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Characterization and Use of Soil and Groundwater Background for the Hanford Site

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EXECUTIVE SUMMARY

The determination of representative background is one of the most important activities for environmental restoration and waste management at the Hanford Site because background is used in defining contamination and establishing cleanup levels. Appropriate use of soil and groundwater background, therefore, requires data that are representative of the range of compositions that exist naturally. The present approach is to establish a background for each waste management unit. This approach has resulted in different definitions of background resulting in varying definitions of contamination and remediation goals, even for adjacent or superimposed units.

This document provides justification for a Site-wide approach to the determination and use of background as an alternative to the use of unit backgrounds in environmental restoration activities on the Hanford Site. One of the main reasons for the use of a Site-wide approach is that all waste management units impact a single vadose zone and a single regional unconfined aquifer. Existing data on the characteristics of the soil and groundwater show that the compositions of most vadose zone sediments can be considered together as a single compositional series and the natural variation in the composition of groundwater and of sediments exists on the scale of the entire Hanford Site.

It is concluded that the Site-wide approach to the characterization and use of background is preferred for environmental restoration because the Site-wide approach more accurately represents the range of natural variability in soil and groundwater composition on the Hanford Site. The Site-wide approach to background characterization also is desirable because this approach provides a more consistent and credible basis for evaluating contamination, and is more efficient.

Results from a preliminary evaluation of soil background data support the concept that the composition of soil and sediments in the vadose zone across the Hanford Site should be viewed and handled together as a single compositional unit. A preliminary set of soil background threshold values has been generated from these data and is included in this report. A plan for systematic sampling and analysis of the vadose zone during fiscal year 1991 also is described. The soil sampling effort and evaluations of existing groundwater data in the context of a Site-wide approach to background are intended to provide additional technical support for the Site-wide approach to the characterization of soil and groundwater background at the Hanford Site.

CONTENTS

EXECUTIVE SUMMARY iii

ABSTRACT viii

GLOSSARY x

1.0 INTRODUCTION 1-1

2.0 SITE-WIDE VERSUS UNIT-BASED APPROACH TO BACKGROUND CHARACTERIZATION AND USE 2-1
- 2.1 REPRESENTATIVE CHARACTERIZATION AND USE OF BACKGROUND 2-1
- 2.2 BENEFITS OF A SITE-WIDE APPROACH 2-3
- 2.3 BACKGROUND CONCEPTUAL MODELS 2-4

3.0 SOIL BACKGROUND 3-1
- 3.1 SOIL BACKGROUND CONCEPTUAL MODEL 3-1
- 3.2 EVALUATION AND STATISTICAL METHODS 3-3
- 3.3 SITE-WIDE SOIL BACKGROUND EVALUATIONS: PRELIMINARY RESULTS 3-4

4.0 GROUNDWATER BACKGROUND 4-1
- 4.1 GROUNDWATER BACKGROUND CONCEPTUAL MODEL 4-2
- 4.2 HANFORD SITE GROUNDWATER BACKGROUND EVALUATIONS: PRELIMINARY RESULTS 4-3

5.0 CONCLUSIONS 5-1

6.0 REFERENCES 6-1

APPENDICES

A. VADOSE ZONE BACKGROUND CONCEPTUAL MODEL . . . . . APP A-i
- A1.0 INTRODUCTION . . . . . APP A-1
- A2.0 HANFORD SITE VADOSE ZONE . . . . . APP A-2
- A3.0 HANFORD FORMATION . . . . . APP A-2
  - A3.1 ORIGIN . . . . . APP A-3
  - A3.2 PHYSICAL CHARACTER AND SPATIAL DISTRIBUTION OF SEDIMENTS . . . . . APP A-3
  - A3.3 COMPOSITIONAL IMPLICATIONS . . . . . APP A-3
- A4.0 EOLIAN DEPOSITS . . . . . APP A-4
- A5.0 WEATHERING . . . . . APP A-4
- A6.0 SUBORDINATE MEMBERS . . . . . APP A-5
- A7.0 SUMMARY . . . . . APP A-6

APPENDICES (cont)

B. EVALUATION AND STATISTICAL METHODS . . . . . APP B-i
B1.0 INTRODUCTION . . . . . APP B-1
B1.1 ANALYTICAL FACTORS IN SOIL COMPOSITION . . . . . APP B-2
B1.1.1 Bulk Composition . . . . . APP B-2
B1.1.2 Leachate Composition . . . . . APP B-3
B1.2 NUGGET EFFECTS . . . . . APP B-3
B1.3 CORRELATION EFFECTS . . . . . APP B-5
B1.4 DATA CONSTRAINTS . . . . . APP B-5
B2.0 STATISTICAL METHODS . . . . . APP B-5
B2.1 FREQUENCY DISTRIBUTIONS . . . . . APP B-6
B2.2 WEIBULL DISTRIBUTION . . . . . APP B-8
B2.2.1 Weibull Equations . . . . . APP B-9
B2.2.2 Comparison to Other Forms . . . . . APP B-10
B2.3 THRESHOLD CALCULATIONS AND SAMPLE PLOTS . . . . . APP B-10
B2.3.1 Truncated Data . . . . . APP B-12
B2.3.2 Example Data and Comparisons . . . . . APP B-12
B2.3.3 Interpretations of t_o . . . . . APP B-12

C. GROUNDWATER BACKGROUND CONCEPTUAL MODEL . . . . . APP C-i
C1.0 INTRODUCTION . . . . . APP C-1
C2.0 AQUIFERS AND HYDROCHEMICAL FACIES . . . . . APP C-1
C2.1 CHEMICAL EVOLUTION OF GROUNDWATER:
CHEMICAL REACTION PATHS . . . . . APP C-2
C2.1.1 Lateral Variations . . . . . APP C-3
C2.1.2 Vertical Variation . . . . . APP C-4
C2.2 MIXING EFFECTS . . . . . APP C-5
C2.3 SAMPLING AND ANALYTICAL CONSIDERATIONS . . . . . APP C-6
C3.0 EVALUATION AND STATISTICAL METHODS . . . . . APP C-7
C4.0 PRELIMINARY RESULTS . . . . . APP C-8
C4.1 LATERAL VARIATIONS . . . . . APP C-8
C4.2 VERTICAL VARIATIONS . . . . . APP C-8
C5.0 SUMMARY . . . . . APP C-9

D. PLANNED ACTIVITIES . . . . . APP D-i
D1.0 INTRODUCTION . . . . . APP D-1
D2.0 SOIL SAMPLING AND ANALYSIS . . . . . APP D-1
D2.1 SUPPORTING INFORMATION AND OTHER
CHARACTERIZATION EFFORTS . . . . . APP D-3
D2.2 ACTIVITY ORGANIZATION . . . . . APP D-4
D3.0 GROUNDWATER . . . . . APP D-5

E. SOIL BACKGROUND COST SAVINGS ESTIMATE . . . . . APP E-i
E1.0 INTRODUCTION . . . . . APP E-1
E2.0 CURRENT DIRECT COSTS . . . . . APP E-1
E3.0 SITE-WIDE SOIL BACKGROUND COST ESTIMATE . . . . . APP E-2

FIGURES

2-1 Hanford Site F2-1

A-1 Schematic Geologic Cross Section Across the Western Pasco Basin . . . . . APP A-1

A-2 Physiographic Map of the Washington Area Near the Close of the Ice Age . . . . . APP A-2

A-3 Generalized Flow Paths of Cataclysmic Ice Age Floods . . . . APP A-3

A-4 Fine-grained Sediments and Vertical Variability of the Hanford formation . . . . . APP A-4

A-5 Coarse-grained Hanford formation Gravels in Outcrop . . . . . APP A-5

A-6 Eolian Deposits on the Hanford Site . . . . . APP A-6

B-1 Role of Scientific and Technical Basis and Background Conceptual Model on Characterization and Evaluation of Background . . . . . APP B-1

B-2 Normally Distributed Data Fitted by Weibull Distribution . . APP B-2

B-3 Lognormally Distributed Data Fitted by Weibull Distribution . . . . . APP B-3

B-4 Lognormally Distributed Data Fitted by Lognormal Distribution . . . . . APP B-4

B-5 Example of Data: 2-Sided Confidence Limits . . . . . APP B-5

B-6 Example of Data: Threshold Calculation . . . . . APP B-6

B-7 Cumulative Distribution Plots of Aluminum Concentrations in Site-wide Soil Background . . . . . APP B-7

B-8 Cumulative Distribution Plots of Aluminum Concentrations in Site-wide Soil Background . . . . . APP B-8

B-9 Cumulative Distribution Plots of Zinc and Manganese Concentrations in Site-wide Soil Background . . . . . APP B-9

B-10 Cumulative Distribution Plots of Arsenic and Iron Concentrations in Site-wide Soil Background . . . . . APP B-10

B-11 Cumulative Distribution Plots of Lead Concentrations in Site-wide Soil Background . . . . . APP B-11

B-12 Raw Plot of Copper Including the 2101-M Pond Data . . . . . APP B-12

FIGURES (cont)

C-1 Geohydrologic Cross Section Across Part of the Hanford Site . . . . . APP C-1

C-2 Land Surface Perspective Map of the Hanford Site . . . . . APP C-2

C-3 Schematic Illustration of the Typical Evolutionary Process of 'Soft' Rainwater to 'Hard' Groundwater Along its Flow Path in an Aquifer . . . . . APP C-3

C-4 Reactions Associated with the Alteration of K-feldspar . . . APP C-4

C-5 Reactions Associated with the Alteration of an End Member Fe-pyroxene . . . . . APP C-5

C-6 Silica Concentration Released During the Dissolution of Silicate Minerals . . . . . APP C-6

C-7 Concentration Relationships with Distance Along a Groundwater Flow Path for Different Flow Conditions . . . . . APP C-7

D-1 Site-wide Soil Background Activities . . . . . APP D-1

D-2 Site-wide Groundwater Background Activities . . . . . APP D-2

TABLES

3-1. Provisional Hanford Site Soil Background Threshold Values T3-1

B-1. Compositional Range of Key Mineral and Rock Constituents in the Hanford Site Vadose Zone . . . . . APP B T-1

B-2. R^2 Versus Distribution Comparison . . . . . APP B T-2

C-1. Chemical Composition of Waters . . . . . APP C T-1

D-1. Soil Background Analytes . . . . . APP D T-1

ABSTRACT

This document provides justification for and describes a Site-wide approach to the determination and use of soil and groundwater background for environmental restoration activities at the Hanford Site as an alternative to the existing practice of determining unit-specific background. The determination of representative background is important because it is used as a basis for defining contamination and cleanup levels, and in assessing risk.

The present approach to background characterization at the Hanford Site is to establish a background for each waste management unit, which yields different definitions of contamination and remediation goals for these common media, and is inefficient and costly. A Site-wide approach to the characterization and use of natural soil and groundwater background yields more representative information on the range of natural compositions. The Site-wide approach provides for greater consistency and technical validity in environmental restoration and closure activities on the Hanford Site.

The Site-wide approach to background characterization has important implications for environmental restoration and closure activities because only media contaminated above the levels of Site-wide background need to be considered for remediation. The Site-wide approach is more efficient because this approach minimizes the misidentification of uncontaminated samples as contaminated, as well as minimizes the allocation of resources for remediation of contamination within the range of natural background that poses no increased risk to human health and the environment.

The Site-wide approach to background characterization is based on preliminary evaluations of soil and groundwater at the Hanford Site, which indicate that (1) the vadose zone can be regarded as a single compositional population, (2) the natural compositional variability of groundwater in the unconfined aquifer and in the soil and sediment of the vadose zone exists on the scale of the Hanford Site, and (3) the composition of both soil and groundwater has finite upper concentration limits. Models for what soil and sediment and groundwater background compositions represent, the nature and scale of compositional variability, and the processes responsible for the variability have been developed.

The key element of the soil background model is that the compositions of most vadose zone sediments are related because the sediments have common origins, sources, and modes of deposition associated with cataclysmic flooding during the Ice Age. The principal compositional components in these sediments are quartz-feldspar silt-sand and basaltic sand. Lateral and vertical compositional variability is attributable to differences in the proportion of these two components. These differences are related to the manner in which the sediments were deposited during and between flooding episodes. Windblown deposits that locally veneer these sediments were derived from the flood deposits and also are compositionally related to the sediments.

The principal concepts in the groundwater background model are that (1) groundwater composition in the unconfined aquifer is influenced by natural recharge, communication with the underlying confined aquifers, and water-rock-air reactions; and (2) the groundwater compositions evolve along reaction paths that converge toward common equilibrium or steady state maximum levels. The largest concentrations of dissolved solids in the unconfined aquifer generally are expected to occur in areas of the most highly evolved groundwater, because of the water-rock-air reactions or communication with the underlying confined aquifer

The results of preliminary evaluations of soil background data support the Site-wide soil background population model. A preliminary set of soil background threshold values has been generated from these data. A plan for systematic sampling and analysis of the vadose zone during fiscal year 1991 is described. This effort will provide data to improve the technical and statistical basis for the Site-wide soil background approach and threshold values. Efforts also are underway to evaluate existing groundwater data from the unconfined aquifer in the context of the groundwater background model.

GLOSSARY

ABBREVIATIONS, ACRONYMS, AND INITIALISMS

CERCLA	*Comprehensive Environmental Response, Compensation, and Liability Act of 1980*
DQO	data quality objectives
Ecology	Washington State Department of Ecology, charged with enforcement of the *Model Toxics Control Act Cleanup Regulations*, as amended, and the *Dangerous Waste Regulations*
Eh	A measure of the oxidation-reduction potential (volts); the difference in potential measured in a cell having both oxidized and reduced forms of an element (measured) and the standard hydrogen electrode potential.[1] (Eh also can be expressed as pE, which is defined as the negative logarithm of the electron activity.)
EPA	U.S. Environmental Protection Agency
Km	kilometer
m	meter
MTCA	*Model Toxics Control Act Cleanup Regulations*, as amended, Washington Administrative Code, Chapter 173-340.
pH	negative logarithm of the hydrogen-ion concentration
ppm	parts per million
RCRA	*Resource Conservation and Recovery Act of 1976*
WAC	Washington Administrative Code
WMU	Waste management unit. As used in this document, WMU refers collectively to CERCLA operable units and RCRA treatment, storage, and/or disposal facilities.

DEFINITION OF TERMS

Definitions with unidentified sources are based on common usage. Several of the longer definitions have been abridged, as noted at the end of the definition.

Anthropogenic. Involving the impact of man on nature: induced or altered by the presence and activities of man.

Aquifer. A lithologic unit or combination of units that has appreciably greater water transmissibility than adjacent units. An aquifer stores and transmits water commonly recoverable in economic useable quantities.

Area background. The concentrations of hazardous substances that are consistently present in the environment in the vicinity of a site, which concentrations are the result of human activities unrelated to the releases from that site.[2]

Background threshold. Based on a tolerance interval approach, background threshold is the concentration level defining the upper limit of what will be considered as part of the background population. Calculating a threshold requires specifying the cumulative frequency distribution, the percentile level, and the coverage. The WAC 173-340-708(11)(d) specifies the 95 percentile and coverage of 95 percent. Departure from the tolerance interval approach requires approval by Ecology for those WMUs under Ecology jurisdiction.

Basalt. A dark- to medium-dark-colored mafic (iron-magnesium rich) extrusive igneous rock with small grains composed primarily of feldspar (calcic plagioclase), pyroxene, with or without olivine, and varying proportions of glass.[1]

Bulk composition. A complete chemical composition of a sample as performed by a method such as x-ray fluorescence or a spectroscopic analysis on a sample completely dissolved by acid digestion preparation techniques.

Cleanup level. The concentration of a hazardous substance in soil, water, air, or sediment that is determined to be protective of human health and the environment under specified exposure conditions.[2]

Cleanup standards. The standards promulgated under the Revised Code of Washington 70.105D.030(2)(d). Establishing cleanup standards requires specification of the following:

- Hazardous substance concentrations that protect human health and the environment ('cleanup levels')
- The location and site where those cleanup levels must be attained ('points of compliance')
- Additional regulatory requirements that apply to a cleanup action because of the type of action and/or the location of the site.

These requirements are specified in applicable federal and state laws and generally are established following selection of a specific cleanup action.[2]

Conceptual model. A symbolic representation of the essential characteristics of a physical system. The representation can be in language, image, or mathematical form.

Contaminant. Any hazardous substance that does not occur naturally or occurs at greater than natural background levels.[2]

Data quality objectives. These are qualitative and quantitative statements that specify the quality of the data required to support agency (EPA) decisions during remedial response activities. For example, depending on the project phase, sufficient data may have to be collected to characterize the site, evaluate remedial alternatives, determine design criteria, or monitor site conditions and/or remedial action effectiveness (EPA/540/g-7/003).[3]

End member. (a) One of the two or more simple compounds of which an isomorphous (solid solution) series is composed. For example, the end members of the plagioclase feldspar series are albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$). (b) One of the two extremes of a series, e.g., types of sedimentary rock or fossils.[4]

Eolian. (a) Pertaining to the wind; especially said of such deposits as loess and dune sand, of sedimentary structures such as wind formed ripple marks, or of erosion and deposition accomplished by the wind. (b) Said of the active phase of a dune cycle, marked by diminished vegetal control and increased dune growth.[4]

Feldspar. A group of silicate minerals that make up about 60 percent of the outer 15 Km of the Earth's crust; the minerals are silicates of aluminum with the metals potassium, sodium, and calcium, and rarely, barium.[1]

Fluvial. (a) Of or pertaining to a river or rivers. (b) Existing, growing, or living in or about a stream or river. (c) Produced by the action of a stream or river.[4]

Groundwater. Water in a saturated zone or stratum beneath the surface of land or below a surface water[2].

Leachate. The liquid resulting from the partial acid digestion and dissolution of a sample. The material resulting from the acid digestion sample preparation method identified by regulatory protocol (e.g., Method 3050 in EPA's SW-846 guidance).

Local background. Refer to "area background".

Loess. A wide spread, homogenous, fine-grained blanket deposit (generally less than 98.4 feet (30 meters) thick), consisting predominately of silt with subordinate grain sizes ranging from clay to fine sand. Loess is generally buff to light yellow or yellowish brown. Loess now is generally believed to be windblown dust of Pleistocene age, carried from desert surfaces, alluvial valleys, and outwash plains, or from unconsolidated glacial or glaciofluvial deposits. The mineral grains, composed mostly of silica and associated heavy minerals, are fresh and angular and generally are held together by calcareous cement. (abridged)[4]

Natural background. The concentration of a hazardous substance consistently present in the environment that has not been influenced by local human activities. For example, several metals naturally occur in the bedrock and soils of Washington State due to the geologic processes that formed these materials, and the concentration of these metals would be considered natural background. Also, low concentrations of some particularly persistent organic compounds such as polychlorinated biphenols (PCBs) can be found in the surficial soils and sediment throughout much of Washington State because of the global use of these hazardous substances. These low concentrations would be considered natural background. Similarly, concentrations of various radionuclides that are present at low concentrations throughout Washington State because of distribution of global radioactive fallout would be considered natural background.[2]

Nugget effect. The variation in sample concentration levels caused by the presence of a nugget of a mineral or phase that is modally subordinate in the parent material.

Operable unit. A group of contiguous past-practice waste sites related by site characteristics or operations so as to be considered collectively for purposes of environmental restoration under the CERCLA process.

Quartz. (a) Crystalline silica, an important rock-forming mineral: SiO_2. (b) A general term for a variety of noncrystalline or cryptocrystalline minerals having the same chemical composition as that of quartz, such as chalcedony, agate, and opal. (abridged)[4]

Sediment. (a) Solid fragmental material that originates from weathering of rocks and is transported by air, water, or ice, or that accumulates by other natural agents, such as chemical precipitation from solution or secretion by organisms; and that forms in layers on the Earth's surfaces at ordinary temperatures in a loose unconsolidated form; e.g., sand, gravel, silt, mud, till, loess, alluvium. (b) Strictly solid material that has settled from a state of suspension in a liquid. In the singular, the term is usually applied to material held in suspension in water or recently deposited from suspension. In the plural, the term is applied to all kinds of deposits, and refers to essentially unconsolidated materials.[4]

Site background. The natural background of the Hanford site. Includes all contributions from anthropogenic sources unrelated to the Hanford Site operations, e.g., regional agricultural chemicals, nuclear weapons testing fallout, etc.

Soil. A mixture of organic and inorganic solids and biota that exists on the Earth's surface above bedrock.

TSD facility. Treatment, storage, and/or disposal facility. A RCRA designation for a facility that handles hazardous waste.

Unconfined aquifer. An aquifer having a water table; an aquifer containing unconfined groundwater.[4]

Unit background. Refer to "area background".

Vadose zone. Zone of aeration. A subsurface zone containing water under pressure less than that of the atmosphere, including water held by capillarity; and containing air or gases generally under atmospheric pressure. This zone is limited above by the land surface and below by the surface of the 'zone of saturation', i.e., the water table. (abridged)[4]

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[1] *Basalt Waste Isolation Project Glossary*, SD-BWI-PMP-005, Rockwell Hanford Operations, Richland, Washington.

[2] *Model Toxics Control Act Cleanup Regulations*, as amended, WAC Chapter 173-340.

[3] EPA documentation as referenced in each definition.

[4] Bates, R.L., 1990, "Glossary of Geology", J.A. Jackson, ed., American Geological Institute, Falls Church, Virginia.

1.0 INTRODUCTION

A fundamental principle in most environmental regulations is that the natural environment should be used as a baseline for defining contamination and cleanup levels (e.g., EPA 1986; Ecology 1991a,1991b). The implied concepts in these regulations are that (1) concentrations of chemicals that occur in the environment naturally are generally not harmful to human health and the environment and (2) the natural environment should not be remediated because remediation would serve no practical purpose. Determination of the range of naturally occurring chemicals is, therefore, one of the most important activities in the environmental restoration mission at the Hanford Site. The focus of this document is on the determination and use of nonradioactive inorganic constituents in the soil and groundwater background at the Hanford Site.

The term 'background' generally refers to the composition of a medium unimpacted by activities at a waste management unit (WMU). [For purposes of this document, WMU refers to either a *Resource Conservation and Recovery Act of 1976* (RCRA) treatment, storage, and/or disposal (TSD) facility or a *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) operable unit.] Several different definitions of background exist in the regulatory guidelines. The ambient concentration of chemicals present in the environment unimpacted by human activities is defined as natural background by the U.S. Environmental Protection Agency (EPA) (EPA 1989c). The concentration of chemicals consistently present in the environment due to human-made, non-site sources (i.e., agriculture, automobiles) is defined by the EPA as anthropogenic background (EPA 1989c), and as natural background by the Washington State Department of Ecology (Ecology) (Ecology 1991b). The Ecology definition of natural background differs from the EPA definition because the term natural background includes constituents such as agricultural byproducts in the Columbia and Yakima Rivers, and radionuclides distributed globally from atmospheric weapons testing.

The two main types of background discussed here are natural background as defined by Ecology, and 'local' or 'area' background (Ecology 1991b). Local or area background refers to the composition of a medium in the vicinity of an individual WMU before its existence. Local background might or might not correspond to natural background and is used, where possible, to distinguish between contamination from a WMU and contamination attributable to other current or previous activities at the Hanford Site. Local or area background is used synonymously with WMU-background in this document. For the purpose of this document, the analytes included in this definition of natural background are only the inorganic constituents.

Background sampling generally is conducted to distinguish site-related contamination from naturally occurring or other non-site related levels of chemicals in media such as soils and groundwater, and also to establish baseline risk levels for the protection of human health and the environment (EPA 1989c). The background-based definition of contamination, i.e., concentrations larger than those that occur naturally, often supersedes more general standards in environmental restoration efforts because the

concentration levels of natural background vary from region to region (EPA 1989c). In risk assessment activities, the natural range of chemical concentrations in soil and water is used to constrain the levels of human and ecosystem exposure to chemicals that are normal for the site or region. This information is used primarily to provide a lower bound of human and environmental toxicity and other health risks.

The concept of a Site-wide approach for characterizing the natural range of compositions for soil/sediment and groundwater background at the Hanford Site is presented in this report. Discussion of the technical feasibility and utility of a Site-wide approach to background characterization for soil and groundwater begins in Section 2.0 with a comparison of the WMU-based approach and the Site-wide approach of background characterization. The issues of what constitutes representative background, and how background is most appropriately characterized for the purposes of environmental restoration, also are addressed.

The technical validity of the Site-wide approach to the characterization of soil and groundwater background also is discussed in the context of the nature of the media and the factors that influence its composition. A description of the physical and chemical characteristics of the soil/sediment in the vadose zone and the groundwater system in the unconfined aquifer beneath the Hanford Site is provided in terms of geologic, geochemical, and hydrologic information and environmental regulations and protocols in Sections 3.0 and 4.0, respectively. The preliminary results of evaluating the existing WMU-based soil background collectively in a Site-wide context also are presented in Section 3.0. Conclusions regarding the justification for the preferred use of Site-wide background in environmental restoration efforts is provided in Section 5.0.

Additional information on the physical and compositional characteristics of soil/sediment and groundwater at the Hanford Site and the known and expected chemical characteristics are provide in Appendices A and C. Discussions of the statistical and nonstatistical methods used in evaluating the soil background data and statistical evaluation of the validity of the Site-wide approach for characterizing soil background are presented in Appendix B. The systematic sampling and analysis of soil/sediment in the vadose zone and data compilation efforts for Site-wide groundwater background planned for fiscal year 1991 are described in Appendix D. Cost savings analysis information associated with a Site-wide approach to the characterization of soil background is included in Appendix E.

The terms soil and sediment used in this report both describe the unconsolidated earth materials that comprise the vadose zone on the Hanford Site, i.e., the zone from the ground surface to the top of the underlying unconfined water table. These terms have specific meanings in environmental regulations that differ from those used in the scientific and engineering communities. For the purpose of this report, the terms soil and sediment are used interchangeably and refer collectively to these materials in the vadose zone. However, the term sediment is used in the geologic context in describing the geology of the vadose zone materials.

2.0 SITE-WIDE VERSUS UNIT-BASED APPROACH TO BACKGROUND CHARACTERIZATION AND USE

The fundamental requirement for background characterization activities concerns representative sampling of the media. Regulatory protocols require that background samples be representative of the medium of interest in the WMU, and unimpacted by activities in the WMU (EPA 1986). The extent to which the samples are representative, however, also depends on the end use of the data (EPA 1987a). The validity of the Site-wide approach to background characterization, therefore, depends on (1) what constitutes representative background for the purpose of environmental restoration and (2) whether a Site-wide background is more representative of the media impacted by WMUs than a WMU-based background for its intended use.

Over 1,500 locations have been identified on the Hanford Site that potentially require some type of characterization as specified in environmental regulations (e.g., EPA 1980; Ecology 1991a, 1991b) and the *Hanford Federal Facility Agreement and Consent Order* (Ecology et al. 1990). There are presently 62 WMUs identified under the RCRA as TSD units (Ecology et al. 1990). The remaining locations identified under the CERCLA or the RCRA corrective action authority *Hazardous and Solid Waste Amendments of 1984* are grouped into 78 operable units.

The current approach for characterizing these WMUs on the Hanford Site is to establish a local background for each RCRA treatment, storage, and/or disposal unit and each operable unit. The composition of soil and/or groundwater from each WMU is compared to the WMU-background to define contamination and assess risk. This approach has led to inconsistencies in identifying contamination and in the evaluation of restoration and baseline risk levels. Consequently, this approach yields different definitions of contamination and different assessments of remediation goals and risk for each WMU, even those WMUs that are adjacent or superimposed.

An alternative approach is to develop a single Hanford Site background for all the sediments in the vadose zone with the same basic characteristics, and a single background for groundwater in the unconfined aquifer. This approach is based on the fact that all the WMUs share a common sequence of vadose zone sediments and a single unconfined aquifer. In this approach, the range of natural compositions within these media is used to establish the Hanford Site background for soil and for groundwater.

2.1 REPRESENTATIVE CHARACTERIZATION AND USE OF BACKGROUND

A Site-wide approach to the characterization of soil and groundwater background for environmental restoration on the Hanford Site is theoretically a more appropriate method than the WMU-based approach to background characterization for several reasons. These reasons are as follows.

- WMU-based local background may not represent the natural range of soil compositions.

- WMU-based local background may not represent natural background for groundwater.

- Environmental restoration activities typically involve soil and groundwater impacted by more than one WMU.

- Environmental restoration activities are performed on the scale of the impacted medium rather than the scale of individual WMUs.

- The WMU-based approach to background characterization is designed for individual WMUs at unrelated sites or regions that do not share a common vadose zone and unconfined aquifer.

For the purpose of environmental restoration, natural background must represent the natural range of compositions within the medium of concern, e.g., soil and/or groundwater. Local WMU-based background at many WMUs may not represent natural background. This is true for soil background in some areas of extensive past-practice activities (e.g., 300 Area; Figure 2-1). This is especially true for local groundwater background where upgradient wells are influenced by other WMUs. In such cases, the local background, i.e., upgradient well water composition, is not natural background, and cannot be used in determining the natural range of compositions, even for individual WMUs.

The characterization of background also must be performed on the same scale as the environmental restoration activities to accurately represent the range of compositions of known or potential impact. Many of the restoration activities must be evaluated and performed on the scale that considers past and present operations that have influenced the soil and groundwater. In most cases, the scale that should be considered for background characterization in environmental restoration activities is larger than the dimensions of individual WMUs. For example, the extent to which groundwater is impacted by a WMU operation typically is much larger than the lateral dimensions of the WMU itself. In this case, representative background is the natural range of compositions that exist in the impacted part of the aquifer laterally and vertically. In such cases, or where upgradient wells are influenced by other WMUs, it may not be possible to determine an appropriate natural background using a WMU-based approach to the characterization of background.

There is also an important distinction between the purpose and use of background in environmental restoration and monitoring efforts. The objective of environmental restoration is to return the Hanford Site to conditions protective of human health and the environment or to pre-operational conditions; whereas, the main objective of monitoring is to detect contamination and identify sources. The ability to recognize contamination on the scale of individual WMUs is important in monitoring active operations and contaminant plumes, and requires local WMU-background, especially for groundwater. However, the identification of contamination from specific WMUs for the purpose of environmental restoration is subordinate to the identification of contamination levels from all sources that exceed the range of natural background. Moreover, contaminant levels within the range of natural background generally are not distinguishable from background.

One concern regarding the use of a site background is whether levels of contamination within the range of natural background pose a risk to human health or the environment. The regulatory agencies recognize that not all contamination poses a threat to human health or to the environment or warrants remediation. For example, regulatory guidelines indicate that chemicals that are present within the range of naturally occurring levels do not pose a risk to human health or the environment unless the natural background levels themselves pose a risk (EPA 1989c). Concerns regarding ecosystem sensitivities to differences in the level of chemicals within the range of natural soil background also have been considered. However, there is no known ecosystem sensitivity of this type within the Hanford Site region, with the exception of small isolated localities in the Cold Creek Valley and West Lake Basin. At these localities, alkali soils have developed naturally over the past 6,000 years and preclude most vegetation with the exception of those plants that can tolerate high salt environments (e.g., Rickard 1964). Compositional outliers such as this are readily recognizable and are included in the data evaluation process. Similar concerns for groundwater are discussed in Section 4.0.

Perhaps the most important difference between the WMU-based approach and the Site-wide approach to background characterization is in the way that the background characterization impacts evaluations and decisions. Decisions concerning the identification of contamination and/or remediation using individual WMU backgrounds are subject to error because WMU local backgrounds are subsets of the natural range of soil background compositions that exist laterally and vertically throughout the Hanford Site or beneath WMUs. For example, the composition of soil or groundwater that exceeds the local background threshold levels in one area, but that is within the range of the Site-wide natural background, would be interpreted as contaminated using a WMU-based background approach. However, for the purposes of environmental restoration, it is impractical to define background, and consequently contamination and baseline risk levels, differently from one place to another for a common medium. In this regard, the use of a Site-wide background provides a basis for minimizing the misidentification of uncontaminated samples as contaminated, and the potential allocation of resources to remediation efforts that serve no purpose.

Thus, representative characterization of the natural range of soil and groundwater background compositions for the purposes of environmental restoration is best obtained using a Site-wide approach rather than a WMU-based approach. It is not intended that a Site-wide background be used to allow any level of contamination to be introduced into the environment from current or future operations. Rather, Site-wide background is intended for use as one of the most appropriate criterion for distinguishing contamination that practically can be considered for corrective action.

2.2 BENEFITS OF A SITE-WIDE APPROACH

The main benefits of a Site-wide approach to the characterization of background for soil and groundwater include the following:

- Consistent and representative characterization of background
- Consistent definition of contamination and assessment of baseline risk
- Greater efficiency in environmental restoration activities.

Alternatively, the WMU-based approach can result in problems in balancing cost in terms of technical and/or statistical validity. In the case of soil background, a small number of surface soil samples often are inadequate for the level of desired statistical confidence, and generally are inadequate to represent the compositional range of the soil background that actually exists on the scale of the impacted medium. However, the number of samples that may be necessary for statistical purposes, and would be representative of the geology and geochemistry, becomes very costly when performed independently for each WMU. The use of appropriate data accumulated from RCRA or CERCLA activities eliminates most problems associated with small sample number statistics, and is one reason for the improved technical basis of the Site-wide approach.

Cost benefits are realized as a result of using the Site-wide approach to characterization of soil and groundwater background. The Site-wide approach also is more efficient than the WMU-based approach. The primary cost benefit is the reduction in the number of background samples and the analyses that are required. The combined cost savings over a WMU-based program of sampling and analysis for soil background alone is estimated at over $10 million (Appendix E). Similar cost savings are expected for Site-wide characterization of groundwater background.

Cost benefits also are likely to result from the improved ability to evaluate the significance of contamination at any WMU. Allocation of resources for environmental restoration will be more efficient, because the range of compositions that naturally exist in the background media will be known. Knowing the compositional range will minimize occasions where uncontaminated media are designated as being contaminated, resulting in subsequent, unnecessary remediation.

2.3 BACKGROUND CONCEPTUAL MODELS

Conceptual models are integral components of the recommended process for identifying the objectives and quality of data collection efforts (EPA 1987b). For the purpose of background characterization, the development of conceptual models is useful because the models provide the scientific and technical basis for what soil or groundwater background compositions represent, and what the compositional populations are or are expected to be. Conceptual models describe the media in the context of the environment in which the media was formed and presently exists. These models are based on information regarding composition, factors that affect composition, and the processes responsible for the lateral, vertical, and temporal variation in composition. In addition, factors that potentially can affect the composition of the media at any point throughout the sampling or analysis process are identified and used. The conceptual model is revised until an adequate description of the system is

obtained. The adequacy of the model is based on factual content and peer review. New data are obtained and evaluated to improve and refine the model and the description of the natural systems.

Conceptual models for the understanding of soil and groundwater background are based on geologic, hydrologic, and geochemical principles. Data types (parameters) include the following:

- Field information on the geologic relationships and history
- Structure
- Stratigraphy
- Physical properties such as grain size
- Hydrologic physical properties (e.g., flow direction, velocity, etc.)
- Lithologic and mineralogic composition, etc.
- Chemical compositional data (e.g., groundwater and soil leachate).

Verification of the models eventually requires a program of systematic sampling and analysis. These models also include the consideration of WMU operations and histories, and the relationships between the natural processes and the expected or observed range of background compositions.

Background conceptual models for the vadose zone sediments and groundwater in the unconfined aquifer at the Hanford Site are described in Sections 3.0, 4.0, Appendix A, and Appendix C.

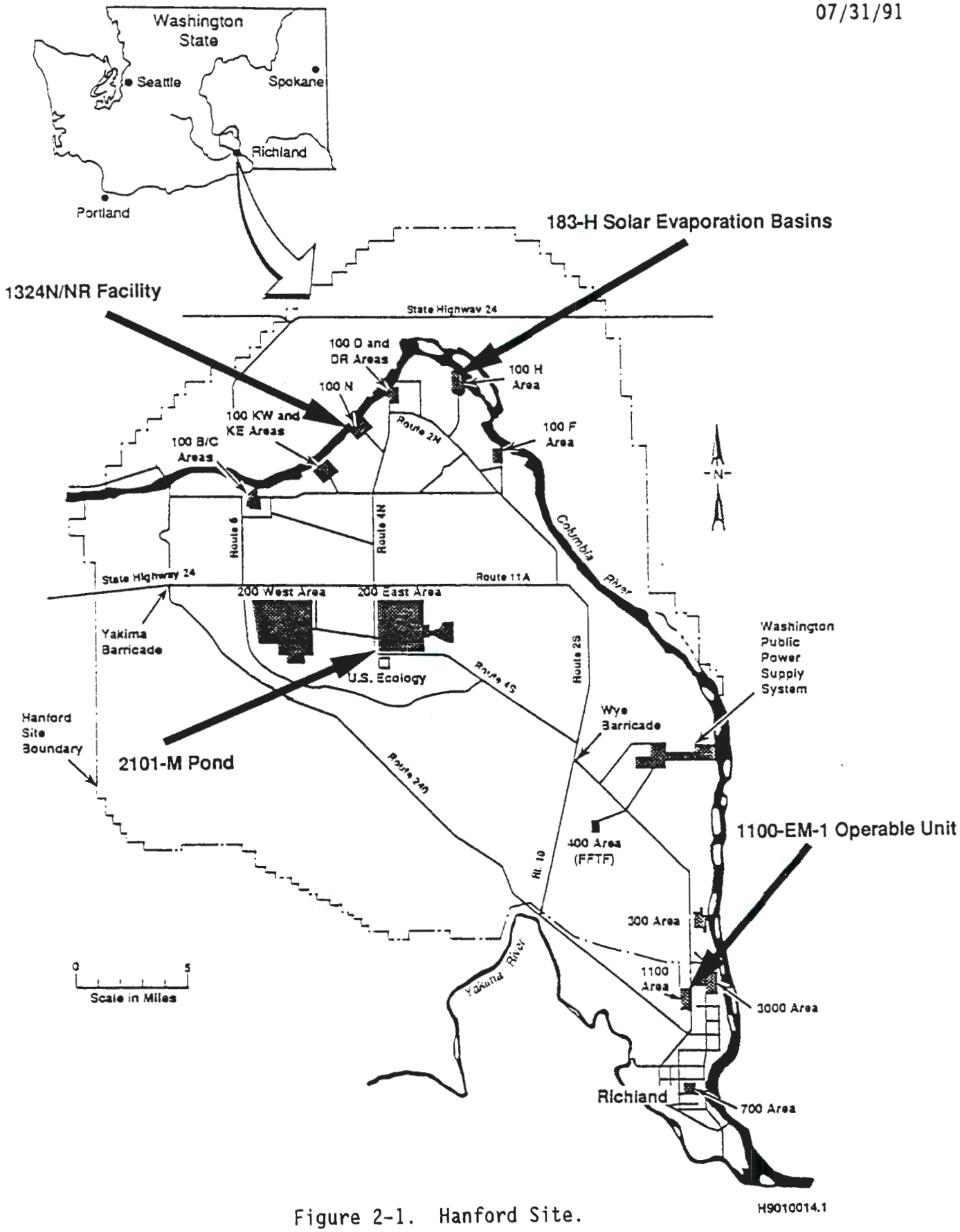

Figure 2-1. Hanford Site.

3.0 SOIL BACKGROUND

The feasibility of a Site-wide approach to characterizing background compositions for soil and sediment in the vadose zone depends on whether these materials can be regarded as having the same basic characteristics (EPA 1989c). The similarities in the basic characteristics of the soil and sediments in the vadose zone are not obvious from the physical appearance of these materials in the field (Appendix A, Figures A-4 to A-6). However, there is a sound geologic and geochemical basis for considering essentially all of the vadose zone together as a single compositional series.

The conceptual model of the vadose zone sediments described in the following sections and in Appendix A contains information on the geology and compositional makeup of the sediments. The purpose of this model is to provide insight regarding the relationships between the physical and compositional characteristics of the vadose zone materials and their compositions, as determined in accordance with regulatory protocols. This soil background conceptual model, therefore, provides a technical basis for characterizing and understanding the characteristics and scale of natural variability in soil background composition within the vadose zone on the Hanford Site.

It is emphasized that the term 'soil' is used in this document only in the regulatory sense and this usage denotes the sediments within the vadose zone, rather than that part of the earth's surface that support plants. Soils in this latter sense have specific properties due to the integrated effects of climate, living matter, parent material, etc. Generally, the uppermost sediments of the Hanford formation and eolian veneer have soil horizons less than a few inches thick (e.g., Appendix A, Figures A-4 to A-6). These soils are considered separately from the vadose zone sediments for the purposes of this report (Appendix A, Sections A5.0 and A6.0). The compositions of the vadose zone materials are dominated by the unaltered components in the sediment.

3.1 SOIL BACKGROUND CONCEPTUAL MODEL

The main element of the soil background conceptual model is that the composition of the vadose zone sediments are related. The relationships are based on the following.

- The finer grained materials in the sediments are composed primarily of varying proportions of two main components.

- Only the finer grained material in these sediments is used in the determination of soil composition, in accordance with regulatory protocols (e.g., EPA 1986).

- There are systematic relationships in the distribution of these two main components laterally and vertically because of the way in which the materials were formed and deposited.

- The compositions of the fine-grained fractions of soil and sediment in the vadose zone primarily reflect the differing proportions of the two main components.

- Compositional ranges attributable to such relationships can be considered as a single group or population of compositions because the range represents a continuous compositional series.

Similarities in the composition of the vadose soils and sediments are expected because of the origin of the sediments. The Hanford formation constitutes a majority of the vadose zone, and is composed primarily of gravel, sand, and silt. Historically, these sediments are related because the sediments have a common origin and were derived from largely common sources. These materials, therefore, have basic similarities in their physical and chemical makeup. The most important similarities are (1) the relationships in physical composition between the fine-grained fractions in the sediments and (2) the chemical relationships in the composition of these materials, as determined by regulatory protocol.

The range of soil compositions within the vadose zone is attributable to the presence of two principal end member components in various proportions. These are: a quartz-feldspar rich end member sediment component and a basalt-rich end member sediment component. The compositions of the sediments are mixtures of the two end members and, thus, have compositions intermediate between those of the two end member components in the following manner:

quartz and feldspar-rich	<---------->	basalt-rich
end member sediment composition	intermediate compositions	end member sediment composition

Both end member components in the sediments originally were deposited as a result of catastrophic floods involving hundreds of cubic miles of water during the most recent Ice Age. The distribution of these materials was controlled by differences in the velocity and energy of the flood waters as the waters flowed through the Pasco Basin. Systematic variations in the velocity and energy of flood waters occurred laterally from the lower energy condition in the bars and banks to the higher energy conditions in the flood channels. The depositional processes associated with these floods resulted in systematic lateral variations in the proportions of the two end member sediment components deposited from individual floods. The flow velocity and energy of the flood waters changed constantly and rapidly throughout the duration of individual floods, and also as the channels shifted from flood to flood. These changes in energy conditions caused differing proportions of the end member sediment to be deposited as the sedimentary sequences accumulated vertically over time.

The scale of compositional variability also is constrained by the origin of the sediments. Vertical variations in composition occur on the scale of the layering (fractions of an inch to tens of feet), and extend throughout the thickness of the vadose zone. The scale of variability laterally corresponds to the cross-sectional dimension of flood waters channeled through this part

of the Pasco Basin. This dimension is about the same as the east-west dimension of the Hanford Site. The scale of longitudinal variability has the dimensions of the entire Pasco Basin. However, the composition of flood deposits south of the Hanford Site also has components originating from the Snake River and Yakima River drainage systems. The potential effects of these factors are not known, however, the efforts do not affect the soil background model for the Hanford Site.

The recent windblown sediments, e.g., sand dunes, that locally veneer the Hanford Site also are expected to be compositionally related to the Hanford formation sediments. These materials are related because the windblown deposits are derived from the flood deposits within the Pasco Basin and adjacent areas by winnowing out the fine-grained material from the flood deposits, and physically fractionating the material by size and density into compositional subsets of the source material. These compositional subsets are composed largely of the same end member sediment components as the flood deposits, but in differing proportions because of the sorting effects of the wind.

This perspective regarding the origin and makeup of the sediments in the vadose zone of the Hanford Site provides a technical basis for regarding the vadose zone as having the same basic characteristics. The soil background conceptual model also identifies the relationship between the physical nature and chemical composition of these sediments. These data also provide a basis for understanding the extent of natural compositional variability in the vadose zone soil and sediments, and the scale on which the variability occurs laterally and vertically. This information, therefore, serves as the technical basis for obtaining a representative characterization of the natural range of soil and sediments in the vadose zone, and in justifying the Site-wide approach to characterization. A more detailed description of the vadose zone model is provided in Appendix A. Analytical factors that influence soil composition, such as the proportions, size, surface area, and solubilities of the constituents in soil samples also are addressed in Appendix A.

3.2 EVALUATION AND STATISTICAL METHODS

The primary way in which soil background compositional data are used in environmental activities is in establishing appropriate baseline concentration levels, which then are used to identify contamination and to assess the risk to human health and the environment. Various statistical techniques and methods can be employed in defining contamination. One of the most common methods employed is to establish a concentration level that is used as the criterion by which samples are considered to be within the natural range of the background levels or are considered to exceed these levels. This background level is referred to as the background threshold (Ecology 1991b). Statistical techniques and methods are used to establish the degree of confidence to be applied to threshold levels. Therefore, the credibility and efficiency of all environmental activities that are based on defining contamination in this way depend on the validity and quality (e.g., representativeness) of the background data.

Corroboration of the feasibility of this concept, however, requires the evaluation of data in the context of the Site-wide approach. The key test is whether the compositions of soil background samples from the vadose zone can be shown to be related in the manner described in Section 3.1. The results of preliminary evaluations on soil background data to test this model are presented in the following section. The statistical and nonstatistical methods employed in the evaluation are discussed in Appendix B.

3.3 SITE-WIDE SOIL BACKGROUND EVALUATIONS: PRELIMINARY RESULTS

One of the main concerns in background characterization efforts is the existence of natural background. A preliminary evaluation of soil background compositional data has been made to determine if contamination of the ground surface is pervasive over the Hanford Site. The soil compositions from samples collected from the surface and from boreholes up to 50 feet deep at background localities in the vicinity of several WMUs were used in the evaluation. The compositions of the samples from all but the upper parts of the boreholes were compared to those at the surface and upper parts of the boreholes. The compositions of the soil samples from the lower parts of the boreholes were regarded as representative of natural background, based on the consideration of potential contaminant source terms, pathways, and mass balance. No preferential patterns of contamination with respect to inorganic constituents were found at or near the surface of the background boreholes at these WMUs. In addition, the surface samples from other WMUs do not appear to indicate any pattern of preferential surface contamination for inorganic constituents. These data indicate that a Site-wide soil background for the vadose zone is possible.

A second consideration regarding the feasibility of the Site-wide approach for soil background is that the soil and sediment in the vadose zone can be regarded as a compositional series in the manner described in Section 3.1. Soil background concentrations from 59 samples at 8 locations in the vicinity of 4 WMUs within the 1100, 100, and 200-E Areas were used in these evaluations (Section 2.0, Figure 2-1). These samples were collected in conjunction with RCRA and CERCLA characterization efforts associated with two surface impoundments--the 2101-M Pond and 1324N/NR Facility; one storage and treatment facility--183-H Solar Evaporation Basins; and one operable unit--1100-EM-1. Data from these samples are the only analyses of soil samples taken for background purposes that have been collected and analyzed according to EPA protocols (e.g., EPA 1986). Although there are some concerns regarding the quality level of these data, these levels are suitable for evaluating the concept of a Site-wide background and establishing preliminary threshold concentrations.

All the samples analyzed to date can be shown to belong to single compositional populations. Cumulative distribution plots for several of the analytes are shown in Appendix B (Figures B-9 and B-10), which illustrate the continuity of the combined data as single populations. It is indicated from these data that the Site-wide approach for soil characterization is feasible.

A tabulation of the provisional soil background threshold values derived from these analyses is provided in Table 3-1. The statistical methods used in the analyses are discussed in Appendix B. Methods for distinguishing differences between anomalously high concentrations that naturally occur in soils and groundwater and contamination also are described in Appendix B, Section B1.2.

Table 3-1. Provisional Hanford Site Soil Background Threshold Values.

Constituent[1]	Concentration threshold[2] (95/95) ppm	Correlation coefficient[3] (r)	Maximum value (nugget effect[4]) ppm	Number of samples[5]
Aluminum	16,573	.994		59
Arsenic	4	.980	8.1	59
Barium	169	.990	229	59
Beryllium	2	.959		43
Cadmium	8	.985		59
Calcium	11,210	.990	14,000	59
Chromium	20	.985	48.3	59
Cobalt	16	.975		43
Copper	21	.959		44
Iron	29,781	.995		59
Potassium	2,740	.990		59
Magnesium	6,480	.990	6,910	59
Manganese	424	.975	533	59
Nickel	18	.985	25.3	59
Lead	10	.992	12.7	52
Strontium	43	.995		38
Vanadium	82	.985		59
Zinc	50	.998	112	59
Ammonium	3	.980		23
Chloride	38	.983		59
Nitrate	<detection limit	--		59
Sulfate	40	.990		38
Fluoride	5	.975		29

[1] Analytes for RCRA analysis per SW-846 6010 plus selected anions.
[2] *Model Toxics Control Act Cleanup Regulations.*
[3] Based on use of the Weibull distribution (Nelson 1982).
[4] Appendix B.
[5] Number of samples differs because of quality control considerations or because some constituents were not analyzed in all data sets.

4.0 GROUNDWATER BACKGROUND

The determination of representative groundwater background provides a basis for defining contamination and cleanup levels in groundwater in the same manner as outlined for soil in Section 3.0. The use of a Site-wide groundwater background in a similar manner as soil background involves determination of representative background on the scale of the medium that has the same basic characteristics (EPA 1989c). For groundwater, this medium is the single unconfined aquifer beneath the Hanford Site. The use of a Site-wide groundwater background in groundwater restoration efforts requires an understanding of the natural variability in composition within the unconfined aquifer rather than on the scale of individual WMUs. The merit of this approach in environmental restoration and closure activities is addressed in this section.

The Site-wide groundwater background approach is recommended because groundwater contamination attributable to individual WMUs typically impacts the aquifer beyond the dimensions of the WMU either laterally or vertically. Thus, for efficient groundwater restoration, remediation, and closure, problems should be addressed on the scale of the aquifer, especially characterization of the natural range of background compositions. Local groundwater background is important and is required for recognizing contamination from individual WMUs. There is no benefit, and great cost, in attempting to remediate parts of the unconfined aquifer beneath the Hanford Site to levels that are within the range of compositions that exist naturally elsewhere in the aquifer and to levels that pose no risk to human health or the environment. Moreover, the relative importance of efforts to distinguish small amounts of contamination below the natural background thresholds for the aquifer serves no purpose in the restoration and closure activities unless the natural background levels themselves pose a risk (EPA 1989c). Groundwater background threshold levels for the Hanford Site are a more appropriate and representative basis for use in groundwater remediation activities.

Determination of Site-wide groundwater background threshold levels requires representative characterization of the range of compositions that occur naturally throughout the unconfined aquifer. However, this type of characterization has not been undertaken previously despite the numerous wells drilled and the many Site-wide studies. Most groundwater characterization and monitoring efforts to date have been conducted to assess the effects of past waste-disposal systems (DOE 1988, pp. 3.9-114) rather than for the purpose of determining the natural range of background compositions for the aquifer. As a result, interpretations regarding Site-wide groundwater background from the groundwater monitoring activities alone must be viewed with caution because the objectives of those activities differed from those required for the determination of the range of natural background compositions.

The main difference is in the type, location, and depth of samples, i.e., representativeness of the data and the basis (e.g., conceptual model) used for interpretation of the data. The basic elements of the groundwater background conceptual model are described in the following section. A more detailed discussion of compositional parameters and their relationship to the

determination of a Site-wide groundwater background are presented in Appendix C. A detailed discussion of evaluation considerations and statistical methods is provided in Appendix C, Section C3.0.

4.1 GROUNDWATER BACKGROUND CONCEPTUAL MODEL

The following are the basic concepts in the groundwater background conceptual model.

- Natural variations exist in the composition of groundwater within the unconfined aquifer beneath the Hanford Site.
- The compositional variability is due to systematic natural processes that control the distribution and range of compositions.
- The natural variability in groundwater composition occurs on the scale of the aquifer both laterally and vertically.

The natural variation in lateral and vertical composition in the aquifer exists because of the influences of recharge, communication with the underlying confined aquifers, and water-rock-air interactions. The trend is for groundwater to become 'harder' as the concentrations of dissolved solids increase by interaction with the aquifer. These reactions do not occur instantaneously, but rather progress with time. The reactions generally approach equilibrium or metastable equilibrium conditions, which effectively buffer the upper concentration limits of groundwater composition for most reaction paths. Thus, there are finite upper concentration limits for most constituents that are controlled by these reactions. The nature of these reactions and processes, as well as the influences of artificial recharge and interaquifer communication, are discussed in detail in Appendix C.

For the purpose of environmental restoration, the upper concentrations within the natural range of groundwater compositions are more important than information concerning the details of how these levels were approached by various reaction paths and influences. It is expected that the highest concentration levels for many constituents are controlled by aquifer-specific reactions between water and the rock-mineral components. Equilibrium controls on 'maximum' concentrations, for example, cause the concentrations to converge toward largely constant levels (Appendix C, Figures C-6 and C-7). In general, groundwater compositions closest to recharge areas have low dissolved solids concentrations, and groundwater with the longest residence time in the aquifer has the highest concentrations of total dissolved solids. The latter is generally the groundwater farthest downgradient from the recharge zones and/or those associated with the parts of the aquifer having low-hydraulic conductivities. These relationships are complicated by the influences of groundwater in the underlying confined aquifer, artificial recharge, and oxidation-reduction, which are addressed in Appendix C.

There could be some concern regarding the potential for small amounts of contamination within the natural range of compositions in the aquifer to compromise the quality of soft water segments of the aquifer, even if there is

no increased risk to human health or the environment. If such levels of contamination can be distinguished from background, the main effect would be for that part of the groundwater system to approach equilibrium by another path, and not to increase reaction path equilibrium levels. In dynamic flow systems, such perturbations also are readily restored to the levels that normally exist (i.e., soft water conditions) for that part of the system. The potential for impacting naturally soft water within the aquifer also is small because the water compositions in the unconfined aquifer already are moderately 'hard' by the time the compositions reach areas impacted by Hanford Site operations, as noted in Appendix C, Section C4.0. There is a significantly greater probability that the naturally hard water in the aquifer has been made artificially softer by the effects of artificial recharge. As noted previously, use of a Site-wide background is intended as the most appropriate criterion for distinguishing contamination that can be practically considered for corrective action, rather than as a level of allowable contamination from current or future operations.

4.2 HANFORD SITE GROUNDWATER BACKGROUND EVALUATIONS: PRELIMINARY RESULTS

The amount of groundwater data that can be used in evaluating the natural range of compositions within the aquifer is under investigation. Groundwater from the unconfined aquifer has been extensively studied by Pacific Northwest Laboratory (DOE-RL 1989) to monitor contaminant movement associated with waste management activities at the Hanford Site (e.g., Raymond et al. 1976; Myers et al. 1976, 1977; Myers 1978; Eddy et al. 1983; Prater et al. 1984, Cline et al. 1985, and Evans et al. 1989). The extent to which these data can be used in the evaluation of natural groundwater background compositions is also under investigation. However, some evaluations have been performed with the data presently available. Qualitative and quantitative evaluations and models of the reactions that take place between groundwater and the dominant solid phases in the unconfined aquifer, and between groundwater and air, have been performed. The results of these evaluations corroborate both the role of air in controlling reactions in the uppermost part of the aquifer and the convergence of unconfined aquifer compositions with those of the confined aquifer groundwater composition (e.g., DOE 1988, pp. 3.9-137 to 143). However, a complete evaluation of the geochemical evolution of the shallow Hanford Site groundwater using a reaction path approach has yet to be performed.

The upper concentration limits within the range of natural groundwater background are of greatest interest for environmental activities, because the limits approach the maximum concentrations that can exist naturally in the aquifer for many components. The groundwaters in the unconfined aquifer with the largest concentrations of dissolved solids have compositions that converge with those in the underlying confined aquifer. This is an expected trend because the basaltic components tend to control the upper concentration levels of the most chemically evolved groundwater for many of the dissolved solids. The compositions of groundwaters from those parts of the unconfined aquifer may, therefore, be appropriate for use as groundwater threshold levels for many constituents. However, the use of these compositional data in establishing a Hanford Site background likely would require corroboration of

reaction path relationships, and additional sampling designed for the measurement of the highest concentration levels in the aquifer. Additional information is provided in Appendix C.

5.0 CONCLUSIONS

The concept of a Site-wide approach to the characterization of soil and groundwater for use in environmental restoration activities at the Hanford Site has a sound scientific and technical basis. The use of a Site-wide approach to the characterization of background is preferred over the present WMU-based approach because the approach provides more accurate and representative information on the natural range of soil and groundwater compositions. The Site-wide approach is regarded as more appropriate for the purpose of environmental restoration activities because: (1) environmental restoration activities are evaluated and performed on the scale of the operational impact to the soil and groundwater, (2) this scale of restoration generally extends beyond the dimensions of individual WMUs, (3) all WMUs share a common vadose zone sequence and groundwater in a single unconfined aquifer, and (4) it is impractical and inefficient to define background differently from one place to another for a common medium.

Preliminary evaluations of available data on soil and groundwater indicate that the Site-wide approach to the characterization of soil and groundwater background is feasible because of the following.

- The compositions of most vadose zone sediments can be considered together as a single compositional series.

- The natural range of variation in the composition of groundwater in the unconfined aquifer and of the sediment in the vadose zone exists on the scale of the entire Hanford Site.

The Site-wide approach to background characterization also is desirable because the approach provides a more consistent and credible basis for evaluating contamination, and is a more efficient method of characterization for the purpose of environmental restoration. The advantages of using a Site-wide approach to the characterization of background include the following:

- Improved efficiency in characterization activities

- Greater consistency in data evaluation and decisions involving environmental restoration

- Improved ability to verify results

- More cost-effective remediation and restoration programs for ensuring protection of human health and the environment.

The Site-wide approach to the characterization and use of soil and groundwater background at the Hanford Site is viable and feasible, and is a technically preferable alternative to the WMU-based approach of background characterization for environmental restoration purposes.

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APPENDICES

CONTENTS

APPENDIX A VADOSE ZONE BACKGROUND CONCEPTUAL MODEL . . . . . APP A-i

APPENDIX B EVALUATION AND STATISTICAL METHODS . . . . . APP B-i

APPENDIX C GROUNDWATER BACKGROUND CONCEPTUAL MODEL . . . . . APP C-i

APPENDIX D PLANNED ACTIVITIES . . . . . APP D-i

APPENDIX E SOIL BACKGROUND COST SAVINGS ESTIMATE . . . . . APP E-i

APPENDIX A

VADOSE ZONE BACKGROUND CONCEPTUAL MODEL

APPENDIX A

VADOSE ZONE BACKGROUND CONCEPTUAL MODEL

A1.0 INTRODUCTION

Recent efforts to provide an improved technical basis for characterizing and understanding soil and/or sediment background at the Hanford Site have resulted in the development of a Hanford Site model for the compositional makeup of the vadose zone and controls on compositional variation. This model has been developed by Hanford Site geoscientists, who individually have studied the geology of the Hanford Site and vicinity for as along as 30 years. The development of this model is based on the geological and geochemical characteristics of the vadose zone sediments and experience of the scientific staff.

It is emphasized that the regulatory use of the terms soil and sediment is different from the geologic or soils science usage. The regulatory usage of the term 'soil' refers to essentially any material other than water or air (e.g., Ecology 1991b), and the term 'sediment' is reserved for the material at the bottom of an open body of water, such as a pond or an estuary. Thus, use of the term 'soil' in this report refers to both the unconsolidated rock material (sediments), and materials that support the growth of land plants and biologic activity (soils), except where a distinction is made. It is noted, however, that the vadose zone on the Hanford Site consists primarily of sediments in the geologic sense and should not be confused with soil as used in a soils science context. Soil as a medium for the growth of land plants is largely restricted to the upper few inches of the vadose zone over most of the Hanford Site. This material is considered together with other subordinate components of the vadose zone in Section 3.0.

The conceptual model for soil background is based on the common and relatively unique origin of the majority of the vadose zone sediments on the Hanford Site. This common origin has resulted in specific similarities in the physical and chemical makeup of sediments across the Hanford site. The basis of the model is the following.

- Only the fine-grained fractions of the vadose zone material are analyzed in the determination of soil composition.

- There are fundamental and predictable genetic and compositional relationships among the compositions of the fine-grained fractions comprising the sediments.

- Most of the vadose zone veneer is derived from the fine-grained fraction of these sediments.

The following sections provide a general overview of the Hanford Site geology and geochemistry and identify those specific concepts that have been incorporated into the vadose zone background conceptual model.

A2.0 HANFORD SITE VADOSE ZONE

The vadose zone of the Hanford Site (i.e., that portion of the sedimentary sequence above the regional water table) is the uppermost part of the sedimentary sequence shown in Figure A-1. This sequence consists primarily of mixtures of gravel, sand, and silt that range in thickness from zero to 800 feet, which accumulated in the Pasco Basin of south central Washington over the past 5 million years (DOE 1988). These sediments overlie the 17 to 6 million year old lavas of the Columbia River Basalt Group (McKee et al. 1977, pp. 464-464; Tolan et al., 1989), which are up to 3 miles thick (Orange and Berkman 1985; DOE 1988; Tolan et al. 1989). The suprabasalt sedimentary sequence consist of two main units, the Ringold Formation and the Hanford formation (Brown 1959, p. 6; Routson and Fecht 1979, p. 10; Tallman et al. 1981, pp 1-2; Bjornstad 1984, 1985; DOE 1988, pp. 1.2-115). The basal Ringold Formation consists of moderately consolidated fluvial-lacustrine sediments, and is the principle member for the unconfined aquifers at the Hanford Site. This unit is overlain by younger proglacial flood deposits of the Hanford formation, which constitutes a majority of the volume of the vadose zone. The Hanford formation is locally overlain by eolian dune, loess deposits, and alluvial deposits largely derived from the reworking of the Hanford formation, which blankets much of the east-central Pasco Basin (DOE 1988).

The Hanford formation is locally interbedded with fluvial deposits from the Columbia, Snake, and Yakima Rivers, and alluvial fan deposits flanking the Pasco Basin highlands. Other subordinate components of the vadose zone include volcanic ash, caliche horizons, clastic dikes, and thin root zone horizons in the uppermost soil. Each of these components is discussed in the following sections.

A3.0 HANFORD FORMATION

The most important unit for characterizing background in the vadose zone is the Hanford formation because it constitutes a majority of the Hanford Site vadose zone and is the dominant source of the eolian deposits. The Hanford formation is a sequence of unconsolidated Pleistocene flood deposits that comprise the upper 50 to 300 feet of the vadose zone throughout most of the Hanford Site. These sediments occur at or near the surface, and extend downward to the regional water table except in places where the Ringold Formation is above the water table. Although there is no formalized stratigraphy for the Hanford formation, a preliminary working model developed by the operating contractor staff has proven to be useful in the development of the conceptual model. In general, four subdivisions tentatively have been recognized based on the isotopic age dating (Mullineaux 1986; Srana-Wojcicki et al, 1987 and on the basis of paleomagnetics (unpublished data).

A3.1 ORIGIN

The Hanford formation is a relatively unique sequence of sediments. Its unusual origin is associated with the cataclysmic flooding that occurred between about 6,000 to 1 million years before present (Millineaux et al. 1978; Waitt 1980). These floods were the result of the periodic failure and breaching of ice dams associated with marginal lakes of the continental ice sheet (Bretz 1928, 1969; Atwater 1984; Waitt 1984, 1985). One such ice dam was ancient Lake Missoula, which was located in the vicinity of the Idaho Panhandle northeast of Spokane, Washington (Figure A-2). The breaching of these ice dams allowed the rapid discharge of vast quantities of water that spread across eastern Washington and down the Columbia River to the Pacific Ocean. These cataclysmic floods shaped the landscape of eastern Washington into a rare geographic province known as the channeled scablands (Figure A-2). The material mobilized and eroded by the flood waters subsequently settled out of the flood waters to form the upper sedimentary sequence that blankets much of the Columbia Plateau (e.g., Easterbrook 1979; Waitt 1984, 1985, 1987). Most of what is now the Hanford Site was the site of primary flood channels (Brown 1959; Tallman et al. 1979, pp. 39-49; Routson and Fecht 1979, pp. 20-21; Bjornstad 1984, 1984) (Figure A-3). Those sediments deposited in the Pasco Basin are referred to as the Hanford formation.

A3.2 PHYSICAL CHARACTER AND SPATIAL DISTRIBUTION OF SEDIMENTS

The Hanford formation consists of a sequence of unconsolidated sedimentary deposits ranging in size from boulder gravels to silt and clay (Figures A-4 and A-5). The proportions of these two components vary vertically and laterally throughout the formation, and primarily reflect the local energy regimes of the flood waters at various places and times within the episodes of cataclysmic flooding (Tallman et al. 1979, pp. 39-49; Routson and Fecht 1979, pp. 20-21; Bjornstad 1984, 1984; Waitt 1987). The finer grained sediments were deposited under conditions of slow-moving or slack water during periods of waning floods, at channel margins, and in the distal areas of flooding (Figure A-4). The coarser, denser, and hydraulically less-mobile gravel and basaltic sand were deposited primarily under conditions of faster flow within the primary flood channels and in the early stages of flooding (Figure A-5). Most places within the path of these floods experienced a range of flow conditions that changed rapidly with time, especially areas within the main flood channels. Because much of the Hanford Site is located in those primary flood channels, a succession of alternating and discontinuous layers of very high-energy, coarse-grained gravel deposits to low-energy silt deposits make up the Hanford formation. These relationships are responsible for the lateral and vertical distribution of the fine- and coarse-grained varieties of sediments throughout the Hanford Site (Figures A-4a and A-5b).

A3.3 COMPOSITIONAL IMPLICATIONS

Although the silt, sand, and gravel deposits in the Hanford formation have a common origin, the deposits appear strikingly different in outcrop

(Figures A-4 and A-5). The finer grained components in all these sediments are composed of differing proportions of quartz and feldspar rich sediment and basaltic-rich sediment. The quartz-feldspar rich silt and sand is the dominant fine-grained constituent of the slack water deposits, and the basaltic sand is the dominant fine- to medium-grained component in the higher energy sediments. Thus, the primary difference in physical composition between the smaller particles in the coarse- and fine-grained sediment fractions is in the proportions of basaltic sand and quartz-feldspar-rich sediment. It is evident from field investigations that there is a nearly complete gradation from pure quartz-feldspar to pure basaltic sand in the finer grained components within these flood deposits. Thus, the bulk compositions of the finer grained fraction of these sediments are expected to have compositions that reflect the variable proportions of these constituents. These factors dominate the leachate composition of the soils, as discussed in Appendix C. The compositions of these soils should, therefore, be representable by a mixing line or a curve between quartz-feldspar and basaltic component compositions. The compositions of these samples, should, therefore, constitute a single statistical distribution for each analyte.

A4.0 EOLIAN DEPOSITS

The younger eolian deposits that locally veneer the Hanford formation are windblown deposits derived largely from erosion and winnowing of the unconsolidated Hanford formation (DOE 1988). These deposits are manifest as dunes (Figure A-6a) and/or a sediment veneer (loess) (Figure A-6b) deposited mainly by west-southwesterly winds. The composition of these sediments represent physically fractionated subsets of the Hanford formation. The typically light colored loess and dunes that are dominant on the southern part of the Hanford Site are composed primarily of the remobilized quartz-feldspar rich sand and silt from the slack-water type material. Conversely, the darker colored loess and dunes, which occur on the northern part of the Hanford Site, have a larger component of basaltic sand material. Some of these eolian sediments are the products of two or more episodes of remobilization and eolian fractionation from the Hanford formation and its counterparts in adjacent areas. Consequently, the composition of the eolian cover on the Hanford Site should be chemically indistinguishable from the composition of the Hanford formation.

A5.0 WEATHERING

Both physical and chemical weathering contribute to the breakdown of the sediments in the vadose zone. The importance of chemical weathering in the characterization of soil background depends on the extent to which the composition of the material in the vadose zone is influenced by this process (Leopold et al. 1964, pp. 40-46). Chemical weathering primarily involves reactions between water, air, and rock material. These reactions include hydrolysis, oxidation, and/or the precipitation of calcium carbonate and salts

(Fairbridge 1972). The effects of chemical weathering on soil composition are most important only under certain conditions such as in wet climates or in rocks or soils that have reacted with water for sufficiently long periods. Weathering and soil formation in semiarid zones, however, is generally more mechanical than chemical or organic (Fairbridge 1972).

The Hanford Site is a semiarid region that receives about 6 to 8 inches (15.2 to 20.3 centimeters) of rainfall annually, most of which returns to the atmosphere by evapotranspiration. Soil moisture profiles (Last et al. 1976; Jones 1978) show that soil moisture generally is less than about 5 percent throughout most of the vadose zone, and that moisture is significantly less in the upper 10 to 20 feet (3.05 to 6.1 meters) during the summer months. Consequently, there is only a sparse development of soils over most of the Hanford Site and these soils support plant growth (DOE 1988) that is largely restricted to the upper few inches of the vadose zone.

The influences of chemical weathering and attendant organic processes on the chemistry of the semiarid soils in the Pasco Basin are expected to be minor and subordinate to physical weathering and fractionation processes. These relationships are reflected by the relatively unaltered nature of the mineral constituents in the sediments of the vadose zone, and the sparse development of soils that support plant growth. It also is notable that even where these are developed, primary soils in semiarid regions tend to reflect the composition of the underlying material without much change by leaching or chemical alteration (Fairbridge 1972, p. 548).

The chemistry of most vadose zone sediments is, therefore, expected to be controlled by the distribution and modal proportions of minerals and rock materials in the sediments. This control results from the primary depositional mechanisms and secondary eolian processes. The main exceptions are the subordinate materials in the vadose zone as identified in Section A6.0.

A6.0 SUBORDINATE MEMBERS

The composition of volumetrically subordinate members within the vadose zone includes the recent Columbia River fluvial deposits, volcanic ashes, clastic dikes, soils supporting plant and biologic activity, as well as caliche and salt deposits (e.g., Rickard 1964; DOE 1988). These materials have compositions that differ from those of the majority of sediments in the vadose zone. Thus, one or more of these members could inadvertently be included in a vadose zone soil background and/or WMU sample. Such samples might appear as compositional and statistical outliers. By recognizing that minor, though possibly distinct members exist, the technical basis for evaluating outlier data is improved.

The compositions of most of these members are reasonably well constrained. Caliche, for example, is primarily $CaCO_3$ with small amounts of Sr in solid solution with the Ca. Volcanic ashes deposited during the eruptions of Cascade volcanoes are primarily dacitic to rhyolitic

compositions, and each of these have different trace element characteristics. In most cases, clastic dikes are fluidized fine- to medium-grained sediment from the Hanford formation. The influences of plants and other biologic activities also can cause the composition of some soils to differ from that of the parent sediments.

The composition of the recent Columbia River fluvial deposits may or may not be consistent with the population of Hanford Site soil background compositions. These sediments are not necessarily related to the Hanford formation sediments because they were deposited in a different manner and are younger. The sediments also may have been modified by the effects of weathering. It is possible, however, that these sediments could be indistinguishable from the array of Hanford Site soils.

The precipitation of salts occurs under certain conditions that can, over long periods, produce an appreciable in situ salt content in the upper few feet of the vadose zone. There is one locality in Cold Creek Valley (Appendix C, Figure C-2) where alkali soils have developed naturally over the past 6,000 years in certain places in Cold Creek Valley (Appendix C, Figure F-2), and West Lake Basin. The soils in these localities preclude most vegetation with the exception of those plants that can tolerate high salt environments (Rickard 1964).

These various types of subordinate members of the vadose zone are included in the soil background model and data evaluation process for completeness, and also to provide a basis for identifying natural compositional outliers. All of these subordinate components are visually distinguishable from the Hanford formation, and thus can be avoided during field sampling, where appropriate, to reduce the impact of outlier data. Extreme compositions associated with these subordinate parts of the vadose zone are to be regarded as separate subsets of natural background, and considered separately from the primary vadose zone soil population.

A7.0 SUMMARY

The essential points of the vadose zone background conceptual model described are the following.

- The Hanford formation is a mixture of quartz-feldspar and basaltic silts and sands plus larger fractions of both types of materials.
- The proportion of quartz-feldspar sands and silts to basaltic sands is the primary factor governing the composition of an individual field sample.
- The occurrence of volumetrically minor components must be accounted for in the interpretation of statistical outliers.

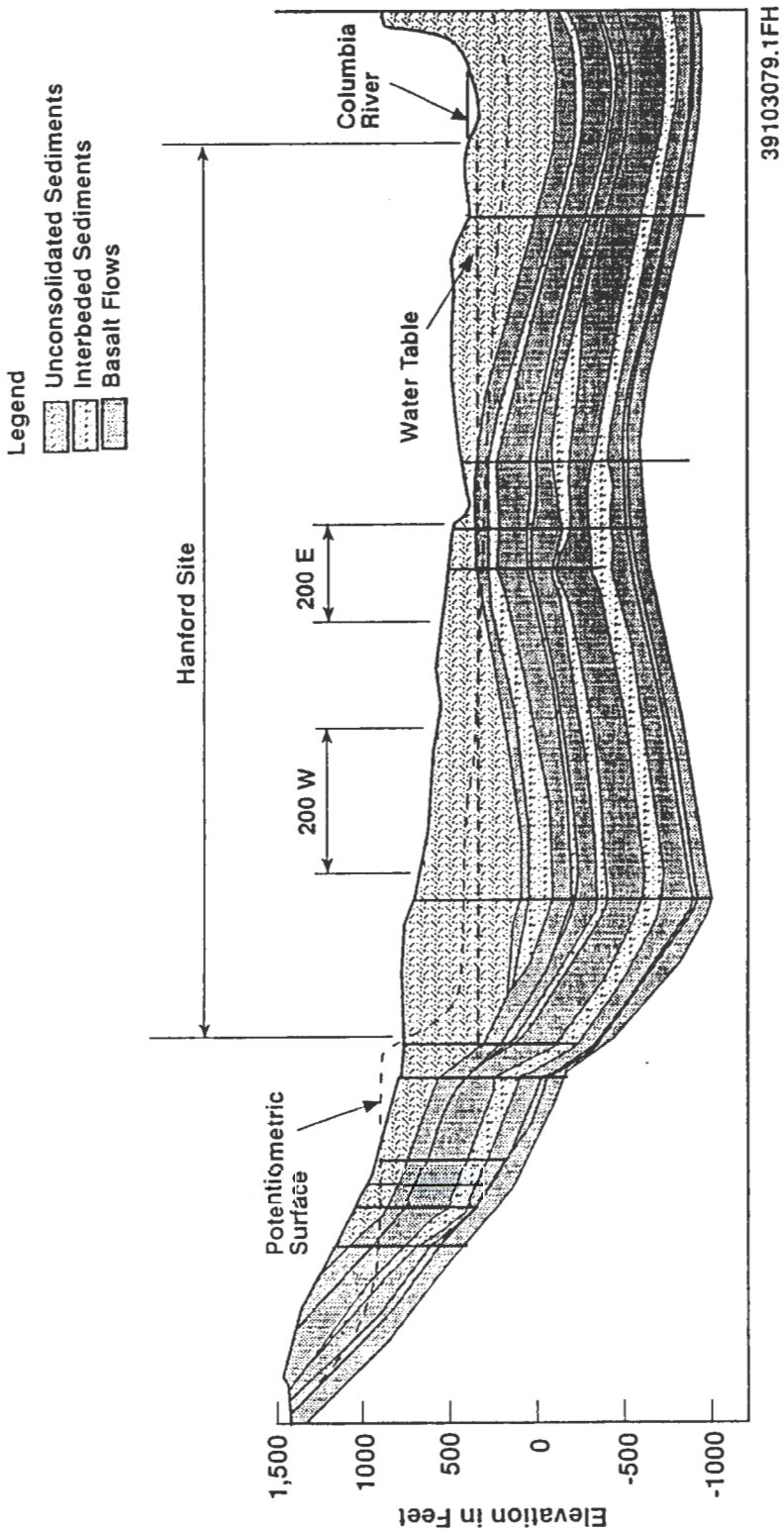


Figure A-1. Schematic Geologic Cross Section Across the Western Pasco Basin (shows the stratigraphic relationships between the Hanford formation, Ringold Formation, and Columbia River Basalts, and also shows the type and lateral extent of variation within the Hanford formation. Vertical exaggeration 52X).

Figure A-2. Physiographic Map of the Washington Area Near the Close of the Ice Age (shows the extent of the Cordilleran Ice Sheet, the site of ice dam failure in Idaho, the general path of cataclysmic flooding and the channeled scablands province in central Washington).

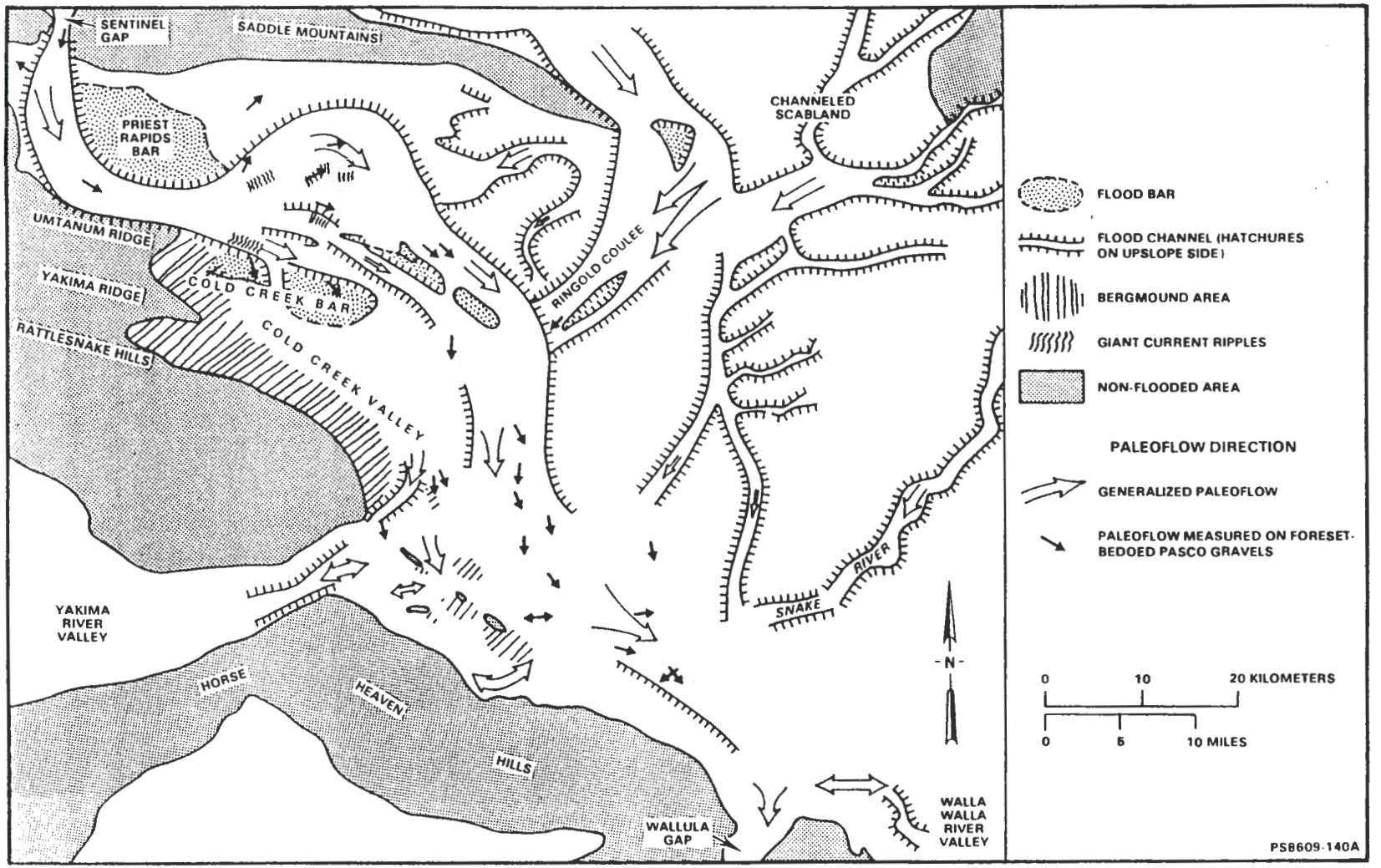
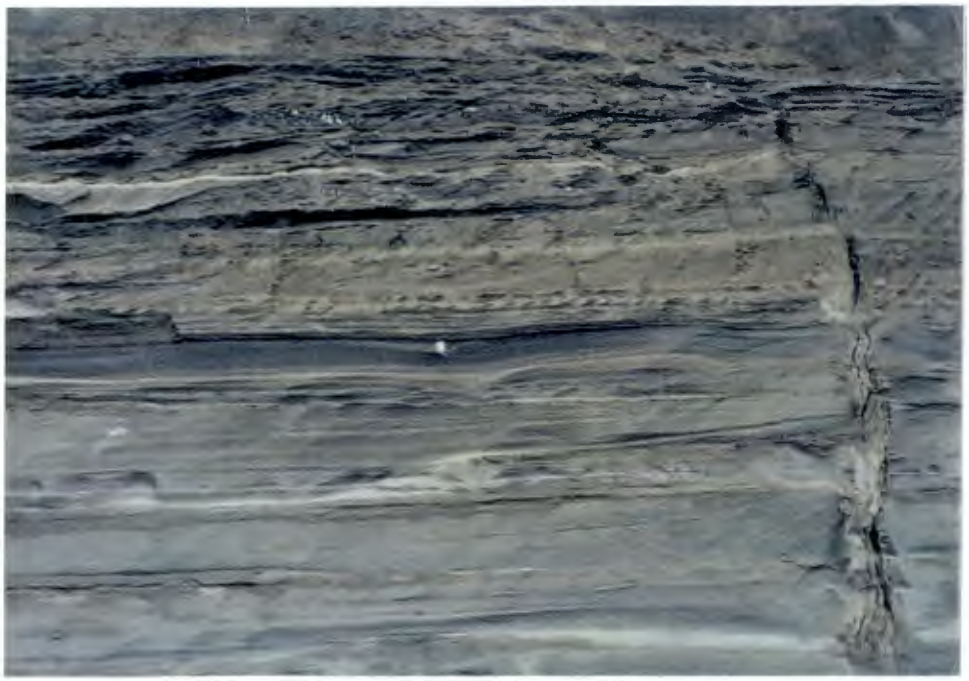


Figure A-3. Generalized Flow Paths of Cataclysmic Ice Age Floods.

(a) The sequence of Hanford formation sediments in this outcrop represent channel gravels deposited in one flood episode (lower gravel unit) overlain by finer grained sediments subsequently deposited from slower moving water. Also, note the intercalation of coarse- and fine-grained layers in the uppermost part of the outcrop, indicative of a rapidly changing depositional environment.



(b) A thick sequence of fine-grained Hanford formation exposed in the U.S. Ecology pit on the Hanford Site represents slackwater bar deposits that occur in the 200 Areas, formed from slowly moving flood waters. Also, note the vertical clastic dike cross-cutting the horizontally layered sediments.

Figure A-4. Fine-grained Sediments and Vertical Variability of the Hanford formation.

(a) Size-graded sequence of gravels ranging from cobble to sand. Ruler is shown for scale.

(b) Dark colored, medium-grained Hanford formation deposits rich in basaltic sand with an interbed of fine-grained slackwater sand rich in quartz and feldspar.

Figure A-5. Coarse-Grained Hanford formation Gravels in Outcrop.

(a) Eolian dunes that veneer parts of the Hanford Site. Note that most of these sands are light-colored (rich in quartz and feldspar). Deflation has locally generated a thin veneer of darker basaltic sand.

(b) Loess deposits that locally veneer the Hanford Site, overlying coarse-grained sediments of the Hanford formation.

Figure A-6. Eolian Deposits on the Hanford Site.

APPENDIX B

EVALUATION AND STATISTICAL METHODS

APPENDIX B

EVALUATION AND STATISTICAL METHODS

B1.0 INTRODUCTION

Statistical and non-statistical methods are used in evaluating the feasibility of the Site-wide background approach and in obtaining background concentration levels for use in identifying contamination and assessing risk. The evaluation of background data begins with the data collection efforts. The development of data quality objectives (DQOs) in these efforts are designed to ensure that the sample population is representative for the intended purposes. The DQOs also are designed to ensure that the appropriate statistical methods are used in the evaluation of the data (EPA 1987b). The conceptual models such as those developed here for soil and groundwater background also are integral components of the DQO development process, providing a basis for construction of sample populations and data interpretations in the data evaluation process (Figure B-1). Special knowledge or potentially mitigating factors that affect the interpretation of the data also must be included in the analysis process.

It is important that statistical methods not override scientific and technical criteria regarding systematic compositional relationships intrinsic to the medium or the compositional distribution, or which may be associated with the analytical processes themselves. The preferred approach for background characterization efforts is to use the conceptual models to guide the statistical interpretation of analytical results. One of the most important aspects of these models is the identification of factors that control the intrinsic and measured composition of soil and groundwater. These factors include the following:

- Mineral composition constraints on soil and groundwater composition
- The effects of the methods of chemical analysis on soil composition
- The implications of naturally buffered groundwater compositions
- The effects of natural difference in composition spatially
- Fractionation processes (e.g., sorption, natural sedimentary processes, and sampling).

Identification of these factors and an understanding of their effects on composition provide insight regarding the evaluation of the compositional data and statistical distributions. For example, the behavior of several of the natural processes identified previously are logarithmic or exponential in nature (e.g., fractionation). This type of insight is a fundamental element of the conceptual model for justifying expected correlations in the composition of materials related by their origin or other natural processes.

Yet, these factors generally are omitted from statistical evaluations in waste management activities.

The data evaluation process also requires decisions regarding the type of comparisons to be made, the type of statistics to be used, and how background threshold levels are to be determined. A background threshold level is an upper limit of the concentration range for the medium (e.g., soil, groundwater, etc.) below which concentrations are considered to be indistinguishable from those in the background population (Section 3.2). These are analogous, and in some cases, equivalent to tolerance interval levels. In general, the manner in which threshold levels are established depends on the statistical method used and the extent to which other pertinent criteria are considered in the evaluation process. The key aspects of the evaluation process for soil background data, in the context of the conceptual model, are summarized in the following sections.

B1.1 ANALYTICAL FACTORS IN SOIL COMPOSITION

The Hanford Site sediments have been analyzed by a variety of methods. The two most common types of chemical compositions are bulk compositions and leachate compositions. Bulk compositions refer to the total composition of a sample. Leachate compositions, which are prescribed by the regulatory agencies (e.g., EPA 1986; EPA 1989d), are partial compositions resulting from partial dissolution, usually in acid. Most data obtained on the chemical composition of geologic materials before or external to environmental compliance activities have been bulk compositions. Thus, there are less data on soil compositions that have been collected from the Hanford Site using the acid leaching methods. At present, there is no basis for correlating data from one method to another for purposes of comparison.

B1.1.1 Bulk Composition

The bulk composition of soil generally is measured by nondestructive methods such as x-ray fluorescence or by the complete dissolution of samples in acid, and analysis by emission and/or absorption spectroscopy methods. These analysis processes do not involve size or chemical fractionation samples.

The bulk compositions of soil end member components, such as those identified in Section 3.1, reflect the proportions and compositions of the constituent minerals and rock in the sample. The chemical compositions of the quartz-feldspar-rich and the basalt-rich end member components of the Hanford vadose zone sediments have not yet been sampled or analyzed. However, the bulk compositions of these materials can be approximated.

The quartz-feldspar-rich sediments are primarily mixtures of quartz, feldspar, and clay minerals having compositions dominated by Si, Al, Ca, and the alkalies Na, and K, with minor Fe, Mg, Mn, and related metals (e.g., Table B-1). Conversely, the basaltic sediments primarily are mixtures of basalt grains from the Columbia River Basalt Group of the Columbia Plateau and

should have compositions that closely mimic those of the parent basalts. These basalts are typically rich in iron with somewhat lower concentrations of Si, Al, and alkalies that are the quartz-feldspar components. The compositions of quartz, some end member feldspars, a typical clay, and a range for Columbia River Basalts are provided in Table B-1 for reference and comparison.

B1.1.2 Leachate Composition

Soil compositions determined in accordance with regulatory protocols (EPA 1986; EPA 1989d) represent the leachate composition of the fine-grained fractions of a sample only, rather than bulk compositions. The process of size fractionation and partial dissolution for determining composition is used as a conservative measure of the mobile constituent concentrations in solids for the purpose of environmental activities.

It is important to recognize, however, that the grain size of the sample strongly influences the composition of the leachate. The extent to which leaching and/or reaction occurs depends on the effective surface area available for reaction. Thus, samples with identical components and identical bulk compositions but different grain sizes can have different leachate compositions. These effects and those of the physical fractionation resulting from sampling and sample preparation are not accounted for by regulatory protocol, and can seriously bias the analytical results. The variability attributable to this effect is presently not considered in the regulatory process. This factor is identified in the soil background conceptual model, however, because it is expected to be a source of at least as much variability as the precision associated with sampling and analysis. Some regulations (e.g., Ecology 1991b) have begun to incorporate requirements for controlling the grain size of soil samples. However, there is presently no information of the effects of leachate composition on grain size and surface area within a controlled range of sizes. Efforts to quantify these effects are identified in Appendix D.

B1.2 NUGGET EFFECTS

Preliminary evaluation of soil background data indicates that the soil background conceptual model also must include a provision for natural concentrations that may appear as anomalous data. There are two main types of anomalous natural background. One type is from the subordinate materials in the vadose zone identified in Appendix A, Section A6.0, e.g., volcanic ash. The other is from samples that contain a small amount of a phase or a component having a large amount of an analyte that is otherwise regarded as a minor or trace constituent. The latter type is known in the mining industry as the nugget effect (Knudsen and Kim), and implies that although a nugget of a mineral or a metal may occur naturally, it only will be found in a small percentage of samples because the overall proportion of the nugget is small.

This effect is potentially important for constituents that are major components of minerals or amorphous material (basaltic glass), which is

modally subordinate in the soil. Examples are the sulfide minerals that can contain hundreds of thousands of parts per million of constituents such as Cu, Pb, Zn, Hg, Cd, together with sulfur. However, the modal abundance of such minerals in the soils or sediment is typically less than 1 percent. Yet, a single grain of such a mineral could cause the concentration of one or more of the elements listed above to be unusually high in a small percentage of the samples collected. Using a statistical approach alone, the small percentage of samples that contain relatively large concentrations of a constituent would be perceived as outliers and would not belong to the same population as the majority of samples.

Minerals or rock constituents that occur in the Pasco Basin sediments, and that could contribute to the nugget effect include sulfide minerals (Cu, Pb, Zn, Hg, Cd, etc.) and certain heavy minerals that commonly are deposited as placers (e.g., monazite, zircon, apatite, rutile, garnet, epidote, tourmaline). These placers commonly contain large amounts of such elements as uranium, thorium, and zirconium, which all have high charge to ionic radius ratios. Other potentially important contributors to the nugget effect include the basaltic material that constitute significant proportions of some vadose zone sediments. Some of the many basalt flows from which the basaltic components were derived contain as much as 3,000 to 4,000 parts per million of barium, and other flows contain 100 to 200 parts per million of chromium (DOE 1988). Fragments of these basalts can produce an occasional data point that appears erroneous, but is, in fact, part of the natural array of compositions. The nugget effect applies to these basalt components because only a few of the many basalt flows have such extreme compositions, and the probability of such basaltic components occurring in a soil in significant amounts is small, but finite.

The difference between anomalously high concentrations in soil samples and the nugget effect can be distinguished by several methods. The first method is to review the analysis for the presence of elements that could form a candidate nugget mineral (e.g., Cu in a copper sulfide). Correlations between elements within candidate nugget minerals provides a basis for discrimination. A second method is to reanalyze a split of the same sample, or a subsequently collected replicate, for which singularly high concentrations are observed, because this effect stems from a small amount of a specific mineral. In general, a low or less-than detection limit concentration will be found in the split if the apparent anomaly is attributable to the nugget effect. Alternatively, a duplication of high concentrations indicates that the sample from that location is distinctly different from the background population. The probability of encountering two consecutive nugget effect compositions for the same type of nugget (e.g., mineral) is the square of the probability of the initial hit. For the minerals under consideration, their frequency of occurrence is on the order of 1 percent or less. Therefore, the probability of two consecutive hits is on the order of 1 in 10,000 or less.

B1.3 CORRELATION EFFECTS

Variations in soil properties tend to be correlated over space--both vertically and horizontally (Klute 1986). That is, two values taken close together tend to be more alike than two values taken further apart. This correlation is a natural result of the depositional process and is the underlying reason why local area background soil samples may not adequately represent the natural range of compositions on the Hanford Site.

The correlation range is the distance over which the data are correlated. Two data values collected at points further apart than the correlation range are uncorrelated, and meet the usual tests for independence of samples. Accounting for the lack of independence within the correlation range can be performed by two methods. The first method is to apply the methods of geostatistics. This requires extensive sampling over a range of distances and can be expensive. The second method is to estimate the correlation range from available data and ensure that samples are taken at distances greater than the estimate. The latter method allows the data to be processed using the methods of classical statistics based on independence of samples. The soil background sampling effort will use the second method.

B1.4 DATA CONSTRAINTS

The compositions of media such as soil and groundwater are non-negative data. In theory, the minimum value for a particular element may equal zero. In practice, the minimum value will be the assigned detection limit of the method. Virtually all analytical laboratories report data as either a positive real number greater than the detection limit, or as an unspecified value less than the stated detection limit (e.g., <10 ppm).

Geochemical data also are bounded at the upper end by constraints on stoichiometric and phase relationships. Encountering data at the upper bound will in effect require a sample of a pure mineral or phase, or equilibrated groundwater. The upper bound for soils will not be encountered in practice and may be ignored, because the Hanford Site soils are mixtures of many minerals. However, the upper bounds for groundwater concentrations are expected to be encountered. The sampling and analysis methods for a Site-wide groundwater background must incorporate this expectation.

B2.0 STATISTICAL METHODS

Various types of statistical methods can be used in the handling of background data and in evaluating the feasibility of the Site-wide approach to background characterization. The use of statistical methods for both purposes requires decisions concerning the type of distribution (e.g., normal, lognormal, etc.) that best describes the data. The technical basis for the use of a Site-wide approach to background characterization does not depend on

the type of distribution used to represent the data. However, many aspects of the evaluation process either depend on the distribution type or are better performed with an appropriate representation of the data, i.e., choice of distribution type.

Three of the most common criteria for choosing an appropriate distribution are the following:

- Knowledge of how the data are generated
- Prior experience with the data
- Judgement of the analyst.

An example of the first criterion is the data generated by a summation of random variables that converges to the normal distribution as the number of variables increase. Lognormal data are generated by multiplication of random variables. Distributions determined to be appropriate for one data type also can provide a basis for handling similar types of data. The third criterion usually involves a trial-and-error approach to the selection of the distribution that best represents the data. The best representation of the data is the primary basis for deciding which distribution is used.

The EPA guidance (EPA 1989b) typically describes a simple decision process involving normal and lognormal distributions for the data. If neither distribution is determined to adequately represent the data, either a nonparametric approach is used, and/or advice from a professional statistician is recommended.

Once a statistical distribution is chosen various statistical methods can be used to evaluate the data provided that method serves the intended purpose (e.g., EPA 1986, 1989a, 1989b; 40 CFR 264). The use of background data involves the comparison of individual sample concentrations to a background threshold. The regulatory agencies typically require this type of comparison to ensure that contamination is not disguised as non-contamination by averaging. This type of comparison (EPA 1989b) defines an upper limit beyond which a sample will be suspected to be contaminated.

B2.1 FREQUENCY DISTRIBUTIONS

A frequency distribution describes how data are distributed over the domain of possible values. There are two types of distributions, a Probability Density Function (PDF) and a Cumulative Density Function (CDF). Both PDFs and CDFs either can be discrete or continuous functions. For the purposes of limiting this discussion to the most relevant topics, only the continuous functions will be considered (Knudsen and Kim 1978).

A PDF is defined by two requirements. The first requirement is that the probability of occurrence of any datum be non-negative over the domain of the

data. The second requirement is that the sum of all the probabilities over the domain equal one. Mathematically this is expressed as:

$$\begin{aligned} &1)\quad f(x) \geq 0 \\ &2)\quad \int_{-\infty}^{+\infty} f(x)\,dx = 1 \end{aligned} \tag{1}$$

For those distributions with a limited domain (e.g., x > 0), then f(x) is defined equal to zero for all x outside that domain. A continuous PDF describes the probability that a particular datum lies between two specified values. For example, consider the uniform distribution on the interval 0 to 1. The probability of a datum occurring between .2 and .4 is:

$$\begin{aligned} &f(x) = 1, \quad 0 \leq x \leq 1 \\ &p(.2 \leq x \leq .4) = \int_{x_1}^{x_2} f(x)\,dx = \int_{.2}^{.4} 1\,dx = x\Big|_{.2}^{.4} = .4 - .2 = .2 \end{aligned} \tag{2}$$

A cumulative distribution function describes the probability that a datum is less than x and is defined by four requirements:

- The CDF lies between 0 and 1 inclusive for all x
- The CDF is non-decreasing as x increases
- The CDF is the integral of the PDF from minus infinity to the value of x
- The minimum value is zero and the maximum value is 1.0.

Expressed mathematically, these requirements are:

$$\begin{aligned} &1)\quad 0 \leq F(x) \leq 1 \quad \textit{for all } x \\ &2)\quad \frac{dF(x)}{dx} \geq 0 \\ &3)\quad F(x_0) = \int_{-\infty}^{x_0} f(x)\,dx \\ &4)\quad F(-\infty) = 0, \quad \textit{and} \quad F(\infty) = 1 \end{aligned} \tag{3}$$

When x has a limited domain, then the CDF is defined as either 0 or 1 for all x outside the specified domain as per the fourth requirement. For the uniform distribution described previously, the probability of x less than x_o is:

$$F(x) = P(x \le x_0) = \int_0^{x_0} f(x)\,dx = \int_0^{x_0} 1\,dx = x\Big|_0^{x_0} = x_0 \qquad (4)$$

Distributions typically contain constants that are adjusted to fit the distribution to the data. These parameters are used to establish the location, scale and, when necessary, the shape of the distribution. The location parameter establishes where the distribution lies along the x axis. For the normal distribution, the mean is a location parameter. The scale parameter determines the spread or width of the distribution. Again, for a normal distribution, the standard deviation is a scale parameter. The shape parameter is used for asymmetrical distributions and describes how skewed the distribution is to one side or the other of center. Whether or not a particular parameter is used in a distribution depends primarily on the mathematical form of the equation and occasionally on the degree of accuracy required by the analyst.

B2.2 WEIBULL DISTRIBUTION

The Weibull distribution is identified here as an alternative for other types of distributions because the distribution either includes or approximates all other distribution types used in environmental activities. The advantages in the use of the Weibull distribution are that it provides a more efficient way of evaluating soil and groundwater data that is actually equivalent or superior to using, e.g., normal or lognormal distributions. The use of this distribution also simplifies the laborious trial-and-error method of determining whether the data are normally or lognormally distributed, or nonparametric, for each analyte in each sample, which is required for properly evaluating the data. It also reduces the use of arbitrary assumptions regarding the distribution type. Provisions for use of alternative statistical methods, where appropriate and justifiable, also exist in the regulatory guidelines (e.g., Ecology 1991b). The following is a description of the utility of the Weibull distribution in evaluating background data.

The Weibull distribution has found considerable utility in many industries concerned with reliability issues. This application marks the first known use for environmental work at the Hanford Site. Comparisons to the more common distributions are made so that the reader can see that the Weibull distribution is a more versatile tool for data analysis.

B2.2.1 Weibull Equations

The PDF for the 2-parameter Weibull distribution is given by Nelson (1982):

$$f(x) = \left(\frac{\beta}{\eta^{\beta}}\right)x^{\beta-1}\exp\left(-\left(\frac{x}{\eta}\right)^{\beta}\right), \quad x > 0$$

$$x = \textit{data value} \tag{5}$$

$$\eta = \textit{scale parameter}$$

$$\beta = \textit{shape parameter}$$

The CDF is formed by integrating equation (1) and results in a much simpler expression:

$$F(x) = 1 - \exp\left(-\left(\frac{x}{\eta}\right)^{\beta}\right), \quad x > 0 \tag{6}$$

The domain of x is all real numbers greater than zero. The range for both the PDF and CDF are 0 to 1 inclusive. Equation 2 describes a 2-parameter Weibull distribution, so called because two constants (eta, beta) are required to completely specify the distribution. The 2-parameter Weibull distribution can be extended easily to a 3-parameter Weibull distribution by subtracting a constant value from x. This subtraction process shifts the data, allowing a better representation of the structure of the data set. This gives a 3-parameter CDF of:

$$F(x) = 1 - \exp\left(-\left(\frac{x-t_o}{\eta}\right)^{\beta}\right), \quad x > t_o \tag{7}$$

$$t_o = \textit{location parameter}$$

The parameters of the distribution can be interpreted as follows. The value of eta is the scale parameter and describes the spread of the distribution. It is the 63.2th percentile of the CDF and has the same units as x. Beta is the shape factor and serves the function of a measure of how skewed the distribution is. Beta is in fact the slope of the CDF. Both eta and beta are restricted to real values greater than zero. The value of t_o is not restricted. When a non-zero t_o value is used, the value of eta and beta applies to the shifted data. Recovery of predicted data from the shifted

distribution requires the addition of t_o to any data values determined from the 3-parameter distribution.

B2.2.2 Comparison to Other Forms

The Weibull distribution is a suitable replacement for several distributions. The most direct replacement is achieved by setting the value of beta to 1. This reduces the CDF directly to the exponential form:

$$f(x) = \frac{1}{\eta} e^{\left(-\frac{x-t_o}{\eta}\right)}, \quad x > t_o \tag{8}$$

For beta in the neighborhood of 3-4, the Weibull distribution also provides an excellent approximation to the normal distribution. Figure B-2 is a plot of normally distributed data fitted by the Weibull distribution. The R^2 value of .997 indicates an excellent fit to the data. The number of sample points (500) is very high for this type of comparison (i.e. high power of test).

The Weibull distribution provides an acceptable alternate to the lognormal distribution. This point is demonstrated in Figure B-3. The 500 data points were sampled from a lognormal distribution and fitted with a Weibull distribution. The R^2 value of 0.985 indicates a very good approximation; however, there is an evident lack of fit at the upper end of the distribution. There the data drifts out of the confidence bands towards the high side. This indicates that the threshold values determined from the Weibull distribution are conservative with respect to the lognormal distribution. For this data, the Weibull distribution gives a value of 623 for the 95/95 double-sided threshold versus 828 for the lognormal distribution (Figure B-4). Obviously, the Weibull distribution yields a more conservative value.

B2.3 THRESHOLD CALCULATIONS AND SAMPLE PLOTS

Two examples of the use of the CDF in the evaluation of data populations and the determination of background threshold values are shown in Figure B-5. Note that these examples are similar to the CDF examples identified by the EPA (EPA 1989b) and are not distribution specific. Therefore, the evaluation methods identified here can be used with any appropriate distribution method. A Weibull distribution has been used in the construction of the CDF in these examples.

The CDF for soil background data from the Hanford Site is shown in Figure B-5 with double-side confidence limits. It is indicated from this plot that: (1) there are no outliers as all the data points fall inside the confidence bands, (2) there are no irregular features to the data (i.e. trends above or below the best fit line or skews about the line), and (3) the

correlation is acceptable (e.g., $r^2 > .90$). Once the data have been inspected in this fashion, a single upper confidence interval is applied and the predicted threshold value determined (Figure B-6).

These evaluations have been performed on the basis of the CDF of the data. The Weibull distribution has been used to generate the CDF. Figure B-7a shows the result for aluminum. The data show a definite nonlinear trend, beginning below the regression line, passing above, then dipping below the line again. This type of nonlinearity can be removed by shifting the data, subtracting a constant, optimum amount (t_o) from all of the data points. Figure B-7b shows the result of this shifting. The amount subtracted is shown in the upper left of the plot. The improvement in the representation of the data is immediately obvious. This can be confirmed by comparing the coefficient of variation in the two figures, .87 for the raw data versus .99 for the shifted data. The interpretation of the value of t_o is discussed in Section B2.3.3.

Once a good representation of the data has been developed, the data can be examined. Figure B-8a shows the data with double-sided 95 percent confidence intervals applied to the best fit line. The confidence interval establishes the boundary within which the data are expected to fall. In this instance, the width of the boundary is such that 95 percent of all data is expected to fall within the confidence interval. Data at the upper end of the distribution that is outside of the confidence band are suspected outliers. Outlier data can be examined individually.

When the data set has been examined for good representation, and outlier data treated, the background threshold level can be calculated. The *Model Toxics Control Act Cleanup Regulations* specify that threshold levels will use the 95/95 level. This means that the upper 95th percent confidence band at the 95th percentile level of the data is the threshold level. Figure B-8b shows a single sided confidence interval. Threshold can be determined graphically by starting at the 95 percent level on the vertical axis, moving horizontally to intersect the confidence band, then dropping to the horizontal axis and reading the data value (12,550 parts per million). This value is the threshold level of the shifted data. To recover the unshifted value, the amount of the shift (3,518) is added to the value read from the plot. The final value determined for aluminum is 16,069 parts per million, shown on the second title line of Figure B-8b. The results of preliminary evaluations of available data are presented in Table 3-1 in Section 3.4. Additional plots for zinc, manganese, arsenic, and iron are included in Figures B-9 and B-10.

Additional steps are required in the evaluation where the coefficient of variation is unusually low (e.g., $r^2<0.90$) or the data are clearly not contained within the confidence bands. Alternate distribution forms (e.g., a lognormal fit) can be tested to determine whether another distribution type better describes the data set; data points outside the confidence bands can be further evaluated or the data can be examined in the context of multiple distributions.

B2.3.1 Truncated Data

Data sets having one or more values that are at or below the limits of detection require some special handling. The inclusion of less-than detection limit values are problematic because these are real data that should be included in the evaluation. However, the assignment of a common value to all less-than detection limit data affects the analysis procedure.

Data that represents less than detection limit results are assigned a common value, usually the claimed detection limit. When the data are included in a probability plot, the data appear as a vertical line at the bottom end of the curve, as in Figure B-11a. The vertical line results from each value being assigned a different percentile rank, yet having a common data value. The plotted data are obviously no longer linear, so that the standard linear regression method must be modified. Data values that are less than detection limit are retained for the purposes of establishing the correct rankings of the higher valued data. However, only the highest ranked detection limit datum is included in the regression analysis, as in Figure B-11b. The term 'inspection fit' is applied to this modification of the regression procedure.

When the claimed detection limit is lower than the real detection limit achieved by the laboratory, plots such as Figure B-12 result. In these cases, reevaluation of the laboratory quality control data is required to establish the correct detection limit. This method for screening data results has led to several instances of reevaluation of laboratory performance, adjustment of the detection limits, and also resampling the WMU.

B2.3.2 Example Data and Comparisons

Table B-2 describes the results of a series of comparisons for several species. The data have been collected according to EPA protocols (EPA 1986) in support of WMU closure activities. The distributions compared are the 2-parameter Weibull, 3-parameter Weibull, and lognormal distributions. The coefficient of variation for each attempted fit is shown, as is the number of samples used in the comparison.

As can be seen in Table B-2, the Weibull distribution consistently gives a better fit than the lognormal. In all cases, the number of data points is sufficient to give a reasonable power of discrimination.

B2.3.3 Interpretations of t_o

In reliability analysis, a positive value for t_o is an indication of a minimum service life for a part. A negative value for t_o is interpreted as a an indication of a limited shelf life (i.e. a failure before being put into service). When these concepts are applied to the Hanford Site soil data, slightly different interpretations result.

Positive t-shifts imply that there is a minimum amount of the material present in all samples taken. This can happen only if a constituent is common

to both end members of the Hanford formation and the constituent is present in significant amounts. The minimum concentration in either end member becomes the expected value of the t-shift.

A zero t-shift (2-parameter distribution) implies that the element is either absent in one end member or present only in trace or modally subordinate amounts. There is no guaranteed minimum amount present in all samples.

Negative t-shifts mathematically are allowed. However, a physical interpretation has not yet been developed. With this in mind, negative t-shifts have not been used in the analysis of the soil data for the Hanford Site.

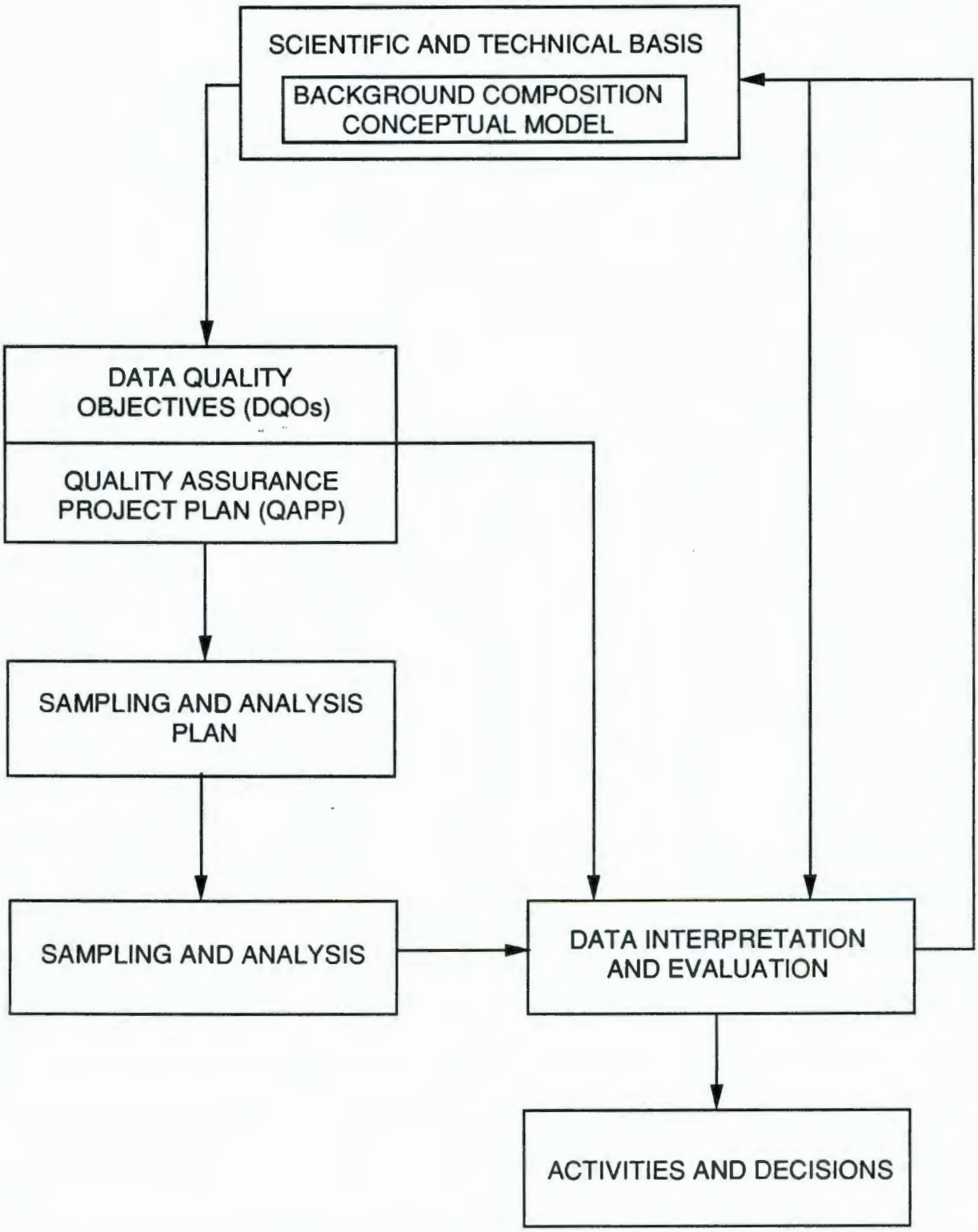


Figure B-1. Role of Scientific and Technical Basis and Background Conceptual Model on Characterization and Evaluation of Background.

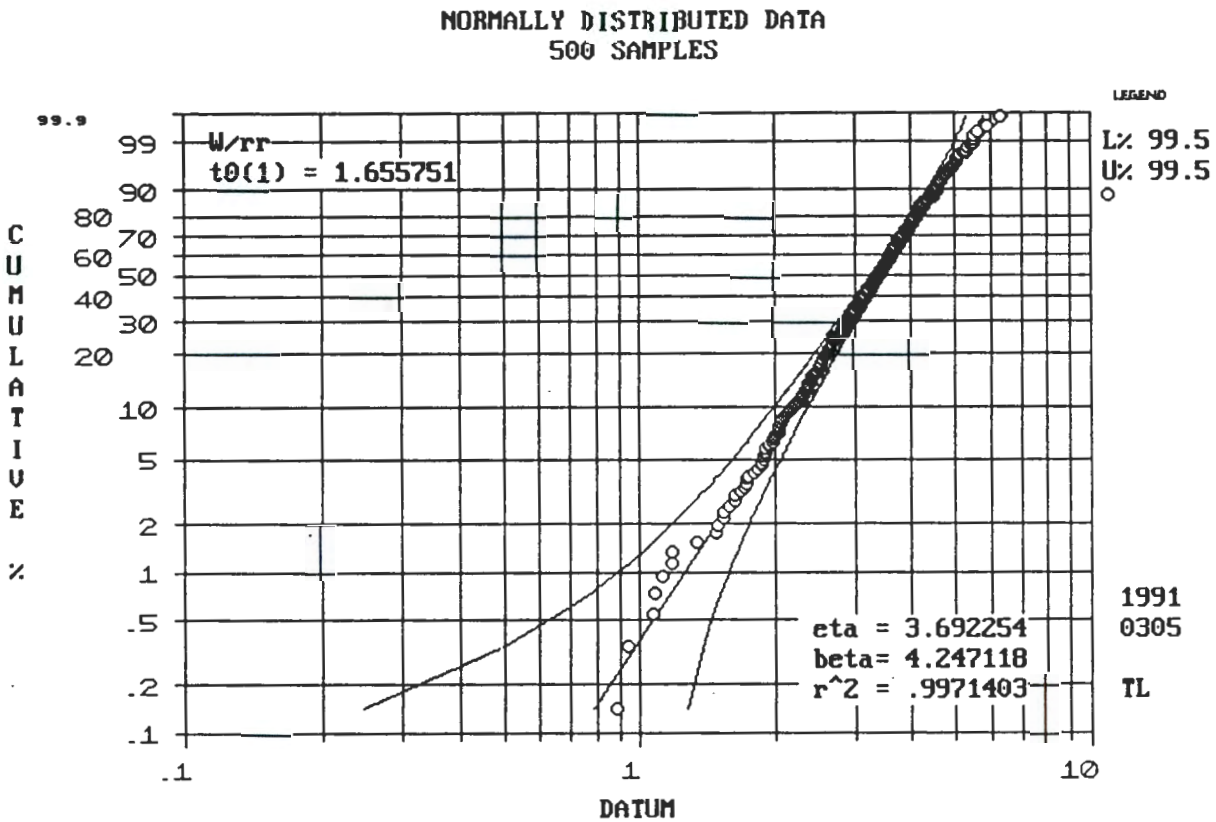


Figure B-2. Normally Distributed Data Fitted by Weibull Distribution.

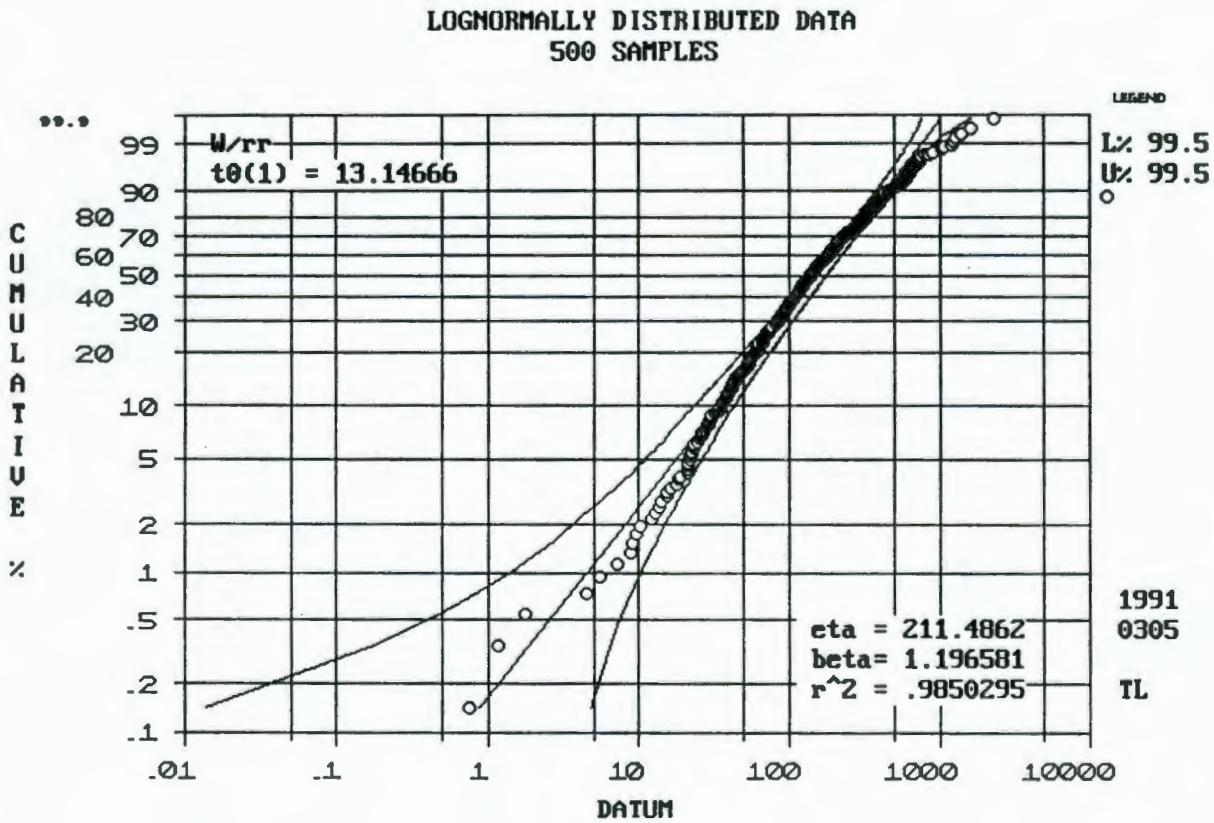


Figure B-3. Lognormally Distributed Data Fitted by Weibull Distribution.

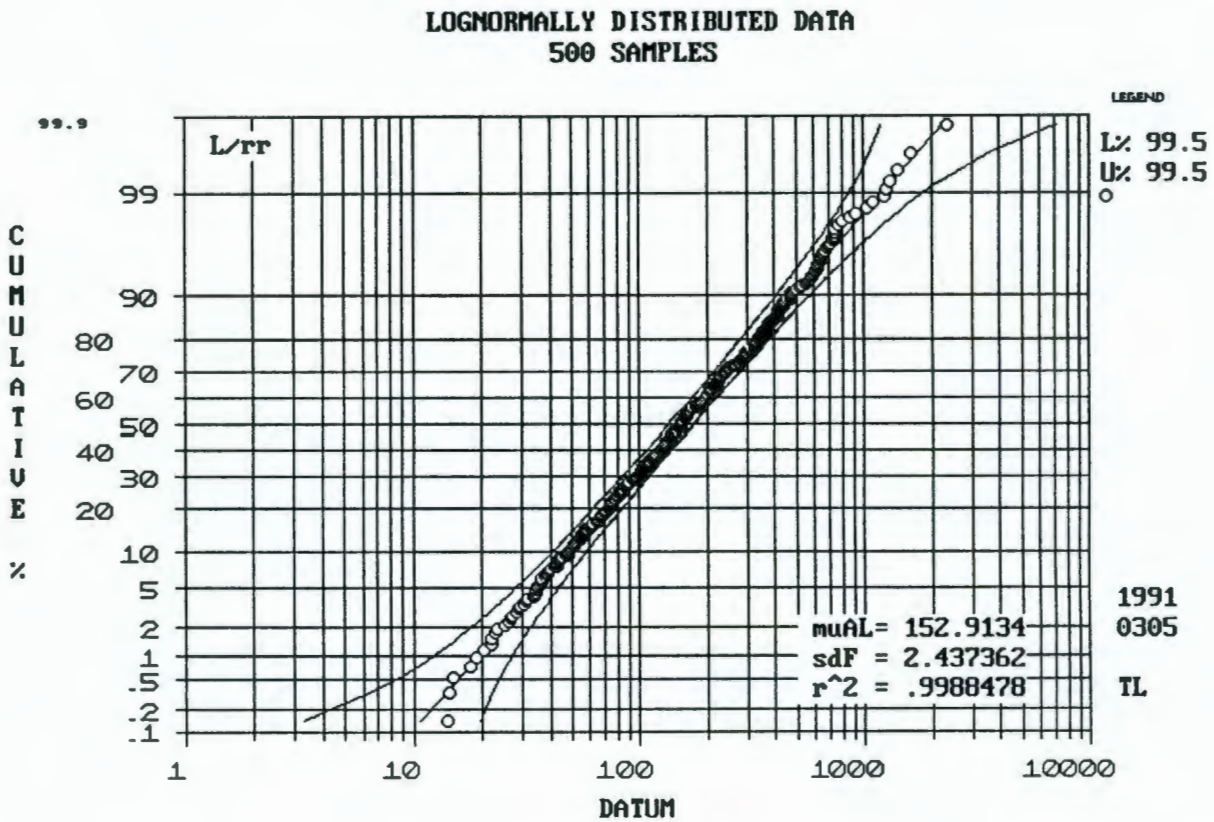


Figure B-4. Lognormally Distributed Data Fitted by Lognormal Distribution.

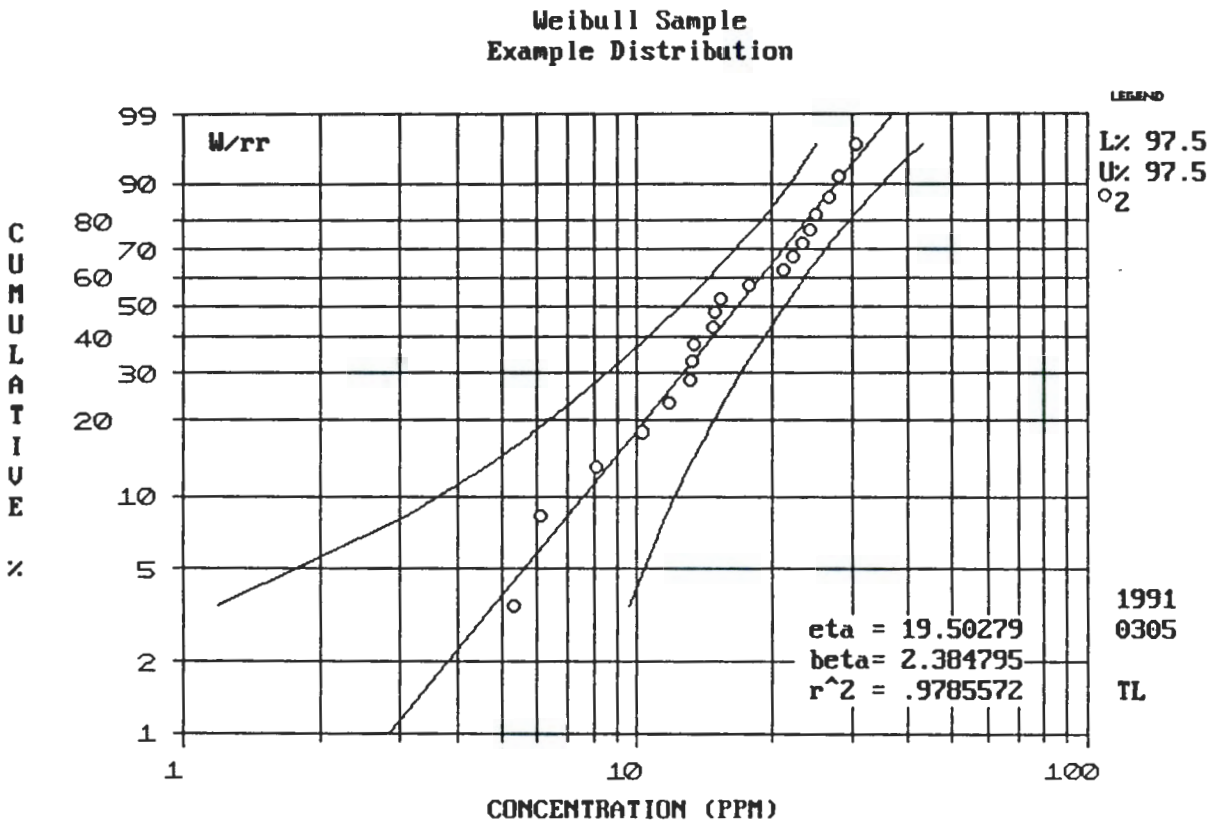


Figure B-5. Example of Data: 2-Sided Confidence Limits.

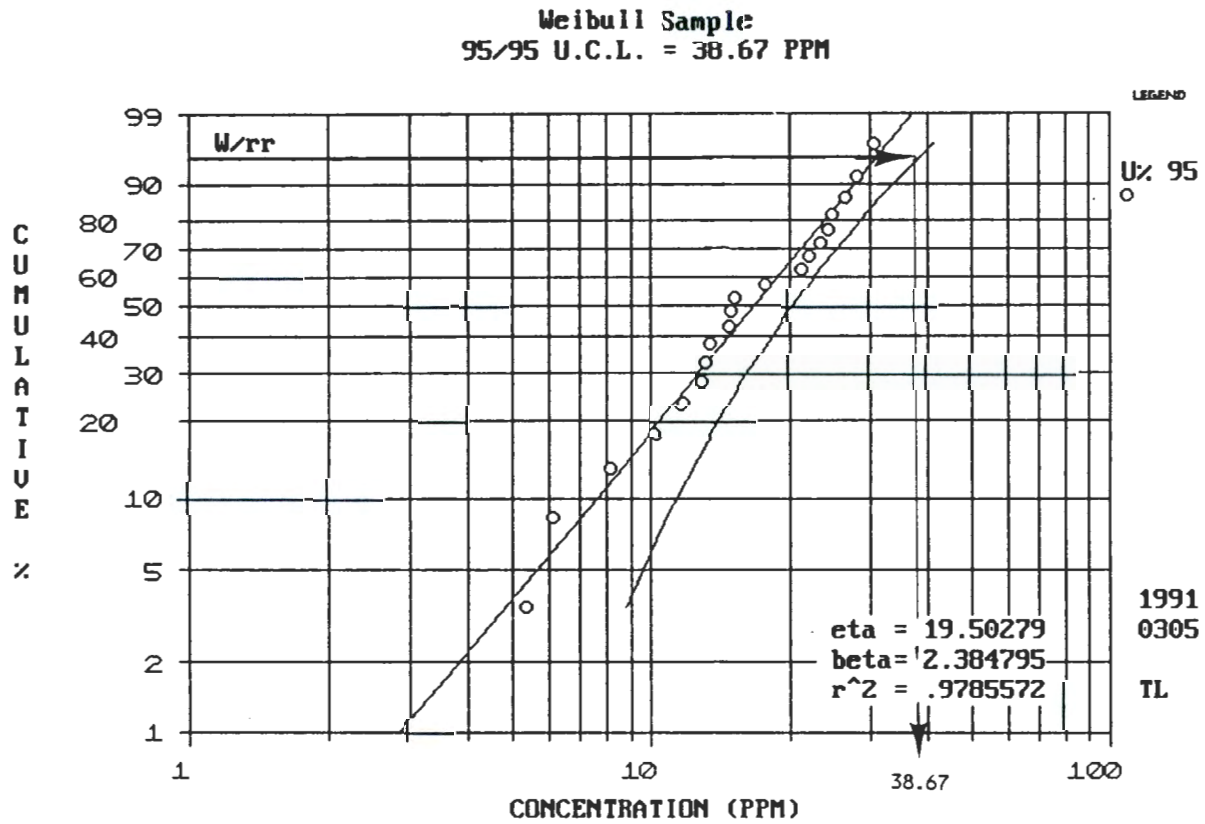
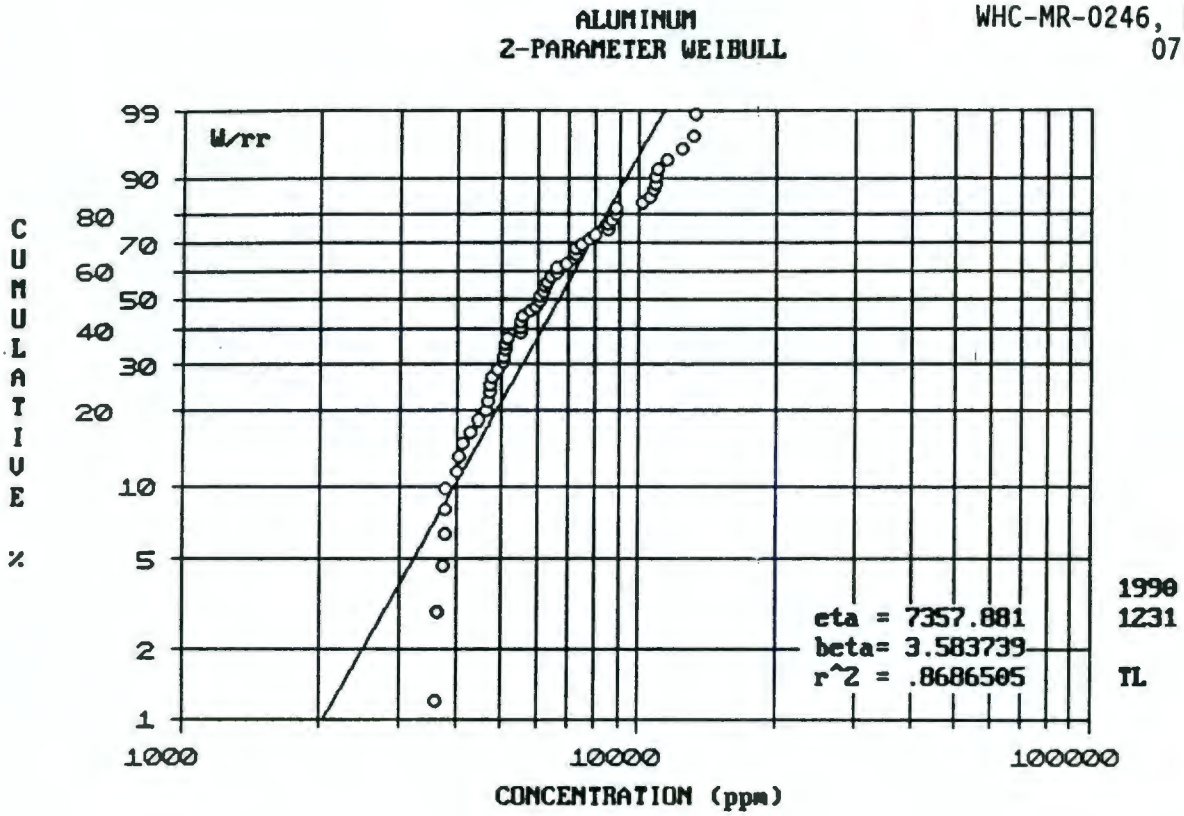


Figure B-6. Example of Data: Threshold Calculation.



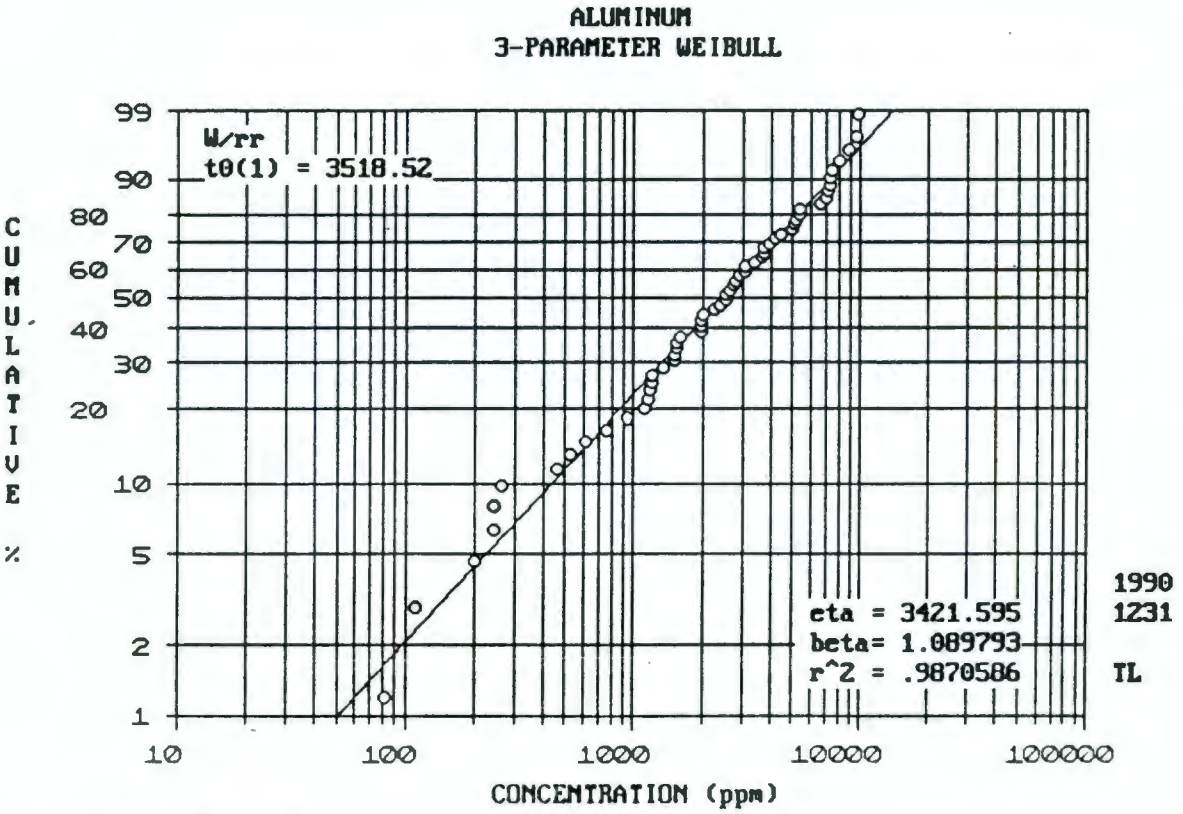
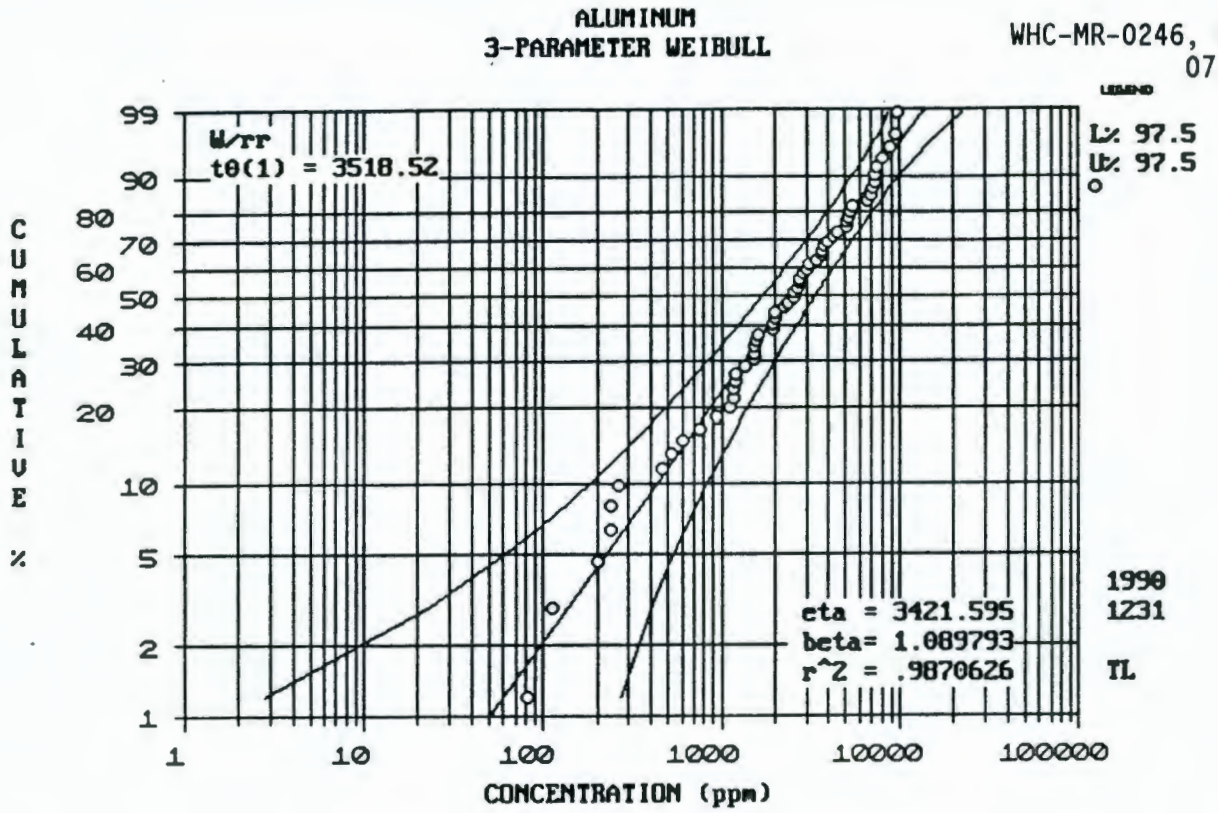


Figure B-7. Cumulative Distribution Plots of Aluminum Concentrations in Site-wide Soil Background.



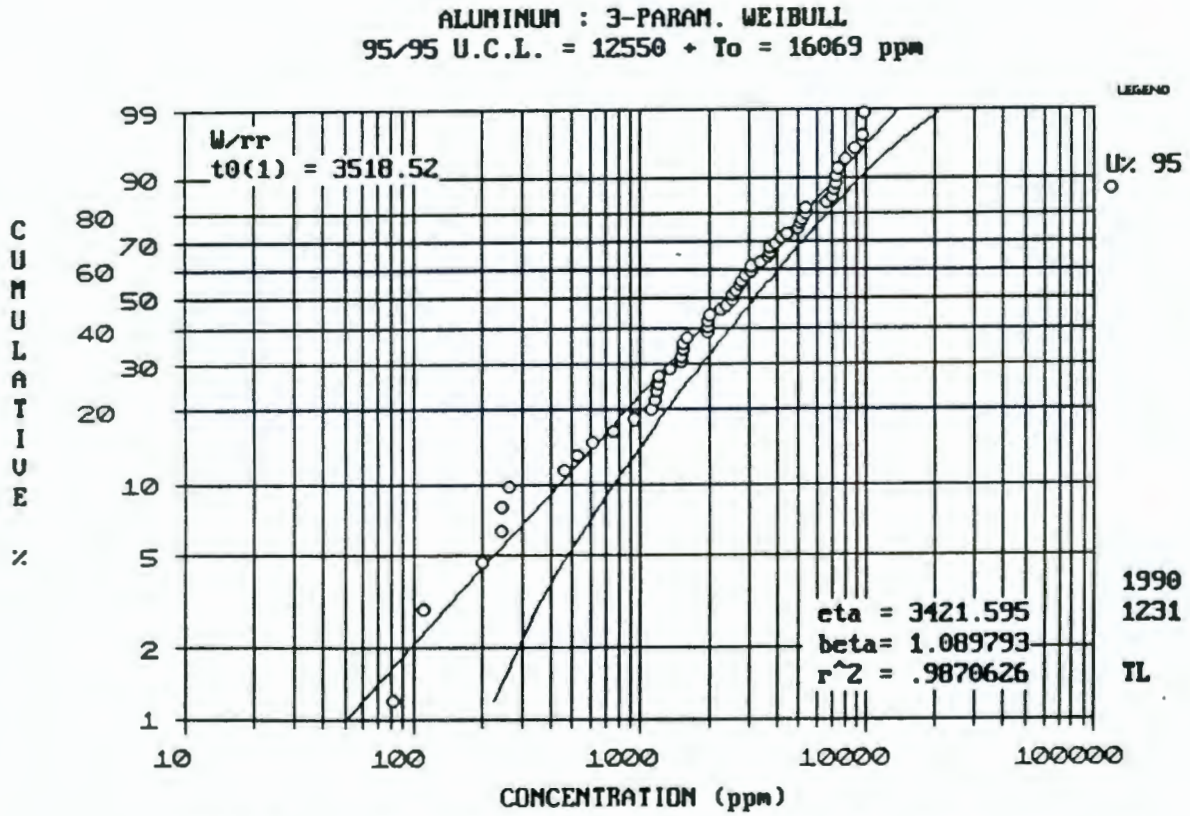
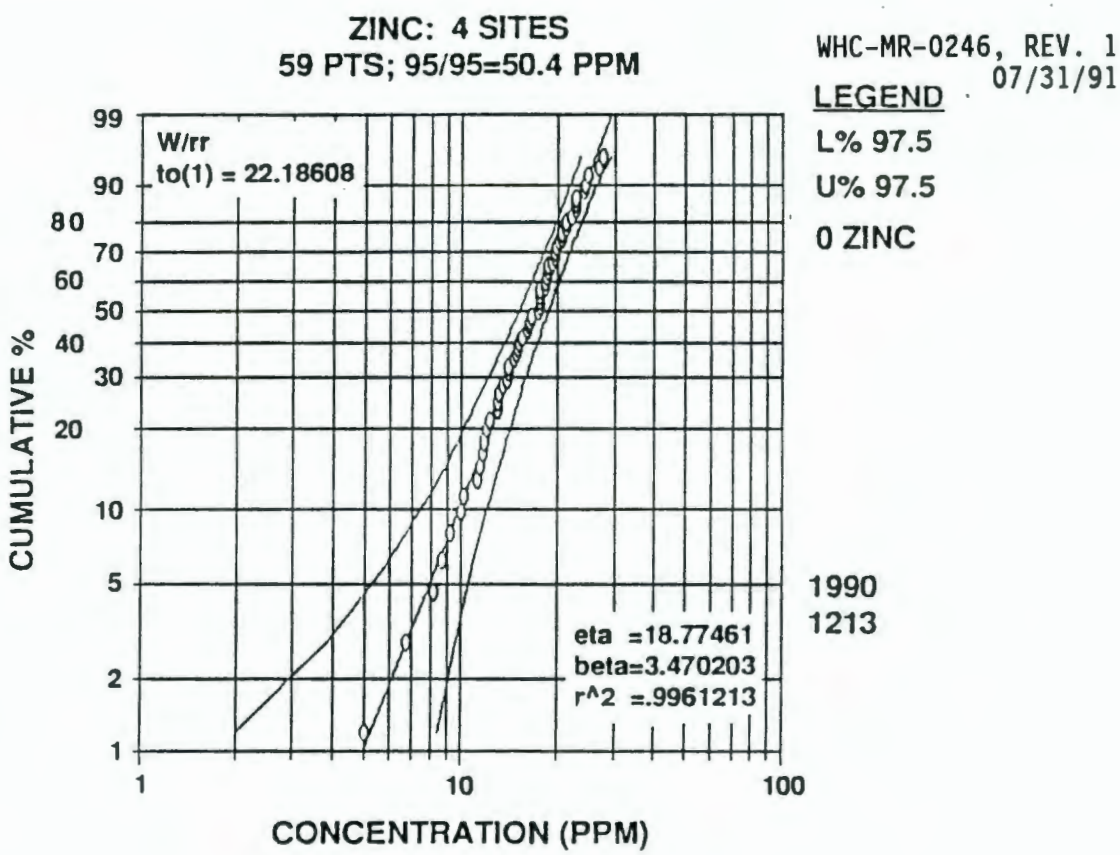


Figure B-8. Cumulative Distribution Plots of Aluminum Concentrations in Site-wide Soil Background.



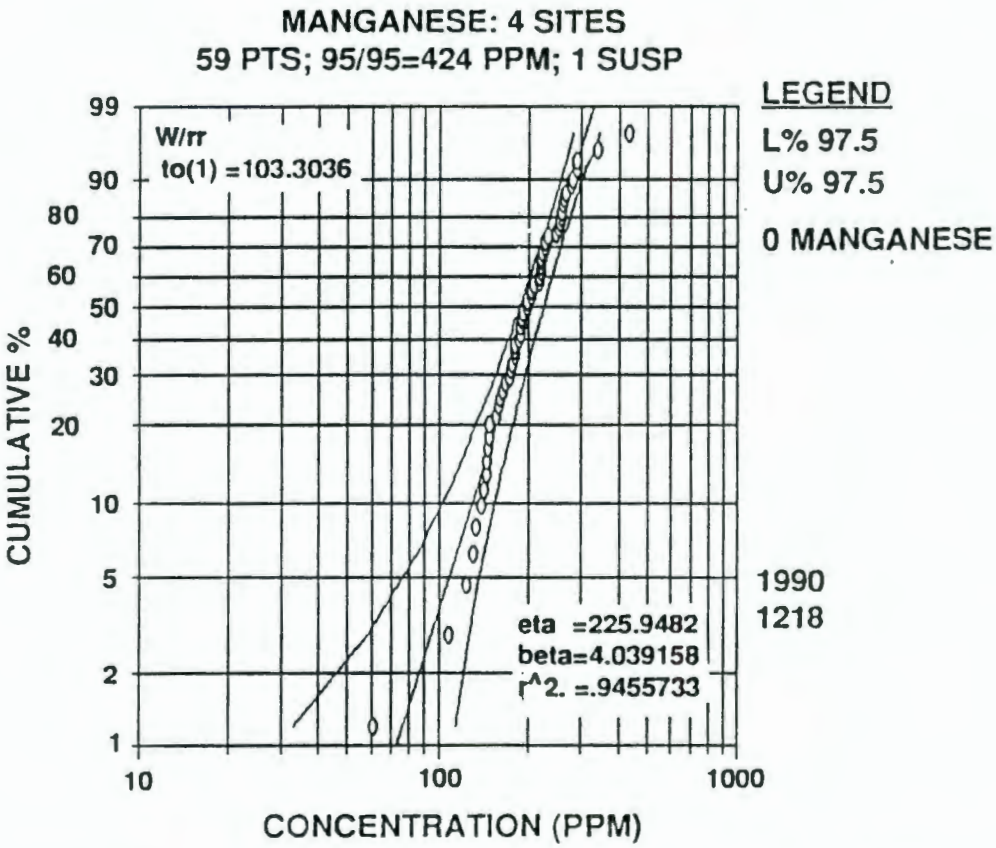
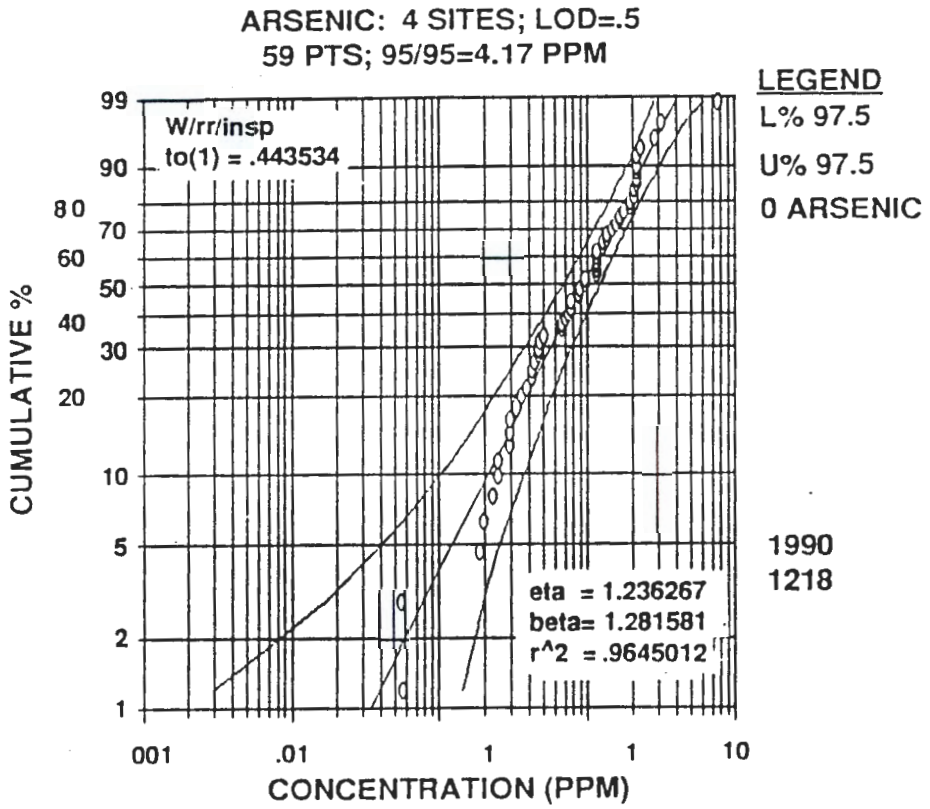


Figure B-9. Cumulative Distribution Plots of Zinc and Manganese Concentrations in Site-wide Soil Background.



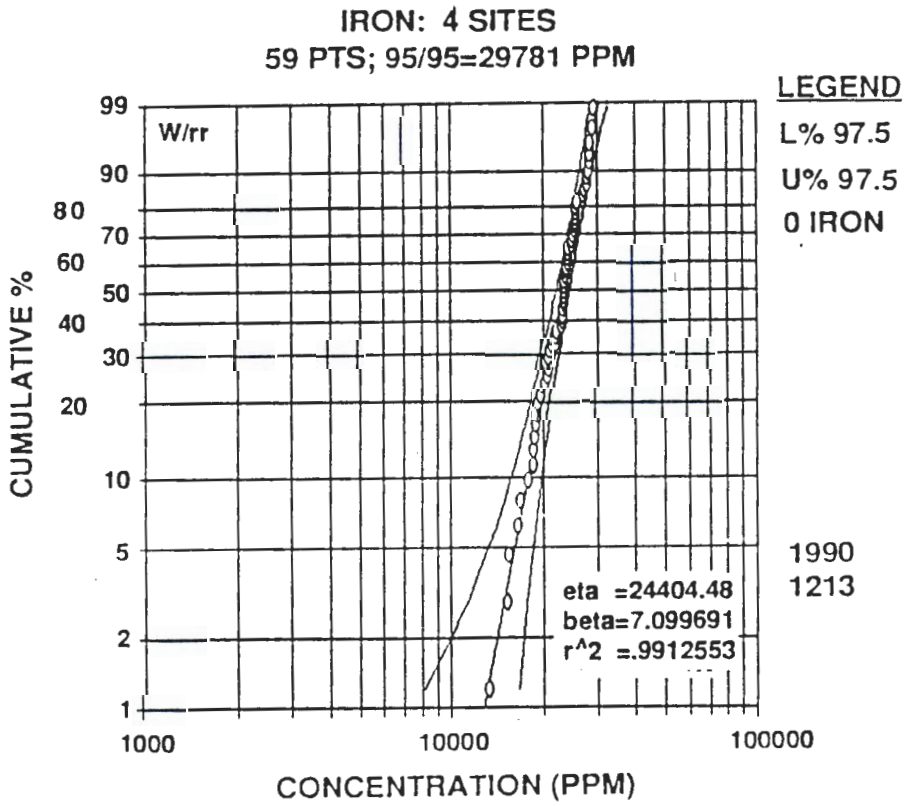
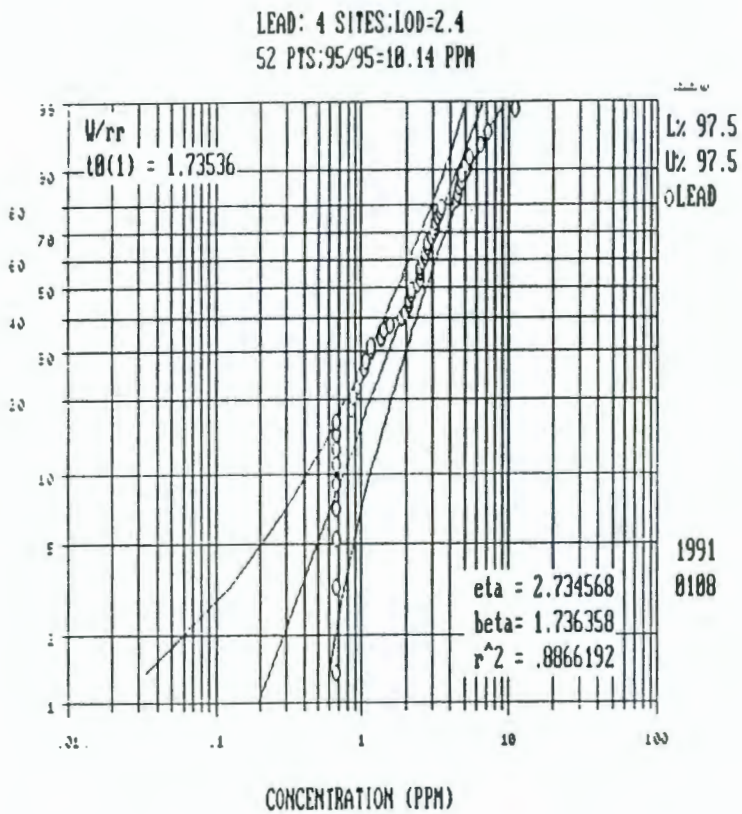
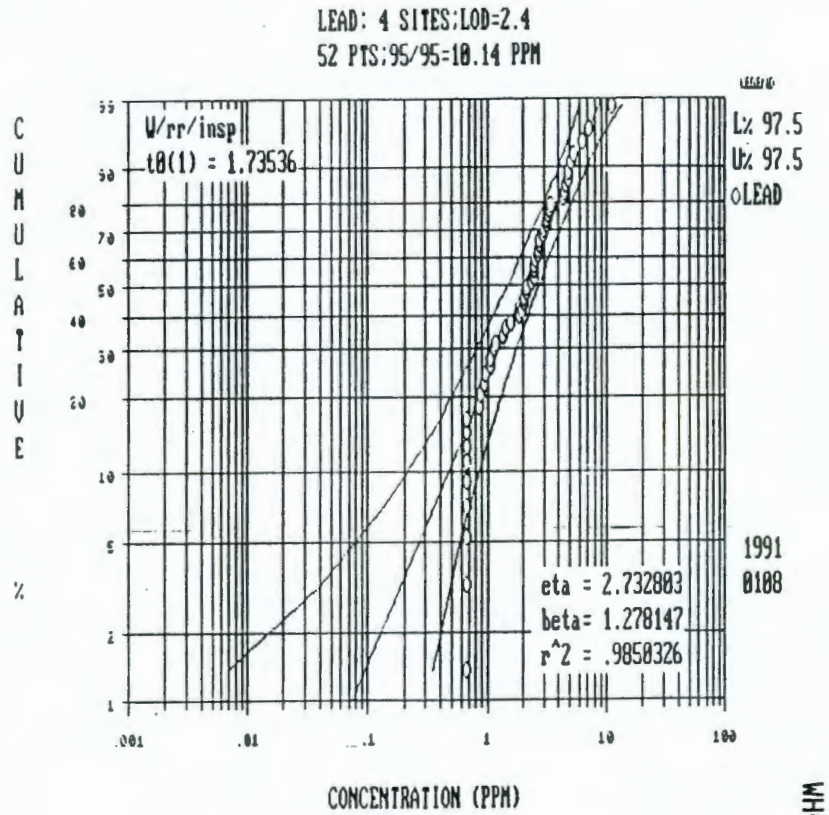


Figure B-10. Cumulative Distribution Plots of Arsenic and Iron Concentrations in Site-wide Soil Background.



Illustrates the effect of less-than-detection limit (<DL) data.



Illustrates the effect of appropriately evaluating the less-than-detection limit (<DL) data.

Figure B-11. Cumulative Distribution Plots of Lead Concentrations in Site-wide Soil Background.

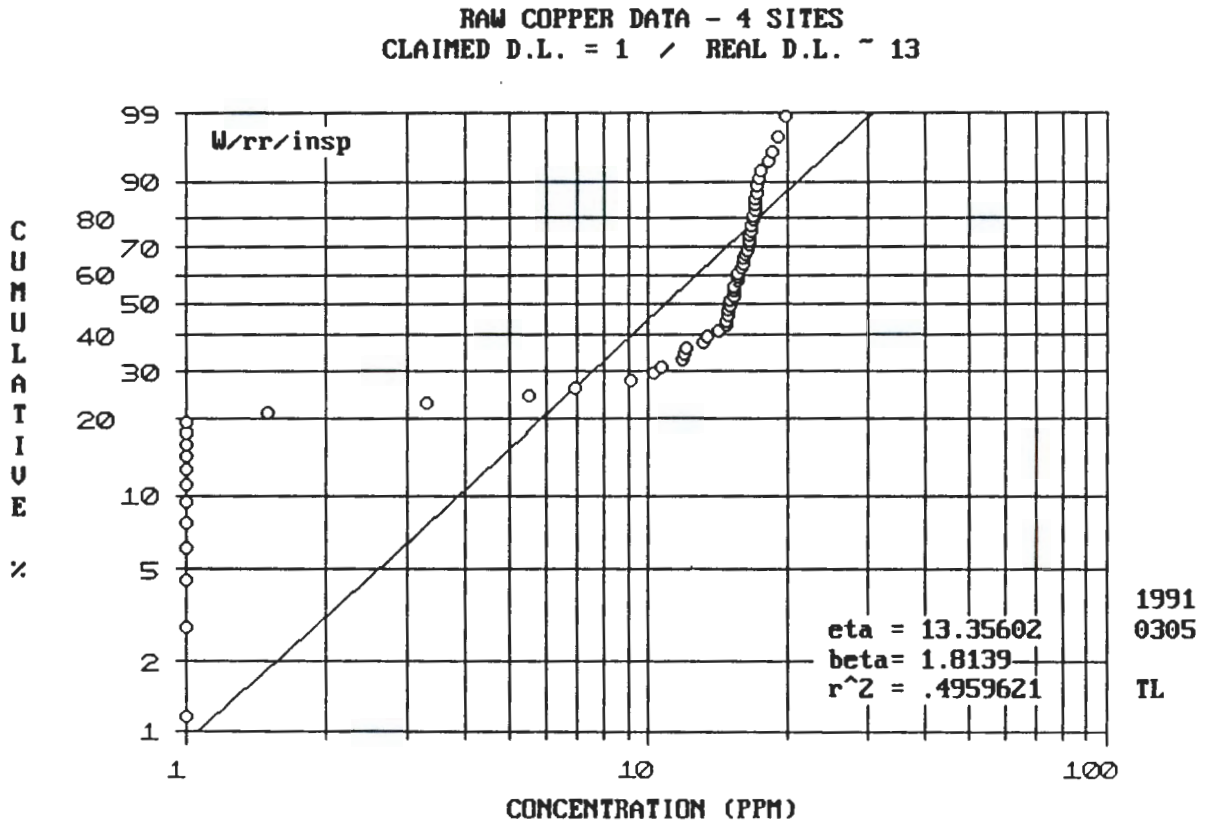


Figure B-12. Raw Plot of Copper Including the 2101-M Pond Data.

Table B-1. Compositional Range of Key Mineral and Rock Constituents in the Hanford Site Vadose Zone.

Constituent	Quartz[1] wt.% (E+04 ppm)	Feldspars[1] wt.% (E+04 ppm)			Pyroxenes[1] wt.% (E+04 ppm)			Basalt[2] wt.% (E+04 ppm)			Glass[2] (in basalt) wt.% (E+04 ppm)			Smectite clay[3] wt.% (E+04 ppm)		
SiO2	100	43.19	-	68.74	59.85	-	45.54	50	-	57	30	-	73	32	-	55
TiO2	-	0		0.08	0		1	0.6	-	3.9	0.6	-	6.4	0.06	-	10
Al2O3	-	18.32	-	36.65	0	-	2	12.8	-	16.5	0.8	-	12	3.1	-	11.4
FeO		0		2.6	0		54.45	10	-	16.6	2	-	47	6.8	-	30
MnO	-	-		-	0		3	0.1	-	0.4	0	-	0.7	0	-	0.64
MgO	-	0		0.15	0		40.15	1.5	-	6.4	0	-	0.8	3.2	-	13.2
CaO	-	0	-	20.16	0	-	25.9	6.2	-	10.5	0.7	-	10	0.6	-	4.5
Na2O	-	0	-	11.82	0	-	0.07	1.1	-	3.8	0	-	2.7	0	-	2.3
K2O	-	0	-	16.92				0.2	-	3.1	0	-	5.7	0.2	-	5

		Feldspars[1] ppm	Pyroxenes[1] ppm	Basalt[3] ppm	Glass[4] (in basalt) ppm	
P2O5	-			2,000 to 4,000	3,200	
SO2	-				600	
U	-			up to 2.5	up to 1.4	
Th				up to 9.2		
Pb	-				up to 12	
Ba	-	up to 15,600		up to 4,000	up to 622	
Zn	-				up to 107	
Cu	-				up to 130	
Ni	-		up to 400		up to 20	
Cr	-		up to 800	up to 200	up to 45	
V	-				up to 475	

[1] Deer et al. 1972
[2] Hoover and Murphy 1989
[3] DOE 1988
[4] Lambert et al. 1989

Table B-2. R^2 Versus Distribution Comparison.

Species	2-Param Weibull	3-Param Weibull	Lognormal	Best fit	ETA BETA t_o	Total samples
Zinc	.972	.996	.963	3-param Weibull	18.8 3.47 22.2	59
Barium	.793	.981	.915	3-param Weibull	34.5 1.09 43.4	59
Copper	.923	---*	.798	2-param Weibull	16.5 6.14 ---	44
Lead	.960	.985	.971	3-param Weibull	2.73 1.28 1.73	52
Chromium	.967	.972	.949	3-param Weibull	8.40 1.83 1.29	59
Iron	.991	---*	.941	2-param Weibull	24400 7.10 ---	59
Arsenic	.889	.965	.962	3-param Weibull	1.24 1.28 .444	59

* The 3-parameter Weibull distribution gives an R^2 of .968 for copper and .993 for iron; however, the value of t_o is negative. Section B2.3.3 presents a discussion of negative t-shifts.

APPENDIX C

GROUNDWATER BACKGROUND CONCEPTUAL MODEL

APPENDIX C

GROUNDWATER BACKGROUND CONCEPTUAL MODEL

C1.0 INTRODUCTION

The model for understanding the known and expected range of groundwater background compositions in the unconfined aquifer at the Hanford Site is based on the principles of hydrology and geochemistry and the characteristics of the aquifer. The primary elements of this model are the following.

- Groundwater background is a range of compositions resulting from natural processes in the unconfined aquifer and underlying confined aquifers.

- Natural processes buffer and control the upper concentration limits of most constituents in groundwater.

The most important factors that potentially influence groundwater background chemistry are: (1) the sources and composition of aquifer recharge, (2) the compositional makeup of the aquifer, (3) internal and chemical controls on groundwater composition within the aquifer (e.g., interaquifer communication, flow rates), and (4) external influences on aquifer composition (e.g., artificial recharge, river water effects). The manner in which these processes are expected to influence and control groundwater composition are described in the following sections.

C2.0 AQUIFERS AND HYDROCHEMICAL FACIES

Differences are expected to exist between the compositions of groundwater from different aquifers or discrete hydrogeologic systems (Figure C-1). Distinct populations of groundwater compositions are referred to as natural background facies (e.g., Freeze and Cherry 1979). At least two hydrochemical facies have been distinguished in the unconfined aquifer on the basis of oxygen isotope characteristics alone (DOE 1988). Although incompletely characterized, there are several hydrogeologic systems beneath the Hanford Site, each with different sources of recharge or influence, and potentially different compositional ranges.

The type and composition of recharge sources are important in understanding and evaluating the chemical evolution and range of natural background compositions. Natural recharge to the unconfined aquifer on the Hanford Site is from rainfall, run-off, springs, and rivers. Natural recharge of the uppermost confined aquifer is primarily from intrabasin highland areas peripheral to the Hanford Site, e.g., Rattlesnake Ridge, Umtanum Ridge, and Yakima Ridge (Figure C-2). Groundwater flow is downgradient from natural recharge areas toward the Columbia River, where groundwater is ultimately discharged. However, the Columbia and Yakima Rivers also contribute locally

and/or seasonally to recharge of the unconfined aquifer (e.g., Newcomb et al. 1972; Graham et al. 1985; Zimmerman et al. 1986).

Artificial recharge from groundwater mounds associated with operations on the Hanford Site has been one of the most important recharge sources to the unconfined aquifer (Newcomb et al. 1972, p. 28). The perturbations of artificial recharge on the hydrologic system composition within the aquifer must, therefore, be included in the model because this source of recharge influences the flow dynamics and chemical evolution within the aquifer. These effects also must be considered in the sampling and evaluation of groundwater data when characterizing background threshold levels (DOE 1988, pp. 3.9-120).

C2.1 CHEMICAL EVOLUTION OF GROUNDWATER: CHEMICAL REACTION PATHS

The fundamental concept in the understanding and valid interpretation of groundwater data is that background composition is not uniform, but varies by an evolutionary process with finite upper limits that are controlled by chemical reactions between the groundwater, aquifer material (i.e., water and rock interactions) and gases (e.g., Freeze and Cherry 1979, pp. 237-297; Brownlow 1979, pp. 177-185; Krauskopf 1979, pp. 532-534; DOE 1988, pp. 3.9-55, 132). These reactions are responsible for such changes as the evolution of soft rain water, which is low in dissolved solids, to hard groundwater containing high concentrations of dissolved solids. This process is a natural consequence of groundwater interaction with the aquifer, which causes the chemistry of groundwater to differ from that of its recharge source(s) in systematic ways that reflect the chemical reaction path of the water and rock system (Figure C-3). The magnitude of these differences can be seen in Table C-1 in which rain water, groundwater, and river water from the Columbia Basin are compared.

The concentrations of most cations and anions in groundwater are associated with water-solid reactions that control the dissolved ion concentration. Examples of two types of chemical reactions between water and solids typically involved in the evolution of groundwater are illustrated in Figures C-4 and C-5. The concentrations of Si, Al, Ca, Na, and K in groundwater are strongly affected by the type of reaction described in Figure C-4 because feldspar is an abundant and ubiquitous mineral in most aquifers, particularly those in the Pasco Basin. Aquifers that contain Fe-bearing minerals affect the groundwater concentrations of Si, Al, Ca, Fe, Mg, and Mn by the type of reaction shown in Figure C-5.

These reactions do not occur instantaneously, but progress with time to approach equilibrium or metastable equilibrium conditions that effectively buffer the groundwater composition. The relationships shown in Figure C-6 illustrate the manner in which reaction between distilled water and several types of minerals are manifest as different reaction paths. In this figure, the concentration of dissolved silicon in the water is seen to increase with time, asymptotically approaching a constant equilibrium concentration for each type of reaction (i.e., saturation conditions). A similar pattern of evolution occurs for all inorganic constituents that are buffered by

interaction with the aquifer. In nature, groundwater composition is affected by many such reactions and may involve metastable reactions as the chemical reaction proceeds toward equilibrium. The specific types of reactions and the extent to which reactions take place depend primarily on the solids (e.g., aquifer minerals) that react with the water and the extent to which these reactions approach completion.

Equilibrium processes buffer the maximum concentration that can exist in the groundwater by solubility controls. Perturbations to the system tend to be minimized by restoration to equilibrium concentrations. These conditions and relationships exist for all constituents buffered by such reactions as long as the buffering capacity of the system is not exhausted (i.e., buffering mineral not completely dissolved). Thus, all reactions theoretically approach equilibrium concentrations either from the lower concentrations, as in the case of surface water introduced into the aquifer, or from higher concentrations, which may occur by the introduction of harder water from an adjacent aquifer or even contaminated water into the system. Unbuffered constituent concentrations increase until the system becomes saturated or oversaturated, at which point a solid phase may precipitate and subsequently buffer the concentration, except where conditions of oversaturation persist.

C2.1.1 Lateral Variations

The most common manifestation of chemical reaction path effects is the lateral variation in groundwater composition downgradient from sources of surface water recharge. In dynamic aquifers like the unconfined aquifer in the Pasco Basin, groundwater compositions are expected to vary systematically with distance from the recharge zone in the manner shown in Figure C-7. The concentration-distance relationships downgradient from areas of surface water recharge, however, are related to the characteristics of the individual hydrogeologic systems. These include recharge composition, physical characteristics of the aquifer, and flow gradients and rates. All of these determine the extent and path of water-rock reactions. A schematic representation of the manner in which the compositional evolution of groundwater varies as a function of flow rate, for example, is illustrated in Figure C-7. The natural reaction path-distance relationships for groundwater composition also can be influenced by seasonal and year-to-year effects on recharge, as implied in Figure C-7.

These effects on groundwater composition result in the lowest dissolved solids concentrations occurring closest to the recharge areas, and the highest total dissolved solids concentrations occurring in groundwater with the longest residence time in the aquifers. This is generally the groundwater that is farthest downgradient from the recharge zones and/or associated with the parts of the aquifer having low-hydraulic conductivities.

Lateral variations associated with mixing of upwelling groundwater from the confined aquifer with surface water from artificial and river recharge sources are discussed in Section C2.2.

C2.1.2 Vertical Variation

Vertical variation in groundwater chemistry of the unconfined aquifer at the Hanford Site is expected to be attributable to the following factors:

- Stratigraphic or structural influences on flow conditions and/or chemical characteristics of the aquifer
- The influences of air on the water-rock reactions in the upper parts of the unconfined aquifer
- The effects of mixing with other aquifers and surface waters.

Vertical variations in the composition of groundwater composition within large sedimentary basins characteristically are manifest as zones that correlate in a general way with lateral variations arising from travel distance and residence time (Domenico 1972). Three main zones are generally recognized:

- An upper zone characterized by active groundwater flushing, with water low in total dissolved solids and HCO_3^- as the dominant anion
- An intermediate zone with less active groundwater circulation and higher total dissolved solids, with sulfate as the normally dominant anion
- A lower zone with very sluggish groundwater flow characterized by high total dissolved solids and high Cl^-.

Significant concentration gradients also are expected to exist vertically within the unconfined aquifer resulting from the influences of air buffered reactions. Reactions between the groundwater and air at the top of the unconfined aquifer in many ways produces the reverse of the normal prograde groundwater evolution path. Groundwater in this part of the aquifer typically has concentrations of dissolved solids that are much lower than those deeper in the aquifer (except for Ca). Air buffered waters also have reduction-oxidation potential (Eh) values as high as +750 mV, whereas the Eh in confined aquifer can decrease to values less than -200 mV (DOE 1988).

The effect of air on groundwater chemistry primarily involves the influences of increased oxygen (oxidation-related reactions) and CO_2 on reactions in the system. These reactions differ significantly from those compositions deeper in the aquifer, because of the amount and source of oxygen available for reaction in the system strongly affects the concentration of total dissolved solids. Reactions that occur under reducing conditions (low oxygen fugacity) permit the concentrations of solids dissolved in the water to be much larger than those that occur under oxidizing (air buffered) conditions (Drever 1982). Water that reacts with air is buffered with respect to oxygen, and consequently is highly oxidized. Groundwater that does not react with air generally is more reducing because the groundwater is buffered internally by reaction with iron (Fe^{2+})- bearing minerals in the aquifer. This is one of the main reason why surface waters have much lower concentrations of total

dissolved solids than groundwater (Table C-1). Conversely, the iron-rich (predominantly Fe^{2+}) basalts in the confined aquifers of the Pasco Basin impose highly reducing conditions and relatively high concentrations of dissolved solids. The effects of CO_2 buffering from air are primarily to increase the concentration of HCO_3^- in the water, which increases dissolved carbonate and elevated levels of associated cations such as Ca and Sr in solution.

Both types of vertical variation in groundwater composition are expected to exist in the unconfined aquifer beneath the Hanford Site. However, the scale on which variations may be manifest in the unconfined aquifer is generally not known. This is largely due to the preponderance of shallow wells in the Hanford Site groundwater monitoring system (DOE 1989), and to the fact that dissolved oxygen content in the groundwater generally has not been included as a data quality objective in groundwater data collection efforts. The results of some Eh measurements on the confined and unconfined aquifers compiled in conjunction with the Basalt Waste Isolation Project efforts are summarized in Section C4.2.

C2.2 MIXING EFFECTS

Variations in the chemistry of the unconfined aquifer due to the effects of mixing with water from the confined aquifer, surface waters from the Columbia and Yakima Rivers, and artificial recharge also are important features of the hydrologic system model. As used here, mixing refers to the variety of interactions resulting from the diffusion across flow lines with different compositions. The most common manifestations of mixing are the existence of discrete hydrochemical regimes and/or the generation of hybrid compositions.

The interaction between the confined and unconfined aquifer at the Hanford Site results from upwelling of groundwater from the underlying confined aquifer into the unconfined aquifer (DOE 1988). The principal effect of this interaction appears to be the generation of distinct hydrochemical regimes. The implications of these regimes on the characterization of natural background for the unconfined aquifer are discussed in Section C3.0.

Where mixing occurs between waters of differing composition, local hybrid groundwater compositions can result in response to a perturbed reaction path. In most cases, mixing causes reactions such as precipitation and/or dissolution to occur, minimizing the effect of the perturbation. Individual constituent concentrations of hybrid groundwater generally are intermediate between that of the parent concentrations. The most important consequence of hybrid groundwater compositions is likely to be the complication of attempts to characterize specific reaction paths. Such complications, however, can be minimized by recognizing the possibility that hybrid compositions exist.

The effects of groundwater-surface water mixing, such as side-bank recharge from the Columbia River, create discrete hydrogeological regimes and hydrochemical facies with compositions that can vary seasonally or as rapidly as changes in river levels. This process is expected to perturb the system

locally by diluting more evolved groundwater with respect to many dissolved solids, and also by modifying the physical conditions (e.g., temperature, Eh, pH, ionic strength) and, consequently, reaction paths. On the scale of the Hanford Site, this type of interaction could be volumetrically minor and subordinate to the large chemical evolution of groundwater in the unconfined aquifer. However, these interactions dominate the local groundwater background at the reactor sites along the Columbia River.

Surface water introduced as artificial recharge from Hanford Site operations largely impacts the unconfined aquifer in the same way as the upwelling of water from the confined aquifer. The main differences in impact are that the groundwater mounds occur at the surface, have chemical compositions that more closely resemble surface (e.g., river) water than groundwater, and also may be contaminated. Thus, the primary influence of artificial recharge is to render parts of the unconfined aquifer unacceptable for the characterization of background. The potential influences of artificial recharge on the ability to determine the natural range of groundwater background composition is discussed in Section C3.0.

C2.3 SAMPLING AND ANALYTICAL CONSIDERATIONS

The processes of sampling and analysis also can influence and/or bias the composition of groundwater samples depending on the manner in which the sampling and analysis are performed. Certain sample modifications are prescribed by regulatory protocols such as filtering and acidifying samples. Although true groundwater composition is the water composition free of suspended solids, suspended particulates in groundwater samples that are not filtered out are subsequently dissolved in the acidification process. Thus, inconsistencies or errors in the filtering process alone can produce erroneous data.

The manner in which the water samples are taken (i.e., pump versus grab samples), and the type and configuration of wells the samples are taken from (e.g., screen length, construction materials, etc.), can seriously impact the composition of a groundwater sample. The effects of reacting a sample of reduced groundwater containing relatively high concentrations of dissolved solids with air in the collection of the sample can rapidly modify the true composition of the sample. The most common modification is the precipitation of amorphous solids, such as ferric hydroxide, and associated sorption of many other dissolved metals. The resulting composition of the sample essentially could be devoid of cations that actually could exist in relatively large concentrations under the reducing conditions within the aquifer. Conversely, chemical reactions between the metallic components of the well can contribute components, especially transition metals, to water samples. Such potential problems have been recognized by the regulatory agencies and have led to the promulgation of sampling protocols and/or material standards. However, these potential influences still must be considered in the screening and interpretation of groundwater data, because such effects are not recognized by statistical methods alone. One example is the recognition that filtered groundwater compositions cannot have larger dissolved solid concentrations

than unfiltered (and acidified) samples. Data of this type that are not identified lead to misinterpretations.

C3.0 EVALUATION AND STATISTICAL METHODS

Many of the statistical methods for evaluating groundwater data are prescribed by regulatory guidelines (EPA 1986; EPA 1989a; EPA 1989b; Ecology 1991b), and different approaches may be prescribed for the various regulatory programs. The same methods used in characterizing and evaluating soil background (Appendix B) in the context of the Site-wide background model also may be used in the evaluation of groundwater background. The main difference between the evaluation of soil and groundwater background is in the nature of the processes that control the range and distribution of compositions as described by the conceptual model.

Individual aquifers and hydrochemical facies constitute discrete compositional populations that generally are discriminated by means of geochemical evaluations. As with soil, background threshold values for groundwater can be determined on the basis of the concentration range of the components and the cumulative distribution. For the natural process of groundwater evolution by rock-water reaction processes, the upper limits of the cumulative distribution should asymptotically approach the equilibrium concentration limits imposed by solubilities, reaction constants, etc. Thus, essentially the same statistical methods used for evaluation of soil background also can be used for evaluating and screening groundwater background, provided that the population is representative of the natural range of compositions. However, the evaluation process should not be limited to a statistical evaluation alone, because the evaluation process can lead to underestimation of the real background levels, especially if the population is not representative of the natural range of compositions.

In general, the true upper limits of the groundwater background compositional range always will be underestimated or misidentified if data with relatively high concentrations cannot be distinguished from contamination. Simple averages, and even values corresponding to an upper confidence or tolerance intervals, are always lower than the concentration levels buffered by equilibrium process because the statistical methods alone have no provisions for factors such as buffered compositions. The present evaluation methods and statistical approaches provide no basis for distinguishing between these two alternatives. Thus, a greater number of groundwater samples alone is of limited benefit to the establishment of background without a conceptual model for understanding the natural distribution and DQOs for sampling and analysis designed specifically for the determination of the natural compositional range.

C4.0 PRELIMINARY RESULTS

The compilation and evaluation of existing data on groundwater in the context of the Site-wide groundwater model have only just begun, and have not progressed as yet to the same extent as have the evaluations of soil background. The compilation and evaluation of existing data and refinement of the conceptual model in context of these evaluations are the primary groundwater background efforts planned for fiscal year 1991. However, preliminary results of these efforts to date appear to generally corroborate the main components of the groundwater background conceptual model. The highlights of these findings pertinent to the evaluation and evolution of the groundwater background conceptual model are summarized in the following sections.

C4.1 LATERAL VARIATIONS

The manifestation of the chemical evolution of groundwater laterally across the Hanford Site previously has not been assessed. It is estimated, however, that the magnitude of compositional changes in groundwater due to reaction path processes should be evident in the groundwater on the scale of the Hanford Site hydrologic system. Information on reaction rates and attendant compositional effects such as that shown in Figure C-7, coupled with groundwater flow velocity, can be used to estimate the importance of this process. For an average flow velocity as fast as 0.6 feet (1.0 meter) per day, it is estimated that groundwater reactions with K-feldspar at 77 °F (25 °C) would approach equilibrium after traveling about 4.35 miles (7 kilometers), and that faster reactions such as those with quartz may approach equilibrium after traveling only about 0.62 mile (1 kilometer). It is estimated that equilibrium would be approached at somewhat greater distances for groundwater at temperatures closer to those of actual aquifer temperatures [52 °F (11 °C)] due to the temperature dependence of reaction constants. The effects of reaction kinetics also would be expected to increase the range of influence for these effects.

These distances are within the range of those from natural recharge areas (e.g., Rattlesnake Ridge, Yakima Ridge) to the Hanford Site. The other notable aspect of these scoping calculations is that for slower flow velocities and/or rapid reactions, the effects of the reaction path process also could be important on the scale of distance between upgradient and downgradient wells at some operable units.

C4.2 VERTICAL VARIATIONS

It is evident that systematic trends in the chemistry of the groundwaters are related to stratigraphic level, based on preliminary geochemical evaluations of the data on groundwater, extending from the upper part of the unconfined aquifer down into the confined aquifers in basalt. Although the extent and nature of vertical chemical variations within the unconfined aquifers are not well constrained, it is indicated from existing data that the

major element compositions of groundwater in the unconfined aquifer converge with those of the confined aquifer groundwater compositions in the Saddle Mountain Basalt (DOE 1988, pp. 3.9-137 to 143). These relationships are not surprising, especially for the parts of the aquifer sediments containing basaltic material. Even small amounts of basaltic material have a great reducing capacity that is controlled by the abundance of and large surface areas of Fe^{2+}-bearing minerals in the basalt (Hoover and Murphy 1989).

Similar conclusions also are indicated by the few measurements of oxidation-reduction potential that have been made in the upper part of the unconfined aquifer (e.g., DOE 1988, pp. 3.9-72). These measurements indicate that reduction-oxidation potentials in the unconfined aquifer range from values of +90 mV, comparable to the oxidizing conditions in surface springs, to values of at least -142 mV, corresponding to reducing conditions, and that these conditions, in turn, overlap with those in the confined basaltic aquifers, which range to Eh values less than -200 mV (DOE 1988, pp. 3.9-72).

The influences of air buffered reactions are expected to be important primarily in the uppermost part of the aquifer. However, the existing population of samples from the unconfined aquifer are so strongly biased to the uppermost part of the aquifer that the monitoring data alone cannot be expected to be representative of the range of natural compositions in the aquifer. Owing to the effects of air buffering, the uppermost parts of the aquifer could be the least representative parts of the overall aquifer chemistry. Because of these effects, the upper part of the aquifer also is expected to have lower dissolved solid concentrations than elsewhere in the aquifer.

C5.0 SUMMARY

A complete evaluation of the geochemical evolution of the shallow Hanford Site groundwater using a reaction path approach has yet to be performed. However, qualitative reaction path evaluations appear to corroborate both the role of air in controlling reactions from the uppermost part of the aquifer as well as the convergence of unconfined aquifer compositions with those of the confined aquifer groundwater composition (DOE 1988, pp. 3.9-137 to 143).

The lower bound of groundwater composition is relatively the soft water from natural surface water recharge. It is possible that the groundwater compositions that most closely approximate the upper concentration limits for most constituents have been measured. Groundwater in the unconfined aquifer with the largest concentrations of dissolved solids are those with compositions that converge with those in the unconfined aquifer. This is an expected trend because the groundwater compositions in the confined aquifer are the most chemically evolved, and have concentrations that more closely approach equilibrium levels. All other naturally occurring compositions are intermediate between these two bounding compositions. The upper limits of this range are of greatest interest to environmental activities, because the upper limits represents the maximum concentrations that would naturally result

in the aquifer. The implications of this upper limit are that Site-wide background threshold levels for constituents expected to approach maximum levels in the more evolved groundwater could be established from these data, but would likely require corroboration involving a sampling effort dedicated to that purpose.

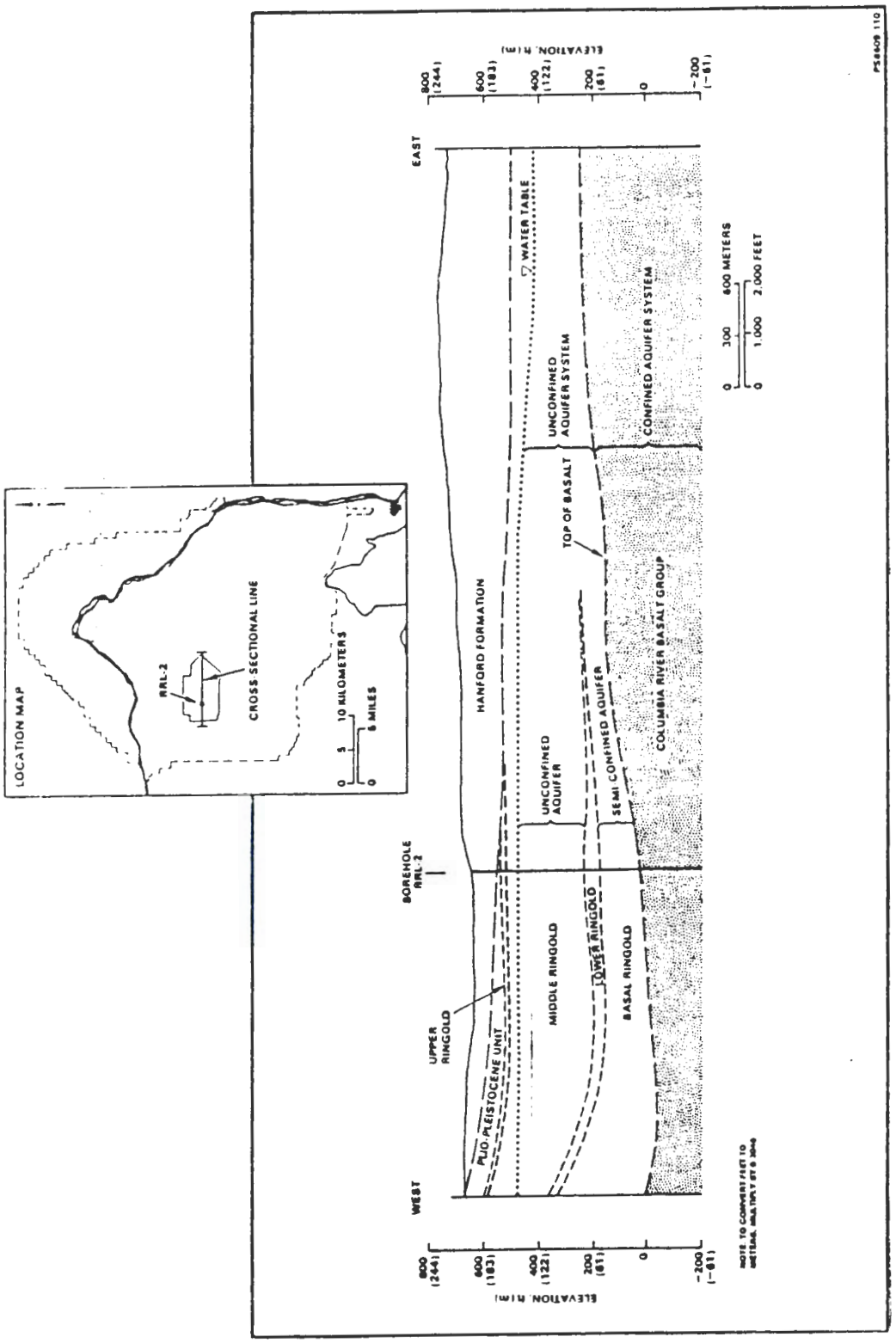


Figure C-1. Geohydrologic Cross Section Across Part of the Hanford Site (shows the relationships between the unconfined and confined aquifers) (vertical exaggerations = 10X) (After Jensen et al. 1986; Landon and Bjornstad 1986).

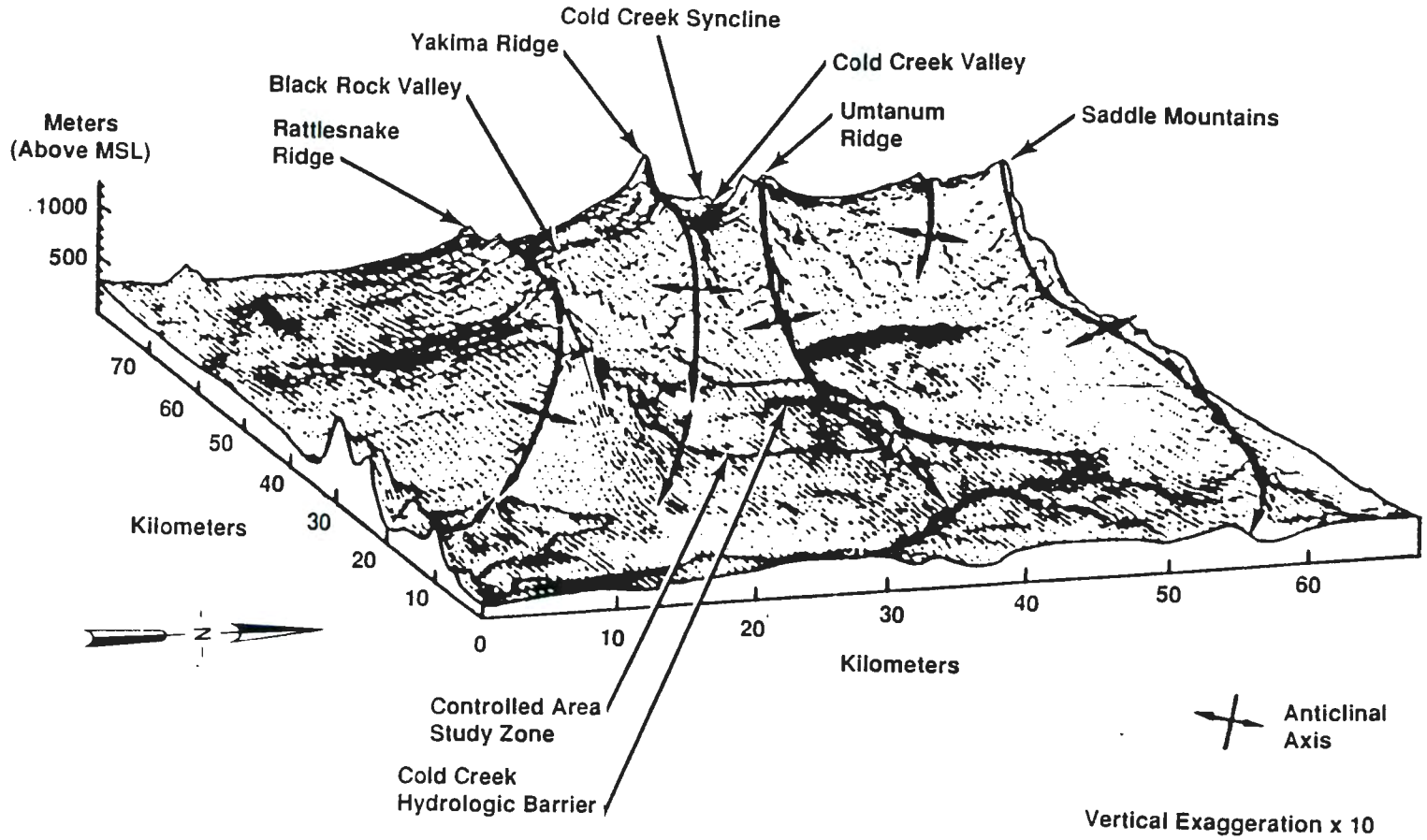


Figure C-2. Land Surface Perspective in the Vicinity of the Hanford Site (shows the main systems of natural recharge to the groundwater on the Hanford Site from rainwater run-off) (vertical exaggeration = 10X).

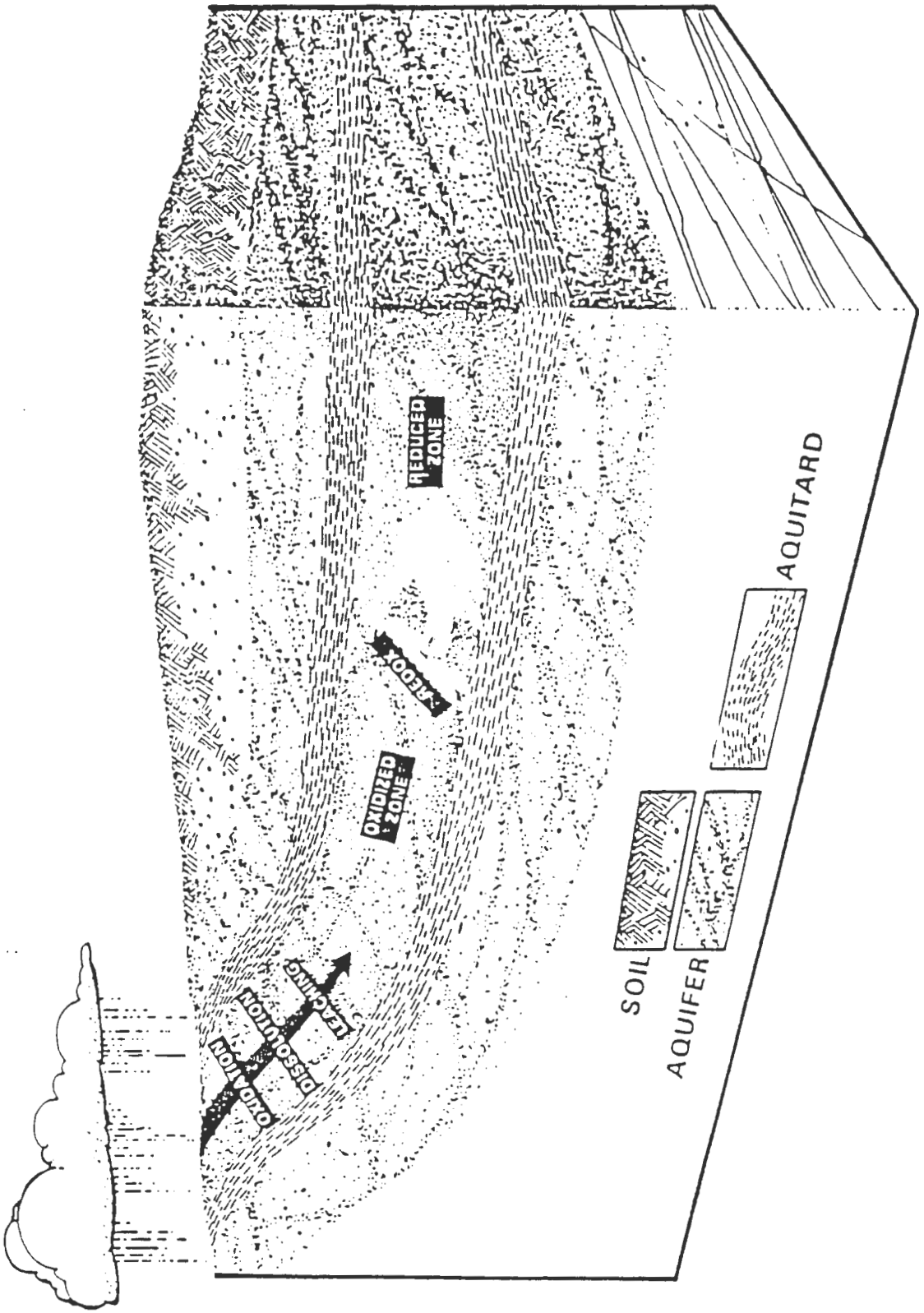


Figure C-3. Schematic Illustration of the Typical Evolutionary Process of 'Soft' Rainwater to 'Hard' Groundwater Along its Flow Path in an Aquifer.

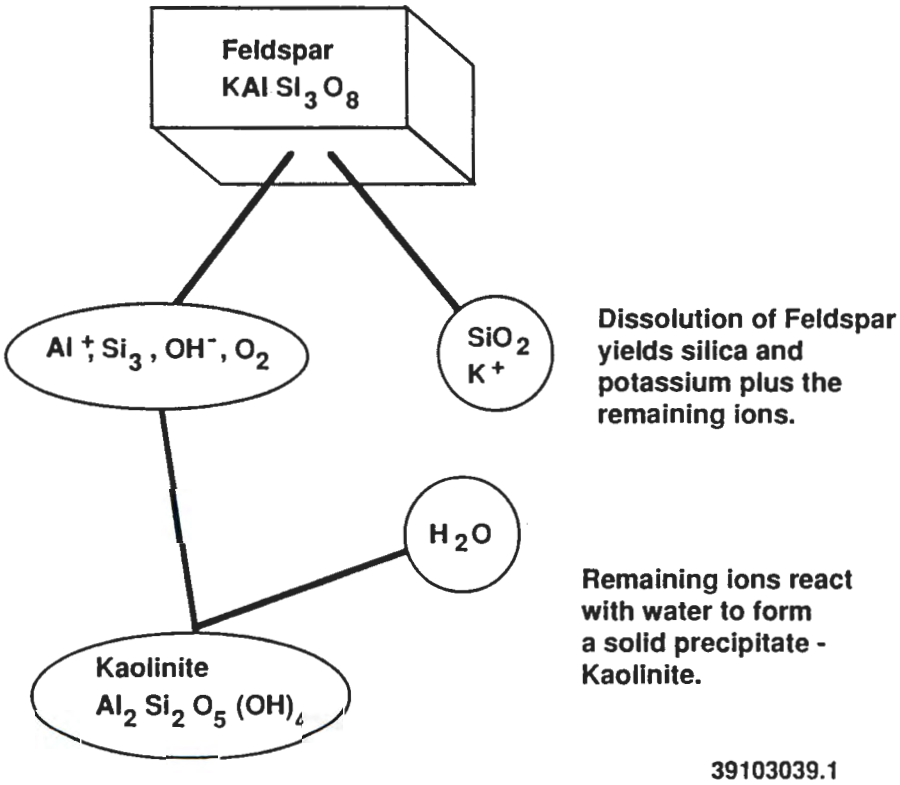


Figure C-4. Reactions Associated with the Alteration of K-feldspar.

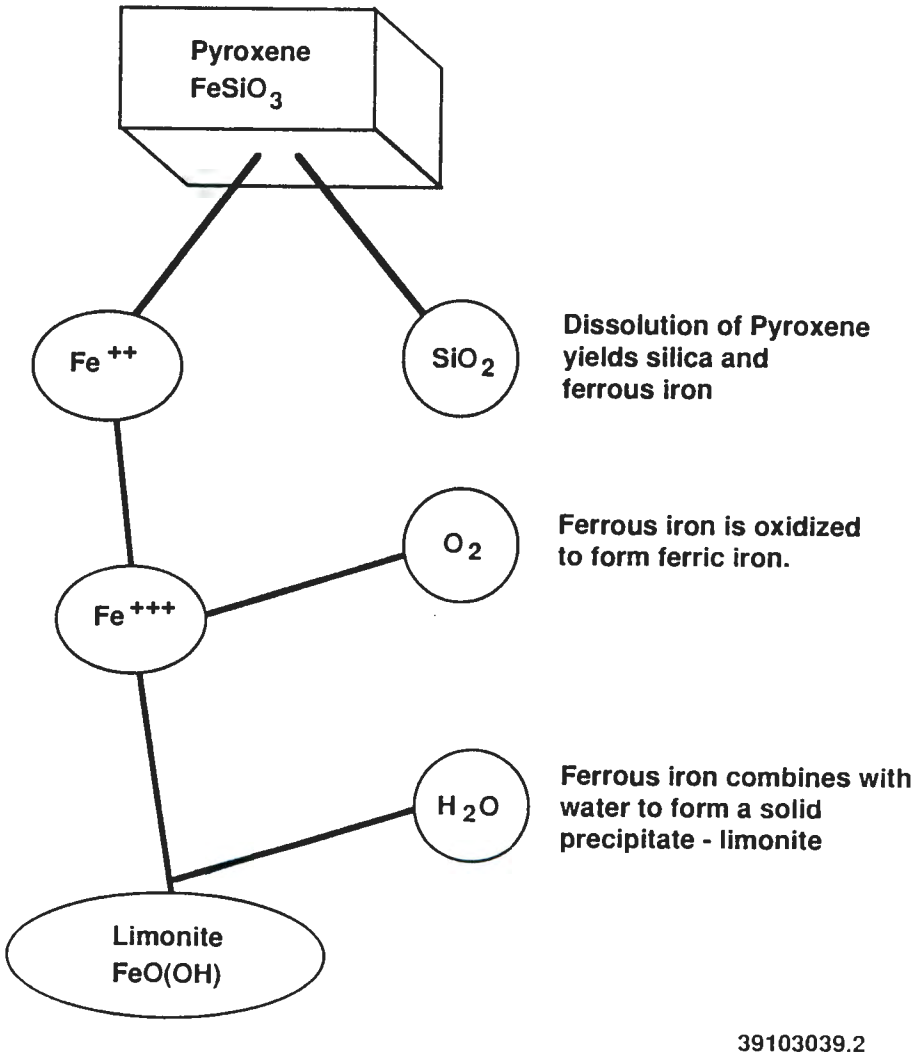


Figure C-5. Reactions Associated with the Alteration of an End Member Fe-pyroxene.

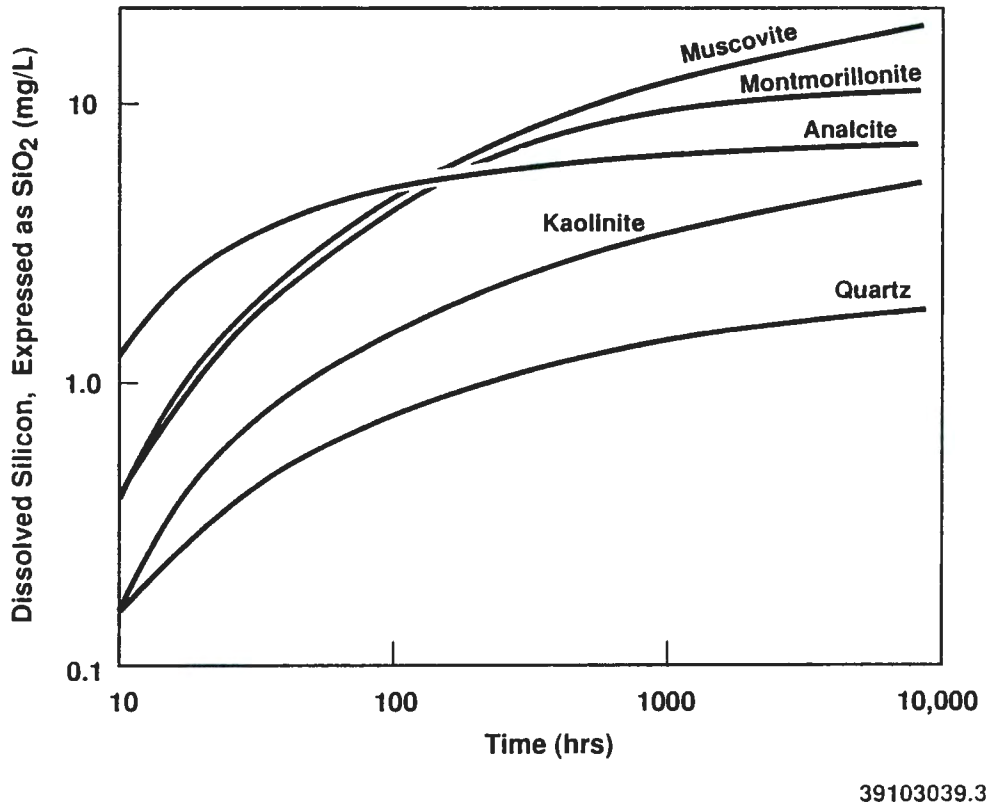


Figure C-6. Silica Concentration Released During the Dissolution of Silicate Minerals in Distilled Water at 25 °C (Bricker 1967).

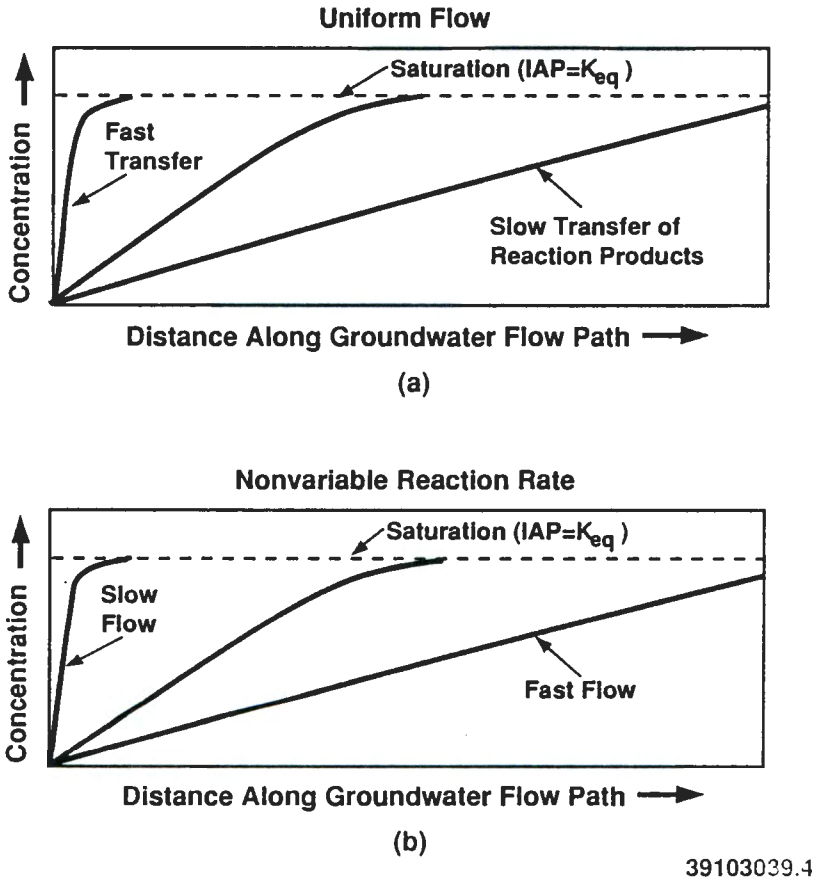


Figure C-7. Concentration Relationships with Distance Along a Groundwater Flow Path for Different Flow Conditions.

Table C-1. Chemical Composition of Waters[1].

Constituent	Sierra Nevada Mountains, rain water[2] mg/L	Columbia River maximum 1985-86 mg/L	Yakima River maximum 1985-86 mg/L	Unconfined aquifer maximum through 1987 mg/L	Cold Creek confined aquifer groundwater mg/L
Si	0	2.1	10.7	45	24
Al	0	-	-	-	0.065
Fe	-	<0.03	<0.015	-	.01-.05
Mn	-	<0.01	0.66	-	0.004
Mg	0.2	5.2	0.023	13	13
Ca	0	22.2	30.3	20	31
Na	0.6	2.5	16.3	58	15
K	0.6	0.91	3	48	3
C/HCO3[2]	3[2]	16.3	29.5	25	-
S/SO4[2]	1.6[2]	13.4	17.9	33	14
Cl	0.2	1.1	6.9	78	8
F	-	0.32	0.22	75	0.6
P		0.02			
N		0.3			
Ammonia		0.04			
Ba					0.04-0.07
Cr					0.034
Ni					0.017-0.03
Cu					0.005
Pb					0.2
Co					0.02
As					0.05
Cd					0.009
^{14}C		107.7	120		
^{3}H		29.8	14		
Eh		25-165	73-170	100-450	
pH				7.1-9.5	

[1] DOE 1988 unless otherwise noted.
[2] Feth et al. 1964.

APPENDIX D

PLANNED ACTIVITIES

APPENDIX D

PLANNED ACTIVITIES

D1.0 INTRODUCTION

The proposed activities for fiscal year 1991 involve two concurrent efforts, (1) a Site-wide effort of soil sampling and analysis for the characterization of soil background and evaluation of the Site-wide conceptual model and (2) an evaluation of existing groundwater background data and models.

The plan for a systematic sampling and analysis of soil on a Site-wide scale has evolved from previous efforts to compile existing soil background data collected according to EPA protocols (EPA 1986), to refine and test conceptual models for soil and groundwater background at the Hanford Site, and to evaluate these data.

The sequence of activities included in this effort are summarized in Figure D-1. The results of previous activities have led to the development and refinement of the soil background conceptual model. The new activities that are to be performed include the following:

- Systematic soil sampling and analysis
- Compilation and determination of supporting geological information
- Other characterization efforts that are important in the evaluation or corroboration of the conceptual model.

The groundwater background efforts for fiscal year 1991 are limited to the compilation and analysis of existing data. These activities are described in Section D3.0.

D2.0 SOIL SAMPLING AND ANALYSIS

A systematic plan of sampling and analysis of background soil and sediment on the Hanford Site will be designed for testing the conceptual model. Data from systematically selected sample locations Site-wide are required to test and corroborate the conceptual model, and will include samples from at least one deep vadose zone borehole. The systematic sampling will be designed for the evaluation of lateral and vertical variability of the vadose zone soil and sediment on the Hanford Site. The data obtained from these samples also will be used to evaluate the extent to which such sampling efforts can be used to represent soil within the confines of the 560 square mile (1,450 square kilometers) Hanford Site area. Data obtained from this effort also will be used to improve the existing database, and used further evaluation and corroboration of the Site-wide background model. Corroboration

of the Site-wide background model will permit the determination of appropriate natural background thresholds from these data, which can be applied to environmental and waste management activities Site-wide.

The criteria to be used in determining sampling locations include the following:

- Sites of no known or suspected contamination and those not in immediate proximity to specific waste sites
- Sites of existing surface excavations where the upper few feet, to tens of feet, of the vadose zone are exposed or can be readily exposed and sampled.
- Locations or sites that are representative of the variety of soil types, including end member types
- Locations or sites that provide reasonable lateral coverage within the context of the previous requirements
- Locations or sites that permit the sampling of the vertical sequence of soil within the vadose zone
- Portions of the vadose zone that most frequently have been impacted by Hanford Site activities (e.g., parts of the stratigraphy most commonly at or near the surface)
- At least one suite of samples from well characterized borehole samples that extend to a greater depth than otherwise available from surface excavations
- Sampling opportunities not otherwise available and that generally meet the aforementioned criteria.

Based on these criteria, the plan for systematic vadose sampling will consist of two phases (1) surface and near surface sampling from existing pits and outcrops and (2) the acquisition of vadose zone samples from boreholes. The surface samples are to be collected from pits and outcrops on the Hanford Site and elsewhere in the Pasco Basin where various parts of the upper vadose zone and vadose zone stratigraphy are freshly exposed and easily sampled. These samples will be used to evaluate lateral variability, lithologic variability (e.g., end member silt and basaltic units), as well as stratigraphic variability (within the limits to which the stratigraphic sequence is exposed in the surface and near surface).

Borehole samples will be samples of opportunity obtained exclusively in conjunction with ongoing drilling efforts in conjunction with CERCLA remedial investigation and feasibility studies, and also Pacific Northwest Laboratory drilling efforts. These vadose zone (and/or groundwater) borehole samples will provide for the systematic sampling of complete vertical sections of the vadose zone at the borehole locations and the evaluation of vertical variation.

Specific sampling and analysis plans will be prepared for each of the two phases of sampling. Most aspects of these two efforts will be similar, and will differ primarily in the differences between sampling methods from boreholes versus surface sites and selected analytes. The analytes of interest in the background sampling effort are the naturally occurring constituents in the soil that are, or could be encountered, in the environmental and/or WMU activities. These primarily include the inorganic cation and anion constituents listed in Table D-1. Some of the cations that are included in Table D-1 are not anticipated to be waste constituents, but are included because the cations are major or minor element components of the soil that are important for correlation and purposes of evaluating the conceptual model.

Many organic constituents also occur naturally in soil and also will be included in the analyte list where appropriate. Most inorganic constituents in background samples are unaffected by the length of the holding time; however, many organic compounds can change with time after the compounds are sampled. Thus, organic constituents could be omitted from the list of constituents for some samples, particularly those samples obtained from boreholes where it is not possible to analyze the samples within EPA holding time limits.

Analysis of the data will include tests for internal consistency and will include the application of professional judgment to aid in distinguishing the possible contamination of a sampling location or particular samples. Description of this aspect of data analysis will be included in the data analysis. Special care also will be exercised in the interpretation of data from samples that might be prone to contaminant retention (e.g., caliche-bearing samples).

D2.1 SUPPORTING INFORMATION AND OTHER CHARACTERIZATION EFFORTS

Supporting geologic information required for the refinement and corroboration of the conceptual model will be obtained from several sources including the Hanford Site, regional personnel, experienced geologic personnel, existing references, and additional field work. This information will be compiled and documented in the summary of results.

Corroboration of the conceptual model also will require some soil characterization efforts that extend beyond those required by EPA or Hanford Site protocols. These characterization efforts involve the identification of the constituent mineral and rock components in the soils and sediments, size fraction measurements, and compositions on a limited number of samples. Bulk chemistry analyses by x-ray fluorescence also will be obtained on a limited number of samples to provide a cross-reference between bulk chemistry and leachate chemistry, and also to provide a basis for the use of x-ray field screening techniques. Some of this additional characterization data will be obtainable from the Pacific Northwest Laboratory database and also from characterization efforts that are planned for some of the borehole samples.

D2.2 ACTIVITY ORGANIZATION

Specific components of the Site-wide soil background characterization activities include the following:

- Description of Hanford Site background working model
- Field reconnaissance and identification of sampling sites
- Preparation of sampling and analysis plans (including DQO and quality assurance project plan)
- Preparation of laboratory analysis work order
- Arrangements for nonprotocol analyses and measurements
- Field sampling
- Laboratory analysis and data generation
- Data validation
- Compilation of new and existing data, data entry, and data screening
- Data interpretation (includes statistical and geochemical analyses)
- Summary and documentation of results.

The organization of these activities and distribution of effort are illustrated in Figure D-2. The sampling and analysis efforts are scheduled to begin with the preparation of sampling and analysis plans, quality assurance project plans, and other required documentation for each of the two phases of sampling. The schedules for these activities depends on the laboratory availability and documentation requirements.

The preliminary breakdown for the distribution of effort in the two main phases of Site-wide soil sampling is summarized as follows:

- Surface and near-surface sampling from outcrops and existing Hanford Site borrow pits (approximately 80 samples)
- Borehole sampling analysis activities (limited to analysis of sample splits)
- Savage Island borehole; eastern Hanford Site boundary borehole (approximately 12 samples)
- Deep microbiology and background borehole; northern Hanford Site boundary, through entire vadose zone (approximately 40 samples)
- CERCLA remedial investigation/feasibility study borehole and groundwater well activities (unscheduled)

- Other borehole activities; e.g., soil column disposal site drilling; 200 East and 200 West Areas (unscheduled).

All borehole sampling and analysis will involve only the acquisition and analysis of sample splits and will involve no drilling costs to this project. Soil background data obtained from borehole and groundwater well activities will yield supplemental data at no cost to the Site-wide background characterization effort.

D3.0 GROUNDWATER

Groundwater background efforts for fiscal year 1991 initially will be limited to the compilation and analysis of existing data, the development and refinement of groundwater background conceptual models, and development of the technical basis for groundwater sampling and analysis.

The activities presently scheduled in fiscal year 1991 include the following:

- The compilation of existing groundwater compositional data
- Development and refinement of groundwater conceptual models for the Hanford Site groundwater background in the context of the hydrologic systems
- Evaluation of geochemical constraints on groundwater-aquifer interaction
- Statistical evaluation of groundwater compositional data
- Limited measurement and sampling at existing well sites.

The organization of these activities is summarized in Figure D-2. The compilation and summary of data include archived water chemistry data from the groundwater monitoring program and other available sources; information on the aquifer components that control chemical reactions and compositions (i.e., phase identification, intensive parameters, phase chemistry); information on the range of intensive parameters within the aquifer regime (e.g., temperature, Eh); and information on the hydrology and geology of the aquifer (e.g., physical and hydrologic properties, flow lines, etc.). The evaluation of these data using statistical, geochemical, and population approaches leads to the development and/or refinement of the conceptual model(s). The results of these activities will be used to identify additional information needs. In the absence of a program of systematic sampling as a follow-on to these activities, it is anticipated that this effort will result only in the identification of additional information needs.

Statistical analysis and population evaluations will be similar to those used for soil, but used for the purpose of discriminating aquifer populations from natural and predicted (e.g., equilibrium) inter-aquifer variation. Data

from other activities, such as the Basalt Waste Isolation Project groundwater data, basalt-water interaction information, and studies on the Hanford and Ringold Formation mineral-rock constituents also will be used to supplement existing data in these evaluations.

Geochemical reaction path modeling also will be initiated. These models will be designed to test the conceptual models for range of groundwater compositions expected in the Hanford Site aquifers as a function of recharge, aquifer type, residence time in the aquifer (water-aquifer reaction time), and other influences (e.g., mixing, external buffering, etc.).

Some measurement from existing groundwater wells for Eh associated with water chemistry could be included in this effort to obtain information not otherwise obtainable from regulatory analyses alone, but that is fundamental to the development, refinement, and corroboration of the conceptual models (e.g., Eh/dissolved oxygen content in groundwater laterally and vertically within the aquifer).

These efforts presumably will culminate in systematic groundwater sampling and analysis activities for the next fiscal year.

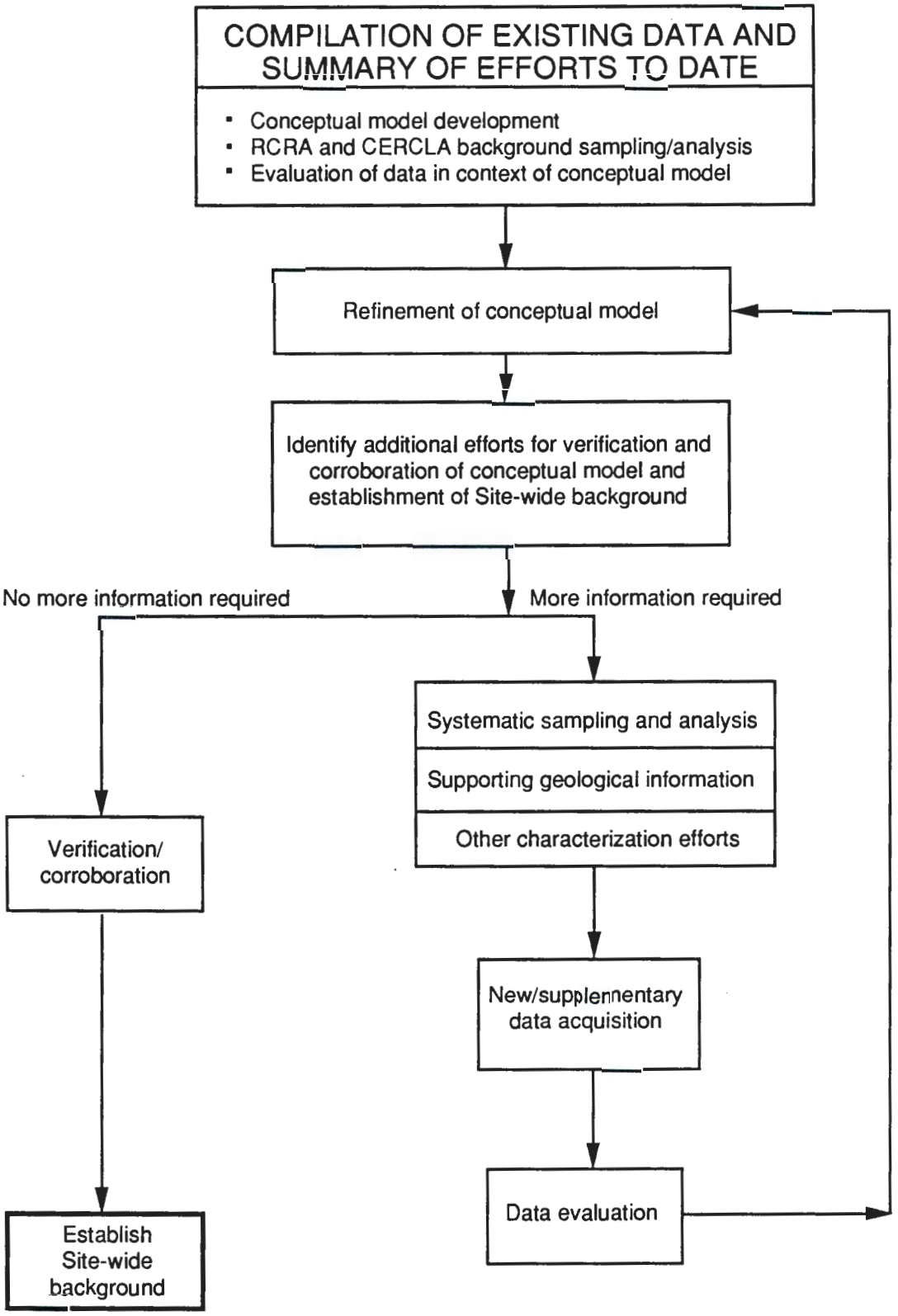


Figure D-1. Site-wide Soil Background Activities.

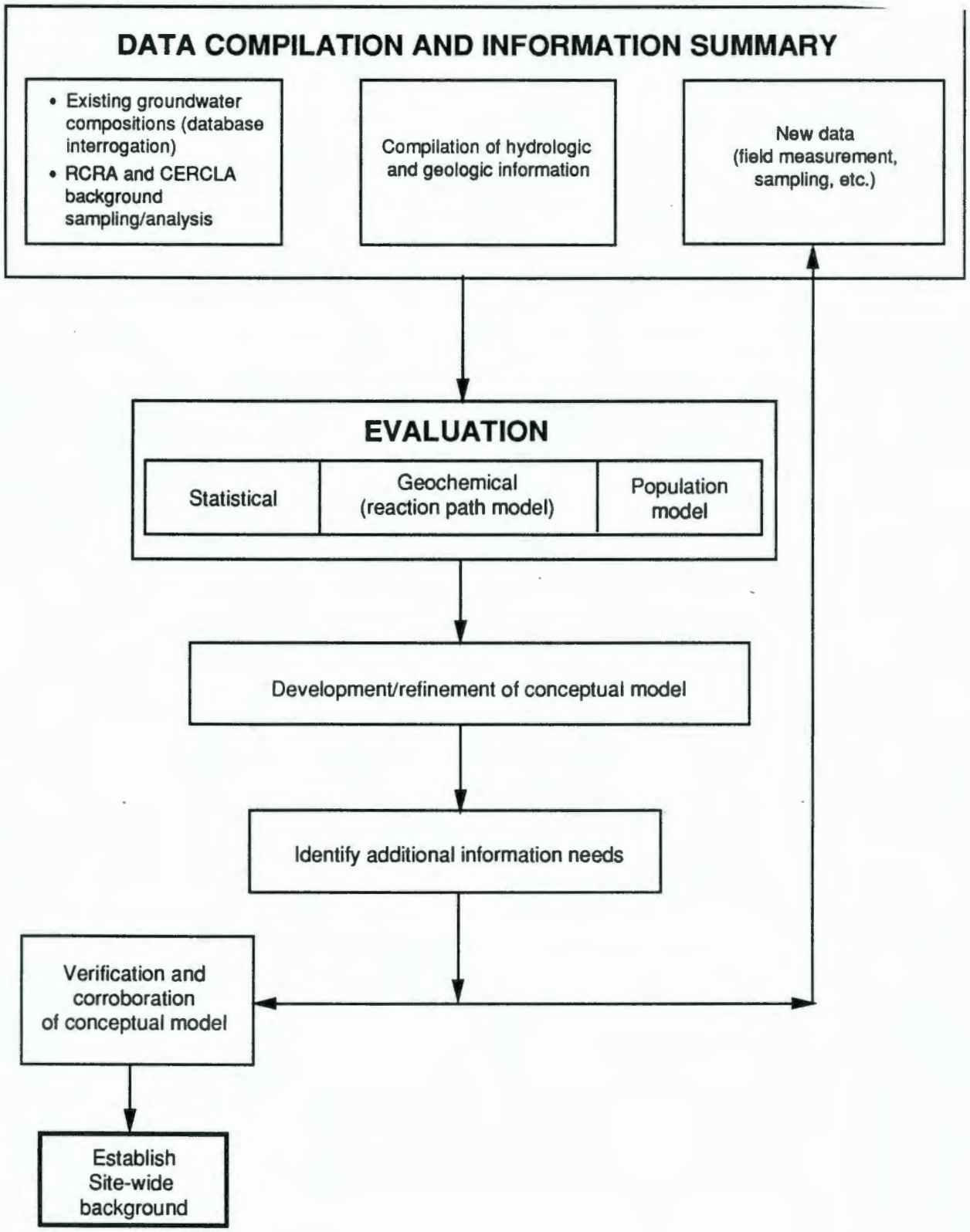


Figure D-2. Site-wide Groundwater Background Activities.

Table D-1. Soil Background Analytes.

Typical EPA Constituents	
Cations	**Anions**
Antimony	Fluoride
Arsenic	Chloride
Barium	Nitrate-nitrite
Beryllium	Phosphate
Cadmium	Sulfate
Chromium	
Cobalt	
Copper	**Others**
Lead	Ammonium
Mercury	Total organic carbon
Nickel	± Semivolatile organics
Selenium	
Silver	
Thallium	
Tin	
Vanadium	
Zinc	
Other Major, Minor, and Indicator Constituents	
Aluminum	Molybdenum
Calcium	Potassium
Iron	Sodium
Lithium	Silicon
Magnesium	Tungsten
Manganese	Titanium

APPENDIX E

SOIL BACKGROUND COST SAVINGS ESTIMATE

APPENDIX E

SOIL BACKGROUND COST SAVINGS ESTIMATE

E1.0 INTRODUCTION

The cost savings that will be realized from implementing a Site-wide soil background program will occur in several areas and forms. The first area of savings is in the area of direct costs associated with the reduced amount of sampling and analysis work to be performed. Associated with this savings is the parallel savings of the reduced amount of documentation to be generated to control the work. The second area of savings is in the benefits to be accrued from consistent application of background levels at all WMUs. Application of a consistent background level at all WMUs will prevent one WMU from being cleaned to a more stringent standard than another, thus ensuring optimum application of cleanup funds. A third area of cost savings will be the intangible costs associated with public and regulatory acceptance of background levels and the reduced amount of effort in the comment resolution process. The discussion in the following sections concerns only the direct cost savings. However, the indirect and intangible cost savings should not be forgotten or ignored.

E2.0 CURRENT DIRECT COSTS

The process of determining a local soil background can be broken down into the following tasks:

Task	Each WMU	All WMUs
Preparation of the field sampling plan	($ 34,400)	$ 4,816,000
Field sampling of the soil	(6,900)	963,000
Laboratory analysis of the soil samples	(33,800)	4,725,000
Data review and validation	(2,800)	398,000
Data analysis	(2,800)	398,000
TOTAL EXISTING BASELINE COST:		**$11,300,000**

The dollar amounts have been computed from both manhour estimates and from examination of cost data for several WMUs on the Hanford Site for which background sampling has been performed. The conversion of manhours to dollars does not include General Services Administration overhead charges (exempt labor = $32.85 per hour, nonexempt = $15.01 per hour).

The number of samples on which the field sampling and analysis costs has been based is 25. This is based on the requirements of the *Model Toxics Control Act* that requires a minimum of 20 samples be collected to establish background. Inclusion of the necessary quality assurance blanks and

duplicates raises the sample number from 20 to 21 or 22. The reject rate determined from contract laboratory program protocol analysis is about one in five samples. This raises the total number of samples required at each site from 21 or 22 to about 25.

E3.0 SITE-WIDE SOIL BACKGROUND COST ESTIMATE

The cost estimate for performing a Site-wide soil background measurement is based on the same type of tasks that are described under Section E2.0, plus additional tasks for identifying the field sampling locations and documenting the new methods. The following cost estimate has been based on a maximum of approximately 170 samples.

Task	Cost
Method documentation	$ 31,000
Identification of field sampling locations	11,000
Preparation of field sampling plan for site background	28,000
Field sampling of soil	47,000
Laboratory analysis of soil samples	230,000
Data review and validation	17,000
Data analysis	17,000
SITE-WIDE SOIL BACKGROUND COST ESTIMATE:	**$381,000**

TOTAL COST SAVINGS

CURRENT DIRECT COSTS	$11,300,000
MINUS SITE-WIDE SOIL BACKGROUND COST	381,000
NET SAVINGS:	**$10,919,000**

Inclusion of the General Services Administration adders into the estimate raises the labor rates by about 50 percent, and adds about 3 million to the estimated savings. The claimed savings of at least $10 million easily is supported by this estimate.