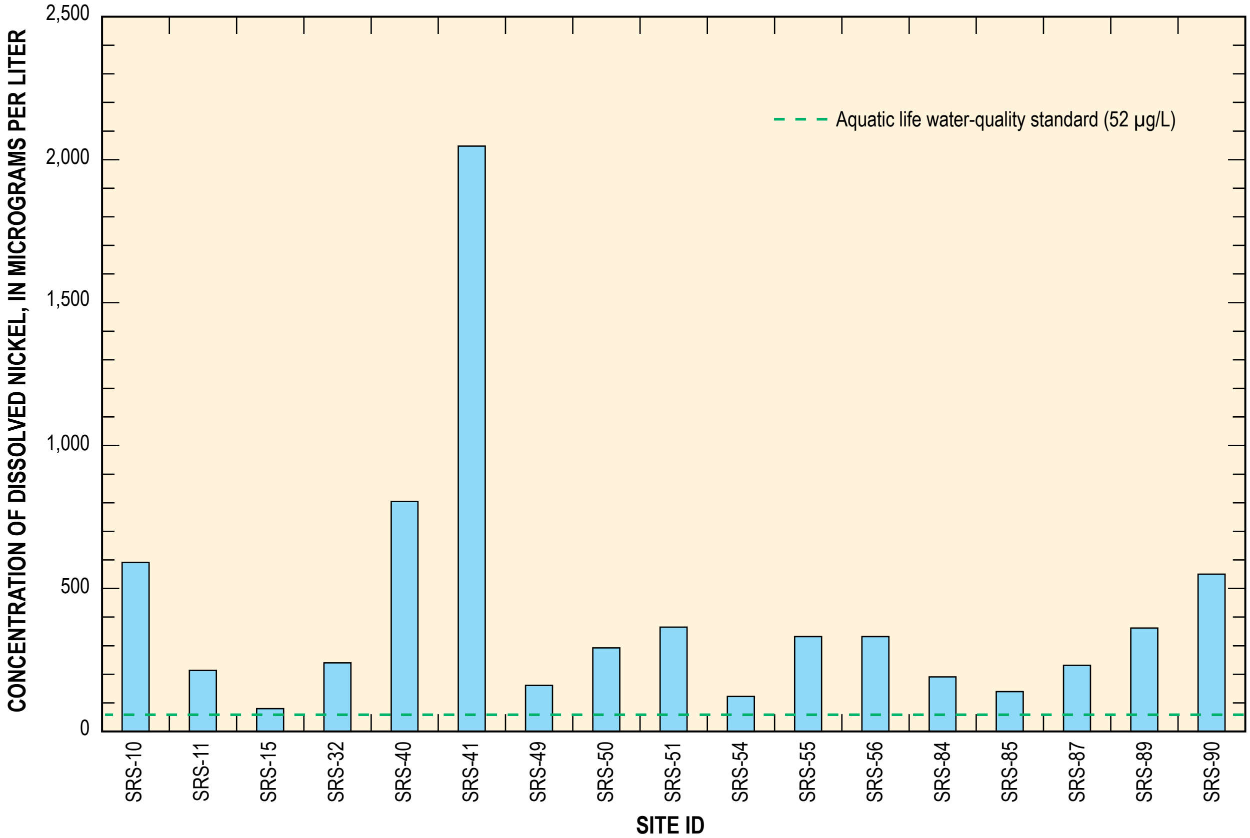


Figure 17. Concentrations of dissolved nickel in uranium waste dump leachate samples that exceeded aquatic life water-quality standards.

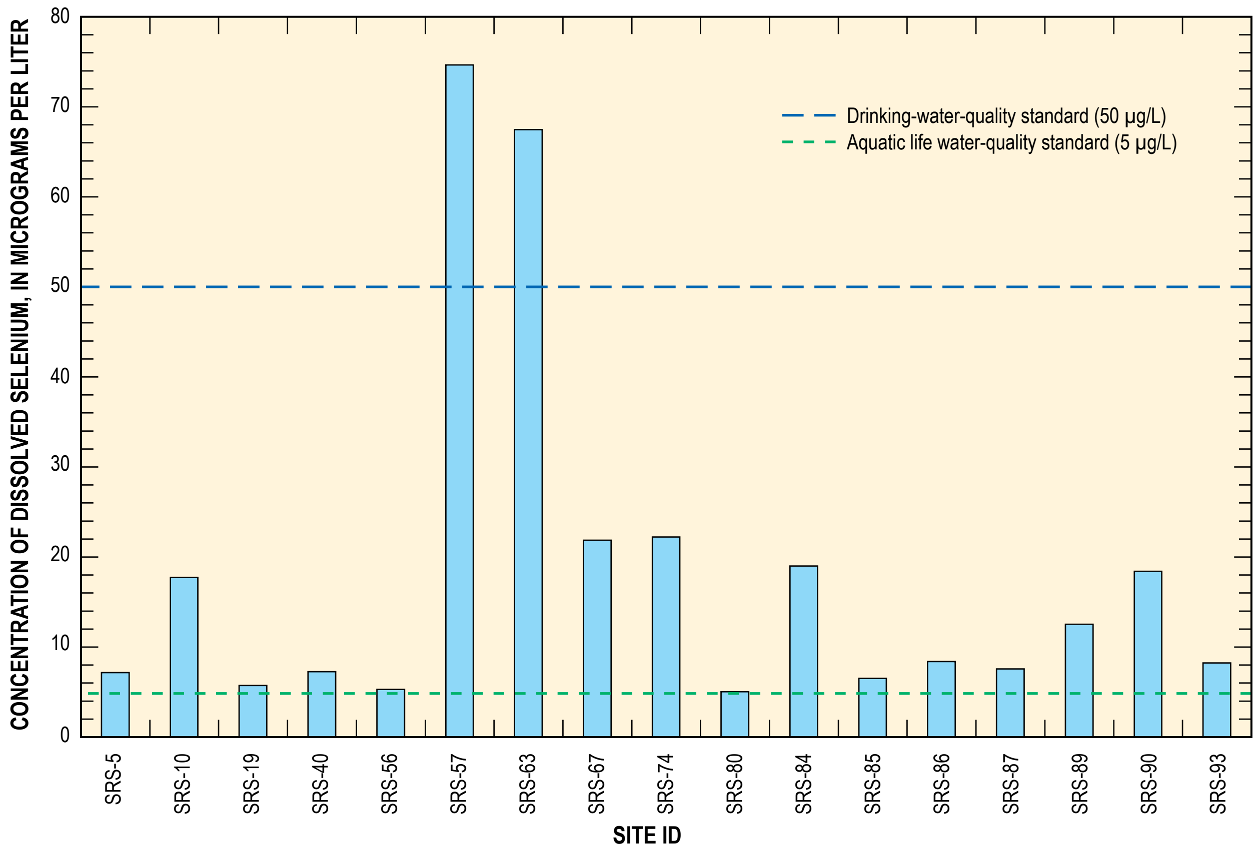


Figure 18. Concentrations of dissolved selenium in uranium waste dump leachate samples that exceeded aquatic life and drinking-water-quality standards.

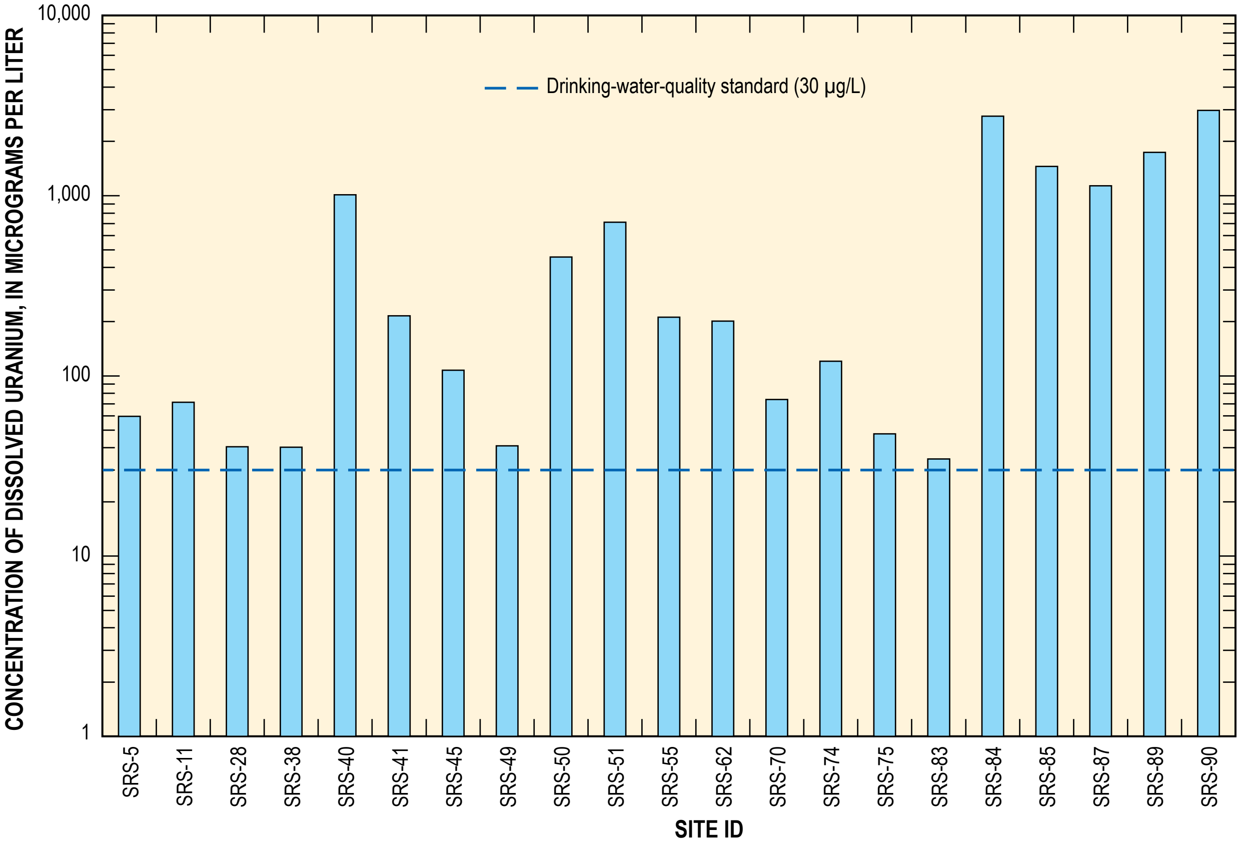


Figure 19. Concentrations of dissolved uranium in uranium waste dump leachate samples that exceeded drinking-water-quality standards.

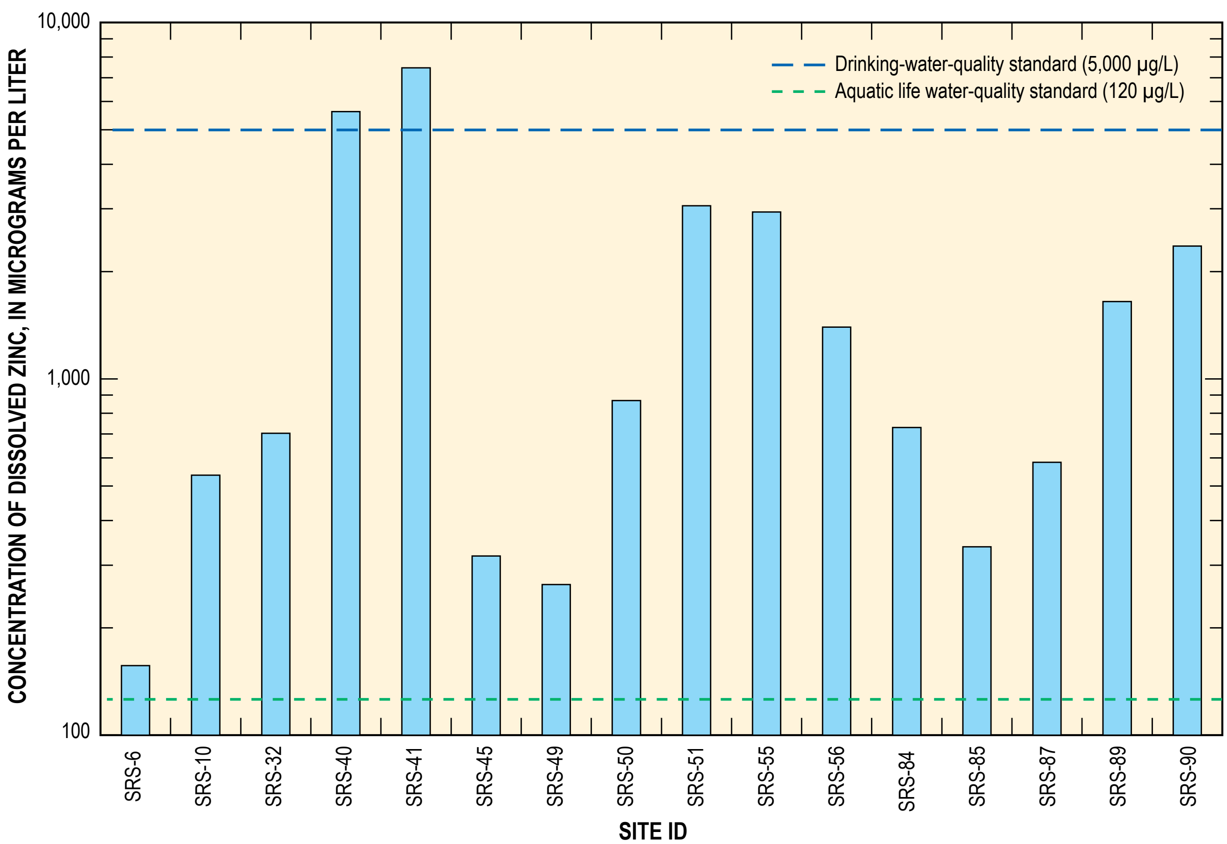


Figure 20. Concentrations of dissolved zinc in uranium waste dump leachate samples that exceeded aquatic life and drinking-water-quality standards.

of drainage basin; length of stream channel by stream order; disturbed area by class (uranium waste dumps, roads, etc.); and surface area covered by vegetation. A SCIMAP analysis could assist regulatory agencies in prioritizing uranium waste dump sites for remediation actions necessary to prevent off-site transport of contaminants during runoff events.

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Table 4. Chemical analysis of leachate samples for trace-element concentrations from uranium waste dump samples, San Rafael Swell, Utah.

[Samples were analyzed at the Inductively Coupled Plasma-Mass Spectrometry Metals Analysis Laboratory at the University of Utah and mercury samples were dd.mm.ss.s, degrees.minutes.seconds; ft, feet; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; SRS, San Rafael Swell; SED,

Site ID	Date	Time (MDT)	Latitude (dd.mm.ss.s)	Longitude (dd.mm.ss.s)	Elevation (ft)	pH (standard units)	Specific Conductance (µS/cm)	Antimony dissolved (µg/L as Sb)	Arsenic dissolved (µg/L as As)	Barium dissolved (µg/L as Ba)	Beryllium dissolved (µg/L as Be)	Cadmium dissolved (µg/L as Cd)
SRS-SED-1	10/10/2006	1240	39 01 42.1	110 43 12.8	5,640	8.2	190	<0.20	0.2	0.97	<0.06	<0.040
SRS-SED-2	10/10/2006	1300	39 01 45.0	110 42 34.1	5,545	7.7	220	<.20	<.20	.85	<.06	<.040
SRS-SED-3	10/10/2006	1130	39 03 01.1	110 35 32.9	5,120	9.3	73	<.20	.21	8.1	<.06	<.040
SRS-SED-4	10/10/2006	1220	38 53 04.1	110 40 19.8	6,660	8.3	43	<.20	.42	4.1	<.06	<.040
SRS-SED-5	10/10/2006	1250	38 53 06.4	110 27 38.4	5,680	9.7	73	<.20	.25	5.4	<.06	<.040
SRS-SED-6	10/11/2006	1210	38 51 29.2	110 28 11.9	4,580	8.7	35	<.20	.39	7.6	<.06	<.040
SRS-SED-7	10/10/2006	1325	38 46 21.0	110 50 11.9	6,920	9.6	34	<.20	.73	7.0	<.06	<.040
SRS-SED-8	10/10/2006	1310	38 46 47.5	110 50 02.1	6,962	8.9	128	<.20	7.3	15	<.06	<.040
SRS-SED-9	10/11/2006	1215	38 48 12.7	110 50 06.8	6,960	8.4	38	<.20	.41	15	<.06	<.040
SRS-SED-10	10/10/2006	1200	38 47 29.2	110 50 00.7	6,950	10.0	56	<.20	.44	12	<.06	<.040
SRS-SED-11	10/10/2006	1330	38 37 30.9	110 46 04.8	5,180	9.7	45	<.20	.46	3.5	<.06	<.040
SRS-SED-12	10/10/2006	1150	38 38 33.8	110 44 19.3	5,600	7.9	74	<.20	.22	23	<.06	<.040
SRS-SED-13	10/10/2006	1140	38 38 19.4	110 44 24.6	5,420	8.8	266	<.20	.43	17	<.06	<.040
SRS-SED-14	10/10/2006	1315	38 45 21.8	110 57 04.6	5,800	8.8	50	<.20	4.0	6.9	<.06	<.040
SRS-SED-15	10/10/2006	1205	38 45 24.7	110 56 57.5	5,820	9.0	78	<.20	3.5	4.0	<.06	<.040
SRS-SED-16	10/10/2006	1230	38 45 21.2	110 56 56.9	5,800	9.3	58	<.20	1.9	8.4	<.06	<.040
SRS-SED-17	10/11/2006	1155	38 44 48.0	110 57 08.0	5,740	8.1	28	<.20	.50	11	<.06	<.040
SRS-SED-18	10/13/2006	1015	38 44 03.8	110 58 01.0	5,620	8.6	74	<.20	1.5	4.6	<.06	<.040
SRS-SED-19	10/11/2006	1550	38 44 17.8	110 57 58.5	5,640	7.0	26	<.20	.63	5.9	<.06	<.040
SRS-SED-20	10/18/2006	1415	38 45 50.9	110 55 31.9	6,000	9.1	36	<.20	.88	7.7	<.06	<.040
SRS-SED-21	10/11/2006	1150	38 41 00.3	110 59 50.0	5,060	7.2	200	<.20	.59	5.3	<.06	<.040
SRS-SED-22	10/11/2006	1205	38 40 59.5	110 59 31.0	5,140	7.0	203	<.20	.64	1.9	<.06	<.040
SRS-SED-24	10/13/2006	1020	38 40 32.8	111 00 14.5	5,300	8.0	36	<.20	.33	4.6	<.06	<.040
SRS-1	10/17/2006	1235	39 05 41.6	110 40 03.8	5,320	5.9	8	<.20	<.20	6.1	<.06	<.040
SRS-2	10/17/2006	1300	39 01 44.5	110 43 06.1	5,800	6.8	607	<.20	.20	3.8	<.06	.108
SRS-3	10/25/2006	1025	39 01 41.0	110 42 56.0	5,900	7.4	174	<.20	<.20	.68	<.06	<.040
SRS-4	10/17/2006	1510	39 01 41.7	110 42 46.7	5,610	8.0	867	<.20	<.20	.43	<.06	<.040
SRS-5	10/30/2006	1455	39 02 19.5	110 44 07.0	5,600	3.9	554	<.20	.81	6	.33	3.2
SRS-6	10/16/2006	1300	39 02 34.7	110 41 50.2	5,660	8.3	198	<.20	<.20	2.6	.60	.288
SRS-7	10/30/2006	1510	39 02 34.1	110 41 53.5	5,740	7.2	263	<.20	<.20	12	<.06	<.040
+SRS-8	10/30/2006	1500	39 03 11.8	110 35 12.3	5,200	6.7	487	<.20	<.20	29	<.06	<.040
SRS-9	10/30/2006	1445	38 53 32.7	110 39 32.7	6,600	7.7	1,146	<.20	.94	29	<.06	<.040
SRS-10	10/17/2006	1225	38 53 22.0	110 41 17.4	6,920	5.9	289	<.20	22	5.6	.08	1.2
SRS-11	10/30/2006	955	38 53 19.1	110 41 07.2	6,860	2.7	1,202	<.20	1.0	1.3	13	.350
SRS-12	10/25/2006	1415	38 53 13.3	110 40 22.8	6,880	6.7	1,123	<.20	.79	4.3	<.06	.051
SRS-13	10/25/2006	1030	38 53 10.8	110 40 28.4	6,830	4.0	528	<.20	.94	2.8	3.0	.057
+RS-14	10/26/2006	1240	38 15 32.0	110 43 44.5	4,800	7.9	221	<.20	.91	7.2	<.06	<.040
SRS-15	10/17/2006	1515	38 52 29.9	110 43 24.8	7,040	5.8	1,316	<.20	.43	2.9	.18	.423
SRS-16	10/30/2006	1010	38 52 29.9	110 43 25.8	7,000	9.0	1,105	<.20	.29	2.6	<.06	.082
SRS-17	10/26/2006	1200	38 54 38.4	110 25 58.5	4,400	8.4	156	<.20	2.1	41	<.06	.275

analyzed at the U.S. Geological Survey National Water Quality Laboratory, Denver, Colorado. Site ID, site identification; MDT, Mountain Daylight Time; sediment; <, less than lower reporting limit (see table 2); E, estimated value; +, geologic background sample]

Chromium dissolved (µg/L as Cr)	Copper dissolved (µg/L as Cu)	Iron dissolved (µg/L as Fe)	Lead dissolved (µg/L as Pb)	Manganese dissolved (µg/L as Mn)	Mercury dissolved (µg/L as Hg)	Molybdenum dissolved (µg/L as Mo)	Nickel dissolved (µg/L as Ni)	Selenium dissolved (µg/L as Se)	Silver dissolved (µg/L as Ag)	Uranium dissolved (µg/L as U)	Vanadium dissolved (µg/L as V)	Zinc dissolved (µg/L as Zn)
<2.0	<0.40	17	<0.08	6.1	<0.010	<4.0	0.43	<0.40	<0.20	0.33	<2.0	<0.60
<2.0	<.40	6.5	<.08	4.5	<.010	<4.0	.30	<.40	<.20	.29	<2.0	<.60
<2.0	<.40	16	<.08	1.3	<.010	<4.0	.41	<.40	<.20	.05	<2.0	.82
<2.0	<.40	36	.12	5.6	<.010	<4.0	.28	<.40	<.20	.08	<2.0	<.60
<2.0	.50	18	.08	6.6	<.010	<4.0	.43	<.40	<.20	.10	<2.0	<.60
<2.0	.42	23	.11	4.6	E.005	<4.0	.22	<.40	<.20	<.04	<2.0	<.60
<2.0	1.5	36	<.08	4.8	<.010	<4.0	.31	<.40	<.20	.81	<2.0	.79
<2.0	5.8	117	.40	5.0	<.010	<4.0	.99	<.40	<.20	4.9	<2.0	2.9
<2.0	<.40	17	<.08	4.5	E.005	<4.0	.19	<.40	<.20	.09	<2.0	<.60
<2.0	.46	20	<.08	5.9	<.010	<4.0	.34	<.40	<.20	.13	<2.0	<.60
<2.0	.94	22	<.08	5.7	<.010	<4.0	.29	<.40	<.20	.15	<2.0	<.60
<2.0	.90	9.8	<.08	.68	<.010	<4.0	.10	<.40	<.20	.47	<2.0	<.60
<2.0	1.0	147	.22	20	<.010	<4.0	.57	<.40	<.20	.30	<2.0	1
<2.0	7.4	89	.50	5.0	<.010	<4.0	.64	<.40	<.20	2.7	<2.0	1.5
<2.0	5.0	55	.45	5.7	<.010	<4.0	.59	<.40	<.20	4.6	<2.0	2.8
<2.0	9.2	103	.65	9.9	<.010	<4.0	1.0	<.40	<.20	3	<2.0	6.4
<2.0	.44	57	.14	6.1	E.006	<4.0	.32	<.40	<.20	.06	2.0	.82
<2.0	.83	54	.09	8.8	E.009	<4.0	.47	<.40	<.20	.16	2.7	.64
<2.0	.80	38	.16	9.1	E.007	<4.0	.33	<.40	<.20	.14	<2.0	.62
<2.0	1.2	33	.09	5.6	0.016	<4.0	.45	<.40	<.20	.26	<2.0	.72
<2.0	<.40	19	<.08	1.6	<.010	<4.0	.14	<.40	<.20	2.7	<2.0	<.60
<2.0	.75	31	.23	4.6	E.005	4.0	.33	<.40	<.20	6.4	<2.0	.67
<2.0	.50	13	<.08	4.8	E.005	<4.0	.18	<.40	<.20	.08	<2.0	<.60
<2.0	<.40	289	.10	2.4	<.010	<4.0	.22	.43	<.20	<.04	<2.0	<.60
<2.0	<.40	<6.0	<.08	69	<.010	<4.0	7.0	.42	<.20	14	<2.0	<.60
<2.0	<.40	32	<.08	3.6	.011	<4.0	.37	<.40	<.20	.10	<2.0	<.60
<2.0	<.40	<6.0	<.08	2.6	.012	<4.0	.37	2.1	<.20	<.04	<2.0	<.60
<2.0	92	6.4	.08	870	<.010	<4.0	35	7.2	<.20	60	<2.0	57
<2.0	8.2	<6.0	.18	22	<.010	<4.0	1.6	<.40	<.20	.64	<2.0	157
<2.0	<.40	<6.0	<.08	12	<.010	<4.0	1.5	4.8	<.20	.10	<2.0	<.60
<2.0	<.40	<6.0	<.08	.28	<.010	<4.0	.06	.62	<.20	.04	<2.0	<.60
<2.0	1.2	<6.0	.09	5.4	E.006	<4.0	.76	1.2	<.20	.28	<2.0	<.60
<2.0	298	13	.23	161	<.010	<4.0	591	18	<.20	10	<2.0	536
12	956	8,704	.17	507	<.010	<4.0	213	4.9	<.20	72	<2.0	48
<2.0	1.7	52	.11	28	E.009	<4.0	1.7	.59	<.20	.15	<2.0	<.60
<2.0	55	10	<.08	111	.014	<4.0	21	.74	<.20	6.6	<2.0	7.6
<2.0	.82	18	<.08	3.2	E.006	<4.0	.35	<.40	<.20	.11	<2.0	.69
<2.0	2.6	20	<.08	621	.011	<4.0	80	1.6	<.20	2.4	<2.0	53
<2.0	.42	<6.0	<.08	53	<.010	<4.0	1.4	2.1	<.20	.47	<2.0	.62
<2.0	1.4	34	<.08	2.1	.017	<4.0	.33	1.4	<.20	1.5	2.2	<.60

Table 4. Chemical analysis of leachate samples for trace-element concentrations from uranium waste dump samples, San Rafael Swell, Utah—

Site ID	Date	Time (MDT)	Latitude (dd.mm.ss.s)	Longitude (dd.mm.ss.s)	Elevation (ft)	pH (standard units)	Specific Conductance (µS/cm)	Antimony dissolved (µg/L as Sb)	Arsenic dissolved (µg/L as As)	Barium dissolved (µg/L as Ba)	Beryllium dissolved (µg/L as Be)	Cadmium dissolved (µg/L as Cd)
SRS-18	10/16/2006	1315	38 53 00.7	110 27 50.4	5,000	8.3	25	<.20	20	9.7	.10	<.040
SRS-19	10/16/2006	1240	38 53 01.1	110 27 48.4	4,960	7.6	22	<.20	20	12	.10	<.040
SRS-20	10/30/2006	1005	38 55 34.6	110 26 56.4	5,000	8.8	282	<.20	2.4	18	<.06	<.040
SRS-22	10/16/2006	1250	38 51 29.2	110 28 12.4	4,580	6.1	253	<.20	.22	10	<.06	.221
SRS-24	10/16/2006	1620	38 45 35.4	110 50 43.7	7,000	5.7	633	<.20	<.20	3.4	.12	.139
+SRS-25	10/19/2006	1050	38 45 33.5	110 51 12.7	7,040	9.4	59	<.20	.97	13	<.06	<.040
SRS-26	10/25/2006	1445	38 46 02.4	110 49 48.9	7,160	7.5	850	<.20	7.1	13	<0.06	<.040
SRS-27	10/17/2006	1250	38 46 31.0	110 50 07.8	7,160	7.4	959	<.20	13	2.5	<.06	.393
SRS-28	10/25/2006	1450	38 46 31.8	110 50 10.1	7,080	6.7	912	<.20	7.1	11	<.06	1.5
SRS-29	10/19/2006	1120	38 46 31.7	110 50 11.2	7,020	8.1	515	<.20	15	20	<.06	.074
SRS-30	10/13/2006	1025	38 46 23.5	110 49 51.4	7,120	7.9	818	<.20	.60	8.0	<.06	<.040
SRS-31	10/17/2006	1455	38 46 47.7	110 50 07.6	7,040	8.8	593	<.20	3.1	5.5	<.06	.167
SRS-33	10/25/2006	1045	38 47 43.4	110 50 07.3	7,045	8.6	261	<.20	22	34	<.06	<.040
SRS-35	10/17/2006	1500	38 47 38.3	110 50 15.4	7,040	7.1	206	<.20	19	12	<.06	<.040
SRS-36	10/11/2006	1625	38 47 39.5	110 50 15.7	7,050	7.4	132	<.20	33	45	<.06	<.040
+SRS-37	10/17/2006	1240	38 47 37.1	110 50 14.9	7,000	9.1	31	<.20	.28	23	<.06	<.040
SRS-38	10/17/2006	1255	38 47 38.2	110 50 16.8	7,020	8.3	85	.37	208	23	<.06	<.040
SRS-39	10/30/2006	1515	38 47 36.9	110 50 17.9	7,040	8.9	48	<.20	56	16	<.06	<.040
SRS-40	10/19/2006	1135	38 47 53.2	110 49 39.3	7,040	3.7	804	<.20	8.8	6.9	1.2	16
SRS-41	10/16/2006	1255	38 47 52.6	110 49 40.0	7,020	4.9	1,047	.35	36	3.9	.58	24
SRS-42	10/25/2006	1455	38 48 11.7	110 50 10.0	7,040	6.3	577	<.20	.72	6.6	<.06	.449
SRS-43	10/26/2006	1235	38 37 34.3	110 46 12.5	5,200	7.9	566	<.20	2.6	7.4	<.06	.054
SRS-44	10/26/2006	1255	38 37 33.4	110 46 09.7	5,180	6.8	369	<.20	1.6	8.3	<.06	<.040
SRS-45	10/26/2006	1250	38 37 32.0	110 46 07.3	5,180	5.0	1,035	<.20	.93	6.8	1.0	3.2
SRS-46	10/16/2006	1625	38 37 40.9	110 45 45.4	5,200	6.9	348	<.20	.78	6.6	<.06	<.040
SRS-47	10/19/2006	1115	38 38 35.7	110 44 21.8	5,600	7.8	361	<.20	1.7	59	.07	.069
SRS-48	10/17/2006	1230	38 38 21.9	110 44 25.3	5,480	6.4	677	<.20	3.2	2.8	<.06	<.040
SRS-49	10/25/2006	1055	38 45 26.3	110 57 07.2	5,920	4.3	172	<.20	2.8	3.4	.89	.824
SRS-50	10/17/2006	1505	38 45 27.7	110 57 05.2	6,000	3.5	444	<.20	5.7	11	3.5	4.8
SRS-51	10/25/2006	1435	38 45 28.0	110 56 57.8	5,880	3.6	320	<.20	8.5	9.6	3.0	15
SRS-52	10/16/2006	1305	38 45 29.8	110 56 57.8	5,880	7.7	420	<.20	10	10	<.06	<.040
SRS-53	10/25/2006	1040	38 45 30.2	110 56 56.2	5,960	8.6	688	<.20	2.4	3.4	<.06	.859
SRS-54	10/19/2006	1140	38 45 31.8	110 56 54.4	5,940	7.2	1,185	<.20	6.7	7.7	<.06	8
SRS-57	10/30/2006	1040	38 44 49.6	110 57 10.3	5,800	7.9	1,302	<.20	15	5.7	<.06	.178
SRS-58	10/30/2006	1025	38 44 50.2	110 57 08.8	5,800	7.8	2,120	<.20	1.1	12	<.06	.068
SRS-59	10/30/2006	1505	38 33 59.4	110 57 00.9	5,000	9.1	211	<.20	1.1	8.7	<.06	<.040
SRS-60	10/19/2006	1105	38 33 53.0	110 56 59.1	5,100	6.2	421	<.20	2.0	9.0	<.06	.085
SRS-61	10/30/2006	1000	38 33 50.8	110 56 59.7	5,040	8.1	337	<.20	1.8	8.8	<.06	.088
SRS-62	10/26/2006	1215	38 33 48.9	110 56 59.8	5,040	7.8	770	<.20	11	13	<.06	<.040
SRS-63	10/26/2006	1245	38 33 46.0	110 56 57.7	5,100	8.8	697	<.20	1.1	25	<.06	<.040
+SRS-64	10/25/2006	1410	38 34 00.7	110 57 06.7	4,880	7.8	662	<.20	1.1	31	<.06	<.040
SRS-65	10/19/2006	1125	38 33 39.5	110 57 16.6	4,860	9.1	227	<.20	12	17	<.06	<.040

Continued.

Chromium dissolved (µg/L as Cr)	Copper dissolved (µg/L as Cu)	Iron dissolved (µg/L as Fe)	Lead dissolved (µg/L as Pb)	Manganese dissolved (µg/L as Mn)	Mercury dissolved (µg/L as Hg)	Molybde-num dissolved (µg/L as Mo)	Nickel dissolved (µg/L as Ni)	Selenium dissolved (µg/L as Se)	Silver dissolved (µg/L as Ag)	Uranium dissolved (µg/L as U)	Vanadium dissolved (µg/L as V)	Zinc dissolved (µg/L as Zn)
<2.0	32	41	1.1	3	E.010	<4.0	1.2	1.5	<.20	10	9.1	3.9
<2.0	45	78	1.1	3.7	<.010	13	3.4	5.7	<.20	7.8	12	5.9
<2.0	1.8	21	<.08	3.8	<.010	<4.0	.36	3.1	<.20	3.9	<2.0	<.60
<2.0	66	<6.0	<.08	6.7	.007	<4.0	2.2	<.40	<.20	11	<2.0	21
<2.0	6.1	38	<.08	238	<.010	<4.0	21	<.40	<.20	.49	<2.0	7.5
<2.0	<.40	42	<.08	2.1	.012	<4.0	.62	.45	<.20	.17	4.2	77
<2.0	3.8	<6.0	<.08	1.6	.012	<4.0	.22	<.40	<.20	5.4	<2.0	<.60
<2.0	14	10	.11	24	<.010	<4.0	5.1	3.8	<.20	13	<2.0	13
<2.0	63	6.3	<.08	70	E.008	<4.0	19	.44	<.20	40	<2.0	100
<2.0	27	121	0.50	5.7	E.007	<4.0	3.8	.48	<.20	16	<2.0	15
<2.0	.66	<6.0	<.08	1.2	<.010	<4.0	.09	.48	<.20	.96	<2.0	<.60
<2.0	8.7	<6.0	<.08	22	.014	<4.0	15	<.40	<.20	3.7	<2.0	43
<2.0	5.2	8.8	<.08	2.2	.013	<4.0	.46	<.40	<.20	9.1	<2.0	<.60
<2.0	4.2	12	.15	2.0	.012	<4.0	.40	<.40	<.20	5.8	<2.0	.98
<2.0	4.2	15	.08	3.0	<.010	<4.0	.56	<.40	<.20	4.3	<2.0	1.8
<2.0	<.40	145	.10	14	<.010	<4.0	.53	<.40	<.20	.41	2.3	1.5
<2.0	34	33	.62	2.5	E.008	<4.0	1.4	.54	<.20	40	14	9.4
<2.0	24	44	.63	1.4	<.010	<4.0	1.2	.52	<.20	8.7	25	8.8
<2.0	325	61,961	1.5	924	.014	<4.0	804	7.3	<.20	1,010	<2.0	5,622
<2.0	12,651	50	.45	1,528	E.008	<4.0	2,047	4.7	<.20	215	<2.0	7,460
<2.0	1.1	10	<.08	205	.012	<4.0	35	.44	<.20	.56	<2.0	35
<2.0	3.8	<6.0	<.08	12	E.010	<4.0	.80	.41	<.20	5.6	<2.0	.88
<2.0	3.3	52	<.08	4.2	E.009	<4.0	.51	<.40	<.20	4.8	<2.0	<.60
<2.0	1,153	6.9	.13	235	E.009	<4.0	48	2.0	<.20	107	<2.0	318
<2.0	4.3	11	<.08	5.6	<.010	<4.0	1.4	<.40	<.20	3.3	<2.0	2.4
<2.0	5.0	224	5.9	15	.024	<4.0	3.0	.49	<.20	30	2.3	14
<2.0	2.0	33	.13	40	E.007	<4.0	4.4	1.6	<.20	2.1	<2.0	23
<2.0	2,973	<6.0	<.08	177	.010	<4.0	161	.44	<.20	41	<2.0	265
<2.0	2,962	41	.70	357	.010	<4.0	292	4.8	<.20	456	<2.0	869
<2.0	6,452	66	.30	208	E.008	<4.0	365	3.4	<.20	712	<2.0	3,060
<2.0	11	17	.83	3.9	E.006	6.4	.69	<.40	<.20	13	<2.0	2.0
<2.0	2.3	<6.0	<.08	3.9	.016	16	1.3	<.40	<.20	15	<2.0	3.2
<2.0	17	13	.49	118	.011	16	122	1.0	<.20	10	<2.0	587
<2.0	20	8.1	.08	106	E.007	<4.0	3.5	75	<.20	10	3.4	8.8
<2.0	.77	<6.0	<.08	4.1	<.010	5.6	.27	2.0	<.20	.93	<2.0	<.60
<2.0	.98	25	.09	5.3	<.010	<4.0	.47	1.9	<.20	.28	3.3	.82
<2.0	2.8	<6.0	<.08	4.0	.011	4.9	.78	.42	<.20	19	<2.0	2.3
<2.0	.42	15	<.08	6.6	<.010	4.3	.58	.55	<.20	12	<2.0	1.2
<2.0	.89	<6.0	.12	3.5	E.006	32	.76	.83	<.20	201	<2.0	<.60
<2.0	1.8	14	<.08	1.8	.011	<4.0	.25	68	<.20	3.4	<2.0	<.60
<2.0	<.40	17	<.08	1.6	E.008	<4.0	.17	3.3	<.20	.94	2.3	<.60
<2.0	1.8	10	<.08	1.3	.012	<4.0	.22	1.2	<.20	11	10	<.60

Table 4. Chemical analysis of leachate samples for trace-element concentrations from uranium waste dump samples, San Rafael Swell, Utah—

Site ID	Date	Time (MDT)	Latitude (dd.mm.ss.s)	Longitude (dd.mm.ss.s)	Elevation (ft)	pH (standard units)	Specific Conductance (µS/cm)	Antimony dissolved (µg/L as Sb)	Arsenic dissolved (µg/L as As)	Barium dissolved (µg/L as Ba)	Beryllium dissolved (µg/L as Be)	Cadmium dissolved (µg/L as Cd)
+SRS-66	10/26/2006	1220	38 33 37.2	110 57 16.0	5,000	9.2	441	<.20	3.8	11	<.06	<.040
SRS-67	10/25/2006	1425	38 33 28.7	110 57 06.4	4,680	7.8	844	<.20	5.8	7.3	.09	<.040
SRS-68	10/26/2006	1205	38 33 24.6	110 57 02.2	4,640	9.2	83	<.20	1.8	15	<.06	<.040
SRS-69	10/25/2006	1510	38 33 19.3	110 57 02.8	4,700	8.4	245	<.20	<.20	19	<.06	<.040
SRS-70	10/30/2006	1450	38 43 17.3	110 58 02.6	5,820	8.0	652	<.20	6.8	13	<.06	<.040
SRS-71	10/18/2006	1425	38 43 25.3	110 58 09.1	5,820	8.0	736	<.20	2.2	6.9	<.06	<.040
SRS-72	10/18/2006	1410	38 44 02.7	110 58 09.3	5,740	8.3	575	<.20	2.5	7.4	<.06	<.040
+SRS-73	10/30/2006	1045	38 44 03.8	110 58 01.0	5,620	8.6	288	<.20	.29	3.3	<.06	<.040
SRS-74	10/18/2006	1420	38 44 17.7	110 58 12.9	5,900	8.4	295	.24	42	18	<.06	<.040
SRS-75	10/30/2006	1030	38 44 24.4	110 58 06.6	5,920	6.0	650	<.20	3.5	4.9	<.06	.562
SRS-76	10/18/2006	1355	38 44 27.0	110 57 47.2	6,020	7.9	1,375	<.20	8.1	8.0	<.06	<.040
SRS-77	10/30/2006	1015	38 44 25.0	110 58 13.0	5,920	7.4	313	<.20	4.7	16	<.06	<.040
SRS-78	10/18/2006	1350	38 44 24.1	110 58 10.1	5,880	8.4	450	<.20	1.1	7.9	<.06	<.040
SRS-79	10/18/2006	1405	38 45 57.4	110 55 31.0	6,140	7.7	1,046	<.20	28	5.4	<.06	.189
SRS-80	10/30/2006	1020	38 45 59.0	110 55 33.2	6,200	7.7	936	<.20	18	2.3	<.06	.825
SRS-81	10/30/2006	1035	38 45 59.9	110 55 39.8	6,160	7.7	790	<.20	18	23	<.06	.086
SRS-83	10/16/2006	1310	38 45 45.4	110 55 42.3	6,160	7.5	698	<.20	39	4.7	<.06	<.040
SRS-84	10/11/2006	1600	38 41 01.9	110 59 42.2	5,140	3.5	856	<.20	.92	.53	5.0	5.2
SRS-85	10/13/2006	1345	38 41 01.0	110 59 45.5	5,100	4.1	780	<.20	.42	2.6	3.0	2.6
+SRS-86	10/13/2006	1355	38 41 00.2	110 59 40.9	5,120	9.3	960	<.20	.36	62	<.06	<.040
SRS-87	10/13/2006	1340	38 41 02.7	110 59 38.7	5,200	4.1	894	<.20	2.3	1.0	3.0	9.4
SRS-88	10/11/2006	1610	38 41 00.2	110 59 38.8	5,160	6.5	1,003	<.20	.45	3.8	<.06	.243
SRS-89	10/13/2006	1400	38 41 01.3	110 59 30.0	5,160	4.0	1,178	.30	6.0	6.0	4.6	16
SRS-90	10/11/2006	1615	38 41 02.7	110 59 30.6	5,200	3.5	1,315	<.20	4.5	6.5	5.7	24
SRS-91	10/16/2006	1615	38 41 23.3	110 59 18.4	5,880	6.7	428	<.20	1.3	3.1	<.06	2.4
SRS-92	10/11/2006	1605	38 41 22.3	110 59 19.7	5,880	6.5	474	<.20	1.5	1.2	<.06	.301
SRS-93	10/16/2006	1555	38 41 17.3	110 59 10.1	5,580	7.0.	577	<.20	3.2	18	<.06	<.040
SRS-94	10/13/2006	1335	38 40 35.2	111 00 19.1	5,400	8.1	692	<.20	4.6	3.4	<.06	1.7

Continued.

Chromium dissolved (µg/L as Cr)	Copper dissolved (µg/L as Cu)	Iron dissolved (µg/L as Fe)	Lead dissolved (µg/L as Pb)	Manganese dissolved (µg/L as Mn)	Mercury dissolved (µg/L as Hg)	Molybde-num dissolved (µg/L as Mo)	Nickel dissolved (µg/L as Ni)	Selenium dissolved (µg/L as Se)	Silver dissolved (µg/L as Ag)	Uranium dissolved (µg/L as U)	Vanadium dissolved (µg/L as V)	Zinc dissolved (µg/L as Zn)
<2.0	.70	37	<.08	1.1	.019	<4.0	.16	6.9	<.20	1.2	9.0	.79
<2.0	.98	16	.14	2.1	.015	<4.0	.50	22	<.20	.59	9.0	<.60
<2.0	1.4	49	.18	2.5	E.008	<4.0	.32	2.3	<.20	.99	6.8	.70
<2.0	.44	23	<.08	2.2	.015	<4.0	.28	1.2	<.20	<.04	<2.0	<.60
<2.0	4.4	9.6	<.08	2.3	<.010	13	.28	3.4	<.20	74	2.7	<.60
<2.0	5.1	18	<.08	17	.011	<4.0	.58	2.2	<.20	4.2	4.4	<.60
<2.0	1.7	7.3	<.08	5.0	.020	<4.0	.25	3.0	<.20	5.6	<2.0	<.60
<2.0	<.40	21	<.08	2.0	<.010	<4.0	.18	.50	<.20	.47	3.8	<.60
<2.0	6.6	<6.0	<.08	5.7	.011	31	.78	22	<.20	120	<2.0	.77
<2.0	1.6	6.2	.14	20	<.010	43	1.8	<.40	<.20	48	<2.0	4.5
<2.0	3.3	7.6	.09	5.7	.018	8.9	.55	3.5	<.20	4.6	<2.0	<.60
<2.0	7.0	32	.98	6.4	<.010	6.8	1.5	.99	<.20	3.6	<2.0	1.3
<2.0	.77	<6.0	<.08	4.7	E.010	<4.0	.28	<.40	<.20	.22	<2.0	<.60
<2.0	2.3	<6.0	<.08	7.8	.015	6.1	1.2	1.4	<.20	14	<2.0	1.3
<2.0	4.5	<6.0	<.08	66	<.010	<4.0	10	5.0	<.20	3.5	<2.0	11
<2.0	1.2	9.4	<.08	14	<.010	<4.0	4.1	3.2	<.20	1.9	<2.0	.84
<2.0	1.6	<6.0	<.08	2.3	<.010	<4.0	.51	4.6	<.20	35	2.3	.63
<2.0	1,106	66	.08	560	E.008	<4.0	191	19	<.20	2,762	2.8	730
<2.0	1,000	53	.24	373	E.006	<4.0	139	6.5	<.20	1,451	<2.0	338
<2.0	0.49	<6.0	<.08	.35	<.010	<4.0	.12	8.4	<.20	.54	<2.0	<.60
<2.0	393	102	.54	466	<.010	<4.0	231	7.6	<.20	1,135	3.6	583
<2.0	1.8	<6.0	<.08	126	E.006	<4.0	19	.77	<.20	13	<2.0	3.4
<2.0	849	140	20	960	E.006	6.3	362	12	<.20	1,737	2.9	1,647
4.1	847	4,109	2.3	1,348	E.006	4.3	550	18	<.20	2,969	2.6	2,356
<2.0	1.6	6.2	<.08	24	E.007	<4.0	15	.61	<.20	17	<2.0	27
<2.0	2.6	15	.11	42	E.006	<4.0	17	<.40	<.20	9.2	<2.0	4.9
<2.0	1.9	<6.0	<.08	10	E.006	4.9	1.4	8.2	<.20	5.8	<2.0	<.60
<2.0	6.7	6.8	3.6	10	E.005	13	2.1	<.40	<.20	16	<2.0	15

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Freeman and others—Assessment of Nonpoint Source Chemical Loading Potential to Watersheds Containing Uranium Waste Dumps Associated with Uranium Exploration and Mining, San Rafael Swell, Utah—SIR 2008-5110