Preliminary Analytical Results for Ash and Burned Soils from the October 2007 Southern California Wildfires

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Overview

The U.S. Geological Survey (USGS) collected ash and burned soils from about 28 sites in southern California wildfire areas (Harris, Witch, Ammo, Santiago, Canyon and Grass Valley) from Nov. 2 through 9, 2007 (table 1). USGS researchers are applying a wide variety of analytical methods to these samples, with the goal of helping identify characteristics of the ash and soils from wildland and suburban burned areas that may be of concern for their potential to adversely affect water quality, human health, endangered species, and debris-flow or flooding hazards. These studies are part of the Southern California Multi-Hazards Demonstration Project, and preliminary findings are presented here.

Sampling and Sample Preparation

Most samples were collected from wildland burn areas and typically include separate samples of ash and underlying burned soil. The goal of the wildland sampling was to understand potential differences in ash and soil characteristics that may result from differences in the type of burned vegetation and underlying bedrock geology. At a given site, sampling of ash and underlying soil was done by the collection and compositing of multiple subsamples at evenly spaced intervals along a transect or on spokes radiating from a centroid; such sampling has been found to produce the most statistically valid representation of spatially heterogeneous materials such as mine wastes (Smith and others, 2000).

Partly in response to a request from a Burned Area Emergency Rehabilitation (BAER) Team, USGS scientists collected composite samples of ash/debris and underlying soil from two burned residential areas within the Grass Valley and Harris burns. Each of these two composite residential samples consists of multiple random grab subsamples collected within or near multiple burned residences.

The USGS also recently acquired hyperspectral remote sensing data with the HyMap imaging spectrometer (Cocks and others, 1998) over several of the burned areas. The detailed chemical and physical properties of the ash and soil samples will be linked to the remote sensing data using field and laboratory reflectance measurements of the samples, resulting in maps that extend estimates of ash impact on environment and health across the burned areas.

Samples were shipped to Denver overnight. Samples were homogenized prior to splitting. Most sample analysis types are being conducted on a split that was obtained by cone-and-quartering of the full sample, and that was then sieved to less than 2mm to remove coarse particles.

Ash analyses completed to date have focused on the residential ash and burned soil samples, and to a lesser extent on wildland samples from the same burned areas. This initial focus is in response to the BAER team request to provide information on burned residences within the Grass Valley fire area. Additional analyses are intended on wildland ash and soil samples from other burned areas, pending funding availability.

Analytical Methods

Analytical methods (Taggart, 2002) performed to date on a subset of the samples include:

(1) Bulk chemical composition on a ground < 2mm split using inductively coupled plasma-mass spectrometry (ICP-MS) for a 44-element suite. The analysis follows 4-acid digestion of the sample; this digestion typically is considered a total digestion of most environmental materials.

(2) Deionized water leach test on an unground <2mm split, to simulate interactions of ash with rainfall (Hageman, 2007). One part ash is added to 20 parts deionized water, the mixture shaken for 5 minutes, and the leachate is then filtered and analyzed for pH, alkalinity, conductivity, anions by ion chromatography, cations and metals by ICP-MS, and mercury by continuous flow injection-cold vapor-atomic fluorescence spectrometry (AFS).

(3) Particle characterization using scanning electron microscopy (SEM)

Samples analyses currently in process include: X-ray diffraction for mineralogy; bioaccessibility of metals and metalloids in simulated biofluids; and, particle size distribution. If additional funding is secured, samples will also be analyzed for organic contaminants, microbial characteristics, and total amounts of and forms of carbon, sulfur, and nitrogen.

Preliminary Findings

Preliminary analyses of the ash and soil samples indicate several features of potential environmental or health concern.

(1) Water leach tests (table 2) show that the residential ash samples generate high pH levels (12.5–12.7). These levels suggest that ash from burned residences can generate caustic alkalinity when it comes into contact with rainwater or water-based body fluids (such as perspiration or fluids lining the respiratory tract). In contrast, similar water leachates of the limited number of wildland ash samples analyzed to date generate somewhat less caustic alkalinity and lower pH (9.8–10.9). USGS water leach tests on ash from vegetation combusted in the laboratory at various controlled temperatures indicate that leachate pH correlates with temperature of combustion, with leachate pH maximizing at 12.5 for combustion temperatures over 600°C (J. Crock, unpub. data). Accordingly, the higher pH and alkalinity of the residential ash leachates compared to wildland ash leachates might indicate that residential fires burned at higher temperatures than did fires in wildland areas; however, the combustion of diverse man-made materials in residences cannot be ruled out as a possible source for the high residential leachate pH values.

The caustic alkalinity of exposed residential and wildland ash may diminish over time as it interacts with and is neutralized by rainwater and atmospheric carbon dioxide. However, further work is needed to determine the rate at which this

neutralization may occur. High-alkalinity rainwater runoff from burned areas may also become neutralized as it mixes with and is diluted by sufficient quantities of near-neutral pH fresh water from unburned areas.

(2) Compared to average US soils, the two residential ash samples can contain elevated arsenic (up to 140 parts per million, ppm or mg/kg), lead (up to 344 ppm), antimony (up to 32 ppm), copper (up to 1,370 ppm), or zinc (up to 2,800 ppm) (table 3). For arsenic, lead, and antimony, concentrations in one or both of the residential composite ash samples approach or exceed U.S. Environmental Protection Agency residential soil Preliminary Remediation Goals (PRGs: 0.4–0.62 ppm arsenic; 31 ppm antimony, 150–400 ppm lead) (EPA, 2004). Chromium levels are also elevated in the residential ash (up to 354 ppm); further analyses are underway to determine what proportion of the chromium in the residential ash is the more toxic hexavalent form. The EPA PRGs are "…tools for evaluating and cleaning up contaminated sites. They are risk-based concentrations that are intended to assist risk assessors and others in initial screening-level evaluations of environmental measurements." (EPA, 2004). Although these PRGs were not designed for wildfire ash, they do provide one possible measure against which the chemical composition of the wildfire ash and burned soils can be preliminarily compared.

The water leach tests performed to date suggest that most of these metals have relatively low solubility under the conditions of this particular leach test; however, further tests are needed, as element solubilities may vary with differences in solid:water ratio. Results of pending physiologically based bioaccessibility tests using simulated gastrointestinal fluids and simulated lung fluids will provide insights into the potential bioaccessibility of these metals and metalloids along ingestion and inhalation pathways.

(3) The BAER team request for sampling and analysis of residences included a request to evaluate whether asbestos is present in or absent from the residential ash. Reconnaissance SEM analyses completed to date have not conclusively identified the presence of asbestos in the residential ash samples. Because the makeup of ash may vary substantially throughout a burned residence, and due to both the reconnaissance nature of our sampling within each residence and the reconnaissance nature of the SEM analyses of the collected samples, the negative finding to date for asbestos does not guarantee that asbestos is absent from the burned residences; it might be present locally in areas of the residences not sampled or analyzed. As noted by CALEPA (2003), potentially higher levels of asbestos (and lead) might be expected in burned residential areas with houses constructed earlier than the early 1980s, when use of asbestos and leaded paints in construction materials was common.

Guidance from the Findings

These USGS findings are consistent with the scientific knowledge about wildfire ash that has led the California Department of Health Services (CDHS, 2003), California EPA (CALEPA, 2003), various California counties (i.e., San Diego County, 2007), and NIOSH (2007, p. 6) to issue advisories regarding appropriate precautionary measures that should be followed by persons working in burned wildland areas or cleaning up burned residences to avoid possible health problems associated with ash exposure. ***Such measures include, for example, use of appropriate respiratory protection, gloves, long-sleeved shirts and long pants, dust mitigation measures, and washing of skin contacted by the ash.***

The USGS results further indicate that ***rainwater runoff from burned residential areas may be a source of high-alkalinity waters with possibly elevated concentrations of some metals or metalloids of health or environmental concern.*** Given the extent of the burned residential areas, these results suggest that residential portions of burned watersheds may need enhanced cleanup attention before the rains, and possibly enhanced monitoring during the rains. Rainwater runoff from the burned residential and wildland areas may also adversely affect water quality and critical species habitat in receiving streams by causing spikes in alkalinity, concentrations of some metals, and levels of some nutrients, as has been noted in burned areas elsewhere in the United States (Surber, 2002; Meixner, 2004).

The results also indicate that more detailed characterization of the ash and debris may be warranted within residential areas. In particular, more detailed characterization will aid in the development of appropriate disposal strategies for materials removed from burned residences that minimize potential metal release from the materials into landfills or the environment.

Results of analyses in progress will be released as they become available.

Needed Additional Studies

The focus of the current study was primarily burned wildland areas. It is important to note that the two residential samples collected are not representative of all residential areas that burned in southern California. Therefore, additional studies are recommended in burned residential areas to fully examine the potential environmental and health issues associated with residential ash and burned soils. Needed studies include, for example (1) variability of ash composition within and between residences in a given neighborhood and (2) variability in ash composition as a function of residence age, type, and setting (such as north- or south-facing slope, proximity to other residences, intensity and duration of fire, and type of construction).

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References

CALEPA, 2003, Safe cleanup of fire ash: http://www.calepa.ca.gov/Disaster/Fire2003/FireAsh.pdf

CDHS, 2003, State health director offers advice on safe cleanup of fire ash: California Dept. of Health Services Press Release 03-89, http://www.applications.dhs.ca.gov/pressreleases/store/PressReleases/03-89.html

Cocks, T., Jenssen, R., Stewart, A., Wilson, I., and Shields, T., 1998, The HyMap airborne hyperspectral sensor: The system, calibration and performance, *in* Proceedings of the 1st EARSEL Workshop on Imaging Spectroscopy, Zurich.

EPA, 2004, U.S. Environmental Protection Agency, Region 9, Preliminary remediation goals, http://www.epa.gov/region09/waste/sfund/prg/index.html - prgtable.

Hageman, P.L., 2007, U.S. Geological Survey field leach test for assessing water reactivity and leaching potential of mine wastes, soils, and other geologic and environmental materials: U.S. Geological Survey Techniques and Methods Report 5-D3, http://pubs.usgs.gov/tm/2007/05D03/pdf/TM5-D3_508.pdf

Meixner, T., 2004, Wildfire impacts on water quality: Southwest Hydrology, Sept./Oct. 2004, p. 23-24, http://www.swhydro.arizona.edu/archive/V3_N5/featurette7.pdf

NIOSH, 2003, Worker safety during fire cleanup: National Institutes of Occupational Safety and Health Fact Sheet, 7 p., http://emergency.cdc.gov/disasters/wildfires/pdf/firecleanupworkers.pdf

San Diego County, 2007, Post-fire health tips and ash and debris cleanup guidance. http://www.sdcountyrecovery.com/documents/AshDebrisPublicHealthTipsCleanup11-08-07.pdf

Smith, K.S., and Huyck, H.L.O., 1999, An overview of the abundance, relative mobility, bioavailability, and human toxicity of metals, Chapter 2, *in* Plumlee, G.S., and Logsdon, M.J., eds., The environmental geochemistry of mineral deposits, Part A: Processes, techniques, and health issues: Reviews in Economic Geology, v. 6A: Littleton, Colorado, Society of Economic Geologists, Inc., p. 29–70.

Smith, K.S., Ramsey, C.A., and Hageman, P.L., 2000, Sampling strategy for the rapid screening of mine-waste dumps on abandoned mine lands, *in* ICARD 2000: Proceedings from the Fifth International Conference on Acid Rock Drainage, Denver, Colorado, May 21-24, 2000: Society for Mining, Metallurgy, and Exploration, Inc., p. 1,453-1,461.

Surber, G., 2002, Section 3, water quality concerns after wildfire, *in* Knight, J.E., ed., *After wildfire—Information for landowners coping with the aftermath of wildfire*: Montana State University Extension Service, p. 9-14, http://www.montana.edu/wwwpb/pubs/445503water.pdf

Taggart, J.E., Jr., ed., 2002, Analytical methods for chemical analysis of geologic and other materials: U.S. Geological Survey Open-File Report 02-0223, http://pubs.usgs.gov/of/2002/ofr-02-0223/

Table 1. Locations and types of samples collected in this study.

SAMPLE ID	Latitude	Longitude	Sampling Type	Location Type
Harris01	32° 37' 53.90"	116° 52' 04.08"	Spoke	Hilltop
Harris02W,S,A	32° 35' 46.3"	116° 46' 05.7"	Opportunistic	Hillside
Harris03A,B,C	32° 35' 46.3"	116° 46' 05.7"	Opportunistic	Tailings pile
Harris04	32° 42' 07.0"	116° 57' 36.9"	Spoke	Hillside near Sweetwater
Harris05	32° 42' 11.0"	116° 57' 39.8"	Spoke	Drainage basin near Sweetwater
Harris06	32° 39' 47.3"	116° 40' 51.2"	Transect	Steep hillside
Harris 07	32° 37' 22.2"	116° 41' 26.6"	Random sampling	Residential, mobile homes
Witch01	33° 09' 09.13"	116° 47' 00.91"	Transect	Steep hillside
Witch02	33° 07' 11.74"	116° 47 27.11"	Transect	Hillside
Witch03	33° 06' 49.4"	116° 49' 01.4"	Grab	Roadcut
Witch04	33° 06' 25.3"	116° 49' 37.3"	Transect	Hilltop
Witch05	33° 05' 2.5"	116° 59' 18.9"	Transect	Dried streambed
Santiago01	33° 43' 12.0"	117° 35' 54.6"	Transect	Sampled streambed from this point then east 150 yards
Santiago02	33° 43' 12.0"	117° 35' 54.6"	Transect	Sampling started and went west 140 yards in streambed
Santiago03	33° 43' 12.0"	117° 35' 54.6"	Transect	Sampling started and went west 140 yards on hillside
Santiago04	33° 43' 11.4"	117° 35' 59.6"	Spoke	Next to dried streambed
Santiago05	33° 43' 03.01"	117° 36' 37.8"	Spoke	Next to dried streambed
Santiago06	33° 42' 59.1"	117° 37' 13.2"	Spoke	Broad valley bottom
Santiago07	33° 43' 04.2"	117° 37' 15.0"	Spoke	Drainage draining into Santiago06 from the north
Santiago08	33° 43' 02.0"	117° 39' 34.6"	Spoke	Hillside
Santiago09	33° 43' 02.0"	117° 39' 34.6"	Grab	Potential hydrophobic soil
Ammo1	33° 22' 52.3"	117° 32' 55.4"	Spoke	Marine base hillside
Canyon01	34° 02' 44.0"	118° 42' 16.8"	Transect	Very steep hillside near Pepperdine U.
Canyon02	34° 3' 53.0"	118° 41' 50.0"	Transect	Steep hillside
Canyon03	34° 3' 45.5"	118° 41' 50.1	Transect	Steep Hillside
Canyon04	34° 01' 57.7"	118° 42' 04.1"	Transect	Hillside near beach
GrassValley01	34° 16' 02.6"	117° 13' 06.0"	Random Sampling	Modern homes
GrassValley02	34° 16' 06.3"	117° 13' 06.6"	Spoke	Hillside

Table 2. Composition of water leachates of California wildfire ash and burned soil samples. Fluoride, chloride, and nitrate by ion chromatography; cations, metals and sulfate by ICP-MS; mercury by AFS. Analytical results are not blank subtracted. nr —not reported, nm—not measured.

Sample	pH	Specific Conductance (µS/cm)	F (mg/L)	Cl (mg/L)	NO_3 (mg/L)	Ag (µg/L)	Al (µg/L)	As (µg/L)
Harris 06 Ash	10.9	890	4.3	32	4.1	<1	252	1
Harris 06 Ash Duplicate	10.8	890	4	31.6	4.11	<1	235	2
Grass Valley 02 Soil	8.2	140	3.2	1.2	0.9	<1	292	1
Grass Valley 02 Ash	9.8	360	1.9	5.4	1.8	<1	4540	1
Grass Valley 01 Soil	10.9	460	0.7	8.1	2	<1	1570	2
Grass Valley 01 Ash	12.7	5040	<.08	70	<.08	<1	73.2	2
Grass Valley 01 Ash (ICP-MS dup)	nm	nm	nm	nm	nm	<1	75.1	1
Harris 07 Soil	10.6	240	1.2	25.3	1	<1	975	219
Harris 07 Ash	12.5	3950	3	285	13.5	<1	3650	13.5
Blank	6	0.77	<.08	<.08	<.08	<1	3.8	<1

Sample	Ba (µg/L)	Be (µg/L)	Bi (µg/L)	Ca (mg/L)	Cd (µg/L)	Ce (µg/L)	Co (µg/L)	Cr (µg/L)
Harris 06 Ash	109	<0.05	<0.2	21.2	0.03	<0.01	0.33	1.5
Harris 06 Ash Duplicate	116	<0.05	<0.2	25.0	0.04	<0.01	0.38	1.5
Grass Valley 02 Soil	29.3	<0.05	<0.2	20.5	<0.02	0.54	0.43	<1
Grass Valley 02 Ash	254	<0.05	<0.2	41.2	<0.02	<0.01	0.24	1.4
Grass Valley 01 Soil	21.3	<0.05	<0.2	63.2	<0.02	0.03	0.10	7.7
Grass Valley 01 Ash	158	<0.05	0.21	668	0.05	<0.01	0.28	31.9
Grass Valley 01 Ash (ICP-MS dup)	153	0.06	<0.2	629	0.06	<0.01	0.48	32.7
Harris 07 Soil	28.3	<0.05	<0.2	24.5	0.04	0.08	0.24	3.0
Harris 07 Ash	1670	<0.05	<0.2	427	0.06	<0.01	<0.02	32.4
Blank	0.41	<0.05	<0.2	<0.2	<0.02	<0.01	<0.02	<1

Table 2—Continued.

Sample	Cs (µg/L)	Cu (µg/L)	Dy (µg/L)	Er (µg/L)	Eu (µg/L)	Fe (µg/L)	Ga (µg/L)	Gd (µg/L)
Harris 06 Ash	0.24	23.9	<0.005	<0.005	0.02	<50	0.68	<0.005
Harris 06 Ash Duplicate	0.25	23.3	<0.005	<0.005	0.02	<50	0.60	<0.005
Grass Valley 02 Soil	<0.02	2.6	0.04	0.02	0.02	50	0.31	0.04
Grass Valley 02 Ash	0.05	4.5	<0.005	<0.005	0.03	<50	1.7	<0.005
Grass Valley 01 Soil	<0.02	2.8	<0.005	<0.005	<0.005	<50	1.3	0.005
Grass Valley 01 Ash	0.32	8.9	<0.005	<0.005	0.02	<50	0.38	<0.005
Grass Valley 01 Ash (ICP-MS dup)	0.32	10.0	0.009	<0.005	0.03	<50	0.39	<0.005
Harris 07 Soil	<0.02	10.4	0.01	<0.005	0.005	<50	0.96	0.009
Harris 07 Ash	0.89	8.7	<0.005	<0.005	0.21	<50	4.5	<0.005
Blank	<0.02	<0.5	<0.005	<0.005	<0.005	<50	<0.05	0.005

Sample	Ge (µg/L)	Hg (ng/L)	Ho (µg/L)	K (mg/L)	La (µg/L)	Li (µg/L)	Lu (µg/L)	Mg (mg/L)
Harris 06 Ash	0.07	25	<0.005	nr	<0.01	12.4	<0.1	7.13
Harris 06 Ash Duplicate	0.08	21	<0.005	nr	<0.01	13.1	<0.1	10.7
Grass Valley 02 Soil	<0.05	6	0.007	3.55	0.28	<0.1	<0.1	1.38
Grass Valley 02 Ash	0.06	8	<0.005	14.6	<0.01	20.9	<0.1	6.05
Grass Valley 01 Soil	<0.05	<5	<0.005	5.99	0.02	0.4	<0.1	0.37
Grass Valley 01 Ash	<0.05	<5	<0.005	14.3	<0.01	12.4	<0.1	0.02
Grass Valley 01 Ash (ICP-MS dup)	<0.05	nm	<0.005	14.2	<0.01	13.5	<0.1	0.04
Harris 07 Soil	0.09	<5	<0.005	3.32	0.04	5.9	<0.1	0.85
Harris 07 Ash	<0.05	<5	<0.005	41.6	0.01	41.3	<0.1	0.03
Blank	<0.05	<5	<0.005	0.06	<0.01	0.6	<0.1	<0.01

Table 2—Continued.

Sample	Mn (µg/L)	Mo (µg/L)	Na (mg/L)	Nb (µg/L)	Nd (µg/L)	Ni (µg/L)	P (mg/L)	Pb (µg/L)
Harris 06 Ash	2.6	21.4	8.91	0.72	<0.01	2.0	0.1	0.2
Harris 06 Ash Duplicate	3.1	18.7	9.66	<0.2	<0.01	2.0	0.1	0.3
Grass Valley 02 Soil	172	<2	0.54	0.20	0.23	1.5	0.3	0.5
Grass Valley 02 Ash	16.9	10.1	0.84	<0.2	<0.01	2.1	0.02	0.3
Grass Valley 01 Soil	1.3	3.0	6.98	<0.2	0.01	0.8	0.02	0.4
Grass Valley 01 Ash	0.3	19.5	25.7	0.31	<0.01	7.1	<0.01	157
Grass Valley 01 Ash (ICP-MS dup)	0.4	18.7	25.4	<0.2	<0.01	11.5	<0.01	163
Harris 07 Soil	4.1	4.6	9.10	<0.2	0.04	1.4	0.1	0.56
Harris 07 Ash	0.4	26.7	97.4	<0.2	<0.01	2.9	<0.01	37.8
Blank	0.3	<2	0.26	<0.2	<0.01	<0.4	<0.01	0.2

Sample	Pr (µg/L)	Rb (µg/L)	Sb (µg/L)	Sc (µg/L)	Se (µg/L)	SiO2 (mg/L)	Sm (µg/L)	SO4 (mg/L)
Harris 06 Ash	<0.01	49.6	8.61	1.1	7.2	7.8	<0.01	170
Harris 06 Ash Duplicate	<0.01	49.6	6.88	0.9	7.3	7.9	<0.01	188
Grass Valley 02 Soil	0.06	2.94	4.84	<0.6	<1	0.9	0.04	8
Grass Valley 02 Ash	<0.01	9.22	7.15	<0.6	3.1	1.1	<0.01	105
Grass Valley 01 Soil	<0.01	2.30	9.89	<0.6	1.6	1.8	<0.01	187
Grass Valley 01 Ash	<0.01	20.8	3.07	<0.6	3.6	1.8	<0.01	986
Grass Valley 01 Ash (ICP-MS dup)	<0.01	21.2	2.43	0.8	3.4	1.8	<0.01	941
Harris 07 Soil	<0.01	1.74	27.5	<0.6	2.7	3.2	<0.01	18
Harris 07 Ash	<0.01	59.2	4.10	<0.6	6.3	3.1	<0.01	107
Blank	<0.01	0.03	1.07	<0.6	<1	<0.2	<0.01	<2

Table 2—Continued.

Sample	Sr (µg/L)	Ta (µg/L)	Tb (µg/L)	Th (µg/L)	Ti (µg/L)	Tl (µg/L)	Tm (µg/L)	U (µg/L)
Harris 06 Ash	218	0.85	<0.005	<0.2	2.8	<0.1	<0.005	<0.1
Harris 06 Ash Duplicate	232	0.23	<0.005	<0.2	2.5	<0.1	<0.005	0.10
Grass Valley 02 Soil	198	0.42	0.006	<0.2	2.7	<0.1	<0.005	0.47
Grass Valley 02 Ash	797	0.20	<0.005	<0.2	1.7	<0.1	<0.005	1.04
Grass Valley 01 Soil	236	0.05	<0.005	<0.2	2.9	<0.1	<0.005	<0.1
Grass Valley 01 Ash	1160	0.28	<0.005	<0.2	13.5	<0.1	<0.005	<0.1
Grass Valley 01 Ash (ICP-MS dup)	1160	0.34	<0.005	<0.2	13.6	<0.1	<0.005	<0.1
Harris 07 Soil	69.5	0.1	<0.005	<0.2	2.6	<0.1	<0.005	0.32
Harris 07 Ash	748	<0.02	<0.005	<0.2	1.7	<0.1	<0.005	<0.1
Blank	<0.5	<0.02	<0.005	<0.2	<0.5	<0.1	<0.005	<0.1

Sample	V (µg/L)	W (µg/L)	Y (µg/L)	Yb (µg/L)	Zn (µg/L)
Harris 06 Ash	39.2	1.88	0.01	0.005	3.6
Harris 06 Ash Duplicate	33.3	1.43	0.01	0.005	2.9
Grass Valley 02 Soil	3.6	<0.5	0.22	0.01	5.2
Grass Valley 02 Ash	6.8	1.93	0.07	<0.005	3.3
Grass Valley 01 Soil	16.4	<0.5	0.01	<0.005	1.9
Grass Valley 01 Ash	10.0	0.62	0.07	<0.005	154
Grass Valley 01 Ash (ICP-MS dup)	10.1	0.50	0.01	0.01	168
Harris 07 Soil	16.9	0.87	0.04	0.008	6.1
Harris 07 Ash	4.0	2.43	0.09	<0.005	71.4
Blank	<0.5	<0.5	<0.01	0.005	9.4

Table 3. Bulk chemical composition of selected California wildfire ash and burned soil samples, as determined by ICP-MS. EPA residential soil preliminary remediation goals vary for chromium, depending upon the proportion of hexavalent chromium (VI) compared to trivalent chromium (III) present.

Sample	Ag ppm	Al ppm	As ppm	Ba ppm	Be ppm	Bi ppm	Ca ppm	Cd ppm	Ce ppm
Detection Limit	< 1	< 50	< 1	< 0.2	< 0.03	< 0.06	< 100	< 0.007	< 0.1
Harris07-soil	3.4	80400	49.4	660	1.3	0.40	29300	2.1	43.1
Harris07-ash	8.5	76000	140	858	0.92	0.54	130000	4.8	35.2
Grass Valley-01soil	< 1	93200	4.0	892	2.1	0.13	42400	0.16	85.0
Grass Valley-01ash	0.96	40800	17.9	541	1.0	0.27	191000	1.0	29.4
EPA Region IX residential soil preliminary remediation goals (EPA, 2004)	390	76000	0.39–0.62	5400	150			37	
Western US soil mean (Smith and Huyck, 1999). *US mean.	0.05*	58000	5.5	580	0.68		18000	0.06*	65

Sample	Co ppm	Cr ppm	Cs ppm	Cu ppm	Fe ppm	Ga ppm	K ppm	La ppm	Li ppm
Detection Limit	< 0.03	< 0.5	< 0.003	< 2	< 50	< 0.02	< 20	< 0.05	< 0.3
Harris07-soil	11.2	55.9	2.0	471	40400	17.4	16800	23.3	14.8
Harris07-ash	12.2	91.1	1.8	1120	23600	15.9	16300	19.8	19.0
Grass Valley-01soil	17.2	175	3.4	404	49900	21.7	23100	54.6	33.9
Grass Valley-01ash	27.3	354	1.4	1370	51200	8.9	11400	16.9	14.2
EPA Region IX residential soil preliminary remediation goals (EPA, 2004)	900	210 (1/6 VI/III), 30 (all VI), 100000 (all III)		3100	23000				1600
Western US soil mean (Smith and Huyck, 1999). *US mean.	7.1	41	6*	21	21000	16	18000	30	22

Table 3—Continued.

Sample	Mg ppm	Mn ppm	Mo ppm	Na ppm	Nb ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	Sb ppm
Detection Limit	< 6	< 0.7	< 0.05	< 20	< 0.1	< 0.3	< 5	< 0.4	< 0.01	< 0.04
Harris07-soil	10200	727	0.86	26600	10	14.0	1080	62.9	58.9	8.6
Harris07-ash	10800	774	3.5	21300	12	41.6	1540	192	58.3	31.5
Grass Valley-01soil	15400	867	8.3	12700	26	14.1	1030	162	122	5.1
Grass Valley-01ash	7840	396	73.0	9360	10	36.6	509	344	47.2	24.9
EPA Region IX residential soil preliminary remediation goals (EPA, 2004)		1800	390			1600		150–400		31
Western US soil mean (Smith and Huyck, 1999). *US mean.	7400	380	0.85	9700	8.7	15	320	17	69	0.47

Sample	Sc ppm	Sr ppm	Th ppm	Ti ppm	Tl ppm	U ppm	V ppm	Y ppm	Zn ppm
Detection Limit	< 0.04	< 0.8	< 0.1	< 40	< 0.08	< 0.02	< 0.2	< 0.05	< 3
Harris07-soil	18.6	199	9.42	5120	0.36	2.13	100	41.1	458
Harris07-ash	10.4	277	5.76	22500	0.38	2.23	67.8	26.0	2220
Grass Valley-01soil	13.7	398	9.31	6730	0.70	3.15	127	29.4	211
Grass Valley-01ash	5.3	392	5.15	6900	0.32	1.89	54.0	15.5	2800
EPA Region IX residential soil preliminary remediation goals (EPA, 2004)		47000			5.2	16	78		23000
Western US soil mean (Smith and Huyck, 1999). *US mean.	8.2	200	9.1	2200		2.5	70	22	55