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DOE/RL-92-24
Rev. 3
Vol. 1 of 2

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Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes

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Revision 3 of DOE/RL-92-24
Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes

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Directions for Updating DOE/RL-92-24 to Revision 3.

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APP D T9.1 through T10.12	APP D T9.1 through T10.12	
Appendix F	Nothing	App. F replaced by DOE/RL-94-72
Binder inserts for Vols. 1 & 2	Binder inserts for Vols. 1 & 2	

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DOE/RL-92-24
Rev. 3
Vol. 1 of 2

UC-630,721

Hanford Site Background: Part 1, Soil Background for Nonradioactive Analytes

Date Published
October 1995

United States
Department of Energy
P.O. Box 550
Richland, Washington 99352

Approved for Public Release

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5285 Port Royal Road
Springfield, VA 22161
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Printed in the United States of America

DISCLM-5.CHP (8-91)

Random samples (104) were collected from 14 outcrop and excavation sites and one borehole. These samples are representative of the material present in most of the recognized sedimentary facies in the vadose zone. For completeness, judgment samples (51) also were collected from the 14 sites, a second borehole, and topsoils from the main terrestrial ecosystems at the Hanford Site. Judgment samples included minor soil types that were potentially missed during random sampling.

The results of the soil background characterization activities primarily fall into two categories: (1) documentation of soil background compositions and (2) validation of the soil background conceptual model that serves as the scientific basis for the use of these data as Sitewide background. The following are the main findings.

- Soils in the vadose zone on the Hanford Site have a range of chemical compositions that can be represented as a single Sitewide compositional population for all naturally occurring inorganic analytes.

- The concentrations of all measured volatile and semivolatile organics, pesticides, and polychlorinated biphenyls are at or below present detection limits for the samples analyzed.

- Sitewide background data can be used for identifying contamination in all soils in the vadose zone on the Hanford Site including the materials from the Hanford formation and younger sediments, Ringold Formation, topsoils, and volcanic ashes.

- Only a small number of the analyzed soil samples have one or more analyte concentrations that are significantly larger than in the majority of soil background samples.

- Unusually high analyte concentrations occur naturally in a small percentage of the soils and can be distinguished from contamination using these data.

These findings support the sampling design and all aspects of the Sitewide background conceptual model. Some of the compositional characteristics of the Sitewide soil background data for 36 inorganic analytes are listed in Summary Table 1. Parameters calculated from the compositional and quality control data also are listed. These include the limit of detection and limit of quantitation calculated from the analysis of reagent blanks. The minimum and maximum concentrations in the primary Sitewide (i.e., random) data set and the highest measured analyte concentration overall (i.e., including judgment samples) are listed in Summary Table 1. Summary Table 2 contains estimated parameters for the systematic random data set. The table includes estimates for the 50th, 80th, 90th, and 95th percentiles as well as upper confidence limits for the estimates of the 80th and 90th percentiles and lower and upper confidence limits for the estimates of the 95th percentiles. The confidence limits are based on 95 percent coverage. These estimates were computed for both the lognormal and Weibull distributions.

The absence of measurable organic chemicals in topsoils is also notable because the samples were collected from topsoils expected to have the largest naturally occurring levels of organic chemicals.

The systematic random data are intended for use as the primary Sitewide soil background data set because these are the only data that can be used for most statistical applications. The judgment data and supporting data on modes, grain size, and bulk composition are also Sitewide background data intended primarily for use in non-statistical comparisons. The general manner in which these Sitewide background data can be used is illustrated in the Summary Figure.

The range of compositions in the primary Sitewide background data set bracket the inorganic analyte concentrations of nearly all soils in the vadose zone, including those of minor soil types. It is notable that the natural concentrations of nearly every inorganic analyte extend to levels that exceed health-based cleanup limits. However, the levels of most inorganic analytes are well below these health-based limits. The highest measured background concentrations occur in three volumetrically minor soil types: (1) highly alkaline soils; (2) one volcanic ash; and (3) topsoils rich in organic carbon, particularly those adjacent to the Columbia River.

The uncertainties associated with the data and parameters calculated from the data also have important implications for data use. The uncertainty levels associated with the laboratory measurement processes, for example, exceed 50 percent for most analytes. Background compositions also can vary by as much as 10 times for some analytes, because of differences in particle size alone. These examples underscore the need for a phased approach to the use of background data and consideration of data uncertainties in evaluating the significance associated with any single analyte concentration or calculated parameter.

These Sitewide soil background data are recommended for use in all environmental restoration and remediation activities on the Hanford Site because these data provide a consistent, technically credible, and efficient basis for identifying and evaluating soil contamination. The benefits of a Sitewide background, however, can be realized only if there also is consistency of data use. Recommended methods of data use are provided in a separate document (DOE-RL 1994).

Summary Table 1. General Characteristics of the Sitewide Background Data.

Analyte	Detection limits		Systematic random samples, concentration in mg/kg		Overall maximum concentration, in mg/kg+
	LOD/CRDL+	LOQ	Minimum+	Maximum+	
Aluminum	21.8	66.1	3,940	18,100	28,800
Antimony	15.7	52.2	15.7	15.7	31
Arsenic	3	N/A	3	11.4	27.7
Barium	4.1	2.7	45.2	221	480
Beryllium	0.46	N/A	0.6	2.1	10
Cadmium	0.24	0.79	0.66	0.66	11
Calcium	175	470	3,820	86,600	105,000
Chromium	1.1	3	2.9	30.6	320
Cobalt	0.88	2.9	5.7	16.9	110
Copper	2.1	6.2	8.1	36.1	61
Iron	75.7	236	13,200	35,100	68,100
Lead	1.1	N/A	1.1	26.6	74.1
Lithium	34	N/A	34	38.2	38.2
Magnesium	18.4	57.9	2,900	10,100	32,300
Manganese	0.63	1.8	196	704	1,110
Mercury	0.16	N/A	0.16	3.8	3.8
Molybdenum	1.4	4.8	2	2	6
Nickel	2.4	7.7	7.2	28.2	200
Potassium	135	451	851	3,280	7,900
Selenium	0.5	N/A	5	6	6
Silicon	5.2	N/A	5.2	583	1,203
Silver	2.1	4.5	1.4	14.6	14.6
Sodium	50.6	140	101	5620	6,060
Thallium	3.7	N/A	3.7	3.7	3.7
Titanium	5	N/A	524	2940	3,180
Vanadium	1.8	5.9	24.3	97.9	140
Zinc	6.4	15.6	30.9	119	366
Zirconium	11	N/A	11	84.8	84.8
Alkalinity	5	N/A	31	37,600	150,000
Ammonia	0.6	N/A	0.6	26.4	26.4
Chloride	1	N/A	1	1,480	1,480
Fluoride	1	N/A	1	73.3	73.3
Nitrate	0.6	N/A	0.6	538	906
Nitrite	21	N/A	21	21	36.5
O-Phosphate	2	N/A	2	225	225
Sulfate	1	N/A	1	4,340	12,600

Minimum and maximum concentrations are from the primary Sitewide (i.e., random) data set. Overall maximum concentrations are the highest measured among all samples.

+ = as reported from the laboratory.
CRDL = contractually required detection limit.
LOD = limit of detection based on analysis of reagent blanks.
LOQ = limit of quantitation based on analysis of reagent blanks.
mg/kg = milligram per kilogram.
N/A = Reagent blank data not applicable for calculation of detection limit.

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Summary Table 2. Hanford Sitewide Background Data, Percentiles and Upper Confidence Limits.

	Lognormal Distribution								Weibull Distribution							
ANALYTE	50%	80%	80% UCL	90%	90% UCL	95% LCL	95%	95% UCL	50%	80%	80% UCL	90%	90% UCL	95% LCL	95%	95% UCL
Aluminum	7600	10100	11000	11800	13000	12000	13300	15100	7383	10113	11053	11933	13263	12133	13643	15500
Antimony	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Arsenic	3.55	5.28	5.89	6.47	7.38	6.61	7.65	9.06	3.56	5.2	5.83	6.44	7.42	6.59	7.71	9.18
Barium	88.4	115	124	132	144	134	148	165	87.3	114.9	124.2	132.8	145.7	134.8	149.3	166.3
Beryllium	1.09	1.35	1.44	1.51	1.62	1.52	1.65	1.8	1.128	1.296	1.376	1.446	1.576	1.466	1.606	1.806
Cadmium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Calcium	9450	14000	15700	17200	19700	17600	20400	24100	9131	14079	15909	17709	20409	18109	21209	25300
Chromium	9.57	14.8	16.7	18.5	21.4	18.9	22.3	26.8	9.34	15.12	17.32	19.22	22.22	19.62	23.02	27.32
Cobalt	11.2	14	14.9	15.7	16.9	15.9	17.3	19.2	11.4	14.25	15.1	15.8	16.8	16	17.1	18.4
Copper	14.4	19	20.6	22	24.1	22.3	24.7	27.9	14.03	18.22	19.92	21.59	24.39	21.99	25.19	29.39
Iron	23600	29200	31000	32600	35000	33000	35600	39000	23750	29750	31450	33050	35250	33450	35850	38750
Lead	5.45	8.24	9.36	10.2	11.7	10.4	12.2	14.5	5.42	8.28	9.31	10.31	11.84	10.54	12.28	14.47
Lithium	28.4	31.7	32.9	33.5	35	33.4	35.1	37.2	26.5	31.2	32.7	33.4	35.1	33.2	35.1	37.2
Magnesium	4980	6260	6680	7060	7620	7140	7780	8580	4830	6140	6610	7060	7750	7160	7950	8950
Manganese	372	460	488	512	550	518	561	613	380	463	486	506	535	511	542	578
Mercury	0.023	0.13	0.22	0.33	0.6	0.36	0.7	1.47	0.084	0.151	0.22	0.35	0.59	0.36	0.7	1.49
Molybdenum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nickel	12.2	16.4	17.8	19.1	21	19.4	21.6	24.5	12.15	16.35	17.75	19.05	20.85	19.35	21.45	23.95
Potassium	1210	1760	1960	2150	2440	2190	2520	2960	1197	1777	1977	2167	2447	2207	2537	2940
Selenium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Silicon	15.4	36.8	37.5	44	55.6	-	59	-	14.12	31.76	40.46	56.06	63.46	-	66.36	-
Silver	0.054	0.3	0.49	0.73	1.33	0.81	1.52	3.16	1.36	1.361	1.366	1.381	1.46	1.387	1.52	2.36
Sodium	231	475	581	690	878	716	937	1274	357.2	459	551	682	984	718	1099	1910
Thallium	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Titanium	1460	2110	2380	2570	2950	2580	3000	3600	1491	2161	2401	2561	2881	2571	2921	3340
Vanadium	54.4	73	79.3	85.1	93.9	86.4	96.4	110	55	74	79.8	85	92.5	86.1	94.6	104.5
Zinc	51.1	61.7	64.9	67.8	72.1	68.5	73.3	79.3	51.7	61.7	64.6	67.1	70.7	67.7	71.6	76.1
Zirconium	20.6	31.8	36.4	39.8	46.8	40	47.8	58.8	21.3	30.6	33.7	35.8	39.6	-	40.1	-
Alkalinity	1100	3960	5680	7710	11800	8240	13300	23000	1055	4248	6008	8008	11688	8508	12888	19800
Ammonia	0.97	4.28	6.48	9.23	15.1	9.95	17.3	32.5	0.88	4.8	7.1	9.8	14.9	10.5	16.6	26.8
Chloride	6.59	39.6	65.5	100	182	109	214	460	4.999	39.8	71.5	116.2	220.2	128.2	259.2	541.2
Fluoride	0.8	1.83	2.31	2.81	3.7	2.93	3.98	5.67	0.87	1.81	2.28	2.81	3.73	2.93	4.02	5.69
Nitrate	3.58	20.9	34.2	52	93.4	56.9	110	232	3.35	19.88	34.28	54.18	99.38	59.68	115.9	234.9
Nitrite	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
O-Phosphate	0.002	0.104	0.31	0.785	2.87	0.958	4.08	21.5	0	0.054	0.21	0.668	2.9	0.85	4.27	22.9
Sulfate	10.4	81.4	145	237	469	263	566	1360	8.8	90.3	162	264	497	292	585	1200

UCL One sided upper confidence limit based on 95% coverage
LCL One sided lower confidence limit based on 95% coverage
\- Not enough data above the reporting limit to provide for a distribution fit

Soil composition determined in this manner also differs from that obtained by use of the toxicity characteristics leaching procedure (TCLP) (40 CFR 261). This procedure extracts analytes from the sample with a weak acetic acid solution. The only other type of chemical composition referred to in this document is the total composition of a bulk sample (referred to as bulk composition).

1.2 DATA QUALITY OBJECTIVES

The data quality objectives (DQO) process recommended by the EPA (EPA 1987) has been used as guidance for all activities associated with the determination of soil background composition (Figure 1-2). Some of the main DQOs developed for the purpose of this project are summarized in the following paragraphs.

The main objective of the activities described in this report is the characterization of the natural composition of the soil on the Hanford Site. These data are specifically intended for use in environmental restoration activities regulated under the *Resource Conservation and Recovery Act* (RCRA) *of 1976* and the *Comprehensive Environmental Response, Compensation, and Liability Act* (CERCLA) *of 1980*, and various DOE Orders.

The use of background (i.e., the natural environment) as a baseline for defining contamination and cleanup levels is a fundamental principle in most environmental regulations (e.g., EPA 1986; WAC 173-303 and 173-340). The implied concepts in these regulations are: (1) concentrations of chemicals that naturally occur in the environment generally are not regarded as harmful to human health and the environment; (2) there generally is no significant benefit in, or reduced risk associated with, reducing the amounts of most constituents below natural levels; and (3) it is generally impractical or impossible to reduce concentration levels below those levels that exist naturally.

The determination of Site-specific analyte concentrations in soil background is an integral part of the environmental restoration activities, and is used in the following ways:

- As a baseline for determining whether contamination is present
- As a primary screening criterion and reference data in baseline risk assessments
- As a goal for cleanup levels
- As a baseline for evaluating treatment technologies
- Any other activities involving or requiring the use of the characteristics and natural composition of the soils.

The principal users of these data for decisions regarding environmental restoration on the Hanford Site include the U.S. Department of Energy, the DOE-RL and other conservators of the Hanford Site, the DOE subcontractors, and the federal and state regulatory agencies.

A Sitewide approach for characterization of soil background was used in this project as an alternative to the determination of background for each waste management unit (WMU). The use of this approach was based on the initial evaluations of available soil background data, geology, and development of a conceptual model to ensure the representativeness, comparability, and completeness of the data collection activities (WHC 1991a).

The Sitewide approach also provides more representative information on the range of natural compositions, and greater consistency and technical validity for use in environmental restoration and closure activities on the Hanford Site. An overview of this concept and approach is presented in Section 2.0. The soil background conceptual model is a key element in providing a scientific basis for the Sitewide background approach, and also for the development and use of other DQOs in understanding and interpreting data relevant to the natural chemical composition of the soils.

Based on the initial evaluations, a sampling and analysis plan and data quality and quantity needs specifically designed for the characterization of soil background at the Hanford Site was developed (Appendix E) and carried out in 1991-92. This report is the compilation of the information, data, evaluations, conclusions, and recommendations resulting from these activities.

1.3 SITEWIDE SOIL BACKGROUND DATA AND DATA USE

The primary application of the soil background data is to provide an improved technical basis and provide consistency in the identification of contamination in soils for all environmental restoration activities. However, these data can be used with different evaluation and statistical methods in areas such as health-based and ecological risk assessments, soil treatment technology, and groundwater chemistry.

The benefits of Sitewide background data for the purpose of identifying contamination, however, only can be realized if there also is consistency in data use. Some of the statistical characteristics of the Sitewide soil background data are summarized in Table 1-1. This table contains two different estimated parameters illustrating that comparison criteria can be calculated from the same Sitewide background data for different contamination scenarios and uses of the data. Still other approaches use the entire range of analyte concentrations and the nature of the natural background distribution as a basis for data use (e.g., Figure 1-3; also refer to Chapter 6.0). Recommended methods for data use are provided in a separate document (DOE-RL 1994).

1.4 DOCUMENT ORGANIZATION

An overview of the Sitewide approach for the characterization and use of soil background for environmental restoration activities on the Hanford Site is presented in Chapter 2.0. Description of the sediments that comprise the vadose zone is contained in Chapter 3.0, along with other pertinent geologic relationships that relate to the understanding of the composition of these materials.

A compilation of information on the physical characteristics of the soils and the processes expected to contribute to or control their chemical compositions, referred to as the conceptual model, are presented in Chapter 4.0. This conceptual model also serves as the technical basis for the Sitewide soil background approach, and for the design of the sampling and analysis plans.

A description of the types of data generated in these activities, as well as an overview of the soil sampling and analysis activities, are contained in Chapter 5.0. The results and evaluations of the compositional data are presented in Chapter 6.0. A summary of the quality control data and a review of data quality are presented in Chapter 7.0. Conclusions and recommendations are presented in Chapter 8.0.

The appendices to this document contain the following: (1) supporting information on the selection and description of soil background sampling sites (Appendix A), (2) narratives on the sampling activities at each of the sampling sites (Appendix B), (3) raw data on the results of laboratory analyses (Appendix C), (4) detailed information on statistical and other types of data analysis (Appendix D), and (5) the original soil background sampling and analysis plan (Appendix E).

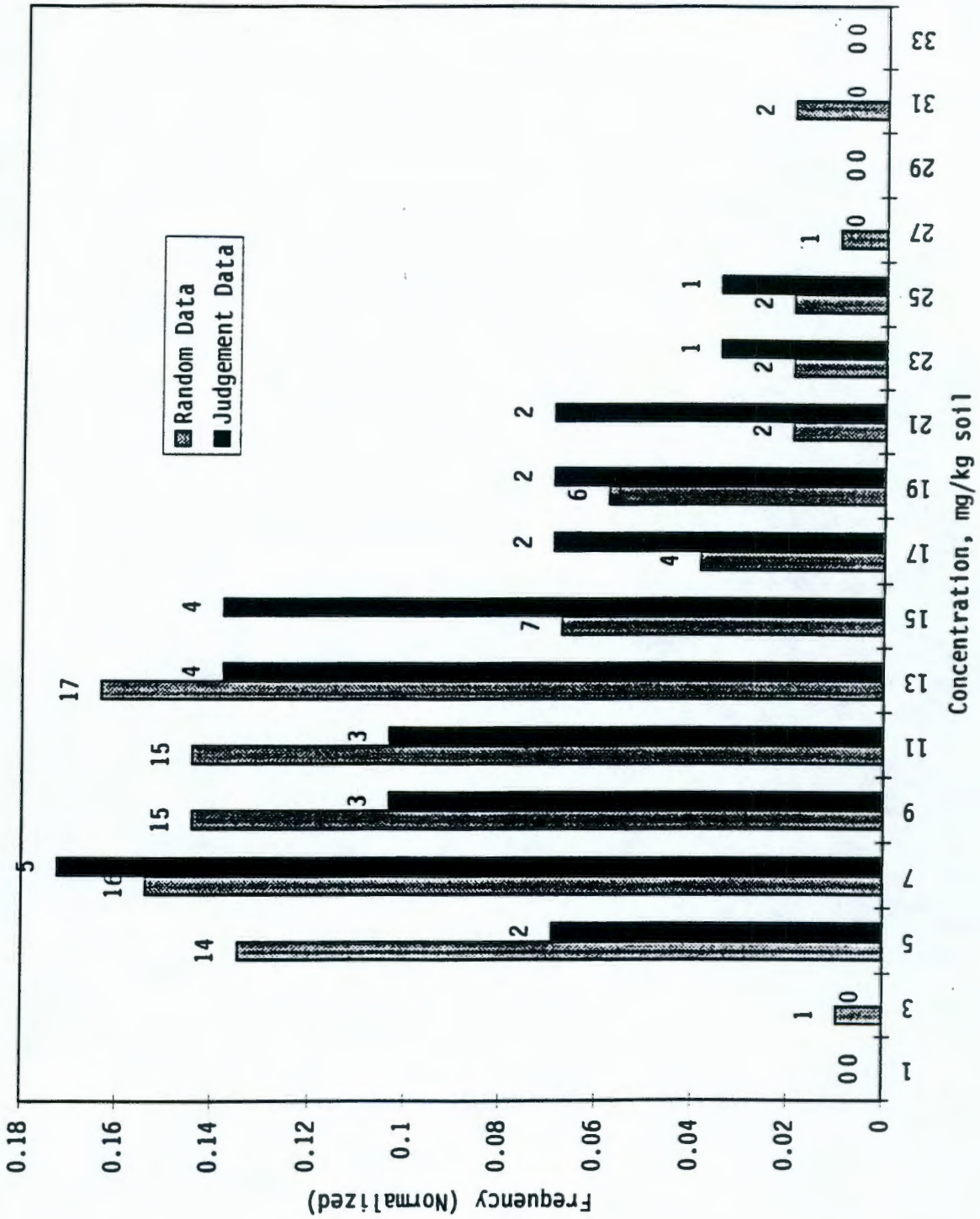


Figure 1-3. An Example of the Distribution of an Analyte Concentration (Chromium) from the Sitewide Soil Background Data. The concentration distributions are based on 104 random samples and 31 judgment samples. The normalized frequency (Y-axis) is concentration frequency normalized to the total number of samples in each of these two sets to make the plots comparable. The actual concentration frequencies are shown at the top of each bar.

Table 1-1. General Characteristics of the Sitewide Background Data.

Analyte	Detection limits		Systematic random, concentration in mg/kg		Overall maximum concentration, in mg/kg+	Type of sample with maximum concentration and sampling site
	LOD/CRDL+	LOQ	Minimum+	Maximum+		
Aluminum	21.8	66.1	3,940	18,100	28,800	Topsoil, playa, E-9
Antimony	15.7	52.2	15.7	15.7	31	Volcanic ash*
Arsenic	3	N/A	3	11.4	27.7	Topsoil, juniper, E-4
Barium	4.1	2.7	45.2	221	480	Volcanic ash*
Beryllium	0.46	N/A	0.6	2.1	10	Volcanic ash*
Cadmium	0.24	0.79	0.66	0.66	11	Volcanic ash*
Calcium	175	470	3,820	86,600	105,000	Topsoil, greasewood, E-2
Chromium	1.1	3	2.9	30.6	320	Ringold Fm*
Cobalt	0.88	2.9	5.7	16.9	110	Volcanic ash*
Copper	2.1	6.2	8.1	36.1	61	Volcanic ash*
Iron	75.7	236	13,200	35,100	68,100	Ringold Fm
Lead	1.1	N/A	1.1	26.6	74.1	Topsoil, juniper, E-4
Lithium	34	N/A	34	38.2	38.2	Random, No. 14*
Magnesium	18.4	57.9	2,900	10,100	32,300	Topsoil, greasewood, E-2
Manganese	0.63	1.8	196	704	1,110	Topsoil, playa, E-10
Mercury	0.16	N/A	0.16	3.8	3.8	Random, No. 15
Molybdenum	1.4	4.8	2	2	6	Ringold Fm
Nickel	2.4	7.7	7.2	28.2	200	Ringold Fm*
Potassium	135	451	851	3,280	7,900	Topsoil, playa, E-9
Selenium	0.5	N/A	5	6	6	Random, No. 15
Silicon	5.2	N/A	5.2	583	1,203	Topsoil, playa, E-10
Silver	2.1	4.5	1.4	14.6	14.6	Random, No. 6
Sodium	50.6	140	101	5620	6,060	Random, No. 12
Thallium	3.7	N/A	3.7	3.7	3.7	Lab detection limit
Titanium	5	N/A	524	2940	3,180	Random, No. 6
Vanadium	1.8	5.9	24.3	97.9	140	Volcanic ash*
Zinc	6.4	15.6	30.9	119	366	Topsoil, juniper, E-4
Zirconium	11	N/A	11	84.8	84.8	Random, No. 10
Alkalinity	5	N/A	5	37,600	150,000	Topsoil, greasewood, E-2
Ammonia	0.6	N/A	0.6	26.4	26.4	Random, No. 14*
Chloride	1	N/A	1	1,480	1,480	Random, No. 11
Fluoride	1	N/A	1	73.3	73.3	Random, No. 10
Nitrate	0.6	N/A	0.6	538	906	Hanford fm judgment, No. 11
Nitrite	21	N/A	21	21	36.5	Topsoil, greasewood, E-2
O-Phosphate	2	N/A	2	225	225	Random, No. 10
Sulfate	1	N/A	1	4,340	12,600	Topsoil, greasewood, E-2

Minimum and maximum concentrations are from the primary Sitewide (i.e., random) data set. Overall maximum concentrations are the highest measured among all samples. Percentiles and threshold levels are based on fitting a Weibull distribution to the primary Sitewide data set for each analyte. Thresholds were not computed for undetected analytes.

+ = as reported from the laboratory.
* = offsite.
CRDL = contractually required detection limit.
LOD = limit of detection based on analysis of reagent blanks.
LOQ = limit of quantitation based on analysis of reagent blanks.
mg/kg = milligram per kilogram.

5.0 DATA AND SAMPLE TYPES

The various types of samples and data collected for characterization of the vadose zone are described in this chapter. These data are used to support the conceptual model, verify the adequacy of the sampling plan design, and provide representative analyte concentrations for use as Sitewide background. These data consist primarily of inorganic and some organic chemical analyses of soils from the vadose zone on the Hanford Site. Information on the quality control and quality assurance parameters associated with these data also are described. The suitability of the data with respect to statistical considerations is presented in Chapter 6.0. Inorganic chemical composition of soils refers to digestate and leachate compositions determined in accordance with EPA protocols (EPA 1986, 1989c), except where otherwise noted.

5.1 DATA TYPES

Four main types of data were collected in conjunction with this project:

(1) Chemical composition of soils collected by systematic random sampling

(2) Chemical composition of soils collected by judgment sampling

(3) Supporting data on the physical and chemical composition of soil materials

(4) Quality assurance and quality control data.

Acquisition of data types 1, 2, and 4 were collected and analyzed in conjunction with the soil sampling plan (Appendix E), hereafter referred to as the Sampling Plan.

The first two data types were collected to characterize the chemical composition of naturally occurring soils in the vadose zone (i.e., soil background). The third data type is used in the validation of the soil background conceptual model, in justifying the use of data types 1 and 2 as Sitewide background, and for use in the DQO process. Data on physical characteristics of the soils that affect chemical composition such as modal and grain size composition, and chemical composition data of various size fractions of soil and basalt are included in this third category. The quality assurance and quality control data (type 4) are used in assessing the analytical quality of the data in accordance with the DQO process.

An overview of the siting process for the selection of sampling locations, the sampling methods, and analytical procedures for data types 1, 2, and 4 are presented in the following sections. The various supporting data types and the purpose of these data also are described in the following sections.

5.2 SAMPLING AND ANALYSIS OF VADOSE ZONE SOILS

Over 170 soil samples were collected and analyzed specifically for the determination of the chemical composition of soil background on the Hanford Site. The majority of these samples were collected for analysis of inorganic analytes in accordance with EPA protocols (EPA 1986, 1989c). Samples from 12 locations also were analyzed for organic compounds, including volatiles, semivolatiles, pesticides, and PCBs.

Two main types of soil samples were collected, systematic random and judgment samples. The systematic random samples were intended to serve as the primary soil background reference data set because these samples provide the only data for which confidence intervals, tolerance limits, and threshold levels can be determined without the introduction of sampling bias.

Judgment samples were collected to characterize the composition of subordinate soil types in the vadose zone with different or potentially extreme analyte concentrations. The data from these samples provide a basis for evaluating the representativeness, completeness, and comparability of the systematic random data over the range of soil compositions in the vadose zone and also for evaluating the composition of minor soil types.

Inorganic analytes were determined for all these samples. Organic field screening was performed at all sampling sites; however, quantitative analysis for organic analytes was restricted to samples of topsoils collected as judgment samples (Section 5.4.2).

5.3 SYSTEMATIC RANDOM SAMPLES AND SAMPLING SITES

A total of 104 systematic random samples were collected from 14 localities and one borehole for the determination of inorganic analytes (Figure 5-1). An additional eight systematic random samples were collected from a second borehole and later reclassified as judgment samples. Twelve of the sampling sites and one of the boreholes are located on the Hanford Site. The other two sites and the second borehole site are located east of the Columbia River, adjacent to the Hanford Site. Of the 104 systematic random samples, 101 are from the Hanford formation and younger soils and three are from the Ringold Formation (borehole samples). Subordinate vadose zone samples such as volcanic ash and soils from the upper 12 inches (30 centimeters) are included in the systematic random data set.

5.3.1 Excavated and Outcrop Sampling Sites

The 14 sampling sites identified in Figure 5-1 all have vertical exposures of the vadose zone. Most of these are excavations associated with gravel quarries and construction activities, and several are natural outcrops (Appendix B). These vertical sections range from 10 to 100 feet (3 to 30 meters) in thickness and enable the geologic relationships of the soils to be determined. These 14 sites were chosen from among 30 localities that best represent the types of materials in the sedimentary facies found in the vadose

biologic effects in the pedogenic soil profiles, including bioaccumulation from the plant uptake. On the Hanford Site, soil profiles are sparsely developed, and organic material is largely restricted to the uppermost parts of the topsoil in the immediate vicinity of plant growth (Chapter 4.0, Section 4.3.2).

Thus, a separate judgment sampling effort was required to obtain representative samples in areas where naturally occurring organics and/or bioaccumulation of inorganic constituents were most likely to occur, and for completeness of sampling for both organic and inorganic analytes. Therefore, the objectives for the collection of these judgment samples and siting criteria differed somewhat from those of other soil background samples.

Most of the same criteria concerning the compositional integrity of the inorganic soil background sampling sites also were applied to the organic sites. However, several additional criteria also were considered. The criteria for selection of sampling sites were based on professional judgment and included the following:

- Sites documented and appearing to be unimpacted by anthropogenic activities (with the exception of the old field ecosystem)
- Sites farther than 150 feet (45 meters) from paved roads
- Sites in places most likely to contain biogenically generated organics and/or bioaccumulations of inorganic constituents.

Twelve sampling localities were selected based on the above criteria and advice from a biologist/ecologist familiar with the Hanford Site. The selected sampling sites are shown in Figure 5-1, and the associated ecosystem characteristics are described in Appendix B, Section B1.2. Four of the sites chosen are within or adjacent to controlled and largely pristine ecology study areas, including two sites on the Arid Lands Ecology Reserve and two sites adjacent to controlled study zones in the 200 Areas established in conjunction with the Basalt Waste Isolation Project.

Samples from the sites shown in Figure 5-1 were collected in late February 1992 from the upper 4 to 12 inches (10 to 30 centimeters) of the surface. The areas chosen for sampling at these sites were in the root zones of representative grasses or the leaf-litter canopy of the dominant or characteristic plant type (i.e., sagebrush, rabbitbrush, greasewood, juniper, and spiny hopsage) (Appendix B).

These sites also were screened for inorganic chemicals. Organic vapor concentrations were measured by analyzing the air (headspace) above the soils in sample containers. Aliquots of each sample from each of the specific organic sites were measured on the day of collection. Similar measurements were made during March 1992 on two or more new samples from each of the 14 inorganic sites discussed previously. A summary of this work is presented in Appendix B.

These samples were submitted for standard laboratory analysis of the following organic compounds: (1) volatile organics, (2) semivolatile organics, and (3) pesticides and PCBs. Inorganic analytes and methods were the same as those for the systematic random samples, with the addition of total organic carbon to the analyte list. Analytical work was performed by the same offsite commercial laboratories used for the majority of the systematic random samples. Supporting work included inorganic analyses on these samples (Table 5-1).

5.5 SUPPORTING DATA TYPES

The types of supporting data consist of two suites of samples collected, processed, and analyzed to provide important information on different physical properties of the soils on and around the Hanford Site. The physical properties investigated were grain size and mineral composition, which were then evaluated to determine their effects on chemical compositions measured by regulatory protocols. X-ray spectral data also were collected as supporting data. A discussion of the collection and analysis of these samples as well as a rationale for this work is presented in the following sections.

The first suite consisted of 31 duplicate samples from the primary inorganic sampling sites. The second suite consisted of 16 additional samples collected from the Hanford formation and analyzed independently by Washington State University (WSU) Department of Geology. All but one of these latter samples was obtained from the same sampling site as those used in the background study and described in this chapter.

All samples were collected by standard soil sampling methods, including decontamination of collection tools between sampling events. One bulk sample from the Columbia River Basalt Group (Umtanum flow) also was obtained from an outcrop in the northwestern portion of the Hanford Site.

The first suite of samples was sieved in an onsite laboratory. The second suite of samples and the basalt sample were transported to WSU for processing, which included crushing the basalt and sieving all samples into 8 size fractions. Finer size fractions from each of the samples were mounted in epoxy and made into petrographic thin sections for determination of the types and abundance of their mineral constituents.

The sieve data were used to quantify grain size variation across the Hanford Site. These data were collected to evaluate the influence of grain size and modal composition on digestate/leachate composition in the manner described in Chapter 4.0, Section 4.1.2. Modal analysis (identification of mineral and rock components and their relative abundances) was performed on the thin sections made from the WSU samples. Five hundred points were counted per sample; over 15 different classes of mineral and rock fragments were determined.

All of the measured size fractions for three of the 16 soil samples were analyzed using both x-ray fluorescence (XRF) spectrometry methods and EPA analysis methods (EPA 1989c). Bulk (total) compositions measured by XRF were

used together with digestate/leachate data to quantitatively evaluate the EF of the digestate/leachate process. These data also were used to evaluate the compositions of different size fractions within these samples. The digestate/leachate data were used primarily to assess the effects of grain size variations within the samples and the influences of differing mineralogies between the samples. The XRF spectrometry analyses on the basalt were used primarily as a control in the evaluation of the grain size effect on digestate/leachate composition.

The Sitewide soil background samples collected for this report were analyzed by XRF methods in a separate study for evaluating the use of these samples in establishing a baseline for in situ field screening of soils for heavy metal contamination (WHC 1992d). Duplicates of the Sitewide soil background samples were characterized in this evaluation using a portable XRF unit and energy dispersive detection methods.

5.6 QUALITY ASSURANCE AND QUALITY CONTROL DATA

The quality assurance and quality control sample data set includes field duplicate samples, field blanks, and blanks prepared at the analytical laboratory. The field duplicate samples were collected and sent to a separate laboratory for analysis to provide a basis for measuring the performance of the primary laboratory; these samples were not used to compute the statistics presented in Chapter 6.0.

At least one sample location at each of the 14 primary inorganic sampling sites was selected randomly for multiple sampling. One sample was submitted to the primary laboratory for analysis and another sample was sent to the secondary laboratory as a duplicate sample.

Field duplicates also were collected at all of the primary sampling sites and screened for organic compounds as a screening measure. One field blank from topsoil judgment sampling was submitted for the analysis of inorganic analytes.

Laboratory blanks were intended to provide an indication of actual detection limits. Based on inquiries at the primary laboratory, it was determined that the laboratory routinely uses a pure silica sand as a solid matrix blank for their internal quality control program. The laboratory was requested to analyze and report on the analysis of the silica sand sample with each batch submitted to the laboratory. The primary laboratory performed these analysis and reported the results in the same manner as regular samples. Unfortunately, the laboratory's reporting process automatically filtered out data less than the contractual detection levels. Most of the data that were returned on analytes with low concentrations were, therefore, reported as values less than the default detection levels rather than actual measurements that could have been used to determine actual detection limits. The data on the silica blanks were suitable only for identifying the presence of laboratory contamination or for other nonstatistical applications.

An independent evaluation of detection and quantitation limits was desired because this parameter affects both the fitting of distributions to the data and evaluations of the reliability of the data for decision making. The determination of the actual levels of detection (for inorganic analytes) associated with the measurement was, therefore, obtained from the replicate analyses of laboratory preparation blanks, reported on form 3 of the EPA's CLP reporting package. These data from each reporting package from the primary laboratory were compiled and used to calculate the limit of detection and limit of quantitation as defined by the American Chemical Society (1983). These same samples also were used to develop control charts of the measurement process for the primary laboratory (Appendix D, Section D2.2).

5.7 RELATIONSHIPS AMONG DATA TYPES

Each of the four main data types described in this chapter have specific roles in the process of determining the validity of the Sitewide concept for the determination and use of soil background on the Hanford Site. The respective roles and relationships among these data types are illustrated in Figure 5-7, and provide the framework for the logical sequence in which the data are interpreted and presented in Chapter 6.0.

The validity and applicability of the Sitewide soil background concept requires specific conditions to be met in a specific sequence. These conditions involve the acceptability of the data, and the validity of the conceptual model that guided the collection and interpretation of the data. These conditions govern the extent to which the soil background data collected can be used as a Sitewide background (i.e., representative of the entire vadose zone).

The first condition is validation of the Sitewide soil background conceptual model. The information in the conceptual model together with analysis of the data constitute the technical basis for the Sitewide background concept. The data on physical composition of the soils and the factors that control the natural chemical composition of soil (i.e., modal and grain size composition and the measurement process) address the first issue listed in Figure 5-8. Some of the data on soil chemistry also address certain other aspects of the conceptual model (e.g., bioaccumulation in topsoil). Data on the physical composition of the soils also form the basis for evaluating whether the soils posses characteristics that justify the use of their chemical compositions as a single Sitewide soil background population. Thus, the use of these data for refinement and validation of the conceptual model is a prerequisite for other aspects of data interpretation.

The second condition to be met in evaluating the Sitewide background concept is whether the data on soil chemistry have the characteristics necessary for their consideration as Sitewide background. These evaluations involve the use of the systematic random data in assessing spatial randomness in composition of the soils, and in fitting statistical distributions for each analyte. The condition for a single Sitewide compositional population implies that the concentrations for essentially all analytes in the systematic random data set should form single statistical distributions.

Analysis of the systematic random data is followed by comparisons of this data set against data from judgment sampling and/or other soil background data. This determines the extent to which this data set can be regarded as sufficiently representative and complete for use as a primary Sitewide soil background data set. The judgment data also provide compositional information on the chemical characteristics of subordinate soil types in the vadose zone and the extent to which these data can be regarded as part of the main population. These judgment data also address validation or refinement of the conceptual model concerning minor soil types and other controls on soil composition.

The overall validity of the chemical data and interpretations depend on the third data type, which provides the basis for evaluation of the data quality. These data include field duplicates and laboratory blanks and duplicates. These data are used to evaluate precision and accuracy of the soil background data set. Together, the analysis of all of these data provide a basis for evaluating the extent to which the DQOs and PARCC parameters have been met.

5.8 COVERAGE AND COMPLETENESS OF SAMPLING

The systematic random samples together with the judgment samples constitute one of the largest known background data sets for a vadose zone composed largely of a single formation. These sampling efforts were designed to the sand size and smaller materials (i.e., ≤2-millimeter size fraction) in the main facies and subordinate soil types known to occur in the vadose zone on the Hanford Site. These samples are believed to have included most, if not all, of the constituent mineral, rock, and organic materials that significantly affect the chemical composition of the vadose zone sediments, including those from sedimentary facies that were not sampled.

Most of the samples collected for the characterization of soil background are from the three main facies of the Hanford formation, which comprise approximately 85 percent of the vadose zone beneath the Hanford Site (Chapter 3.0, Section 3.1). The second greatest number of samples were of surficial deposits. Both the Hanford formation sediments and the surficial deposits are important because they are in the uppermost 15 feet (4.6 meters) of the vadose zone where a majority of soil characterization associated with environmental restoration on the Hanford Site is expected to take place (WAC 173-340-740(6)(c)). Several samples from the Ringold Formation facies also were collected, primarily from the boreholes.

The only types of soil material not sampled were some subordinate and volumetrically minor varieties. These include the alluvial fan facies of the Ringold Formation, the Plio-Pleistocene pre-Missoula gravel facies, and Hanford formation materials containing Ringold and Plio-Pleistocene rip-up clasts. However, there is no reason to believe that these materials contain components that would cause their chemical compositions to differ significantly from those that were sampled (i.e., the three facies of the Hanford formation, upper and middle Ringold facies, eolian deposits, Columbia River Overbank deposits, stream outwash deposits, clastic dike material, and

topsoils). Provisions for the recognition of natural outliers are included in *Hanford Site Background Data Applications Guide: Part 1, Soil* (DOE-RL 1994).

The data types qualitatively described here are presented and evaluated in Chapter 6.0. The quality of the data is addressed separately in Chapter 7.0.

6.0 RESULTS AND EVALUATIONS

The main findings resulting from the characterization of soil background composition on the Hanford Site are summarized in this chapter. The data and evaluations associated with these characterization efforts primarily involve the chemical analysis of soil background samples, and include the characterization of physical composition. Three main types of data are presented: (1) soil compositions of 104 samples collected by systematic random sampling and determined in accordance with EPA protocols, (2) soil compositions from 51 judgment samples, and (3) other data supporting evaluation of the conceptual model. Quality assurance and quality control data are presented in Chapter 7.0.

6.1 OVERVIEW OF MAIN FINDINGS

The main findings fall into two categories: (1) results concerning the range of analyte concentrations in vadose zone soils and the implications for using this range as soil background on the Hanford Site and (2) results relating to validation of the soil background conceptual model. Results from the second category are important because the results provide the technical basis and justification for use of the chemical compositional data as Sitewide background.

6.1.1 Soil Composition and Hanford Sitewide Background

The main findings and interpretations resulting from the efforts to characterize the composition of soil background on the Hanford Site include the following.

- Soils in the vadose zone on the Hanford Site have a range of chemical compositions that can be represented as a single Sitewide compositional population for all naturally occurring inorganic analytes.

- Only a small number of the analyzed soils have one or more analyte concentrations that are significantly larger than in the majority of soil background samples.

- The concentrations of all measured organic analytes were found to be at or below present detection limits in the samples analyzed.

- These data can be used as the primary basis for identifying contamination in essentially all soils in the vadose zone on the Hanford Site including the materials from the Hanford formation and younger sediments, Ringold Formation, topsoils, and volcanic ashes.

- Unusually high analyte concentrations that occur naturally can be evaluated using these data.

The most important finding is that there is a single population of natural soil composition on the Hanford Site (i.e., a Sitewide background) that applies to all inorganic constituents for essentially all soils in the vadose zone. The significance of this result is that the soil background data can be used for all environmental restoration activities on the Hanford Site. These soil background data therefore are valid for use in identifying contamination in soils and for use in other related applications (Chapter 1.0, Section 1.3). Summary statistics for the reference Sitewide soil background data set are provided in Table 6-1 and Table 6-2.

6.1.2 Soil Background Conceptual Model

The interpretation and effective application of soil background data to environmental restoration activities on the Hanford Site requires an understanding of what the data represent and the factors that influence composition and variability in the data. This primarily involves validation of the soil background conceptual model. The following is a summary of the main results regarding factors that control soil composition.

- The range of chemical compositions of a suite of samples is primarily controlled by the types and proportions of mineral and rock constituents.

- Grain size substantially influences the chemical composition of samples determined in accordance with regulatory protocols.

- The effects of grain size and modal composition of soil chemistry are interrelated.

- The analyzed soils in the vadose zone are related because the soils are all composed principally of basaltic material, feldspar, and quartz.

- Basaltic material in the soil samples is capable of controlling the abundance of most analyte concentrations.

These factors are related and all contribute to the range of chemical compositions in soils in the manner described in the soil background conceptual model. The data and results relating to validation of the conceptual model are presented in Section 6.2. The data and results provide a basis for interpreting the chemical compositional data presented and evaluated in Section 6.3 in the context of Sitewide background.

6.2 SITEWIDE SOIL BACKGROUND CONCEPTUAL MODEL VALIDATION

Two important objectives of this study have been to understand the nature and processes that affect and control the natural composition of soils on the Hanford Site and to evaluate the validity of the Sitewide approach to the determination and use of soil background data. Validation of the soil background conceptual model is a prerequisite for (1) consideration of the

quartz (silica) in factor 6. These three factors account for 10, 11, and 6 percent of the variation in these data, respectively.

The first two factors account for 62 percent of the variance of the Sitewide background reference data set, but neither factor appears to represent any single mineral component. These two factors include most of the major elements associated with basalt and feldspar. These site-specific characteristics reflect the combined effects of the physical composition of the soils (i.e., modal composition and grain size) and EF for the soils. The interelement correlations calculated for this data set are listed in Appendix D, Table D-5. Analytes with an insufficient number of samples above the limit of detection (Chapter 7.0, Section 7.2.2) could not be calculated and were not included in the analysis.

An example of the use of factor analysis and interelement correlation is the determination of whether elevated levels of analytes, such as nickel and chromium in soil, represent natural exceedances, contributions from substances such as stainless steel (e.g., from drill bits), or other contamination. These characteristics of the soil background population also are used in evaluating the extent of lead contamination in the soils from automobile emissions (Section 6.4). Use of interelement correlations is included in the framework for the use of soil background data in environmental restoration activities on the Hanford Site (Appendix F).

6.3.2.3 Threshold Levels. Background threshold levels for the analytes are characteristics of a data set that refer to an upper confidence interval of a percentile of the systematic random distribution. Specific threshold levels for each analyte can be calculated from the distribution of this Sitewide background data set. However, calculated threshold levels depend on the confidence interval and percentile used in the calculation, how the data are used, and also on the null hypotheses associated with a particular use. Different analyte threshold levels therefore can be calculated from this data set, depending on the parameters used in the calculation. Several thresholds have been calculated and these are shown in Summary Table 2. Summary Table 2 contains estimated parameters for the systematic random data set. The table includes estimates for the 50th, 80th, 90th, and 95th percentiles as well as upper confidence limits for the estimates of the 80th and 90th percentiles and lower and upper confidence limits for the 95th percentile. The confidence limits are based on 95 percent coverage. These estimates were computed for both the lognormal and Weibull distributions. Statistical calculations are described further in Appendix D, Section D1.1.

Threshold levels for each of the 36 analytes measured in the Sitewide soil background data set are presented in Table 6-9. The threshold levels are based on three sets of confidence interval and percentile criteria, for both lognormal and Weibull distributions. It is notable that the threshold levels of most analytes calculated for lognormally distributed data are somewhat larger than those calculated using Weibull distributions (Section 6.2.3).

These threshold values are presented as characteristics of the Sitewide soil background population that can be used in a number of ways. Threshold levels might not be the most appropriate application of soil background data for some uses and should not serve as the sole basis for data interpretation

without also considering other characteristics of the data set. These other characteristics include the uncertainties associated with data, interelement correlations, and consideration of the natural concentrations in outliers and judgment samples.

6.3.2.4 Outliers. The results of statistical analysis of the systematic random sample data indicate that only 17 of the 104 samples in the data set have analyte concentrations so large as to be regarded as statistical outliers (Table 6-10), and censored from the calculation of population characteristics. These outliers are limited to only seven analytes: calcium, fluoride, lead, silicon, sodium, zinc, and zirconium. Thirteen of these samples have only one analyte outlier, one sample has outliers only for calcium and sodium, and the remaining three samples have outliers only for fluoride and zirconium. Details regarding the statistical characteristics and criteria for classification as an outlier are presented in Appendix D, Section D2.11.3.

The composition of most of these outliers appears to be attributable to carbonate-bearing and/or alkaline soils indigenous to this region that are characteristically enriched in calcium and/or sodium and/or fluoride. The calcium outliers are interpreted to be associated with somewhat larger contents of calcium carbonate ($CaCO_3$) based on their correlation with alkalinity in these samples (Figures 6-12 and 6-13). The sodium outliers are all from the Rattlesnake Springs locality (Sampling Site No. 12), which is recognized as a locality of highly alkaline soil and salt-tolerant flora (Rickard 1964). These soils also contain some of the largest measured concentrations of chloride and sulfate. Outliers of this type also have characteristic interelement correlations for these analytes that occur in salt-rich alkaline soil regions.

The outliers for zinc and zirconium do not have any obvious associations or interelement correlations. The magnitude of these analyte concentrations are most easily explained as samples containing larger amounts of basalt and/or basaltic material richer in zinc and zirconium, which is consistent with the range of concentrations known to occur in the basalts (Chapter 4.0, Table 4-1). Alternatively, these outliers could represent examples of the nugget effect, possibly associated with trace amounts of zircon in sampling site 10, and a zinc-bearing mineral in sampling sites 2 and 6.

The one outlier for lead was collected from the riparian zone of the Columbia River, which contains generally elevated levels of lead, cadmium, and zinc. Section 6.3.3.5 describes the chemical characteristics of the riparian zone in more detail.

6.3.3 Judgment Samples, Subordinate Soil Types, and Exceedances

The chemical compositions of naturally occurring soil types collected as judgment samples are presented in this section. Compositional data on two types of judgment samples are presented: (1) judgment samples collected at the 14 systematic random localities and (2) topsoils from the main terrestrial ecosystems. Data on Ringold Formation sediments also are included in this section.

These samples were collected for the purpose of documenting and evaluating the composition of soil types in the vadose zone that might not have been included in the systematic random sampling. The bias involved in the collection of these samples precludes the inclusion of these data with the systematic random data in the calculation of Sitewide background population characteristics. These data are, therefore, used to supplement the background reference data set for completeness, and for evaluating the representativeness and comparability of the background reference data.

These evaluations were performed by comparing the analyte concentrations of the judgment samples to those of the background reference population using the 95/95 threshold values as the reference for comparison for most analytes. Threshold values were calculated from the systematic random data for Weibull distributions of all analytes. The LOQ (Chapter 7.0) also was used as a comparison criterion for analytes in the reference population having threshold levels based on detection limits, or for analytes with less than 10 data points above detection (Chapter 7.0, Section 7.2.2). For the purpose of these comparisons, exceedances are defined as any analyte concentration exceeding the reference comparison levels described above. Analyte concentrations less than these reference levels are regarded as consistent with those of the Sitewide reference population. This method of comparison is considered to be appropriate because it involves the comparison of natural background data with the characteristics of the background reference population. This comparison method also is more rigorous than other tests (e.g., Bernoulli trial comparison across all the analytes in each sample), and involves the evaluation of each analyte exceedance in each sample. The overall number and type of exceedances and the significance of these exceedances are discussed in Sections 6.5 and in Chapter 7.0, Section 7.3.

6.3.3.1 General Relationships. The most important feature of the judgment sample data is that the analyte concentrations in most of these samples are consistent with those in the Sitewide reference data set, i.e., there are relatively few exceedances. There also are no systematic exceedances that violate the conceptual model. Most of the observed exceedances involve analytes associated with alkaline soils and topsoil rich in organic carbon. The analyte concentrations for the main types of judgment samples are listed and compared to the threshold values in Tables 6-11 to 6-18. A complete listing of the chemical compositions of the judgment samples is provided in Appendix C.

The following is a summary of the general relationships between the analyzed compositions of these soils compared to the reference levels of the Sitewide soil background data set.

- The analyte concentration for all analyzed eolian and alluvial samples are within the range of the reference population for all constituents.

- The compositions of Ringold Formation judgment samples in the vadose zone are comparable to the reference population, with only a few notable exceptions.

- The compositions of analyzed volcanic ashes largely are indistinguishable from those of vadose zone sediments, but one offsite ash sample is markedly different.

- Pedogenic topsoils have compositions that are largely comparable to the parental vadose zone sediments (Sitewide population), with the exception of certain analytes and specific ecosystem-topsoil associations.

A description of the type and extent of exceedances that occur in the judgment samples and subordinate soil types are described in the following sections.

6.3.3.2 Judgment Samples From Inorganic Sampling Sites. The compositions of the 31 judgment samples collected from the same localities as systematic random samples are listed in Appendix C. A summary of the analyte concentrations that exceed the 95/95 threshold levels in the Sitewide background reference population is presented in Table 6-11. Nine of the 31 judgment samples have at least one analyte with concentrations that exceed the Sitewide reference levels. Six of these samples have an exceedance for only one analyte. The most notable features associated with this group of samples are (1) most of these samples represent subordinate members of the vadose zone (e.g., clastic dikes, volcanic ash, and caliche-rich soil) and (2) with the exception of sample B01497, a majority of these exceedances involve analytes associated with the highly alkaline and carbonate-rich soils (i.e., calcium, sodium, nitrate, sulfate, alkalinity).

In all but one of the judgment samples, only one exceedance was observed for the analytes barium, lead, manganese, and mercury. The exceedance levels for these analytes are all only slightly larger than the reference threshold (i.e., less than 1.3 times larger). The one exception is a near-surface sample (B01497) with exceedances for aluminum, barium, manganese, and potassium that are noticeably larger than those of the reference thresholds (up to 1.7 times larger for barium). The exceedances for beryllium and zinc in this sample are only sightly larger than those of the reference thresholds.

Overall, the number of exceedances in the judgment sample data set is remarkably small, and well below the 5 percent statistically expected for a comparison of this type. These exceedances largely are restricted to subordinate soil types. The analytes associated with most of these exceedances also are few in number and are those expected to have naturally elevated concentrations in alkaline soils. It also is indicated from the concentrations of these exceedances that most do not reflect nugget effects, but rather expected statistical exceedances.

6.3.3.3 Ringold Sediments. The compositions of judgment samples from the Ringold Formation sediments (Table 6-12a and 6-12b) fall into two main groups: (1) those collected within the vadose zone at offsite localities and (2) those collected in the saturated zone from the Yakima Barricade borehole. Only the compositions of the first group are discussed here. Samples in the second group were analyzed in conjunction with the groundwater background characterization efforts and are listed for information only.

The concentrations of most analytes in the samples of Ringold Formation sediments from the Savage Island borehole and an offsite surface sample are comparable to those in the Sitewide background reference data set (Table 6-13a and 6-13b). The main exceedances are in the contents of silica (up to 10 times threshold levels), and in the apparent contents of cadmium (2 to 3 times the threshold levels) for all of these samples. No significant exceedances were observed for the subsurface Ringold Formation sediments except for the markedly elevated concentrations of chromium and nickel in one sample (SB-1004) in approximately the same ratio as in stainless steel. The one sample collected at the surface of the island and the duplicate of this sample have somewhat elevated levels of aluminum, chromium, and potassium compared to those of the reference background levels. These characteristics are more likely to reflect the biologic and pedogenic effects of topsoil than intrinsic characteristics of Ringold Formation sediments, especially considering that this sample was collected from the topsoil on an island in the Columbia River. It also is notable that the three Ringold Formation samples in the lower part of the vadose zone from the Yakima Barricade borehole, included in the Sitewide background reference data set (HEIS numbers B014J3, B014J4, and B014J5), also have analyte concentrations that are indistinguishable from those of other vadose zone materials.

It is indicated from these results that the composition of most Ringold Formation sediments expected to occur in the vadose zone on the Hanford Site have analyte concentrations consistent with those of the Sitewide reference population, with the exception of only two analytes, silica and cadmium. Silica generally is not an analyte of significant concern. The exceedances for cadmium are suspect because cadmium is an analyte that occurs at concentrations near detection levels, and also because the samples from Savage Island were analyzed at a different laboratory than those of the Sitewide reference samples, which did not provide information for the calculation of LOD and LOQ values. A sample interpreted to be a volcanic ash (SB-1002) is discussed in the following section.

6.3.3.4 Volcanic Ash. Compositions of five volcanic ash samples encountered in the upper 5 to 10 feet (1.5 to 3 meters) of the vadose zone are listed in Table 6-14. Four of these samples were included in the judgment samples from the systematic random sampling sites, and one (sample SB-1002) was from the Savage Island borehole. The concentrations of analyte exceedances for these samples are listed in Table 6-15. These ash compositions probably represent only three volcanic ash units because the three samples from Sampling Site No. 5 all appear to have been collected from the same ash unit (Mazama ash) and the three samples all have similar compositions.

All of these volcanic ash samples except the one sample from Savage Island have compositions comparable to those of the Sitewide background population. The ash sample (B01427) collected from the characteristically alkaline soils from Rattlesnake Springs on the Arid Lands Ecology Reserve (Sampling Site No. 12) has exceedances for the same analytes (calcium, sodium, and alkalinity) as other samples collected from this and other sites of highly alkaline soils (Section 6.3.2.4). The compositions of the three ash samples from Sampling Site No. 5 show no exceedances for any of the analytes.

The composition of a sample from Savage Island, interpreted to be a volcanic ash within the Ringold Formation, has elevated concentrations for at least 12 analytes, some of which are the largest analyte concentrations yet found in the vadose zone (Table 6-15). This unidentified ash unit clearly is different in composition from any other material analyzed in the vadose zone. It is not known whether this unit occurs in the vadose zone on the Hanford Site.

The analyzed volcanic ashes in the Hanford formation and younger units therefore appear to have compositions that are comparable to, and adequately represented by, the Sitewide soil background data. However, only two of the four ashes known to occur within the vadose zone on the Hanford Site might have been sampled (Chapter 3.0, Figure 3-10). The compositions (Table 6-15) represent at least two of these volcanic ashes, presumably Mazama ash and Glacier Peak ash. However, these ashes presently cannot be correlated to specific units on the basis of composition because the digestate compositions differ significantly from those of bulk compositions, and only bulk compositions of these volcanic ashes presently exist in the literature.

6.3.3.5 Topsoils. The compositions of samples collected in the upper few inches (centimeters) of the topsoil in terrestrial ecosystems on the Hanford Site (Chapter 5.0, Section 5.4.2) are listed in Table 6-16. In general, these data show that the majority of the topsoils on the Hanford Site have analyte concentrations no larger than those of the Sitewide soil background reference levels (Table 6-17). However, the topsoils in three of the ecosystems have distinctively higher concentrations for many analytes. These three soil association types are: (1) highly alkaline soils of playa and ephemeral drainages, (2) riparian ecosystem soils, and (3) the grassy soils on Rattlesnake Mountain.

The compositions of the highly alkaline soils collectively have exceedances for nearly every analyte. Two types of highly alkaline topsoils were collected: one in the leaf-litter canopy of spiny hopsage in the cryptogamic soil of a playa (B06146 and B06147), and one in the leaf-litter canopy of a greasewood plant (B061379) from Rattlesnake Springs on the Arid Lands Ecology Reserve. The analyte type and magnitude of these exceedances are likely to be attributable to both the accumulation of evaporite salts associated with these ecosystems, and also to the bioaccumulation of analytes associated with organic material (e.g., leaf litter) derived from these distinctive plant types (Rickard 1964).

Many, if not most, of the exceedances in the playa samples might reflect the effects of bioaccumulation in these topsoils. This interpretation is based on the general absence of chloride exceedances and of other analytes strongly correlated with evaporite minerals in these samples, and on the relatively high total organic carbon contents, which are two of the largest measured (1.7 to 5.2 percent by weight). The elevated concentrations of analytes such as barium, cadmium, lead, and magnesium in the sample from Rattlesnake Springs also might be attributable to bioaccumulation effects. This is because these analytes were not found to be correlated with calcium, sodium, potassium, nitrate, phosphate, sulfate, and alkalinity, which characteristically are found in alkaline soils elsewhere in the vadose zone containing little or no organic material.

The riparian and related topsoils adjacent to the Columbia River have three to five times larger concentrations of cadmium, lead, and zinc compared to other vadose zone soils. The topsoil sample in the canopy zone of junipers adjacent to the riparian area also contains 2.5 times more arsenic than the Sitewide reference levels. The levels of copper were only slightly larger than those of the Sitewide reference value. These soils also have relatively larger amounts of organic carbon (1.4 to 2 percent by weight). These exceedances are significant because these soils are the most common types found in the vicinity of the production reactors.

The other main variant soil type is from the grassy soils developed in thick topsoils on the eastern facing slope of Rattlesnake Mountain. This sample contains concentrations of cadmium, lead, manganese, potassium, silver, and phosphate up to two times larger than those of the reference threshold values, and also has a relatively large organic carbon content compared to other soils (about 2 percent by weight).

Only two other analyte exceedances occur in all the samples collected from the ecosystems of the upper and lower Columbia River Plain, oldfield, and 200 Plateau, which cover a majority of the Hanford Site. These exceedances are (1) lead in a sample from the oldfield ecosystem measuring about twice that of the reference threshold and (2) a phosphate concentration 1.7 times that of the reference threshold from the leaf-litter canopy of sagebrush in the lower Columbia River Plain ecosystem.

6.3.4 Comparisons to Unit-Based Backgrounds

The Sitewide soil background reference values also were compared to the analyte concentrations of 58 individual samples from earlier unit-based soil background characterization activities at various locations across the Hanford Site, including the 100 Areas (DOE-RL 1988), the 200 Area (DOE-RL 1989), and the 1100 Area (DOE-RL 1990). The composition of these samples (Appendix C) was determined in the same manner as the Sitewide judgment samples (EPA 1986, 1989c), but at different laboratories. These comparisons are presented in Table 6-18 as an independent evaluation of the representativeness, completeness, and comparability of the Sitewide soil background data. These samples were collected from localized parts of the vadose zone adjacent to or in the vicinity of a WMU and specifically were collected for the purpose of representing unit-based soil background for individual units. These samples were collected by a combination of judgment surface sampling (DOE-RL 1989), highly localized random sampling on the scale of less than 108 square feet (10 square meters), and sampling from boreholes (DOE-RL 1988, 1989).

Only eight of the 58 samples have analyte concentrations that exceed the Sitewide background reference values, with the exception of cadmium concentrations. Of these eight samples, most are for only one analyte. A single exceedance was observed for nickel, chromium, manganese, and zinc. Two exceedances were observed for barium, and four for sodium. Twenty-two exceedances were found for cadmium. The concentration levels for most of these exceedances are not significantly larger than the reference threshold levels, except for sodium in the data set from the 200 Area (DOE-RL 1989).

The most significant group of exceedances is for cadmium, which is the only exceedance observed in 22 of the samples. All of these exceedances are about 10 times larger than those of the reference threshold value, and all of these samples are from the 100 Area in riparian and adjacent soils. Thirteen of the samples (DOE-RL 1988) were collected in a 10 foot (3 meter) by 10 foot (3 meter) grid, and essentially represent a single composite sample of the soil in this small area. The magnitude of the exceedances in the 22 samples could be a characteristic of riparian soils, because elevated cadmium was one of the distinguishing characteristics of these topsoils (Section 6.3.3.5). The extent to which these concentrations represent characteristics of riparian soils, or aspects of the data quality, cannot be determined without the assessment of the LOD and LOQ specific to these earlier data sets that contained insufficient information for these calculations.

Of the remaining exceedances, only those for sodium and manganese from the 200 Area data set (DOE-RL 1989) are larger than the number or magnitude expected from this type of comparison. The sodium levels in these samples are slightly larger than the reference threshold level, and could either reflect the alkaline characteristics of the soils, or uncertainty in the data. The single manganese outlier in this data set might represent the nugget effect in this sample.

6.4 OTHER RESULTS AND EVALUATIONS

The following sections contain information and evaluations relating to the Sitewide soil background data to x-ray spectra, occurrence of anthropogenic lead, and health-based levels.

6.4.1 Sitewide Soil Background X-ray Spectra

The Sitewide soil background samples (Table 6-19) also were analyzed by x-ray fluorescence (XRF) methods using a portable XRF unit and energy dispersive detection methods (ED-XRF) (WHC 1992d). Spectral scans for these samples were obtained using americium-241 and curium-244 sources (e.g., Figure 6-14). This 'scan' model approach for soil background is based on the observation that materials with similar matrices should exhibit similar XRF spectra under similar measurement conditions for a given energy source and intensity. These background samples produce a largely characteristic spectral pattern because the range of total counts observed for over 125 soil background samples is relatively small and distinctive for nearly all measured analyses. The only exceptions are the larger range of total counts observed for iron, which has the highest count rate, and to a lesser extent, manganese, and cobalt, which have spectral positions adjacent to iron.

These spectral scans indicate that the 'characteristic' spectral patterns of the soil background samples can be used to identify anomalously high concentrations of heavy metals in soils or other surfaces (WHC 1992d). The results of this work further demonstrates the utility of the Sitewide approach to the characterization and use of soil background data. The results also corroborate the assertion in the conceptual model that the materials in the vadose zone have certain physical and chemical compositions that enable most

of the material to be characterized and regarded collectively as a single Sitewide background population.

The use of the quantitative bulk and digestate compositional data provided in this report, combined with characteristic spectral scan patterns from field screening ED-XRF, also might provide a basis for semiquantitative ED-XRF analyses and/or enhancement of the field screening analysis methods.

6.4.2 Anthropogenic Lead in Soils

The question of whether any of the soil samples from the background sampling sites contain residual lead contamination from vehicle exhaust particulates, particularly those from sample sites located near roads (Chapter 5.0, Section 5.3.3), also has been evaluated. This was performed by evaluating interelement correlations with lead, and comparing the distribution of lead in soils from sites near roads to those from sites away from roads.

The systematic random data were divided into two subsets based on their proximity to roadways. The subset closest to roadways consisted of samples from Sampling Site No.'s 1, 5, 6, 7, 8, 9, 13, and 14. A number of these sites are located in and around the 200 Areas, as described in Appendix A, Section A2.3. The second subset consists of samples from the remaining sites that are not near roadways. Evaluation of these two subsets provides a basis for determining whether there is any bias in the concentration of lead of these subsets.

The concentrations of lead and aluminum both were evaluated because the positive correlation between these two analytes (r^2 = .55+) appears to be a characteristic of the natural background population that can be used in this comparison. This evaluation was, therefore, based on the assumption that (1) soils affected by the addition of lead from vehicle exhaust would be expected to have lead concentrations larger than those from other sites and (2) samples containing anthropogenic lead would not be correlated with analytes like aluminum in the same manner as uncontaminated samples.

The results of this evaluation (Figure 6-15) show that there is no indication of higher lead concentrations in samples collected from sites nearest to roads on the Hanford Site. The concentrations of lead generally are smaller in the soil samples nearest roads even though the two data sets show the same interelement correlation trend for lead and aluminum (Figure 6-15). This result is the opposite of that expected for soils contaminated from vehicular emissions.

The lead content in these soils appears to be controlled by factors other than proximity to roadways. The controlling factor for the generally larger concentrations of aluminum and lead in samples farthest from roads most likely is the somewhat smaller grain size of the soils in this subset of samples. Compositions of soils with smaller particle sizes have been shown to have digestate/leachate compositions with somewhat larger concentrations of lead (Section 6.2.2.2). The sample sites near roadways primarily are coarser grained sediments from gravel quarry sites located near roadways. It is,

therefore, indicated that there is no measurable anthropogenic lead contamination from vehicle exhaust in the Sitewide soil background samples.

6.4.3 Comparison of Sitewide Background Data to Health-Based Limits

The Sitewide soil background data and health-based protection levels identified in the Model Toxics Control Act (MTCA) (WAC 173-340) are summarized in Table 6-20 as a means of comparing these background data to a set of calculated risk-based cleanup standards. This type of comparison provides insight regarding the utility and adequacy of these data for use in risk assessment applications. The average and maximum analyte concentrations, LOD levels, and 95/95 threshold levels are tabulated together with the MTCA health-based concentration limits for soil ingestion and Method B exposure parameters. The 95/95 threshold levels are used here as one type of calculated statistical characteristic of the background population that can be used in making comparisons for individual analytes. These data are also compared to a hazard index of 0.1 calculated in the manner recommended in the Hanford Site Baseline Risk Assessment Methodology (HSBRAM) (DOE-RL 1992a) as an example for evaluating the significance and adequacy of the data for use in assessing the combined risks from multiple analytes.

- Only a small number of samples in the Sitewide background data set have analyte concentrations that exceed the 95/95 threshold levels. There are naturally occurring exceedances for nearly all of the inorganic analytes in the Sitewide background data set. However, these exceedances occur in a relatively small number of samples (refer to Sections 6.3.2.4 and 6.3.3).

- The largest measured background concentrations exceed the secondary screening 10 percent of MTCA chronic toxicity carcinogenicity for nine inorganic analytes; antimony, arsenic, cadmium, chromium (as Cr VI), manganese, mercury, nickel, and vanadium for chronic toxicity; and arsenic and beryllium for carcinogenicity (Table 6-20).

- Other than arsenic, none of the analytes in the Sitewide background data set have concentrations that exceed residential soil ingestion levels for chronic toxicity calculated using a hazard index of 1.0, and most samples have concentrations significantly below these toxicity limits. However, the maximum levels of some analytes in the background data sets (e.g., antimony) are not significantly different from these calculated toxicity levels. The background levels of some analytes that have concentrations individually less than a health-based protection level, may collectively have concentrations that contribute significantly to risk based on criteria such as hazard quotient (Table 6-20).

- The detected levels of arsenic and beryllium in all of the naturally occurring soils have concentrations that are significantly above the calculated residential carcinogenicity limits. The maximum concentrations of arsenic and beryllium that occur naturally are over 40 and 50 times larger than these carcinogenicity limits, respectively.

- The actual detection limits achieved at the CLP laboratories are generally smaller than residential toxicity limits, and most are significantly less. However, the LOD for arsenic and beryllium are much greater than calculated carcinogenicity limits (6 to 10 times greater).

It is indicated from these comparisons that the majority of the naturally occurring soils in the vadose zone at the Hanford Site have analyte concentrations that do not exceed the calculated health-based levels for chronic toxicity by ingestion. The technical basis for the calculation of the carcinogenicity levels for arsenic and beryllium, however, appears to be very poor based on the soil background data. The naturally occurring levels of several metals in the soils could be expected to exceed recommended screening levels for certain soil types, e.g., topsoils rich in organic carbon. Therefore, it is indicated that these secondary screening levels might be too stringent if significant numbers of background samples fail to pass this screen. The detection levels for all of the analytes are sufficiently sensitive for the application of these data in baseline risk assessments.

6.5 SUMMARY AND DISCUSSION

The results of these evaluations provide both physical and chemical data on the composition of naturally occurring soils in the vadose zone on the Hanford Site. These results confirm that a Sitewide soil background is a viable concept for use in environmental restoration activities on the Hanford Site, and also provide the database for this Sitewide background. All aspects of the conceptual model that constitute the basis for the Sitewide approach to the determination and use soil background data have been confirmed and refined. The Sitewide soil background data also have been shown to be sufficiently representative of soils throughout the vadose zone and appropriate for use in the identification of contamination in essentially all types of soils.

The inorganic chemical composition of Sitewide soil background data is represented by two data sets, a primary random data set and a judgment data set. The statistical characteristics of the primary data set, based on systematic random sampling, serve as the basis for statistical application of the data and the calculation of comparison and screening criteria such as threshold levels. The second data set, based on judgment sampling, was used to corroborate the representativeness of the primary data set, and together with the conceptual model, serves as a basis for distinguishing contamination from natural outliers and exceedances.

There were no volatile or semivolatile organic chemicals, pesticides, or PCBs detected in any of the 12 representative topsoils from the selected terrestrial ecosystems. These results initially were intended to provide preliminary information on the maximum range to which naturally occurring organic chemical might occur in the soils on the Hanford Site. However, it is indicated from the absence of these organic chemicals from the soils in which natural organic chemicals should be largest that further sampling and analysis for the characterization of natural background for organic analytes might not be warranted.

Some of the most significant results of this study involve the validation and refinement of the Sitewide soil background conceptual model. These findings relate primarily to documentation of the physical characteristics of the vadose zone soils and the factors that influence their chemical composition. These results include the following.

- The range of chemical compositions of the soils reflect variations in the types and proportions of rock and mineral constituents (mode) and grain size.

- The vadose zone soils on the Hanford Site primarily are composed of relatively unaltered mixtures of basaltic material, quartz, and feldspar.

- The compositions of the soils are related because of similarities in their origins and source materials.

- The physical similarities and relationships between these soils are manifested chemically as a single compositional population having a continuous range of concentrations for each analyte, and can be described as single statistical distributions.

The range of chemical compositions of the vadose zone soils reflects the range of modal and grain size composition of the soils, and the extent to which individual analytes are extracted from these soils during their preparation for analysis (e.g., partial acid digestion). The effectiveness of extraction (EF) of individual analytes from the soils varies with mineral or rock type, and increases with decreasing grain size. Hanford Site soil compositions reflect EFs that vary from over 90 percent for analytes such as lead, to less than 1 percent for analytes such as sodium.

Basaltic material in the soils has been shown to be capable of dominating the chemical composition of the soils for nearly all analytes. For most analytes, the primary effects of quartz and feldspar are as dilutants. The main exceptions are for analytes that also occur in feldspar (e.g., calcium, sodium, and potassium). Accessory minerals such as salts and calcium carbonate also contribute to, or dominate, the abundances of analytes such as calcium, sodium, alkalinity, and chloride in certain minor soil types.

The systematic random set of soil compositional data adequately represents essentially all soil types in the vadose zone, including eolian and alluvial deposits, Ringold Formation sediments, and most volcanic ashes and topsoils. Comparisons to previously determined WMU-based soil backgrounds also indicate that this systematic random data set is sufficiently robust for use as Sitewide background.

The most notable anomalies in soil composition occur almost exclusively in two main types of topsoils: those with relatively large amounts of organic carbon and those in highly alkaline topsoils. Highly alkaline topsoils with a relatively low amount of organic carbon typically have elevated concentrations of calcium, sodium, potassium, nitrate, phosphate, sulfate, and alkalinity; those with larger amount of organic carbon have relatively elevated concentrations for nearly all analytes [compared to the upper threshold for

the Sitewide soil background (Table 6-2)]. The topsoils richest in organic carbon (riparian topsoils and grassy soils on the flank of Rattlesnake Mountain) all have elevated levels of cadmium and lead, up to five times larger than the reference threshold levels. Somewhat larger concentrations of barium, magnesium, manganese, zinc, and potassium also occur in the leaf litter canopy of specific plant types such as spiny hopsage, greasewood, and juniper.

The elevated levels of analytes in the highly alkaline soils lowest in organic carbon are interpreted to result from the physical accumulation of salts by evaporation. The elevated concentrations of lead and cadmium appear to be an important characteristic of soils with more organic material. This appears to be related to bioaccumulation associated with specific plant types. This characteristic of the riparian soils is important because these soils are found throughout the 100 Areas.

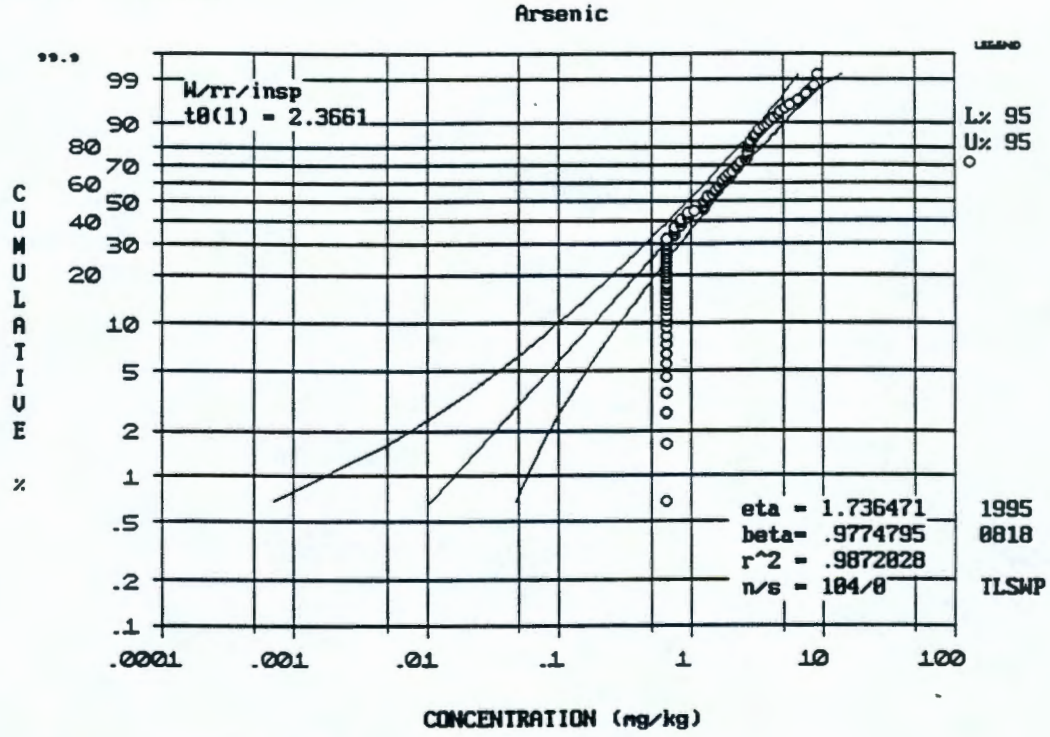
One of the most important conclusions drawn from comparing the Sitewide background data to other soil compositions is that caution must be used in interpreting the concentrations of analytes with naturally occurring abundances that are at or near detection limits. This is a concern because the quality assurance and quality control of a given laboratory, and especially the actual LOD and LOQ associated with the measurement of these analytes, can be the most important factor in interpreting the concentrations for these analytes. In the Sitewide soil background data set, these analytes include silver, molybdenum, thallium, cadmium, selenium, mercury, antimony, lithium, nitrite, and phosphate.

Data collected in conjunction with this study can be used as Sitewide soil background for environmental restoration activities across the Hanford Site. The statistical characteristics of the systematic random data set can be used in identifying contamination in all types of vadose zone soils because all of the DQO and PARCC parameters required for the use of these data in this capacity have been met.

The manner in which the Sitewide data are used in the identification of contamination is of fundamental importance. This issue is important because a variety of statistical parameters and/or comparison criteria (e.g., threshold levels) can be calculated from these data for different types of contamination scenarios. However, the use of a Sitewide soil background is lost if there is no consistency or guidance concerning the manner in which these data are, or should be used. It also is imperative that users of the data understand the uncertainties and limitations of these data in making decisions regarding the presence or absence of contamination. The threshold levels presented in Table 6-2, for example, are commonly used parameters that can be calculated in many ways based on the level of confidence and coverage desired, but which also have inherent limitations in their use. There also is considerable uncertainty associated with any given threshold level and individual analyte concentration measurement for an analyte resulting from the uncertainties involved in the sample collection and analysis processes. It is, inappropriate for major programmatic or activity decisions using soil background data to be based exclusively on such factors as threshold exceedances.

The importance of appropriate and consistent use of the Sitewide background data for activities specific to the Hanford Site therefore has led to the development of a framework for recommended guidance regarding data use, contained in *Hanford Site Background Data Applications Guide: Part 1, Soil* (DOE-RL 1994). This guidance includes a phased approach to the evaluation of soil compositional data, and technically justifiable statistical methods that can be used in the identification of contamination in soils for the primary contamination scenarios that occur on the Hanford Site. One of the main points of emphasis resulting from this aspect of the evaluation and incorporated in the background framework guidance (DOE-RL 1994) is that the manner in which primary screening criteria are chosen generally is no more important than the manner in which the exceedances are interpreted and handled. It is in this context that the Sitewide soil background data presented here are justified as sufficiently adequate to represent all soil types in the vadose zone on the Hanford Site.

(a) Arsenic--Weibull



(a) Arsenic--Lognormal

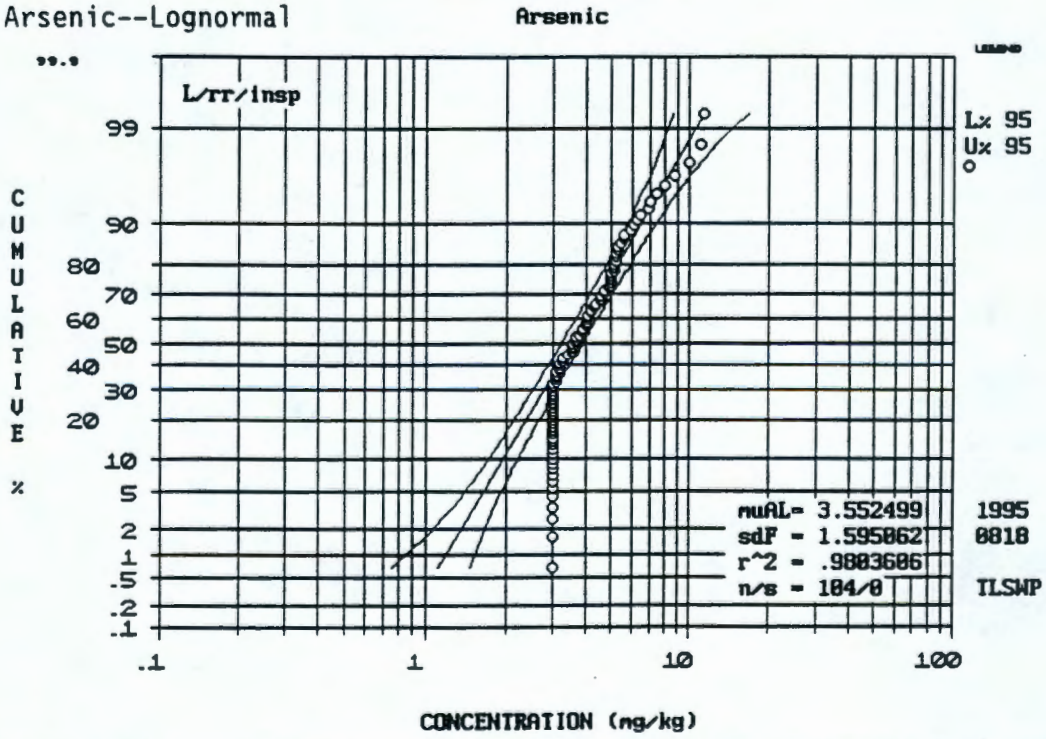
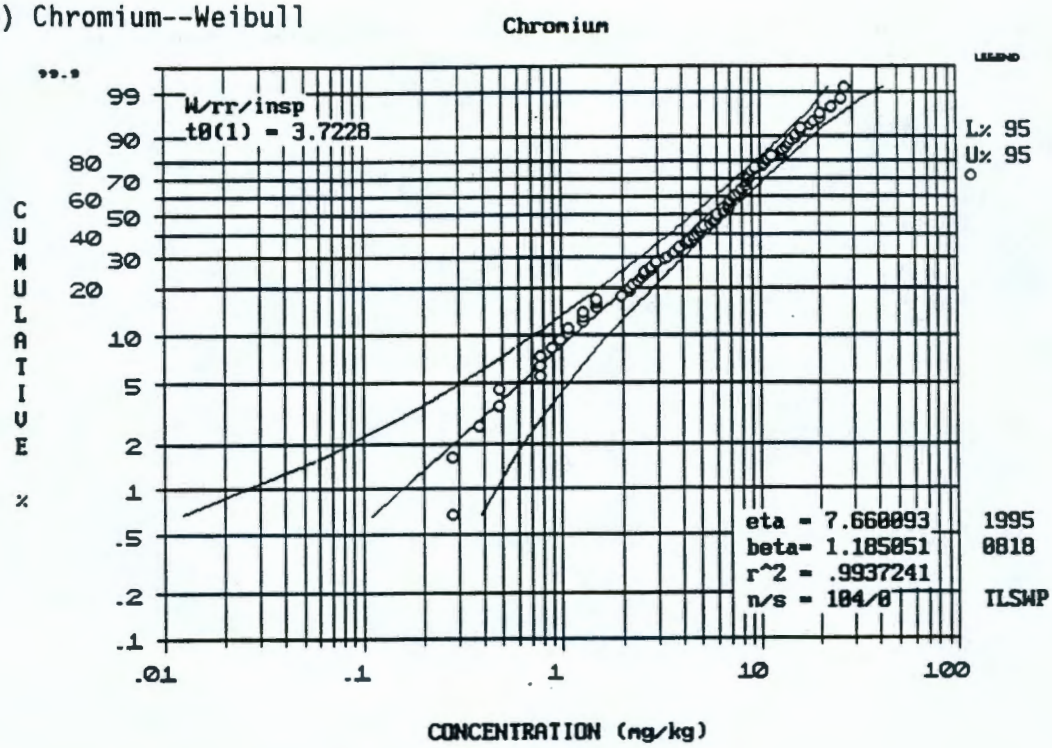


Figure 6-11.a. Cumulative Distribution Plots for Sitewide Soil Background Data (Random Data Set) for Arsenic. Regression lines are shown together with upper 95 percent confidence level line; r^2 is a goodness of fit parameter where 1.0 is a perfect fit.

(b) Chromium--Weibull



(b) Chromium--Lognormal

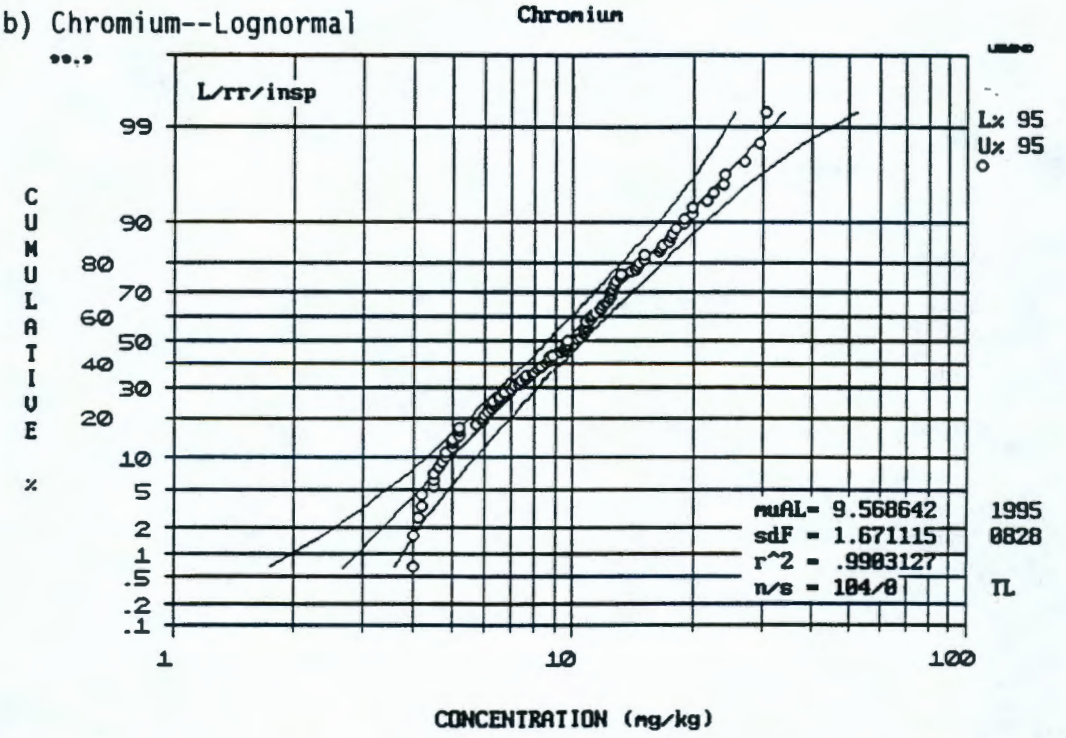
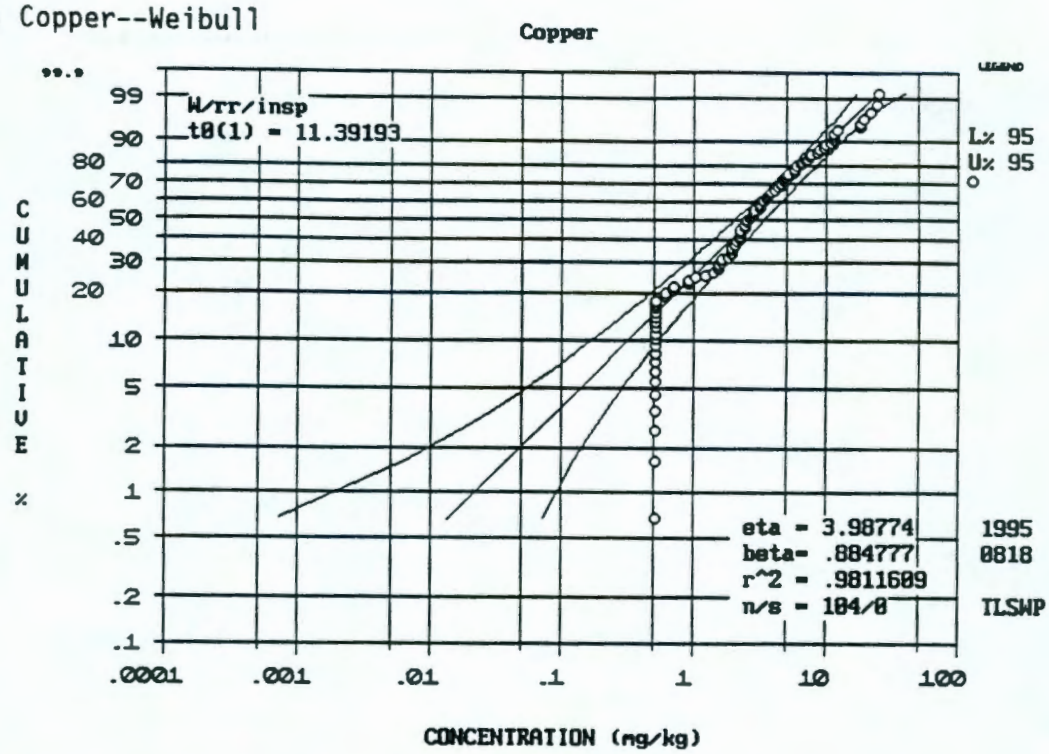


Figure 6-11.b. Cumulative Distribution Plots for Sitewide Soil Background Data (Random Data Set) for Chromium. Regression lines are shown together with upper 95 percent confidence level line; r^2 is a goodness of fit parameter where 1.0 is a perfect fit.

(c) Copper--Weibull



(c) Copper--Lognormal

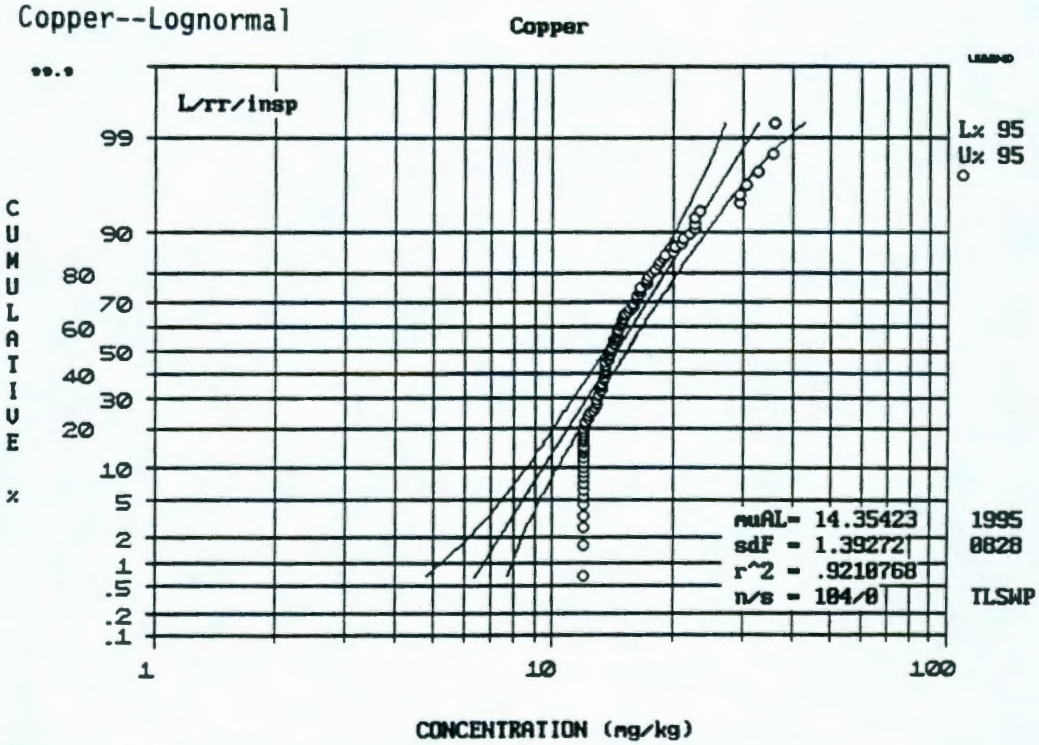
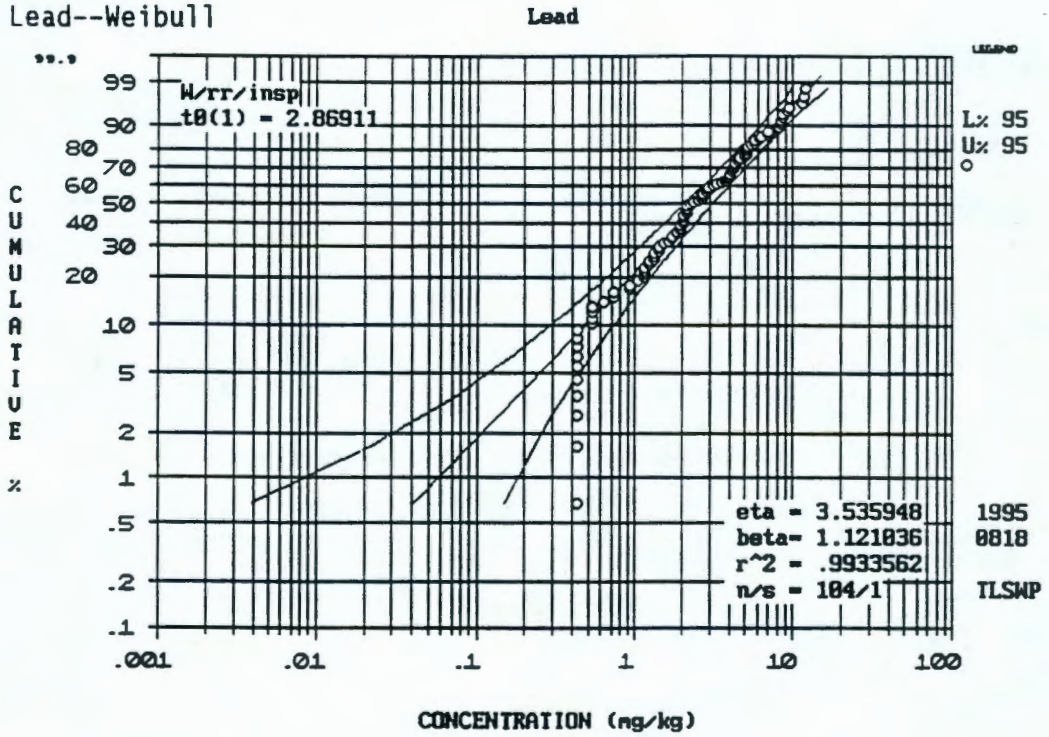


Figure 6-11.c. Cumulative Distribution Plots for Sitewide Soil Background Data (Random Data Set) for Copper. Regression lines are shown together with upper 95 percent confidence level line; r^2 is a goodness of fit parameter where 1.0 is a perfect fit.

(d) Lead--Weibull



(d) Lead--Lognormal

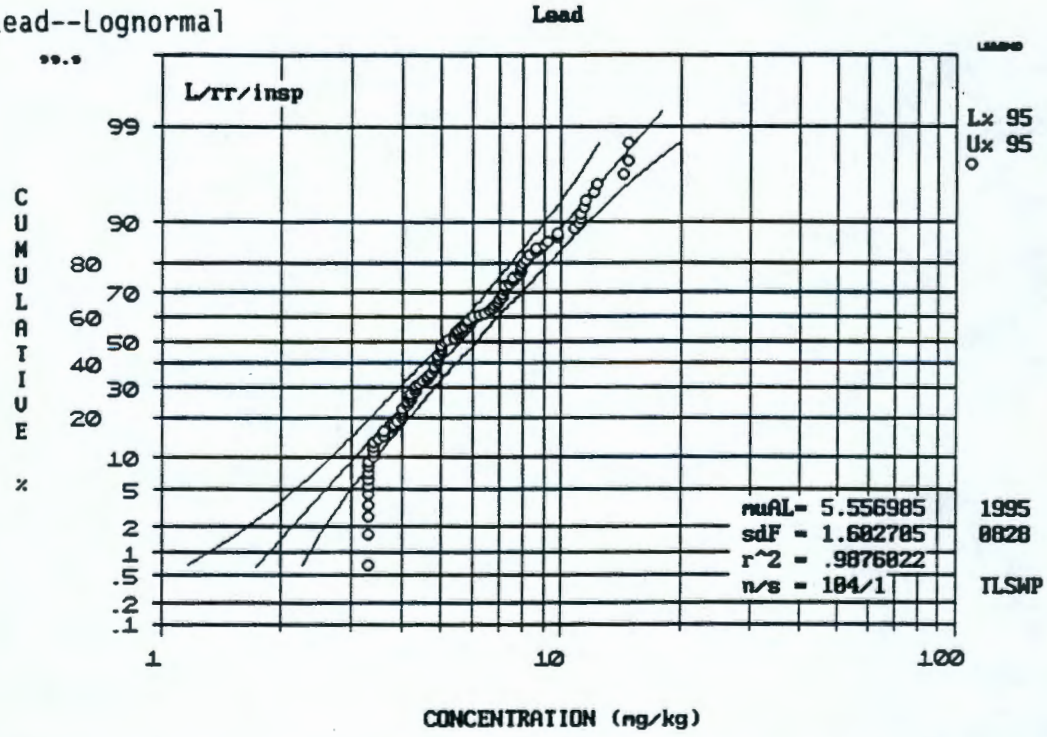


Figure 6-11.d. Cumulative Distribution Plots for Sitewide Soil Background Data (Random Data Set) for Lead. Regression lines are shown together with upper 95 percent confidence level line; r^2 is a goodness of fit parameter where 1.0 is a perfect fit.

Table 6-1. Summary Statistics for Sitewide Soil Background Compositional Data on Inorganic Analytes (systematic random reference data set). All values in mg/kg except skewness, which is dimensionless. Number of samples refers to numbers of validated data for each analyte.

Analyte	No. of samples	Minimum	Maximum	Mean	Standard deviation	Skewness
Aluminum	104	3940	18100	8080	3060	1.51
Antimony	54	15.7	15.7	15.7	0.00	0.00
Arsenic	104	3	11.4	4.2	1.68	2.18
Barium	104	45.2	221	92.7	30.2	1.39
Beryllium	104	0.60	2.1	1.2	0.28	0.49
Cadmium	104	0.66	0.66	0.66	0.00	0.00
Calcium	104	3820	86600	11500	10100	5.01
Chromium	104	2.9	30.6	10.9	5.76	1.24
Cobalt	104	5.7	16.9	11.7	2.96	-0.14
Copper	104	8.1	36.1	15.5	5.30	2.05
Iron	104	13200	35100	24500	5770	-0.10
Lead	104	1.1	26.6	6.3	3.46	2.50
Lithium	66	34	38.2	34.1	0.62	5.40
Magnesium	104	2900	10100	5180	1510	1.46
Manganese	104	196	704	384	93.1	0.46
Mercury	104	0.16	3.8	0.26	0.47	6.42
Molybdenum	58	2	2	2	0.0	0.00
Nickel	104	7.2	28.2	13.0	4.73	1.35
Potassium	104	851	3280	1370	555	1.20
Selenium	85	5	6	5.0	0.11	9.22
Silicon	101	5.2	583	32.2	75.1	5.98
Silver	104	1.4	14.6	1.6	1.30	10.1
Sodium	104	101	5620	439	625	6.69
Thallium	104	3.7	3.7	3.7	0.00	0.00
Titanium	83	524	2940	1600	653	0.34
Vanadium	104	24.3	97.9	57.6	19.4	0.33
Zinc	104	30.9	119	53.0	13.2	1.69
Zirconium	83	11	84.8	23.6	12.8	2.16
Alkalinity	104	31	37600	3410	6510	3.17
Ammonia	104	0.6	26.4	3.6	5.74	2.26
Chloride	103	1	1480	68.3	205	4.63
Fluoride	103	1	73.3	2.4	7.48	8.70
Nitrate	104	0.6	538	30.1	90.2	4.34
Nitrite	104	21	21	21	0.00	0.00
O-Phosphate	104	2	225	4.7	22.2	9.69
Sulfate	104	1	4340	192	693	4.86

mg/kg = milligrams per kilogram.

Table 6-2. Detection Limits and Maximum Concentrations for Sitewide Soil Background. Analyte concentrations are in units of mg/kg.

Analyte	Detection limits (mg/kg):		Maximum concentration (mg/kg)	Sample type and location with maximum concentration
	LOD	LOQ		
Aluminum	21.8	66.1	28,800	Topsoil, playa, E-9
Antimony	15.7	52.2	31	Volcanic ash*
Arsenic**	3	N/A	27.7	Topsoil, juniper, E-4
Barium	0.87	2.7	480	Volcanic ash*
Beryllium**	0.41	N/A	10	Volcanic ash*
Cadmium	0.24	0.79	11	Volcanic ash*
Calcium	175	470	105,000	Topsoil, greasewood, E-2
Chromium	1.1	3.0	320	Ringold Formation*
Cobalt	0.88	2.9	110	Volcanic ash*
Copper	2.1	6.2	61	Volcanic ash*
Iron	75.7	236	68,100	Ringold Formation
Lead**	1.1	N/A	74.1	Topsoil, juniper, E-4
Magnesium	18.4	57.9	32,300	Topsoil, greasewood, E-2
Manganese	0.63	1.8	1,110	Topsoil, playa, E-10
Mercury**	0.16	N/A	3.8	Random, #15
Nickel	2.4	7.7	200	Ringold Formation*
Potassium	135	451	7,900	Topsoil, playa, E-9
Selenium**	5	N/A	6	Random, #15
Silver	2.1	4.5	14.6	Random, #6
Sodium	50.6	140	6,060	Random, #12
Thallium**	3.7	N/A	3.7	Laboratory detection limit
Vanadium	1.8	5.9	140	Volcanic ash*
Zinc	6.4	15.6	366	Topsoil, juniper, E-4
Molybdenum	1.4	4.8	6	Ringold Formation
Lithium**	34	N/A	38.2	Random, #14*
Titanium**	5	N/A	3,180	Random, #6
Zirconium**	11	N/A	84.8	Random, #10
Ammonia**	0.6	N/A	26.4	Random, #14
Alkalinity**	5	N/A	150,000	Topsoil, greasewood, E-2
Silicon**	5.2	N/A	1,202.9	Topsoil, playa, E-10
Fluoride**	1	N/A	73.3	Random, #10
Chloride**	1	N/A	1,480	Random, #11
Nitrite**	21	N/A	36.5	Topsoil, greasewood, E-2
Nitrate**	1.6	N/A	906	Hanford formation judgment, #11
O-Phosphate**	2	N/A	225	Random, #10
Sulfate**	1	N/A	12,600	Topsoil, greasewood, E-2

LOD = limit of detection.
LOQ = limit of quantitation.
mg/kg = milligrams per kilogram.
N/A = not available.
* = offsite.
** = values reported were laboratory detection limits. No quality control data available for independent calculation of LOD.

Table 6-9.a. Sitewide Soil Background Threshold Levels Calculated from the Systematic Random Data Set Using Lognormal Distribution Results. Analyte concentrations are in units of mg/kg.

ANALYTE	50%	80%	80% UCL	90%	90% UCL	95% LCL	95%	95% UCL
Aluminum	7600	10100	11000	11800	13000	12000	13300	15100
Antimony	-	-	-	-	-	-	-	-
Arsenic	3.55	5.28	5.89	6.47	7.38	6.61	7.65	9.06
Barium	88	115	124	132	144	134	148	165
Beryllium	1.09	1.35	1.44	1.51	1.62	1.52	1.65	1.80
Cadmium	-	-	-	-	-	-	-	-
Calcium	9450	14000	15700	17200	19700	17600	20400	24100
Chromium	9.57	14.8	16.7	18.5	21.4	18.9	22.3	26.8
Cobalt	11.2	14.0	14.9	15.7	16.9	15.9	17.3	19.2
Copper	14.4	19.0	20.6	22.0	24.1	22.3	24.7	27.9
Iron	23600	29200	31000	32600	35000	33000	35600	39000
Lead	5.45	8.24	9.36	10.2	11.7	10.4	12.2	14.5
Lithium	28.4	31.7	32.9	33.5	35.0	33.4	35.1	37.2
Magnesium	4980	6260	6680	7060	7620	7140	7780	8580
Manganese	372	460	488	512	550	518	561	613
Mercury	2.3e-02	0.13	0.22	0.33	0.60	0.36	0.70	1.47
Molybdenum	-	-	-	-	-	-	-	-
Nickel	12.2	16.4	17.8	19.1	21.0	19.4	21.6	24.5
Potassium	1210	1760	1960	2150	2440	2190	2520	2960
Selenium	-	-	-	-	-	-	-	-
Silicon	15.40	36.8	37.5	44.0	55.6	-	59.0	-
Silver	5.4e-02	0.30	0.49	0.73	1.33	0.81	1.52	3.16
Sodium	231	475	581	690	878	716	937	1274
Thallium	-	-	-	-	-	-	-	-
Titanium	1460	2110	2380	2570	2950	2580	3000	3600
Vanadium	54.4	73.0	79.3	85.1	93.9	86.4	96.4	110
Zinc	51.1	61.7	64.9	67.8	72.1	68.5	73.3	79.3
Zirconium	20.6	31.8	36.4	39.8	46.8	40.0	47.8	58.8
Alkalinity	1100	3960	5680	7710	11800	8240	13300	23000
Ammonia	9.7e-01	4.28	6.48	9.23	15.1	10.0	17.3	32.5
Chloride	6.59	39.6	65.5	100	182	109	214	460
Fluoride	8.0e-01	1.83	2.31	2.81	3.70	2.93	3.98	5.7
Nitrate	3.58	20.9	34.2	52.0	93.4	56.9	110	232
Nitrite	-	-	-	-	-	-	-	-
O-Phosphate	2.1e-03	1.0e-01	3.1e-01	7.9e-01	2.87	0.96	4.08	21.5
Sulfate	10.4	81.4	145	237	469	263	566	1360

UCL One sided upper confidence limit based on 95% coverage
LCL One sided lower confidence limit based on 95% coverage
\- Not enough data above the reporting limit to provide for a distribution fit

Table 6-9.b. Sitewide Soil Background Threshold Levels Calculated from the Systematic Random Data Set for Using Weibull Distribution Results. Analyte concentrations are in units of mg/kg.

ANALYTE	50%	90%	80% UCL	90%	90% UCL	95% LCL	95%	95% UCL
Aluminum	7383	10113	11053	11933	13263	12133	13643	15500
Antimony	-	-	-	-	-	-	-	-
Arsenic	3.56	5.2	5.83	6.44	7.42	6.59	7.71	9.18
Barium	87.3	114.9	124.2	132.8	145.7	134.8	149.3	166.3
Beryllium	1.1275	1.296	1.376	1.446	1.576	1.466	1.606	1.81
Cadmium	-	-	-	-	-	-	-	-
Calcium	9131	14079	15909	17709	20409	18109	21209	25309
Chromium	9.34	15.12	17.32	19.22	22.22	19.62	23.02	27.32
Cobalt	11.4	14.25	15.1	15.8	16.8	16	17.1	18.4
Copper	14.03	18.22	19.92	21.59	24.39	21.99	25.19	29.39
Iron	23750	29750	31450	33050	35250	33450	35850	38750
Lead	5.42	8.28	9.31	10.31	11.84	10.54	12.28	14.47
Lithium	26.5	31.2	32.7	33.4	35.1	33.2	35.1	37.2
Magnesium	4830	6140	6610	7060	7750	7160	7950	8950
Manganese	380	463	486	506	535	511	542	578
Mercury	0.08375	0.1507	0.22	0.35	0.59	0.36	0.7	1.49
Molybdenum	-	-	-	-	-	-	-	-
Nickel	12.15	16.35	17.75	19.05	20.85	19.35	21.45	23.95
Potassium	1197	1777	1977	2167	2447	2207	2537	2937
Selenium	-	-	-	-	-	-	-	-
Silicon	14.12	31.76	40.46	56.06	63.46	-	66.36	-
Silver	1.3600019	1.3613	1.36594	1.3807	1.46	1.3868	1.52	2.36
Sodium	357.2	459	551	682	984	718	1099	1909
Thallium	-	-	-	-	-	-	-	-
Titanium	1491	2161	2401	2561	2881	2571	2921	3341
Vanadium	55	74	79.8	85	92.5	86.1	94.6	104.5
Zinc	51.7	61.7	64.6	67.1	70.7	67.7	71.6	76.1
Zirconium	21.3	30.6	33.7	35.8	39.6	-	40.1	-
Alkalinity	1055	4248	6008	8008	11688	8508	12888	19788
Ammonia	0.88	4.8	7.1	9.8	14.9	10.5	16.6	26.8
Chloride	5	39.8	71.5	116	220	128	259	541
Fluoride	0.87	1.81	2.28	2.81	3.73	2.93	4.02	5.69
Nitrate	3.35	19.88	34.28	54.18	99.38	59.68	115.88	234.88
Nitrite	-	-	-	-	-	-	-	-
O-Phosphate	0.000141	0.0535	0.21	0.668	2.9	0.85	4.27	22.9
Sulfate	8.8	90.3	162	264	497	292	585	1202

UCL One sided upper confidence limit based on 95% coverage

LCL One sided lower confidence limit based on 95% coverage

\- Not enough data above the reporting limit to provide for a distribution fit

Table 6-10. Outlier Concentration Data, by Analyte, from the Sitewide Background Reference Population (systematic random data set).

Analyte	Inorganic sampling site	Sample	Distribution	Value (mg/kg)	95/95 threshold (mg/kg)
Calcium	15	B014K4	Both	8660000	25309
	15	B014K5	Both	5290000	
	14	B01422	Both	3950000	
Fluoride	10	B01467	Both	73.3	5.7
	10	B01462	Both	20.1	
	10	B01463	Both	16.6	
Lead	4	B01457	Both	26.6	14.5
Silicon	3	B01B72	Both	583	121
	3	B01B71	Both	454	
	3	B01B73	Both	211	
	3	B01B76	Both	112	
	4	B01459	Both	104	
Sodium	12	B01422	Lognormal	56200	1909
	12	B01425	Lognormal	33900	
Zinc	6	B01486	Both	119	76
	2	B01431	Both	99.8	
Zirconium	10	B01462	Weibull	84.8	55
	10	B01467	Weibull	65.7	
	10	B01468	Weibull	57.1	
	10	B01463	Weibull	53.9	
	10	B01464	Weibull	48.8	

mg/kg = milligrams per kilogram.

Table 6-11. Exceedances for Judgement Samples Collected from the Systematic Random Samping Sites. Analyte Concentrations are in units of mg/kg.

			HEIS Id	B01497	B01409	B01427	B01B62	B01492	B014B5	B01499	B014F0	B01435
			Site	9	11	12	3	6	8	9	11	2
			Descriptor	SAND	CLASTIC DIKE	ASH	FINE GRAIN	CLASTIC DIKE	FINE GRAIN	CALICHE	CLASTIC DIKE	CALICHE
			Number of Exceedances	6	5	4	1	1	1	1	2	1
	Detection limits:		95/95									
Analyte (mg/Kg)	LOD	LOQ	Threshold									
Aluminum	21.8	66.1	15500	23000	15700							
Antimony	15.7	52.2	NC									
Arsenic	N/A	N/A	9.18		11.2							
Barium	0.87	2.7	166	294	198							
Beryllium	N/A	N/A	1.8	2.1								
Cadmium	0.24	0.79	NC									
Calcium	175	470	25300			37500				25400		39300
Chromium	1.1	3.0	27.3									
Cobalt	0.88	2.9	18.4									
Copper	2.1	6.2	29.4									
Iron	75.7	236	38750									
Lead	N/A	N/A	14.5		19.1							
Lithium	N/A	N/A	37									
Magnesium	18.4	57.9	8950									
Manganese	0.63	1.8	578	814				602				
Mercury	N/A	N/A	1.49						1.7			
Molybdenum	1.4	4.8	NC									
Nickel	2.4	7.7	24.0									
Potassium	135	451	2940	3630								
Selenium	5	N/A	NC									
Silicon	N/A	N/A	NC									
Silver	2.1	4.5	2.36									
Sodium	50.6	140	1910			2460						
Thallium	3.7	N/A	NC									
Titanium	N/A	N/A	3340									
Vanadium	1.8	5.9	105									
Zinc	6.4	15.6	76.1	79.9								
Zirconium	N/A	N/A	NC									
Ammonia	N/A	N/A	26.8									
Alkalinity	N/A	N/A	19800			27500						
Chloride	N/A	N/A	541			543					555	
Fluoride	N/A	N/A	5.7									
Nitrate	N/A	N/A	235		906		299				778	
Nitrite	21	N/A	NC									
O-Phosphate	N/A	N/A	22.9									
Sulfate	N/A	N/A	1200									

HEIS = Hanford Environmental Information System
LOD = limit of detection.
LOQ = limit of quantitation.
mg/Kg = milligram per kilogram.
N/A = not available.
NC = not computed
Only those samples with one or more analyte concentrations (mg/kg) greater than the reference threshold or LOQ levels are reported.

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Table 6-12.a. Digestate and Leachate Compositions of Ringold Formation Sediments (from the saturated zone beneath the Yakima Barricade borehole). Analyte concentrations are in units of mg/kg. (Sheet 1 of 2)

			Sample Id	B06JB8	B06JB9	B06JC0	B06JC1	B06JC2	B06JC3	B06JC4	B06JC5
			Depth (ft)	395	429	429	530	569	610.3	613.2	634
	Detection limits:		95/95								
Analyte (mg/kg)	LOD	LOQ	Threshold								
Aluminum	21.8	66.1	15500	3850	6240	4200	7080	16100	23700	14000	9770
Antimony	15.7	52.2	NC	15.7	28.5		15.7	15.7	15.7	<20	15.7
Arsenic	N/A	N/A	9.18	3	3	3	3	3.7	3	1.7	3
Barium	0.87	2.7	166	53.1	75.8	49	97.9	147	125	81	80
Beryllium	N/A	N/A	1.8	0.46	0.46		0.46	1.3	0.81	<1.0	0.73
Cadmium	0.24	0.79	NC	0.66	0.89		0.66	0.8	0.81	<1.0	0.73
Calcium	175	470	25300	1870	3680	2600	3610	8110	18200	11000	6340
Chromium	1.1	3.0	27.3	9.3	11.6	10	11.7	29.3	17.5	7	19.1
Cobalt	0.88	2.9	18.4	5.9	10.7	4	6.3	12	27.7	18	8.7
Copper	2.1	6.2	29.4	6.1	8	9	6.7	23.7	26.1	13	20.3
Iron	75.7	236	38750	12200	19900	17000	19100	68100	32800	15000	12300
Lead	N/A	N/A	14.5	2.1	4.6	1.5	4.1	11.8	8.7	5.7	8.2
Magnesium	18.4	57.9	8950	2110	3140	2100	3050	9970	8090	4900	6410
Manganese	0.63	1.8	578	285	477	250	299	487	970	410	252
Mercury	N/A	N/A	1.49	0.16	0.16		0.16	0.16	0.16	<0.05	0.16
Molybdenum	1.4	4.8	NC		6	2	2.1	2.7	2.7		2.4
Nickel	2.4	7.7	24.0	11.3	9.6	8	11.5	26.1	18.5	10	20.6
Potassium	135	451	2940	851	905	851	851	2320	4410	2700	2290
Selenium	5	N/A	NC	5	5		5	5	5	<0.05	5
Silicon	N/A	N/A	NC							1200	
Silver	2.1	4.5	2.36	1.4	1.6		3.5	4	4	<1.0	1.4
Sodium	50.6	140	1910	98.7	397	190	150	159	209	170	346
Thallium	3.7	N/A	NC	3.7	3.7		3.7	3.7	3.7	<0.05	3.7
Titanium	N/A	N/A	3340								
Vanadium	1.8	5.9	105	19.7	51.5	35	39	100	47.6	13	24.7
Zinc	6.4	15.6	76.1	19.3	31.2	25	77.9	77.1	87.1	42	43.8
Zirconium	N/A	N/A	NC							12	
Alkalinity	N/A	N/A	19800	895.14		60				0.59	
Chloride	N/A	N/A	541	9.14	3.92	3	1.39			6	
Fluoride	N/A	N/A	5.7	1.23			1				
Nitrate	N/A	N/A	235	2.69			0.6			0.7	
Nitrite	21	N/A	NC	21		21	21			<4.0	
O-Phosphate	N/A	N/A	22.9	2	2		2			<2.0	
Sulfate	N/A	N/A	1200	26.6	5.8	9	4.7			37	

Table 6-12.b. Digestate and Leachate Compositions of Ringold Formation Sediments (from the Ringold formation sediments in the vadose Zone from the Savage Island borehole). Analyte concentrations are in units of mg/kg. (Sheet 2 of 2)

			Sample Id	SB-1001	SB-1001D	SB-1003	SB-1004	SB-1005	SB-1006	SB-1007	SB-1020	SB-1021	B06153
			Depth (ft)	1	1	10	15	20	25	30	Surface	Duplicate	Outcrop
	Detection limits:		95/95										
Analyte (mg/kg)	LOD	LOQ	Threshold										
Aluminum	21.8	66.1	15500	15000	14000	8400	7600	6500	6500	4800	18000	18000	7870
Antimony	15.7	52.2	NC										11.8
Arsenic	N/A	N/A	9.18	4.7	3.7	3	3	3	3	3	3.4	3.6	6.5
Barium	0.87	2.7	166	130	130	79	66	72	72	56	150	150	132
Beryllium	N/A	N/A	1.8	0.71	0.67	0.46	0.46	0.46	0.46	0.46	0.9	0.89	1
Cadmium	0.24	0.79	NC	1.4	1.5	1.4	1.6	1.4	1.4	0.88	2.2	1.9	0.61
Calcium	175	470	25300	9200	8400	7300	4900	5000	5000	2900	6200	6000	2880
Chromium	1.1	3.0	27.3	30	18	12	320	11	10	7	45	34	10
Cobalt	0.88	2.9	18.4	9.7	9.7	7.6	8.7	10	9.5	5.6	11	10	8
Copper	2.1	6.2	29.4	15	15	9.1	16	12	12	12	20	20	9.8
Iron	75.7	236	38750	22000	21000	17000	17000	19000	19000	12000	25000	24000	22300
Lead	N/A	N/A	14.5	9.3	6.3	3.7	3.1	2.5	2.2	2.5	9.4	8.9	9.2
Magnesium	18.4	57.9	8950	7400	7000	5700	4600	4300	4400	3000	7900	7800	3600
Manganese	0.63	1.8	578	350	350	290	300	290	290	180	410	410	201
Mercury	N/A	N/A	1.49										0.1
Molybdenum	1.4	4.8	NC				5						2.9
Nickel	2.4	7.7	24.0	25	18	14	200	11	11	9	32	27	6.5
Potassium	135	451	2940	2400	2400	1600	1300	1000	1000	851	4600	4300	1500
Selenium	5	N/A	NC										1.2
Silicon	N/A	N/A	NC	710	730	660	600	570	560	520	940	720	28.9
Silver	2.1	4.5	2.36										2
Sodium	50.6	140	1910	240	250	820	470	490	470	310	210	220	202
Thallium	3.7	N/A	NC										0.61
Titanium	N/A	N/A	3340	840	890	980	950	1700	1700	800	830	790	1070
Vanadium	1.8	5.9	105	42	41	35	33	45	46	27	43	42	53.9
Zinc	6.4	15.6	76.1	53	50	39	38	36	36	23	61	61	38.8
Zirconium	N/A	N/A	NC										24.1
Alkalinity	N/A	N/A	19800										601
Chloride	N/A	N/A	541			34	34						8.94
Fluoride	N/A	N/A	5.7	7	5.4	2.6					2.2	2.2	1.18
Nitrate	N/A	N/A	235								56	69	23
Nitrite	21	N/A	NC										<.2
O-Phosphate	N/A	N/A	22.9										<.6
Sulfate	N/A	N/A	1200			113	99	20	34				56.2

HEIS = Hanford Environmental Information System
LOD = limit of detection.
LOQ = limit of quantitation.
mg/Kg = milligram per kilogram.
N/A = not available.
NC = not computed

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Table 6-13.a. Analyte Exceedance for Ringold Formation Sediments from the Saturated Zone in the Yakima Barricade Borehole. Analyte concentrations are in units of mg/kg. (Sheet 1 of 2)

			Sample Id	B06JB8	B06JB9	B06JC0	B06JC1	B06JC2	B06JC3	B06JC4	B06JC5
			Depth (ft)	395	429	429	530	569	610.3	613.2	634
	Detection limits:		95/95								
Analyte (mg/kg)	LOD	LOQ	Threshold								
Aluminum	21.8	66.1	15500					16100	23700		
Antimony	15.7	52.2	NC								
Arsenic	N/A	N/A	9.18								
Barium	0.87	2.7	166								
Beryllium	N/A	N/A	1.8								
Cadmium	0.24	0.79	NC		0.89			0.8	0.81	<1.0	
Calcium	175	470	25300								
Chromium	1.1	3.0	27.3					29.3			
Cobalt	0.88	2.9	18.4						27.7		
Copper	2.1	6.2	29.4								
Iron	75.7	236	38750					68100			
Lead	N/A	N/A	14.5								
Magnesium	18.4	57.9	8950					9970			
Manganese	0.63	1.8	578						970		
Mercury	N/A	N/A	1.49								
Molybdenum	1.4	4.8	NC		6						
Nickel	2.4	7.7	24.0					26.1			
Potassium	135	451	2940						4410		
Selenium	5	N/A	NC								
Silicon	N/A	N/A	NC								
Silver	2.1	4.5	2.36				3.5	4	4		
Sodium	50.6	140	1910								
Thallium	3.7	N/A	NC								
Titanium	N/A	N/A	3340								
Vanadium	1.8	5.9	105								
Zinc	6.4	15.6	76.1				77.9	77.1	87.1		
Zirconium	N/A	N/A	NC								
Alkalinity	N/A	N/A	19800								
Chloride	N/A	N/A	541								
Fluoride	N/A	N/A	5.7								
Nitrate	N/A	N/A	235								
Nitrite	21	N/A	NC								
O-Phosphate	N/A	N/A	22.9								
Sulfate	N/A	N/A	1200								

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Table 6-13.b. Analyte Exceedance for Ringold Formation Sediments in the Vadose Zone from the Savage Island Borehole. Analyte concentrations are in units of mg/kg. (Sheet 2 of 2)

			Sample Id	SB-1001	SB-1001D	SB-1003	SB-1004	SB-1005	SB-1006	SB-1007	SB-1020	SB-1021	B06153
			Depth (ft)	1	1	10	15	20	25	30	Surface	Duplicate	Outcrop
	Detection limits:		95/95										
Analyte (mg/kg)	LOD	LOQ	Threshold										
Aluminum	21.8	66.1	15500								18000	18000	
Antimony	15.7	52.2	NC										
Arsenic	N/A	N/A	9.18										
Barium	0.87	2.7	166										
Beryllium	N/A	N/A	1.8										
Cadmium	0.24	0.79	NC	1.4	1.5	1.4	1.6	1.4	1.4	0.88	2.2	1.9	
Calcium	175	470	25300										
Chromium	1.1	3.0	27.3	30			320				45	34	
Cobalt	0.88	2.9	18.4										
Copper	2.1	6.2	29.4										
Iron	75.7	236	38750										
Lead	N/A	N/A	14.5										
Magnesium	18.4	57.9	8950										
Manganese	0.63	1.8	578										
Mercury	N/A	N/A	1.49										
Molybdenum	1.4	4.8	NC				5						
Nickel	2.4	7.7	24.0	25			200				32	27	
Potassium	135	451	2940								4600	4300	
Selenium	5	N/A	NC										
Silicon	N/A	N/A	NC										
Silver	2.1	4.5	2.36										
Sodium	50.6	140	1910										
Thallium	3.7	N/A	NC										
Titanium	N/A	N/A	3340										
Vanadium	1.8	5.9	105										
Zinc	6.4	15.6	76.1										
Zirconium	N/A	N/A	NC										
Alkalinity	N/A	N/A	19800										
Chloride	N/A	N/A	541										
Fluoride	N/A	N/A	5.7	7									
Nitrate	N/A	N/A	235										
Nitrite	21	N/A	NC										
O-Phosphate	N/A	N/A	22.9										
Sulfate	N/A	N/A	1200										

HEIS = Hanford Environmental Information System
LOD = limit of detection.
LOQ = limit of quantitation.
mg/Kg = milligram per kilogram.
N/A = not available.
NC = not computed
Only those samples with one or more analyte concentrations (mg/kg) greater than the reference threshold or LOQ levels are reported.

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Table 6-14. Digestate and Leachate Compositions of Volcanic Ashes.
Analyte concentrations are in units of mg/kg.

			Sample Id	SB-1002	B014G0	B014G1	B014G6	B01427
			Site	Savage Island	5	5	5	12
			Depth (ft)	5	4	4	6	7
	Detection limits:		95/95					
Analyte (mg/Kg)	LOD	LOQ	Threshold					
Aluminum	21.8	66.1	15500	10000	7600	6520	6900	7200
Antimony	15.7	52.2	NC	31	11.1	11.1	15.7	
Arsenic	N/A	N/A	9.18	3.7	4.3		3	4.5
Barium	0.87	2.7	166	480	65.2	65.2	64.3	83.4
Beryllium	N/A	N/A	1.8	10	0.71		0.72	0.62
Cadmium	0.24	0.79	NC	11			0.66	0.66
Calcium	175	470	25300	12000	19300	18100	12200	37500
Chromium	1.1	3.0	27.3	53	14.6	13.3	15.7	6.8
Cobalt	0.88	2.9	18.4	110	7.4		7.4	6.1
Copper	2.1	6.2	29.4	61	13.6	14	13.1	11.6
Iron	75.7	236	38750	19000	16300	13600	16100	12300
Lead	N/A	N/A	14.5	3.9	4.2	2.1	3.8	3.8
Magnesium	18.4	57.9	8950	7300	4410	4600	4700	6250
Manganese	0.63	1.8	578	430	279	253	282	214
Nickel	2.4	7.7	24.00	110	11.5	9.6	12.5	7.7
Potassium	135	451	2940.0	2000	1010		1000	1470
Silicon	N/A	N/A	NC	760	9.63		8.82	31.3
Sodium	50.6	140	1910	1500	256		210	2460
Titanium	N/A	N/A	3340	1000	743	606	757	587
Vanadium	1.8	5.9	105	140	37.3	27.4	37.4	27.3
Zinc	6.4	15.6	76.10	140	35.5	30.7	36.7	24.2
Ammonia	N/A	N/A	26.8		8.57	1.8	0.96	1.32
Alkalinity	N/A	N/A	19800		2860		1990	27500
Chloride	N/A	N/A	541	90	13.4	13	2.01	543
Fluoride	N/A	N/A	5.7	4.2	1	1	1	1
Nitrate	N/A	N/A	235		6.76	1.8	2.02	3.39
Sulfate	N/A	N/A	1200	293	125	140	1.7	833

HEIS = Hanford Environmental Information System
LOD = limit of detection.
LOQ = limit of quantitation.
mg/Kg = milligram per kilogram.
N/A = not available.
NC = not computed
Reference 95/95 threshold and LOQ values are included for comparison.

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Table 6-15. Analyte Exceedances for Volcanic Ashes.
Analyte Concentrations are in units of mg/kg.

			Sample Id	SB-1002	B014G0	B014G1	B014G6	B01427
			Site	Savage Island	5	5	5	12
			Depth (ft)	5	4	4	6	7
	Detection limits:		95/95					
Analyte (mg/Kg)	LOD	LOQ	Threshold					
Aluminum	21.8	66.1	15500					
Antimony	15.7	52.2	NC					
Arsenic	N/A	N/A	9.18					
Barium	0.87	2.7	166	480				
Beryllium	N/A	N/A	1.8	10				
Cadmium	0.24	0.79	NC	11				
Calcium	175	470	25300					37500
Chromium	1.1	3.0	27.3	53				
Cobalt	0.88	2.9	18.4	110				
Copper	2.1	6.2	29.4	61				
Iron	75.7	236	38750					
Lead	N/A	N/A	14.5					
Magnesium	18.4	57.9	8950					
Manganese	0.63	1.8	578					
Nickel	2.4	7.7	24.00	110				
Potassium	135	451	2940.0					
Silicon	N/A	N/A	NC					
Sodium	50.6	140	1910					2460
Titanium	N/A	N/A	3340					
Vanadium	1.8	5.9	105	140				
Zinc	6.4	15.6	76.10	140				
Ammonia	N/A	N/A	26.8					
Alkalinity	N/A	N/A	19800					27500
Chloride	N/A	N/A	541					543
Fluoride	N/A	N/A	5.7					
Nitrate	N/A	N/A	235					
Sulfate	N/A	N/A	1200					

HEIS = Hanford Environmental Information System
LOD = limit of detection.
LOQ = limit of quantitation.
mg/Kg = milligram per kilogram.
N/A = not available.
NC = not computed
Only those samples with one or more analyte concentrations (mg/kg) greater than the reference threshold or LOQ levels are reported.
The value reported is the concentration for the analyte exceeding these reference levels.

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Table 6-16.a. Digestate and Leachate Compositions of Topsoils Collected from the Main Terrestrial Ecosystems on the Hanford Site. Analyte concentrations are in units of mg/kg. (Sheet 1 of 2)

			HEIS Id	B06137	B06139	B06140	B06141	B06142	B06143
			Site Descriptor	E-1 Rattlesnake Mountain	E-2 Rattlesnake Spring Greasewood	E-3 Riparian grass	E-4 Riparian juniper	E-5 NE of 200E BWIP ECA* Big sage	E-6 Old Field
	Detection limits:		95/95						
Analyte (mg/kg)	LOD	LOQ	Threshold						
Aluminum	21.8	66.1	15500	14400	7600	9940	10200	6170	10400
Antimony	15.7	52.2	NC	29.1	17.4	13.7	14.2	12.6	13.3
Arsenic	N/A	N/A	9.18	4	3.1	7.7	27.7	2.4	7
Barium	0.87	2.7	166	144	190	88.8	90.8	76	113
Beryllium	N/A	N/A	1.8	1.7	0.9	0.94	0.98	0.87	1.2
Cadmium	0.24	0.79	NC	1.2	0.9	3.1	2.9	0.65	0.69
Calcium	175	470	25300	4980	105000	5650	5820	3590	4210
Chromium	1.1	3.0	27.3	21.6	7.2	19.6	20.4	7.1	13.6
Cobalt	0.88	2.9	18.4	17.5	8.1	10.1	10.6	9.5	11.3
Copper	2.1	6.2	29.4	24.8	19.5	31.8	32.9	8.9	12.4
Iron	75.7	236	38750	29600	14800	20300	20800	20900	26900
Lead	N/A	N/A	14.5	38.2	12	67.4	74.1	8.4	35.4
Magnesium	18.4	57.9	8950	5050	32300	5110	5250	3550	4510
Manganese	0.63	1.8	578	668	518	297	304	333	463
Mercury	N/A	N/A	1.49	0.12	0.15	0.12	0.12	0.11	0.12
Molybdenum	1.4	4.8	NC	4.3	4.2	3.3	3.4	3	3.2
Nickel	2.4	7.7	24.0	24	12.3	20	19.9	10.8	14.3
Potassium	135	451	2940	3610	6410	2020	2100	1440	2550
Selenium	5	N/A	NC	0.96	1.2	0.94	0.98	0.87	0.92
Silicon	N/A	N/A	NC	53.1	94.5	110.9	11.2	75.4	119.9
Silver	2.1	4.5	2.36	6	3	2.4	2.5	2.2	2.3
Sodium	50.6	140	1910	272	5120	273	263	214	227
Thallium	3.7	N/A	NC	0.72	0.9	0.71	0.74	0.65	0.69
Titanium	N/A	N/A	3340	1520	808	1010	1000	1730	1930
Vanadium	1.8	5.9	105	64.7	30.5	43.6	44.7	50	61.4
Zinc	6.4	15.6	76.1	60.6	50	356	366	43.3	62.8
Zirconium	N/A	N/A	NC	27.2	29.9	23.6	24.5	21.6	26.2
Ammonia	N/A	N/A	26.8	13.4	9.8	0.71	0.96	1.14	2.24
Organic Carbon	N/A	N/A	NC	21442	51635	19774	13742	6991	12327
Alkalinity	N/A	N/A	19800	1100	150000	9.7	1580	673	768
Chloride	N/A	N/A	541	3.07	1	0.88	1.06	0.39	0.53
Fluoride	N/A	N/A	5.7	0.94	<2	0.94	1.2	0.84	1
Nitrate	N/A	N/A	235	10.3	585	12.4	7.11	2.7	3.13
Nitrite	21	N/A	NC	0.54	36.5	<.3	0.54	<.3	<.3
O-Phosphate	N/A	N/A	22.9	20.7	18.8	3.13	4.51	7.36	9.21
Sulfate	N/A	N/A	1200	1.7	12600	13.5	4.67	1.12	5.81

Table 6-16.b. Digestate and Leachate Compositions of Topsoils Collected from the Main Terrestrial Ecosystems on the Hanford Site. (Sheet 2 of 2)

Analyte Concentrations are in units of mg/kg.

Analyte (mg/Kg)	Detection limits: LOD	LOQ	95/95 Threshold	B06144 E-7 Columbia River Plain sagebrush	B06145 E-8 Columbia River Plain rabbitbrush	B06146 E-9 Playa	B06147 E-10 Playa Duplicate	B06148 E-11 Columbia River Plain BWIP ECA*	B06149 E-11 Columbia River Plain Blank	B06150 E-12 200 Plateau BWIP ECA* Big sage
			HEIS Id Site Descriptor							
Aluminum	21.8	66.1	15500	6610	6390	28800	22900	9980	16.2	6340
Antimony	15.7	52.2	NC	12.4	12.6	16.4	17.9	12.8	0	12.6
Arsenic	N/A	N/A	9.18	3.1	3.7	5	5.4	2.5	0.6	2.6
Barium	0.87	2.7	166	62	66.5	241	241	118	7	86.9
Beryllium	N/A	N/A	1.8	0.64	0.65	2.5	2.3	1.1	0.4	0.87
Cadmium	0.24	0.79	NC	0.64	0.65	0.85	0.85	0.66	0.6	0.65
Calcium	175	470	25300	3490	5110	13900	12300	4240	213	3570
Chromium	1.1	3.0	27.3	12.8	12.4	26.5	22.7	12.4	1.4	7.4
Cobalt	0.88	2.9	18.4	6.4	6.9	26	25.3	12.1	2	10
Copper	2.1	6.2	29.4	10.3	11.1	40.3	39.8	12.4	3.6	10
Iron	75.7	236	38750	14100	14400	53600	48300	24900	12.4	20900
Lead	N/A	N/A	14.5	8.1	5.4	26.5	19.9	9.9	4.2	7.8
Magnesium	18.4	57.9	8950	4110	4270	9960	9120	4190	498	3420
Manganese	0.63	1.8	578	289	288	1100	1110	459	1.2	381
Mercury	N/A	N/A	1.49	0.11	0.11	0.14	0.14	0.11	0.1	0.11
Molybdenum	1.4	4.8	NC	3	3	3.9	4	3.1	2.8	3.1
Nickel	2.4	7.7	24.0	13.5	14.3	31.3	28.7	13.9	6.4	9.6
Potassium	135	451	2940	1790	1680	7900	7130	2320	260	1530
Selenium	5	N/A	NC	0.86	0.87	1.1	1.1	0.88	0.8	0.87
Silicon	N/A	N/A	NC	34.6	33.3	682	1202.9	226.1	N/A	113.4
Silver	2.1	4.5	2.36	2.1	2.2	2.8	2.8	2.2	2	2.2
Sodium	50.6	140	1910	211	214	33.6	284	218	197	215
Thallium	3.7	N/A	NC	0.64	0.65	0.85	0.85	0.66	0.3	0.65
Titanium	N/A	N/A	3340	642	633	2550	2040	1670	2.2	1560
Vanadium	1.8	5.9	105	25.9	26	90.3	82.1	58.1	4	47.1
Zinc	6.4	15.6	76.1	38.3	38.8	103	95.5	50.8	10	44.4
Zirconium	N/A	N/A	NC	21.4	21.7	73.3	59.7	27.2	20	22.4
Ammonia	N/A	N/A	26.8	2.57	1.68	<.2	<.2	<.2	N/A	<.2
Organic Carbon	N/A	N/A	NC	7452	5328	16886	23690	9294	N/A	3702
Alkalinity	N/A	N/A	19800	686	1910	15100	11300	1200	N/A	434
Chloride	N/A	N/A	541	1.28	0.56	0.52	0.55	0.71	N/A	2.52
Fluoride	N/A	N/A	5.7	0.72	0.68	0.95	1.19	1.79	N/A	0.87
Nitrate	N/A	N/A	235	66.3	6.12	21	30.5	53.9	N/A	2.6
Nitrite	21	N/A	NC	0.6	<.3	<.3	<.03	<.3	N/A	<.3
O-Phosphate	N/A	N/A	22.9	21.3	3.4	23.4	18.2	18.3	N/A	6.75
Sulfate	N/A	N/A	1200	29.1	6.18	5.05	6.44	12.7	N/A	2.06

* BWIP ECA = A Basalt Waste Isolation Project Ecological Controlled Area
HEIS = Hanford Environmental Information System-
LOD = limit of detection.
LOQ = limit of quantitation.
mg/Kg = milligram per kilogram.
N/A = not available.
NC = not computed
Reference 95/95 threshold and LOQ values are included for comparison.

Table 6-17.a. Exceedances for Topsoil. (Sheet 1 of 2)

Analyte Concentrations are in units of mg/kg.

Analyte (mg/Kg)	Detection limits: LOD	LOQ	HEIS Id / Site Descriptor / 95/95 Threshold	B06137 E-1 Rattlesnake Mountain	B06139 E-2 Rattlesnake Spring Greasewood	B06140 E-3 Riparian grass	B06141 E-4 Riparian juniper	B06142 E-5 NE of 200E BWIP ECA* Big sage	B06143 E-6 Old Field
Aluminum	21.8	66.1	15500						
Antimony	15.7	52.2	NC						
Arsenic	N/A	N/A	9.18				27.7		
Barium	0.87	2.7	166		190				
Beryllium	N/A	N/A	1.8						
Cadmium	0.24	0.79	NC	1.2	0.9	3.1	2.9		
Calcium	175	470	25300		105000				
Chromium	1.1	3.0	27.3						
Cobalt	0.88	2.9	18.4						
Copper	2.1	6.2	29.4			31.8	32.9		
Iron	75.7	236	38750						
Lead	N/A	N/A	14.5	38.2		67.4	74.1		35.4
Magnesium	18.4	57.9	8950		32300				
Manganese	0.63	1.8	578	668					
Mercury	N/A	N/A	1.49						
Molybdenum	1.4	4.8	NC						
Nickel	2.4	7.7	24.0						
Potassium	135	451	2940	3610	6410				
Selenium	5	N/A	NC						
Silicon	N/A	N/A	NC						
Silver	2.1	4.5	2.36	6	3	2.4	2.5		
Sodium	50.6	140	1910		5120				
Thallium	3.7	N/A	NC						
Titanium	N/A	N/A	3340						
Vanadium	1.8	5.9	105						
Zinc	6.4	15.6	76.1			356	366		
Zirconium	N/A	N/A	NC						
Ammonia	N/A	N/A	26.8						
Organic Carbon	N/A	N/A	NC						
Alkalinity	N/A	N/A	19800		150000				
Chloride	N/A	N/A	541						
Fluoride	N/A	N/A	5.7						
Nitrate	N/A	N/A	235		585				
Nitrite	21	N/A	NC						
O-Phosphate	N/A	N/A	22.9						
Sulfate	N/A	N/A	1200		12600				

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Table 6-17.b. Exceedances for Topsoil. (Sheet 2 of 2)

Analyte Concentrations are in units of mg/kg.

Analyte (mg/Kg)	Detection limits: LOD	LOQ	HEIS Id / Site / Descriptor / 95/95 Threshold	B06144 / E-7 / Columbia River Plain sagebrush	B06145 / E-8 / Columbia River Plain rabbitbrush	B06146 / E-9 / Playa	B06147 / E-10 / Playa duplicate	B06148 / E-11 / Columbia River Plain BWIP ECA*	B06149 / E-11 / Columbia River Plain Blank	B06150 / E-12 / 200 Plateau BWIP ECA* Big sage
Aluminum	21.8	66.1	15500			28800	22900			
Antimony	15.7	52.2	NC							
Arsenic	N/A	N/A	9.18							
Barium	0.87	2.7	166			241	241			
Beryllium	N/A	N/A	1.8			2.5	2.3			
Cadmium	0.24	0.79	NC			0.85	0.85			
Calcium	175	470	25300							
Chromium	1.1	3.0	27.3							
Cobalt	0.88	2.9	18.4			26	25.3			
Copper	2.1	6.2	29.4			40.3	39.8			
Iron	75.7	236	38750			53600	48300			
Lead	N/A	N/A	14.5			26.5	19.9			
Magnesium	18.4	57.9	8950			9960	9120			
Manganese	0.63	1.8	578			1100	1110			
Mercury	N/A	N/A	1.49							
Molybdenum	1.4	4.8	NC							
Nickel	2.4	7.7	24.0			31.3	28.7			
Potassium	135	451	2940			7900	7130			
Selenium	5	N/A	NC							
Silicon	N/A	N/A	NC							
Silver	2.1	4.5	2.36			2.8	2.8			
Sodium	50.6	140	1910							
Thallium	3.7	N/A	NC							
Titanium	N/A	N/A	3340							
Vanadium	1.8	5.9	105							
Zinc	6.4	15.6	76.1			103	95.5			
Zirconium	N/A	N/A	NC							
Ammonia	N/A	N/A	26.8							
Alkalinity	N/A	N/A	19800							
Organic Carbon	N/A	N/A	NC							
Chloride	N/A	N/A	541							
Fluoride	N/A	N/A	5.7							
Nitrate	N/A	N/A	235							
Nitrite	21	N/A	NC							
O-Phosphate	N/A	N/A	22.9			23.4				
Sulfate	N/A	N/A	1200							

* BWIP ECA = A Basalt Waste Isolation Project Ecological Controlled Area
HEIS = Hanford Environmental Information System-
LOD = limit of detection.
LOQ = limit of quantitation.
mg/Kg = milligram per kilogram.
N/A = not available.
NC = not computed
Reference 95/95 threshold and LOQ values are included for comparison.

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Table 6-18.a. Analyte Exceedances for Unit-Based Backgrounds. (Sheet 1 of 7)
Analyte Concentrations are in units of mg/kg.

			Unit	2101-M	2101-M	2101-M	2101-M	2101-M	2101-M	2101-M	2101-M
			Sample Id	M131	M132	M133	M134	M135	M136	M137	M138
			Well No.	2101M-1	2101M-1	2101M-1	2101M-1	2101M-2	2101M-2	2101M-2	2101M-2
			Depth (ft)	1.0	3.5	6.0	8.5	11.0	5.0	10.0	15.0
	Detection limits:		95/95								
Analyte (mg/Kg)	LOD	LOQ	Threshold		*		*	*	*	*	*
Aluminum	21.8	66.1	15500								
Antimony	15.7	52.2	NC								
Arsenic	N/A	N/A	9.18								
Barium	0.87	2.7	166			205					
Beryllium	N/A	N/A	1.8								
Cadmium	0.24	0.79	NC								
Calcium	175	470	25300								
Chromium	1.1	3.0	27.3								
Cobalt	0.88	2.9	18.4								
Copper	2.1	6.2	29.4								
Iron	75.7	236	38750								
Lead	N/A	N/A	14.5								
Magnesium	18.4	57.9	8950								
Manganese	0.63	1.8	578			2870					
Molybdenum	1.4	4.8	NC								
Nickel	2.4	7.7	24.0								
Potassium	135	451	2940								
Silver	2.1	4.5	2.36								
Sodium	50.6	140	1910								
Titanium	N/A	N/A	3340								
Vanadium	1.8	5.9	105								
Zinc	6.4	15.6	76.1	112							
Ammonia	N/A	N/A	26.8								
Chloride	N/A	N/A	541								
Fluoride	N/A	N/A	5.7								
Nitrate	N/A	N/A	235								
Sulfate	N/A	N/A	1200								

Table 6-18.b. Analyte Exceedances for Unit-Based Backgrounds. (Sheet 2 of 7)
Analyte Concentrations are in units of mg/kg.

			Unit	2101-M	2101-M	2101-M	2101-M	2101-M	2101-M	2101-M	2101-M
			Sample Id	M139	M140	M141	M142	M143	M144	M145	M146
			Well No.	2101M-3	2101M-3	2101M-3	2101M-3	2101M-4	2101M-4	2101M-4	2101M-4
			Depth (ft)	1.0	3.5	6.0	8.5	11.0	5.0	10.0	15.0
	Detection limits:		95/95								
Analyte (mg/Kg)	LOD	LOQ	Threshold	*	*	*	*	*	*	*	*
Aluminum	21.8	66.1	15500								
Antimony	15.7	52.2	NC								
Arsenic	N/A	N/A	9.18								
Barium	0.87	2.7	166								
Beryllium	N/A	N/A	1.8								
Cadmium	0.24	0.79	NC								
Calcium	175	470	25300								
Chromium	1.1	3.0	27.3								
Cobalt	0.88	2.9	18.4								
Copper	2.1	6.2	29.4								
Iron	75.7	236	38750								
Lead	N/A	N/A	14.5								
Magnesium	18.4	57.9	8950								
Manganese	0.63	1.8	578								
Molybdenum	1.4	4.8	NC								
Nickel	2.4	7.7	24.0								
Potassium	135	451	2940								
Silver	2.1	4.5	2.36								
Sodium	50.6	140	1910								
Titanium	N/A	N/A	3340								
Vanadium	1.8	5.9	105								
Zinc	6.4	15.6	76.1								
Ammonia	N/A	N/A	26.8								
Chloride	N/A	N/A	541								
Fluoride	N/A	N/A	5.7								
Nitrate	N/A	N/A	235								
Sulfate	N/A	N/A	1200								

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Table 6-18.c. Analyte Exceedances for Unit-Based Backgrounds. (Sheet 3 of 7)
Analyte Concentrations are in units of mg/kg.

			Unit	1324-N	1324-N	1324-N	1324-N	1324-N	1324-N	1324-N	1324-N
			Sample Id	1NN	2NN	3JF	4JF	5JF	6JF	8JF	9JF
			Well No.	1324N-1	1324N-2	1324N-3	1324N-4	1324N-5	1324N-6	1324N-7	1324N-8
			Depth (ft)	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5
	Detection limits:		95/95								
Analyte (mg/Kg)	LOD	LOQ	Threshold								
Aluminum	21.8	66.1	15500								
Antimony	15.7	52.2	NC								
Arsenic	N/A	N/A	9.18								
Barium	0.87	2.7	166								
Beryllium	N/A	N/A	1.8								
Cadmium	0.24	0.79	NC	7.1	7.4	6.1	7	6.4	6.5	6.6	7.5
Calcium	175	470	25300								
Chromium	1.1	3.0	27.3								
Cobalt	0.88	2.9	18.4								
Copper	2.1	6.2	29.4								
Iron	75.7	236	38750								
Lead	N/A	N/A	14.5								
Magnesium	18.4	57.9	8950								
Manganese	0.63	1.8	578								
Molybdenum	1.4	4.8	NC								
Nickel	2.4	7.7	24.0								
Potassium	135	451	2940								
Silver	2.1	4.5	2.36								
Sodium	50.6	140	1910								
Titanium	N/A	N/A	3340								
Vanadium	1.8	5.9	105								
Zinc	6.4	15.6	76.1								
Ammonia	N/A	N/A	26.8								
Chloride	N/A	N/A	541								
Fluoride	N/A	N/A	5.7								
Nitrate	N/A	N/A	235								
Sulfate	N/A	N/A	1200								

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Table 6-18.d. Analyte Exceedances for Unit-Based Backgrounds. (Sheet 4 of 7)

Analyte Concentrations are in units of mg/kg.

			Unit	1324-N	1324-N	1324-N	1324-N	1324-N	1100-EM	1100-EM	1100-EM
			Sample Id	10JF	11JF	12JF	13JF	14JF	AH217	AH218	AH222
			Well No.	1324N-9	1324N-10	1324N-11	1324N-12	1324N-13	1100EM/NS	1100EM/NS	1100EM/NS
			Depth (ft)	10.5	10.5	10.5	10.5	10.5	0.5	0.5	0.5
	Detection limits:		95/95								
Analyte (mg/Kg)	LOD	LOQ	Threshold						*	*	*
Aluminum	21.8	66.1	15500								
Antimony	15.7	52.2	NC								
Arsenic	N/A	N/A	9.18								
Barium	0.87	2.7	166								
Beryllium	N/A	N/A	1.8								
Cadmium	0.24	0.79	NC	7.1	7.9	6.5	7.6	7.7			
Calcium	175	470	25300								
Chromium	1.1	3.0	27.3								
Cobalt	0.88	2.9	18.4								
Copper	2.1	6.2	29.4								
Iron	75.7	236	38750								
Lead	N/A	N/A	14.5								
Magnesium	18.4	57.9	8950								
Manganese	0.63	1.8	578								
Molybdenum	1.4	4.8	NC								
Nickel	2.4	7.7	24.0								
Potassium	135	451	2940								
Silver	2.1	4.5	2.36								
Sodium	50.6	140	1910								
Titanium	N/A	N/A	3340								
Vanadium	1.8	5.9	105								
Zinc	6.4	15.6	76.1								
Ammonia	N/A	N/A	26.8								
Chloride	N/A	N/A	541								
Fluoride	N/A	N/A	5.7								
Nitrate	N/A	N/A	235								
Sulfate	N/A	N/A	1200								

Table 6-18.e. Analyte Exceedances for Unit-Based Backgrounds. (Sheet 5 of 7)

Analyte Concentrations are in units of mg/kg.

			Unit	1100-EM	1100-EM	1100-EM	1100-EM	1100-EM	1100-EM	1100-EM	1100-EM
			Sample Id	AH223	AH224	AH225	A0302	A0306	A0101	A0104	A0105
			Well No.	1100EM/NS	1100EM/NS	1100EM/NS	HRL-1	HRL-1	DP-7	DP-7	DP-7
			Depth (ft)	0.5	0.5	0.5	7.5	12.9	1.4	12.9	17.3
	Detection limits:		95/95								
Analyte (mg/Kg)	LOD	LOQ	Threshold	*	*	*	*	*	*	*	*
Aluminum	21.8	66.1	15500								
Antimony	15.7	52.2	NC								
Arsenic	N/A	N/A	9.18								
Barium	0.87	2.7	166								
Beryllium	N/A	N/A	1.8								
Cadmium	0.24	0.79	NC								
Calcium	175	470	25300								
Chromium	1.1	3.0	27.3								
Cobalt	0.88	2.9	18.4								
Copper	2.1	6.2	29.4								
Iron	75.7	236	38750								
Lead	N/A	N/A	14.5								
Magnesium	18.4	57.9	8950								
Manganese	0.63	1.8	578								
Molybdenum	1.4	4.8	NC								
Nickel	2.4	7.7	24.0								
Potassium	135	451	2940								
Silver	2.1	4.5	2.36								
Sodium	50.6	140	1910								
Titanium	N/A	N/A	3340								
Vanadium	1.8	5.9	105								
Zinc	6.4	15.6	76.1								
Ammonia	N/A	N/A	26.8								
Chloride	N/A	N/A	541								
Fluoride	N/A	N/A	5.7								
Nitrate	N/A	N/A	235								
Sulfate	N/A	N/A	1200								

Table 6-18.f. Analyte Exceedances for Unit-Based Backgrounds. (Sheet 6 of 7)
Analyte Concentrations are in units of mg/kg.

			Unit	1100-EM	1100-EM	1100-EM	1100-EM	1100-EM	1100-EM	1100-EM	1100-EM	1100-EM
			Sample Id	A0109	A0201	A0203	A0204	A0206	A0207	A0208	A0209	A0210
			Well No.	DP-7	BAP-2	BAP-2	BAP-2	BAP-2	BAP-2	BAP-2	BAP-2	BAP-2
			Depth (ft)	29.2	1.3	9.0	12.3	18.3	18.3	20.3	26.2	34.9
	Detection limits:		95/95									
Analyte (mg/Kg)	LOD	LOQ	Threshold		*	*	*	*	*		*	*
Aluminum	21.8	66.1	15500									
Antimony	15.7	52.2	NC									
Arsenic	N/A	N/A	9.18									
Barium	0.87	2.7	166	229								
Beryllium	N/A	N/A	1.8									
Cadmium	0.24	0.79	NC									
Calcium	175	470	25300									
Chromium	1.1	3.0	27.3							48.3		
Cobalt	0.88	2.9	18.4									
Copper	2.1	6.2	29.4									
Iron	75.7	236	38750									
Lead	N/A	N/A	14.5									
Magnesium	18.4	57.9	8950									
Manganese	0.63	1.8	578									
Molybdenum	1.4	4.8	NC									
Nickel	2.4	7.7	24.0							25.3		
Potassium	135	451	2940									
Silver	2.1	4.5	2.36									
Sodium	50.6	140	1910									
Titanium	N/A	N/A	3340									
Vanadium	1.8	5.9	105									
Zinc	6.4	15.6	76.1									
Ammonia	N/A	N/A	26.8									
Chloride	N/A	N/A	541									
Fluoride	N/A	N/A	5.7									
Nitrate	N/A	N/A	235									
Sulfate	N/A	N/A	1200									

Table 6-18.g. Analyte Exceedances for Unit-Based Backgrounds. (Sheet 7 of 7)
Analyte Concentrations are in units of mg/kg.

Analyte (mg/Kg)	Detection limits: LOD	LOQ	Unit / Sample Id / Well No. / Depth (ft) 95/95 Threshold	183H AB-044	183H AB-045	183H AB-046	183H AB-047	183H AB-050	183H AB-051	183H AB-052	183H AB-053	183H AB-054
Aluminum	21.8	66.1	15500									
Antimony	15.7	52.2	NC									
Arsenic	N/A	N/A	9.18									
Barium	0.87	2.7	166									
Beryllium	N/A	N/A	1.8									
Cadmium	0.24	0.79	NC	5.2	5.1	5.7	5.7	6	5.9	5.9	4.7	5.1
Calcium	175	470	25300									
Chromium	1.1	3.0	27.3									
Cobalt	0.88	2.9	18.4									
Copper	2.1	6.2	29.4									
Iron	75.7	236	38750									
Lead	N/A	N/A	14.5									
Magnesium	18.4	57.9	8950									
Manganese	0.63	1.8	578									
Molybdenum	1.4	4.8	NC									
Nickel	2.4	7.7	24.0									
Potassium	135	451	2940									
Silver	2.1	4.5	2.36									
Sodium	50.6	140	1910									
Titanium	N/A	N/A	3340									
Vanadium	1.8	5.9	105									
Zinc	6.4	15.6	76.1									
Ammonia	N/A	N/A	26.8									
Chloride	N/A	N/A	541									
Fluoride	N/A	N/A	5.7									
Nitrate	N/A	N/A	235									
Sulfate	N/A	N/A	1200									

* No analytes above reference thresholds.
HEIS = Hanford Environmental Information System
LOD = limit of detection.
LOQ = limit of quantitation.
mg/Kg = milligram per kilogram.
N/A = not available.
NC = not computed
Only those samples with one or more analyte concentrations (mg/kg) greater than the reference threshold or LOQ levels are reported.
The value reported is the concentration for the analyte exceeding these reference levels.

Table 6-20. Comparison of Sitewide Background Data to Health Based Levels.

Analyte	Limit of Detection	95/95 Threshold (Weibull), mg/kg	Maximum Background Level	WAC-173-340** Residential Chronic Toxicity Limits (as of 8/94), mg/kg	0.1 X Toxicity Limit, mg/kg	Toxicity Hazard Quotient***, based on maximal data	Analytes with some background levels greater than a primary screen	Analytes with some background levels greater than a secondary screen
Aluminum	21.8	15500	28,800	-			Aluminum	
Antimony	15.7	N/C	31	32	3.2	0.97	Antimony	Antimony
Arsenic	3	9.18	27.7	60	6	0.46	Arsenic	Arsenic
Barium	4.1	166.3	480	5600	560	0.09	Barium	
Beryllium	0.46	1.806	10	400	40	0.03	Beryllium	
Cadmium	0.66	N/C	11	80	8	0.14	Cadmium	Cadmium
Calcium	189	25309	105,000	-			Calcium	
Chromium	1.8	27.32	320	400	40	0.80	Chromium	Chromium
Cobalt	1.6	18.4	110	-			Cobalt	
Copper	2.1	29.39	61	3000	300	0.02	Copper	
Iron	75.7	38750	68,100	-			Iron	
Lead	1.1	14.47	74.1	-			Lead	
Lithium	34	37.2	38.2	-			Lithium	
Magnesium	249	8950	32,300	-			Magnesium	
Manganese	0.63	578	1,110	11200	1120	0.10	Manganese	
Mercury	0.16	1.49	3.8	24	2.4	0.16	Mercury	Mercury
Molybdenum	1.4	N/C	6	400	40	0.02	Molybdenum	
Nickel	7.2	23.95	200	1600	160	0.13	Nickel	Nickel
Potassium	851	2937	7,900	-			Potassium	
Selenium	5	N/C	6	400	40	0.02	Selenium	
Silicon	5.2	N/C	1,203	-			Silicon	
Silver	1.4	2.36	14.6	400	40	0.04	Silver	
Sodium	98.7	1909	6,060	-			Sodium	
Thallium	3.7	N/C	3.7	-				
Titanium	5	3341	3,180	-				
Vanadium	2	104.5	140	560	56	0.25	Vanadium	Vanadium
Zinc	6.4	76.1	366	24000	2400	0.02	Zinc	
Zirconium	11	N/C	84.8	-			Zirconium	
Alkalinity	5	19788	150,000	-			Alkalinity	
Ammonia	0.6	26.8	26.4	-				
Chloride	1	541	1,480	8000	800	0.19	Chloride	Chloride
Fluoride	1	5.69	73.3	4800	480	0.02	Fluoride	
Nitrate	0.6	235	906	128000	12800	0.01	Nitrate	
Nitrite	21	N/C	36.5	8000	800	0.00	Nitrite	
O-Phosphate	2	22.9	225	-			O-Phosphate	
Sulfate	1	1202	12,600	-			Sulfate	
Carcinogenic Analytes			Carcinogenicity Limits (mg.kg)	0.1 X Carcinogenicity Limits(mg/kg)				
Arsenic	3	9.18	27.7	1.43	0.143		Arsenic	Arsenic
Beryllium	0.46	1.806	10	0.233	0.0233		Beryllium	Beryllium
Cadmium	0.24	N/C	11	0.164	0.0164		Cadmium	Cadmium

* Assumed Chromium VI
*** Hazard Quotient=Concentration Value/Chronic Toxicity Limit
Total Hazard Quotient=3.4

** Model Toxics Control Act
N/C=Not Computed

9.0 REFERENCES

9.1 DOCUMENTS

ACS, 1983, "Principles of Environmental Analysis, American Chemical Society Committee on Environmental Improvement," *Analytical Chemistry*, v. 55, pp. 2210-2218.

Aitchison, J. and J.A.C. Brown, 1957, *The Lognormal Distribution with Special Reference to its Use in Economics*, Cambridge, Cambridge University Press.

APHA, 1989, *Standard Methods for the Examination of Water and Wastewater*, American Public Health Association, Washington, D.C.

ASME, 1985, *Measurement Uncertainty-Instruments and Apparatus*, PTC 19.1, The American Society of Mechanical Engineers, New York, New York.

ASTM, 1990, *Annual Book of ASTM Standards*, American Society for Testing and Materials, Philadelphia, Pennsylvania.

Baker, U.R., B.N. Bjornstad, A.J. Busacca, K.R. Fecht, E.P. Kiver, U.L. Moody, J.G. Rigby, O.F. Stradling, and A.M. Tallman, 1991, "Quanternary Geology of the Columbia Plateau" in Quanternary Nonglacial Geology; Conterminous U.S., v. K-2 of *The Geology of North America*, ed. R.B. Morrison, Geological Society of America, Boulder, Colorado.

Baker, V.R. and R.O. Bunker, 1985, "Cataclysmic Late Pleistocene Flooding from Glacial Lake Missoula: A Review," Quanternary Science Reviews 4:1-41.

Bates, R.L., 1990, *Glossary of Geology*, J.A. Jackson, ed., American Geological Institute, Falls Church, Virginia.

Best, M.G., 1982, *Igneous and Metamorphic Petrology*, W.H. Freeman and Company, San Francisco, California.

Bjornstead, B.N., 1984, *Suprabasalt Stratigraphy Within and Adjacent to the Reference Repository Location*, SD-BWI-DP-039, Rockwell Hanford Operations, Richland, Washington.

Bjornstead, B.N., 1985, *Late-Cenozoic Stratigraphy and Tectonic Evolution Within a Subsiding Basin, South-Central Washington, Geologic Society of America Abstracts with Programs*, v. 17, no. 7, p. 524.

Bretz, J.H., 1928, "The Channeled Scabland of Eastern Washington," *Geographical Review*, v. 18, p. 446-477.

Bretz, J.H., 1969, "The Lake Missoula Floods and the Channeled Scabland," *Journal of Geology*, v. 77, pp. 505-543.

Cochran, W.G., 1946, "Relative Accuracy of Systematic and Stratified Samples for a Certain Class of Populations", *Ann. Math. Statist.*, 17:164-177.

9513386.2624

Conover, W.J., 1981, *Practical Nonparametric Statistics*, 2nd edition, John Wiley and Sons, New York, New York.

Davis, J.C., 1986, *Statistics and Data Analysis in Geology*, John Wiley and Sons, New York, New York.

Deroanne-Bauvin, J., E. Delcarte, and R. Impens, 1987, "Monitoring of Lead Deposition near Highways: A Ten Years Study," *The Science of the Total Environment*, 59(1987)257-266, Elsevier Science Publishers B.V., Amsterdam.

DOE, 1987, *Final Environmental Impact Statement: Disposal of Hanford Defense High-Level, Transuranic and Tank Wastes*, Vol. 1-5, DOE/EIS-0113, U.S. Department of Energy, Washington, D.C.

DOE, 1988, *Site Characterization Plan, Reference Repository Location, Hanford Site, Washington*, Consultation Draft, DOE/RW-0164, U.S. Department of Energy, Office of Civilian Radioactive Waste Management, Washington, D.C.

DOE-RL, 1988, *183-H Solar Evaporation Basins Closure/Post-Closure Plan*, DOE/RL 88-04, U.S. Department of Energy, Richland Field Office, Richland, Washington.

DOE-RL, 1989, *2101-M Pond Interim Status Closure Plan*, DOE/RL 88-41, U.S. Department of Energy, Richland Field Office, Richland, Washington.

DOE-RL, 1990, *Phase I Remedial Investigation Report for the Hanford Site, 1100-EM-1 Operable Unit*, DOE/RL-90-18, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE-RL, 1992a, *Hanford Site Baseline Risk Assessment Methodology*, DOE/RL-91-45, U.S. Department of Energy, Richland Operations Office, Richland, Washington.

DOE-RL, 1992b, *Hanford Site Groundwater Background*, DOE/RL-92-23, U.S. Department of Energy, Richland Field Office, Richland, Washington.

DOE-RL, 1994, *Hanford Site Background Data Applications Guide: Part 1, Soil*, DOE/RL-94-72, U.S. Department of Energy, Richland Field Office, Richland, Washington.

Dragun, J.D., 1988, *The Soil Chemistry of Hazardous Materials*, Hazardous Materials Control Research Institute, Silver Spring, Maryland.

Ecology, EPA, and DOE, 1992, *Hanford Federal Facility Agreement and Consent Order*, 2 vols., Washington State Department of Ecology, U.S. Environmental Protection Agency, U.S. Department of Energy, Olympia, Washington.

EG&G, 1990, *An Aerial Radiological Survey of the Hanford Site and Surrounding Area Richland, Washington*, 10617-1062, EG&G/Energy Measurements, Las Vegas, Nevada.

EPA, 1986, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods*, SW-846, Supplement 1990, EPA-600/4-79-019, U.S. Environmental Protection Agency, Washington, D.C.

EPA, 1987, *Data Quality Objectives for Remedial Response Activities, Development Process*, EPA/540/87/003, U.S. Environmental Protection Agency, Washington, D.C.

EPA, 1989a, *Methods for Evaluating the Attainment of Cleanup Standards, Volume 1: Soils and Solid Media*, EPA 230/02-89-042, U.S. Environmental Protection Agency, Washington, D.C.

EPA, 1989b, *Risk Assessment Guidance for Superfund: Human Health Evaluation Manual*, Part A, Interim Final, U.S. Environmental Protection Agency, Washington, D.C.

EPA, 1989c, *USEPA Contract Laboratory Program, Statement of Work for Inorganics Analysis; Multi-Media Concentration*, U.S. Environmental Protection Agency, Washington, D.C.

Fairbridge, R.W., 1972, *The Encyclopedia of Geochemistry and Environmental Sciences*, Encyclopedia of Earth Sciences Series, Vol. IVA, ed. R.W. Fairbridge, Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania.

Fecht, K.R., 1987, "Paleodrainage of the Columbia River on the Columbia Plasteau of Washington State: A Summary," in *Selected Papers on the Geology of Washington*; by Washington Divison of Geology and Earth Resources, Bulletin 77, p. 219-248.

Fecht, K.R., S.P. Reidel, and A.M. Tallman, 1985, *Paleodrainage of the Columbia River System on the Columbia Plateau of Washington State: A Summary*, RHO-BW-SA-318P, Rockwell Hanford Operations, Richland, Washington.

Finney, D.J., 1948, "Random and Systematic Sampling in Timber Surveys", *J. Forestry*, 22:64-99.

Gilbert, R.O., 1987, *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold, New York.

Gilbert, R.O. and J.C. Simpson, 1990, "Statistical Sampling and Analysis Issues and Needs for Testing Attainment of Background-Based Cleanup Standards at Superfund Sites," in H. Lacayo, R.J. Nadeau, G.P. Patil and L. Zaragoza, eds., *Proceedings of the Workshop on Superfund Hazardous Waste: Statistical Issues in Characterizing a Site: Protocols, Tools, and Research Needs*, Center for Statistical Ecology and Environmental Statistics, Pennsylvania State University, University Park, Pennsylvania, pp. 1-19.

Hajek, B.F., 1966, *Soil Survey Hanford Project in Benton County Washington*, BNWL-243, Pacific Northwest Laboratory, Richland, Washington.

9513386.2623

Hasel, A.A., 1938, "Sampling Errors in Timber Surveys", *J. Agric. Res.*, 57:713-736.

Helgeson, H.C. and W.M. Murphy, 1983, "Calculations of Mass Transfer as a Function of Time and Surface Area in Geochemical Processes, I. Computational Approach," *Mathematical Geology*, 15, p. 109-130.

Hoover, J.D., 1989, "The Chillded Marginal Gabbro and Other Contact Rocks of the Skaergaard Intrusion", *Journal of Petrology*, Vol. 30, Part 2, pp. 441-476.

Hoover, J.D. and W.M. Murphy, 1989, "Quench Fractionation in Columbia River Basalt and Implications for Basalt-Groundwater Interaction," in S.P. Reidel and P.R. Hooper, eds., *Volcanism and Tectonism in the Columbia River Flood-Basalt Province*, Geologic Society of America, Boulder, Colorado, Special Paper 239.

Hunt, C.B., 1972, *Geology of Soils Their Evolution, Classification, and Uses*, W.H. Freeman and Company, San Francisco, California.

Jackson, M.L., 1970, "Determination of Carbon in Solid Material by Combustion by LECO Carbon Determinator", in *Soil Chemical Analysis*, 6th Edition.

Johnson, R.A., S. Verrill, and D.H. Moore II, 1987, "Two Sample Rank Tests for Detecting Changes that Occur in a Small Proportion of the Treated Population," *Biometrics*, 43:641-655.

Jones, T.L., 1978, *Sediment Moisture Relations: Lysimeter Project 1976-1977 Water Year*, RHO-ST-15 (pp. 1-18 and Appendices V-1 through V-26), Rockwell Hanford Operations, Richland, Washington.

Kaiser, H.F.A., 1970, "A Second Generation Little Jiffy," *Psychometrika*, Vol. 35, p. 401.

Klute, A., ed., 1986, *Methods of Soil Analysis*, Number 9 in the series "Agronomy," American Society of Agronomy, Inc, Soil Science Society of America, Inc., Madison, Wisconsin.

Knudsen, H.P. and Y.C. Kim, 1978, *A Short Course on Geostatistical Ore Reserve Estimation*, Department of Mining, College of Mines, University of Arizona (Chapter 2, page 41), Tucson, Arizona.

Kocher, A.E. and A.J. Strahorn, 1919, *Soil Survey of Benton County, Washington*, U.S. Government Printing Office.

Last, G.V., P.G. Easley, and D.J. Brown, 1976, *Soil Moisture Transport During the 1974-1975 and 1975-1976 Water Years*, ARD-ST-146, Atlantic Richfield Hanford Company, Richland, Washington.

Leopold, L.B., M.G. Wolman, and J.P. Miller, 1964, *Fluvial Processes in Geomorphology*, W.H. Freeman and Company, San Francisco, California, pp. 40-46.