Chapter 9

TRACE ELEMENT CHEMISTRY OF SOIL AND DUST SAMPLES IN THE NELLIS DUNES RECREATION AREA

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1. Introduction

Many naturally occurring chemical elements are potentially hazardous to health when inhaled. In particular, the elements arsenic, lead, cadmium and mercury are known to cause multiple adverse health effects (Jarup, 2003; Plumlee et al., 2006). Naturally occurring mineral dusts such as those at NDRA, are composed of a mixture of minerals, sorbed chemical elements, and biological substances, each with differing biosolubility and bioreactivity (Plumlee et al., 2006). There is limited information about the effects from exposure to two or more substances and thus, it is not known whether their ultimate effects are synergistic (enhanced) or antagonistic (reduced). In instances where one or more hazardous elements are found, site-specific health risk assessments are necessary to evaluate the biological effects from inhalation of these complex mixtures of substances.

Because both ORV activity and natural wind conditions at NDRA were found to emit substantial amounts of dust, we wanted to determine the concentrations of trace elements in dust and whether these concentrations might pose a potential threat to ORV operators or other visitors at the site. To do this, we initially scanned soil samples for 66 different elements using inductively coupled plasma mass spectroscopy (ICP-MS). Based on those initial results we narrowed our focus to 18 elements, and analyzed several different grain size fractions of soils and airborne samples that were derived from specific map units at NDRA.

2. Materials and methods

2.1 Field procedures

Soil samples were collected from the upper 2-3 cm of the 17 different surface types in the Nellis Dunes area and from five unpaved areas used for parking. Dust samples were also collected from 16 of the 17 surface types and from five unpaved parking areas using a Portable In Situ Wind Erosion Laboratory (PI-SWERL). This instrument creates an increased wind shear near the ground producing wind erosion under controlled conditions, and allows collection of the emitted particles. A detailed description of the instrument can be found in Chapter 4 of this report. PI-SWERL samples were collected both on ORV trails and on undisturbed terrain. No samples were collected from areas of outcropping bedrock or outcropping petrocalcic horizons, which contain negligible emittable dust.

Fig. 1 shows the sampling locations. Note that the scale of the map does not allow a clear distinction between the PI-SWERL sampling spots on the trails and the corresponding spots on undisturbed terrain. Therefore, the number of sampling locations is substantially greater than the number shown on the map.

2.2 Laboratory procedures

The soil samples collected from each of the surface units were air dried and sieved to remove coarse fragments (>2 mm). The <2 mm fraction was then acid digested in accordance with EPA Method 3052 (USEPA, 1996). Following digestion, the soil samples were initially scanned for 66 different elements using inductively coupled plasma mass spectroscopy (ICP-MS). The purpose of the initial semi-quantitative scan was to identify potential elements of environmental concern in the samples. Based on the results of the semi-quantitative scan, the following elements were identified as elements of potential concern: arsenic (As), cobalt (Co), chromium (Cr), cesium (Cs), copper (Cu), cadmium (Cd), silver (Ag), nickel (Ni), lead (Pb), strontium (Sr), uranium (U), vanadium (V), thallium (Tl), boron (B), molybdenum (Mo), antimony (Sb), and mercury (Hg). The soil and unpaved parking area samples were then re-analyzed quantitatively for these elements using ICP-MS. The arsenic results are addressed in Chapter 10 in this report and are not discussed further in the current chapter.

Analyses for the elements of potential environmental concern were also made on dust samples collected using the PI-SWERL. These samples were dry sieved to 60 µm. The 60 µm limit was used as a cut-off for total suspendable particles (TSP), because it represents

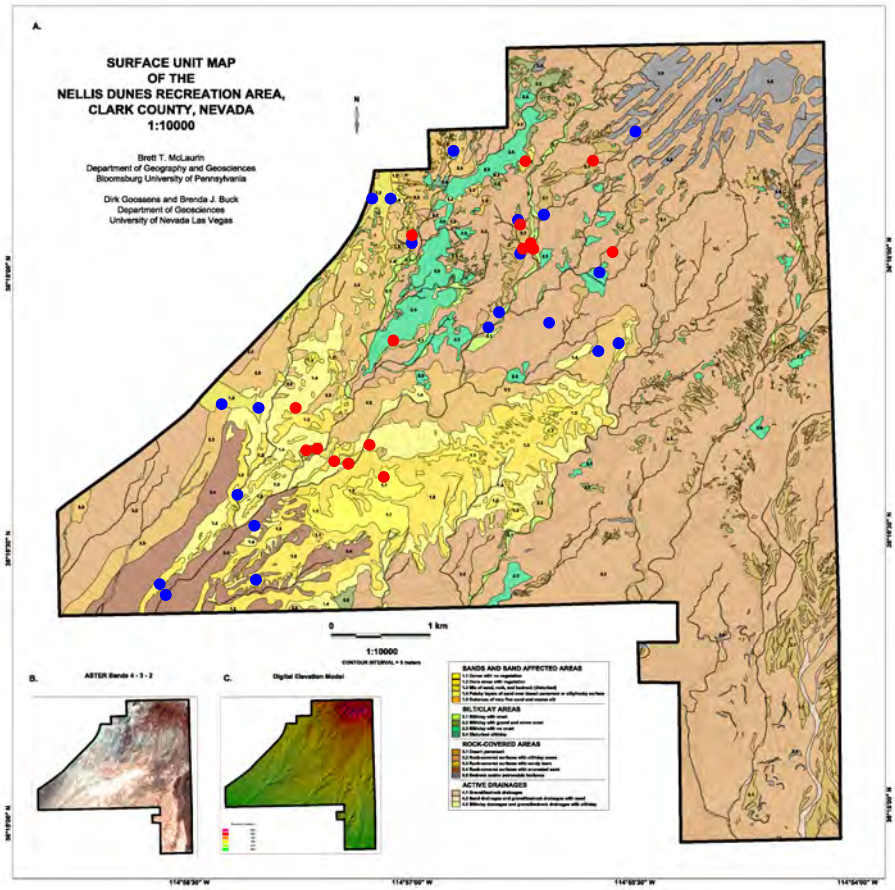

Fig. 1: Location of the sampling sites. More than one sample may have been taken from the locations indicated on the map (see text for details). Blue: soil samples; red: PI-SWERL samples.

the maximum size of grains that will still be transported in short-term suspension during average wind speed and turbulence (Pye and Tsoar, 1990). It also nearly coincides with the maximum diameter of silt (52 µm or 63 µm, depending on which criterion is used; Goossens and Buck, 2009). Coarser particles are unlikely to be transported very far or inhaled and therefore were excluded from this study.

To determine the water soluble constituents in the PI-SWERL samples, 1:10 soil:water extracts were prepared on the 0-60 µm size fraction. Finer size fractions could not be separated without the use of water, which would result in the loss of information regarding the concentrations of the water soluble components. The 1:10 extracts were used instead of a saturated paste because of limited sample sizes. These samples were allowed to sit overnight and were then filtered to obtain the supernatant. The supernatant solution was also analyzed by ICP-MS using similar instrument settings and quality control measures.

The remaining sample was then separated into <10 µm (PM10) and 10-60 µm size fractions by sedimentation and wet sieving and acid-digested in accordance with EPA Method 3052 prior to analysis.

3. Results

3.1 Soil and PI-SWERL samples

The concentrations of Cu, Cd, Ag, Ni, Pb, U, V, B, and Mo were typically lower, sometimes by as much as one order of magnitude, in the soil samples as compared to the PI-SWERL samples (Tables 1 and 2). These results are expected because of the larger particle size (<2 mm) of the soil samples as compared to the PI-SWERL samples (<10 µm and 10-60 µm). The x-ray diffraction (XRD) results (see Chapter 8) demonstrated that the finer fractions of the samples are dominated by smectite minerals, which are known to be major contributors to soil cation exchange capacity (CEC) and therefore, affect the retention of metals in the soil (Reid-Soukup and Ulery, 2002). The amount of smectite in the soil samples is "diluted" relative to that in the PI-SWERL samples, because smectite is only present in the finest portions of these samples.

The concentrations of Co, Cr, Cs, Tl, Sb, Sr, and Hg in the soil samples were generally similar to those in the PI-SWERL samples (Tables 1 and 2).

In general, the lowest elemental concentrations in the soil samples occurred in the sand areas, particularly in unit 1.2 (dunes with vegetation). These results are expected because the sand areas have the lowest proportion of clay and silt, and are thus less likely to have smectite or other highly chemically reactive minerals that will retain metals. The lowest reported concentrations of Pb, Sr, Mo, Sb, and Tl occurred in samples from the parking lots. The highest concentrations of most elements, as expected, occurred in samples from silt/clay areas, particularly in units 2.2 (silt/clay with gravel) and 2.3 (aggregated silt).

In contrast, the lowest elemental concentrations in the PI-SWERL samples occurred in various units, and not within the sand areas. This may be caused by variations in clay mineral composition as well as other minor mineralogical differences between samples. XRD analyses showed that the mineralogical composition of the clay (<2 µm) and silt (2-20 µm) fractions of the samples is relatively uniform, and dominated by smectite minerals. The highest elemental concentrations are primarily in unit 1.5, which consists of outcrops of very fine sand and coarse silt. The results of the XRD analyses showed that the <2 µm and 2 to 20 µm fractions of this sample are dominated by highly crystalline smectite. Therefore, combining the trace element results with the XRD results suggests that unit 1.5 smectite may have a lower layer charge than most of the other smectites

present in the Nellis Dunes area. Smectites with lower layer charge have a greater shrink-swell capacity than smectites with higher layer charge resulting in greater amounts of water, hydrated metal cations and organic molecules being attracted to the interlayer region (Reid-Soukup and Ulery, 2002).

3.2 Soluble PI-SWERL extracts

The pH values of the soluble PI-SWERL extracts are near-neutral to alkaline, ranging from 6.58 to 9.11 (Table 3). Electrical conductivity (EC) values of the extracts range from 0.06 to 2.43 dS m^{-1} and document the salinity of most of the soils in the NDRA,

Table 1: Soil sample chemistry

Surface Unit	Trace Elements									Trace Elements						
	Co	Cr	Cs	Cu	Cd	Ag	Ni	Pb	Sr	U	V	Tl	B	Mo	Sb	Hg
					$\mu g\ g^{-1}$								$\mu g\ g^{-1}$			
	United States Environmental Protection Agency Regional Screening Levels[1]								United States Environmental Protection Agency Regional Screening Levels[1]							
Residential Soil	23	NP	NP	3,100	70	390	1,500	400	47,000	230	390	NP	16,000	390	31	5.6
Groundwater Protection	0.49	NP	NP	51	1.4	1.6	48	NP	770	49	180	NP	23	3.7	0.66	0.03
Unit 1: Sand Areas																
1.1	7.58	9.28	1.31	3.39	0.13	0.34	3.95	13.99	169.92	1.19	8.75	0.335	0.97	1.16	1.10	0.015
1.2	5.68	7.23	1.19	4.69	0.12	0.32	3.91	16.95	150.19	1.19	7.28	0.292	0.34	1.09	0.93	0.019
1.3	9.29	13.83	1.88	5.86	0.18	0.62	6.71	14.88	236.09	1.78	21.36	0.308	2.49	1.41	1.11	0.049
1.4	9.65	16.99	1.47	5.22	0.14	0.49	6.44	18.03	213.20	1.32	17.24	0.314	5.28	1.20	1.15	0.018
1.5	7.17	14.09	3.90	4.92	0.10	0.59	5.67	18.13	310.62	4.60	25.26	0.545	6.29	4.39	1.15	0.026
Unit 2: Silt/clay Areas																
2.1	10.35	20.18	1.83	8.06	0.18	0.78	8.96	26.66	277.08	3.01	32.86	0.50	8.05	1.87	1.35	0.032
2.2	7.02	9.11	6.34	5.63	0.09	0.25	6.00	13.53	199.55	7.44	38.97	1.05	6.53	8.01	1.15	0.036
2.3	13.93	43.50	0.54	22.23	0.50	0.90	20.98	29.69	206.45	4.81	90.71	0.80	34.78	2.42	1.76	0.038
2.4	8.60	16.06	3.15	6.65	0.15	0.52	6.94	19.63	205.57	2.17	26.11	0.43	5.60	1.49	1.20	0.023
Unit 3: Rock-covered Areas																
3.1	10.45	24.97	0.95	11.79	0.28	0.58	12.38	23.94	205.90	2.96	38.18	0.51	11.29	2.19	1.58	0.029
3.2	11.78	24.45	0.65	12.59	0.25	0.41	12.38	28.27	239.25	2.33	38.32	0.40	11.74	1.62	1.57	0.033
3.3	12.87	24.03	0.64	13.46	0.26	0.34	12.59	25.36	209.35	1.88	33.57	0.38	11.58	1.72	0.90	0.051
3.4	8.61	20.69	2.19	6.95	0.20	0.60	8.24	21.62	188.01	2.15	29.69	0.39	6.20	1.64	1.24	0.028
3.5	12.66	34.71	0.21	15.97	0.41	0.61	17.42	27.97	210.73	2.93	51.72	0.46	15.83	1.91	1.82	0.036
Unit 4: Drainage Areas																
4.1	13.98	19.73	2.96	11.21	0.32	0.62	10.70	26.70	630.01	3.60	38.70	0.70	9.23	4.56	1.70	0.036
4.2	8.08	10.53	3.48	7.50	0.24	0.26	6.72	20.58	132.04	3.07	19.04	0.54	4.00	3.16	1.31	0.039
4.3	16.14	22.11	1.62	9.39	0.69	0.72	12.38	18.23	821.05	3.46	40.75	0.59	10.15	4.47	1.50	0.031
Unpaved Parking Areas																
NA[2]	9.77	15.80	1.56	8.42	0.26	0.28	7.46	10.90	109.45	1.39	21.87	0.27	4.85	1.00	0.54	0.019
NA	9.97	16.39	1.47	7.30	0.29	0.35	8.17	12.15	120.01	1.59	20.86	0.26	4.26	1.18	0.53	0.026
NA	11.48	18.07	1.36	459.0	0.20	0.33	7.58	77.38	149.97	1.54	23.73	0.26	4.44	1.25	0.66	0.016
NA	12.13	14.20	1.99	7.36	0.23	0.25	7.11	21.44	128.79	2.12	22.70	0.50	5.02	2.53	0.83	0.020
Buffalo River Standard																
NA	16.9	118.7	0.8	70.1	2.9	1.4	36.0	245.0	144.7	3.2	81.4	1.0	45.2	4.8	4.3	0.6
	13-14	118-126	5.7-5.9	NP[3]	2.6-3.2	NP	39-47	133-167	NP	3.0-3.2	91-99	NP	NP	NP	2.8-3.4	NP
Bradford et al. 1996[4]																
	3-47	23-1579	1-9	9-96	0.1-1.7	0.1-8.3	9-509	12-97	20-271	1-21	39-288	0.2-1.1	1-74	0.1-9.6	0.2-2.0	0.1-0.9
	14.9	122	3.1	28.7	0.36	0.8	57	23.9	128	4.7	112	0.56	19	1.3	0.6	0.26
Shacklette & Boerngen, 1984[4]																
	<3-50	36586	NP	2-300	NP	NP	<5-700	<10-700		1-8	7-500	NP	<20-300	<3-7	NP	<0.01-4.6
	7.1	41	NP	21	NP	NP	15	17	200	2.5	70	NP	23	0.85	NP	0.046

NOTES:

1. The Screening Levels (SLs) are developed using risk assessment guidance from the EPA Superfund program and are used for site "screening" and as initial cleanup goals, if applicable. The groundwater protection concentrations shown are soil concentrations considered to be protective of groundwater resources.
2. NA = Not applicable
3. NP = Not provided.
4. Reported concentrations of trace elements in soil samples in these publications.

Table 2: Trace element concentrations in PI-SWERL samples

Surface Unit Sample	Particle Size (µm)	Co	Cr	Cs	Cu	Cd	Ag	Ni	Pb	Sr	U	V	Tl	B	Mo	Sb	Hg
		µg g^{-1}														µg g^{-1}	
		United States Environmental Protection Agency Regional Screening Levels[1]															
Residential Soil		23	NP	NP	3,100	70	390	1,500	400	47,000	230	390	NP	16,000	390	31	5.6
Groundwater Protection		0.49	NP	NP	51	1.4	1.6	48	NP	770	49	180	NP	23	3.7	0.66	0.03
Unit 1: Sand Areas																	
1.1R	<10	12.35	24.93	1.32	45.48	0.67	0.33	25.53	27.36	153.56	3.52	83.83	0.59	95.84	3.37	1.64	0.056
	10 to 60	9.54	23.65	2.15	24.78	0.45	0.29	17.47	21.26	162.62	3.49	55.80	0.50	41.72	3.92	1.36	0.140
1.1NR	<10	12.02	21.92	1.73	46.49	0.71	0.34	25.58	24.62	156.40	2.93	77.13	0.54	91.19	3.14	1.51	0.097
	10 to 60	8.52	21.50	1.72	43.77	0.41	0.27	15.31	16.54	121.86	3.10	49.45	0.48	30.09	3.16	1.06	0.102
1.2R	<10	12.07	34.14	1.39	29.71	0.46	4.73	25.60	19.78	159.84	3.80	100.48	0.54	93.01	2.05	1.17	0.044
	10 to 60	10.90	25.80	1.99	26.62	0.37	0.24	18.84	18.35	159.65	4.47	66.20	0.57	44.39	4.29	1.23	0.081
1.2NR	<10	11.79	40.83	3.16	36.22	0.63	1.54	27.30	21.12	100.24	3.11	101.43	0.53	109.29	2.19	1.24	0.046
	10 to 60	10.47	25.90	2.00	21.61	0.37	0.51	18.52	21.13	183.93	3.70	67.87	0.55	49.16	2.56	1.12	0.076
1.3R	<10	11.85	23.33	1.81	32.86	0.55	0.50	24.20	31.34	128.82	3.11	80.41	0.70	94.71	4.54	1.79	0.066
	10 to 60	11.04	23.89	1.90	28.83	0.90	0.28	18.74	30.93	99.62	3.92	61.40	0.73	46.34	4.79	1.57	0.070
1.3NR	<10	9.31	14.23	1.30	28.50	0.48	0.24	19.20	33.08	102.13	2.28	62.48	0.49	72.01	2.63	1.64	0.045
	10 to 60	9.26	23.59	1.67	28.96	0.42	0.23	18.93	27.79	123.12	2.86	55.36	0.54	41.30	2.97	1.52	0.062
1.4R	<10	10.12	20.68	1.41	39.30	0.77	0.22	22.77	32.36	110.93	2.25	67.20	0.44	75.79	2.28	1.68	0.046
	10 to 60	9.92	32.65	1.30	39.38	0.54	0.41	19.56	30.62	160.33	3.11	66.98	0.45	41.79	2.47	1.36	0.061
1.4NR	<10	12.98	26.84	1.94	40.88	0.78	0.36	26.83	28.46	128.92	2.55	80.68	0.52	76.88	4.26	1.46	0.069
	10 to 60	10.42	37.17	1.15	32.06	0.52	0.32	22.02	23.04	187.60	3.52	78.51	0.48	45.80	2.35	1.53	0.056
1.5R	<10	13.41	29.97	4.32	28.55	0.60	0.57	30.36	19.16	148.19	9.64	125.82	0.85	99.97	39.87	2.30	0.039
	10 to 60	15.40	30.55	2.15	21.59	0.69	0.31	26.39	18.69	144.06	10.36	76.08	0.99	67.09	42.17	2.73	0.078
1.5NR	<10	11.44	27.73	6.45	28.43	1.07	0.45	23.43	17.52	108.27	11.12	106.37	0.92	116.43	58.60	1.75	0.038
	10 to 60	14.44	32.19	5.38	26.71	1.41	0.63	23.43	20.68	193.07	15.03	88.47	1.20	91.81	74.77	1.82	0.051
Unit 2: Silt/clay Areas																	
2.1R	<10	10.14	24.79	2.41	27.15	0.49	0.32	22.14	19.25	161.73	3.29	83.98	0.80	62.71	12.11	1.30	0.034
	10 to 60	12.06	30.53	2.16	29.65	0.53	0.26	25.08	18.82	167.56	4.50	77.34	1.00	57.75	10.21	1.54	0.049
2.1NR	<10	10.88	25.41	2.13	35.27	0.58	0.53	24.94	19.16	141.14	3.37	91.66	0.87	90.62	9.92	1.43	0.043
	10 to 60	10.49	29.16	1.94	27.07	0.48	0.28	21.62	19.79	135.97	4.06	74.30	0.88	47.37	11.72	1.47	0.044
2.2R	<10	10.53	22.93	4.10	22.14	0.34	0.23	20.34	13.45	185.67	3.30	121.51	0.77	62.98	5.01	1.08	0.038
	10 to 60	12.33	33.22	2.59	24.89	0.32	0.38	22.58	17.81	167.40	3.92	115.24	0.96	57.10	5.22	1.28	0.048
2.2NR	<10	9.97	40.33	2.17	33.65	0.50	0.53	24.38	20.33	163.28	5.80	130.79	0.77	79.40	9.04	1.14	0.047
	10 to 60	10.71	33.54	1.85	29.59	0.52	0.30	22.26	22.49	249.34	6.09	105.57	0.82	61.72	8.20	1.44	0.052
2.3R	<10	11.06	34.36	4.41	30.06	0.57	0.54	25.04	15.43	106.85	3.24	108.04	0.69	90.11	1.62	0.93	0.020
	10 to 60	12.59	34.00	1.94	30.51	0.57	0.58	23.54	22.39	182.03	3.82	86.54	0.78	62.68	2.33	1.12	0.043
2.3NR	<10	11.90	40.44	2.42	36.30	0.68	0.61	27.07	18.24	171.22	3.95	115.59	0.73	87.37	2.08	1.17	0.033
	10 to 60	13.69	33.38	2.22	33.50	0.55	0.46	23.88	20.71	211.84	4.18	87.32	0.80	63.38	2.78	1.41	0.033
2.4R	<10	11.48	37.27	2.13	30.75	0.56	0.47	26.47	16.57	214.19	3.48	109.09	0.57	101.22	1.46	1.00	0.027
	10 to 60	11.00	29.05	1.57	26.56	0.48	0.37	23.08	18.33	215.23	3.48	88.04	0.54	71.59	1.70	1.08	0.035
2.4NR	<10	11.67	49.18	1.87	36.64	0.63	0.56	28.22	17.31	159.00	3.61	118.45	0.54	106.34	1.42	1.04	0.038
	10 to 60	11.65	37.83	1.36	29.33	0.50	0.68	25.05	18.67	210.61	4.16	100.95	0.62	87.75	1.85	1.17	0.037

NOTES:

1. The Screening Levels (SLs) are developed using risk assessment guidance from the EPA Superfund program and are used for site "screening" and as initial cleanup goals, if applicable. The groundwater protectionconcentrations shown are soil concentrations considered to be protective of groundwater.
2. NP = Not provided
3. Reported range of concentrations in wind-erodible Owens Lake playa crusts.
4. Reported range of concentrations in the <50 µm fractions of dust samples from the southwestern United States.
5. Concentrations shown are for one dust sample from the eastern Mojave Desert and one from southeastern Nevada. The concentrations are estimated from Figure 3 in the manuscript.

Table 2 (ctd.): Trace element concentrations in PI-SWERL samples

Surface Unit Sample	Particle Size (µm)	Co	Cr	Cs	Cu	Cd	Ag	Ni	Pb	Sr	U	V	Tl	B	Mo	Sb	Hg
		µg g^{-1}														µg g^{-1}	
		United States Environmental Protection Agency Regional Screening Levels[1]															
Residential Soil		23	NP	NP	3,100	70	390	1,500	400	47,000	230	390	NP	16,000	390	31	5.6
Groundwater Protection		0.49	NP	NP	51	1.4	1.6	48	NP	770	49	180	NP	23	3.7	0.66	0.03
Unit 3: Rock-covered Areas																	
3.1R	<10	11.81	42.70	1.86	31.29	0.38	0.43	29.49	14.14	140.42	2.19	77.39	0.52	66.71	2.96	1.25	0.026
	10 to 60	10.75	38.51	1.28	35.42	0.55	0.24	23.75	14.44	99.99	2.98	72.97	0.49	49.75	2.80	1.29	0.028
3.1NR	<10	10.44	37.77	1.65	27.68	0.34	0.38	26.08	12.50	124.19	1.93	68.45	0.46	59.00	2.62	1.11	0.023
	10 to 60	10.03	33.72	1.16	24.81	0.41	0.23	22.39	15.91	115.00	2.96	75.80	0.47	51.03	2.74	1.39	0.030
3.2R	<10	11.42	34.90	1.16	27.26	0.71	0.17	28.02	12.34	126.60	2.60	72.59	0.47	65.50	2.82	1.24	0.025
	10 to 60	10.23	42.39	0.82	22.38	0.45	0.27	23.10	13.31	158.78	3.02	73.38	0.46	52.24	2.47	1.20	0.027
3.2NR	<10	10.39	29.08	1.15	28.21	0.76	0.16	26.03	19.14	98.77	2.16	65.21	0.43	58.25	2.44	1.32	0.026
	10 to 60	10.93	41.21	0.86	26.95	0.43	0.32	23.64	19.02	111.66	3.11	80.28	0.41	51.56	2.44	1.50	0.024
3.3R	<10	12.99	34.44	1.43	32.55	0.54	0.24	31.92	15.59	161.80	2.35	77.65	0.66	67.14	3.39	1.33	0.033
	10 to 60	10.37	32.94	1.22	26.80	0.45	0.20	23.20	14.20	182.58	2.32	66.75	0.55	48.10	2.50	1.17	0.038
3.3NR	<10	11.42	29.60	2.02	34.37	0.62	0.26	26.03	25.51	174.88	2.23	73.17	0.58	69.28	2.99	1.35	0.050
	10 to 60	9.97	24.05	2.33	27.39	0.46	0.21	20.59	14.97	162.24	3.99	71.15	0.84	50.59	7.68	1.28	0.029
3.4R	<10	10.02	23.52	2.27	26.42	0.48	3.29	20.44	13.66	117.36	2.47	66.80	0.55	61.32	2.44	0.99	0.039
	10 to 60	9.50	21.85	2.59	27.68	0.46	0.21	17.41	16.14	75.98	3.40	59.75	0.62	40.15	4.41	1.34	0.022
3.4NR	<10	13.12	20.25	1.57	39.76	0.56	0.29	26.32	23.24	114.11	3.04	84.04	0.66	94.95	2.91	1.41	0.063
	10 to 60	8.54	19.55	2.37	26.00	0.37	0.17	17.23	18.15	90.81	3.04	62.70	0.54	51.38	4.61	1.61	0.027
Unit 4: Drainage Areas																	
4.1R	<10	11.35	24.07	1.64	29.36	0.62	0.20	24.50	15.81	112.33	3.51	79.86	0.72	69.40	5.65	1.23	0.035
	10 to 60	9.44	21.49	1.28	26.19	0.65	0.20	18.43	10.91	112.73	3.95	59.86	0.72	50.52	6.92	1.15	0.040
4.1NR	<10	11.70	22.86	1.47	46.79	0.64	0.21	26.26	18.75	152.31	4.08	87.67	0.83	80.63	7.57	1.44	0.032
	10 to 60	9.57	19.91	1.85	25.85	0.49	0.24	21.23	14.91	143.00	3.93	71.81	0.83	54.28	7.68	1.27	0.032
4.2R	<10	10.48	19.31	2.49	28.06	0.55	0.17	20.85	19.65	104.10	3.63	73.47	0.65	54.80	4.61	1.27	0.021
	10 to 60	7.20	12.18	1.76	21.56	0.35	0.17	13.97	11.72	55.69	2.74	50.12	0.49	40.05	10.00	2.41	0.023
4.2NR	<10	10.10	17.49	1.26	31.23	0.48	0.18	21.73	26.03	102.85	3.18	77.16	0.60	62.00	3.40	1.31	0.037
	10 to 60	7.97	16.61	1.84	25.44	0.36	0.16	16.87	24.93	81.65	2.96	61.54	0.51	52.82	3.59	1.36	0.028
4.3R	<10	11.46	24.62	1.17	28.18	0.63	0.17	27.24	19.71	164.03	3.51	83.98	0.61	68.63	4.93	1.36	0.040
	10 to 60	9.83	26.12	1.65	22.42	0.41	0.25	21.72	17.18	162.76	3.77	76.58	0.60	56.09	5.28	1.33	0.035
4.3NR	<10	9.11	20.92	1.36	25.28	0.53	0.38	22.75	20.25	207.84	4.12	80.87	0.58	72.88	6.37	1.34	0.037
	10 to 60	8.86	27.76	1.42	21.15	0.40	0.71	21.12	17.51	204.39	4.26	73.88	0.58	61.70	5.74	1.33	0.033
Parking Lot Areas																	
PLN#1	<10	9.33	17.57	0.81	25.91	0.76	0.23	21.87	18.01	74.37	1.97	55.71	0.45	46.19	2.25	1.11	0.102
	10 to 60	7.25	19.35	0.98	18.93	0.62	0.28	16.52	13.48	86.80	1.83	50.40	0.38	49.02	1.96	0.98	0.065
PLN#2	<10	10.75	25.63	0.87	27.54	0.53	0.23	24.10	18.06	114.39	2.21	67.78	0.52	49.33	2.30	1.21	0.050
	10 to 60	10.41	29.48	1.28	24.67	0.40	0.22	21.08	18.90	160.70	2.71	76.84	0.49	54.02	2.52	1.23	0.028
PLS#1	<10	11.07	25.19	0.73	65.16	0.43	0.33	25.43	19.31	153.63	2.32	69.85	0.49	63.15	2.86	1.21	0.030
	10 to 60	9.81	25.46	0.86	43.99	0.46	0.17	22.86	18.13	132.54	2.33	67.30	0.42	47.28	2.39	1.16	0.035
PLS#2	<10	10.54	13.14	0.95	59.15	1.51	0.23	23.76	44.21	71.68	2.09	61.77	0.44	50.24	2.38	1.51	0.042
	10 to 60	9.62	28.26	0.87	59.37	0.81	0.25	19.93	33.23	106.84	2.49	70.35	0.37	35.96	2.16	1.35	0.024
PLSE#1	<10	9.17	19.84	1.37	30.49	0.48	0.14	18.51	19.50	84.12	2.54	59.13	0.56	39.29	3.71	1.32	0.029
	10 to 60	9.25	20.59	2.08	25.19	0.38	0.18	17.38	20.25	89.90	2.75	56.11	0.60	37.91	3.76	1.28	0.023
Reference Samples																	
BRS 1		16.74	121.58	0.80	113.55	3.78	1.37	52.08	151.60	62.34	2.78	113.06	0.93	108.65	10.06	4.65	0.075
BRS 2		14.34	114.60	0.98	96.56	3.21	1.14	45.93	123.65	49.26	2.44	104.98	0.82	115.90	4.82	3.46	0.335
BRS 3		15.19	128.25	0.83	100.95	3.44	1.16	49.11	122.38	49.35	2.65	113.66	0.83	127.76	5.41	4.61	0.376
BRS 4		14.18	122.23	1.11	97.80	3.06	0.98	44.70	116.85	69.02	2.21	105.77	0.79	109.72	5.72	3.23	0.321
BRS5		14.40	115.55	1.39	102.31	3.22	1.11	47.33	128.65	55.28	2.02	107.79	0.81	114.15	4.71	3.30	0.308
Buffalo River Ref. Material 8704		13.14 - 14.00	18.1 - 125.77	1 - 5.95	NP(2)	55 - 3.23	NP	12 - 46.6	33 - 167	NP	2.96 -3.22	90.6 - 98.6	NP	NP	NP	5 - 3.39	NP
Gill et al. 2002[3]		NP	19.0-41.0	NP	1.0-36.0	NP	NP	9.0-19.0	17-32	50-1200	NP	22-127	NP	NP	NP	NP	NP
Reheis et al. 2002[4]		NP	26-90	7.2-11	NP	0.5-9.3	NP	28-60	170-360	280-960	3.4-4.7	NP	NP	NP	NP	2.0-11	NP
Reheis et al. 2009[5]		15, 12	80, 40	8, 6	100, 450	NP	NP	80, 30	90, 300	600, 600	4, 3	180, 100	1, 1	NP	2, 3	5, 6	NP

NOTES:

1. The Screening Levels (SLs) are developed using risk assessment guidance from the EPA Superfund program and are used for site "screening" and as initial cleanup goals, if applicable. The groundwater protectionconcentrations shown are soil concentrations considered to be protective of groundwater.
2. NP = Not provided
3. Reported range of concentrations in wind-erodible Owens Lake playa crusts.
4. Reported range of concentrations in the <50 µm fractions of dust samples from the southwestern United States.
5. Concentrations shown are for one dust sample from the eastern Mojave Desert and one from southeastern Nevada. The concentrations are estimated from Figure 3 in the manuscript.

Table 3: pH, electrical conductivity (EC) and water soluble trace element concentrations in PI-SWERL samples

Sample ID	pH	EC[1] dS m^{-1}	Co	Cr	Cs	Cu	Cd	Ag	Ni	Pb	Sr	U	V	Tl	B	Mo	Sb	Hg
						µg g-1								µg g^{-1}				
Unit 1: Sand Areas																		
1.1R[2]	8.23	2.43	0.084	0.109	0.005	0.52	0.021	0.004	1.84	0.013	343.73	0.051	1.07	0.004	12.35	0.42	0.064	0.010
1.1NR[3]	7.81	0.90	0.032	0.101	0.003	0.27	0.006	0.002	0.74	0.004	125.53	0.033	0.67	0.002	7.00	0.13	0.027	0.004
1.2R	7.83	0.76	0.049	0.253	0.004	0.49	0.003	0.001	0.54	0.005	132.86	0.118	2.00	0.003	13.37	0.39	0.041	0.011
1.2NR	8.18	0.18	0.012	0.148	0.001	0.39	0.001	ND[4]	0.12	0.002	34.83	0.026	1.72	0.001	3.97	0.09	0.021	0.004
1.3R	8.47	0.62	0.009	0.463	0.001	1.10	0.006	ND	0.13	0.018	17.90	0.114	3.12	0.002	26.62	1.00	0.154	0.009
1.3NR	8.15	0.28	0.065	0.171	0.002	0.68	0.013	0.001	0.92	0.005	142.22	0.025	0.44	0.002	7.18	0.26	0.063	0.004
1.4R	7.44	1.85	0.039	0.654	0.003	1.32	0.003	0.001	0.55	0.003	108.55	0.074	3.66	0.005	15.81	0.54	0.331	0.013
1.4NR	7.43	1.42	0.164	0.608	0.006	2.16	0.014	0.002	2.83	0.017	528.82	0.099	1.97	0.007	32.52	0.78	0.245	0.011
1.5R	7.86	2.87	0.116	0.150	0.034	0.44	0.035	0.001	2.02	0.006	539.43	0.696	0.81	0.012	115.77	8.75	0.028	0.003
1.5NR	7.55	2.31	0.104	0.285	0.03	0.65	0.059	0.003	1.69	0.005	392.40	1.168	0.30	0.021	174.42	13.53	0.024	0.003
Unit 2: Silt/clay Areas																		
2.1R	7.50	1.70	0.072	0.238	0.006	0.49	0.019	0.006	1.66	0.030	440.87	0.105	0.95	0.011	13.29	1.09	0.052	0.003
2.1NR	8.05	0.35	0.015	0.278	0.003	0.63	0.002	ND	0.25	0.002	124.79	0.052	1.61	0.006	8.00	0.40	0.050	0.004
2.2R	7.86	2.15	0.104	0.237	0.008	0.38	0.015	0.005	2.23	0.040	278.92	0.104	3.49	0.005	11.51	0.42	0.034	0.007
2.2NR	7.84	2.11	0.103	0.244	0.004	0.26	0.012	0.001	2.23	0.024	357.23	0.082	2.65	0.002	9.25	0.25	0.028	0.003
2.3R	7.74	1.78	0.216	0.288	0.021	3.05	0.035	0.011	4.39	0.046	1344.60	0.590	3.89	0.014	77.07	3.72	0.073	0.004
2.3NR	7.83	2.19	0.09	0.167	0.005	0.33	0.011	0.002	1.93	0.009	503.32	0.317	0.79	0.004	25.91	1.22	0.031	0.002
2.4R	7.63	2.08	0.174	0.221	0.008	0.99	0.013	0.003	3.77	0.010	959.26	0.338	10.80	0.006	46.05	0.67	0.081	0.006
2.4NR	7.76	1.46	0.052	0.230	0.004	0.51	0.009	0.005	0.84	0.005	213.50	0.067	2.19	0.003	14.93	0.22	0.025	0.004
Unit 3: Rock-covered Areas																		
3.1R	7.91	0.72	0.016	0.270	0.002	0.32	0.005	0.002	0.38	0.012	83.53	0.015	0.75	0.003	13.07	0.17	0.023	0.003
3.1NR	8.29	0.38	0.010	0.254	0.001	0.45	0.001	0.002	0.25	0.002	47.32	0.010	0.79	0.002	11.47	0.22	0.040	0.003
3.2R	8.06	0.42	0.010	0.282	0.001	0.32	0.005	ND	0.19	0.002	166.43	0.029	1.43	0.002	14.16	1.00	0.033	0.005
3.2NR	8.60	0.30	0.022	0.388	0.020	0.35	0.003	0.004	0.11	0.076	4.38	0.014	1.63	0.002	12.15	0.15	0.024	0.002
3.3R	8.21	0.30	0.014	2.425	0.001	0.44	0.002	ND	0.18	0.016	39.02	0.031	0.40	0.003	2.80	0.16	0.081	0.005
3.3NR	8.11	0.32	0.014	0.556	0.002	0.58	0.004	ND	0.25	0.003	52.38	0.035	0.78	0.003	6.71	0.24	0.097	0.006
3.4R	8.13	0.07	0.017	0.315	0.003	0.71	0.002	ND	0.26	0.003	47.76	0.036	1.00	0.003	6.61	0.23	0.106	0.007
3.4NR	6.58	0.06	0.008	0.152	0.001	0.14	ND	0.001	0.05	0.004	6.50	0.005	0.59	0.001	2.08	0.04	0.015	0.003
Unit 4: Drainage Areas																		
4.1R	7.87	2.26	0.127	0.278	0.004	0.54	0.010	0.004	2.47	0.010	583.80	0.208	0.83	0.009	24.99	1.22	0.056	0.006
4.1NR	8.39	0.48	0.131	0.323	0.004	0.59	0.010	0.001	2.57	0.005	617.38	0.154	0.90	0.008	20.24	1.27	0.056	0.003
4.2R	7.71	1.74	0.081	0.432	0.005	0.84	0.010	0.002	1.65	0.003	294.95	0.080	0.69	0.005	22.09	0.74	0.047	0.004
4.2NR	7.87	1.26	0.174	0.776	0.007	0.55	0.008	0.002	1.32	0.005	275.58	0.311	0.88	0.011	45.89	1.93	0.199	0.006
4.3R	8.07	0.40	0.013	0.343	0.002	0.26	0.002	ND	0.23	ND	73.05	0.025	1.27	0.003	10.74	0.35	0.051	0.004
4.3NR	8.56	0.12	0.017	0.387	0.003	0.49	0.002	0.001	0.33	ND	132.16	0.063	0.65	0.002	19.06	0.36	0.055	0.004
Parking Lot Areas																		
PLN#1	8.03	0.85	0.059	0.419	0.004	0.91	0.004	0.001	0.77	0.012	159.56	0.061	0.84	0.004	36.50	0.52	0.161	0.006
PLN#2	7.93	1.03	0.048	0.089	0.002	0.45	0.006	ND	0.53	0.005	121.20	0.077	0.72	0.002	26.99	0.30	0.111	0.004
PLS#1	9.11	1.96	0.031	1.248	0.003	2.75	0.007	0.050	0.25	0.020	9.54	0.212	5.80	0.002	114.04	1.70	0.265	0.023
PLS#2	8.31	0.50	0.022	0.355	0.001	1.12	0.014	ND	0.40	0.010	78.61	0.042	1.16	0.002	25.41	0.50	0.293	0.007
PLSE#1	8.28	0.44	0.022	0.50	0.004	0.73	0.004	0.002	0.29	0.004	89.81	0.091	2.36	0.004	35.57	1.07	0.197	0.01

NOTES:
1. EC = Electrical conductivity
2. R samples collected within tracks
3. NR samples collected in undisturbed areas
4. ND = Not detected

particularly considering the dilution factor of 10. The analytical results indicate that elevated concentrations of Sr, U, V, B, Mo, and Ni are present in some of the samples. Strontium concentrations range from 4.37 to 1,345 µg g^{-1}, U from 0.003 to 1.17 µg g^{-1}, V from 0.30 to 10.80 µg g^{-1}, B from 3.96 to 174 µg g^{-1}, Mo from 0.038 to 3.72 µg g^{-1}, and Ni from 0.05 to 4.39 µg g^{-1}.

Strontium is a relatively common trace element in the Earth's crust and is likely to be concentrated in intermediate magmatic rocks and in carbonate sediments. Strontium also behaves similarly to calcium (Ca) in the environment and is often associated with Ca in soil and sediments. Strontianite ($SrCO_3$) is easily solublized and its dissolution may be responsible for the elevated Sr concentrations (Kabata-Pendias, 2001). Under arid conditions, U forms compounds with varying solubility with oxides, carbonates, phosphates, vanates, and arsenates (Kabata-Pendias, 2001). The elevated concentrations of soluble B may result from the presence of soluble sodium borate salts, which commonly occur in alkaline soils in arid regions (McBride, 1994). Vanadium and Mo are also known to have high availability and bioavailability in oxidized soils that are neutral to alkaline.

3.3 Comparison of trace element concentrations with EPA screening levels

The concentrations of trace elements in the digested soil and PI-SWERL samples were initially compared with the USEPA Region 3, 6, and 9 screening levels (SLs) for chemical contaminants in residential soils and soil concentrations considered to be protective of groundwater resources (USEPA, 2010). The SLs are developed using risk assessment guidance from the EPA Superfund program and are used for site "screening" and as initial cleanup goals, if applicable. The risk-based SLs are considered by the EPA to be protective for humans (including sensitive groups) over a lifetime. However, it should be noted that the SLs may not be applicable at a particular site and they do not address non-human health endpoints, including ecological impacts.

None of the reported trace element concentrations in the soil, unpaved parking lot and PI-SWERL samples exceed the EPA's SLs for residential soil.

The reported concentrations of Co in all of the samples exceed the EPA SLs considered to be protective of groundwater (Tables 1 and 2). The SL for Sb is exceeded in all samples except for two of the unpaved parking lot soil samples. Ten of the soil samples and 53 of the PI-SWERL samples exceed the SL for Hg. Thirty-one of the PI-SWERL samples also exceed the SL for Mo, and all of the PI-SWERL samples and one soil sample exceed the SL for B. Three of the PI-SWERL and one of the soil samples collected in the unpaved parking lots exceed the SL for Cu, two PI-SWERL samples exceed the SL for Cd, and one PI-SWERL sample exceed the SL for Ag. None of the reported concentrations of Ni, Sr, U, and V in the samples exceeded the SLs for groundwater for these elements. The EPA has not established SLs for groundwater for Cr, Cs, Tl, and Pb.

Although the reported concentrations of some of the trace elements exceed the EPA SLs, the potential risk to groundwater resources from leaching of these elements is considered to be minimal in the Nellis Dunes area. This is because groundwater in the Nellis Dunes

area is deep (>30 m below ground surface), and the arid climate minimizes leaching. However, the water-soluble concentrations of Sr, U, V, B, Mo, and Ni (see Table 3) may be of concern because of the potential for downstream contamination from runoff. Lake Mead, a major drinking water source for Las Vegas, is located hydrogeologically downgradient of the NDRA. In addition, if inhaled, these water-soluble elements may have an increased effect on health because of their solubility (Plumlee et al., 2006).

4. Comparison of trace element concentrations with reported regional concentrations of trace elements

In 1961, a sampling program was initiated by the United States Geological Survey (USGS) with the objective of providing estimates of the range of elemental abundances in surficial materials throughout the conterminous United States (Shacklette and Boerngen, 1984). The results of this study indicated that soils in the western United States generally had the highest average elemental concentrations when compared with soil samples from the eastern United States (Shacklette and Boerngen, 1984). The reported range of concentrations for each element and the average concentrations for samples collected in the western United States in this study are summarized in Table 1. More recently, total elemental analyses were performed on 50 soils collected throughout California. The reported concentration ranges and average concentrations of trace elements in these soils are also shown in Table 1 (Bradford et al., 1996).

The trace element concentrations in the Nellis Dunes soil samples generally fall within the ranges reported for the Shacklette and Boerngen (1984) and Bradford et al. (1996) studies with a few exceptions. The sample from one of the unpaved parking areas (PLS#2) had an anomalously high concentration of copper (459 $\mu g\ g^{-1}$). Copper concentrations in the other soil samples were within the ranges reported in the other studies, and ranged from 3.39 to 22.23 $\mu g\ g^{-1}$. Elevated concentrations of Sr, 630 and 821 $\mu g\ g^{-1}$, respectively, were also reported in two of the samples collected from the drainage areas (surface units 4.1 and 4.3). The high concentrations of Sr in these drainage areas may result from dissolution and transport of soluble Sr-containing minerals during rainfall events.

At least three regional studies have published the chemical composition of dust. Gill et al. (2002) studied the chemical composition of wind erodible crusts in playa sediments at Owens Lake, California. Reheis et al. (2002) studied the contribution of different local sources to dust in the southwestern United States by comparing elemental analyses of dust samples from potential source sediments, such as alluvial and playa deposits. Reheis et al. (2009) also conducted a compositional study of two dust samples collected in the desert southwest, United States. One of these samples was collected from the Cima Volcanic field approximately 130 km southwest of Las Vegas. The second sample was

collected in Lower Kyle Canyon approximately 40 km northwest of Las Vegas. The reported concentrations of trace elements in these three studies are summarized in Table 2. It should be noted that not all three studies analyzed for the same elements. Additionally, the elemental concentrations were not reported in the Reheis et al. (2009) study. Rather, the concentrations were provided in a bar graph figure; the concentrations shown in Table 2 were estimated from this figure. Finally, only the Gill et al. (2002) study includes the concentrations of soluble constituents in the elemental analyses. However, soluble salts were removed prior to total elemental analyses in the Reheis et al. (2002) and Reheis et al. (2009) studies. In the following text we compare only the insoluble trace element results to the Gill et al. (2002) and Reheis et al., (2002, 2009) studies.

The concentrations of Co, Cr, Cs, Cu, Cd, Ni, Pb, U, V, Tl, Mo, and Sb in the Nellis Dunes PI-SWERL samples generally fall within the ranges reported for dust samples in one or more of the three studies cited above with a few exceptions. The Pb concentrations in the PI-SWERL samples range from 10.91 to 44.21 $\mu g\ g^{-1}$, and are within, or slightly higher, than the range of Pb concentrations (17 to 32 $\mu g\ g^{-1}$) reported by Gill et al. (2002). However, the Pb concentrations are one order of magnitude lower than those reported in the Reheis et al. (2002) and Reheis et al. (2009) studies (280-960 $\mu g\ g^{-1}$ and 90 and 300 $\mu g\ g^{-1}$), respectively. The Sr concentrations are also lower in all of the PI-SWERL samples, ranging from 55.69 to 208 $\mu g\ g^{-1}$. The reported range of Sr concentrations in the Gill et al. (2002) and Reheis et al. (2002) studies were 450 to 1200 $\mu g\ g^{-1}$, and 280 to 960 $\mu g\ g^{-1}$, respectively. The estimated concentration of Sr in the two dust samples analyzed in the Reheis et al. (2009) study was 600 $\mu g\ g^{-1}$. The Mo concentrations in the PI-SWERL samples are generally within the range of concentrations (2 to 11 $\mu g\ g^{-1}$) reported by Reheis et al. (2002), and the concentrations in the two dust samples (5 and 6 $\mu g\ g^{-1}$), reported in Reheis et al. (2009), except for the samples from surface unit 1.5. Molybdenum concentrations in the four samples from unit 1.5 are nearly one order of magnitude higher ranging from 39.9 to 74.8 $\mu g\ g^{-1}$. It is unclear why the Mo concentrations in the PI-SWERL samples from this unit are elevated.

5. Summary and conclusions

In summary, the concentrations of most of the trace elements analyzed were higher in the PI-SWERL samples than in the soil samples. These results are expected because of the larger particle size of the soil samples as compared to the PI-SWERL samples. The finer fractions of the samples are dominated by smectite minerals which are known to increase the retention of metals in the soil. Some of the highest concentrations of trace elements occurred in the PI-SWERL samples from surface unit 1.5. The reported concentrations of trace elements in the soil and PI-SWERL samples generally fall within the ranges reported previously by other investigators.

The reported concentrations of trace elements in the soil and PI-SWERL samples do not exceed the EPA's SLs for residential soil. However, the concentrations of some of the trace elements do exceed the EPA SLs considered to be protective of groundwater resources. The potential risk to groundwater resources from leaching of these elements is considered to be minimal in the Nellis Dunes area. This is because groundwater in the Nellis Dunes area is deep (>30 m below ground surface), and the arid climate minimizes leaching. The water-soluble concentrations of Sr, U, V, B, Mo, and Ni may be of potential concern if they are transported downstream in runoff. Lake Mead, a major drinking water source for Las Vegas, is located hydrogeologically downgradient of the NDRA. These water-soluble elements may also affect health if inhaled.

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