

NUCLEAR REGULATORY COMMISSION

Project WM-10

Notice of Availability -

-Draft Site Characterization Analysis

AGENCY: Nuclear Regulatory Commission.

ACTION: Notice of Availability.

SUMMARY: The Nuclear Regulatory Commission (NRC) has published a Draft Site Characterization Analysis (DSCA) of the U.S. Department of Energy's Site Characterization Report for the Basalt Waste Isolation Project, a potential high-level waste repository site on the Hanford Reservation in the State of Washington.

ADDRESSES: A single copy of the DSCA (NUREG-0960) is available free upon written request to the extent of supply from the GPO Sales Program, Division of Technical Information and Document Control, U.S. Nuclear Regulatory Commission, Washington, DC 20555, (301)492-9530. The DSCA is available for public inspection at the Commission's Public Document Room, 1717 H Street NW, Washington, D.C. 20555, and the Local Public Document Room, Richland Public Library, Swift and Northgate Streets, Richland, Washington 99352.

FOR FURTHER INFORMATION CONTACT: Mr. Robert E. Browning, Acting Director, Division of Waste Management, Nuclear Regulatory Commission, Washington, DC 20555, Telephone (301)427-4200.

SUPPLEMENTARY INFORMATION: On November 12, 1982, the U.S. Department of Energy (DOE) submitted to the Nuclear Regulatory Commission (NRC) the DOE's Site Characterization Report (SCR) for the Basalt Waste Isolation Project (BWIP), designated as NRC Project WM-10. The BWIP SCR was submitted under the provisions of NRC's procedural rule, 10 CFR Part 60, Section 60.11.

While NRC staff was analyzing the BWIP SCR, the Nuclear Waste Policy Act (NWPA) of 1982, Public Law 97-425, was enacted into law. Under Section 113(b)(1) of that Act, DOE is required to submit to NRC, the host state, and any affected Indian tribe on whose reservation a candidate site is located for review and comment: (1) a general plan for site characterization activities to be conducted at such candidate site; (2) a description of the possible waste form or package; and (3) a conceptual repository design that takes into account likely site-specific requirements. The site characterization plan (SCP) required by the Act is similar, but not identical, to the SCR described in NRC's procedural rule, 10 CFR Part 60, Section 60.11.

We understand that DOE intends to submit to NRC later this year an SCP and related documents specified in the Act for BWIP. We also

FR NOTICE

- 3 -

understand that these documents will supersede the November 1982 BWIP SCR and will provide information not included in the November 1982 BWIP SCR.

Upon receipt later this year, NRC will review the BWIP SCP. The NRC is also looking at the impact of the NWPA on NRC's procedural rule. However, pending any changes to NRC's procedural rule, we intend to provide NRC staff's draft analysis of the BWIP SCP for public review and comment prior to publication of a final analysis by NRC staff. Since the NRC staff has completed its review of the November 1982 BWIP SCR, we are publishing our draft analysis of that document now in order to provide DOE and all other interested parties with our views on the proposed site characterization program identified in the BWIP SCR.

Dated at Silver Spring, Maryland, this 31st day of March 1983.

FOR THE NUCLEAR REGULATORY COMMISSION

151

Robert E. Browning, Acting Director
Division of Waste Management

~~ELD via telecon:~~
per REB

OFC :	WMPI :	WMPI :	WMPI :	WM :	:	:	:
NAME :	NStill/ RMacDougall :	DMattson :	JOBunting :	RBrowning :	:	:	:
DATE :	83/03/31 :	3/ /83 :	3/ /83 :	3/31/83 :	:	:	:

Document No. WM-10
This document consists of 220 pages
No. 26 of 100 copies, Series

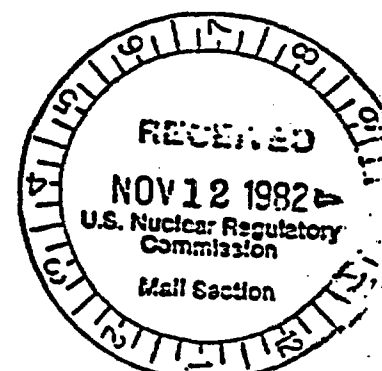
Site Characterization Report for the Basalt Waste Isolation Project

November 1982



Prepared by Rockwell Hanford Operations
Under Contract DE-AC06-77RLO1030

Prepared For:
U.S. Department of Energy
Assistant Secretary for Nuclear Energy
Office of Terminal Waste Disposal
and Remedial Action
Washington, D.C. 20545



VOLUME I

CONTENTS

EXECUTIVE SUMMARY.	1
CHAPTER 1. INTRODUCTION	1.1-1
1.1 Regional Setting	1.1-1
1.2 Background	1.2-1
1.3 The Hanford Site	1.3-1
1.3.1 Geographic Setting	1.3-1
1.3.2 Geologic Setting	1.3-3
1.4 Purpose and Scope.	1.4-1
1.5 Contents	1.5-1
1.5.1 Chapter 1: Introduction	1.5-1
1.5.2 Chapter 2: Decision Process for Choosing a Reference Repository Location and an Alternate Repository Location.	1.5-1
1.5.3 Chapter 3: Geologic Description of the Reference Repository Location and the Surrounding Area	1.5-1
1.5.4 Chapter 4: Geoengineering	1.5-1
1.5.5 Chapter 5: Hydrogeology	1.5-2
1.5.6 Chapter 6: Geochemistry	1.5-2
1.5.7 Chapter 7: Surface Hydrology.	1.5-2
1.5.8 Chapter 8: Climatology, Meteorology, and Air Quality.	1.5-2
1.5.9 Chapter 9: Environmental, Land-Use, and Socio- economic Characteristics	1.5-2
1.5.10 Chapter 10: Repository Design	1.5-3
1.5.11 Chapter 11: Waste Package	1.5-3
1.5.12 Chapter 12: Performance Assessment.	1.5-3
1.5.13 Chapter 13: Site Issues and Plans	1.5-3
1.5.14 Chapter 14: Geoengineering and Repository Design Issues and Plans	1.5-3
1.5.15 Chapter 15: Waste Package and Site Geochemistry Issues and Plans	1.5-4
1.5.16 Chapter 16: Performance-Assessment Issues and Plans	1.5-4
1.5.17 Chapter 17: Site Characterization Program	1.5-4
1.5.18 Chapter 18: Quality Assurance	1.5-4
1.5.19 Chapter 19: Identification of Alternate Sites	1.5-4
1.6 References	1.6-1

CHAPTER 2. DECISION PROCESS FOR CHOOSING A REFERENCE REPOSITORY LOCATION AND AN ALTERNATE REPOSITORY LOCATION.	2.0-1
2.1 Site-Identification Methodology.	2.1-1
2.1.1 Identification of Siting Objectives and Development of Guidelines.	2.1-1
2.1.2 Screening Process.	2.1-6
2.1.3 Ranking Process.	2.1-7
2.1.4 Development of a Data Base	2.1-13
2.2 Technical Factors.	2.2-1
2.3 Environmental Factors.	2.3-1
2.4 Legal and Institutional Factors.	2.4-1
2.4.1 Federal Legal Framework.	2.4-1
2.4.2 State and Local Laws	2.4-1
2.4.3 Public Involvement	2.4-1
2.5 Decision-Making Analysis	2.5-1
2.5.1 Results of the Screening Process	2.5-1
2.5.2 Results of the Ranking Process	2.5-19
2.6 Identification of Principal Borehole/Exploratory Shaft Site.	2.6-1
2.7 Identification of Candidate Repository Horizons.	2.7-1
2.8 References	2.8-1
 CHAPTER 3. GEOLOGIC DESCRIPTION OF THE REFERENCE REPOSITORY LOCATION AND THE SURROUNDING AREA.	 3.1-1
3.1 Introduction	3.1-1
3.2 Site Penetrations	3.2-1
3.2.1 Repository Feasibility and Siting Boreholes.	3.2-1
3.2.2 Site Boreholes	3.2-5
3.2.3 Status	3.2-5
3.3 Physiography and Topography.	3.3-1
3.4 Geomorphology.	3.4-1
3.4.1 Application of Geomorphic Information to Site Identification.	3.4-1
3.4.2 Geomorphology of the Reference Repository Location	3.4-1
3.5 Stratigraphy and Lithology	3.5-1
3.5.1 Regional Stratigraphic Framework	3.5-1
3.5.2 Relationship of Candidate Area to the Regional Framework	3.5-8
3.5.3 Surface Geology.	3.5-9
3.5.4 Stratigraphic and Lithologic Framework of the Reference Repository Location.	3.5-9
3.5.5 Future Rock Formation and Alteration	3.5-38
3.5.6 Status	3.5-39
3.6 Geophysical Studies of the Hanford Site and the Reference Repository Location.	3.6-1
3.6.1 Seismic Reflection and Refraction.	3.6-1
3.6.2 Magnetics.	3.6-3
3.6.3 Gravity.	3.6-10
3.6.4 Magnetotelluric Surveys.	3.6-13

3.6.5	Regional Heat Flow	3.6-17
3.6.6	Remote Sensing	3.6-20
3.6.7	Borehole Geophysical Logging	3.6-25
3.6.8	Status	3.6-27
3.7	Structural Geology and Tectonics	3.7-1
3.7.1	Tectonic Framework	3.7-1
3.7.2	Tectonic History	3.7-1
3.7.3	Seismicity of the Columbia Plateau	3.7-34
3.7.4	Seismicity of the Reference Repository Location.	3.7-54
3.7.5	Status	3.7-55
3.8	Long-Term Regional Stability	3.8-1
3.8.1	Preliminary Deformation Rate	3.8-1
3.8.2	Synopsis of Current Tectonic Models.	3.8-2
3.8.3	Status	3.8-6
3.9	Mineral Resources.	3.9-1
3.9.1	Subsurface Mining.	3.9-1
3.9.2	Mineral-Resource Values--Reference Repository Location and Vicinity.	3.9-1
3.9.3	Assessment of Comparison Area - Columbia Plateau Region	3.9-6
3.9.4	Analysis of Resources - Relative Attractiveness of the Reference Repository Location for Mineral- Resource Exploration and Development	3.9-6
3.9.5	Status	3.9-6
3.10	Summary of Unresolved Issues	3.10-1
3.11	References	3.11-1
CHAPTER 4. GEOENGINEERING		4.0-1
4.1	Mechanical Properties of Rock Units - Continua	4.1-1
4.1.1	General.	4.1-1
4.1.2	Test Methods and Results	4.1-1
4.1.3	Discussion of Results.	4.1-7
4.1.4	Summary.	4.1-10
4.2	Mechanical Properties of Rock Units - Large Scale.	4.2-1
4.2.1	General.	4.2-1
4.2.2	Borehole Jacking Tests	4.2-2
4.2.3	Jointed Block Test	4.2-5
4.2.4	Discussion of Results.	4.2-11
4.2.5	Summary.	4.2-11
4.3	Mechanical Properties of Rock Units - Discontinua.	4.3-1
4.3.1	General.	4.3-1
4.3.2	Field Investigation.	4.3-1
4.3.3	Laboratory and In Situ Testing	4.3-2
4.3.4	Summary.	4.3-6
4.4	Thermal and Thermomechanical Properties - Laboratory Results	4.4-1
4.4.1	General.	4.4-1
4.4.2	Results and Discussion	4.4-1
4.4.3	Summary.	4.4-4

4.5	Thermal and Thermomechanical Properties - In Situ.	4.5-1
4.5.1	General.	4.5-1
4.5.2	Full-Scale Heater Tests.	4.5-2
4.5.3	Instrumentation Performance.	4.5-8
4.5.4	Summary.	4.5-9
4.6	Stress Field	4.6-1
4.6.1	General.	4.6-1
4.6.2	Stress Measurements by Hydraulic Fracturing.	4.6-2
4.6.3	Geologic Evidence.	4.6-11
4.6.4	Summary.	4.6-11
4.7	Special Geoengineering Properties.	4.7-1
4.7.1	Potential for Rock Bursts and Sudden Collapse of Mined Openings	4.7-1
4.7.2	Potential for Thermal Degradation and Slabbing	4.7-1
4.8	Excavation Characteristics of the Rock Mass.	4.8-1
4.8.1	General.	4.8-1
4.8.2	Existing Basalt Construction Experience.	4.8-1
4.8.3	Excavation Effects on the Rock Mass.	4.8-3
4.8.4	Summary.	4.8-4
4.9	Summary of Unresolved Issues	4.9-1
4.10	References	4.10-1
CHAPTER 5. HYDROGEOLOGY		5.1-1
5.1	Regional and Site Hydrogeologic Investigations	5.1-1
5.1.1	Introduction	5.1-1
5.1.2	Rock Units	5.1-3
5.1.3	Hydrologic Characteristics	5.1-12
5.1.4	Potentiometric Levels.	5.1-47
5.1.5	Regional Hydrochemistry.	5.1-80
5.1.6	Isotope Hydrochemistry	5.1-140
5.1.7	Interrelationship of Hydrologic Systems.	5.1-181
5.1.8	Groundwater Velocity and Travel Times.	5.1-189
5.1.9	Groundwater Uses	5.1-189
5.1.10	Reexamination of Conceptual Model.	5.1-198
5.2	Site Hydrogeologic System.	5.2-1
5.2.1	Hydrologic Characteristics	5.2-1
5.2.2	Potentiometric Levels.	5.2-4
5.2.3	Groundwater Hydrochemistry	5.2-13
5.3	Summary of Unresolved Issues	5.3-1
5.4	References	5.4-1

FIGURES:

1-1.	Location of the Pasco Basin and the Hanford Site, Washington State	1.1-2
1-2.	Regions That are Being Considered for Geologic Disposal of Radioactive Waste.	1.2-3
1-3.	The Hanford Site	1.3-2
1-4.	Stratigraphy of the Columbia River Basalt Group, Yakima Basalt Subgroup, and Intercalated and Suprabasalt Sediments Within the Pasco Basin	1.3-4
1-5.	Generalized Cross Section Through the Pasco Basin.	1.3-5
1-6.	Repository Siting Process.	1.4-2
2-1.	Repository-Site Process.	2.0-1
2-2.	Location of the Reference Repository Location and Alternate Repository Location.	2.0-3
2-3.	Elements of Site Identification Methodology.	2.1-2
2-4.	Relationships of Terms Used in Screening and Ranking	2.1-4
2-5.	Approach to Guideline Development.	2.1-5
2-6.	The Overlay Process Used in Site Screening	2.1-8
2-7.	Relationship of Area Designations and Screening Steps.	2.1-9
2-8.	Illustrative Example of the Screening Process.	2.1-10
2-9.	Pasco Basin and Hanford Site Boundaries.	2.5-2
2-10.	Pasco Basin Candidate Area	2.5-5
2-11.	Subareas Within Pasco Basin.	2.5-8
2-12.	Hanford Site: Compilation of Available Area and Site Localities.	2.5-11
2-13.	Site Localities on the Hanford Site.	2.5-12
2-14.	Initial Candidate Sites on the Hanford Site.	2.5-16
2-15.	Ten Candidate Sites in the Cold Creek Syncline Area (after eliminating sites Y and Z from further consideration)	2.5-18
2-16.	Reference Repository Location, Site A-H, and Alternate Site J	2.6-2
3-1.	Location of the Columbia Plateau, Hanford Site, Cold Creek Syncline, and Reference Repository Location.	3.1-2
3-2.	Stratigraphy of the Columbia River Basalt Group, Yakima Basalt Subgroup, and Intercalated and Suprabasalt Sediments Within the Pasco Basin	3.1-3
3-3.	Location Map for Key Boreholes Used in Basalt Waste Isolation Project Studies.	3.2-3
3-4.	Stratigraphic Levels Penetrated by Boreholes on the Hanford Site and Vicinity.	3.2-4
3-5.	Borehole Location Map, Reference Repository Location	3.2-6
3-6.	Physiographic Provinces of the Pacific Northwest	3.3-2
3-7.	Divisions of the Columbia Intermontane Province.	3.3-3
3-8.	Map of Major Landform Systems, Pasco Basin	3.3-4
3-9.	Geomorphic Map, Reference Repository Location.	3.4-2
3-10.	Regional Columbia River Basalt Group Stratigraphic Nomenclature	3.5-3
3-11.	General Stratigraphic Relationship of Suprabasalt Sediments.	3.5-5
3-12.	Generalized Locations of The Dalles Group and Their Depositional Basins.	3.5-7

FIGURES (Contd.):

3-13.	General Geologic Map of the Pasco Basin.	3.5-10
3-14.	Generalized Structure Cross Section.	3.5-11
3-15.	Generalized Surficial Geologic Map of the Reference Repository Location.	3.5-12
3-16.	Generalized Cross Section Through the Reference Repository Location.	3.5-13
3-17.	Stratigraphic Nomenclature, Pasco Basin, Cold Creek Syncline	3.5-14
3-18.	Location Map, Pasco Basin and Surrounding Areas (showing location of boreholes penetrating the candidate repository horizons and geologic sections) .	3.5-16
3-19.	Isopach Map of the Middle Sentinel Bluffs Flow, Pasco Basin and Vicinity	3.5-17
3-20.	General Stratigraphic Relationships Among Grande Ronde Basalt Flow Sequences in the Pasco Basin	3.5-18
3-21.	Isopach Map of the Umtanum Flow, Pasco Basin and Vicinity	3.5-20
3-22.	Fence Diagram, Upper Grande Ronde Basalt, Crescent Bar to Sentinel Bluffs	3.5-21
3-23.	Fence Diagram, Upper Grande Ronde Basalt, Sentinel Bluffs to Borehole DC-6.	3.5-22
3-24.	Fence Diagram, Upper Grande Ronde Basalt, Boreholes DC-4 to DDH-3.	3.5-23
3-25.	Stratigraphic Column, Reference Repository Location. . .	3.5-24
3-26.	Typical Intraflow Structures Present in a Grande Ronde Basalt Flow.	3.5-26
3-27.	Intraflow Structure Types.	3.5-27
3-28.	Fence Diagram, Umtanum Flow.	3.5-29
3-29.	Cliff Exposure, Umtanum Flow at Emerson Nipple Section .	3.5-30
3-30.	Isopach Map of the Flow Top of the Middle Sentinel Bluffs Flow, Pasco Basin and Vicinity.	3.5-34
3-31.	Isopach Map of the Flow Top of the Umtanum Flow.	3.5-36
3-32.	Location of 1979 and 1980 Seismic-Reflection Surveys . .	3.6-2
3-33.	Seismic-Reflection Anomaly Location Map.	3.6-4
3-34.	Aeromagnetic Surveys Including Columbia Plateau Area . .	3.6-5
3-35.	Pasco Basin Aeromagnetic Surveys	3.6-8
3-36.	Locations of Ground-Magnetic Surveys	3.6-9
3-37.	Pasco Basin Ground-Magnetic Surveys.	3.6-11
3-38.	Location Map - Regional Gravity.	3.6-12
3-39.	Tensor Magnetotelluric-Survey Station Location	3.6-14
3-40.	Electrical Strike, Tensor-Magnetotelluric Data from Fiscal Year 1978 and 1979 Surveys.	3.6-16
3-41.	Temperature Gradient Measurements and Regional Heat Flow Reported for the Pasco Basin and Vicinity	3.6-19
3-42.	Remote-Sensing Studies Conducted Within the Columbia Plateau	3.6-24
3-43.	Illustrative Borehole Geophysical Log Response in Columbia River Basalt.	3.6-26
3-44.	Gamma-Gamma-Log Response, Grande Ronde Basalt, Sentinel Bluffs Sequence	3.6-28

FIGURES (Contd.):

3-45.	Informal Structural Subdivisions of the Columbia Plateau	3.7-2
3-46.	Chronology of Igneous Activity in the Pacific Northwest.	3.7-3
3-47.	Generalized Tectonic Map of Part of the Columbia Plateau	3.7-5
3-48.	Faults of the Pasco Basin.	3.7-9
3-49.	Comparison of the Interpreted Strain Geometry of the Umtanum Anticline with a Photomosaic of a Canyon in the Priest Rapids Area	3.7-21
3-50.	Folds of the Pasco Basin	3.7-22
3-51.	Top-of-Basalt Contour Map.	3.7-27
3-52.	Interpretive Bedrock-Structure Map	3.7-29
3-53.	Schematic Cross Section, Cold Creek Syncline (illustrating predicted distribution of faults with respect to folds)	3.7-30
3-54.	Historical Seismicity of the Columbia Plateau Tectonic Province.	3.7-36
3-55.	Instrumental Seismicity (post-1969) above Magni- tude 3.0, Columbia Plateau Tectonic Province	3.7-42
3-56.	Instrumental Seismicity of the Pasco Basin	3.7-43
3-57.	Well-Located Shallow Earthquakes, Pasco Basin and Surrounding Area, 1969-1979.	3.7-45
3-58.	Cumulative Number of Events per Year Versus Magnitude for Entire Region.	3.7-46
3-59.	Columbia Plateau Earthquakes Focal-Mechanism Summary	3.7-50
3-60.	Hanford Seismic Array.	3.7-56
3-61.	Simple Translation Model of Oblique-Transform Faulting and Compressional Folding	3.8-4
3-62.	Locations of the Reference Repository Location Vicinity, Pasco Basin, Adjacent-Counties, and Columbia Plateau Study Areas	3.9-2
4-1.	Strength Versus Confining Stress for Pomona Basalt	4.1-8
4-2.	Effects of Confining Stress and Temperature on the Deformation Modulus for Umtanum Basalt Specimens	4.1-9
4-3.	Average Modulus Value (uncorrected) Versus Orienta- tion, from Modified Goodman Jack Tests in the Colonnade Zone of Pomona Flow at the Near-Surface Test Facility Site	4.2-4
4-4.	Block Test Number 1 Flat Jack and Grouting Boxes	4.2-6
4-5.	Heater and Instrumentation Holes - Block Test Step 1	4.2-7
4-6.	Individual Stress Cancellation Values for Vibrating Wire Stressmeters in Step 1 of the Block Test.	4.2-8
4-7.	Temperature and Flat Jack Pressure Cycles During Step 1	4.2-10
4-8.	Plan View of Boreholes Drilled for Full-Scale Heater Test No. 1.	4.5-3
4-9.	Plan View of Boreholes Drilled for Full-Scale Heater Test No. 2.	4.5-4
4-10.	Heater Power Levels for Full-Scale Heater Test No. 1	4.5-5
4-11.	Heater Power Levels for Full-Scale Heater Test No. 2	4.5-5

FIGURES (Contd.):

4-12.	Comparison of Full-Scale Heater Test No. 2 Actual Data with Predictive Analysis Value.	4.5-6
4-13.	Axial Temperature Profile in Basalt-at 0.71 Meter (2.3 Feet) from Heater-Hole Axis on Test Day 259 for Full-Scale Heater Test No. 1	4.5-7
4-14.	Axial Temperature Profile in Basalt at 0.40 Meter (1.3 Feet) from Heater-Hole Axis on Test Day 259 for Full-Scale Heater Test No. 1	4.5-7
4-15.	Map of the Hanford Site Showing Location of Drill Hole DB-15 and DC-12	4.6-3
4-16.	Basalt Core Recovered from Borehole DC-12 at Test Depth Between 1,011 and 1,014 Meters (3,317 and 3,325 feet).	4.6-5
4-17.	Typical Pressure-Time Curve Obtained in Borehole DC-12 at Test Depth of 1,013 Meters (3,323 feet)	4.6-6
4-18.	Pressure-Time Curve Plotted on a Semi-Logarithmic Paper to Determine the Shut-In Pressure at Test Depth of 1,036 Meters (3,400 Feet)	4.6-7
4-19.	A Typical Fracture Impression Obtained at Test Depth (1,013 meters (3,323 feet)), Exhibiting Two Vertical Fractures Approximately 180 Degrees Apart.	4.6-8
4-20.	Variation of Ratio of Average Horizontal Stress to Vertical Stress with Depth Below Surface	4.6-12
5-1.	Geographic Setting of the Pasco Basin.	5.1-2
5-2.	Hydrologic Test Sites for Individual Formations Within the Columbia River Basalt Group	5.1-5
5-3.	Areal Distribution of Formations Within the Columbia River Basalt Group	5.1-8
5-4.	Outcrop Distributions of the Saddle Mountains, Wanapum, and Grande Ronde Basalts and Overburden Sediments.	5.1-9
5-5.	Flow Chart of General Procedures Used in Hydrologic Testing.	5.1-15
5-6.	Guidelines for Application Range of Test Methods for Test Zones at the Hanford Site	5.1-16
5-7.	Borehole Geophysical Log for Borehole DB-15.	5.1-18
5-8.	Borehole Geophysical Log for Borehole DC-6	5.1-19
5-9.	Borehole Geophysical Log for Borehole DC-7	5.1-20
5-10.	Borehole Geophysical Log for Borehole DC-12.	5.1-21
5-11.	Borehole Geophysical Log for Borehole DC-14.	5.1-22
5-12.	Borehole Geophysical Log for Borehole DC-15.	5.1-23
5-13.	Borehole Geophysical Log for Borehole DC-16.	5.1-24
5-14.	Borehole Geophysical Log for Borehole RRL-2.	5.1-25
5-15.	Areal Distribution of Hydraulic Conductivity Across the Hanford Site for the Unconfined Aquifer.	5.1-26
5-16.	Comparison of Equivalent Hydraulic-Conductivity Values for all Flow Tops and Interbeds Tested Within the Columbia River Basalts.	5.1-29
5-17.	Comparison of Equivalent Hydraulic Conductivity Values Versus Depth for Flow Interiors (colonnade and entablature) of Selected Columbia River Basalts.	5.1-32

FIGURES (Contd.):

5-18.	Equivalent Hydraulic Conductivity Values for Test Intervals Across Interbeds and Flow Tops in Borehole DB-13	5.1-33
5-19.	Equivalent Hydraulic Conductivity Values for Test Intervals Across Interbeds and Flow Tops in Borehole DB-15	5.1-34
5-20.	Equivalent Hydraulic Conductivity Values for Test Intervals Across Flow Tops in Borehole DC-6.	5.1-35
5-21.	Equivalent Hydraulic Conductivity Values for Test Intervals Across Flow Tops in Borehole DC-7.	5.1-36
5-22.	Equivalent Hydraulic Conductivity Values for Test Intervals Across Flow Tops and One Interbed in Borehole DC-12	5.1-37
5-23.	Equivalent Hydraulic Conductivity Values for Test Intervals Across Flow Tops and Interbeds in Borehole DC-14	5.1-38
5-24.	Equivalent Hydraulic Conductivity Values for Test Intervals Across Flow Tops and Interbeds in Borehole DC-15	5.1-39
5-25.	Equivalent Hydraulic Conductivity Values for Test Intervals Across Mostly Flow Tops and Interbeds in Borehole DC-16A	5.1-40
5-26.	Equivalent Hydraulic Conductivity Values for Test Intervals Across Mostly Flow Tops and Interbeds in Borehole RRL-2.	5.1-41
5-27.	Hydraulic Conductivity of Various Crystalline and Argillaceous Rocks	5.1-48
5-28.	Elevation of the Groundwater Table Within the Pasco Basin.	5.1-50
5-29.	Estimated 1944 Water-Table Map for the Hanford Site.	5.1-51
5-30.	Comparison of Hydraulic Heads in the Rattlesnake Ridge Interbed to Water-Table Elevation.	5.1-52
5-31.	Potentiometric Map for and Inferred Flow Directions of Groundwater Within the Mabton Interbed Beneath the Hanford Site	5.1-54
5-32.	Total Nitrogen-Nitrate (N as NO ₃) Concentration for Groundwater Within the Saddle Mountain Basalt in the Pasco Basin	5.1-58
5-33.	Hydrograph for Well 10N/30E-19E Located North of Pasco, Washington.	5.1-59
5-34.	Hydraulic Head Measurements Within the Saddle Mountains and Wanapum Basalts in Borehole DB-15.	5.1-65
5-35.	Hydraulic Head Measurements Within the Grande Ronde Basalt in Borehole DC-6.	5.1-66
5-36.	Hydraulic Head Measurements Within the Grande Ronde Basalt in Borehole DC-7.	5.1-67
5-37.	Hydraulic Head Measurements Within the Wanapum and Grande Ronde Basalts in Borehole DC-12	5.1-68
5-38.	Hydraulic Head Measurements Within the Columbia River Basalts in Borehole DC-14.	5.1-69

FIGURES (Contd.):

5-39.	Hydraulic Head Measurements Within the Columbia River Basalts in Borehole DC-15.	5.1-70
5-40.	Hydraulic Head Measurements Within the Saddle Mountains and Wanapum Basalts at Borehole DC-16A	5.1-71
5-41.	Hydraulic Head Measurements Within the Columbia River Basalts at Borehole RRL-2.	5.1-72
5-42.	Three-Dimensional Perspective Views Showing Composite Potentiometric Surfaces for Various Strata Within the Columbia River Basalts	5.1-76
5-43.	Three-Dimensional Perspective Views Showing the Potentiometric Surface Configuration of the Saddle Mountains and Wanapum Basalt	5.1-77
5-44.	Locations and Vertical-Head Distributions of Washington State Department of Ecology Test/Observation Wells.	5.1-78
5-45.	Selected Examples of Hydrographic Data for Wells Within the Columbia Plateau Region.	5.1-81
5-46.	Sampling Sites for Groundwater Collected from Columbia River Basalt Zones.	5.1-84
5-47.	Chemical Composition of Groundwater Within the Columbia River Basalt Group.	5.1-86
5-48.	Nitrate-Ion Distribution in Unconfined Groundwater . . .	5.1-89
5-49.	Location of Boreholes on the Hanford Site for Which Groundwater Hydrochemistry is Available from the Saddle Mountains Basalt.	5.1-92
5-50.	Hydrochemical Facies Map for Aquifers and Springs in the Saddle Mountains Basalt Within the Pasco Basin . .	5.1-97
5-51.	Chemical Composition of Springs and Groundwater Sampled from the Saddle Mountains Basalt	5.1-99
5-52.	Saturation Index Data for Calcite and Cristobalite for Selected Saddle Mountains Basalt Groundwaters. . .	5.1-100
5-53.	Distribution of Total Dissolved Solids and Inferred Flow Direction of Groundwater Within the Mabton Interbed.	5.1-102
5-54.	Mabton Interbed Groundwater Temperature in Boreholes on the Hanford Site.	5.1-106
5-55.	Boreholes with Hydrochemical Data from Groundwater Within the Wanapum Basalt on the Hanford Site.	5.1-109
5-56.	Major Inorganic Hydrochemistry for Groundwater Zones in Boreholes DC-14 and DB-15 Within the Wanapum Basalt	5.1-113
5-57.	Major Inorganic Composition of Wanapum Groundwaters from Inside and Outside the Cold Creek Syncline. . . .	5.1-114
5-58.	Calcite and Cristobalite Saturation Index for Selected Groundwaters Within the Wanapum Basalt. . . .	5.1-117
5-59.	Borehole Locations Where Hydrochemical Data Are Available from Within the Grande Ronde Basalt.	5.1-123
5-60.	Chemical Composition of Groundwater Within the Grande Ronde Basalt Beneath the Hanford Site	5.1-126

FIGURES (Contd.):

5-61.	Saturation Index for Calcite and Cristobalite in Selected Groundwater Zones Within the Grande Ronde Basalt	5.1-128
5-62.	Stiff Diagrams for Selected Intervals in Borehole DB-15	5.1-134
5-63.	Stiff Diagrams for Selected Intervals in Borehole DC-6.	5.1-135
5-64.	Stiff Diagrams for Selected Intervals in Borehole DC-12	5.1-136
5-65.	Stiff Diagrams for Selected Intervals in Borehole DC-14	5.1-137
5-66.	Stiff Diagrams for Selected Intervals in Borehole DC-15	5.1-138
5-67.	Tritium Distribution in the Unconfined Aquifer Beneath the Hanford Site	5.1-143
5-68.	Generalized Plot of Delta Oxygen-18 Versus Delta Hydrogen-2, Showing the Meteoric Water Line and Possible Secondary Fractionation Processes	5.1-145
5-69.	Plot of Delta Hydrogen-2 Versus Delta Oxygen-18 for the Deep Basalts Beneath the Hanford Site.	5.1-147
5-70.	Distribution of Deuterium Within Three Formations of the Columbia River Basalt at the Hanford Site	5.1-148
5-71.	Distribution of Oxygen-18 Within Three Formations of the Columbia River Basalt at the Hanford Site	5.1-149
5-72.	Deuterium and Oxygen-18 Relationship for Groundwater Within the Saddle Mountains and Wanapum Basalts at Borehole DB-15.	5.1-150
5-73.	Deuterium and Oxygen-18 Relationships for Ground- waters Within the Columbia River Basalts at Borehole DC-14	5.1-151
5-74.	Deuterium and Oxygen-18 Relationships for Ground- waters Within the Columbia River Basalts at Borehole DB-15	5.1-152
5-75.	Variation of Delta Oxygen-18 and Delta Hydrogen-2 as a Function of Depth in Borehole DB-15	5.1-153
5-76.	Variation of Delta Oxygen-18 and Delta Hydrogen-2 as a Function of Depth in Borehole DC-15	5.1-154
5-77.	Distribution of Delta Carbon-13 Values of Bicar- bonate Within Selected Columbia River Basalt Group Groundwaters at the Hanford Site	5.1-160
5-78.	Distribution of Delta Carbon-13 Values of Bicar- bonate for Selected Springs in the Vicinity of the Hanford Site	5.1-161
5-79.	Relationship of Delta Carbon-13 (HCO_3) and Percent of Total Dissolved Gas Versus Depth in Borehole DC-15.	5.1-162
5-80.	Eh-pH Diagram for Stable Sulfur Species at 25°C and 1 Atmosphere Total Pressure.	5.1-163
5-81.	Sulfate Versus Delta Sulfur-34 (sulfate) for Basalt Groundwaters at the Hanford Site	5.1-165

FIGURES (Contd.):

5-82.	Areal Plot of Corrected Carbon-14 Ages for Groundwater from the Mabton Interbed	5.1-171
5-83.	Location of Wells Used by Silar When Studying the Carbon-14 Age of Groundwater in Eastern Washington State.	5.1-175
5-84.	Total Uranium Versus Activity Ratio for the Springs and the Columbia River Basalt Groundwaters Beneath the Hanford Site	5.1-177
5-85.	Possible Changes of Uranium-234/Uranium-238 as a Function of Time and Position in a Flow System	5.1-178
5-86.	Distribution of Chlorine-36 to Total Chlorine with Depth for Selected Intervals Within the Columbia River Basalt Group.	5.1-181
5-87.	Comparison of Columbia River Stage Fluctuations with Well Hydrograph Response in Three Unconfined-Aquifer Well Sites at the Hanford Site	5.1-183
5-88.	Streamflow Rates for the Yakima and Columbia Rivers Near the Hanford Site and Hydrographs for Two Nearby Boreholes	5.1-185
5-89.	Selected Hydrochemistry for Borehole DC-15	5.1-186
5-90.	Areal Hydrochemical Data for Groundwater Within the Priest Rapids Member	5.1-188
5-91.	Frequency of Well-Use Types Listed by Depth Intervals. .	5.1-193
5-92.	Water-Table Rise Beneath the Hanford Site, 1944-1978 . .	5.1-195
5-93.	Location of Unconfined-Aquifer Test Sites Within the Reference Repository Location.	5.2-2
5-94.	Water-Table Map for the Unconfined Aquifer Within the Reference Repository Location.	5.2-5
5-95.	Water-Table Rise Within the Reference Repository Location Attributable to Water-Disposal Activities	5.2-6
5-96.	Estimated 1944 Water-Table Map Within the Reference Repository Location Prior to Water-Disposal Activities	5.2-8
5-97.	Unconfined Water-Level Responses in Wells Within and Adjacent to the Reference Repository Location.	5.2-9
5-98.	Hydrograph of the Water Levels in the DC-1 Piezometers from 1972 Through 1981	5.2-12
5-99.	Location of Unconfined-Aquifer Well Sites Within the Reference Repository Location.	5.2-14
5-100.	Chemical Composition of Groundwater Within the Unconfined Aquifer in the Reference Repository Location . .	5.2-16
5-101.	Nitrate Ion Distribution in Unconfined Groundwater Beneath the Reference Repository Location.	5.2-18
5-102.	Temperature Distribution in Unconfined Groundwater . . .	5.2-20
5-103.	Tritium Hydrographs for Wells 699-35-66 and 699-37-82A Completed in the Unconfined Aquifer Within the Reference Repository Location	5.2-22

TABLES:

2-1.	Area Designations Used in Screening.	2.1-11
2-2.	Steps in the Ranking Process.	2.1-12
2-3.	Summary Description of Technical Factors Considered in the Siting Process.	2.2-2
2-4.	Summary of Screening Guidelines.	2.2-9
2-5.	Summary Description of Environmental Factors Considered in the Siting Process.	2.3-2
2-6.	Considerations, Measures, and Guidelines Used in the Candidate-Area Screening of the Pasco Basin.	2.5-3
2-7.	Considerations, Measures, and Guidelines Used in Subarea Screening of the Pasco Basin.	2.5-7
2-8.	Estimated Range of Existing Conditions at Site Localities on the Hanford Site.	2.5-13
2-9.	Criteria Matrix Descriptors.	2.5-20
2-10.	Ranking Criteria.	2.5-24
2-11.	Candidate Site Measure Matrix.	2.5-25
2-12.	Criteria Ranges and Rank Order of Weights.	2.5-26
2-13.	Results of Ranking.	2.5-27
3-1.	Summary and Description of Hanford Site Boreholes.	3.2-2
3-2.	Aeromagnetic Surveys.	3.6-6
3-3.	Gravity Investigations.	3.6-13
3-4.	Geoelectric Layers and Interpreted Rock Type.	3.6-15
3-5.	Geothermal Gradients Calculated for Selected Borehole Logs from Wells Within the Hanford Site.	3.6-18
3-6.	Remote-Sensing Studies of the Columbia Plateau and Surrounding Area.	3.6-21
3-7.	Calculated Long-Term Probability of Consequent Volcanic Events.	3.7-6
3-8.	Faults Within the Pasco Basin.	3.7-10
3-9.	Characteristics of Folds Within the Pasco Basin.	3.7-23
3-10.	Felt and Recorded Earthquakes Within the Columbia Plateau and Surrounding Area through 1980.	3.7-39
3-11.	Eastern Washington Focal Mechanism Solutions.	3.7-48
3-12.	Projected Gross and Net Values and Estimated Present Values of Mineral Resources in the Adjacent Counties Study Area, 1981-2005.	3.9-4
3-13.	Development, Production, and Marketing Costs of Known or Potential Geologic Resources of the Reference Repository Location Vicinity Study Area and the Remainder of the Columbia Plateau.	3.9-5
3-14.	Projected Gross and Net Values and Estimated Present Values of Mineral Resources in the Columbia Plateau Study Area, 1981-2005.	3.9-7
3-15.	Economic Comparisons of Mineral-Resource Values-- the Reference Repository Location Vicinity Versus the Remainder of the Columbia Plateau.	3.9-8
4-1.	Mechanical Characteristics of Basalts Used for Concep- tual Design.	4.1-2
4-2a.	Physical and Mechanical Property of Hanford Site Basalt Entablature Zones.	4.1-3

TABLES (Contd.):

4-2b.	Physical and Mechanical Property of Hanford Site Basalt Colonnade Zones	4.1-4
4-2c.	Physical and Mechanical Property of Hanford Site Basalt Interflow Zones	4.1-5
4-3.	Physical- and Mechanical-Property Tests.	4.1-6
4-4.	Goodman Jack Test: Modulus Values in the Entablature Zone of the Pomona Flow at the Near-Surface Test Facility	4.2-3
4-5.	Step 1 - Modulus of Deformation for Pomona Entabla- ture at the Near-Surface Test Facility	4.2-9
4-6.	Coefficient of Friction of Joints for Umtanum Entabla- ture Samples Tested in Triaxial Compression at 20°C.	4.3-4
4-7.	Coefficient of Friction of Joints for Umtanum Entabla- ture Samples Tested in Triaxial Compression at Elevated Temperatures.	4.3-5
4-8.	Thermal and Thermomechanical Characteristics of Basalts Used for Conceptual Design	4.4-1
4-9.	Thermal Properties of Hanford Site Basalts	4.4-2
4-10.	Thermal Property Tests	4.4-3
4-11.	Summary of In Situ Stress Data Obtained by the Hydro- fracturing Method.	4.6-9
4-12.	Comparison of the Three Principal Stresses Measured by Overcoring and Hydrofracturing Methods in Pomona Basalt at the Near-Surface Test Facility Level	4.6-10
4-13.	Construction Projects Completed in Basalt.	4.8-2
5-1.	Principal Groups Involved in Basalt Hydrologic Testing.	5.1-4
5-2.	Dimensional Statistics of the Principal Strati- graphic Units Within the Columbia Plateau.	5.1-6
5-3.	General Information Regarding Groundwater Hydrology.	5.1-11
5-4.	General Ranges and Values for Selected Hydrologic Properties	5.1-28
5-5.	Equivalent Hydraulic Conductivity for Selected Stratigraphic Intervals.	5.1-30
5-6.	Comparison of Equivalent Hydraulic Conductivity Values Between the Middle Sentinel Bluffs and Umtanum Flows.	5.1-43
5-7.	Hydraulic Heads Within Selected Stratigraphic Intervals in the Saddle Mountains Basalt	5.1-56
5-8.	Areal Head Gradients in Selected Members of the Wanapum Basalt	5.1-62
5-9.	Areal Head Gradient in the Middle Sentinel Bluffs and Umtanum Flow Tops of the Grande Ronde Basalt	5.1-63
5-10.	Construction Data for Washington State Department of Ecology Test/Observation Wells in Eastern Washington	5.1-79
5-11.	Range in Concentration and Mean Composition of Major Chemical Constituents Within Groundwater of the Columbia River Basalt Group.	5.1-85
5-12.	Range and Median Concentrations of Trace Elements for Groundwater Within Columbia River Basalt	5.1-87

TABLES (Contd.):

5-13.	Range in Concentration and Mean Composition for Major Chemical Constituents Within Groundwater in the Unconfined Aquifer at Hanford.	5.1-88
5-14.	Range and Median Concentrations of Trace Elements for Unconfined Groundwater at Hanford.	5.1-90
5-15.	Location, Depth, and Date of Groundwater-Sample Collection for Zones Within the Saddle Mountains Basalt	5.1-93
5-16.	Range in Concentration and Mean Composition of Major Chemical Constituents for Groundwater Within the Mabton Interbed and Saddle Mountains Basalt.	5.1-96
5-17.	Range and Median Concentrations of Trace Elements for Groundwater Within Saddle Mountains Basalt at the Hanford Site	5.1-103
5-18.	Formation Fluid Temperature Within the Saddle Mountains Basalt in Selected Boreholes on the Hanford Site . . .	5.1-104
5-19.	Dissolved Gas Content and Makeup for Groundwater Collected from the Saddle Mountains Basalt in Borehole DC-15	5.1-107
5-20.	Location, Depth, and Date of Groundwater-Sample Collection for Zones Within the Wanapum Basalt	5.1-111
5-21.	Range in Concentration and Mean Composition of Major Inorganic Constituents and Hydrochemical Parameters for Wanapum Basalt Groundwater on the Hanford Site . .	5.1-112
5-22.	Total Dissolved Solids and Chloride Concentration in Priest Rapids Groundwater.	5.1-115
5-23.	Range and Median Concentrations of Trace Elements for Groundwater Within the Wanapum Basalt.	5.1-116
5-24.	Formation Temperature Within the Wanapum Basalt in Selected Boreholes on the Hanford Site	5.1-119
5-25.	Potentiometric Measurement of Eh in Groundwaters Collected From Zones Within the Wanapum Basalt	5.1-120
5-26.	Distribution of Dissolved Gas-Components in Wanapum Basalt Zones	5.1-121
5-27.	Location, Depth, and Date of Groundwater Collection for Selected Zones Within the Grande Ronde Basalt. . .	5.1-124
5-28.	Range of Concentration and Mean Composition of Major Inorganic Constituents and Hydrochemical Parameters Within the Groundwater of the Grande Ronde Basalt. . .	5.1-125
5-29.	Range and Median Concentrations of Trace Elements for Groundwater Within the Grande Ronde Basalt	5.1-129
5-30.	Formation Fluid Temperatures for Groundwater Zones in the Grande Ronde Basalt in Selected Boreholes on the Hanford Site	5.1-130
5-31.	Measured Potentiometric Eh Values for Groundwater Collected from Zones Within the Grande Ronde Basalt. .	5.1-131
5-32.	Distribution of Dissolved Gas Components in Grande Ronde Basalt Zones.	5.1-133
5-33.	Stratigraphic Location of Hydrochemical and Isotopic Breaks Beneath the Hanford Site.	5.1-139

TABLES (Contd.):

5-34.	Natural Abundance of Some Isotopes Presently Being Used and/or Considered for Use in Hydrologic Studies. .	5.1-141
5-35.	Ranges and Mean Values of Delta Oxygen-18 and Delta Hydrogen-2 for the Three Major Basalt Formations Beneath the Hanford Site	5.1-155
5-36.	Ranges and Mean Values of Delta Oxygen-18 and Delta Hydrogen-2 for the Three Major Basalt Formations Both Inside and Outside the Cold Creek Syncline Area, Hanford Site	5.1-157
5-37.	Calculated Mean Surface Air Temperature from Delta Oxygen-18 and Delta Hydrogen-2 Values for Basalts Beneath the Hanford Site	5.1-158
5-38.	Values of Delta Carbon-13 for Various Natural Materials	5.1-159
5-39.	Values of Delta Carbon-13 for Both Bicarbonate and Methane from Various Wells at the Hanford Site	5.1-163
5-40.	Sulfur Isotopic Composition for the Principal Sources of Sulfate in Groundwater.	5.1-164
5-41.	Mean Tritium Concentrations (in tritium units) for Columbia River Basalts from Selected Boreholes and the Columbia River	5.1-167
5-42.	Mean Carbon-14 Age Calculations for the Columbia River Basalt Groundwaters Beneath the Hanford Site	5.1-170
5-43.	Range and Mean Values for Activity Ratios and Total Uranium for Spring and Groundwater Samples from Columbia River Basalts at the Hanford Site	5.1-178
5-44.	Distribution of Wells According to Major Use Categories Within the Columbia Plateau and the Pasco Basin. . . .	5.1-191
5-45.	Distribution of Wells Within the Columbia Plateau and Pasco Basin According to Use	5.1-192
5-46.	Groundwater Use in the Pasco Basin	5.1-193
5-47.	Primary References for Hydrologic Testing Data and Conceptual Models.	5.1-199
5-48.	Hydraulic-Property Values for the Unconfined Aquifer Within the Reference Repository Location and the Entire Hanford Site.	5.2-3
5-49.	Expected Range and Mean of Hydraulic-Property Values for the Columbia River Basalt Group Within the Reference Repository Location.	5.2-3
5-50.	Anticipated Hydraulic-Head Conditions Within Confined Aquifers of the Columbia River Basalt Group in the Reference Repository Location	5.2-10
5-51.	Expected Range in Concentration and Mean Composition for Major Chemical Constituents for Groundwater Within the Unconfined Aquifer in the Reference Repository Location and the Entire Hanford Site. . . .	5.2-15
5-52.	Historic Major Inorganic- and Hydrochemical-Parameter Analyses for the Unconfined Aquifer at Well 699-27-8	5.2-19

TABLES (Contd.):

5-53.	Anticipated Range in Concentration and Mean Composition of Major Chemical Constituents for Columbia River Basalt Groundwaters Within the Reference Repository Location.	5.2-24
5-54.	Historic Major Inorganic and Hydrochemical Parameter Analyses for Groundwater Within the Upper Wanapum Basalt in the Cold Creek Valley.	5.2-25
5-55.	Principal Dissolved-Gas Components Anticipated in Columbia River Basalt Groundwater Within the Reference Repository Location.	5.2-27
5-56.	Expected Range and Mean Values in Stable Isotopic Content for Columbia River Basalt Groundwater Within the Reference Repository Location	5.2-28
5-57.	Expected Range and Mean Radioisotope Content for Columbia River Basalt Groundwaters Within the Reference Repository Location.	5.2-30

Site Characterization Report for the Basalt Waste Isolation Project

November 1982



**Prepared by Rockwell Hanford Operations
Under Contract DE-AC06-77RLO1030**

**Prepared For:
U.S. Department of Energy
Assistant Secretary for Nuclear Energy
Office of Terminal Waste Disposal
and Remedial Action
Washington, D.C. 20545**

VOLUME II

CONTENTS

CHAPTER 6. GEOCHEMISTRY	6.0-1
6.1 Host Rock Geochemistry.	6.1-1
6.1.1 General Description of Host Rock.	6.1-1
6.1.2 Bulk Chemical Composition of Grande Ronde Basalt. . .	6.1-5
6.1.3 General Mineralogy and Petrography of Grande Ronde Basalt.	6.1-11
6.1.4 Primary Phases in Grande Ronde Basalt	6.1-11
6.1.5 Secondary Phases.	6.1-16
6.1.6 Composition of Interbeds in the Pasco Basin	6.1-24
6.2 Groundwater Geochemistry.	6.2-1
6.2.1 Major Inorganic Content	6.2-1
6.2.2 Trace Elements.	6.2-4
6.2.3 Hydrochemical Field Parameters.	6.2-5
6.2.4 Dissolved Gas	6.2-8
6.3 Chemistry of Waste, Barriers, and Near-Field Environment. . .	6.3-1
6.3.1 Waste Forms	6.3-1
6.3.2 Barrier Materials	6.3-8
6.3.3 Near-Field Environment.	6.3-11
6.4 Geochemical Retardation	6.4-1
6.4.1 Radionuclide Solubilities	6.4-1
6.4.2 Radionuclide Sorption	6.4-5
6.5 Natural Analogs	6.5-1
6.5.1 Waste Form Analogs.	6.5-1
6.5.2 Canister and Overpack Analogs	6.5-10
6.5.3 Backfill Analogs	6.5-11
6.6 Field Tests	6.6-1
6.7 Summary	6.7-1
6.8 Summary of Unresolved Issues.	6.8-1
6.9 References.	6.9-1
 CHAPTER 7. SURFACE HYDROLOGY.	 7.1-1
7.1 Hydrologic Description.	7.1-1
7.1.1 Regional.	7.1-1
7.1.2 Pasco Basin	7.1-4
7.1.3 Hanford Site and Reference Repository Location. . . .	7.1-8
7.1.4 Streamflow Characteristics.	7.1-11
7.1.5 Water Control Structures.	7.1-12
7.2 Floods.	7.2-1
7.2.1 Flood History	7.2-1
7.2.2 Flood Potential	7.2-3
7.3 Surface Water Use and Demand for Water Within the Pasco Basin	7.3-1
7.3.1 Surface Water Use	7.3-1
7.3.2 Surface Water Demand.	7.3-2
7.3.3 Surface Water Intakes	7.3-2

7.4	Surface Water Quality	7.4-1
7.4.1	Pasco Basin	7.4-1
7.4.2	Water Quality	7.4-1
7.4.3	Water Quality Associated With Hanford Site Operations.	7.4-13
7.5	Summary of Unresolved Issues.	7.5-1
7.6	References.	7.6-1

CHAPTER 8. CLIMATOLOGY, METEOROLOGY, AND AIR QUALITY. 8.1-1

8.1	Recent Climate and Meteorology.	8.1-1
8.1.1	General Climate of the Region	8.1-1
8.1.2	Sources of Regional and Local Climate Information	8.1-7
8.1.3	Specific Climatic Elements.	8.1-10
8.2	Air Quality	8.2-1
8.2.1	Ambient Air Quality	8.2-1
8.2.2	Emissions	8.2-1
8.2.3	Baseline Concentrations	8.2-2
8.2.4	Basalt Waste Isolation Project Air Quality Impacts.	8.2-4
8.3	Long-Term Climatic Assessment	8.3-1
8.3.1	Paleoclimatology.	8.3-1
8.3.2	Future Climatic Variation	8.3-10
8.4	Meteorological Requirements for the Reference Repository Location	8.4-1
8.4.1	Dispersion Evaluations.	8.4-1
8.4.2	Meteorological Conditions for Design Bases.	8.4-6
8.4.3	Site Paleoclimatic Data	8.4-16
8.5	Summary of Unresolved Issues.	8.5-1
8.6	References.	8.6-1

CHAPTER 9. ENVIRONMENTAL, LAND-USE, AND SOCIOECONOMIC CHARACTERISTICS. 9.1-1

9.1	Environmental Characteristics	9.1-1
9.1.1	Ecology	9.1-1
9.1.2	Climate	9.1-19
9.1.3	Geology	9.1-19
9.1.4	Air Quality	9.1-19
9.1.5	Water Quality and Use	9.1-19
9.1.6	Radiological Background	9.1-19
9.2	Land-Use Characteristics.	9.2-1
9.2.1	Land-Use Categories	9.2-1
9.2.2	Land-Use Change	9.2-5
9.2.3	Ownership	9.2-7
9.2.4	Aesthetics and Recreation	9.2-8
9.2.5	Historic, Archaeological, and Cultural Resources.	9.2-8

9.3	Socioeconomic Characteristics	9.3-1
9.3.1	Demography.	9.3-1
9.3.2	Economy	9.3-1
9.3.3	Service Facilities.	9.3-16
9.3.4	Government and Institutional Organizations.	9.3-22
9.4	Summary of Unresolved Issues.	9.4-1
9.5	References.	9.5-1

CHAPTER 10. REPOSITORY DESIGN 10.0-1

10.1	Conceptual Design Bases	10.1-1
10.1.1	Functions and General Criteria.	10.1-1
10.1.2	Reference Repository Location	10.1-2
10.1.3	Site Arrangement.	10.1-2
10.2	Surface Facilities and Systems.	10.2-1
10.2.1	Surface Facilities.	10.2-1
10.2.2	Waste Handling Systems.	10.2-5
10.2.3	Service Systems	10.2-7
10.3	Access Shafts	10.3-1
10.3.1	Shaft No. 1 - Confinement Air Exhaust Shaft	10.3-1
10.3.2	Shaft No. 2 - Waste Transport Shaft	10.3-1
10.3.3	Shaft No. 3 - Confinement Air Intake Shaft.	10.3-2
10.3.4	Shaft No. 4 - Service Shaft	10.3-2
10.3.5	Shaft No. 5 - Basalt Transport Shaft.	10.3-3
10.3.6	Shaft Pillar.	10.3-4
10.3.7	Shaft Design Options.	10.3-4
10.4	Design of Underground Openings.	10.4-1
10.4.1	Subsurface Facilities	10.4-1
10.4.2	Waste Storage Panels.	10.4-5
10.4.3	Waste Storage Holes	10.4-5
10.5	Strength of Rock Mass	10.5-1
10.5.1	Results of Rock Stress Analysis	10.5-3
10.5.2	Thermomechanical Considerations	10.5-7
10.5.3	Rock Support.	10.5-9
10.5.4	Effects of Stratification on Design	10.5-9
10.5.5	Effects of Other Waste Receipt Ratios on Design	10.5-10
10.6	Construction of Access Shafts and Subsurface Facilities	10.6-1
10.6.1	Access Shafts Construction.	10.6-1
10.6.2	Underground Openings Construction	10.6-1
10.6.3	Construction Contingency Plans.	10.6-3
10.7	Backfill.	10.7-1
10.7.1	Backfill Material	10.7-1
10.7.2	Backfilling Procedure	10.7-1
10.7.3	Effects of Retrievability on Design	10.7-2
10.8	Sealing of Shafts, Boreholes, and Underground Openings.	10.8-1
10.8.1	Seal Design	10.8-5
10.9	Unresolved Repository Issues.	10.9-1
10.10	References.	10.10-1

CHAPTER 11.	WASTE PACKAGE	11.0-1
11.1	Waste Forms	11.1-1
	11.1.1 Reprocessed High-Level Waste (Borosilicate Glass) . .	11.1-1
	11.1.2 Spent Fuel.	11.1-19
	11.1.3 Strength and Weaknesses of Reference Waste Forms. . .	11.1-27
	11.1.4 Summary of Important Conclusions.	11.1-30
11.2	Design Concepts	11.2-1
	11.2.1 Waste Package Description	11.2-1
	11.2.2 Functions of a Waste Package for Basalt	11.2-6
	11.2.3 Reference Horizontal Borehole Emplacement	11.2-9
	11.2.4 Tunnel Emplacement Alternate	11.2-10
	11.2.5 Waste Package Component Reliability	11.2-10
	11.2.6 Summary of Important Conclusions	11.2-12
11.3	Research and Development	11.3-1
	11.3.1 Approach to Research and Development	11.3-1
	11.3.2 Status of Research and Development	11.3-2
	11.3.3 Summary of Important Conclusions	11.3-37
11.4	Emplacement Conditions	11.4-1
	11.4.1 Physicochemical Conditions	11.4-1
	11.4.2 Radiological Conditions	11.4-17
	11.4.3 Summary of Important Conclusions	11.4-21
11.5	Alternate Waste Package	11.5-1
11.6	Summary	11.6-1
11.7	Summary of Unresolved Issues	11.7-1
11.8	References.	11.8-1
CHAPTER 12.	PERFORMANCE ASSESSMENT.	12.0-1
12.1	Long-Term Repository Performance Issues	12.1-1
	12.1.1 Groundwater Flow Paths and Travel Times	12.1-1
	12.1.2 Repository Release Rates	12.1-2
	12.1.3 Releases to the Accessible Environment.	12.1-2
	12.1.4 Related Issues	12.1-3
12.2	Approach to Long-Term Repository Performance Analysis	12.2-1
	12.2.1 Long-Term Repository Performance Analysis Framework.	12.2-1
12.3	Predictive Models	12.3-1
	12.3.1 Mathematical Models	12.3-1
	12.3.2 Numerical Models	12.3-5
	12.3.3 Code Verification and Benchmarking	12.3-15
12.4	Preliminary Long-Term Repository Performance Analysis	12.4-1
	12.4.1 Far-Field Studies to Assess Compliance with U.S. Nuclear Regulatory Commission Proposed Technical Criteria for Groundwater Transit Time . .	12.4-1
	12.4.2 Very Near-Field Studies to Assess Compliance with U.S. Nuclear Regulatory Commission Proposed Technical Criteria for Repository Releases.	12.4-24
	12.4.3 Near-Field Studies to Assess Compliance with U.S. Environmental Protection Agency Draft Regulations	12.4-28

12.4.4	Summary of Conclusions from Preliminary Long-Term Repository Performance Analysis	12.4-50
12.4.5	Assessment of Uncertainty in Performance Assessment Results	12.4-52
12.5	Summary of Unresolved Issues	12.5-1
12.6	References	12.6-1

FIGURES:

6-1.	Stratigraphy of the Reference Repository Location . . .	6.1-2
6-2.	Typical Intraflow Structures Present in a Grande Ronde Basalt Flow	6.1-4
6-3.	Magnesium Oxide Plotted Versus Titanium Dioxide for Grande Ronde Basalt Chemical Types and Subtypes . . .	6.1-7
6-4.	Magnesium Oxide and Titanium Dioxide Plotted Versus Stratigraphic Depth in Borehole DC-6.	6.1-8
6-5.	Zirconium and Chromium Plotted Versus Stratigraphic Position in Borehole DC-6	6.1-10
6-6.	Compositions of All Clays (mostly smectite) Formed Prior to Deposition of Zeolite or Silica.	6.1-17
6-7.	Compositions of First and Second Generations of Secondary Zeolite	6.1-18
6-8.	Volume Percent, Filled and Unfilled Fractures, Rocky Coulee, McCoy Canyon, and Museum Flows.	6.1-20
6-9.	A Typical Crystallization Sequence for Secondary Minerals.	6.1-23
6-10.	Location of Boreholes Used for Geochemical Studies of Groundwater.	6.2-2
6-11.	Measured Fluid Temperature Versus Depth in Selected Boreholes in the Hanford Site	6.2-6
6-12.	Calculated Pressure Versus Depth in Selected Boreholes in the Hanford Site	6.2-7
6-13.	Solubility of UO_2 in Water as a Function of Temperature; fO_2 in the Experiments Buffered by the Equilibrium Between UO_2 and UO_3 under Oxidizing Conditions.	6.3-2
6-14.	Solution Concentrations of Various Ions from PNL 76-68 Glass as a Function of Time at 300°C, 30 Megapascals in Deionized Water.	6.3-6
6-15.	Comparison of Estimated Solubilities for Actinide Compounds $UO_2(c)$, $UO_2(OH)_2 \cdot H_2O$, $NpO_2(c)$, $PuO_2(c)$, and Am (soil) with the Maximum Permissible Concentrations Under Repository Conditions at 25°C, 0.1 Megapascal, pH 10, and Eh 0.29 Volt (oxidizing) or -0.27 Volt (reducing)	6.4-4
6-16.	Distribution of Activated Kaolin Throughout the Basalt Column after Particulate Flow Experiments. . .	6.4-15
6-17.	Minimum Time Required for Anhydrous Thermal Reconstruction of Natural Glass to a Depth of 10 Microns as a Function of Temperature	6.5-2
6-18.	Time Required for the Hydrothermal Reconstruction of Natural Glass (perlite) to a Depth of 100 Microns as a Function of Temperature	6.5-4

FIGURES (Contd.):

6-19.	Experimental Hydration Rate Curve for Obsidian at 100°C.	6.5-5
6-20.	Logarithm of Hydration Constant as a Function of Inverse Temperature for Natural Rhyolitic Glass Samples	6.5-6
6-21.	Comparison of Relative Toxicities of Various Natural Ores to Nuclear Wastes Using Low-Grade Uranium Ore.	6.5-9
7-1.	Columbia River Drainage Basin	7.1-2
7-2.	Hydrologic Basins Designated for the Columbia Plateau	7.1-3
7-3.	Locations of Principal Dams Within the Columbia Plateau Study Area.	7.1-5
7-4a.	Schematic Representation of the Hydraulic Regime of the Columbia River Showing Major Dams	7.1-6
7-4b.	Schematic Representation of the Hydraulic Regime of the Snake River Showing Major Dams.	7.1-7
7-5.	Schematic of the U.S. Geological Survey Gauging Network for the Pasco Basin	7.1-9
7-6.	Surface Water Bodies Including Ephemeral Creeks on the Hanford Site	7.1-10
7-7.	Yakima River at Kiona, Annual Mean Daily Discharge, Log-Pearson III Distribution.	7.1-13
7-8.	Yakima River at Kiona, Annual Peak Instantaneous Flow, Log-Pearson III Distribution.	7.1-13
7-9.	Yakima River at Kiona, Family of Low-Flow Curves, Log-Pearson III Distribution.	7.1-14
7-10.	Columbia River Below Priest Rapids Dam, Annual Mean Daily Discharge, Log-Pearson III Distribution	7.1-14
7-11.	Columbia River Below Priest Rapids Dam, Annual Peak Instantaneous Flow, Log-Pearson III Distribution.	7.1-15
7-12.	Columbia River Below Priest Rapids Dam, Family of Low-Flow Curves, Log-Pearson III Distribution	7.1-15
7-13.	Schematic Cross Section of the Priest Rapids Dam and Related Facilities.	7.1-18
7-14.	Plan of Ben Franklin Dam.	7.1-19
7-15.	Inundation Along the Hanford Reach of the Columbia River Resulting from Operation of Ben Franklin Dam.	7.1-20
7-16.	Predicted Water Table Resulting from Ben Franklin Dam 122-Meter (400-Foot) Pool	7.1-21
7-17.	Predicted Water Table Rise for Ben Franklin Dam with 122-Meter (400-Foot) Pool	7.1-22
7-18.	Flooded Area During the 1894 Flood.	7.2-2
7-19.	Flooded Area from a 100-Year Flood of the Yakima River in the Vicinity of the Hanford Site	7.2-4
7-20.	Flooded Area for the Probable Maximum Flood	7.2-5
7-21.	Flooded Area Resulting from a 50-Percent Breach of Grand Coulee Dam.	7.2-7
7-22.	Drainage Area Map of the Cold Creek Watershed	7.2-8
7-23.	Projected Demand for Water in the Pasco Basin	7.3-9
7-24.	Surface Water Intakes in the Pasco Basin.	7.3-10
7-25.	Surface Water Monitoring Stations	7.4-4

FIGURES (Contd.):

7-26.	Comparison of 1979 Monthly Mean Temperature Distributions Along the Columbia River Within the Pasco Basin	7.4-11
7-27.	Comparison of 1979 Monthly Mean Temperature Distributions of Columbia River Tributaries Within the Pasco Basin	7.4-12
7-28.	Monthly Sediment Discharge Totals in 1979 for the Yakima River at Kiona, Washington	7.4-14
7-29.	Monthly Mean Specific Conductance in 1979 of the Snake River Near Burbank, Washington.	7.4-15
8-1.	The Hanford Site in Relation to Surrounding Terrain	8.1-2
8-2.	Surface-Wind Roses for Various Locations on and Surrounding the Hanford Site, Based on 5-Year Averages, 1952-1956	8.1-4
8-3.	Schematic Flow Pattern Associated with a Surface High Centered East of the Region.	8.1-5
8-4.	Schematic Flow Pattern Typically Associated with High Pressure to the West and Low Pressure to the East of the Region.	8.1-6
8-5.	Return Periods of Rainfall Intensity and Duration Based on the Period 1947-1969 at the Hanford Meteorological Station.	8.1-12
8-6.	Water Balance at Hanford.	8.1-16
8-7.	Monthly Average Wind Roses for the Hanford Meteorological Station Based on 15.2-Meter Level Wind Data, 1955-1970.	8.1-22
8-8.	Seasonal and Diurnal Variation in the 15.2-Meter Level Windspeed (meters per second), 1955-1970.	8.1-23
8-9.	Wind Roses as a Function of Stability and for all Stabilities of the Hanford Meteorological Station, Based on Winds at 60 Meters and Air Temperature Stabilities Between 1 and 60 Meters for the Period 1955 through 1970	8.1-24
8-10.	General Trends in Global-Scale Climate for the Past Million Years.	8.3-2
8-11.	Maximum Extent of Glaciation During the Last Ice Age.	8.3-6
8-12.	Peak Wind-Gust Return-Probability Diagram	8.4-8
8-13.	Lowest Temperatures During Each of the 68 Winters at the Hanford Site Between 1912 and 1980 and Their Probability of Occurrence	8.4-12
8-14.	Highest Temperatures During Each of the 66 Summers at Hanford Between 1912 and 1980 (1943-1944 Missing) and Their Probability of Occurrence.	8.4-14
9-1.	Map of the Hanford Site	9.1-2
9-2.	Major Plant Communities of the Hanford Site	9.1-3
9-3.	General Food Web Diagram for the Hanford Site	9.1-5
9-4.	Map of the 200 Areas Controlled Zone Showing the Reference Repository Location and the Sample Points	9.1-20
9-5.	Land Use Adjacent to the Reference Repository Location.	9.2-2
9-6.	Utilities and Communications	9.2-6
9-7.	Primary Impact Area	9.3-2

FIGURES (Contd.):

9-8.	U.S. Census Populations for 1980 of Cities Within an 80-Kilometer (50-Mile) Radius of the Hanford Meteorological Station	9.3-3
10-1.	Repository Cutaway.	10.0-2
10-2.	Reference Repository Location Showing Exploratory Shaft-Phase I Site and Principal Borehole (RRL-2)	10.1-3
10-3.	Site Arrangement.	10.1-5
10-4.	Surface Facilities Plan--Central Process Area	10.2-3
10-5.	Waste Canister in Horizontal Storage Borehole	10.2-6
10-6.	Shaft-Pillar Ventilation Flow Paths	10.2-9
10-7.	Cooling Water System.	10.2-11
10-8.	Shaft-Pillar Layout	10.3-5
10-9.	Alternate Shaft-Pillar Arrangements	10.4-2
10-10.	Subsurface Facilities Layout (bow-tie arrangement).	10.4-3
10-11.	Waste Storage Panel Cross Sections.	10.4-6
10-12.	Orientation of Rock Stresses and Excavations.	10.5-4
10-13.	Maximum Theoretical Thermoelastic Rock Stress, Variation with Time (2:1 horizontal to vertical stress ratio; commercial high-level waste).	10.5-6
10-14.	Backfill/Retrievability Decision Flowchart.	10.7-4
10-15.	Role of Various Isolation Components and Their Contribution to the Control of Radionuclide Releases	10.8-2
10-16.	Determination of Maximum Permissible Release.	10.8-4
10-17.	Multiple-Zoned Plugs for Tunnels.	10.8-6
10-18.	Detail of Shaft Cut-Off Collar.	10.8-7
11-1.	Centerline Temperatures of a Reference Canister Containing 72-68 Waste Glass (PW-4b type waste), Cooled in Air and Water	11.1-19
11-2.	Typical Light Water Reactor Fuel Assemblies of Recent Design	11.1-21
11-3.	Decay Heat as a Function of Time for Typical Pressurized Water Reactor and Boiling-Water Reactor Spent-Fuel Canisters Using Intact Assemblies.	11.1-28
11-4.	Early Waste Package Emplacement Concept	11.2-2
11-5.	Typical Waste Package Emplacement Concept for Basalt.	11.2-3
11-6.	Waste Canister in Horizontal Storage Borehole	11.2-5
11-7.	Solubility of UO_2 in Water as Function of Temperature; fO_2 in the Experiments Buffered by the Equilibrium Between UO_2 and UO_3 Under Oxidizing Conditions.	11.3-4
11-8.	The Approach to Equilibrium Using a Hydrogen Diffusion Membrane	11.3-5
11-9.	Scanning Electron Micrograph of a Section through the Product of a 4-Week Hydrothermally Treated Sample of a PNL 76-68 Glass Specimen	11.3-11
11-10.	Composition Distance Profile for Leached PNL 76-68 Glass Sphere Shown in Figure 11-9	11.3-12
11-11.	Solution Concentrations of Various Ions from PNL 76-68 Glass as a Function of Time at 300°C, 30 Megapascals in Deionized Water	11.3-14

FIGURES (Contd.):

11-12.	Temperature-Versus-Time Curves for Different Components of a Vertically Emplaced Spent Fuel Waste Package in a Repository Located in Basalt	11.3-17
11-13.	Peak Temperature-Versus-Backfill Conductivity for a Spent Fuel Element Waste Package.	11.3-18
11-14.	Temperature-Versus-Time Curves for Different Components of a Vertically Emplaced Commercial High-Level Waste Package in a Repository Located in Basalt . . .	11.3-19
11-15.	Temperature-Versus-Time Curves for Different Components of a Vertically Emplaced Defense High-Level Waste Package in a Repository Located in Basalt . . .	11.3-19
11-16.	Selected Major Cation Concentrations in Solutions Taken from SPCW 1-1 (SPC-4 + groundwater) Plotted as a Function of Time	11.3-24
11-17.	Selected Major Cation Concentrations in Solutions Taken from BSPW 1-1 (basalt + SPC-4 + groundwater) Plotted as a Function of Time	11.3-25
11-18.	Dehydration of Fracture Mineralization at 0.1 Megapascal.	11.3-29
11-19.	Dehydration of Fracture Mineralization at 30 Megapascals.	11.3-29
11-20.	Schematic Representation of Groundwater Flow Path for Case I.	11.3-33
11-21.	Schematic Representation of Groundwater Flow Path for Case II	11.3-34
11-22.	Summary of Grande Ronde Groundwater Composition	11.4-2
11-23.	Divariant Curve (liquid-vapor) for Water (H ₂ O).	11.4-5
11-24.	Variation Trend of Solution pH as a Function of Time. .	11.4-9
11-25.	Relationship Between Estimated pH Resulting from the Dissociation of Silicic Acid and pH-Measured in the Hanford Basalt/Groundwater System Between 100° and 300°C	11.4-10
11-26.	Plot of Ph Versus 1/T for Groundwater in Equilibrium with Umtanum Basalt	11.4-11
11-27.	Cylinder (Canister) Radius Versus Water-to-Fuel Ratio for the Onset of Critical Conditions in Spent-Fuel Waste Packages	11.4-20
11-28.	An Alternate Waste Package Borehole Emplacement Concept	11.5-1
12-1.	Relationship Between Individual Models and Outstanding Long-Term Performance Assessment Issues	12.2-6
12-2.	Relationship of Important Processes Occurring in the Vicinity of a Repository.	12.3-1
12-3.	Typical System Model.	12.3-14
12-4.	Location of Cold Creek Syncline Siting Area, Showing the Reference Repository Location and Borehole DC-3 .	12.4-2
12-5.	Plan View (X-Y) of Two Streamlines Originating at the Repository, Assessment of Effectiveness of Geologic Isolation Systems (AEGIS) Model.	12.4-10

FIGURES (Contd.):

12-6.	East-West Cross-Sectional View (X-Z) of Two Streamlines Originating at the Repository, Assessment of Effectiveness of Geologic Isolation System (AEGIS) Model	12.4-11
12-7.	North-South Cross-Sectional View (X-Z) of Two Streamlines Originating at the Repository, Assessment of Effectiveness of Geologic Isolation System (AEGIS) Model	12.4-11
12-8.	Planar View of Streamlines from Hypothetical Repository to Boundary.	12.4-16
12-9.	Location of Boreholes Used in the Kriging Analysis.	12.4-19
12-10.	Schematic Representation of Groundwater Flow Path for Case I.	12.4-26
12-11.	Schematic Representation of Groundwater Flow Path for Case II	12.4-27
12-12.	Simplified Stratigraphic Section for Columbia River Basalt.	12.4-31
12-13.	Groundwater Pathlines and Travel Times for Middle Sentinel Bluffs Flow: No-Disruption Base Case.	12.4-38
12-14.	Groundwater Pathlines and Travel Times for Umtanum Flow: No-Disruption Base Case.	12.4-39
12-15.	Carbon-14 Concentration Contours at 10,000 Years for Middle Sentinel Bluffs Flow: No-Disruption Base Case.	12.4-41
12-16.	Carbon-14 Concentration Contours at 10,000 Years for Umtanum Flow: No-Disruption Base Case.	12.4-43
12-17.	Groundwater Flow Pathlines for Middle Sentinel Bluffs Flow: Fault Scenario.	12.4-45
12-18.	Groundwater Flow Pathlines for Umtanum Flow: Fault Scenario.	12.4-46
12-19.	Carbon-14 Concentration Contours for Middle Sentinel Bluffs Flow: Fault Scenario.	12.4-48
12-20.	Carbon-14 Concentration Contours for Umtanum Flow: Fault Scenario.	12.4-49

TABLES:

6-1.	Major-Element Composition of Grande Ronde Flows	6.1-6
6-2.	Element Compositions of Grande Ronde Basalt Flows Determined by Instrumental Neutron Activation Analysis.	6.1-9
6-3.	Petrographic Characteristics of Primary Phases in Grande Ronde Basalt	6.1-12
6-4.	Secondary Minerals Identified in Grande Ronde Basalt, Pasco Basin	6.1-13
6-5.	Mean Composition of Hanford Clay and Zeolite with Structural Formulas	6.1-19
6-6.	Relative Proportions of Secondary Minerals in	

TABLES (Contd.):

	Grande Ronde Basalt, Pasco Basin.	6.1-19
6-7.	Summary of Hydrochemical Data Available for Middle Sentinel Bluffs and Umtanum Flow Tops and Bottoms from Boreholes on the Hanford Site.	6.2-3
6-8.	Range and Median Values of Trace Elements for Ground- water Within the Grande Ronde Basalt Beneath the Hanford Site.	6.2-4
6-9.	Median Value and Range in Composition of Dissolved Gas in Grande Ronde Basalt Groundwater.	6.2-8
6-10.	Comparison of the Compositions of Residual Solutions from Experiments Reacting Alternate Waste Forms with Distilled Water at 30 Megapascals.	6.3-4
6-11.	Composition of Supercalcine SPC-4	6.3-7
6-12.	Waste Package Component Functions Versus Repository History for Reference Waste Package Conceptual Design	6.3-9
6-13.	Candidate Backfill Tailoring Agents for Reducing the Mobility of Key Radionuclides in a Repository Constructed in Basalt	6.3-10
6-14.	Analyses of Cesium Remaining in Solution from Hydro- thermally Treated Mixtures of Basalt Phases or Basalts with Cesium Phases	6.3-12
6-15.	SrZrO ₃ Interactions with Basalt or Basalt Phases under Hydrothermal Conditions at 200°C for 2 Months and 300°C for 1 Month	6.3-13
6-16.	Synthetic Groundwater Compositions	6.4-7
6-17.	Groundwater Composition Effects on Radionuclide Distribution Coefficient Values for Umtanum Basalt and Associated Secondary Minerals	6.4-7
6-18.	Temperature Effects on Radionuclide Distribution Coefficient Values for Umtanum Basalt	6.4-9
6-19.	Effect of Eh Conditions on Radionuclide Distribution Coefficient Values for Umtanum Basalt	6.4-10
6-20.	Current Conservative Best Estimates for Radionuclide Distribution Coefficient Values for the Columbia River Basalt Geohydrologic System	6.4-12
6-21.	Sorption Isotherms for Selected Radionuclides on Umtanum Basalt	6.4-13
7-1.	Design Data for Principal Dams and Reservoirs Within the Columbia Plateau	7.1-16
7-2.	Design Statistics for Priest Rapids Dam	7.1-17
7-3.	Benton and Franklin Counties 1975 Water Use Totals and Composition	7.3-1
7-4.	Projected Population of the Pasco Basin, 1980-2080.	7.3-3
7-5.	Projected Water Demand From Households, Governments, and Nonagricultural, Nonindustrial Business in the Pasco Basin, 1980-2080	7.3-4
7-6.	Projected Industrial Employment in the Pasco Basin, 1980-2080	7.3-5
7-7.	Projected Industrial Water Demand in the Pasco Basin, 1980-2080	7.3-6

TABLES (Contd.):

7-8.	Projected Agricultural Water Demand in the Pasco Basin, 1980-2080	7.3-7
7-9.	Projected Total Water Demand in the Pasco Basin, 1980-2080	7.3-8
7-10.	Summary of Downstream Surface Water Uses for the Columbia River	7.3-11
7-11.	Comparative Contribution of Pasco Basin Surface Flow Inputs Based on Water Year 1979 Discharge Statistics	7.4-2
7-12.	Washington State Water Quality Standards for the Hanford Reach of the Columbia River	7.4-3
7-13.	Summary of U.S. Geological Survey Surface Water Quality Sampling Activities Within the Pasco Basin	7.4-5
7-14.	Comparison of 1980 "Class A" Quality Parameters Upstream and Downstream from the Hanford Site	7.4-6
7-15.	Radiological Quality of the Columbia River Upstream of the Hanford Site, 1980	7.4-7
7-16.	Radiological Quality of the Columbia River Downstream of the Hanford Site, 1980	7.4-8
7-17.	Comparison of Extreme and Average Surface Water Temperatures Recorded at Various Stations Within the Pasco Basin	7.4-10
7-18.	Extreme Load and Concentration Values and 1979 Total Load of Suspended Sediment Within the Yakima River at Kiona, Washington	7.4-13
7-19.	Summary of U.S. Geological Survey Surface Water Quality Data for Stations on the Columbia River Within the Pasco Basin	7.4-16
7-20.	Summary of U.S. Geological Survey 1979 Surface Water Quality Data for Columbia River Tributaries	7.4-20
8-1.	Instrument Height Locations at the Hanford Meteorological Station	8.1-8
8-2.	Averages and Extremes of Precipitation at the Hanford Meteorological Station, 1912-1980	8.1-11
8-3.	Average Return Period and Existing Record for Various Precipitation Amounts and Intensities During Specified Time Periods at Hanford Meteorological Station Based on Extreme-Value Analysis of 1947-1969 Records	8.1-13
8-4.	Thornthwaite-Mather Water Balance for Hanford, Washington, 150-Millimeter Root-Zone Water Capacity	8.1-15
8-5.	Averages and Extremes of Temperature at the Hanford Meteorological Station, 1912-1980	8.1-17
8-6.	Averages and Extremes of Relative Humidity at the Hanford Meteorological Station, 1946-1980	8.1-18
8-7.	Monthly Averages of Psychrometric Data, 1950-1980	8.1-19
8-8.	Wind Averages and Peak Wind Gusts at the Hanford Meteorological Station, 1945-1980	8.1-21

TABLES (Contd.):

8-9.	Frequency of Wind Direction at the 1,500-Meter Level Over the Hanford Meteorological Station on a Seasonal and Annual Basis	8.1-25
8-10.	Mean Seasonal and Annual Afternoon Mixing Heights for the Spokane Area	8.1-25
8-11.	Tornado and Funnel Cloud History Within 161 Kilometers of the Hanford Meteorological Station	8.1-26
8-12.	Number of Thunderstorm Days at the Hanford Meteorological Station, 1945-1980	8.1-28
8-13.	Distribution of Hailstorm Days by Month, 1947-1970.	8.1-28
8-14.	National Ambient Air Quality Standards	8.1-30
8-15.	Summary of Hanford Duststorm Statistics, 1953-1970	8.1-30
8-16.	Number of Days with Heavy Fog at the Hanford Meteorological Station, 1945-1980	8.1-31
8-17.	Mandatory Class I Areas in the Pacific Northwest	8.2-3
8-18.	Estimates of Glacial Age Surface Temperature Deficits (relative to the present)	8.3-4
8-19.	Characteristics of Existing Ice Sheets and of the Maximum Quaternary Ice Cover	8.3-7
8-20.	Estimates of Minimum and Maximum Temperature Change and Rate of Change from the Present	8.3-11
8-21.	Annual Joint Windspeed, Direction, and Stability Frequencies for Hanford Meteorological Station Based on Hanford Delta-Temperature Stability Groups, 1955-1970	8.4-2
8-22.	Annual Joint Windspeed, Direction, and Stability Figures for Hanford Meteorological Station Based on Pasquill-Gifford Delta-Temperature Stability Groups, 1955-1970	8.4-3
8-23.	Computer Models Available at Hanford for X/Q , D/Q Long-Term Assessment	8.4-5
8-24.	Accident-Case Models Available to Meet U.S. Nuclear Regulatory Commission Guidelines	8.4-7
8-25.	Design Basis Tornado Characteristics	8.4-7
8-26.	Highest Average Monthly Windspeed and Peak Gusts	8.4-9
8-27.	Miscellaneous Snowfall Statistics, 1946 Through 1980.	8.4-10
8-28.	Periods of Extreme Cold Temperature and Persistence	8.4-11
8-29.	Statistics for Two Periods of Extreme High Temperatures	8.4-13
8-30.	Detailed Estimates of the Dust Loadings for the Six Worst Storms, Based on Surface Observations of the Hanford Meteorological Station, 1953-1970	8.4-15
8-31.	Characteristics of Paleoclimate Data Sources	8.4-17
9-1.	Plant Species Known to Occur on the Reference Repository Location	9.1-6
9-2.	Mammal Species Reported to Occur on the Hanford Site.	9.1-11
9-3.	Birds Common to the Hanford Site	9.1-13
9-4.	Reptilian and Amphibian Species Reported to Occur on the Hanford Site	9.1-17
9-5.	Darkling Beetle and Grasshopper Species Known to Occur on the Reference Repository Location	9.1-18

TABLES (Contd.):

9-6.	Summary of Radiological Data from Control Plot No. 2 for 1976 and 1977	9.1-21
9-7.	Median Concentrations of Man-Made Radionuclides in Soil and Vegetation in the Hanford Area Environs . .	9.1-22
9-8.	Summary of 1978 Radiological Data at Seven Sample Sites Along the 200 West Area Fence	9.1-23
9-9.	Summary of 1979 Radiological Data at Seven Sample Sites Along the 200 West Area Fence	9.1-24
9-10.	Washington State Register of Historic Places in Counties Adjacent to the Hanford Site	9.2-9
9-11.	Population Size Based on Census, Current Estimates, and Forecasts for Benton and Franklin Counties and the Primary Impact Area--1970-2000	9.3-4
9-12.	Components of Population Change by County and State . .	9.3-5
9-13.	Population Distribution by Age and Sex	9.3-5
9-14.	Personal Income by Major Sources, Richland- Kennewick-Pasco Standard Metropolitan Statistical Area 1972-1977.	9.3-6
9-15.	Resident Labor Force and Employment, Washington State and Benton-Franklin Counties.	9.3-8
9-16.	Richland-Kennewick-Pasco Standard Metropolitan Statistical Area Employment and Average Annual Worker Needs by Occupational Group, 1976-1985	9.3-10
9-17.	Tri-Cities Total Housing Stock (in units)	9.3-11
9-18.	Benton and Franklin Counties Real Estate Sales	9.3-12
9-19.	Unsold Housing Inventory by Price Range for Tri-Cities Area, 1978 and 1979	9.3-12
9-20.	Local Government Revenues and Expenditures	9.3-13
9-21.	Police Protection in 1978	9.3-16
9-22.	Fire Protection in 1978	9.3-16
9-23.	School Enrollment in Tri-Cities Districts, May 1975 and May 1978	9.3-17
9-24.	Educational Services in Benton and Franklin Counties, Fall 1979	9.3-17
9-25.	Percent Occupancy for Setup and Licensed Beds for the Tri-Cities Area Hospitals, 1972, 1976, and 1978 .	9.3-19
9-26.	Water Resources, Benton and Franklin Counties, 1970 and 1978	9.3-20
9-27.	Sewer Systems and Storm Water, Benton and Franklin Counties, 1978	9.3-21
9-28.	Transportation Facilities	9.3-23
9-29.	Local Government Functions in the Primary Impact Area .	9.3-24
10-1.	Conceptual Design Basis Waste Receipts.	10.1-2
10-2.	Subsurface Ventilation Requirements	10.2-8
10-3.	Key Features of the Most Favorable Alternate Repository Arrangements Considered.	10.4-1
10-4.	Rock-Mass Conceptual Design Assumptions (Umtanum horizon)	10.5-2
10-5.	Thermal and Stress Reference Design Values.	10.5-8
11-1.	Reference High-Level Waste Solids (calcine) Compositions.	11.1-3

TABLES (Contd.):

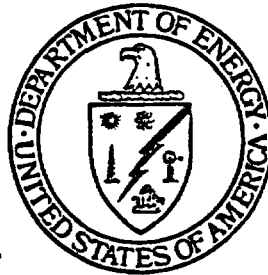
11-2.	Reference Waste Borosilicate Glass Compositons.	11.1-6
11-3.	Crystalline Phases in Waste-Glass Formulations.	11.1-7
11-4.	Typical Waste Glass Compositions.	11.1-9
11-5.	Chemical Composition of Reference Combined High-Level and Intermediate-Level Liquid Waste in Calcine Form.	11.1-10
11-6.	Chemical Composition of Fission Products and Actinides (plus daughters) at the Time of Reprocessing of Reference Commercially High-Level Waste.	11.1-11
11-7.	General Composition and Physical Properties of Reference Commercial High-Level waste Glass	11.1-12
11-8.	Chemical Composition of Defense Waste Sludge	11.1-14
11-9.	Isotopic Content of Defense Waste Sludge	11.1-15
11-10.	Chemical Composition of Defense Waste Sludge-Based Waste-Glass Form	11.1-16
11-11.	Isotopic Content of Defense Waste Sludge Based on Waste-Glass Form.	11.1-17
11-12.	Physical Properties of Waste-Glass Forms for Defense Waste Sludge	11.1-18
11-13.	Heat-Generation Rates of Simulated PW-4b Waste Glass 72-68	11.1-18
11-14.	Reported Fission Product Phase Chemistry in Spent Fuel.	11.1-26
11-15.	Leachability of Simulated Wate Forms.	11.1-29
11-16.	Waste Package Component Functions Versus Repository History for Reference Waste Package Conceptual Design.	11.2-7
11-17.	Results of Screening Corrosion Tests of Canister/Overpack Materials at 250°C, 5 MPa, and Under Anoxic Conditions	11.2-11
11-18.	Simulated Spent Fuel Fission Products Formulation (burnup of 33,000 Mwd/thm).	11.3-6
11-19.	Compositions of Residual Solutions from Experiments Reacting Simulated Spent Fuel with Distilled Water at 30 Megapascals	11.3-7
11-20.	Compositions of Residual Solutions from Experiments Reacting Simulated PNL 76-68 Glass in Distilled Water at 30 Megapascals	11.3-9
11-21.	Assumptions Used for Modeling of Spent Fuel Waste Packages in Basalt.	11.3-16
11-22.	Composition of Supercalcine SPC-4	11.3-22
11-23.	Composition of Simulated Grande Ronde Basalt Groundwater	11.3-26
11-24.	Nuclides Whose Release Rates Must Be Less Than 10^3 per Year to Meet U.S. Environmental Protection Agency Release Draft Limits.	11.3-35
11-25.	Comparison of Estimated Actinide Release Rates from a Repository in Basalt with Release Rates Required to Meet Current U.S. Environmental Protection Agency Draft Limits	11.3-36

TABLES (Contd.):

11-26.	Summary of Repository Equilibrium Conditions.	11.4-17
11-27.	Expected Repository Conditions at the Emplacement Location.	11.6-3
12-1.	Potential Release Inducing Phenomena.	12.2-3
12-2.	Summary of Codes for Repository Performance Analysis. .	12.3-6
12-3.	Hydraulic Conductivities Assumed by Los Alamos Technical Associates, Inc./Intera Environmental Consultants, Inc.	12.4-4
12-4.	Thickness and Porosity of Each Model Layer Assumed by Los Alamos Technical Associates, Inc./ Intera Environmental Consultants, Inc.	12.4-4
12-5.	Major Assumptions in the Assessment of Effectiveness of Geologic Isolation Systems (AEGIS) Basalt Demonstration	12.4-9
12-6.	Effective Hydraulic-Conductivity Values Used in the Initial MAGNUM 3D Pasco Basin Simulation.	12.4-14
12-7.	Hydraulic Conductivity Data Used in the Kriging Analysis.	12.4-20
12-8.	Parameters for Horizontal Streamtubes	12.4-20
12-9.	Parameters for Vertical Streamtubes	12.4-21
12-10.	Groundwater Velocities, Flow Rates, and Travel Times for Horizontal Streamtubes.	12.4-21
12-11.	Groundwater Velocities, Flow Rates, and Travel Times for Vertical Streamtubes.	12.4-22
12-12.	Groundwater Travel Times for Each Scenario.	12.4-22
12-13.	Summary of Pre-Waste-Emplacement Travel Time Estimates	12.4-23
12-14.	Description and Dimensions of Rock Layers for the Geologic Conceptual Model	12.4-32

Site Characterization Report for the Basalt Waste Isolation Project

November 1982



**Prepared by Rockwell Hanford Operations
Under Contract DE-AC06-77RLO1030**

**Prepared For:
U.S. Department of Energy
Assistant Secretary for Nuclear Energy
Office of Terminal Waste Disposal
and Remedial Action
Washington, D.C. 20545**

VOLUME III

CONTENTS

INTRODUCTION TO ISSUES AND PLANS CHAPTER	13.0-1
CHAPTER 13. SITE ISSUES AND PLANS	13.1-1
13.1 Introduction	13.1-1
13.2 Summary of Criteria Fully Satisfied.	13.2-1
13.3 Unresolved Issues and Plans for Their Resolution	13.3-1
13.3.1 Geologic and Hydrologic Considerations: Issues and Work Elements	13.3-1
13.3.2 Environmental and Socioeconomic Considerations	13.3-84
13.4 Summary of Basalt Waste Isolation Project Site Activities.	13.4-1
13.5 Site Criteria/Issues/Work Elements	13.5-1
13.6 Summary	13.6-1
13.7 References	13.7-1
CHAPTER 14. GEOENGINEERING AND REPOSITORY DESIGN ISSUES AND PLANS	14.1-1
14.1 Introduction	14.1-1
14.2 Summary of Criteria Fully Satisfied	14.2-1
14.2.1 Issues	14.2-1
14.2.2 Criteria	14.2-1
14.3 Unresolved Issues and Plans for Their Resolution.	14.3-1
14.3.1 Repository Design, Construction, and Operations Issues and Work Elements	14.3-1
14.3.2 Repository Performance Confirmation Issues and Work Elements.	14.3-75
14.4 Summary of Basalt Waste Isolation Project Repository Design and Construction and Performance Confirmation Activities.	14.4-1
14.5 Repository Criteria/Issues/Work Elements.	14.5-1
14.6 Summary	14.6-1
14.7 References.	14.7-1
CHAPTER 15. WASTE PACKAGE AND SITE GEOCHEMISTRY ISSUES AND PLANS.	15.1-1
15.1 Introduction.	15.1-1
15.2 Summary of Criteria Fully Satisfied	15.2-1
15.2.1 Issues	15.2-1
15.2.2 Criteria	15.2-1

15.3	Unresolved Issues and Plans for Their Resolution.	15.3-1
15.3.1	Waste Package Design Issues and Work Elements.	15.3-1
15.3.2	Site Geochemistry Issues and Work Elements	15.3-34
15.3.3	Testing and Performance Confirmation Issues and Work Elements.	15.3-49
15.4	Summary of Basalt Waste Isolation Project Waste Package Design, Site Geochemistry, and Related Testing and Performance Activities.	15.4-1
15.5	Waste Package and Site Geochemistry Criteria/Issues/ Work Elements	15.5-1
15.6	Summary	15.6-1
15.7	References.	15.7-1

CHAPTER 16. PERFORMANCE ASSESSMENT ISSUES AND PLANS 16.1-1

16.1	Introduction	16.1-1
16.1.1	Criteria Organization and Selection of Issues	16.1-2
16.1.2	Work Element Analysis: Data Needs and Status	16.1-5
16.1.3	Issues/Work Elements Numbering System	16.1-5
16.1.4	Organization of Chapter 16	16.1-7
16.2	Summary of Fully Addressed Criteria	16.2-1
16.2.1	Issues	16.2-1
16.2.2	Criteria	16.2-1
16.3	Unresolved Issues and Plans for Their Resolution	16.3-1
16.3.1	Preplacement Site Performance	16.3-1
16.3.2	Postclosure Performance of the Engineered System.	16.3-4
16.3.3	Postclosure Performance of the Waste Isolation System.	16.3-7
16.3.4	Preclosure Repository Performance	16.3-9
16.4	Summary of Basalt Waste Isolation Project Performance Assessment Activities	16.4-1
16.5	Performance Assessment Criteria/Issues/Work Elements	16.5-1
16.6	Summary	16.6-1
16.7	References	16.7-1

CHAPTER 17. SITE CHARACTERIZATION PROGRAM 17.1-1

17.1	Introduction	17.1-1
17.2	In Situ Test Facilities	17.2-1
17.2.1	Overview	17.2-1
17.2.2	Exploratory Shaft-Phase I Activities.	17.2-3
17.2.3	Exploratory Shaft-Phase I Testing	17.2-7
17.2.4	Relationship of Exploratory Shaft-Phase I Test Program Objectives to the Site Characterization Report Work Elements.	17.2-14
17.2.5	Exploratory Shaft-Phase I Construction	17.2-21
17.2.6	Exploratory Shaft-Phase II Activities	17.2-22
17.2.7	Exploratory Shaft-Phase II Tests	17.2-24

17.2.8	Relationship of Exploratory Shaft-Phase II Test Program Objectives to the Site Characterization Report Work Elements.	17.2-29
17.2.9	Exploratory Shaft-Phase II Construction.	17.2-33
17.2.10	Decommissioning Considerations	17.2-33
17.3	Planning Summary.	17.3-1
17.4	U.S. Nuclear Regulatory Commission Issues	17.4-1
17.5	References.	17.5-1

CHAPTER 18. QUALITY ASSURANCE 18.0-1

18.1	Organization	18.1-1
18.2	Quality Assurance Program	18.2-1
18.3	Design Control	18.3-1
18.4	Procurement Document Control	18.4-1
18.5	Instructions, Procedures, and Drawings	18.5-1
18.6	Document Control	18.6-1
18.7	Control of Purchased Items and Services	18.7-1
18.8	Identification and Control of Items	18.8-1
18.9	Control of Processes	18.9-1
18.10	Inspection	18.10-1
18.11	Test Control	18.11-1
18.12	Control of Measuring and Test Equipment	18.12-1
18.13	Handling, Storing, and Shipping	18.13-1
18.14	Inspection, Test, and Operating Status	18.14-1
18.15	Control of Nonconforming Items	18.15-1
18.16	Corrective Action	18.16-1
18.17	Quality Assurance Records	18.17-1
18.18	Audits	18.18-1
18.19	References	18.19-1

CHAPTER 19. IDENTIFICATION OF ALTERNATE SITES 19.1-1

19.1	Introduction	19.1-1
19.2	Generic National Waste Terminal Storage Siting Process.	19.2-1
19.3	Salt (Bedded/Domed) as an Alternative	19.3-1
19.3.1	Gulf Coast Region Salt Dome Basins	19.3-1
19.3.2	Bedded Salt of the Paradox Basin	19.3-1
19.3.3	Bedded Salt of the Permian Basin	19.3-4
19.3.4	Bedded Salt of the Salina Basin.	19.3-4
19.3.5	Summary of Planned Characterization Activities for Salt	19.3-4
19.4	Tuff as an Alternative.	19.4-1
19.4.1	Nevada Test Site Investigations.	19.4-1
19.4.2	Exploration of Tuff.	19.4-1
19.4.3	Summary of Planned Characterization Activities for Tuff	19.4-1

19.5	Granite, Other Crystalline Rocks, and Other Media as Alternatives	19.5-1
19.5.1	Granite and Other Crystalline Rocks.	19.5-1
19.5.2	Other Media.	19.5-1
19.5.3	Summary of Planned Activities for Granite, Other Crystalline Rocks, and Other Media	19.5-1
19.6	References.	19.6-1

APPENDIX - GLOSSARY FOR THE SITE CHARACTERIZATION REPORT

APPENDIX - ACRONYMS AND ABBREVIATIONS

FIGURES:

13-1.	Key Proposed Criteria Governing the Site Issues and Work Elements	13.1-2
13-2.	Existing and Planned Boreholes at the Hanford Site. . .	13.3-8
13-3.	Location Index Map.	13.3-27
13-4.	Logic Diagram for Site.	13.4-2
14-1.	Key Proposed Criteria Governing the Geoengineering and Repository Design Issues and Work Elements. . . .	14.1-2
14-2.	Logic Diagram for Geoengineering and Repository Design.	14.4-2
15-1.	Key Proposed Criteria Governing Waste Package, Site Geochemistry, and Testing and Performance Confir- mation Issues and Work Elements	15.1-2
15-2.	Solid Dissolution Behavior as a Function of Time. . . .	15.3-16
15-3.	Logic Diagram for Waste Package and Site Geochemistry .	15.4-2
16-1.	Relationship of Performance Assessment to Other Basalt Waste Isolation Project Activities	16.1-3
16-2.	Criteria Governing Performance Assessment Issues and Work Elements	16.1-4
16-3.	Logic Diagram for Performance Assessment.	16.4-2
17-1.	Exploratory Shaft Schedule for Test Plans, Construction, and Testing	17.2-2
17-2.	Location of Exploratory Shaft, Principal Borehole (RRL-2), and Two Support Boreholes (RRL-6 and RRL-14)	17.2-5
17-3.	Exploratory Shaft-Phase I Conceptual Arrangement. . . .	17.2-6
17-4.	Preliminary Stratigraphy in the Principal Borehole (RRL-2)	17.2-11
17-5.	Conceptual Test Borehole Locations for Exploratory Shaft-Phase I	17.2-15
17-6.	Exploratory Shaft	17.2-23
17-7.	Exploratory Shaft-Phase II Conceptual Configuration . .	17.2-25
17-8.	Schedule for Resolution of Site Issues.	17.3-2
17-9.	Schedule for Resolution of Geoengineering and Repository Design Issues.	17.3-3
17-10.	Schedule for Resolution of Waste Package and Site Geochemistry Issues.	17.3-4

FIGURES (Contd.):

17-11.	Schedule for Resolution of Performance Assessment Issues.	17.3-5
17-12.	Summary Schedule for the License Application.	17.3-6
18-1.	Basalt Waste Isolation Project Management Organization.	18.1-2
18-2.	Rockwell Hanford Operations Organization.	18.1-3
18-3.	Rockwell Hanford Operations/Basalt Waste Isolation Project Organizations	18.1-5
19-1.	National Waste Terminal Storage Program Organization.	19.1-2
19-2.	Regions That are Being Considered for Geologic Disposal of Radioactive Waste	19.1-3
19-3.	National Waste Terminal Storage Program Schedule for Accomplishing Site-Specific Characterization Leading to First Repository	19.1-4
19-4.	Eight Gulf Coast Region Salt Domes Recommended for Further Study by the U.S. Geological Survey	19.3-2
19-5.	Areas of the Paradox Basin Identified for Further Evaluation.	19.3-3
19-6.	Map of the Permian Basin.	19.3-5
19-7.	Map of Michigan and Northern Appalachian Basins	19.3-6
19-8.	Location of the Nevada Test Site and Current Exploration Areas	19.4-2

TABLES:

13-1.	Issues for Site	13.1-3
13-2.	Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.A	13.3-3
13-3.	Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.B	13.3-18
13-4.	Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.C	13.3-39
13-5.	Work Element Analysis: Data Needs and Status Supporting Geologic and Hydrologic Considerations, Issue S.1.D	13.3-60
13-6.	Work Element Analysis: Data Needs and Status Supporting Environmental and Socioeconomic Considerations.	13.3-85
13-7.	Criteria, Issues, and Work Elements for Site.	13.5-2
14-1.	Issues for Geoengineering and Repository Design	14.1-3
14-2.	Work Element Analysis: Data Needs and Status Supporting Geoengineering and Repository Design	14.3-2
14-3.	Work Element Analysis: Data Needs and Status Supporting Performance Confirmation	14.3-76
14-4.	Criteria, Issues, and Work Elements for Geoengineering and Repository Design	14.5-2

TABLES (Contd.):

15-1.	Issues for Waste Package, Site Geochemistry, and Testing and Performance Confirmation.	15.1-3
15-2.	Work Element Analysis: Data Needs and Status Supporting Waste Package Design Issues and Work Elements.	15.3-2
15-3.	Work Element Analysis: Data Needs and Status for Site Geochemistry Issues and Work Elements.	15.3-35
15-4.	Work Element Analysis: Data Needs and Status for Testing and Performance Confirmation Work Elements. .	15.3-50
15-5.	Criteria, Issues, and Work Elements for Waste Package and Site Geochemistry	15.5-2
16-1.	Issues for Performance Assessment	16.1-6
16-2.	Criteria, Issues, and Work Elements for Performance Assessment.	16.5-2
17-1.	Basalt Waste Isolation Project Issues Identified in Chapters 13, 14, 15, and 16	17.1-2
17-2.	Principal Borehole Tests.	17.2-9
17-3.	Shaft Sinking Demonstration--Key Results.	17.2-12
17-4.	Shaft-Seal Verification--Key Results.	17.2-13
17-5.	Pre-Station Hydrologic Isolation Assessment Data--Key Results	17.2-16
17-6.	Pre-Station Breakout and Shaft Station Geomechanics Characterization Data	17.2-17
17-7.	Test Program Objectives, Tests, and Site Characterization Report Work Element Matrix for Exploratory Shaft-Phase I	17.2-18
17-8.	Tests to Support Geotechnical Characterization.	17.2-27
17-9.	Tests to Support Determination of Hydrologic Properties.	17.2-28
17-10.	Near-Surface Test Facility Applicability Studies. . . .	17.2-28
17-11.	Test Program Objectives, Tests, and Site Characterization Report Work Element Matrix for Exploratory Shaft-Phase II.	17.2-30
17-12.	Issues Scheduled to be Resolved in Time to Report in the Final BWIP Semiannual Progress Report and the License Application	17.3-1
17-13.	U.S. Nuclear Regulatory Commission Issue Questions. . .	17.4-2

APPENDIX C

BWIP ISSUES IDENTIFIED BY NRC, ISSUE RATINGS, AND CORRELATION TO DOE ISSUES

TABLE OF CONTENTS

	<u>Page</u>
1. Introduction	C-1
2. Definition of Site Issues and Repository Elements	C-2
3. Development of NRC BWIP Issues	C-3
4. Issue Ratings	C-4
5. Correlation of NRC and DOE Issues and Work Elements	C-5

LIST OF FIGURES

		<u>Page</u>
Figure C-1	Repository System Elements and Performance Issues Related to Long-term Performance after Permanent Closure	C-6
C-2	Logic for Breakdown of NRC BWIP Issues	C-7
C-3	Process Used for Identifying NRC BWIP Issues	C-8

LIST OF TABLES

		<u>Page</u>
C-1	Correlation of NRC Performance Issues and 10 CFR Part 60	C-9
C-2	Correlation of NRC Site Issues and DOE Issues and Work Elements Identified by DOE	C-10
C-3	Correlation of NRC Specific Issues ⁿ and NRC Performance Issues	C-27
C-4	Rating of the Site Characterization Program using the NRC Issues.	C-31
C-5	List of DOE Issues	C-35
C-6	List of DOE BWIP Issues and Work Elements	C-37

1 INTRODUCTION

The Basalt Waste Isolation Project (BWIP) Site Characterization Report (SCR) is an issue-oriented document, as specified by the Nuclear Regulatory Commission (NRC) Standard Format and Content for Site Characterization Reports, Regulatory Guide 4.17. The Department of Energy (DOE) issues and related work elements provide the framework used to present the site characterization plans in the SCR.

The objectives of NRC's SCR analysis are to first, determine if the SCR adequately identifies the issues at the site; and second, determine if the plans to resolve the issues are adequate. This analysis is intended to assure that all significant questions relevant to future repository licensing are raised as early in site characterization as possible, given existing knowledge. To aid in this analysis, the NRC independently developed an issues list which provides a framework for the analysis. The NRC issues also aid in simplifying the complex problem of assessing repository performance by logically and systematically breaking the problem into more manageable parts, such that the inter-relationships between parts or between the parts and the performance objectives of 10 CFR Part 60 are clear. This breakdown facilitates integration of the many disciplines contributing to issue analyses and performance assessment. In the future the NRC issues ~~will~~ also provide an organizational structure for tracking DOE site characterization activities.

Appendix C gives a complete listing of the issues identified by both NRC ^{staff} and DOE. It describes the logic and process that the NRC staff used to identify BWIP site issues and correlates these issues to those identified by DOE in the SCR. Ratings of the BWIP program for each NRC issue are also presented. The NRC issue list in this appendix is a further development of a list first produced in May 1982.

2 DEFINITION OF SITE ISSUES AND REPOSITORY ELEMENTS

For the SCA
A site issue, as here used, is a question about a specific site that must be answered or resolved to complete licensing assessments of the site and design suitability in terms of 10 CFR Part 60. Site issues are not necessarily controversial questions. Site issues can be divided into performance issues and specific issues. Performance issues are broad questions concerning both the operational and long-term performance of the various elements, or barriers, of the overall repository system (e.g., waste form, waste package, see Figure C-1). Performance issues include the integration of numerous specific issues. Generally, these are questions about conditions and processes (information needed) which must be considered in assessing the performance issues. Specific issues encompass many levels of detail. The use of performance and specific issues does not necessarily reflect degrees of importance in repository performance. It is conceivable that a detailed specific issue could be of equal or greater importance than a particular performance issue. Questions related to matters such as methods of data collection, data analysis, performance modeling and performance validation are not considered as issues but, rather, concerns addressed in the analysis of each issue.

used in the SCR
The DOE definition of issue is somewhat different in emphasis from NRC's definition given above. This difference should be considered when comparing

the two lists of issues. The DOE SCR defines an issue "...as a technical question about which there is debate or controversy. Issues are technical questions that arise when the available information or technology is insufficient to make a specific decision or come to a specific conclusion about some aspect of repository siting or development" (SCR, page 13.0-1). Furthermore, methods of study are considered to be issues. DOE has also defined work elements in the SCR "...as a technical activity required to satisfy all or part of a criterion and/or to resolve an issue identified for siting and/or developing a nuclear waste repository in basalt" (SCR, page 13.0-1).

Many of the issues identified by NRC are related to various elements of a repository system. These elements and other terms important to repository performance are defined below and illustrated in Figure C-1.

"Accessible environment" means (1) the atmosphere, (2) the land surface, (3) surface water, (4) oceans, and (5) parts of the lithosphere that are more than ten kilometers in any direction from the original location of any of the radioactive wastes in the disposal system.

"Backfill" means material which might be emplaced in the underground openings of the underground facility other than the emplacement holes, shafts and boreholes.

"Controlled area" means a surface location, to be marked by suitable monuments extending horizontally no more than 10 kilometers in any direction from the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure.

"Disturbed zone" means that portion of the controlled area whose physical or chemical properties have changed as a result of underground facility construction or from heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository.

"Emplacement hole" means an opening in the rock directly surrounding the waste package.

"Engineered barrier system" means the waste packages and the underground facility.

"Far field" means the portion of the geologic setting that lies between the outer edge of the disturbed zone and the accessible environment.

"Geologic setting" means the geologic, hydrologic, and geochemical systems of the region in which a geologic repository operations area is or may be located.

"Packing" means that part of the waste package which is emplaced between the outer container and the rock wall of the emplacement hole.

"Underground facility" means the underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals. Also included is the surrounding rock that provides structural support.

"Waste form" mean the radioactive waste materials and any encapsulating or stabilizing matrix.

"Waste package" means the waste form and any containers, shielding, packing and other components surrounding the waste form.

3 DEVELOPMENT OF NRC ISSUES

Before the receipt of the SCR,

- A The NRC staff identifies a set of issues which systematically considers the required assessments necessary to independently evaluate, during licensing, the performance of ~~PROPOSED~~ a repository. Issues are logically broken down from broad to more specific levels of detail. This breakdown facilitates the focus of the SCR analysis on individual, detailed site characterization plans as well as the integration of plans from the broad view of the overall repository system. The logic and process used for issue identification are illustrated in Figures C-2 and C-3.

These potential As shown in Figure C-3, issue development involves two main stages. First, the site characterization matters are divided into safety assessment and environmental assessment. Secondly, safety assessment is subdivided into assessments related to two time periods: to permanent closure (operational) and after permanent closure (long-term). ~~The HRS~~ safety issues are derived directly from 10 CFR 60, and the environmental/institutional issues are derived from 10 CFR 51. Further issue development entails dividing the performance objectives of 10 CFR 60 into performance issues corresponding to the individual performance of the various system elements or barriers. These system elements are shown schematically in Figure C-1 and are defined in Section 2. Table C-1 correlates the performance issues to the performance objectives of 10 CFR 60.

Significant conditions and processes are then identified for each performance issue. These significant conditions and processes are those which 1) exist prior to repository disturbance, 2) could cause future changes, and 3) result from change. They also fall into the categories of natural, (e.g., faulting) repository induced (e.g., thermal buoyancy), and human induced (e.g., withdrawal of water resources). Many conditions or processes are important to more than one performance issue. This duplication of conditions and processes is eliminated by combining similar or repeated conditions or processes into a final set of specific issues. This final set of specific issues is then divided between six technical review groups (Groundwater, Waste Form/Waste Package, Retardation, Design of Facility, Geology, and Environmental Institutional). Table C-2 lists all of the performance and specific issues. These issue statements are numbered and listed by the groups described above. This list should be used as the master reference list of issue statements when particular issues are referenced only by their number in the SCA chapters or appendices.

Table C-3 correlates specific issues to performance issues in a matrix form. This table shows: 1) the importance of specific issues to repository performance; 2) how specific issues are integrated to address each performance issue; and 3) how any single specific issue might contribute to assessing more than one performance issue. For example, investigations of faults and fractures (specific issue 5.1) combine with various groundwater and retardation issues to understand the performance issues of water contacting the backfill (B.3), disturbed zone transport (B.9), farfield transport (B.10), and pre-waste emplacement groundwater travel time (B.11). Table C-3 in combination with Table C-1 also shows how each issue is based on the performance objectives of 10 CFR 60.

Developing the specific issues involved judgment as to which conditions and processes are considered to be significant to performance issues. Therefore, every possible condition and process is not listed, rather only those judged by the NRC staff as potentially significant. Issue identification is based on technical reviews of various BWIP related documents, site visits, workshops and research activities conducted by NRC, DOE and other organizations.

Judgment is a factor in breaking down the specific issues to various levels of detail. Different levels of breakdown reflect the degree of emphasis on a particular program area at this stage in site characterization. For example, more detail is developed for issues related to the site rather than repository design because site investigations provide input to repository design and because many site investigations take months or years to conduct and therefore require long lead times for planning.

4 ISSUE RATINGS

The NRC site issues are used as a framework for an analysis by the NRC staff of the BWIP site characterization program. This section summarizes this analysis by presenting ratings for each site issue.

All issue ratings are supported by site issue analyses (SIA). There are no SIAs for the performance issues, since all the SIAs for supporting specific issues collectively make up an analysis of each performance issue. All of the SIAs are compiled into one single document and copies are located in the NRC Public Document Room. Issue ratings are further supported by the chapters and technical appendices in the SCA. This supporting material is referenced in Table C-4.

which are working papers developed during the early stages of the SCR analysis.

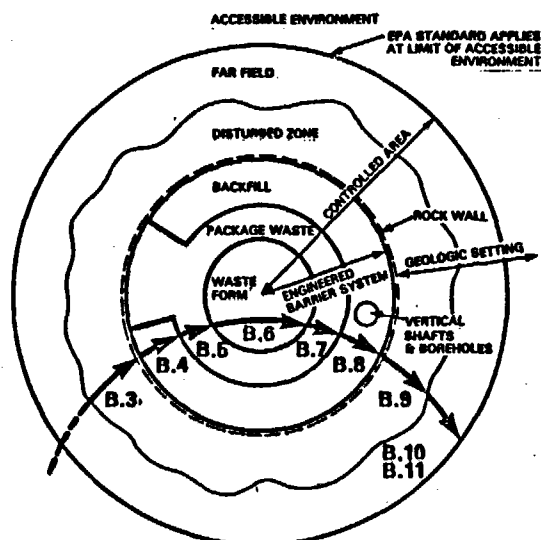
Issue ratings are given for the following four categories: 1) importance to repository performance and suitability, 2) ease of resolution, 3) current level of resolution, based on SCR contents and information gained during technical interactions with DOE and DOE contractors, and 4) likely level of resolution with proposed site characterization plans described in the SCR. The ratings represent a consensus judgment made by the respective technical review team members. Issue ratings, rating classes, and symbols are shown in Table C-5. An indeterminate rating is assigned when insufficient information is available in the SCR and referenced documents, to make a judgment.

5 CORRELATION OF NRC AND DOE ISSUES AND WORK ELEMENTS

The DOE site characterization plans are organized and presented using this issue/work element structure. Tables C-5 and C-6 list the numbered DOE issues and work elements.

The analysis of the site characterization program for each NRC issue included identifying and evaluating those DOE issues and work ~~elements~~^{elements} which correspond partially or completely to the NRC issue. Table C-2 shows this correlation of DOE issue and work element numbers to the NRC issues. Table C-2, C-5, and C-6 together are intended to be a cross-referencing tool for relating NRC's analysis in the SCA chapters and SIAs to DOE's plans in the SCR.

DIAGRAMMATIC PLAN VIEW



PERFORMANCE ISSUES

- B.3 When and how does water contact the backfill?
- B.4 When and how does water contact the waste package?
- B.5 When and how does water contact the waste form?
- B.6 When, how, and at what rate are radionuclides released from the waste form?
- B.7 When, how, and at what rate are radionuclides released from the waste package?
- B.8 When, how, and at what rate are radionuclides released from the backfill?
- B.9 When, how, and at what rate are radionuclides released from the disturbed zone?
- B.10 When, how, and at what rate are radionuclides released from the far field to the accessible environment?
- B.11 What is the pre-waste emplacement groundwater travel time along the fastest path of radionuclides travel from the disturbed zone to the accessible environment?

DIAGRAMMATIC CROSS SECTION VIEW

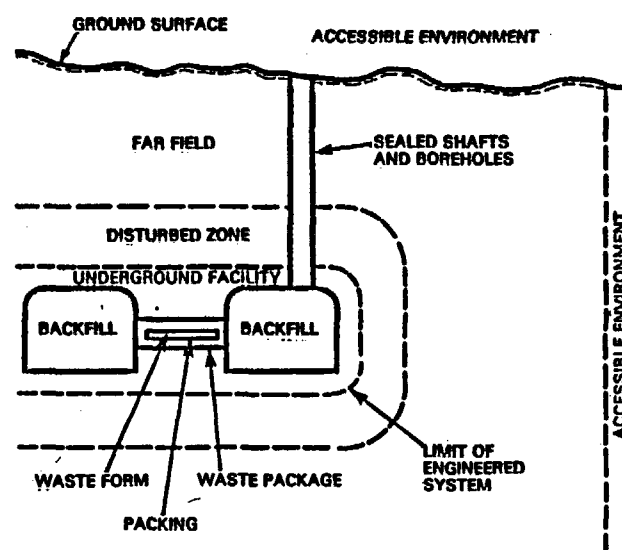


FIGURE C-1 REPOSITORY SYSTEM ELEMENTS AND PERFORMANCE ISSUES RELATED TO LONG-TERM PERFORMANCE AFTER PERMANENT CLOSURE

PERFORMANCE OBJECTIVES
10 CFR 60, 10 CFR 61

PERFORMANCE ISSUES

SPECIFIC ISSUES
SIGNIFICANT
CONDITIONS & PROCESSES

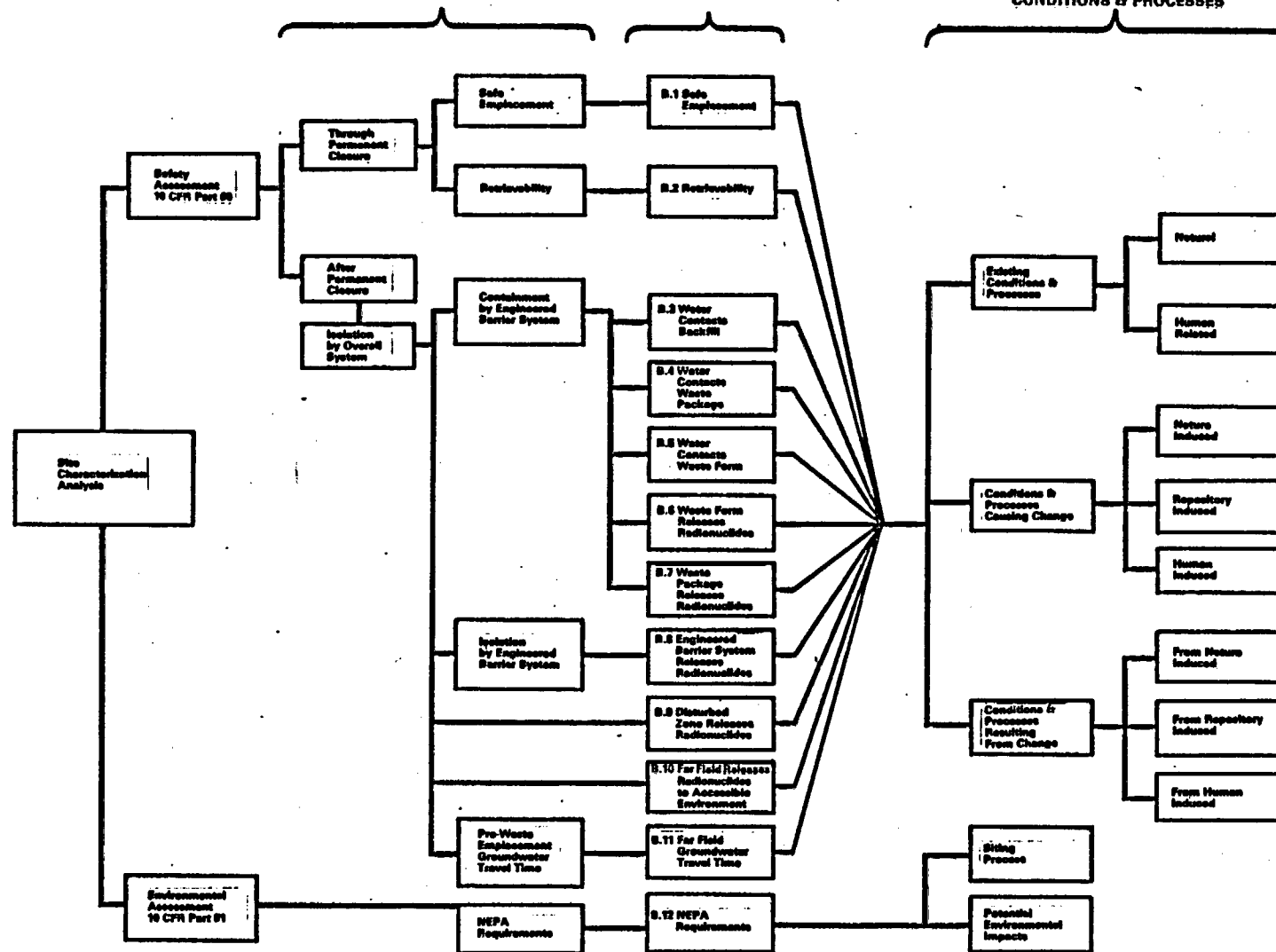


FIGURE C-2 LOGIC FOR BREAKDOWN OF NRC BWIP ISSUES

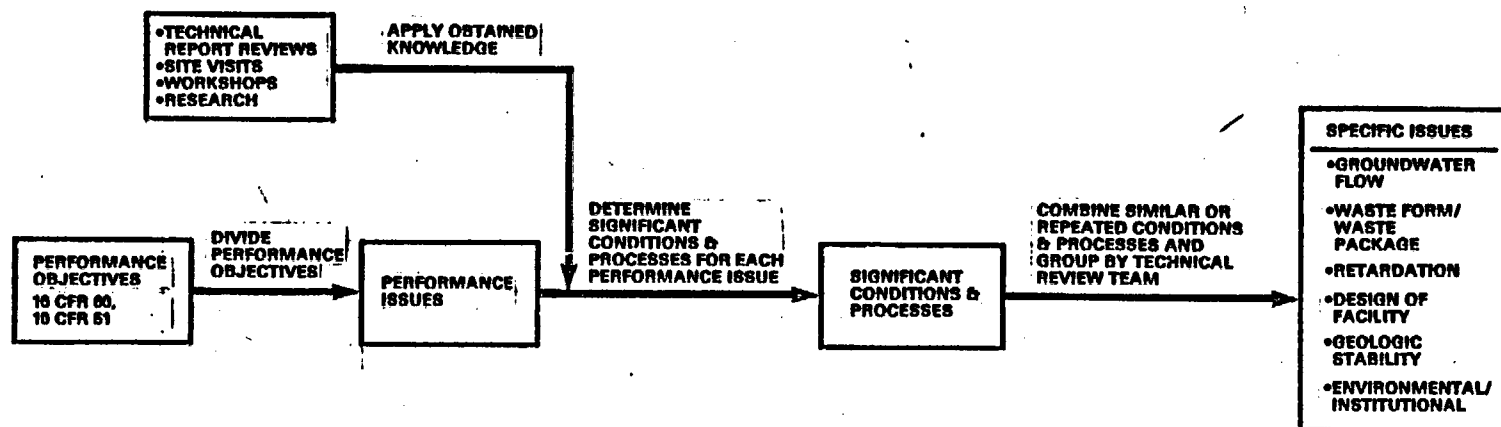


FIGURE C-3 PROCESS USED FOR IDENTIFYING NRC BWIP ISSUES

TABLE C-1. CORRELATION OF ~~BETWEEN~~⁷ NRC PERFORMANCE ISSUES AND 10 CFR PART 60

10 CFR PART 60 PERFORMANCE OBJECTIVES	PERFORMANCE ISSUES
SAFETY	
<ul style="list-style-type: none"> Performance of the geologic repository operations area through permanent closure 10 CFR 60.111 	<ul style="list-style-type: none"> B.1 How do the design criteria and conceptual design address releases of radioactive materials to unrestricted areas within the limits specified in Part 20?
<ul style="list-style-type: none"> Performance of the overall system after permanent Closure 10 CFR 60.112 	<ul style="list-style-type: none"> B.2 How do the design criteria and conceptual design accommodate the retrievability option? B.3 When and how does water contact the backfill? B.4 When and how does water contact the waste package? B.5 When and how does water contact the waste form? B.6 When, how, and at what rate are radionuclides released from the waste form? B.7 When, how, and at what rate are radionuclides released from the waste package? B.8 When, how, and at what rate are radionuclides released from the backfill? B.9 When, how, and at what rate are radionuclides released from the disturbed zone? B.10 When, how, and at what rate are radionuclides released from the farfield to the accessible environment?
<ul style="list-style-type: none"> Protection against radiation exposures and releases of radioactive material, 10 CFR 60.111a Retrievability of waste, 10 CFR 60.111b Containment by the engineered barrier system, 10 CFR 60.113(a)(ii)(A) Isolation by the engineered barrier System, 10 CFR 60.113(a)(ii)(B) Pre-waste emplacement groundwater travel time, 10 CFR 60.113(a)(2) 	<ul style="list-style-type: none"> B.11 What is the pre-waste emplacement groundwater travel time along the fastest path of radionuclide travel from the disturbed zone to the accessible environment?
ENVIRONMENTAL	
<ul style="list-style-type: none"> Nuclear facility NEPA requirements 10 CFR 51 	<ul style="list-style-type: none"> B.12 Have the NEPA environmental/institutional/siting requirements for nuclear facilities been met?

Table C-2 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC	ISSUES AND WORK ELEMENT IDENTIFIED BY DOE ISSUE NO. WORK ELEMENT NO.
PERFORMANCE ISSUES	
B.1 How do the design criteria and conceptual design address releases of radioactive materials to unrestricted areas within the limits specified in Part 20?	
B.2 How do the design criteria and conceptual design accommodate the retrievability option?	
B.3 When and how does water contact the backfill?	
B.4 When and how does water contact the waste package?	
B.5 When and how does water contact the waste form?	
B.6 When, how, and at what rate are radionuclides released from the waste form?	
B.7 When, how, and at what rate are radionuclides released from the waste package?	
B.8 When, how, and at what rate are radionuclides released from the backfill?	
B.9 When, how, and at what rate are radionuclides released from the disturbed zone?	
B.10 When, how, and at what rate are radionuclides released from the far field to the accessible environment?	
B.11 What is the prewaste emplacement groundwater travel time along the fastest path of radionuclide travel from the disturbed zone to the accessible environment?	
B.12 Have the NEPA environmental/institutional/siting requirements for nuclear facilities been met?	

o Issues having a site issue analysis (SIA)

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE	
		ISSUE NO.	WORK ELEMENT NO.
SPECIFIC ISSUES			
1.0	Groundwater		
o	1.1 What is the nature of the present groundwater system?	S.1.A S.1.B S.1.C S.1.D	S.1.3.A-S.1.6.A S.1.7.A-S.1.10.A S.1.12.B, S.1.13.B, S.1.24.C-S.1.31.C, S.1.33.C-S.1.36.C S.1.37.D-S.1.40.D, S.1.51.D, S.1.54.D, S.1.58.D
o	1.1.1 What is the three-dimensional distribution of hydrogeologic parameters (including vertical and horizontal hydraulic conductivity, hydraulic head, effective porosity, double porosity, dispersivity, and matrix diffusion)?	S.1.A S.1.B S.1.C S.1.D	S.1.3.A-S.1.5.A, S.1.7.A-S.1.10.A S.1.12.B, S.1.13.B, S.1.24.C, S.1.25.C, S.1.30.C, S.1.33.C, S.1.34.C, S.1.36.C, S.1.38.D-S.1.40.D, S.1.51.D,
o	1.1.1.1 What are the distributions of measured hydrogeologic parameters of each unit tested? S.1.51.D	S.1.C S.1.D	S.1.24.C, S.1.25.C, S.1.38.D-S.1.40.D,
o	1.1.1.2 What are the distributions of <u>interpolated</u> hydrogeologic parameters of each unit?	S.1.C S.1.D	S.1.24.C, S.1.25.C., S.1.38.D-S.1.40.D, S.1.51.D
o	1.1.2 What are the groundwater recharge and discharge locations, mechanisms, and amounts for the Pasco Basin?	S.1.C S.1.D	S.1.25.C-S.1.28.C, S.1.30.C, S.1.33.C, S.1.35.C, S.1.36.C, S.1.51.D
o	1.1.3 What are the boundary conditions of the flow systems significant to repository performance?	S.1.C S.1.D	S.1.25.C-S.1.27.C., S.1.30.C, S.1.33.C, S.1.34.C, S.1.36.C, S.1.38.D-S.1.40.D, S.1.51.D

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ISSUE NO.	ELEMENT IDENTIFIED BY DOE WORK ELEMENT NO.
o	1.1.4 How and to what extent is groundwater flow affected by structural discontinuities?	S.1.C S.1.D	S.1.24.C, S.1.25.C, S.1.27.C, S.1.28.C- S.1.32.C, S.1.41.D S.1.30.C, S.1.33.C, S.1.34.C, S.1.36.C, S.1.38.D-S.1.40.D, S.1.44.D, S.1.45.D S.1.48.D, S.1.49.D S.1.51.D, S.1.54.D- S.1.58.D
o	1.1.5 How and to what extent is groundwater flow affected by stratigraphic and lithologic discontinuities?	S.1.C S.1.D	S.1.24.C, S.1.25.C, S.1.27.C-S.1.30.C, S.1.33.C, S.1.34.C, S.1.36.C, S.1.38.D- S.1.40.D
o	1.1.6 What is the hydrochemistry of the groundwater systems of the Pasco Basin?	S.1.A S.1.C S.1.D	S.1.5.A, S.1.6.A, S.1.8.A, S.1.9.A, S.1.26.C, S.1.36.C, S.1.38.D-S.1.40.D
o	1.1.7 What is the conceptual groundwater model(s)?	S.1.C S.1.D	S.1.24.C, S.1.25.C, S.1.27.C-S.1.30.C, S.1.35.C, S.1.36.C, S.1.38.D-S.1.40.D
o	1.1.8 What are the mathematical models used to predict groundwater flow?	S.1.C S.1.D	S.1.C S.1.31.C, S.1.33.C S.1.34.C, S.1.37.D
o	1.2 What are the types, probabilities, and nature of natural changes that would affect groundwater flow?	S.1.C S.1.D	S.1.32.C, S.1.41.D, S.1.44.D, S.1.45.D S.1.48.D, S.1.49.D
o	1.2.1 What are the types, probabilities, and nature of catastrophic Columbia River flooding changes that would affect groundwater flow?	S.1.C S.1.D	S.1.32.C, S.1.41.D, S.1.44.D, S.1.45.D
o	1.2.2 What are the types, probabilities, and nature of glaciation changes that would affect groundwater flow? (see also 5.33)	S.1.C S.1.D	S.1.32.C, S.1.41.D, S.1.45.D, S.1.48.D, S.1.49.D

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE	
		ISSUE NO.	WORK ELEMENT NO.
o	1.2.3 What are the types, probabilities, and nature of precipitation/evapotranspiration changes that would affect groundwater flow?	S.1.C S.1.D	S.1.32.C, S.1.41.D, S.1.49.D
o	1.3 What are the types, probabilities, and nature of human-induced changes (excepting repository-induced changes) that would affect groundwater flow? (see also 5.4)	S.1.D	S.1.41.D, S.1.44.D- S.1.48.D, S.1.50.D, S.1.51.D
o	1.3.1 How does the value of water resources in the Pasco Basin compare with the values in other surrounding areas of similar size, and what is the potential for future use?	S.1.D	S.1.41.D, S.1.46.D, S.1.47.D
o	1.3.2 What are the types, probabilities, and nature of water resource development (drilling) changes that would affect groundwater flow?	S.1.D	S.1.41.D, S.1.46.D, S.1.47.D, S.1.50.D
o	1.3.3 What are the types, probabilities, and nature of groundwater withdrawals and recharge changes that would affect groundwater flow? (see also 5.4.1, 5.4.2)	S.1.D	S.1.41.D, S.1.46.D, S.1.47.D, S.1.50.D, S.1.51.D
o	1.3.4 What are the types, probabilities, and nature of changes from dam construction on the Columbia River that would affect groundwater flow?	S.1.D	S.1.41.D, S.1.44.D- S.1.48.D, S.1.51.D
o	1.4 What are the expected effects over time on groundwater flow paths, velocities, dispersivities, discharges, and travel times resulting from repository-induced changes (including underground facility construction, dewatering and long-term stability, borehole/shaft seal failure, thermomechanical, thermal buoyancy, and thermal alteration of fracture filling minerals)?	S.1.C S.1.D	S.1.24.C, S.1.25.C S.1.27.C-S.1.31.C, S.1.33.C, S.1.34.C, S.1.36.C, S.1.37.D- S.1.41.D, S.1.51.D
o	1.5 What are the expected effects over time on groundwater flow paths, velocities, dispersivities, discharges, and travel times resulting from human-induced changes, excepting repository-induced changes (including water resource exploration, groundwater withdrawals and recharges, dam construction on the Columbia River, and human induced structure and tectonic changes)?	S.1.C S.1.D	S.1.24.C, S.1.25.C S.1.27.C-S.1.31.C, S.1.33.C, S.1.34.C, S.1.36.C, S.1.37.D- S.1.41.D, S.1.44.D- S.1.48.D, S.1.50.D, S.1.51.D

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE	
		ISSUE NO.	WORK ELEMENT NO.
o	1.6 What are the expected effects over time on groundwater flow paths, velocities, dispersivities, discharges, and travel times resulting from natural changes (including catastrophic Columbia River flooding, glaciation, precipitation/evapotranspiration, structure and tectonic stress)?	S.1.C S.1.D	S.1.24.C, S.1.25.C S.1.27.C-S.1.34.C, S.1.36.C, S.1.37.D- S.1.41.D, S.1.44.D, S.1.49.D, S.1.51.D- S.1.61.D
2.0	Waste Form/Waste Package		
o	2.1 What are the possible mechanisms by which water will penetrate packing materials around containers?	W.1.B	W.1.15.B
o	2.2 To what extent over time will groundwater flow, temperature or other effects change the ability of packing materials to control flow through those materials? What chemical and physical changes are possible? What are the chemical and physical properties?	W.1.A	W.1.3.A, W.1.3.A, W.1.B W.1.16.B
o	2.3 What are the hydrothermal conditions with time at the surfaces of the waste form and containers and within packing materials which influence property changes and radionuclide release?	W.1.A	W.1.2.A, W.1.12.A
o	2.4 What are the possible mechanical failure modes for the container?	W.1.A	W.1.2.A, W.1.6.A
o	2.5 What are the chemical and physical property changes in container materials and what are the resultant properties?	W.1.A W.1.B	W.1.6.A, W.1.7.A, W.1.12.A, W.1.19.B
o	2.6 What are the mechanical loads on containers vs. time? How do the packing materials affect the loading?	W.1.A	W.1.2.A
o	2.7 What are the possible corrosion failure modes for the container?	W.1.A	W.1.6.A
o	2.8 What is the effect of packing materials on the corrosion mechanisms for the container?	W.1.A	W.1.6.A
o	2.9 How do Eh, pH and PO ₂ change with time in the vicinity of the container and in the packaging?	W.1.A	W.1.2.A, W.1.3.A, W.1.5.A
o	2.10 What is the radiolytic generation of hydrogen, oxygen and other species due to gamma radiation in the vicinity of the container?	W.1.A	W.1.3.A

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE	
		ISSUE NO.	WORK ELEMENT NO.
o	2.11 What is the dependence of the oxygen removal rate from packing materials upon temperature, pressure, radiolysis, packing materials physical characteristics, groundwater flow rates and composition and time?		W.1.A W.1.2.A, W.1.3.A W.1.5.A
o	2.12 How do microbes effect conditions affecting corrosion modes? What effect do microbes have on the conditions affecting transport?	None	None
o	2.13 What is the solubility of radionuclides vs. time in the vicinity of the waste form and packing materials? How are radionuclides released from the waste form?	None	None
o	2.14 What properties of the waste form change with time and alter the ability of the waste form to contribute to the overall performance of the repository system or impact the performance of other barrier materials and properties of the site?	W.1.A W.3.A	W.1.1.A, W.1.6.A, W.1.12.A, W.3.7.A
o	2.15 What is the effect of water residence time on release of radionuclides from the waste form?	None	None
o	2.16 What are the ranges of residence times of a unit volume of water in contact with a unit area waste form and when do the residence times occur? For spent fuel how do hulls change the effective residence time?	None	None
o	2.17 How do the packing (spent fuel hulls if applicable), canister, and container materials and/or their alteration products interact with the waste form to cause its alteration and/or effect release radionuclides?	W.1.A W.3.A	W.1.12.A, W.3.1.A
o	2.18 How does the Eh, pH and PO ₂ change with time in the vicinity of the surface of the waste form? (Relates to 2.9)	W.1.A	W.1.2.A, W.1.3.A, W.1.5.A
o	2.19 What is the production of particles and colloids (by or near the waste form) which can hold or transport radionuclides or effect waste form degradation?	W.1.A	W.1.10.A
o	2.20 For spent fuel what are the failure mechanisms for hulls and what is their failure rate?	W.1.A	W.1.6.A
o	2.21 What are the transport and retardation processes and how do they effect the flux of radionuclides with time in packing materials?	None	None

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE ISSUE NO.	WORK ELEMENT NO.
o	2.22 How do the species which incorporate radionuclides change with time in the waste package? (This includes particles, colloids and solubles.)	None	None
o	2.23 Can actinides be concentrated to increase heating in the packing materials or create a potential for criticality?	W.1.A	W.1.10.A
o	2.24 How do radionuclides migrate through failed containers and how does this change with time? (Relates to 2.5)	W.3.A	W.3.3.A, 3.3.6.A
o	2.25 What are the convective flows in the waste package vs. time? (Relates to 2.1)	None	None
o	2.26 Does alpha radiation in the waste packing materials affect chemistry and hence transport and species identification?	W.1.A W.1.10.A	W.1.3.A, W.1.10.A
o	2.27 What are the conditions which affect criticality?	W.1.A	W.1.10.A
3.0	Retardation		
o	3.1 What is the expected solubility of released radionuclides in the disturbed zone (excluding the waste package) and the far field through time?	R.1.D S.1.C S.1.D W.1.A W.2.A W.3.A W.2.B W.2.D	R.1.18.D, S.1.26.C, S.1.38.D, S.1.39.D, W.1.4.A, W.1.10.A, W.1.12.A, W.2.4.A, W.2.5.A, W.2.6.A, W.2.8.A, W.2.9.B, W.2.11.A, W.2.12.D, W.2.13.D
	3.1.1 How does <u>precipitation/co-precipitation</u> affect radionuclide migration from the vicinity of the outermost packing material/rock/backfill interfaces to the accessible environment through time?	W.1.A W.2.A	W.1.4.A, W.1.12.A, W.2.4.A
	3.1.2 How does <u>speciation</u> affect radionuclide solubility?	S.1.D W.1.A W.2.A	S.1.39.D, W.1.4.A, W.2.4.A
	3.1.3 How do <u>colloids</u> affect radionuclide solubility/concentration?	W.1.A W.2.A	W.1.10.A, W.2.4.A, W.2.6.A

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE	
		ISSUE NO.	WORK ELEMENT NO.
o	3.2 What is the expected retardation of released radionuclides in the disturbed zone (excluding the waste package) and the far field through time?	R.1.D S.1.A S.1.D W.1.A W.2.A W.2.B W.2.D W.3.A	R.1.19.D, S.1.5.A, S.1.6.A, S.1.8.A, S.1.9.A, S.1.38.D, W.1.1.A, W.1.10.A, W.1.12.A, W.1.15.B, W.1.16.B, W.1.18.B, W.1.19.B, W.2.1.A, W.2.4.A, W.2.5.A, W.2.6.A, W.2.8.A, W.2.9.B, W.2.12.D, W.2.13.D
	3.2.1 How do chemical changes in the outermost packing material influence radionuclide migration from the vicinity of the <u>outermost packing material/rock/backfill</u> interfaces through time?	S.1.A W.1.A W.1.B W.2.A	S.1.5.A, S.1.6.A, S.1.8.A, S.1.9.A, W.1.1.A, W.1.12.A, W.1.15.B, W.1.16.B, W.1.18.B, W.2.4.A
	3.2.2 How does <u>backfill</u> mineralogy influence radionuclide migration through time?	W.1.A W.1.B W.2.A	W.1.12.A, W.1.15.B, W.1.16.B, W.1.18.B, W.2.4.A
	3.2.3 How does the <u>disturbed zone</u> mineralogy influence radionuclide migration through time?	W.2.A W.2.D	W.2.1.A, W.2.4.A, W.2.13.D
	3.2.4 How does the <u>far field</u> mineralogy influence radionuclide migration through time?	W.2.A W.2.D	W.2.1.A, W.2.4.A, W.2.13.D
	3.2.5 How does <u>sorption</u> in the disturbed zone (excluding the waste package) and far field affect radionuclide migration through time?	W.2.A	W.2.1.A, W.2.4.A,
	3.2.6 How does <u>solubility/concentration</u> of radionuclides in the disturbed zone (excluding the waste package) and the far field affect radionuclide migration through time?	W.1.A W.2.A	W.1.12.A, W.2.4.A, W.2.5.A
	3.2.7 How do <u>colloids/particulates</u> affect radionuclide migration/retardation in the disturbed zone (excluding the waste package) and the far field through time?	W.2.A	W.2.4.A, W.2.6.A

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE ISSUE NO.	WORK ELEMENT NO.
o	3.3 How is the migration behavior (including solubility and retardation) of radionuclides being validated/verified?	None	None
o	3.4 How are the geochemical data that have been and will be gathered be shown to be appropriate for use in anticipated performance assessment methods?	None	None
o	3.5 What is the mineralogy/petrology/chemistry of the backfill prior to emplacement?	S.1.D S.1.A	W.1.5.A, W.1.7.A, W.1.12.A
o	3.6 What is the mineralogy/petrology/chemistry of the disturbed zone/far field host rock prior to waste emplacement?	S.1.A S.1.D W.1.A W.2.A	S.1.5.A, S.1.6.A, S.1.8.A, W.1.5.A, W.1.7.A, W.1.12.A, W.2.1.A
o	3.7 What is the mineralogy/petrology/chemistry of secondary minerals of the disturbed zone/far field host rock prior to waste emplacement?	S.1.A S.1.D W.1.A W.2.A	S.1.5.A, S.1.6.A, S.1.8.A, W.1.5.A, W.1.7.A, W.2.1.A
o	3.8 What are the geochemical conditions expected under anticipated and unanticipated repository scenarios at the outer waste package interface with the host rock/backfill, in the disturbed zone and in the far field, through time?	R.1.D S.1.A S.1.C W.1.A W.1.C W.2.A W.2.C W.2.D	R.1.23.D, S.1.5.A, S.1.26.C, W.1.2.A, W.1.4.A, W.1.5.A, W.1.15.A, W.1.16.A, W.1.26.C, W.2.1.A, W.2.13.D
	3.8.1 What are the geochemical conditions (e.g., <u>groundwater</u> , <u>species</u> , <u>concentrations</u> Eh, <u>ph</u> , and others as appropriate) anticipated in the <u>backfill</u> through time?	S.1.C W.1.A W.1.C W.2.A W.2.D	S.1.26.C, W.1.2.A, W.1.4.A, W.1.5.A, W.1.15.A, W.1.16.A, W.1.26.C, W.2.1.A, W.2.13.D
	3.8.2 What are the geochemical conditions (e.g., <u>groundwater</u> , <u>species</u> , <u>concentrations</u> , Eh, <u>pH</u> and others as appropriate) anticipated in the disturbed zone environment through time?	S.1.C W.1.A W.2.A W.2.D	S.1.26.C, W.1.4.A, W.1.5.A, W.1.26.C, W.2.1.A, W.2.13.D

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE	
		ISSUE NO.	WORK ELEMENT NO.
	3.8.3 What are the geochemical conditions (e.g., <u>groundwater, species, concentration, Eh, pH</u> and others as appropriate) anticipated in the <u>far field</u> rock environment through time?	S.1.C W.1.A W.2.D	S.1.26.C, W.1.4.A W.1.5.A, W.2.13.D
o	3.9 What are the geochemical reactions (including thermochemical reactions) expected under anticipated and unanticipated repository scenarios from the outer waste package interfaces with the host rock/backfill, through the disturbed zone and the far field, through time?	S.1.D W.1.A W.1.B W.2.A	W.1.1.A, W.1.3.A, W.1.5.A, W.1.8.A, W.1.12.A, W.1.16.B, W.1.17.B, W.1.18.B, W.1.19.B, W.2.2.A, W.2.3.A, W.2.7.A, W.2.10.C
	3.9.1 What are the geochemical reactions anticipated in the <u>backfill</u> through time?	W.1.A W.1.B W.2.A	W.1.1.A, W.1.12.A, W.16.B, W.2.3.A
	3.9.2 What are the geochemical reactions anticipated in the <u>disturbed zone rock/fracture-filling materials</u> (disturbed zone) environment through time?	W.1.A	W.1.1.A, W.2.3.A W.2.A
	3.9.3 What are the geochemical reactions anticipated in the <u>far field rock/fracture filling-materials</u> environment through time?	W.2.A	W.2.3.A
	3.9.4 What are the geochemical reactions anticipated in <u>seals</u> within the disturbed zone and far field environment through time?	W.2.A	W.2.3.A
	3.9.5 What are the geochemical reactions anticipated in the <u>ground-water</u> within the disturbed zone and far field environment through time?	W.2.A	W.2.3.A
	3.9.6 What are the effects of gamma and alpha <u>radiolysis</u> products on backfill, disturbed zone and far field host rock relevant to assessment of radionuclide retardation?	W.1.A W.2.A	W.1.3.A, W.1.8.A, W.1.17.B, W.2.3.A, W.2.7.A
	3.9.7 How fast does the <u>Eh</u> (in the disturbed zone) return to "ambient" conditions after repository sealing?	W.2.C	W.1.A W.1.5.A, W.2.3.A. W.2.10.C

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE	
		ISSUE NO.	WORK ELEMENT NO.
4.0	Design of Facility		
4.1	Are the repository design criteria and the functional description (prior to decommissioning) shown to be complete and accurate with respect to the performance objectives?	None	R.1.27, R.1.28, R.1.31, R.1.35, R.1.44, R.1.49, R.1.52, R.1.59, R.1.61, R.1.62, R.1.64, R.1.68, R.1.72, P.4.1, P.4.2, P.4.3, P.4.4
	4.1.1 How do the design criteria and conceptual design address releases of radioactive materials to unrestricted areas within the limits specified in Part 20? (Broad issue B.1)	None	P.4.1, P.4.2, P.4.3, P.4.4, R.1.35, R.1.49, R.1.52, R.1.64
o	4.1.2 How do the design criteria and conceptual design accommodate the retrievability option? (Broad issue B.2)	None	R.1.59, R.1.61, R.1.62, R.1.68
4.2	Can stability of the repository be maintained in the presence of coupled in-situ, excavation induced and thermal stress during construction and operation of the repository?	R.1.A R.1.B R.1.C	R.1.1.A, R.1.2.A, R.1.3.A, R.1.4.A, R.1.5.A, R.1.8.A, R.1.11.B, R.1.12.B, R.1.13.B, R.1.14.C, R.1.15.C
	4.2.1 How is the conceptual design shown by analysis to accommodate in-situ stresses, and mechanical and thermal effects due to construction of the repository and waste emplacement?	R.1.A R.1.B	R.1.1.A, R.1.2.A, R.1.13.B
o	4.2.2 What are the in situ stress conditions and how do stress conditions vary with time and temperature?	R.1.A R.1.B R.1.C	R.1.4.A, R.1.5.A, R.1.8.A, R.1.12.B, R.1.14.C, R.1.15.C
o	4.2.3 What are the rock mass strength properties and how do they vary with time and temperature?	R.1.B	R.1.11.B
o	4.2.4 What are the rock mass deformation characteristics and how do they vary with time and temperature?	R.1.A R.1.B	R.1.3.A, R.1.11.B

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE ISSUE NO.	WORK ELEMENT NO.
4.3	How can isolation capability of the underground facility be maintained in the presence of coupled in situ, excavation induced, and thermal stresses?	R.1.A R.1.D	R.1.9.A, R.1.10.A, R.1.16.D, R.1.17.D, R.1.22.D, R.1.47, R.1.57, R.1.70, R.1.71
o	4.3.1 How does construction modify the groundwater flow characteristics in and around the underground facility?	R.1.D	R.1.16D, R.1.17.D, R.1.70, R.1.71
o	4.3.1.1 What will be the rate of groundwater inflow into the repository?	None	R.1.71
	4.3.1.2 How will the head distribution vary after construction?	None	R.1.71
	4.3.2 How do thermal loads modify the flow characteristics in and around the underground facility?	R.1.D	R.1.22.D, R.1.70, R.1.71
o	4.3.3 What are the physical conditions (e.g., temperature pressure, stress etc) anticipated in and around the underground facility through time?	None	R.1.47, R.1.57, R.1.70
4.4	What is the maximum expected radionuclide release rate from the engineered system and is this rate in compliance with NRC technical criteria?	R.1.D W.1.A	R.1.19.D, R.1.20.D, R.1.55, R.1.56, R.1.66, R.1.66, R.1.67
o	4.4.1 What are the physical conditions (e.g., temperature, pressure, stress, permeability, etc.) anticipated in the backfill through time?	R.1.D	R.1.19.D, R.1.20.D, R.1.66, R.1.67
4.5	Can repository shafts and exploratory boreholes be constructed and sealed adequately?	R.1.D	R.1.18.D, R.1.20.D, R.1.21.D, R.1.23.D, R.1.24.D, R.1.25.D, R.1.26.D, R.1.72
o	4.5.1 How is repository performance expected to be affected by construction of the Exploratory Shaft?	None	None
o	4.5.2 How is repository performance expected to be affected by repository shafts?	R.1.D	R.1.24.D

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE ISSUE NO.	WORK ELEMENT NO.
4.5.3 How is repository performance expected to be affected by exploratory boreholes?		R.1.D	R.1.23.D
5.0	Geology		
o	5.1 What are the structural discontinuities in the Pasco Basin under present conditions?	S.1.A S.1.B S.1.D	S.1.2.A, S.1.3.A, S.1.5.A, S.1.8.B, S.1.11.B-S.1.14.B, S.1.18.B, S.1.19.B, S.1.55.D, S.1.58.D
	5.1.1 What is the significance of the aeromagnetic anomalies that define intact blocks in the Cold Creek Syncline?	S.1.A S.1.B	S.1.2.A, S.1.12.B
	5.1.1.1 What is the significance of the N-96 and N-84 anomalies?	S.1.A S.1.B	S.1.2.A, S.1.12.B
	5.1.2 What is the probability and nature of undetected faulting in the controlled area?	S.1.A S.1.B S.1.D	S.1.3.A, S.1.5.A, S.1.13.B, S.1.18.B, S.1.19.B, S.1.55.D
	5.1.2.1 East-west faulting?	S.1.A S.1.B S.1.D	S.1.3.A, S.1.5.A, S.1.13.B, S.1.18.B, S.1.19.B, S.1.55.D
	5.1.2.2 North-west faulting?	S.1.A S.1.B S.1.D	S.1.3.A, S.1.5.A, S.1.13.B, S.1.18.B, S.1.19.B, S.1.55.D
	5.2 What are the stratigraphic discontinuities of the Pasco Basin under present conditions?	S.1.A	S.1.1.A, S.1.4.A, S.1.5.A, S.1.7.A, S.1.9.A

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE ISSUE NO.	WORK ELEMENT NO.
o	5.2.1 What is the lateral continuity and variation in thickness of the Umtanum Flow and Middle Sentinel Bluffs Flow?	S.1.A	S.1.1.A, S.1.4.A
5.3	What are the probabilities and nature of natural changes that would affect repository performance?	S.1.A S.1.B S.1.D	S.1.2.A, S.1.3.A S.1.15.B-S.1.18.B, S.1.20.B, S.1.23.B, S.1.52.B, S.1.41.D, S.1.44.D, S.1.54.D- S.1.57.D, S.1.59.D, S.1.60.D
o	5.3.1 What is the probability of earthquake activity in or near the Pasco Basin affecting repository performance?	S.1.B S.1.D	S.1.16.B, S.1.18.B, S.1.53.D, S.1.57.D
	5.3.1.1 What is the seismic hazard and risk to surface and subsurface facilities within the controlled zone?	S.1.B S.1.D	S.1.18.B, S.1.53.D, S.57.D
o	5.3.2 What is the nature and probability of renewed volcanism in or near the Pasco Basin affecting repository performance?	S.1.B S.1.D	S.1.23.B, S.1.59.D
	5.3.2.1 Flood basalt?	S.1.B S.1.D	S.1.23.B, S.1.59.D
	5.3.2.2 Air fall tephra?	S.1.B	S.1.23.B
	5.3.2.3 Ash flows?	S.1.B	S.1.23.B
	5.3.2.4 Flooding with water (damming Wallula Gap)?	S.1.B	S.1.23.B
o	5.3.3 What is the probability of glaciation in or near the Pasco Basin affecting repository performance? (see also 1.2.2)	S.1.D	S.1.41.D, S.1.60.D
	5.3.3.1 What is the probability that differential loading caused by glaciation can result in a change in the state of stress?	S.1.D	S.1.41.D, S.1.60.D
	5.3.3.2 What is the probability that water loading from ice melt flooding will cause a change in the state of stress?	S.1.D	S.1.41.D, S.1.60.D

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE ISSUE NO.	WORK ELEMENT NO.
5.3.4	What is the probability and nature of structural deformation in the Pasco Basin that would effect repository performance?	S.1.A S.1.B S.1.D	S.1.2.A, S.1.3.A, S.1.15.B, S.1.17.B, S.1.18.B, S.1.20.B, S.1.52.B, S.1.54.D- S.1.56.D
5.3.4.1	What tectonic models are being considered and what are the bounding conditions (geologic constraints)?	S.1.B	S.1.17.B, S.1.52.B
5.3.4.2	What is the state of stress at depth and how does it relate to the regional stress field?	S.1.B	S.1.15.B
5.3.4.3	What is the probability and nature of future faulting in the controlled zone?	S.1.B S.1.D	S.1.18.B, S.1.20.B, S.1.54.D
5.3.4.3.1	What is the probability of future faulting in the repository shearing the backfill or waste package?	S.1.B S.1.D	S.1.18.B, S.1.20.B S.1.54.D
5.4	What are the probabilities and nature of human-induced changes, excluding repository construction, that would affect repository performance? (see also 1.3)	S.1.D	S.1.41.D, S.1.44.D, S.1.50.D
o	5.4.1 What are the probabilities that groundwater withdrawals would affect repository performance? (see also 1.3.3)	S.1.D	S.1.50.D
	5.4.1.1 What is the probability that groundwater withdrawals for irrigation would trigger micro-earthquake or earthquake swarms?	None	None
o	5.4.2 What are the probabilities and nature of groundwater recharge that would affect repository performance? (see also 1.3.3)	S.1.D	S.1.41.D
	5.4.2.1 What is the probability that fluids injected into the confined aquifer at the 200W area will trigger earthquake swarms in the controlled zone?	S.1.D	S.1.50.D

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE ISSUE NO.	WORK ELEMENT NO.
5.4.2.2	What is the probability that water impoundments behind possible future dam construction (Ben Franklin dam) will cause micro-earthquakes or earthquake swarms?	None	None
5.4.2.3	What is the probability that flooding due to upstream dam failure will cause micro-earthquakes or earthquake swarms?	S.1.D	S.1.44.D
6.0	Site Screening and Environmental/Institutional		
o	6.1 How did DOE select the Pasco Basin from among other candidate areas?	None	None
o	6.2 How did DOE select the reference repository location (RRL) from among the other sites in the Pasco Basin?	None	None
o	6.3 Are there any obvious environmental concerns that could preclude the reference repository location (RRL) from being considered as one of the candidate sites in DOE's subsequent application for an authorization to construct a repository?	None	S.2.1, S.2.5
	6.3.1 Will the reference repository location (RRL) at Hanford adversely affect the Rattlesnake Hills Critical Wildlife Habitat in the Cold Creek Critical Wildlife Habitat?	None	S.2.1
	6.3.2 Will constructing and operating a repository adversely affect six species of rare, threatened or unique birds, which have been identified on or near the Hanford Reservation?	None	S.2.1
	6.3.3 Could a repository at Hanford, particularly during construction generate dust which would degrade the air quality?	None	S.2.5
	6.3.4 Will dust affect three species of endangered/threatened plants within the Arid Lands Ecology Reserve?	None	S.2.1, S.2.5
	6.3.5 During construction, water will be needed for drilling and dust control. Given the arid environment of the Pasco Basin, could a repository compete with irrigated agriculture for a limited supply of water?	None	S.2.1, S.2.5

Table C-3 Correlation of NRC Site Issues and DOE Issues and Work Elements

ISSUES IDENTIFIED BY NRC-		ISSUES AND WORK ELEMENT IDENTIFIED BY DOE ISSUE NO.	WORK ELEMENT NO.
6.3.6	Since HLW must be transported across the nation to reach a repository at Hanford, Washington, what are the resultant environmental impacts, if any?	None	None
6.3.7	Is the RRL site one of the best sites that can reasonably be found?	None	None
7.0	Other		
7.1	How is the accessible environment defined and where is it located?		
7.2	How is the disturbed zone defined and where is it located?		
7.3	What are the most likely performance scenarios?		

3

TABLE C-1 CORRELATION OF NRC SPECIFIC ISSUES TO PERFORMANCE ISSUES

SPECIFIC ISSUES	PERFORMANCE ISSUES												
	SAFETY											ENVIRON- MENTAL	
	Through Permanent Closure	After Permanent Closure											
		B.1	B.2	B.3	B.4	B.5	B.6	B.7	B.8	B.9	B.10		
1.0 Groundwater Flow													
1.1	•	•	•							•	•	•	•
1.1.1	•	•	•							•	•	•	•
1.1.1.1	•	•	•							•	•	•	•
1.1.1.2	•	•	•							•	•	•	•
1.1.2	•	•	•							•	•	•	•
1.1.3	•	•	•							•	•	•	•
1.1.4	•	•	•							•	•	•	•
1.1.5	•	•	•							•	•	•	•
1.1.6	•	•	•							•	•	•	•
1.1.7	•	•	•							•	•	•	•
1.1.8	•	•	•							•	•	•	•
1.2			•							•	•		
1.2.1			•							•	•		
1.2.2			•							•	•		
1.2.3			•							•	•		
1.3			•							•	•		
1.3.1			•							•	•		•
1.3.2			•	•	•	•	•	•		•	•		
1.3.3			•							•	•		
1.3.4			•							•	•		
1.4			•							•	•		•
1.5			•							•	•		
1.6			•							•	•		
2.0 Waste Form/Waste Package													
2.1					•		•						
2.2					•		•						
2.3					•	•	•						
2.4					•		•						
2.5					•		•						

3
TABLE C-7 CORRELATION OF NRC SPECIFIC ISSUES TO PERFORMANCE ISSUES

SPECIFIC ISSUES	PERFORMANCE ISSUES												
	SAFETY											ENVIRON- MENTAL	
	Through Permanent Closure		After Permanent Closure										
B.1	B.2	B.3	B.4	B.5	B.6	B.7	B.8	B.9	B.10	B.11	B.12		
2.6					•		•						
2.7					•		•						
2.8					•		•						
2.9					•		•						
2.10					•		•						
2.11					•		•						
2.12					•		•						
2.13					•	•	•						
2.14						•							
2.15						•							
2.16						•							
2.17						•							
2.18						•							
2.19						•							
2.20						•							
2.21							•						
2.22							•						
2.23							•						
2.24							•						
2.25							•						
2.26					•		•						
2.27							•						
3.0 Retardation													
3.1								•	•	•			
3.1.1								•	•	•			
3.1.2								•	•	•			
3.1.3								•	•	•			
3.2								•	•	•			
3.2.1								•	•				
3.2.2								•					
3.2.3									•				
3.2.4										•			
3.2.5									•	•			
3.2.6									•	•			
3.2.7									•	•			
3.3													
3.4													
3.5				•				•					
3.6			•						•	•			
3.7			•						•	•	•		
3.8			•	•				•	•	•			

3
TABLE C-4 CORRELATION OF NRC SPECIFIC ISSUES TO PERFORMANCE ISSUES

SPECIFIC ISSUES	PERFORMANCE ISSUES												
	SAFETY											ENVIRON- MENTAL	
	Through Permanent Closure		After Permanent Closure										
B.1	B.2	B.3	B.4	B.5	B.6	B.7	B.8	B.9	B.10	B.11	B.12		
3.8.1				•				•					
3.8.2			•						•				
3.8.3										•			
3.9			•	•				•	•	•			
3.9.1				•				•					
3.9.2			•						•				
3.9.3			•							•			
3.9.4				•				•					
3.9.5			•						•	•			
3.9.6			•	•				•	•	•			
3.9.7			•						•				
4.0 Design of Facility													
4.1	•	•											
4.1.1	•												
4.1.2		•											
4.2	•	•											
4.2.1	•	•											
4.2.2	•	•	•										
4.2.3	•	•	•										
4.2.4	•	•	•										
4.3			•	•				•	•				
4.3.1			•	•				•	•				
4.3.1.1			•	•				•	•				
4.3.1.2			•	•				•	•				
4.3.2			•	•				•	•				
4.3.3			•						•				
4.4													
4.4.1			•	•				•					
4.5			•						•				
4.5.1			•						•				
4.5.2			•						•				
4.5.3			•						•				
5.0 Geologic Stability													
5.1	•	•	•						•	•	•		
5.1.1	•	•	•						•	•	•		
5.1.1.1	•	•	•						•	•	•		
5.1.2	•	•	•						•	•	•		
5.1.2.1	•	•	•						•	•	•		
5.1.2.2	•	•	•						•	•	•		
5.2	•	•	•						•	•	•		
5.2.1	•	•	•						•	•	•		

TABLE C-3 CORRELATION OF NRC SPECIFIC ISSUES TO PERFORMANCE ISSUES

SPECIFIC ISSUES	PERFORMANCE ISSUES												
	SAFETY											ENVIRONMENTAL	
	Through Permanent Closure		After Permanent Closure										
	B.1	B.2	B.3	B.4	B.5	B.6	B.7	B.8	B.9	B.10	B.11	B.12	
5.3	●	●	●	●	●	●	●	●	●	●			
5.3.1	●	●	●	●	●	●	●	●	●	●			
5.3.1.1	●	●											
5.3.2			●						●	●			
5.3.2.1			●						●	●			
5.3.2.2			●						●	●			
5.3.2.3			●						●	●			
5.3.2.4			●						●	●			
5.3.3			●						●	●			
5.3.3.1			●						●	●			
5.3.3.2			●						●	●			
5.3.4			●						●	●			
5.3.4.1			●						●	●			
5.3.4.2			●						●	●			
5.3.4.3			●						●	●			
5.3.4.3.1				●	●	●	●	●					
5.4			●	●	●	●	●	●	●	●			
5.4.1			●						●	●			
5.4.1.1			●						●	●			
5.4.2			●						●	●			
5.4.2.1			●						●	●			
5.4.2.2			●						●	●			
5.4.2.3			●						●	●			
6.0 Site Screening and Environmental Institutional													
6.1												●	
6.2												●	
6.3												●	
6.3.1												●	
6.3.2												●	
6.3.3												●	
6.3.4												●	
6.3.5												●	
6.3.6												●	
6.3.7												●	
7.0 Other												●	
7.1										●	●		
7.2									●		●		
7.3			●	●	●	●	●	●	●	●	●		

TABLE C-7⁴ RATING OF NRC PERFORMANCE AND SPECIFIC ISSUES

SPECIFIC ISSUES 0 Site Issue Analysis (SIA) Complete	ISSUE RATING*				REFERENCE TO SCA CHAPTER AND APPENDICES
	Importance	Ease of Resolution	Current Level of Resolution	Likely Level of Resolution With Proposed Plans	
1.0 Groundwater Flow					
1.1	●	●	●	●	4,E,F,G,H,I,O
1.1.1	●	●	●	●	4,E,G,H,I
1.1.1.1	●	●	●	●	4,E,H
1.1.1.2	●	●	●	●	4,H,I
1.1.2	●	○	●	?	4,G,I,O
1.1.3	●	●	●	●	4,E,G,H,I,O
1.1.4	●	●	●	●	4,E,H,O
1.1.5	●	●	●	●	4,E,H,O
1.1.6	○	●	○	○	4,F
1.1.7	●	●	●	●	4,E,G,H,I,O
1.1.8	○	●	○	○	4,11
1.2	●	○	○	?	
1.2.1	●	○	○	○	
1.2.2	●	○	○	?	
1.2.3	●	○	○	?	
1.3	○	●	●	?	
1.3.1	●	○	○	○	
1.3.2	○	○	○	?	
1.3.3	●	●	●	?	
1.3.4	●	○	○	○	
1.4	●	●	●	?	
1.5	○	●	●	?	
1.6	●	○	○	?	
2.0 Waste Form/Waste Package					
2.1	●	○	●	○	8,R
2.2	●	●	●	○	8,R
2.3	●	○	●	○	8,Q,R
2.4	○	●	●	○	8 P
2.5	○	○	●	○	P

***RATING TERMS AND SYMBOLS**

Importance With Respect to Suitability:	Critical ●	Significant ○	Minor ●	
Ease of Resolution:	Difficult ●	Moderate ○	Easy ●	
Current Level of Resolution:	Unresolved ●	Partially Resolved ○	Resolved ●	Indeterminate** ?
Likely Level of Resolution With Proposed Plans: ..	Unresolved ●	Partially Resolved ○	Resolved ●	Indeterminate** ?

**Indeterminate means that a judgment could not be made because information about current knowledge or future plans are either vague, too general, or not presented.

TABLE C-7 RATING OF NRC PERFORMANCE AND SPECIFIC ISSUES

SPECIFIC ISSUES	ISSUE RATING*				REFERENCE TO SCA CHAPTER AND APPENDICES
	Importance	Ease of Resolution	Current Level of Resolution	Likely Level of Resolution With Proposed Plans	
2.6	O	O	●	O	
2.7	●	O	●	O	P
2.8	O	O	●	O	
2.9	O	O	●	O	Q
2.10	O	O	●	O	
2.11	O	●	●	O	
2.12	O	O	●	●	
2.13	●	O	●	O	Q
2.14	●	O	●	O	Q
2.15	●	O	●	O	Q
2.16	●	O	●	O	Q
2.17	O	●	●	O	
2.18	O	O	●	O	Q
2.19	O	O	●	O	
2.20	●	O	●	O	
2.21	●	O	●	O	R
2.22	O	O	●	O	
2.23	O	O	●	●	
2.24	O	O	●	O	
2.25	O	O	●	O	
2.26	O	O	●	O	
2.27	O	O	●	●	
3.0 Retardation					
3.1	●	O	O	?	6,U
3.1.1	●	O	O	?	6,U
3.1.2	●	O	O	?	6,U
3.1.3	●	O	●	?	6,U
3.2	●	O	O	?	6,T
3.2.1	●	O	O	?	6,T
3.2.2	●	O	O	?	6,T
3.2.3	●	O	O	?	6,T
3.2.4	●	O	O	?	6,T
3.2.5	●	O	O	?	6,T
3.2.6	●	O	O	?	6,T
3.2.7	●	O	●	?	6,T
3.3	●	O	●	?	6
3.4	●	O	●	?	6
3.5	●	●	O	?	6
3.6	●	●	O	?	6
3.7	●	●	O	?	6
3.8	●	O	O	?	S,T,U

4
TABLE C-1 RATING OF NRC PERFORMANCE AND SPECIFIC ISSUES

SPECIFIC ISSUES	ISSUE RATING*				REFERENCE TO SCA CHAPTER AND APPENDICES
	Importance	Ease of Resolution	Current Level of Resolution	Likely Level of Resolution With Proposed Plans	
3.8.1	●	○	○	?	S,T,U
3.8.2	●	○	○	?	S,T,U
3.8.3	●	○	○	?	S,T,U
3.9	●	○	○	?	T,U
3.9.1	●	○	○	?	T,U
3.9.2	●	○	○	?	T,U
3.9.3	●	○	○	?	T,U
3.9.4	●	○	○	?	T,U
3.9.5	●	○	○	?	T,U
3.9.6	●	○	○	?	T,U
3.9.7	●	○	○	?	T,U
4.0 Design of Facility					
4.1	●	○	○	○	7
4.1.1	●	○	●	●	
4.1.2	●	●	●	●	
4.2	●	○	●	○	7
4.2.1	●	○	●	○	
4.2.2	○	●	●	●	
4.2.3	○	●	●	○	
4.2.4	○	●	●	○	
4.3	●	●	●	○	7
4.3.1	○	○	●	○	
4.3.1.1	○	○	●	●	
4.3.1.2	●	○	●	●	
4.3.2	○	○	●	○	
4.3.3	○	○	●	○	
4.4	●	●	●	○	7
4.4.1	○	○	●	●	
4.5	●	○	●	○	
4.5.1	●	○	●	○	
4.5.2	○	○	●	○	
4.5.3	●	○	●	○	7
5.0 Geologic Stability					
5.1	●	●	●	●	5
5.1.1	●	●	○	●	5
5.1.1.1	●	○	○	●	
5.1.2	●	●	○	●	5
5.1.2.1	●	●	●	●	
5.1.2.2	●	○	○	●	
5.2	●	●	●	○	5
5.2.1	●	●	○	●	5

4
TABLE C-7 RATING OF NRC PERFORMANCE AND SPECIFIC ISSUES

SPECIFIC ISSUES	ISSUE RATING*				REFERENCE TO SCA CHAPTER AND APPENDICES
	Importance	Ease of Resolution	Current Level of Resolution	Likely Level of Resolution With Proposed Plans	
5.3	●	○	○	○	
5.3.1	●	○	●	?	5.2
5.3.1.1	●	●	○	?	5.2
5.3.2	○	●	●	●	
5.3.2.1	●	●	●	●	
5.3.2.2	○	●	●	●	
5.3.2.3	●	●	●	●	
5.3.2.4	●	●	●	●	
5.3.3	○	○	○	?	
5.3.3.1	●	●	●	?	
5.3.3.2	●	●	●	?	
5.3.4	●	●	○	○	5
5.3.4.1	○	●	○	○	5
5.3.4.2	●	●	○	○	
5.3.4.3	●	●	○	○	5
5.3.4.3.1		●	●	○	
5.4	●	○	○	●	
5.4.1	○	○	●	○	
5.4.1.1	○	○	●	?	AA
5.4.2	●	○	●	?	
5.4.2.1	●	○	●	?	AA
5.4.2.2	●	●	●	?	AA
5.4.2.3	●	●	●	?	AA
6.0 Site Screening and Environmental/Institutional					
6.1	●	○	●	?	
6.2	●	●	●	○	
6.3	●	○	○	●	
6.3.1	○	○	○	○	
6.3.2	●	○	○	○	
6.3.3	○	○	○	○	
6.3.4	●	○	○	○	
6.3.5	○	○	○	○	
6.3.6	○	○	●	?	
6.3.7					
7.0 Other					
7.1					
7.2					
7.3					

⁵
TABLE C-~~8~~ LIST OF DOE ISSUES
(SCR, pages 17.1-2 and 17.1-3)

Key Issues

- S.1.D What is the total amount (activity) of radionuclides potentially releasable to the accessible environment in a 10,000-year period, and is this amount in compliance with appropriate U.S. Environmental Protection Agency Regulations?
- R.1.A Can stability and isolation capability of the repository be maintained in the presence of coupled in situ, excavation-induced, and thermal-induced stresses?
- R.1.D Can repository shafts, tunnels, and exploratory boreholes be constructed and sealed without causing preferential pathways for groundwater or increasing the potential for radionuclide migration from a nuclear waste repository such that compliance with appropriate U.S. Environmental Protection Agency regulations is not possible?

Issues

- S.1.A What are the geologic, mineralogic, and petrographic characteristics of the candidate repository horizons and surrounding strata within the reference repository location?
- S.1.B What are the nature and rates of past, present, and projected structural and tectonic processes within the geologic setting and reference repository location?
- S.1.C Are the pre-waste-emplacement groundwater travel times near the repository sufficient to assure compliance with U.S. Nuclear Regulatory Commission proposed technical criteria?
- W.1.A Does the very near-field interaction between the waste package and its components, the underground facility, and the geologic setting compromise waste package or engineered system performance? (i.e., What is the maximum expected release rate from the engineered system, and does the geologic setting prevent the waste package containment objective from being achieved?)
- W.1.B Is a unique borehole backfill required?
- W.2.A Are the geochemical and hydrologic properties of the geologic setting (in conjunction with the waste forms) sufficient to meet or exceed U.S. Nuclear Regulatory Commission proposed waste isolation requirements?
- W.2.B What is the relative importance of waste form leach rates versus solubility of key radionuclides in the near-field environment for controlling release?

- W.2.C Can valid Eh measurements for the candidate repository horizons in the reference repository location be made either by potentiometric measurement or indirectly by measurement of dissolved redox couples?
- W.2.D To what degree does the geologic setting retard migration of key radionuclides from the engineered system in meeting U.S. Environmental Protection Agency draft release criteria?
- W.3.A How can very near-field waste/barrier/rock materials interaction data, as measured experimentally, be extrapolated over time to reasonably assure that overall waste package and repository performance meets regulatory criteria?
- R.1.B Can satisfactory representative measurements or estimates of rock-mass strength be obtained?
- R.1.C Are current methods of in situ stress measurement used at depth reliable enough to provide satisfactory data for design requirements?

TABLE C-6 LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
S.1. - Geology and Hydrology	
S.1.A What are the geologic, mineralogic, and petrographic characteristics of the candidate repository horizons and surrounding strata within the reference repository location?	<p>S.1.1.A Determine the thickness and continuity of the candidate repository horizons within the reference repository location.</p> <p>S.1.2.A (Included in S.1.12.B) Determine the dip, strike, fold wavelength, and fold amplitude of the candidate repository horizons within the reference repository location.</p> <p>S.1.3.A (Included in S.1.12.B) Determine what deformational features are likely to intersect the candidate repository horizons within the reference repository location.</p> <p>S.1.4.A Determine the primary internal structure of the candidate repository horizons within the reference repository location.</p> <p>S.1.5.A (Related to S.1.9.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the orientation, distribution, aperture infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within the candidate repository horizons.</p>

Issues	Work element
	<p>S.1.6.A (Related to S.1.5.A, S.1.8.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the mineralogic, petrographic, and chemical characteristics of the candidate repository horizons including the composition, texture, and abundance of both primary and secondary phases; apply data as appropriate to predict fracture distribution in Work Element S.1.5.A.</p> <p>S.1.7.A (Related to S.1.11.B) Determine the stratigraphic characteristics of the flows above and below the candidate repository horizons.</p> <p>S.1.8.A (Related to S.1.6.A, S.1.7.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the structural, textural, mineralogic, and petrographic characteristics of the rocks above and below the candidate repository horizons.</p> <p>S.1.9.A (Related to S.1.5.A, S.1.7.A, W.2.1.A, W.2.4.A, and W.2.13.D) Determine the orientation, distribution, aperture infilling (secondary mineralization), and origin of fractures, discontinuities, and heterogeneities within rocks above and below the candidate repository horizons.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	<p>S.1.10.A (Related to S.1.27.C, S.1.28.C, S.1.29.C, and S.1.30.C)</p> <p>Determine the presence and characteristics of other possible anomalies that could serve as zones of greater permeability.</p>
<p>S.1.B</p> <p>What are the nature and rates of past, present, and projected structural and tectonic processes within the geologic setting and reference repository location?</p>	<p>S.1.11.B (Related to S.1.17.B)</p> <p>Evaluate the regional structural and tectonic setting of the Pasco Basin.</p> <p>S.1.12.B (Related to S.1.11.B and S.1.29.C)</p> <p>Determine the location of folds and faults in the Pasco Basin area with emphasis on the reference repository location.</p> <p>S.1.13.B</p> <p>Evaluate the type and amount of displacement, geometry (width and continuous length), and age of faults within the Pasco Basin.</p> <p>S.1.14.B</p> <p>Evaluate the relationship of folding and faulting in the Yakima fold belt; evaluate the relationship of Yakima folds to structures that may be present in rocks beneath the Columbia River basalt within the Pasco Basin.</p>

Issues	Work element
	<p>S.1.15.B (Related to S.1.13.B, R.1.3.A, and R.1.6.A)</p> <p>Evaluate the geologic (long-term) and contemporary rate of deformation and stress field in the Pasco Basin and reference repository location.</p> <p>S.1.16.B (Related to R.1.29 and R.1.30)</p> <p>Determine the seismicity of the Pasco Basin and reference repository location.</p> <p>S.1.17.B (Related to S.1.11.B through S.1.16.B, and S.1.23.B)</p> <p>Develop a conceptual model that can be used to evaluate the past, present, and projected tectonic setting of the reference repository location.</p> <p>S.1.18.B (Included in S.1.12.B, S.1.13.B, and S.1.14.B)</p> <p>Determine the presence of active faults within the geologic setting; evaluate their rupture length.</p> <p>S.1.19.B (Included in S.1.12.B and S.1.13.B)</p> <p>Determine if Quaternary faulting is present within the disturbed zone.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element	Issues	Work element
	<p>S.1.20.B (Included in S.1.12.B through S.1.16.B)</p> <p>Determine the presence of faults of any age within the disturbed zone; determine the potential for movement along existing faults and fractures within the disturbed zone; determine the potential for generation of new faults and fractures within the disturbed zone.</p> <p>S.1.21.B (Included in S.1.11.B, S.1.12.B, and S.1.15.B)</p> <p>Evaluate the nature of structural deformation such as uplift, subsidence, folding, and fracturing during the Quaternary Period.</p> <p>S.1.22.B (Included in S.1.16.B)</p> <p>Determine if earthquakes are correlatable with tectonic processes and/or features within the reference repository location; if correlatable, predict the frequency and magnitude of future events.</p> <p>S.1.23.B (Related to S.1.17.B)</p> <p>Determine the nature of igneous activity within the Pasco Basin.</p>	<p>S.1.C</p> <p>Are the pre-waste-emplacement groundwater travel times near the repository sufficient to assure compliance with U.S. Nuclear Regulatory Commission proposed technical criteria?</p>	<p>S.1.24.C (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, S.1.39.D, S.1.40.D, and S.1.51.D)</p> <p>Determine the hydraulic properties of the groundwater flow systems.</p> <p>S.1.25.C (Related to S.1.27.C, S.1.28.C, S.1.29.C, S.1.30.C, S.1.33.C, S.1.36.C, S.1.39.C, S.1.40.D, S.1.41.D, S.1.45.D, and S.1.51.D)</p> <p>Determine the hydraulic heads of the groundwater flow systems.</p> <p>S.1.26.C (Related to S.1.27.C, S.1.28.C, S.1.29.C, S.1.30.C, S.1.33.C, S.1.34.C, S.1.39.D, S.1.40.D, R.1.34, R.1.63, R.1.64, R.1.65, W.2.1.A, W.2.2.A, W.2.4.A, W.2.5.A, and W.2.13.D)</p> <p>Determine the hydrochemistry of the basalt groundwater system.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	<p>S.1.27.C (Related to S.1.7.A, S.1.9.A, S.1.12.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, and S.1.33.C)</p> <p>Determine the geometry of and interaction between the confined flow systems.</p> <p>S.1.28.C (Related to S.1.4.A, S.1.7.A, S.1.8.A, S.1.10.A, S.1.11.B, S.1.12.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.30.C, S.1.31.C, and S.1.51.D)</p> <p>Determine the extent of vertical groundwater movement between the confined, unconfined, and surface water systems.</p> <p>S.1.29.C (Related to S.1.7.A, S.1.11.B, S.1.12.B, S.1.17.B, S.1.24.C, S.1.25.D, S.1.26.C, S.1.27.C, S.1.28.C, S.1.33.D, and S.1.41.D)</p> <p>Determine the hydrologic characteristics and influences of structure and stratigraphic discontinuities that may shorten groundwater flow paths and solute transport times.</p>

Issues	Work element
	<p>S.1.30.C (Related to S.1.7.A, S.1.9.A, S.1.11.B, S.1.12.B, S.1.17.B, S.1.24.D through S.1.29.C, and S.1.31.C)</p> <p>Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models.</p> <p>S.1.31.C (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, and S.1.39.D)</p> <p>Develop and/or modify numerical codes that adequately simulate groundwater flow, natural hydrochemical species transport, and travel times under pre-waste-emplacement conditions.</p> <p>S.1.32.C (Included in S.1.41.D)</p> <p>Evaluate the ranges of relevant hydrogeologic conditions since the start of the Quaternary Period.</p> <p>S.1.33.C (Related to S.1.30.C, S.1.31.C, S.1.34.C, S.1.37.D, S.1.39.D, and S.1.41.D)</p> <p>Using selected models, predict groundwater travel time from the repository location to the accessible environment under pre-waste-emplacement conditions.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	<p>S.1.34.C (Related to S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, S.1.31.C, and S.1.33.C)</p> <p>Determine the bounds of uncertainty in model predictions of pre-waste-emplacment groundwater travel time.</p> <p>S.1.35.C (Included in S.1.30.C)</p> <p>Determine the groundwater content of the host rock.</p> <p>S.1.36.C (Included in S.1.30.C)</p> <p>Determine the nature of groundwater circulation in the host rock.</p>
<p>Issue S.1.D</p> <p>What is the total amount (activity) of radionuclides potentially releasable to the accessible environment in a 10,000-year period, and is this amount in compliance with appropriate U.S. Environmental Protection Agency regulations?</p>	

Issues	Work element
	<p>S.1.37.D (Related to S.1.30.C, S.1.31.C, S.1.33.C, S.1.34.C, and S.1.39.D)</p> <p>Develop and/or modify numerical codes that can reliably predict the changes in the processes determining the rate and extent of radionuclide transport under post-waste-emplacment conditions.</p> <p>S.1.38.D (Related to S.1.24.C, R.1.3.A, R.1.12.B, R.1.67, W.1.4.A, W.1.10.A, W.1.12.A, W.1.19.B, W.2.1.A, W.2.2.A, W.2.5.A, and W.2.9.B)</p> <p>Determine the radionuclide transport, thermal, and mechanical properties of the geohydrologic system.</p> <p>S.1.39.D (Related to S.1.24.C through S.1.30.C, S.1.37.D, S.1.38.D, S.1.40.D, R.1.13.D, R.1.20.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D)</p> <p>Using selected models, predict radionuclide mass fluxes to the accessible environment.</p> <p>S.1.40.D (Related to S.1.39.D)</p> <p>Determine the bounds of uncertainty in the model predictions of radionuclide fluxes to the accessible environment.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element	Issues	Work element
	<p>S.1.41.D (Related to S.1.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.23.B, S.1.24.C through S.1.26.C, and S.1.30.C)</p> <p>Identify credible disruptive events and potentially unfavorable process scenarios and estimate the associated properties and conditions of the host basalt near the repository site; develop bounding estimates for probabilities of occurrence for each event, as needed.</p>		<p>S.1.43.D (Related to S.1.30.C, S.1.33.C, S.1.39.D, S.1.40.D, S.1.41.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D)</p> <p>Determine whether the range of hydrogeologic conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.</p>
	<p>S.1.42.D (Related to S.1.6.A, S.1.9.A, S.1.26.D, S.1.39.D, S.1.40.D, S.1.41.D, and W.2.13.D)</p> <p>Determine whether the range of geochemical conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.</p>		<p>S.1.44.D (Related to S.1.45.D, S.1.48.D and S.1.49.D)</p> <p>Determine the potential for, and effect of, failure of existing or planned man-made surface water impoundments.</p>
			<p>S.1.45.D (Related to S.1.16.B, S.1.41.D, S.1.46.D, and S.1.49.D)</p> <p>Determine the effect of potential impoundments on the groundwater flow system.</p>
			<p>S.1.46.D (Related to S.1.41.D, S.2.1, and S.2.4)</p> <p>Determine the potential for human activity to cause significant changes in the surface and groundwater hydrology.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element	Issues	Work element
	<p>S.1.47.D (Related to R.1.34)</p> <p>Determine the potential for and the effect of occupancy and modification of the Columbia River flood plain.</p> <p>S.1.48.D (Included in S.1.45.D)</p> <p>Determine the potential for and magnitude of impoundment that could affect a change in the regional groundwater flow.</p> <p>S.1.49.D (Related to S.1.41.D, S.1.44.D, S.1.45.D, S.1.60.D, and S.2.5)</p> <p>Evaluate the effect of possible climatic changes.</p> <p>S.1.50.D (Related to S.1.41.D, R.1.18.D, and R.1.20.D)</p> <p>Determine the potential effect of boreholes on repository performance.</p> <p>S.1.51.D (Included in S.1.41.D)</p> <p>Determine the effect on waste isolation of potential changes in such hydrologic conditions as hydraulic gradient, average interstitial</p>		<p>velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.</p> <p>S.1.52.D (Related to S.1.17.B, S.1.39.D, S.1.40.D, S.1.41.D, R.1.3.A, R.1.29, R.1.30, W.1.2.A)</p> <p>Determine whether the range in tectonic and structural conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.</p> <p>S.1.53.D (Included in S.1.16.B, S.1.17.B, and S.1.52.D)</p> <p>Determine the historical seismicity of the geologic setting and if there are any historical earthquakes that could adversely affect the repository.</p> <p>S.1.54.D (Included in S.1.11.B through S.1.17.B, and S.1.52.D)</p> <p>Determine the effect of an active fault within the geologic setting on repository performance.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element	Issues	Work element
	<p>S.1.55.D. (Included in S.1.11.B through S.1.17.B, and S.1.52.D)</p> <p>Determine the effect of an active fault within the disturbed zone on repository performance.</p> <p>S.1.56.D (Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, and S.1.52.D)</p> <p>Determine the effect of faults and fractures on repository performance.</p> <p>S.1.57.D (Included in S.1.16.B, S.1.17.B, and S.1.52.D)</p> <p>Determine the effect of seismicity on repository performance.</p> <p>S.1.58.D (Included in S.1.4.A, S.1.5.A, S.1.8.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.52.D, and S.1.60.D)</p> <p>Determine the effect of structural deformation such as uplift, subsidence, folding, and fracturing on repository performance.</p>		<p>S.1.59.D (Related to S.1.17.B, S.1.23.B, S.1.41.D, and R.1.34)</p> <p>Determine the potential for breach of a repository by future fissure eruptions of Columbia River basalt; determine the effect of other types of igneous activity within and in the vicinity of the Pasco Basin.</p> <p>S.1.60.D (Related to S.1.15.B, S.1.17.B, S.1.45.D, S.1.49.D, and S.1.51.D)</p> <p>Determine whether the range of geomorphic conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.</p> <p>S.1.61.D (Included in S.1.60.D)</p> <p>Determine the likelihood of repository exhumation due to extreme erosion over the next 10,000 years.</p>
S.2 - Environment and Socioeconomics			
	None.		<p>S.2.1 (Related to S.1.46.D, S.2.3, and S.2.4)</p> <p>Establish baseline ecologic, radiologic, sociopolitical, and economic conditions against which impacts can be assessed and mitigation measures proposed.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
None.	<p>S.2.2 (Related to S.2.3)</p> <p>Determine if subsurface mining is present within the disturbed zone.</p> <p>S.2.3 (Related to S.2.1, S.2.2, and R.1.34)</p> <p>Determine the gross value, net value, and commercial potential of resources within the disturbed zone and within similar-size areas that are representative of and located within the geologic setting.</p>
None.	<p>S.2.4</p> <p>Identify the distribution of land ownership, use, and control of the repository area.</p>
None.	<p>S.2.5 (Related to S.1.49.0)</p> <p>Determine the meteorologic, climatologic, and air-quality conditions to be used as design and operating bases and assess future climatic changes that may affect repository performance.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
R.1 - Design	
R.1.A Can stability and isolation capability of the repository be maintained in the presence of coupled in situ, excavation-induced, and thermal-induced stresses?	<p>R.1.1.A Determine the methodology for design and analysis of subsurface openings and their support systems.</p> <p>R.1.2.A Evaluate the effect of underground construction sequence on the stability of openings.</p> <p>R.1.3.A Determine the magnitude and the rate of deformation of tunnels and canister boreholes resulting from in situ, excavation-induced, and thermal-induced stresses, and how deformation is affected by backfill.</p> <p>R.1.4.A Determine the magnitude and distribution of excavation-induced stresses for single and multiple openings.</p> <p>R.1.5.A Determine the magnitude and distribution of thermal stresses in the rock mass for the proposed waste package storage configuration.</p>

Issues	Work element
	<p>R.1.6.A (Related to R.1.7.A and R.1.4B) Determine from case history evaluations the combinations of stress fields, rock properties, geologic structural features, and mine geometries that are typical of rock burst-prone areas, and assess the probability of rock bursts at or near the repository site.</p> <p>R.1.7.A (Related to R.1.6.A and R.1.4B) Document occurrences of dynamic instability of test excavations at depth at the repository site.</p> <p>R.1.8.A (Related to R.1.14.C and R.1.15.C) Determine the spatial variation of in situ stresses in the region of the repository.</p> <p>R.1.9.A Determine the potential for subsidence caused by mine openings.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
R.1.B Can satisfactory representative measurements or estimates of rock-mass strength be obtained?	R.1.10.A Define the acceptable range of test results for intact rock and rock-mass characteristics to support design activities. R.1.11.B (Identical to R.2.3) Measure rock strength and deformation characteristics on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture. R.1.12.B (Identical to R.2.4) Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture. R.1.13.B Develop and validate mechanical, thermal, and thermomechanical models for performance of in situ tests and for design and performance of the repository.
R.1.C Are current methods of in situ stress measurement used at depth reliable enough to provide satisfactory data for design requirements?	R.1.14.C (Related to R.1.8.A and R.1.15.C) Develop stress measurement methods that will yield valid data in closely jointed basalt. R.1.15.C (Related to R.1.8.A and R.1.14.C) Establish methods of validating measured in situ stress data.

Issues	Work element
R.1.D Can repository shafts, tunnels and exploratory boreholes be constructed and sealed without causing preferential pathways for groundwater or increasing the potential for radionuclide migration from a nuclear waste repository such that compliance with appropriate U.S. Environmental Protection Agency regulations is not possible?	R.1.16.D Evaluate and select methods of excavation and rock support that can economically and safely be constructed and at the same time maintain isolation capability of the engineered system. R.1.17.D Develop or adapt instrumentation and test methods to measure the nature and extent of rock-mass disturbance caused by candidate excavation methods and stress redistribution around tunnels and boreholes.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	<p>R.1.18.D</p> <p>Identify performance requirements for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste.</p> <p>R.1.19.D</p> <p>Select materials and develop testing techniques required to meet repository room and tunnel sealing criteria.</p> <p>R.1.20.D</p> <p>Determine the effect of temperature, rock-mass deformation, groundwater flow, and groundwater chemistry on materials used for seals.</p> <p>R.1.21.D</p> <p>Develop grouts and grouting techniques that ensure acceptable sealing of the disturbed rock zone.</p>

Issues	Work element
	<p>R.1.22.D</p> <p>Determine the effects of temperature, rock-mass deformation, and time on the permeability of the sealed rock zone.</p> <p>R.1.23.D</p> <p>Select materials and develop testing techniques required to meet borehole sealing criteria.</p> <p>R.1.24.D</p> <p>Develop construction and test techniques required to meet repository tunnel and shaft sealing criteria.</p> <p>R.1.25.D</p> <p>Prepare final specifications for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste.</p> <p>R.1.26.D</p> <p>Develop methods and equipment for backfilling and sealing the repository, and demonstrate their effectiveness.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element	Issues	Work element
None.	<p>R.1.27</p> <p>Determine which facilities or systems within the facility will be designated and classified as high-level waste facilities.</p>		<p>R.1.31</p> <p>Develop shielding requirements, operating, and access control procedures to limit the dose to repository personnel.</p>
None.	<p>R.1.28</p> <p>Assess the effects of adverse conditions on the design and performance of the repository.</p> <p>R.1.29 (Related to R.1.30)</p> <p>Assess the effects of seismic events on underground openings during construction and operations.</p> <p>R.1.30 (Related to R.1.29)</p> <p>Assess the effects of seismic events on repository tunnel and shaft seals.</p>	<p>None.</p> <p>None.</p>	<p>R.1.32</p> <p>Develop the procedures and requirements for controlling access to the repository site.</p> <p>R.1.33</p> <p>Determine the techniques to be used for limiting, monitoring, and controlling the airborne radioactivity in the repository.</p> <p>R.1.34</p> <p>Develop a design that will protect operations personnel against the effects of natural phenomena and environmental conditions.</p> <p>R.1.35</p> <p>Determine the impact of the dynamic effects of equipment failure on safety-related systems and components.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element	Issues	Work element
None.	<p>R.1.36</p> <p>Define the structures or equipment necessary so that disruptive natural or man-induced events such as intrusion of gas, water, or explosion will not spread through the repository.</p>	None.	<p>R.1.41</p> <p>Define what requirements are necessary to permit evacuation of personnel under emergency conditions.</p>
None.	<p>R.1.37</p> <p>Determine the extent and severity of potential fires and explosions in the repository and their effect on the stability of the rock support systems and other safety-related systems.</p> <p>R.1.38</p> <p>Define which combustible materials can be used in the design of components and equipment that have been designated as safety-related systems.</p> <p>R.1.39</p> <p>Develop fire and explosion alarm and protection systems for all equipment and facilities within the repository operations area that are required for safe operation of the repository.</p> <p>R.1.40</p> <p>Determine the reliability and protection required to ensure that safety-related systems operate adequately under adverse or emergency conditions.</p>	<p>None.</p> <p>None.</p> <p>None.</p> <p>None.</p> <p>None.</p>	<p>R.1.42</p> <p>Determine what facilities, equipment, and services are required to ensure a safe and timely response to any emergency conditions.</p> <p>R.1.43</p> <p>Determine which systems require redundant power supply, uninterrupted service, or standby service in the event of loss of primary power.</p> <p>R.1.44</p> <p>Determine which structures, systems, and components are important to safety; develop and implement appropriate inspection, testing, and maintenance programs.</p> <p>R.1.45</p> <p>Assess the potential for criticality for the proposed waste packages and storage orientations under fully flooded storage conditions.</p> <p>R.1.46</p> <p>Determine what instrumentation and control systems are required to monitor and control safety-related systems.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	<p>R.1.47 (Related to R.2.5)</p> <p>Develop, as required, instrumentation to measure stresses, deformation, temperature, and pore pressures reliably until backfill is emplaced.</p> <p>R.1.48 (Related to R.1.6.A and R.1.7.A)</p> <p>Develop or adapt instrumentation and monitoring techniques to predict rock bursts.</p>
None.	<p>R.1.49</p> <p>Determine the requirements necessary to assure that safety-related systems provide adequate protection to construction and operations personnel.</p>
None.	<p>R.1.50</p> <p>Determine the requirements and procedures necessary for the safe receipt and surface storage of radioactive wastes.</p>
None.	<p>R.1.51</p> <p>Determine the ventilation requirements for the surface facilities that will contain radioactive materials.</p>

Issues	Work element
None.	<p>R.1.52 (Related to R.1.33)</p> <p>Determine what equipment and controls are necessary to measure the amount and concentrations of radionuclides in any effluents from surface facilities with sufficient precision to determine that they conform to statutory release requirements.</p>
None.	<p>R.1.53</p> <p>Determine the facilities that are required for the treatment, processing, or packaging of radioactive waste generated at the repository operations area to permit safe disposal or transportation of these wastes.</p> <p>R.1.54</p> <p>Determine the requirements for design of the surface waste disposal facilities to facilitate decommissioning.</p>
None.	<p>R.1.55 (Related to W.1.12.A)</p> <p>Determine that the interaction between the waste package, the underground facilities, and the geologic setting does not compromise the performance of the underground facilities.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	<p>R.1.56 (Related to R.1.18.D, R.1.19.D, and R.1.66).</p> <p>Determine how to control groundwater influx and transit in the repository to maintain radionuclide release from engineered systems within the U.S. Nuclear Regulatory Commission appropriate release standards.</p> <p>R.1.57</p> <p>Provide an appropriate orientation, geometry, waste placement, and layout of the repository to ensure structural stability and containment of radionuclides.</p>
None.	<p>R.1.58</p> <p>Design the underground facility with sufficient flexibility to allow for adjustments during construction that will accommodate site-specific conditions identified by in situ testing or monitoring.</p>

Issues	Work element
None.	<p>R.1.59</p> <p>Define the requirements necessary to allow for the emplacement or retrieval of waste packages during continuous excavation and construction of the repository.</p> <p>R.1.60 (Included in R.1.36)</p> <p>Determine what safety requirements are necessary to isolate waste package storage rooms from other areas in the event that accidents occur.</p>
None.	<p>R.1.61</p> <p>Develop rock support systems that are compatible with decommissioning requirements and that will function satisfactorily in the repository environment for the period of construction, operation, and retrieval (including effects of cooling prior to backfilling or retrieval).</p> <p>R.1.62</p> <p>Define the requirements, equipment, and procedures necessary to retrieve the radioactive waste after emplacement in the repository if retrieval is ultimately required.</p>
None.	

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
None.	R.1.63 (Related to R.1.56) Assess the requirements to monitor and provide effective control of groundwater intrusion, service water intrusion, or gas inflow into the repository during construction.
None.	R.1.64 Define subsurface ventilation requirements for the control of radioactive particulates and gases within and releases from the subsurface facility.
	R.1.65 Define ventilating system requirements during normal operations, including controls to ensure continued operation under emergency conditions.
None.	R.1.66 Determine functional requirements for selecting locations of repository seals and backfills as engineered barriers to effectively retard groundwater movement and radionuclide migration.
	R.1.67 Determine radionuclide sorption requirements for backfill materials to be used for repository rooms and tunnels.

Issues	Work element
None.	R.1.68 Define the appropriate requirements, equipment, and procedures necessary to handle, emplace, and retrieve the radioactive waste under operating conditions.
None.	R.1.69 (Related to R.1.50) Design hoist and hoist loading systems with sufficient capacity, redundancy, and monitoring systems to ensure that radioactive materials will be handled in a safe and reliable manner.
None.	R.1.70 Determine the coupled effects of stress and elevated temperatures on the permeability of the rock mass.
	R.1.71 Estimate the extent of drying and resaturation of the host rock and backfill as functions of time and distance from the emplaced waste package, and determine the effects of such on the host rock.
None.	R.1.72 Prepare procedures that will ensure the development of a complete documented history of repository construction as specified in 60.134(c).

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
None.	<p>R.1.73</p> <p>Prepare specifications for the control of explosives to include the provisions of 30 CFR 57.6.</p>
None.	<p>R.1.74</p> <p>Define and implement appropriate training, testing, certification, and qualification programs for operating and supervisory personnel.</p>
None.	<p>R.1.75</p> <p>Define and implement methods and designs that will minimize resource utilization to the extent compatible with safety and performance requirements.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
R.2 - Performance Confirmation	
None.	<p>R.2.1</p> <p>Determine which characteristics of the natural and engineered systems need to be measured or monitored for performance confirmation, and establish any required baseline values for those characteristics prior to repository construction.</p>
None.	<p>R.2.2</p> <p>Develop a plan for comparing confirmation data and conditions during construction and operation with design data and conditions to determine if significant differences exist that will require modification to the design or construction method.</p> <p>R.2.3 (Identical to R.1.11.8)</p> <p>Measure rock strength and deformation characteristics on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.</p> <p>R.2.4 (Identical to R.1.12.8)</p> <p>Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.</p>

Issues	Work element
None.	<p>R.2.5 (Related to R.1.47)</p> <p>Deploy instrumentation, as required, to reliably measure stresses, deformation, temperature, and pore pressures until backfill is emplaced.</p>
None.	<p>R.2.6</p> <p>Conduct field tests, as required, of borehole plugging to demonstrate that materials and emplacement methods meet requirements.</p>
None.	<p>R.2.7</p> <p>Conduct field tests, as required, of repository room, tunnel, and shaft backfill placement to demonstrate that materials and emplacement methods meet requirements.</p>
None.	<p>R.2.8</p> <p>Conduct field tests, as required, of repository tunnel and shaft seals to demonstrate that materials emplacement methods meet functional requirements.</p>
None.	<p>R.2.9</p> <p>Develop, as required, instrumentation, techniques, and procedures for monitoring the integrity of the waste package in situ.</p> <p>R.2.10</p> <p>Develop a laboratory testing and monitoring program, as required, to evaluate the internal and external condition of representative waste packages subjected to a simulated repository environment.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	<p>W.1.10.A (Identical to W.2.6.A)</p> <p>Determine the formation and stability of radionuclide complexes and/or colloids over expected repository near-field and far-field conditions.</p> <p>W.1.11.A (Included in W.1.2.A and W.1.6.A)</p> <p>Determine the chemical properties and inflow rate of groundwater and their effect on canister corrosion during the 1,000-year containment period.</p> <p>W.1.12.A (Identical to W.2.3.A and W.1.19.B, includes discussion of W.1.9.A)</p> <p>Determine the extent to which the interaction between the canister materials, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides.</p>
<p>W.1.8</p> <p>Is a unique borehole backfill required?</p>	<p>W.1.13.B</p> <p>Assess the impact of waste storage in a borehole with no backfill on waste containment and isolation.</p> <p>IF A UNIQUE BOREHOLE BACKFILL IS REQUIRED, THE FOLLOWING FACTORS ARE NEEDED. SOME OF THESE FACTORS MAY NEED COMPLETION TO DECIDE ISSUE W.1.8.</p> <p>W.1.14.B</p> <p>Determine the need for special tailoring agents in backfill to moderate the corrosivity (Eh and pH) of the groundwater contacting the canister.</p>

Issues	Work element
	<p>W.1.15.B (See also W.1.16.B)</p> <p>Define the characteristics of the backfill materials required to retard the flow of groundwater to the canister. Identify potential backfill materials with these characteristics.</p> <p>W.1.16.B</p> <p>Define the characteristics of the backfill material required to reduce the rate of radionuclide release from the waste package. Identify backfill materials with these characteristics.</p> <p>W.1.17.B (Identical to W.1.8.A, included in W.1.3.A)</p> <p>Determine the effect of radiation damage on the performance of the waste form, backfill, and host rock.</p> <p>W.1.18.B (Identical to W.1.1.A)</p> <p>Determine the maximum operating temperature limits for waste form, backfill, canister, and host rock.</p> <p>W.1.19.B (Identical to W.1.12.A and W.2.3.A)</p> <p>Determine the extent to which the interaction between the canister material, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides.</p> <p>W.1.20.B (Included in W.2.13.D)</p> <p>Determine if a waste package backfill is required to provide acceptable containment in the event of premature canister failure.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
W.1 - Waste Package	
W.1.A Does the very near-field interaction between the waste package and its components, the underground facility, and the geologic setting compromise waste package or engineered system performance? (i.e., What is the maximum expected release rate from the engineered system, and does the geologic setting prevent the waste package containment objective from being achieved?)	<p>W.1.1.A (Identical to W.1.18.B) Determine the maximum operating temperature limits for waste form, backfill, canister, and host rock.</p> <p>W.1.2.A (Related to W.1.7.A, includes discussion of W.1.11.A) Determine conditions that affect design of waste packages, including thermal loading, mechanical loading, and chemical environment, during handling, shipment, emplacement, retrieval, and after repository decommissioning.</p> <p>W.1.3.A (Identical to W.2.7.A, includes discussion of W.1.8.A) Determine the effect of the waste package radiation environment on near-field geochemistry, waste package, and barrier material performance.</p> <p>W.1.4.A (Identical to W.2.5.A, W.2.9.B, see W.1.12.A) Determine the projected solubilities, kinetic behavior, and distribution of aqueous waste species for key radionuclides which might be released from the waste package.</p>

Issues	Work element
	<p>W.1.5.A (Identical to W.2.2.A) Determine the extent of Eh-pH and groundwater compositional control by the host basalt after repository closure.</p> <p>W.1.6.A (Includes discussion of W.1.11.A, see also W.2.2.A) Determine the susceptibility of candidate canister materials to degradation (i.e., corrosion, hydriding, fatigue, etc.) in the repository near-field environment.</p> <p>W.1.7.A (Related to W.1.2.A) Determine design properties, including thermal, physical, mechanical, and chemical, for waste package component materials and host rock.</p> <p>W.1.8.A (Included in W.1.3.A) Determine the effect of radiation on the performance of the waste form, backfill, and near-field host rock.</p> <p>W.1.9.A (Included in W.1.12.A) Determine the release rate (performance) of candidate waste forms in the repository near-field environment.</p>

TABLE LIST OF DOE DWIP ISSUES AND WORK ELEMENTS

Issues	Work element
None.	<p>W.1.21</p> <p>Develop waste package acceptance specifications for waste solidification that meet U.S. Nuclear Regulatory Commission proposed requirements.</p>
None.	<p>W.1.22</p> <p>Develop waste package acceptance specifications for consolidation that meet U.S. Nuclear Regulatory Commission proposed requirements.</p>
None.	<p>W.1.23</p> <p>Develop waste package acceptance specifications for combustibles that meet U.S. Nuclear Regulatory Commission proposed requirements.</p>
None.	<p>W.1.24</p> <p>Determine the impact of the reprocessing technique (including waste fractionization) on waste package design.</p>
	<p>W.1.25</p> <p>Develop waste package acceptance specifications for explosive, pyrophoric, and chemically reactive materials that meet U.S. Nuclear Regulatory Commission proposed requirements.</p>

Issues	Work element
None.	<p>W.1.26</p> <p>Develop waste package acceptance specifications for free liquids that meet U.S. Nuclear Regulatory Commission proposed requirements.</p>
None.	<p>W.1.27</p> <p>Determine the waste package handling, shipping (including drop tests), emplacement, and retrievability requirements.</p>
None.	<p>W.1.28</p> <p>Develop waste package acceptance specifications for identification that meet U.S. Nuclear Regulatory Commission proposed requirements.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
W.2 - Site Geochemistry	
W.2.A Are the geochemical and hydrologic properties of the geologic setting (in conjunction with the waste forms) sufficient to meet or exceed U.S. Nuclear Regulatory Commission proposed waste isolation requirements?	W.2.1.A (Related to W.2.4.A) Determine the effect on radionuclide mobility of changes in the primary and secondary mineralogical conditions in the near field and far field of the repository, along the expected pathway to the biosphere. W.2.2.A (Identical to W.1.5.A) Determine the extent of Eh-pH and groundwater compositional control by the host basalt after repository closure. W.2.3.A (Identical to W.1.12.A and W.1.19.B) Determine the effects of waste/barrier/rock/water interactions on the performance of the underground facility or geologic setting. W.2.4.A Demonstrate that geochemical conditions in the near and far field are such that transport of radionuclides is retarded for sufficient time to satisfy waste isolation requirements. W.2.5.A (Identical to W.1.4.A and W.2.9.B) Determine the projected solubilities and distribution of aqueous species for key radionuclides which might be released from the waste package. W.2.6.A (Identical to W.1.10.A) Determine the formation and stability of radionuclide complexes and/or colloids over expected repository near- and far-field conditions.

Issues	Work element
	W.2.7.A (Identical to W.1.3.A) Determine the effect of the waste package radiation environment on near-field geochemistry, waste package, and barrier-material performance. W.2.8.A Determine acceptable release rates of key radionuclides from the engineered system as a function of containment time, groundwater travel time to the accessible environment, and water flow through the repository.
W.2.B What is the relative importance of waste form leach rates versus solubility of key radionuclides in the near-field environment for controlling release?	W.2.9.B (Identical to W.1.4.A and W.2.5.A) Determine the projected solubilities and distribution of aqueous species for key radionuclides which might be released from the waste package.
W.2.C Can valid Eh measurements for the candidate repository horizons in the reference repository location be made either by potentiometric measurement or indirectly by measurement of dissolved redox couples?	W.2.10.C Determine the method and technique that can be utilized to provide valid in situ Eh measurements for the reference repository location.
None.	W.2.11 (Discussed in W.2.13.D) Determine how the geochemical and physical properties of the geologic setting mitigate the impact of premature failure of the waste package.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
W.2.D To what degree does the geologic setting retard migration of key radionuclides from the engineered system in meeting U.S. Environmental Protection Agency draft release criteria?	W.2.12.D (Related to W.2.11) Determine on a radionuclide-specific basis whether U.S. Nuclear Regulatory Commission proposed repository release rates or U.S. Environmental Protection Agency draft release limits are the limiting repository requirements. W.2.13.D (Includes discussion of W.1.20.B and W.2.11) Determine to what degree the characteristics of the geologic setting complement the engineered system.

Issues	Work element
W.3 - Testing and Performance Confirmation	
W.3.A How can very near-field waste/barrier/rock materials interaction data, as measured experimentally, be extrapolated over time to reasonably assure that overall waste package and repository performance meets regulatory criteria?	W.3.1.A Define appropriate statistical techniques so that laboratory and field materials interaction data can be extrapolated over time to provide a reasonable assurance of the long-term performance of the engineered system. W.3.2.A Determine the thermodynamic and kinetic arguments that can be used to extrapolate short-term (less than 2 years per experiment) materials test (hydrothermal) data. W.3.3.A Develop and/or use numerical modeling techniques to predict the environmental conditions, package degradation, and radionuclide behavior of emplaced wastes in or near the engineered system. W.3.4.A Determine what natural analogues of waste package components can be used to verify the compatibility of the waste package with the repository environment. W.3.5 Develop an acceptance test procedure for waste packages.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
None.	<p>W.3.6</p> <p>Determine and conduct field, engineering, and in situ testing as may be appropriate to meet design needs and U.S. Nuclear Regulatory Commission proposed performance requirements.</p> <p>W.3.7</p> <p>Determine suitability of using nonradioactive chemical analogues for actual waste forms in the hydrothermal testing program.</p>
None.	<p>W.3.8</p> <p>Determine requirements for monitoring. Define parameters, methodology, interpretive criteria, and actions.</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
P.1 - Preemplacement Site Performance	
S.1.C-SC Are the pre-waste-emplacement groundwater travel times near the repository sufficient to assure compliance with U.S. Nuclear Regulatory Commission proposed technical criteria?	<p>P.1.1-SC (Identical to P.2.1-WA and P.3.1-SD)</p> <p>Prepare a systems description for postclosure repository performance defining all subsystem models (including those used for preem- placement assessment), as well as the criteria on which they are based.</p> <p>S.1.30.C-SC (Related to S.1.7.A, S.1.9.A, S.1.11.B, S.1.17.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.29.C, and S.1.31.C)</p> <p>Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models.</p> <p>S.1.31.C-SC (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, and S.1.39.D)</p> <p>Develop and/or modify numerical codes that adequately simulate groundwater flow and travel times under pre-waste-emplacement conditions.</p>

Issues	Work element
	<p>S.1.33.C-SC (Related to S.1.30.C, S.1.31.C, S.1.34.C, S.1.37.D, S.1.39.D, and S.1.41.D)</p> <p>Using selected models, predict groundwater travel time from the repository location to the accessible environment under pre-waste-emplacement conditions.</p> <p>S.1.34.C-SC (Related to S.1.24.C, S.1.25.C, S.1.26.C, S.1.30.C, S.1.31.C, and S.1.33.C)</p> <p>Determine the bounds of uncertainty in model predictions of pre-waste-emplacement groundwater travel time.</p> <p>W.2.13.D-SC (Includes discussion of W.1.20.B and W.2.11.C)</p> <p>Determine to what degree the characteristics of the geologic setting complement the engineered system.</p> <p>P.1.2-SC (Identical to P.2.2-WA and P.3.2-SD)</p> <p>Conduct verification, validation, and benchmarking of all codes used for performance assessment.</p> <p>P.1.3-SC (Identical to P.2.3-WA and P.3.3-SD)</p> <p>Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979).</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element	Issues	Work element
P.2 - Postclosure Performance of the Engineered System			
W.1.A-WA (Related to W.2.A, W.3.A, R.1.A, R.1.B, and R.1.D) Does the very near-field interaction between the waste package and its components, the underground facility, and the geologic setting compromise waste package or engineered system performance? (i.e., What is the maximum expected release rate from the engineered system, and does the geologic setting prevent the waste package containment objective from being achieved?)	P.2.1-WA (Identical to P.1.1-SC and P.3.1-SD) Prepare a systems description for postclosure repository performance, defining all subsystem models (including those used for preemplacement assessment) as well as the criteria on which they are based. W.1.12.A-WA (Identical to W.2.3.A and W.1.19.B, includes discussion of W.1.9.A) Determine the extent to which the interaction between the canister materials, waste form, backfill, and host rock in a saturated environment results in retardation of radionuclides. W.3.1.A-WA Define appropriate statistical techniques so that laboratory and field materials interaction data can be extrapolated over time to provide a reasonable assurance of the long-term performance of the engineered system.		W.3.2.A-WA Determine the thermodynamic and kinetic arguments that can be used to extrapolate short-term (less than 2 years per experiment) materials test (hydrothermal) data. W.3.3.A-WA Develop and/or use numerical modeling techniques to predict the environmental conditions, package degradation, and radionuclide behavior of emplaced wastes in or near the engineered system. W.3.4.A-WA Determine what natural analogues of waste package components can be used to verify the compatibility of the waste package with the repository environment. R.1.2.A-WA Evaluate the effect of underground construction sequence on the stability of openings. R.1.3.A-WA Determine the magnitude and the rate of deformation of tunnels and canister boreholes resulting from in situ, excavation-induced, and thermal stresses, and how deformation is affected by backfill.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element	Issues	Work element
	<p>R.1.5.A-WA</p> <p>Determine the magnitude and distribution of thermal stresses in the rock mass for the proposed waste package storage configuration.</p> <p>R.1.9.A-WA</p> <p>Determine the potential for subsidence caused by mine openings.</p> <p>R.1.10.B-WA</p> <p>Define the acceptable range of test results for intact rock and rock-mass characteristics to support design activities.</p> <p>R.1.13.B-WA</p> <p>Develop and validate mechanical, thermal, and thermomechanical models for performance of in situ tests and for design and performance of the repository.</p> <p>R.1.18.D-WA</p> <p>Identify performance requirements for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste.</p> <p>R.1.22.D-WA</p> <p>Determine the effects of temperature, rock-mass deformation, and time on the permeability of the sealed rock zone.</p>		<p>R.1.29-WA (Related to R.1.30)</p> <p>Assess the effects of seismic events on underground openings during construction and operations.</p> <p>R.1.66-WA</p> <p>Determine functional requirements for selecting locations of repository seals and backfills as engineered barriers to effectively retard groundwater movement and radionuclide migration.</p> <p>R.1.67-WA</p> <p>Determine radionuclide sorption requirements for backfill materials to be used for repository rooms and tunnels.</p> <p>P.2.2-WA (Identical to P.1.2-SC and P.3.2-SD)</p> <p>Conduct verification, validation, and benchmarking of all codes used for performance assessment.</p> <p>P.2.3-WA (Identical to P.1.3-SC and P.3.3-SD)</p> <p>Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979).</p>

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element	Issues	Work element
P.3 - Postclosure Performance of the Waste Isolation System			
Issue S.1.0-SD (Related to Issue W.2.D) What is the total amount (activity) of radionuclides potentially releasable to the accessible environment in a 10,000-year period, and is this amount in compliance with appropriate U.S. Environmental Protection Agency regulations? (Related to Issue W.2.D)	P.3.1-SD (Identical to P.1.1-SC and P.2.1-WA) Prepare a systems description for postclosure repository performance defining all subsystem models (including those used for preem-placement assessment), as well as the criteria on which they are based. S.1.41.0-SD (Related to S.1.A through S.1.10.A, S.1.11.B through S.1.17.B, S.1.23.B, S.1.24.C through S.1.26.C, and S.1.30.C) Identify credible disruptive events and potentially unfavorable process scenarios and estimate the associated properties and conditions of the host basalt near the repository site; develop bounding estimates for probabilities of occurrence for each event, as needed.		S.1.30.C-SD (Related to S.1.7.A, S.1.9.A, S.1.11.B, S.1.17.B, S.1.24.C, S.1.25.C, S.1.26.C, S.1.27.C, S.1.28.C, S.1.29.C, and S.1.31.C) Develop a conceptual hydrologic model that can be used to evaluate the hydrogeologic setting of the repository and as input to the performance assessment models. S.1.37.D-SD (Related to S.1.30.C, S.1.31.C, S.1.33.C, S.1.34.C, and S.1.39.D) Develop and/or modify numerical codes that can reliably predict the changes in the processes determining the rate and extent of radionuclide transport under post-waste-emplacement conditions. S.1.39.D-SD (Related to S.1.24.C through S.1.30.C, S.1.37.D, S.1.38.D, S.1.40.D, R.1.13.D, W.1.20.D, W.2.4.A, W.2.8.A, W.2.11.D, and W.2.13.D) Using selected models, predict radionuclide mass fluxes to the accessible environment.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	<p>S.1.40.D-SD (Related to S.1.39.D)</p> <p>Determine the bounds of uncertainty in the model predictions of radio-nuclide fluxes to the accessible environment.</p> <p>P.3.2-SD (Identical to P.1.2-SC and P.2.2-WA)</p> <p>Conduct verification, validation, and benchmarking of all codes used for performance assessment.</p> <p>P.3.3-SD (Identical to P.1.3-SC and P.2.3-WA)</p> <p>Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979).</p> <p>P.3.4-SD</p> <p>Perform a postclosure performance assessment for the waste isolation system for inclusion in the License Application.</p>

Issues	Work element
P.4 - Preclosure Repository Performance	
None identified.	<p>P.4.1</p> <p>Prepare an operating performance systems description identifying all engineered system structures, sub-systems, and components important to safety.</p> <p>P.4.2 (Done in parallel with Work Element P.4.2)</p> <p>Prepare a preliminary preclosure repository safety assessment for normal operations and accidental conditions, based on the repository and waste package conceptual designs.</p> <p>P.4.3 (Done in parallel with Work Element P.4.2)</p> <p>Select and characterize preclosure failure scenarios.</p> <p>R.1.35</p> <p>Determine the impact of the dynamic effects of equipment failure on safety-related systems and components.</p> <p>R.1.49</p> <p>Determine the requirements necessary to assure that safety-related systems provide adequate protection to construction and operations personnel.</p> <p>P.4.4</p> <p>Prepare a preclosure safety performance assessment for normal operations and for accidental failure scenarios, including preventive and mitigative measures, for inclusion in the License Application.</p>

Appendix D

Reserved

APPENDIX E
POTENTIAL FOR LARGE-SCALE PUMP TESTS
IN THE GRANDE RONDE

TABLE OF CONTENTS

1. INTRODUCTION
2. ASSUMED HYDROSTRATIGRAPHY
3. AQUIFER RESPONSE
 - 3.1 Hantush-Jacob Solution
 - 3.2 Modified Hantush Solution
 - 3.3 Applications
4. AQUITARD RESPONSE
5. CONCLUSIONS
6. REFERENCES

LIST OF FIGURES

Figure

- 1 Assumed Hydrostratigraphy at the Reference Repository Location
- 2 Mathematical Model
- 3 Case I: Predicted Hydraulic Response in Aquifer D; $r=50$ ft
- 4 Case I: Predicted Hydraulic Response in Aquifer D; $r=500$ ft
- 5 Case I: Predicted Hydraulic Response in Aquifer D; $r=3000$ ft
- 6 Case I: r vs. t for Aquifer Drawdown of 2.0 ft
- 7 Case I: r vs. t for Aquifer Drawdown of 10.0 ft
- 8 Case II: Predicted Hydraulic Response in Aquifer B; $r=30,000$ ft
- 9 Case II: Predicted Hydraulic Response in Aquifer B; $r=100,000$ ft
- 10 Case II: r vs. t for Aquifer Drawdown of 2.0 ft
- 11 Case II: r vs. t for Aquifer Drawdown of 10 ft
- 12 Case I: Predicted Hydraulic Response in Aquitard E; $r=50$ ft,
 $z=40$ ft
- 13 Case I: Predicted Hydraulic Response in Aquitard E; $r=100$ ft,
 $z=50$ ft
- 14 Case I: Predicted Hydraulic Response in Aquitard E; $r=500$ ft,
 $z=40$ ft

POTENTIAL FOR LARGE-SCALE PUMP TESTS IN THE GRANDE RONDE

1 INTRODUCTION

All natural geologic media exhibit some degree of heterogeneity. Single borehole tests, as reported in the SCR for the Hanford Site, stress a relatively small volume of the medium. The radius of influence of such tests is estimated to be on the order of tens to hundreds of feet. At this small scale, DOE test results indicate that hydraulic properties of a hydrostratigraphic unit can vary by orders of magnitude over relatively short distances.

Large scale pump tests stress a much larger volume of the medium. If the radius of influence of the test is sufficiently large, the hydraulic response of the system reflects the combined effects of individual heterogeneities. Analysis of such tests will provide bulk values of hydraulic parameters which are necessary for regional analysis. A large-scale pump test is normally monitored by observation wells or piezometers because factors affecting groundwater flow at a production well (i.e., skin effect) do not generally affect the hydraulic response at observation wells. Therefore uncertainty in calculated parameters is reduced.

This study was made in order to illustrate the potential value of conducting large-scale pump tests in the Grande Ronde. In particular, the ability of such tests to significantly stress large regions surrounding the pumping well and to yield information about bulk horizontal and vertical hydraulic conductivity is discussed. Hydrogeologic properties thought to be typical of the Reference Repository Location (RRL) are used in the analysis. Several analytical methods along with the various limitations and conditions on their use are described. For illustrative purposes, a simple analytical method is utilized to calculate the hydraulic response to pumping. The basic conclusions which are reached as a result of the study are probably valid unless the hydrogeology at the RRL is very substantially different from that assumed below.

2. ASSUMED HYDROSTRATIGRAPHY

The assumed hydrostratigraphy of the Grande Ronde near the potential repository horizon (dense Umtanum) is shown in Figure 1. This idealized hydrostratigraphy is based on preliminary data (i.e., prior to publication of the SCR) from hole RRL-2 and other boreholes in the area (DC-3, DC-4). Thicknesses and transmissivities of the assumed hydrostratigraphic units may vary from those actually measured in the field. Aquifers are delineated as hydrostratigraphic units B, D, and F, while aquitards are represented by units A, C, and E.

These hydrostratigraphic units do not necessarily correspond to units chosen by DOE for purposes of numerical modeling (SCR, Chapter 12).

The following analytical methods are available for determining in situ hydraulic properties in an aquifer-aquitard system:

- o Hantush and Jacob (1955) Solution;
- o Modified Hantush (1960) Solution; and
- o Neuman and Witherspoon (1972) Ratio Method.

For a given set of parameters, the solutions can be used to predict the hydraulic response of the system.

Analytical solutions can be related to the mathematical model shown in Figure 2. All solutions are based on the following assumptions:

- o Aquifers and aquitards have uniform thicknesses and are homogeneous with respect to hydraulic properties.

Geologic data from the Pasco Basin indicate that stratigraphic thicknesses of basalt units do not change drastically over distances of practical consideration. However, the thickness, distribution and characteristics of intraflow structures such as the flow top, colomade/entablature and fanning structures are highly variable and relatively unpredictable. Single borehole tests by DOE suggest that significant heterogeneity may exist within basalt units. If the scale of the test is sufficiently large and the distribution of heterogeneity somewhat random, it is commonly possible to assume a homogeneous system with averaged (or bulk) hydraulic properties. After a test is performed, the assumption can be evaluated by comparing the measured response (at numerous observation points) with the ideal response predicted by the mathematical model.

- o Aquifers and aquitards are seemingly infinite in radial extent.

This assumption implies that the lateral extent of hydrostratigraphic units is greater than the radius of influence of the test. Since the radius of influence increases with time, this assumption is usually satisfied by early-time data. The validity of late-time data can be evaluated, based on a comparison between measured/ideal response and a hydrogeologic knowledge of the system. This assumption need not be satisfied in order to obtain valuable data. Test results can be analyzed to yield information on the location and properties of hydrogeologic boundaries such as faults and changes in lithology.

- o The pumped aquifer is isotropic in the horizontal plane.

Horizontal anisotropy in hydraulic properties has not been measured in Pasco Basin basalts. The degree of horizontal anisotropy can be evaluated by comparing test results from observation points with different directions from the pumping well.

- o Approximately uniform hydraulic heads exist throughout the system prior to pumping.

This assumption implies that pre-test hydraulic gradients are small compared to gradients imposed by the pumping well. Head measurements by DOE indicate that natural hydraulic gradients in the Pasco Basin are sufficiently small to be neglected.

- o The aquifer is pumped at a constant discharge rate.
- o The pumping well penetrates the entire aquifer.
- o Wellbore storage is neglected.

In most cases, wellbore storage in the pumping well does not affect the hydraulic response at observation wells.

- o Water removed from storage and/or derived from leakage is instantaneously discharged at the pumping well.

Due to limitations of the mathematical model and uncertainty in hydraulic properties, the numerical results of this study should be considered first-order approximations.

It is customary to simplify the mathematics by assuming essentially horizontal flow in aquifers and vertical flow in aquitards. Hantush (1967) indicates that the assumption is valid if:

$$\frac{Kb_i}{K_i b} > 100, \quad i = 1, 2, \quad (1)$$

where all parameters are defined in Figure 2. This relationship is consistent with observations of Neuman and Witherspoon (1969a), which suggest that the errors introduced by the assumption are less than 5% when the hydraulic conductivities of aquifers are more than two orders of magnitude greater than that of aquitards. Aquitards at Hanford are composed of dense basalt which tends to be predominantly fractured in the vertical direction. This probably results in an anisotropic medium with vertical permeability greater than horizontal permeability. For this reason, the above criteria are probably over-conservative.

3 AQUIFER RESPONSE

For the purpose of this study it is assumed that a fully penetrating production well is pumped, and the hydraulic response of the pumped aquifer is measured at observation wells. The Hantush-Jacob solution and the Modified Hantush solution can be used to estimate the hydraulic response of a confined leaky aquifer as a result of pumping.

These solutions assume that drawdown in the unpumped aquifers is negligible during the test, which implies that boundaries A and B (in Figure 2) are constant head boundaries with zero drawdown. This assumption was investigated by Neuman and Witherspoon (1969a). They indicate that one is probably justified in neglecting drawdown in the unpumped aquifer if:

$$\frac{K_i b_i}{K_b} > 100, \quad i = 1, 2. \quad (2)$$

If leakage occurs from other aquitards (i.e., those not included in the model), drawdown in the unpumped aquifers will be reduced. Since this is likely to occur in Grande Ronde basalts, the above condition is probably over-conservative.

Neuman and Witherspoon also conclude that drawdown in the unpumped aquifers is negligible at early times; that is, when

$$t > \frac{0.1 S'_{si} (b'_i)^2}{K'_i}, \quad i = 1, 2. \quad (3)$$

3.1 Hantush-Jacob Solution

If aquitard storage is neglected, drawdown in the pumped aquifer is given by the following equation:

$$s(r, t) = \frac{Q}{4\pi K b} W(u, r/B) = \frac{Q}{4\pi K b} L(u, v) \quad (4)$$

Values of $W(u, r/B)$ are tabulated in Hantush (1956), and type curves for the function $L(u, v)$ are presented in Lohman (1972) and Reed (1980). Lohman (1972) describes a curve matching procedure whereby values of K , S_s , and v can be determined from time-drawdown measurements in observation wells. The assumption of negligible aquitard storage implies that leakage into the pumped aquifer is proportional to the hydraulic gradient across the leaky aquitards (i.e., described by Darcy's law). Neuman and Witherspoon (1969b) conclude that this assumption is valid if:

$$\beta < 0.01, \quad (5)$$

where β is defined in Figure 2.

3.2 Modified Hantush Solution

If aquitard storage is significant, drawdown in the pumped aquifer at early times is given by:

$$s(r, t) = \frac{Q}{4\pi K b} H(u, \beta) \quad (6)$$

for:

$$t > \frac{0.1 S'_{si} (b'_i)^2}{K'_i}, \quad i = 1, 2. \quad (7)$$

The function $H(u, \beta)$ is tabulated in Hantush (1960), and presented as type curves in Lohman (1972) and Reed (1980). The curve matching procedures given in Lohman (1972) can be used to determine K , S_s , and β from time-drawdown measurements in observation wells.

At later times the following equation is used:

$$s(r, t) = \frac{Q}{4\pi K b} L(u\delta, v) \quad (7)$$

for

$$t > \frac{5 S_{s1}' (b_1')^2}{K_1'} \quad i = 1, 2 \quad (8)$$

If the parameter δ (see Figure 2) is approximately equal to one, the late-time solution is equivalent to the Hantush-Jacob solution. In most cases, late-time data fall on the flat portion of the "L" type-curves and the curve matching procedure is indeterminant. Thus, hydraulic properties cannot be uniquely determined from this solution.

A solution which can be used in practical application is not available for intermediate times. In this case, aquifer drawdown is estimated by interpolating between the early- and late-time solution.

Numerical models are also useful in evaluating leaky aquifer pump tests. Appropriate models are not limited by the criteria stated above and thus can be used to predict the aquifer response for a wide range of hydrogeologic conditions. In practice, however, the simple analytical solutions often give results very similar to numerical models.

3.3 Applications

Case I: The following parameter values were used to simulate pumping of the interval located between the Thorough Runner and dense Umtanum zone:

$K = 4.8 \times 10^{-2}$ ft/day (1.7×10^{-7} m/s); Pumped Aquifer D
 $S = 10^{-7}$ ft⁻¹ (3.3×10^{-7} m⁻¹)
 $b^s = 500$ ft (152 m)

$K_1' = K_2' = K' = 2.8 \times 10^{-3}$ to 2.8×10^{-6} ft/day
 (10^{-8} to 10^{-11} m/s)
 $S_{s1}' = S_{s2}' = S_s' = 10^{-8}$ ft⁻¹ (3.3×10^{-8} m⁻¹)

$b_1' = 360$ ft (110 m); Upper Aquitard C
 $b_2' = 85$ ft (26 m); Lower Aquitard E

$K_1 = 4.9$ ft/day (1.7×10^{-5} m/s): Upper Unpumped Aquifer B
 $b_1 = 175$ ft (53 m)

$K_2 = 2.6 \times 10^{-1}$ ft/day (9.2×10^{-7} m/s): Lower Unpumped Aquifer F
 $b_2 = 20$ ft (6 m)

$Q = 30$ gpm (1.9 l/s)

Hydraulic properties were estimated from the results of tests performed in Grande Ronde basalts and/or generic information. Four values of aquitard vertical hydraulic conductivity have been assumed, corresponding to a range of possible values at the Hanford site. Comparison of results can be used to evaluate the significance of vertical leakage as a function of aquitard permeability.

The assumption of vertical flow was checked using equation (1). The vertical flow criteria is satisfied by values of aquitard hydraulic conductivity of less than 8.2×10^{-5} ft/day (2.9×10^{-10} m/s). However, for the purpose of this study, vertical flow was assumed valid for all values of aquitard hydraulic conductivity. Because of the anisotropic nature of the dense basalt (i.e., $K'_v > K'_h$), this assumption will probably not produce significant errors.

The assumption of negligible drawdown in unpumped aquifers was checked using equation (2). Both of the unpumped aquifers failed to meet this criteria; thus the solutions given in equations (3) and (6) will theoretically be in error. However, as discussed above, this criteria is probably overrestrictive because the unpumped aquifers are subject to leakage from above or below. Therefore, for the purpose of this study, the solutions in equations (3) and (6) are assumed valid.

Figure 3, 4 and 5 show the predicted hydraulic response in the pumped aquifer at radial distances of 50, 500 and 3000 feet (15, 152 and 914 meters), respectively. Aquitard storage was ignored; thus the Hantush-Jacob solution [equation (4)] was used to obtain the predicted responses. Although the aquitard storage criteria in equation (5) is not satisfied when K'_v is high and r is large, evaluation of the parameter δ indicates a value approximately equal to one. Thus, the Modified Hantush method will yield nearly identical results to the Hantush-Jacob method for late-time data and the curves in Figures 3 to 5 should be approximately correct.

The results show that aquitard leakage is less significant at small radial distances, early times, and for low values of aquitard hydraulic conductivity. Leakage can be neglected altogether for conditions where the hydraulic response converges to the nonleaky (Theis) solution. The figures indicate that a more reliable determination of aquifer parameters (K , S) is made from observation wells at small radial distances and from data obtained at early times. More reliable estimation of aquitard properties is obtained from observation wells at larger radial distances using later-time data.

By evaluating the analytical solutions, the functional relationship between time and radial distance can be determined for any fixed value of drawdown. Figures 6 and 7 show the relationship between r and t for fixed aquifer drawdowns of 2.0 and 10.0 feet (0.6 and 3.0 meters) respectively. The lower range of drawdown which can be readily measured in observation wells during a pump test is expected to be about 2 feet (0.6 meters). Therefore, for practical purposes, the radial distance to the 2 foot (0.6 meter) drawdown contour can be considered the effective radius of influence of the test. The results indicate that in 100 days, which is considered a reasonable pumping period, the two-foot drawdown contour will extend to about 17,000 feet (5200 meters) from the pumping well for the non-leaky case. Aquitard

hydraulic conductivity (K') has a significant effect upon the extent of the two-foot drawdown contour for values of K' greater than about 2.8×10^{-5} ft/day (10^{-8} m/s). Values of K' less than this do not produce a response easily distinguishable from the non-leaky case within a pumping period of 100 days. The effect of aquitard hydraulic conductivity upon the 10 foot (3.0 meter) drawdown response is similar to that for the two-foot drawdown.

Case II: The following parameter values were used to simulate pumping of the upper Grande Ronde interflow:

$$\begin{aligned} K &= 4.97 \text{ ft/day } (1.7 \times 10^{-5} \text{ m/s}); \text{ Aquifer B} \\ S_s &= 10^{-7} \text{ ft}^{-1} (3.3 \times 10^{-8} \text{ m}^{-1}) \\ b &= 175 \text{ ft } (53 \text{ m}) \end{aligned}$$

$$\begin{aligned} K_1' = K_2' = K' &= 2.8 \times 10^{-3} \text{ to } 2.8 \times 10^{-6} \text{ ft/day} \\ & \quad (10^{-8} \text{ to } 10^{-11} \text{ m/s}) \\ S_{s1}' = S_{s2}' = S_s' &= 10^{-8} \text{ ft}^{-1} (3.3 \times 10^{-8} \text{ m}^{-1}) \end{aligned}$$

$$\begin{aligned} b_1' &= 100 \text{ ft } (30 \text{ m}); \text{ Upper Aquitard A} \\ b_2' &= 360 \text{ ft } (110 \text{ m}); \text{ Lower Aquitard C} \end{aligned}$$

$$\begin{aligned} K_1 &= 4.8 \times 10^{-2} \text{ ft/day } (1.7 \times 10^{-7} \text{ m/s}); \text{ Lower Unpumped Aquifer D} \\ b_1 &= 500 \text{ ft } (152 \text{ m}) \end{aligned}$$

$$Q = 1000 \text{ gpm } (63 \text{ l/s})$$

Data pertaining to the aquifer immediately above the Grande Ronde Interflow were not available at RRL-2. Thus, for simplicity the unpumped aquifer above the Grande Ronde Interflow was assumed to have negligible drawdown.

Drawdown in the Upper Grande Ronde Interflow as a function of time is shown in Figures 8 and 9 at radial distances of 30,000 and 100,000 feet (9144 and 30480 meters) respectively. These plots were developed using the Hantush-Jacob method. For this case the assumption of vertical aquitard flow [equation (1)] is satisfied for all assumed values of aquitard hydraulic conductivity. However, equation (2) indicates that some drawdown can be expected in the underlying unpumped aquifer (and also probably in any overlying aquifer). Therefore, the solution is theoretically in error and more refined analytical or numerical methods may be needed to give accurate results. The aquitard storage criteria [equation (6)] is also not satisfied at the large radial distances considered. However, as in Case I, the δ factor is approximately equal to one. Therefore, the late-time Modified Hantush Method and the Hantush-Jacob Method will yield nearly equivalent results.

Figures 10 and 11 show the relationship between r and t for aquifer drawdowns of 2.0 and 10.0 feet (0.6 and 3.0 meters) using the Hantush-Jacob solution. Due to the large hydraulic conductivity of the pumped aquifer, it is likely that drawdowns will be significant in unpumped aquifers. This will cause the mathematical solution to underestimate pumped aquifer drawdowns and underestimate the radial extent of a fixed values of drawdown at a given time.

In the highly-transmissive Upper Grande Ronde Interflow, the two-foot drawdown contour theoretically extends to a distance of about 270,000 feet (52,000 meters)

from the pumping well at 100 days for the nonleaky case. This distance is not realistic because hydrogeologic boundaries will be encountered before the drawdown extends this far. However, it does illustrate that large-scale pumping in a highly-transmissive zone can affect a large portion of the Pasco Basin. The effect of aquitard hydraulic conductivity greater than about 2.8×10^{-5} ft/day (10^{-10} m/s) upon the extent of the drawdown cone is substantial within a 100-day period.

4 AQUITARD RESPONSE

The above discussion assumes that drawdown observations are made only in the pumped aquifer. Increased knowledge would result from drawdown observations in the confining layers. The analytical solution of Neuman and Witherspoon (1969a, 1969b) predicts the response to pumping of piezometers completed in aquitards above and below the pumped aquifer. Under certain conditions, the Neuman and Witherspoon (1972) "ratio method" provides an efficient analytical method for predicting aquitard response. They also describe procedures for calculating K , S , and the ratio (K'/S'), from time-drawdown data using piezometers in both the aquifer and aquitard.

The ratio method is valid for the following conditions:

$$\beta < 1.0 \quad (9)$$

$$t > \frac{0.1 S'_{s1} (b'_1)^2}{K'_1}, \quad i = 1, 2. \quad (3)$$

where all parameters are defined in Figure 2. Since β is proportional to radial distance, the first condition can usually be satisfied by locating the piezometer at a sufficiently small radial distance. The second criterion tends to be over-conservative in practical applications (Neuman and Witherspoon, 1972). The smaller the distance between the piezometer and the boundary of the pumped aquifer, the more conservative is the time criterion. If the preceding conditions are satisfied, drawdown at an aquitard piezometer is given by:

$$S'(r, z, t) = s(r, t) F(t_0, t'_0) \quad (10)$$

The function $F(t_0, t'_0)$ is tabulated in Witherspoon et al., (1967, Appendix G). Figures 12, 13 and 14 show the calculated response of piezometers in aquitard E (dense Umtanum) for $z = 40$ ft (12 m) at radial distances of 50, 100 and 500 feet (15, 30, and 152 meters), when aquifer D is pumped. Solid lines indicate conditions for which the time criterion is satisfied. Because the time criterion tends to be over-conservative, dashed lines are included which show the theoretical aquitard response at larger times. However, the actual piezometer response could depart significantly from the dashed portion of the curves. Figures 12 through 14 indicate that the most reliable determination of aquitard properties is made from piezometers at small radial distances (i.e., where the hydraulic response is described by the solid lines). At larger distances, the time criterion becomes too restrictive for aquitards

with relatively high hydraulic conductivity. The figures also indicate that aquitard response may be exceedingly rapid for high K' values.

It should be noted that the ratio method requires that aquitard response be measured at a point (the location of the observation piezometer). It is questionable whether representative bulk hydraulic conductivity measurements can be obtained from piezometers completed within a medium such as dense basalt, since the piezometers may not intersect permeable fractures or other features contributing to the bulk vertical hydraulic conductivity. Thus, the Hantush-Jacob method described previously may yield better bulk parameter estimates.

5 CONCLUSIONS

Proper design, performance and analysis of large-scale pump tests may significantly increase the knowledge of the hydrogeologic system at the RRL and the entire Pasco Basin. In particular, it may be possible to determine the magnitude of vertical hydraulic conductivity in confining layers as well as the large-scale hydraulic properties and continuity of aquifers.

Results of the relatively simple analyses conducted for this study indicate that, for the assumed hydrogeologic conditions in the Grande Ronde near the RRL, it is possible to stress very large areas by pump testing. Furthermore, the analyses indicate that test results based on aquifer response may be useful in determining aquitard hydraulic conductivities on the order of 2.8×10^{-5} ft/day (10^{-10} m/s) or greater. Lower values of aquitard hydraulic conductivity do not result in significant leakage to the aquifer within a pumping period of about 100 days. However, it may be possible to measure aquitard hydraulic conductivity using test results based on aquitard response.

The analytical solutions assume that hydrostratigraphic units are laterally continuous and uniform with respect to hydraulic properties. If this is true, analysis of test results can provide reliable estimates of hydraulic parameters for large-scale modeling. If hydrostratigraphic units are discontinuous and/or strongly heterogeneous, a comparison between measured and ideal response can be used to evaluate the significance of these features on the regional scale. In addition, it may be possible to quantify these effects through the use of numerical models. For instance, structural features, such as faults or stratigraphic discontinuities, may act as hydrogeologic boundaries which affect the time-drawdown response (Lohman, 1972). By appropriately locating observation piezometers, the location and characteristics of discontinuities can often be determined from pump test data.

The NRC staff considers the type of tests described in this Appendix to be the state-of-the-art method of determining bulk values of horizontal and vertical hydraulic conductivity prior to construction of an underground test facility. Although single-hole methods have been attempted by various researchers, the resulting values of hydraulic conductivity should be considered spot-values representative of the immediate area around the borehole (i.e., probably a radius of 50 feet or less). In assessing a large hydrogeologic system, it is essential to measure hydraulic parameters on a large scale and to demonstrate the continuity (or lack of continuity) of the system over a large areal extent. This study demonstrates that large-scale pumping tests with multiple observation piezometers are potentially useful in assessing the hydrogeologic system in the Pasco Basin, as required by proposed 10 CFR 60.

6 REFERENCES

Hantush, M. S., and C. E. Jacob, "Nonsteady Radial Flow in an Infinite Leaky Aquifer," Trans. Amer. Geophys. Union 36, 95-100, 1955.

Hantush, M. S., "Analysis of Data from Pumping Tests in Leaky Aquifers," Trans. Amer. Geophys. Union 37, 702-714, 1956.

Hantush, M. S., "Modification of the Theory of Leaky Aquifers," J. Geophys. Res. 65, 3713-3725, 1960.

Hantush, M. S., "Flow of Groundwater in Relatively Thick Leaky Aquifers," Water Resources Research 3(2), 583-590, 1967.

Lohman, S. W., "Groundwater Hydraulics," U.S. Geol. Survey Prof. Paper 708, 1972.

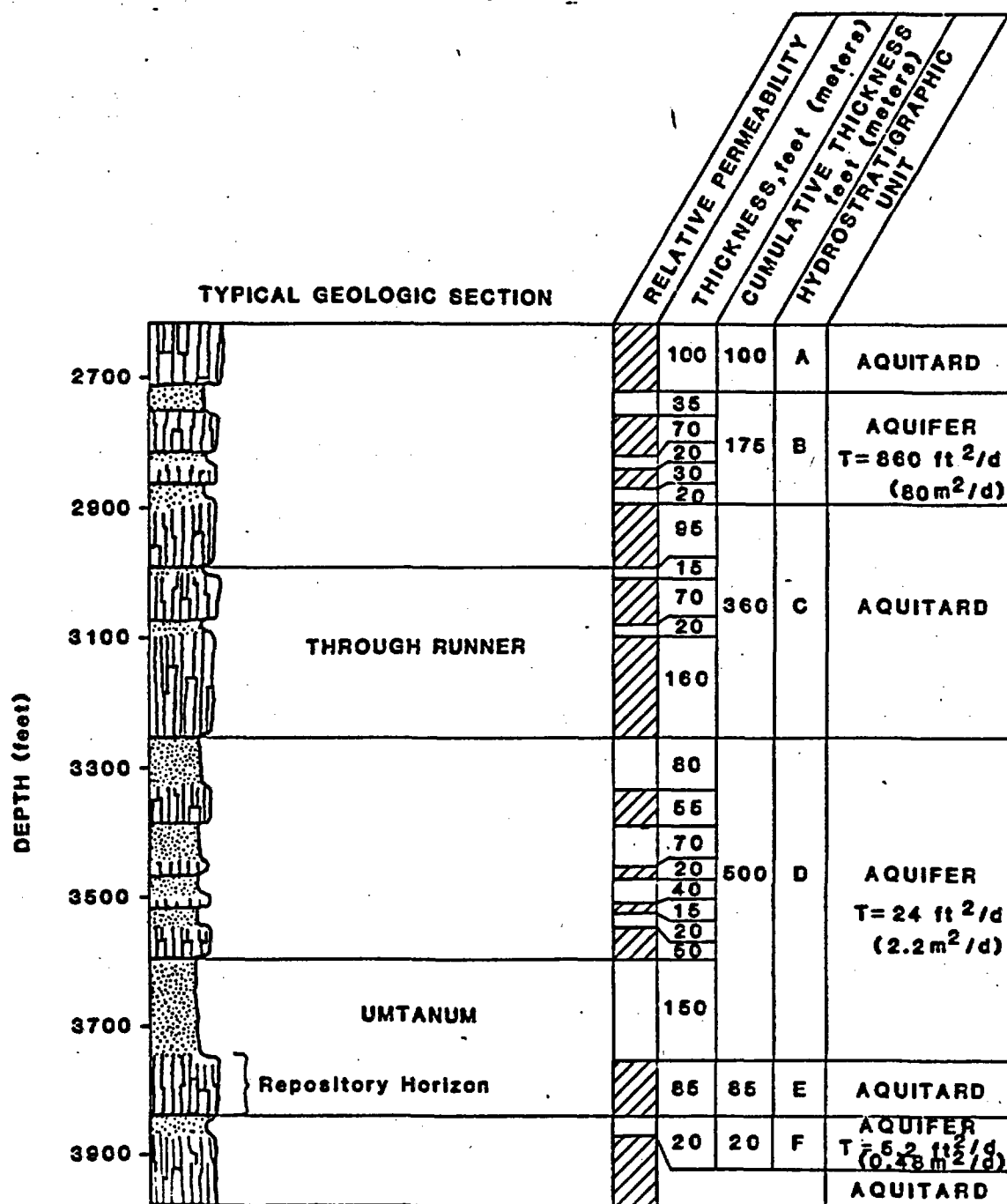
Neuman, S. P., and P. A. Witherspoon, "Theory of Flow in a Confined Two-Aquifer System," Water Resources Res. 5, 803-816, 1969a.

Neuman, S. P., and P. A. Witherspoon, "Applicability of Current Theories of Flow in Leaky Aquifers," Water Resources Res. 5, 817-829, 1969b.

Neuman, S. P., and P. A. Witherspoon, "Field Determination of the Hydraulic Properties of Leaky Multiple-Aquifer Systems," Water Resources Res. 8, 1284-1298, 1972.

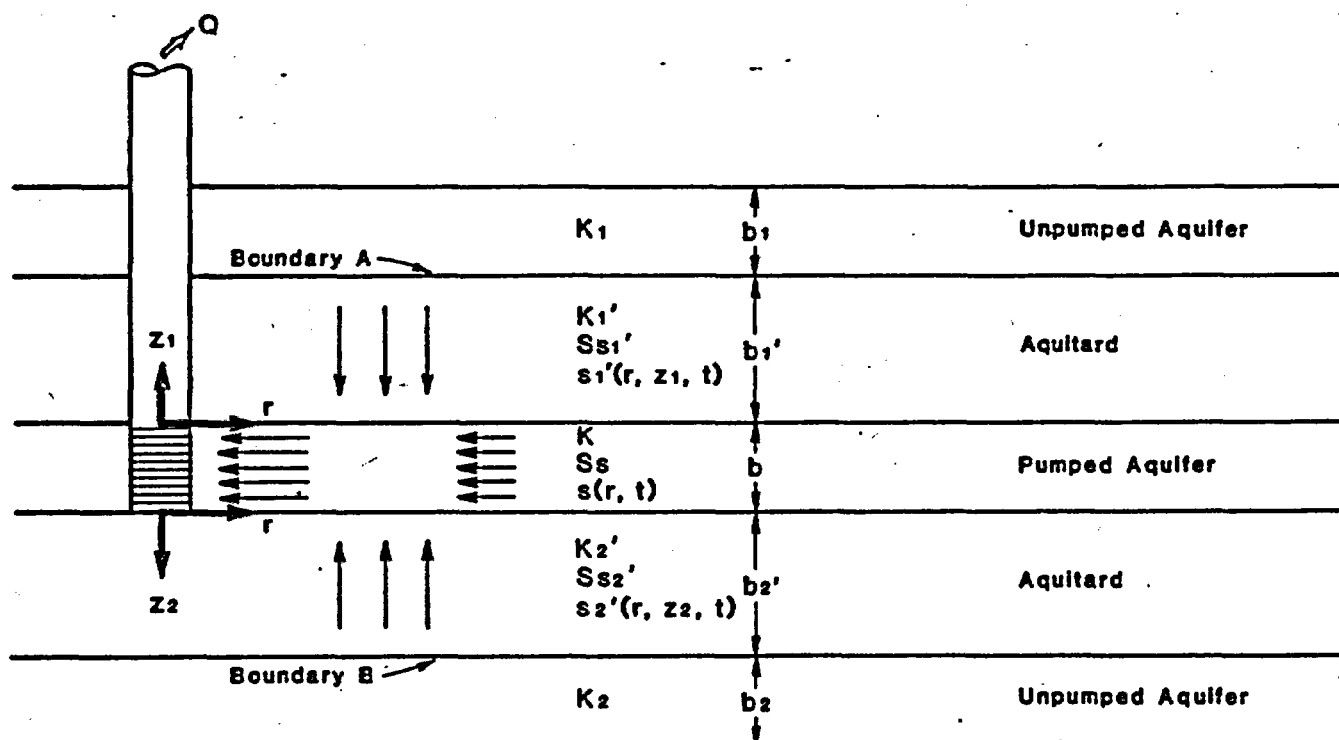
Reed, J. E., "Type Curves for Selected Problems of Flow to Wells in Confined Aquifers," Techniques of Water-Resources Investigations of the U.S. Geological Survey, U.S. Govt. Printing Office, Washington, D.C., 1980.

Witherspoon, P. A., et al., Interpretation of Aquifer Gas Storage Conditions from Water Pumping Tests, American Gas Association, Inc., New York, 1967.



EXPLANATION

- High Relative Permeability (Flow Top)
- Low Relative Permeability (Dense Basalt)



NOMENCLATURE

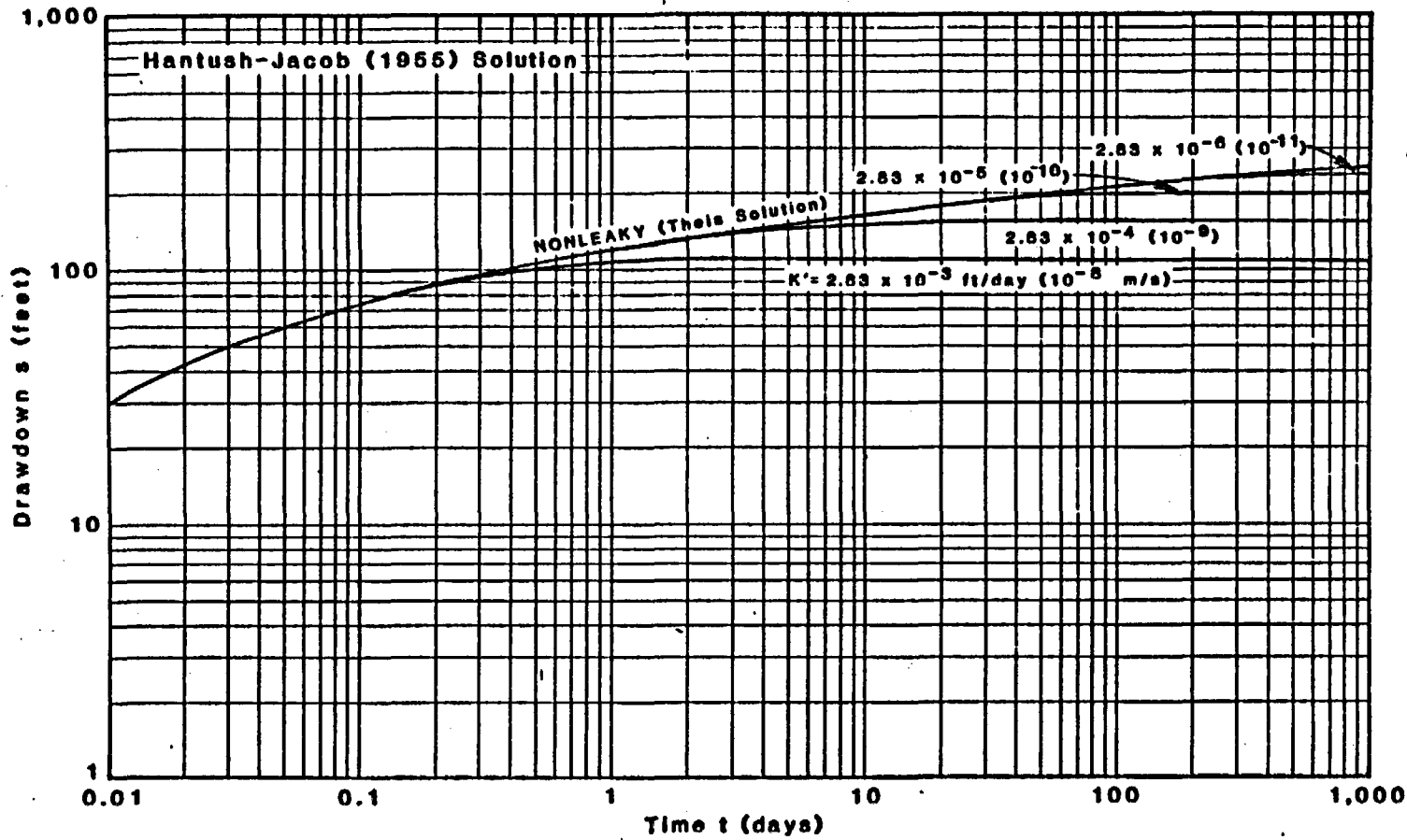
- K = aquifer horizontal hydraulic conductivity ($L T^{-1}$)
 Ss = aquifer specific storage (L^{-1})
 b = aquifer thickness (L)
 s = aquifer drawdown (L)
 K' = aquitard vertical hydraulic conductivity ($L T^{-1}$)
 Ss' = aquitard specific storage (L^{-1})
 b' = aquitard thickness (L)
 s' = aquitard drawdown (L)
 r = radial distance (L)
 z = aquitard vertical distance (L)
 t = time since beginning of pumping (T)
 K_1 = unpumped aquifer horizontal hydraulic conductivity ($L T^{-1}$)
 b_1 = unpumped aquifer thickness (L)

DIMENSIONLESS PARAMETERS

$$\begin{aligned}
 \frac{r}{B} &= r \left(\sqrt{\frac{1}{Kb} \left(\frac{K_1'}{b_1'} + \frac{K_2'}{b_2'} \right)} \right) \\
 v &= \frac{1}{2} \left(\frac{r}{B} \right) \\
 \beta &= \frac{r}{4b} \left(\sqrt{\frac{K_1' Ss_1'}{K Ss}} + \sqrt{\frac{K_2' Ss_2'}{K Ss}} \right) \\
 u &= \frac{Ss r^2}{4Kt} \\
 \delta &= 1 + \left(\frac{Ss_1' b_1' + Ss_2' b_2'}{3 Ss b} \right) \\
 t_D &= \frac{1}{4u} = \frac{Kt}{Ss r^2} \\
 t_D' &= \frac{K't}{Ss' z^2}
 \end{aligned}$$

CASE I: PREDICTED HYDRAULIC RESPONSE
IN AQUIFER D; r=50 FEET

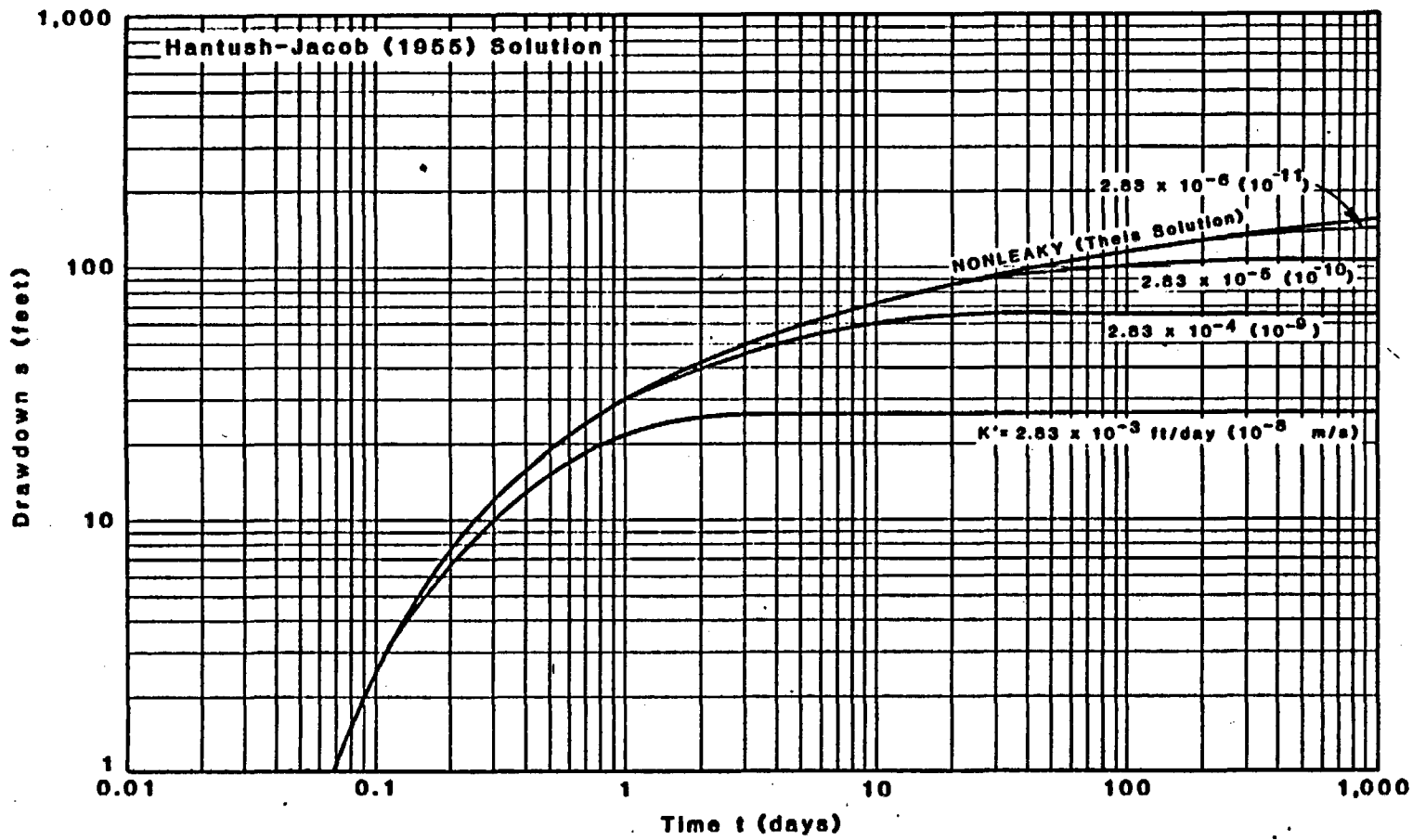
Figure 3



E-13

Build 0304/10/15/1005don

Figure 4

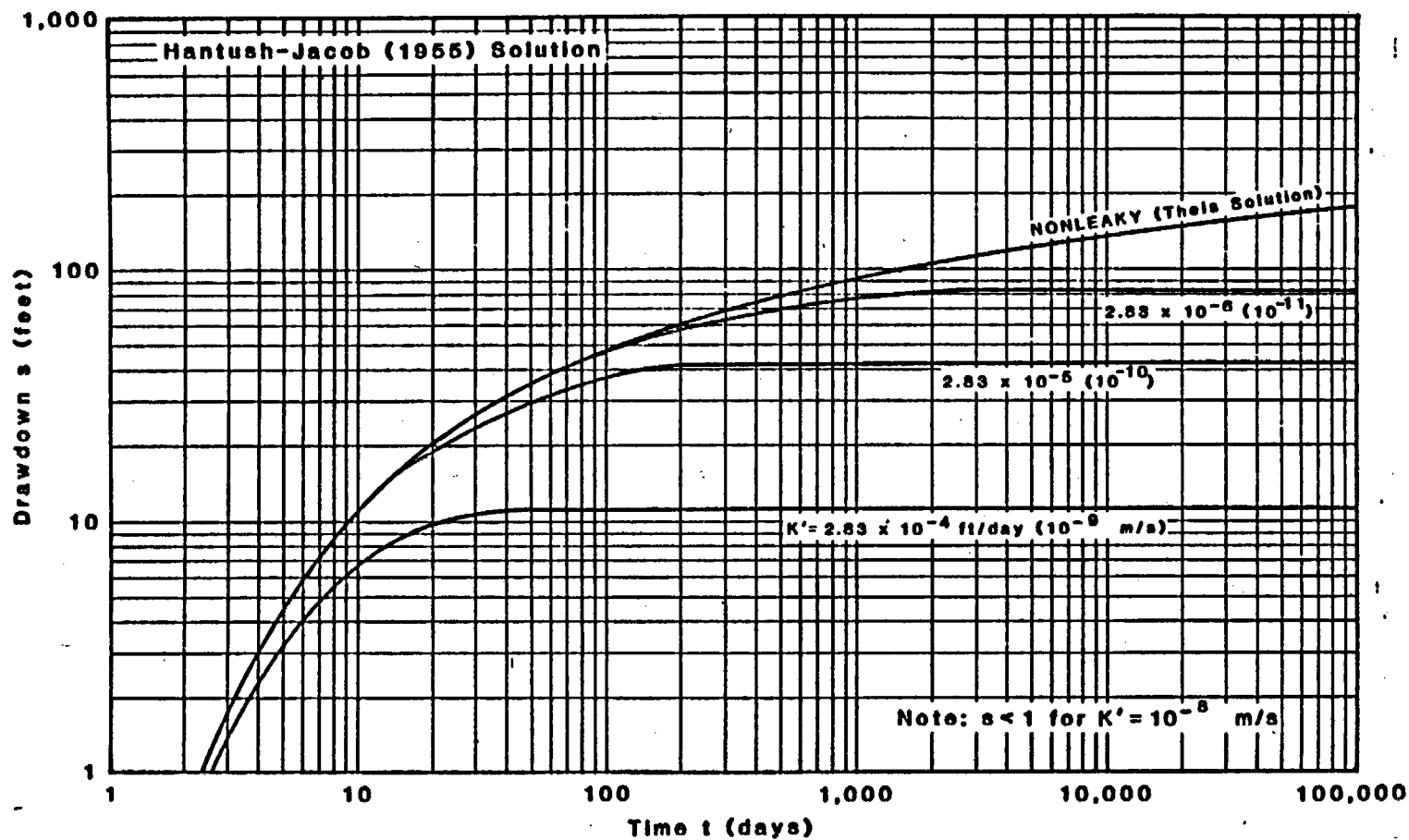


E-14

BUTA 0504/0504/1095dm

CASE I: PREDICTED HYDRAULIC RESPONSE
IN AQUIFER D; r=3000 FEET

Figure 5

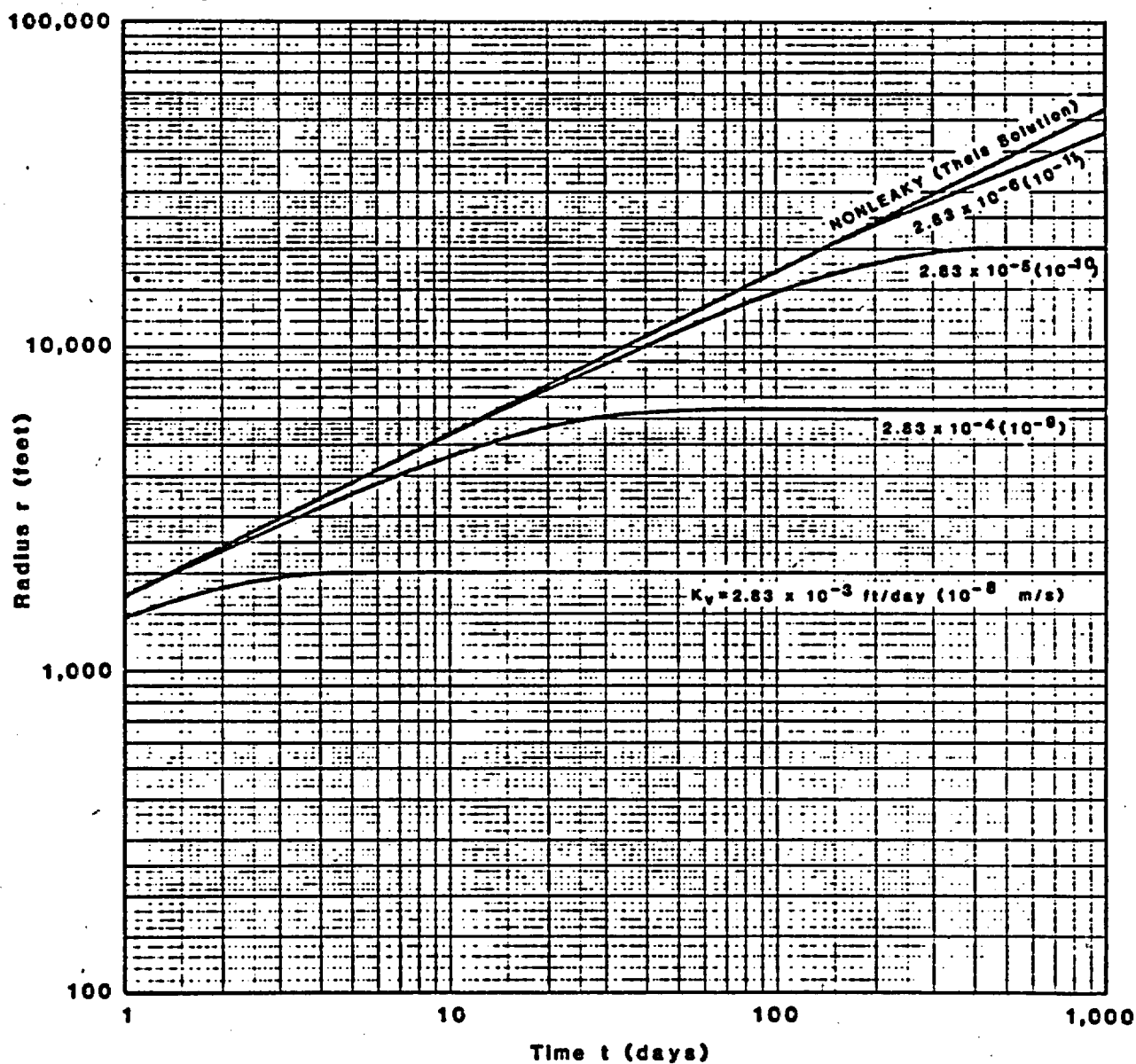


E-15

BUILT 05/15/1978/LE9346

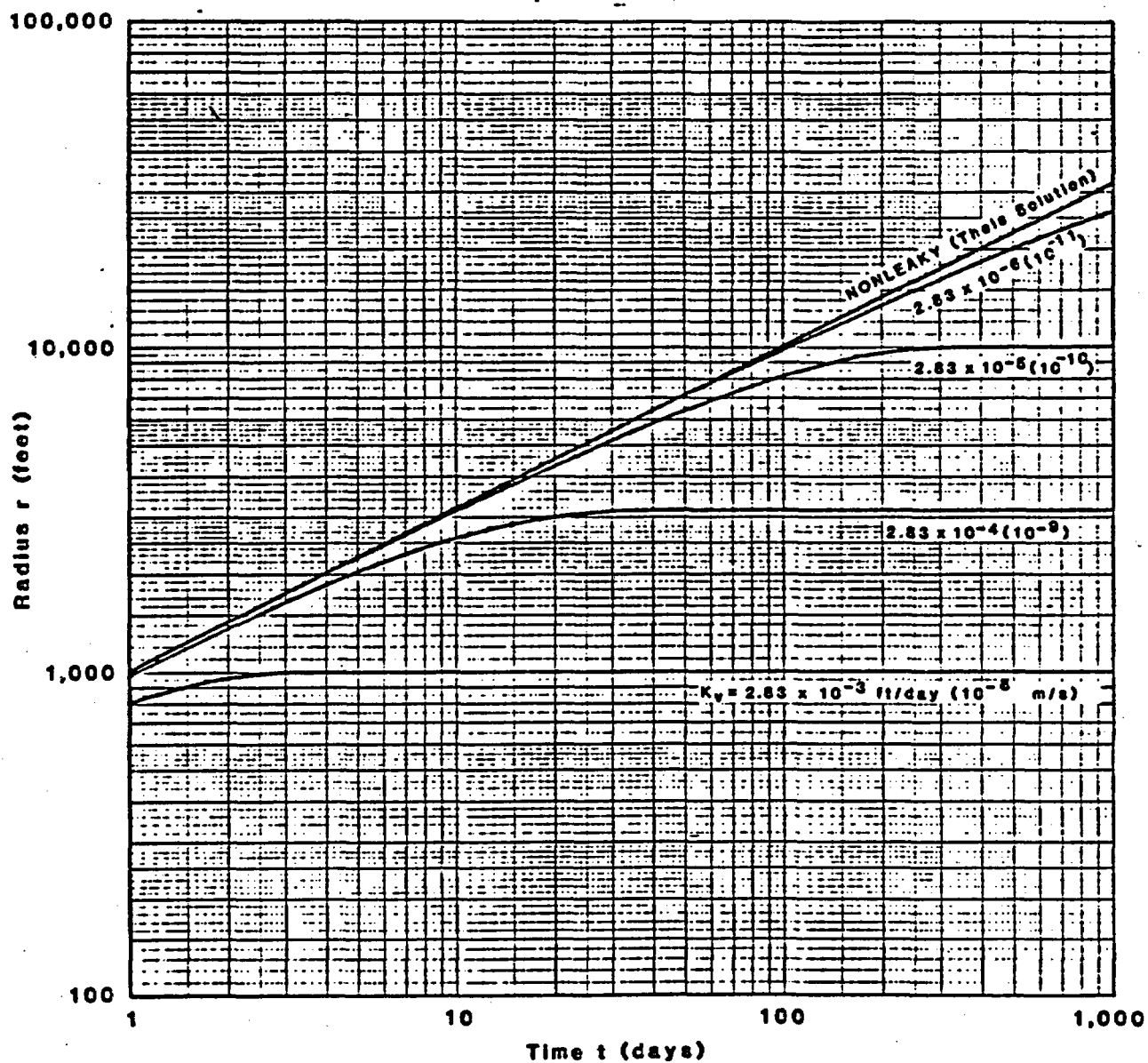
CASE I: r vs. t FOR AQUIFER DRAWDOWN
OF 2.0 FEET

Figure 6



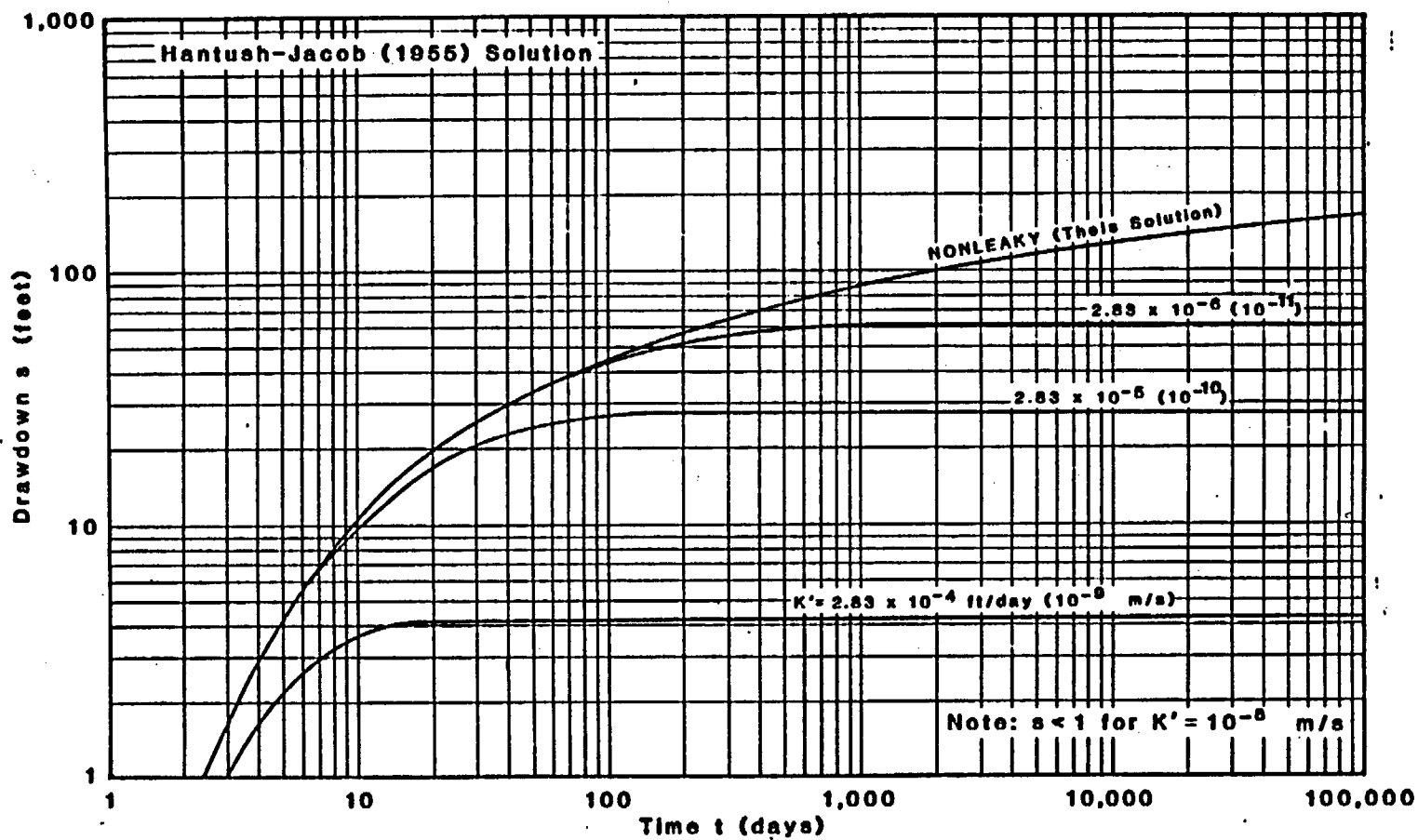
CASE I: r vs. t FOR AQUIFER DRAWDOWN
OF 10.0 FEET

Figure 7



CASE II: PREDICTED HYDRAULIC RESPONSE
IN AQUIFER B; $r = 30,000$ FEET

Figure 8



E-18

60770 05/11/2009 / Los Angeles

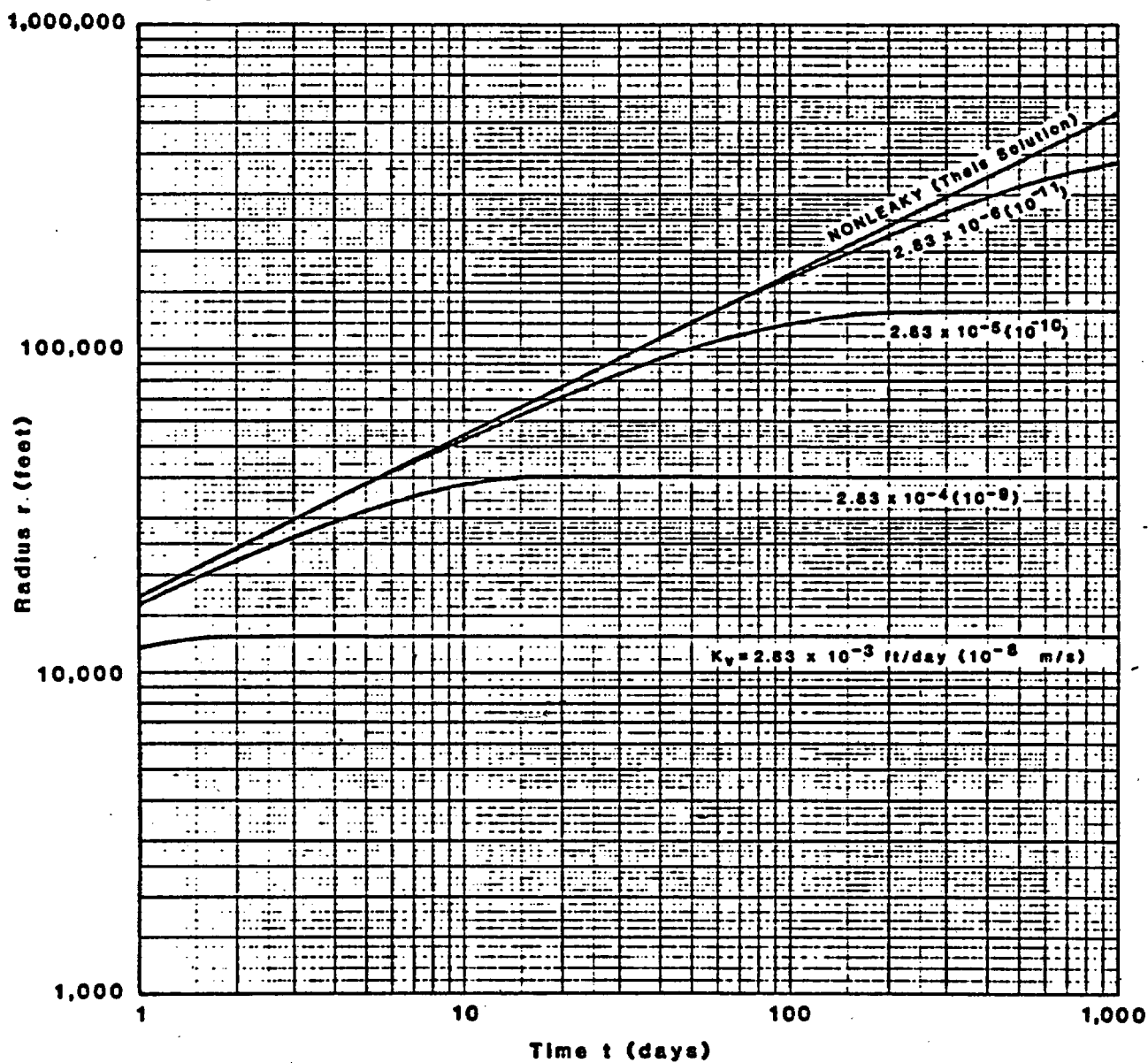
Figure 9



8427 OSCA/1000 / 1095dm

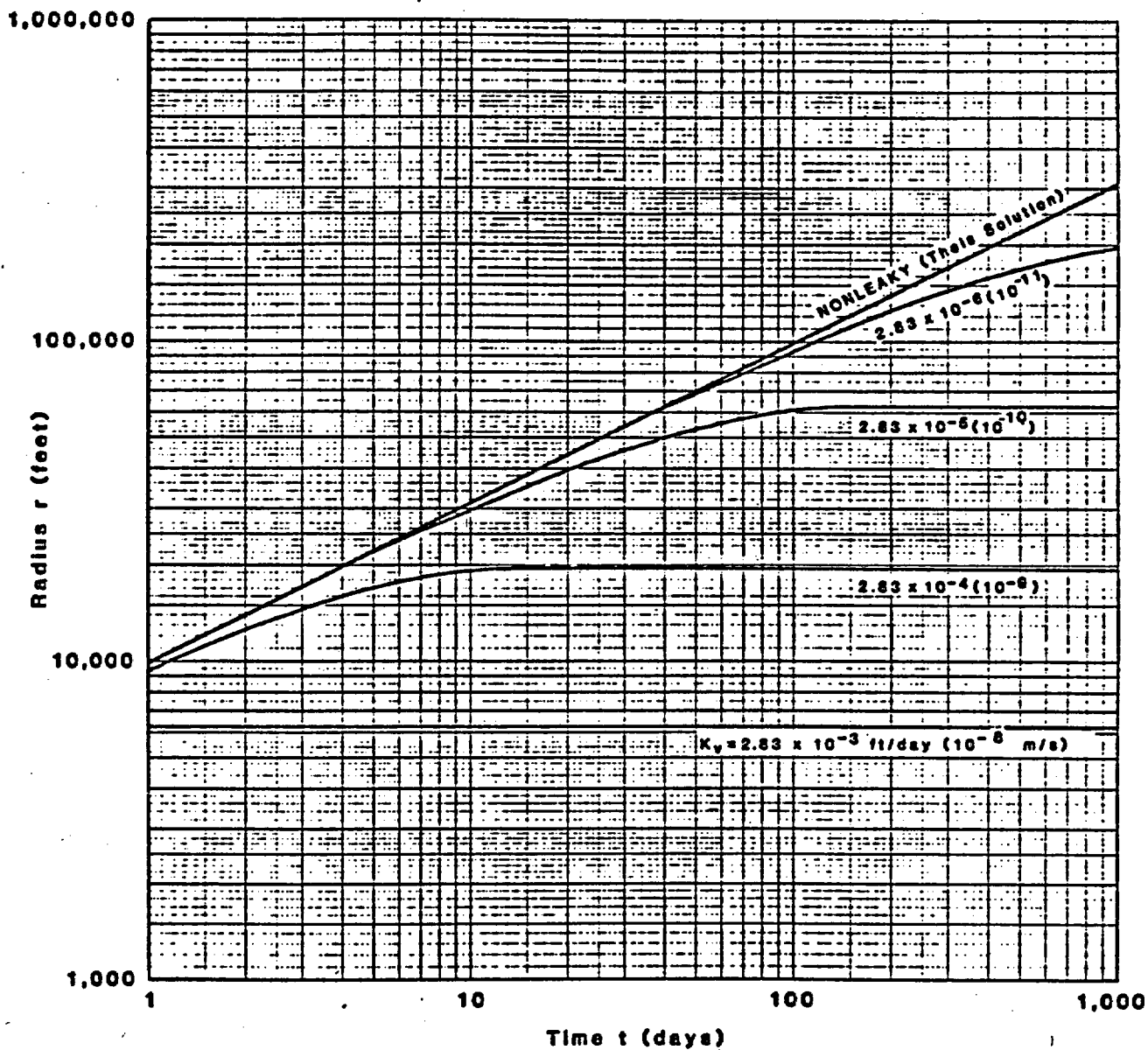
CASE II: r vs. t FOR AQUIFER DRAWDOWN
OF 2.0 FEET

Figure 10



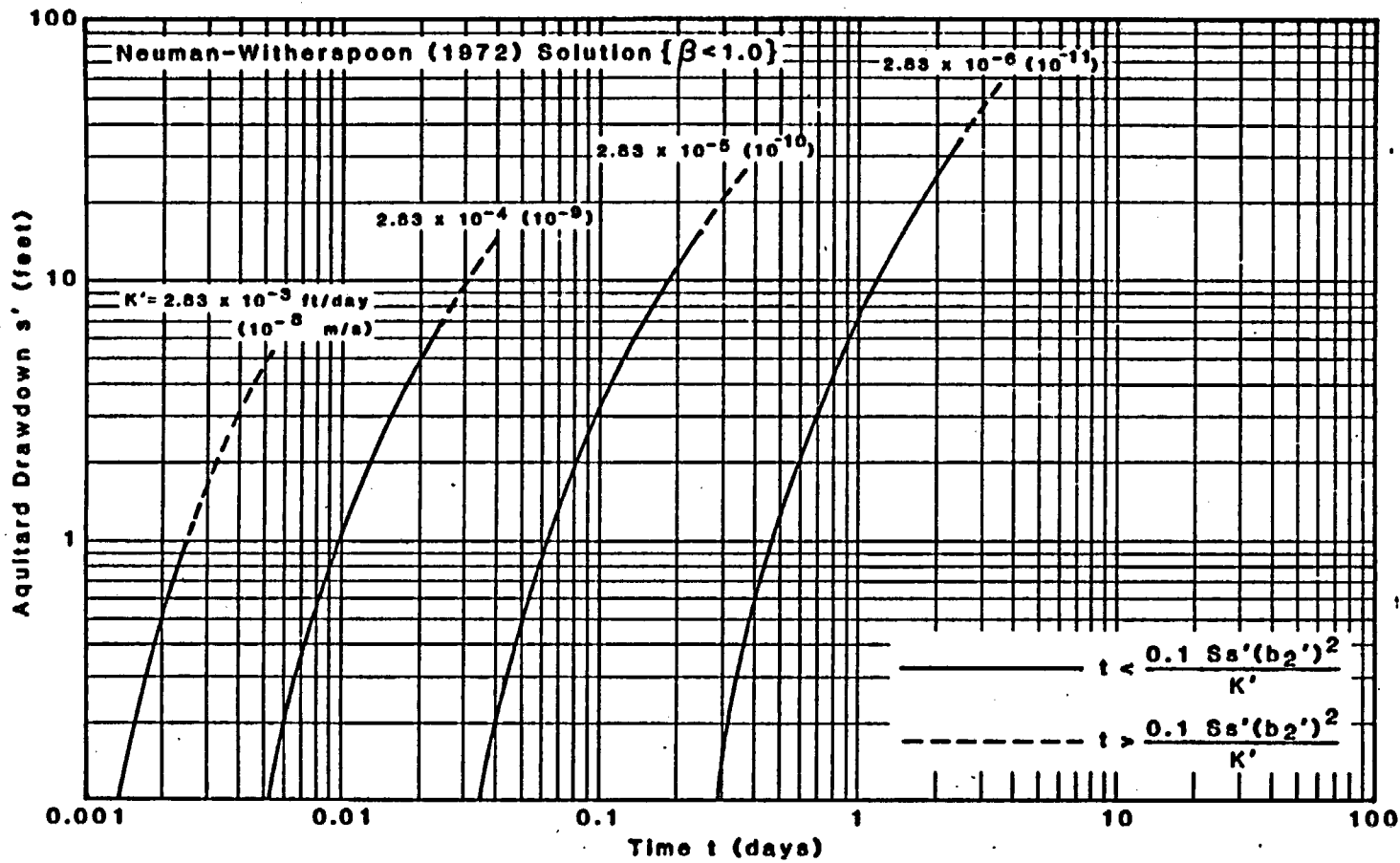
CASE II: r vs. t FOR AQUIFER DRAWDOWN
OF 10 FEET

Figure 11



CASE I: PREDICTED HYDRAULIC RESPONSE
IN AQUITARD E; $r = 50$ FEET; $z = 40$ FEET

Figure 12.

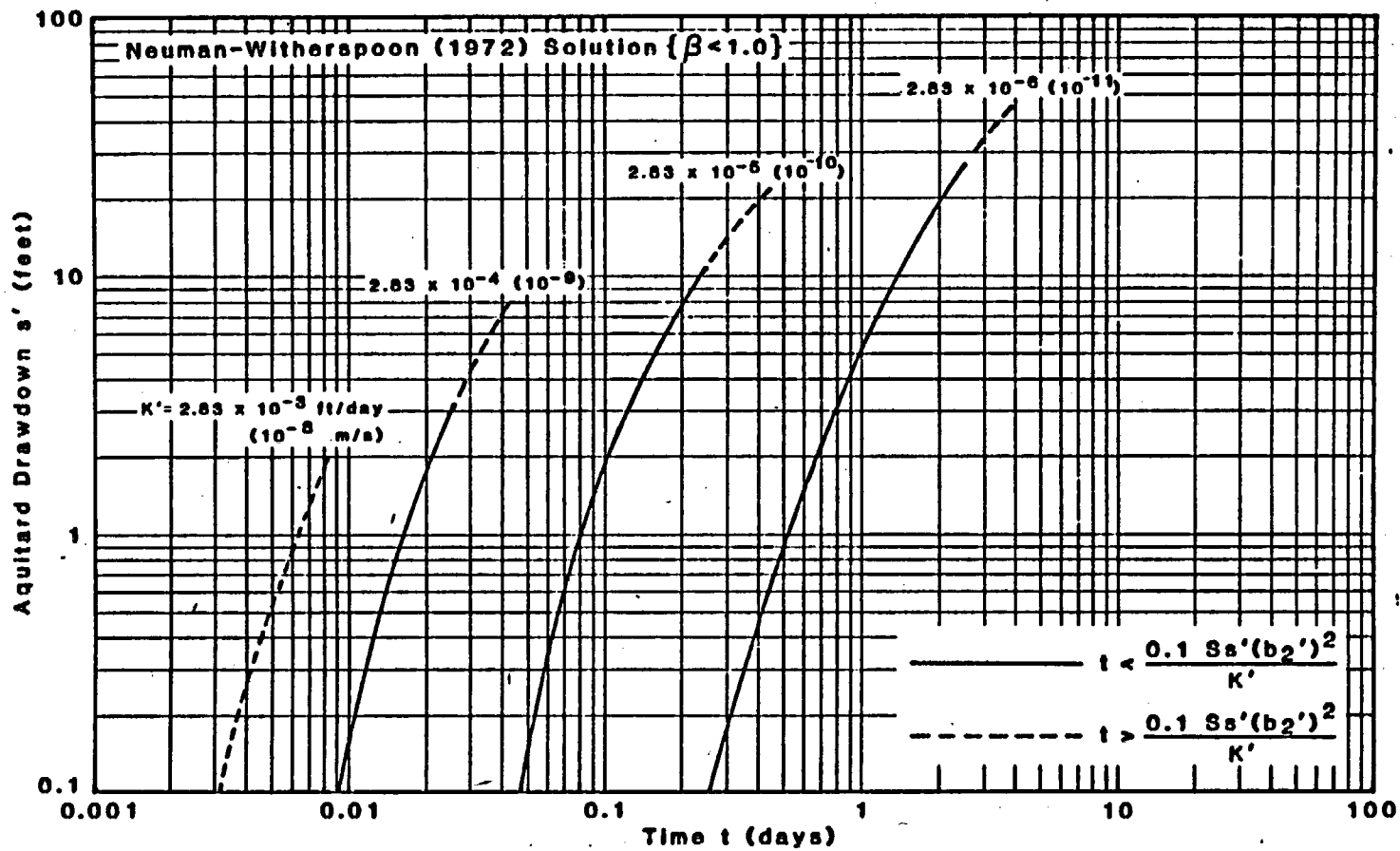


E-22

AQUITARD E; $r = 50$ FEET; $z = 40$ FEET

CASE 1: PREDICTED HYDRAULIC RESPONSE
IN AQUITARD E; r = 100 FEET; z = 40 FEET

Figure 13

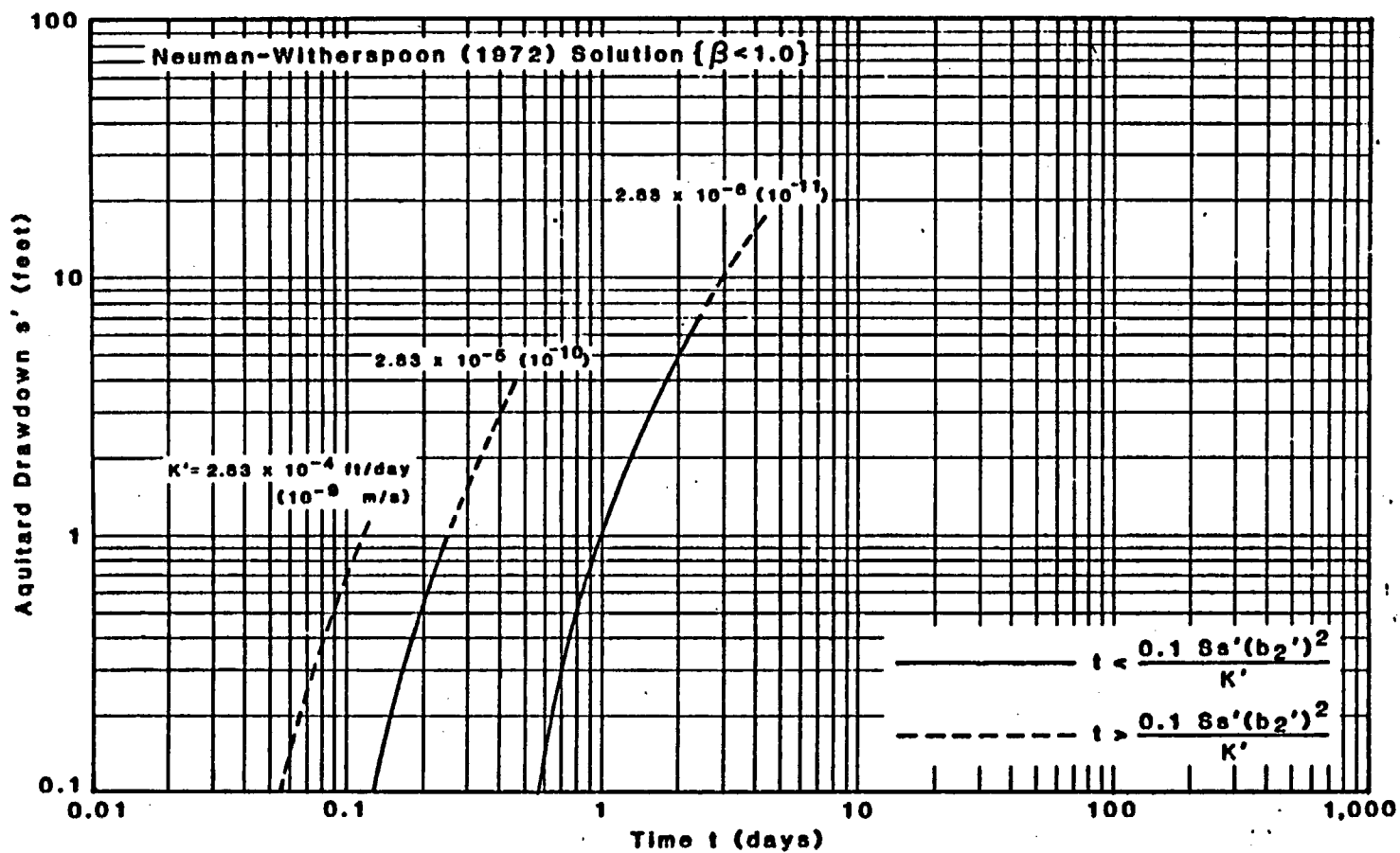


E-23

8/17/04/003/2.4/14

CASE I: PREDICTED HYDRAULIC RESPONSE
IN AQUITARD E; $r = 500$ FEET; $z = 40$ FEET

Figure 14



E-24

HAULT BAY / L. J. M.

APPENDIX F

REVIEW OF HYDROCHEMICAL CHARACTERIZATION

RELATED TO FLOW SYSTEM INTERPRETATION

IN HANFORD BASALTS

TABLE OF CONTENTS

	<u>Page</u>
1 INTRODUCTION	1
2 GENERAL BACKGROUND	1
3 DATA ACQUISITION AND INTEGRITY	2
4 HYDROCHEMISTRY	6
4.1 Major Ion Chemistry	6
4.2 Methane	10
4.3 Oxygen-18 and Deuterium	10
4.4 Carbon-14 Age Dating	16
5 CONCLUSIONS	17
6 REFERENCES	20

APPENDIX A SELECTED KEY HYDROCHEMICAL DATA

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Locations of Boreholes for Which Detailed Hydrochemical Data Are Available	3
2	Geochemical Profiles: Chloride, Sodium	8
3	Geochemical Profiles: Oxygen-18	12
4	Geochemical Profiles: Deuterium	13
5	^{18}O - ^2H Relationship	
6	Geochemical Profiles: Carbon-13	

LIST OF TABLES

Table

- A-1 Selected Key Hydrochemical Data - Borehole DB-15
- A-2 Selected Key Hydrochemical Data - Borehole DC-6
- A-3 Selected Key Hydrochemical Data - Borehole DC-12
- A-4 Selected Key Hydrochemical Data - Borehole DC-14
- A-5 Selected Key Hydrochemical Data - Borehole DC-15

1 INTRODUCTION

This appendix provides an assessment of the hydrochemical discussions and conclusions contained in Chapter 5 of the BWIP Site Characterization Report (SCR). This assessment is directed towards the use of hydrochemical data as a means of identifying sources and ages of groundwater in various stratigraphic zones and as a means of evaluating the degree of vertical mixing between these zones.

Much of the basic hydrochemical data upon which the discussions and conclusions in the SCR are based is not presented in the SRC, which generally contains data summaries such as data groupings or other interpreted data forms. These summaries and interpreted forms are generally not suitable as a basis for independent evaluation of the discussions and conclusions in the SRC. As such, the hydrochemical sections in Chapter 5 of the SCR cannot be considered to be documented scientific evidence from which scientific conclusions regarding the use of hydrochemical data at the BWIP site can be drawn.

Because the discussions and conclusions in the hydrochemical sections of Chapter 5 in the SCR cannot be assessed based on the data presentations in the SRC, efforts were made to obtain much of the basic hydrochemical data used by Rockwell Hanford in the preparation of the SCR. Hydrochemical data were provided to the NRC staff by Rockwell Hanford Operations at the BWIP hydrogeology workshop held on July 20-27, 1982 at Hanford. Hydrochemical data were also obtained from Rockwell Hanford Report RHO-BWI-ST-5, entitled "Hydrologic Studies Within the Columbia Plateau, Washington."

The basic hydrochemical data for groundwater at the BWIP site obtained from these sources include:

- major ions
- minor and trace elements
- dissolved gases
- pH, Eh
- stable isotopes = oxygen-18, deuterium, carbon-13, sulfur-34
- radioactive isotopes = carbon-14, tritium, chlorine-36

Data that offer the greatest potential for use in groundwater flow system characterization are concentrations of major ions, methane, stable isotopes (oxygen-18, deuterium, carbon-13) and radioactive isotopes (carbon-14, tritium). Data on minor and trace elements, pH, Eh, sulfur-34, chlorine-36, and uranium provide little information on age, origin and mixing of groundwater and are not discussed here. Sodium and chloride data for the groundwaters in the Saddle Mountains were not made available at the BWIP workshop and are not tabulated in the SCR, so consideration of these ions in this Appendix is limited to deeper hydrogeologic zones.

2 GENERAL APPROACH

The general approach to detailed hydrochemical investigations of a groundwater flow system normally involves the characterization of the chemical and isotopic composition of the groundwater at representative locations in the groundwater system. The chemical and isotopic composition of groundwater often reflects the source and origin of the groundwater, the type and nature of the geologic

materials in which it has been in contact, and the relative age or time that the water has been in the groundwater system. Therefore, in favorable circumstances information on the chemical and isotopic composition of the groundwater and the spatial variations in the composition of the groundwater can provide valuable insight to the understanding of a groundwater system. Hydrochemical data are generally used to supplement or support geologic and hydrologic information in the development of an overall conceptual model for a groundwater system, which includes interpretation pertaining to the origin, age and mixing of groundwater in various zones in the system.

In Chapter 5 of the SCR, the main thrust in the use of the hydrochemical information is towards the development of interpretations of the groundwater age, origin and mixing. These interpretations are based on the hydrochemical data without detailed consideration given to the weighting of other forms of evidence from the geologic or physical hydrogeologic data bases. In general, hydrochemical data rarely can be used singularly as irrefutable evidence for acceptance or rejection of one hypothesis or another. Although the NRC staff stresses that recognition be given to this limitation on the usage of hydrochemical data, no attempt has been made in this Appendix to develop detailed evaluations of the hydrochemical data in an integrated manner with the geologic and physical hydrogeologic data. Time limitations precluded such an approach because the SCR is not a suitable base document for direct integration of hydrochemical and hydrogeologic information.

The approach taken in this Appendix is to use only the basic hydrochemical data obtained primarily at the BWIP hydrogeology workshop to assess the discussions and conclusions presented in the hydrochemical sections of the SCR.

A listing of the key hydrochemical data is provided in Tables A1 through A5 in Appendix A. The locations of boreholes for which there are detailed hydrochemical data are shown in Figure 1.

3 DATA ACQUISITION AND INTEGRITY

Specific descriptions of the equipment and procedures used in the acquisition of the hydrochemical data at the BWIP site are not presented in the SCR. Information on these topics was obtained during the BWIP hydrogeology workshop and through telephone communications. According to Rockwell Hanford Operations, hydrochemical samples generally were collected near the end of the drill-and-test sequence in each borehole. River water and bentonite mud were used as a drilling fluid; therefore, development of each sample interval was undertaken to remove the effects of the drilling operations. The development procedures included swabbing and/or airlift development to remove drilling fluid. Water samples were generally taken with a submersible pump. It is recognized by DOE that complete removal of the effects of the drilling water and mud is a difficult task.

During the development period, water was analyzed for chemical parameters which could indicate the presence of drilling fluid. These parameters included selected ions, temperature, conductivity and pH. Apparently, stabilization of these parameters to background levels was considered by Rockwell to indicate that the drilling fluid had been removed. Drilling mud tracers including fluorocene, total organic carbon and lithium were also monitored prior to

sampling as indicators of successful development. Tritium analyses of water samples were also conducted. Although the results were not available at the time of sampling, later they provided a basis for evaluation of the degree of removal of drilling fluid from the sampled zones.

The question of how long a borehole should be pumped or purged of the drilling fluids before sampling is normally very difficult to answer. The available hydrochemical data indicate that Columbia River water with Tritium activities of 50 to 60 T.U. was generally used for drilling water. The tritium activities in the majority of the groundwater samples from the basalt formations were less than 1 T.U. This suggests that nearly all of the drilling water was removed from the vicinity of the boreholes prior to sampling, and that the drilling water has not had a substantial influence on the gross chemical composition of the samples.

The influence of residual drilling mud in the formation on the chemical composition of the groundwater samples is much more difficult to assess. During drilling, the bentonite drilling mud may penetrate the rock formation but may not be entirely removed during the developmental pumping of the sample interval. Bentonite mud has a high cation exchange capacity and could significantly alter the concentrations of cations such as calcium and sodium in the groundwater due to ion exchange reactions with the bentonite. The extent to which drilling mud will influence the groundwater chemistry depends on the amount of drilling mud which remains in the formation, the exchangeable cations in the drilling mud, and the original chemical composition of the groundwater. Because it is virtually impossible to determine the locations and amounts of drilling mud which might remain in the formation, the possible influence of drilling mud on the groundwater samples can only be assessed qualitatively based on the overall consistency of the hydrochemical results. It is desirable that in future drilling at the BWIP site, mudless drilling methods be used.

Groundwater samples for chemical analyses were filtered through 0.45 micron filter membranes, and aliquots for the analysis of major cations and heavy metals were appropriately preserved with acid. Samples for the analysis of oxygen-18, deuterium and tritium do not require special preservation techniques. No information has been received on the chemical composition of the particulate matter contained on the filters.

Nonconservative hydrochemical parameters such as pH and Eh (redox potential) were measured in the field immediately following sample collection. Changes in temperature, pressure and sample exposure to the atmosphere can cause major changes in pH and Eh between the time sample water leaves the formation and the time measurements are made at the surface. Degassing of carbon dioxide from the groundwater during sampling can be expected to increase the pH measured at the surface. The exposure of groundwater samples to oxygen in the atmosphere during sampling can increase the Eh measured at the surface. For these reasons, pH and Eh data summarized in the SCR are not likely to be representative of the actual in situ groundwater conditions. These considerations are acknowledged in the SCR, and although the measured pH and Eh may provide indications of the in situ conditions, critical hydrochemical interpretations are not based on these parameters.

Although it is the opinion of the NRC staff that the use of mud for drilling the monitoring holes at the BWIP site is undesirable with respect to the integrity of hydrochemical data, the NRC staff considers the procedures used by Rockwell for borehole development prior to sampling and for water sampling to be adequate as a means of acquiring useful data on major ions, fluoride, stable isotopes such as oxygen-18 and deuterium, tritium, and dissolved gases such as methane, nitrogen and carbon dioxide. These are the most important hydrochemical parameters for evaluation of the origin and mixing of the groundwater. The possibility that significant drilling mud exists in the formation zones jeopardizes the integrity of data on trace elements and some other constituents. Whether or not the sampling methods used by Rockwell for collection of Carbon-14 and Carbon-13 samples are adequate cannot be ascertained with the available information.

The specific analytical methods used in the laboratory for determination of the concentrations of the various constituents in the groundwater samples are not described in the SCR. The precision of the analyses in terms of blind replicate samples is not indicated. The reproducibility of results that would be obtained by repetitive sampling on a particular sampling occasion is not described in the SCR, nor has it been indicated in any other communications. It is possible, however, without a formal evaluation of the precision of the analytical laboratory methods to conduct a gross assessment of the analytical determinations. This is done by means of the comparison of the total ionic charge balance represented by cations and anions.

The charge balance error is expressed generally as a percentage and is calculated from a complete chemical analysis as:

$$\frac{(\text{meq/L of Cations}) - (\text{meq/L of Anions})}{(\text{meq/L of Cations}) + (\text{meq/L of Anions})} \times 100$$

Because a groundwater sample should be electrically neutral, an ideal chemical analysis would yield a charge balance error equal to zero. It is common practice in hydrochemical studies for charge balance errors of less than ± 10 percent to be considered satisfactory. Charge balance errors much greater than ± 10 percent generally are considered to be unsatisfactory, and such analyses should not be used in detailed hydrochemical interpretations. The charge balance errors for samples reported in the SCR are calculated as:

$$\frac{(\text{meq/L of Anions}) - (\text{meq/L of Cations})}{(\text{meq/L of Cations})} \times 100$$

Hydrochemical data referred to in the SCR only include those analyses with a charge balance of ± 5 percent when calculated in this way. This method of calculation and the 5% criterion of acceptability are more stringent than is normally used in hydrochemical investigations of natural groundwater flow systems. There is no indication in the SCR of how many chemical analyses were rejected and not used in further interpretation. Inspection of the hydrochemical data obtained at the BWIP hydrogeology workshop for the Wanapum and Grande Ronde Basalts indicate that 17 of 51 groundwater analyses were rejected on the basis of the 5% criterion and the SCR method of calculation. In con-

trast only 1 of the 51 samples would be rejected on the basis of the 10% criterion and the calculation method commonly used.

The more stringent criterion for the acceptability of chemical analyses (i.e., < 5% error) is probably unwarranted and results in the loss of useful data. The loss of useful data is an issue of significance because hydrochemical data in most groundwater zones at the BWIP site are sparse.

The data summarized in the SCR and that provided at the BWIP hydrogeology workshop include:

- o 45 groundwater samples from 21 boreholes in the Saddle Mountains Basalt
- o 27 groundwater samples from six boreholes in the Wanapum Basalt
- o 18 groundwater samples from four boreholes in the Grande Ronde Basalt.

Relative to the number of borehole monitoring sites that are commonly used in important studies of hydrogeological systems in which major waste-disposal is under consideration, the number of boreholes that penetrate the proposed disposal zone is small. All of the deep holes are located a considerable distance to the east or southeast of the Reference Repository (Figure 1). For statistical data evaluations, the total number of chemical analyses from the Grande Ronde is particularly inadequate. The hydrochemical data represent groundwater obtained from the most permeable zones in the stratigraphic sequence, and they generally cannot be used to ascertain the chemical composition of water in the lower permeability zones.

4 HYDROCHEMISTRY

4.1 Major Ion Chemistry

The groundwater in the basalt formations at the Hanford site can be categorized according to its major-ion chemical composition. There are three principal chemical types characterized by the predominant ions:

- o Na - HCO_3
- o Na - Cl - HCO_3
- o Na - Cl

The vertical distributions of these chemical types in the groundwater in boreholes DB-15, DC-6, DC-12, DC-14 and DC-15 are shown in Figure 2. The Na- HCO_3 groundwater generally occurs in the Saddle Mountains Basalt; the Na-Cl- HCO_3 in the Wanapum Basalt, and the Na-Cl groundwater in the Grande Ronde Basalt. In borehole DC-12, Na-Cl- HCO_3 groundwater occurs in both the Wanapum and Grande Ronde Basalt. The progression from Na- HCO_3 groundwater in the upper basalt formations to Na-Cl groundwater at depth is associated with a moderate increase in total dissolved solids concentrations from an average of 400 mg/L in the Saddle Mountains to an average of 800 mg/L in the Grande Ronde.

A generalization that is commonly used in regional groundwater studies is that the progression from Na- HCO_3 through Na-Cl- HCO_3 to Na-Cl generally represents a long-term hydrochemical evolution in which the Na-Cl groundwater represents

the oldest groundwater, which has traveled the longest flow path (Chebatarev, 1959; Domenico, 1972). This generalization was developed from studies of deep groundwater flow systems in sedimentary basins in which the groundwater chemically evolves from fresh to saline. The progression from Na-HCO₃ groundwater to Na-Cl groundwater at the Hanford site is interpreted in the SCR as indicating that the residence time or age of the groundwater, and the length of flow path traveled by the groundwater, increases with depth. However, the progression from Na-HCO₃ to Na-Cl groundwater at the Hanford site is associated with only a small increase in the salinity of the groundwaters. The slightly higher chloride concentrations of groundwater in the Grande Ronde Basalt should not be taken as evidence that groundwater in the Grande Ronde is necessarily older or has traveled along flow paths separate from the groundwater in the Wanapum.

As illustrated in Figure 2, there are distinct differences in the chemical composition of the groundwaters in different basalt formations in boreholes DB-15, DC-14 and DC-15. In the SCR it is concluded that there is no significant mixing between the formations. These differences are compatible with an interpretation that there is a considerable degree of flow-system separation between the formations, but the differences alone cannot be used to determine the percentage of mixing that may be occurring. One of the limiting factors in the assessment of the apparent chloride differences is the lack of information on the sources of chloride within the basalt units and the release kinetics. The variations observed in the chloride concentrations with depth will be influenced by the sources of chloride in various basalt and interbed formations, by anion exchange reactions and by matrix diffusion processes. The higher concentrations of chloride in the deeper basalts (i.e., Grande Ronde) may be the result of larger amounts of soluble chloride bearing minerals in the deeper formations. Anion exchange and matrix diffusion reactions could also either increase or decrease the chloride concentrations in groundwater, depending upon the hydrochemical conditions. The potential effect of matrix diffusion on chloride concentrations due to diffusion of chloride from the rock matrix into the fractures through which the active groundwater flow occurs, or from the fractures into the matrix, is uncertain. Matrix diffusion has, however, been suggested as having a potentially significant effect on solute migration in fractured rock (Grisak and Pickens, 1981; Neretnieks et al., 1982; Feenstra et al. [in preparation]).

The mixing of chemical constituents between formations generally results from groundwater flow between formations in response to hydraulic gradients. Interpretations of the degree of groundwater discharge flow between formations must consider the groundwater gradients, the local and regional stratigraphy and structure, and flux rates in addition to the hydrochemical data. It is imperative to know the hydraulic properties of the units before drawing any strong conclusions regarding vertical mixing based solely on hydrochemical data.

The diffusion of chemical constituents between formations in response to chemical concentration gradients is generally negligible with respect to mixing by groundwater flow, but could be important if groundwater flow is slow, and diffusion coefficients and concentration gradients are high.

Even if the hydrochemical data are used in a coupled manner with other types of data, it is expected that reliable quantitative interpretations of the extent of potential mixing between the different basalt formations in boreholes

DB-15, DC-14 and DC-15 will not be forthcoming because the sample locations are separated vertically by distances of 50 to 300 m. The sodium chloride concentrations of one sample from the interface between the Wanapum and Grande Ronde in borehole DC-15 is transitional between the concentrations in the overlying and underlying formations. This suggests that a mixing zone may exist between the formations, but spacing of the samples generally prevents the definition of any such mixing zone, particularly across the contact. In borehole DC-12 there are no major differences in the sodium and chloride concentrations between the Wanapum and Grande Ronde formations. This lack of difference is consistent with an interpretation that locally there is considerable mixing between these formations. This interpretation based solely on the hydrochemical data, however, cannot be taken as conclusive.

The degree of vertical mixing between the formations will be difficult to reduce if the lateral groundwater flow in adjacent formations is sufficient to dilute any leakage between formations and mask the hydrochemical evidence of the mixing. For example, the chloride concentrations in borehole DC-15 range from 10-50 mg/l in the Wanapum Basalt and from 200-250 mg/l in the Grande Ronde Basalt. Vertical leakage from the Grande Ronde to the Wanapum could contribute to as much as 10-20 percent of the total groundwater flow in the Wanapum before chloride concentrations would be increased to levels above those characteristic of the Wanapum. The average horizontal transmissivity and consequently the horizontal groundwater flow within the Grande Ronde Basalt is approximately 6 percent of that in the Wanapum Basalt. (Transmissivity 387 ft²/day compared to 6550 ft²/day, see Appendix H). This indicates that the entire flow of the Grande Ronde could discharge to the Wanapum without an identifiable change in the chloride concentrations in the Wanapum. Therefore, although major ion hydrochemical data may not indicate identifiable vertical leakage between the basalt formations, it should not be concluded that significant vertical leakage does not occur.

4.2 Methane

The analyses of dissolved gases in the groundwaters indicate that methane is the predominant constituent in the Saddle Mountains and Wanapum Basalts, comprising from 60 to 98 percent of the total dissolved gas. Methane comprises from <0.01 to 1.6 percent of the total dissolved gas in the groundwater of the Grande Ronde in boreholes DB-6 and DC-14, but comprises 98 percent of the total dissolved gas in the Grande Ronde in borehole RRL-2.

The delta carbon-13 of the methane ranges from -44 to -66 per mil (PDB). This suggests that the methane in the groundwater is the result of methanogenic bacteria which utilize organic geologic material in the interbeds and flowtops to generate methane (Barker and Fritz, 1981). The difference between the methane concentrations in the Saddle Mountains, Wanapum and Grande Ronde is attributed to the less frequent occurrence of interbeds in the Grande Ronde Basalt with a correspondingly smaller amount of available organic material.

The production of methane in the groundwater can have an important influence on the interpretation of carbon-14 age dating of the groundwater. This will be discussed in a following section.

4.3 Oxygen-18 and Deuterium

The groundwater in the basalt formations can be categorized into three groups according to its delta oxygen-18 and delta deuterium isotopic compositions in the same way as described for the chemical composition. As is the case for the major ion chemistry, distinct differences in the delta oxygen-18 and delta deuterium of the groundwater generally occur between the different basalt formations. Group I generally represents the shallow groundwaters in the Saddle Mountains and Wanapum Basalt, and is characterized by delta oxygen-18 of -20.5 to -16.5 per mil (SMOW) and delta deuterium of -155 to -135 per mil (SMOW). Group II generally represents groundwater in the Grande Ronde and is characterized by delta oxygen-18 of -15 to 13.5 per mil (SMOW) and delta deuterium of -135 to -110 per mil (SMOW). Group III represents the groundwater in borehole DC-12 and is a transition between the other two groups. Profiles of the delta oxygen-18 and deuterium in the groundwater in boreholes DC-12, DB-15, DC-6, DC-14 and DC-15 are shown in Figures 3 and 4.

These profiles indicate distinct differences in the delta oxygen-18 and deuterium of the groundwater between the Saddle Mountains and Wanapum Basalt in DB-15; and distinct differences between the Wanapum and Grande Ronde Basalts in DC-14 and DC-15. In borehole DC-12, there are no distinct differences between the Wanapum and Grande Ronde Basalt, and the delta oxygen-18 and deuterium values are intermediate between the range of values observed in the other boreholes.

Although the vertical positions of breaks in the delta oxygen-18 and deuterium in the groundwater between the different basalt formations are generally consistent with the breaks in the major ion chemistry (see Figure 2); they are not identical. For example, the Na-HCO₃ groundwater in the Saddle Mountains has an oxygen-18 and deuterium isotopic composition characteristic of Group I. The NaCl groundwater in the Grande Ronde of boreholes DC-6, 14 and 15 has an oxygen-18 and deuterium isotopic composition characteristic of Group II. However, the Na-Cl-HCO₃ groundwater which occurs throughout the Wanapum and in the Grande Ronde in borehole DC-12 does not have an oxygen-18 and deuterium isotopic composition of a particular group. The Na-Cl-HCO₃ groundwater in the Wanapum in boreholes DC-14 and 15 is characteristic of Group I, whereas the Na-Cl-HCO₃ groundwater in the Wanapum of DC-12 and DB-15 and the Grande Ronde of DC-12 is characteristic of Group III.

In the same way that the breaks in the major ion chemistry suggest some degree of separation of flow in the different basalt formations, the breaks in delta oxygen-18 and deuterium also suggest some degree of separation of flow. However, the delta oxygen-18 and deuterium do not provide a more quantitative indication of the rate of leakage or vertical mixing between the formations. However, because the differences in delta oxygen-18 between the formations is no larger than approximately 5 to 6 per mil, vertical mixing could contribute as much as 10-20 percent of the total flow in adjacent formations before the delta oxygen-18 in the receiving formation would be identifiably changed.

The delta oxygen-18 and deuterium in groundwater is influenced predominantly by the climatic conditions which prevailed during recharge of precipitation to the groundwater system. In theory, it should be possible therefore to use

the delta oxygen-18 and deuterium data to assist in the interpretation of the origin and age of the groundwaters in the different basalt formations.

Origin and age interpretations are generally ambiguous unless major climatic changes have occurred during the time span of groundwater recharge to the various zones in the flow system. The delta oxygen-18 and deuterium values of precipitation, and consequently of recharge to the groundwater system, will be lower (more negative) in cold climatic conditions and in areas of high elevation. A decrease of 1°C in the mean annual temperature would result in a decrease of approximately 0.7 per mil in the mean delta oxygen-18 of precipitation and a decrease of approximately 6 per mil in the mean delta deuterium (Dansgaard, 1964). Mean values of delta oxygen-18 in precipitation in mountainous areas can decrease by from 0.15 to 0.5 per mil per 100 meter increase in elevation, while delta deuterium can decrease by 1 to 4 per mil (Gat, 1980). Consequently, if the delta oxygen-18 and deuterium of groundwater is found to be less (more negative) than the present precipitation in the suspected recharge areas, it may indicate that the groundwater has recharged at a time when climatic conditions were colder or that it recharged at a higher elevation than suspected. Evidence that groundwater recharged during different climatic conditions (such as during the last glaciation) may provide information on the age of the groundwater. Similarly, evidence that the groundwater recharged at a particular elevation may suggest locations where groundwater recharged.

The delta oxygen-18 and deuterium of the groundwaters at the Hanford site should be evaluated with due consideration of the isotopic composition of both present and past inputs to the groundwater system in order to evaluate the possible origins and ages of the groundwaters in the basalt formations. Information on the isotopic composition of present inputs to the groundwater systems can be derived from the analysis of the delta oxygen-18 and deuterium of the precipitation or irrigation water in the suspected recharge areas. Information on the isotopic compositions of past input to the groundwater systems can be estimated based on the elevation and paleoclimatic conditions which may have existed in the suspected recharge areas. No such information on the isotopic composition of present or past input to the groundwater system is presented in the SCR. Consequently, it is not possible, at this time, to evaluate the possible origins and ages of the groundwaters in detail using the delta oxygen-18 and deuterium isotopic data.

The delta oxygen-18 and deuterium of the groundwaters can also be altered by isotopic exchange with minerals in the groundwater system. The potential for isotopic exchange must be considered together with data on the isotopic composition of inputs to the groundwater system in order to evaluate the origin and age of the groundwaters using the delta oxygen-18 and deuterium data. The delta oxygen-18 of groundwater can be increased (to more positive values) by exchange with silicate or carbonate minerals in the basalt formations. The elevated temperatures (50°-60°C) and suspected long residence time for groundwater in the Grande Ronde Basalt would enhance the potential for delta oxygen-18 isotopic exchange between the groundwater and minerals in the basalt. The delta deuterium of groundwater can be increased by exchange with hydrogen sulfide in the groundwater. This process would seem unlikely in the groundwaters at the Hanford site, because hydrogen sulfide was not reported in the

groundwaters. However, there is no indication in the SCR as to whether or not H_2S analyses were conducted on any of the groundwater samples.

The following is an example of the type of interpretation which may be possible using the delta oxygen-18 and deuterium isotopic data from the Hanford site, but which has not been presented in the SCR. Delta oxygen-18 and deuterium data are generally presented in a plot of delta deuterium versus oxygen-18. The delta deuterium-delta oxygen-18 relationship for groundwater from the basalt formations at the Hanford site and for springs emerging from the Saddle Mountains Basalt in the Rattlesnake Hills is shown in Figure 5. This relationship is shown together with the Global Meteoric Water Line defined by Craig (1961). Most groundwaters will plot along or close to this line unless they have been influenced by isotopic exchange processes (Fritz and Frape, 1982). The springs in the Rattlesnake Hills plot along the meteoric waterline, whereas the groundwaters from the basalt formations are shifted to the right of the meteoric waterline. Although isotopic data for present precipitation in Hanford area are not available, the springs in the Rattlesnake Hills provide an indication of the isotopic composition of the present inputs to the local groundwater system. The springs in the Rattlesnake Hills have tritium activities of 10 to 100 T.U. and therefore represent water that contains appreciable percentages of water that entered the groundwater system since 1953.

The delta oxygen-18 and deuterium of the groundwater likely differ from those of the springs in the Rattlesnake Hills and from the meteoric waterline due to differences in the climatic conditions which prevailed during their recharge.

Groundwaters in the basalt formations generally have tritium activities of less than 1 T.U. and represent water which has recharged to the basalt prior to 1953. Based on the measured hydraulic conductivities and hydraulic gradients in the basalt formations and the distances from the suspected recharge areas, the groundwaters in the basalt formations could be thousands of years old, and could have recharged under very different climatic conditions than those presently prevailing in the Hanford area. For example, the delta oxygen-18 and deuterium of the groundwater in the Saddle Mountains and Wanapum Basalt in boreholes DB-15, DC-14 and DC-15 (Group I) are less than (more negative) those of the springs in the Rattlesnake Hills. This suggests that these groundwaters may have recharged to the basalt at a time when a colder climate prevailed, or in an area of higher elevation. Similarly, although the delta oxygen-18 values for the Group II waters are shifted to the right of the meteoric waterline, the delta deuterium values for the Group II groundwaters may suggest that these groundwater recharged at a time when climatic conditions were similar to those at present in the Hanford area. The increase in delta oxygen-18 (shift to the right) for the Group II waters may have resulted from exchange with minerals in the basalt formations. The Group III groundwaters may represent waters which recharged at a time when climatic conditions were intermediate between those for the Group I and Group II waters, or may represent the mixing of the shallow Group I groundwaters and deeper Group II groundwaters in the area of borehole DC-12.

In order to develop a detailed evaluation of the origins and ages of groundwaters in the basalt formations using the delta oxygen-18 and deuterium isotopic data, it will be necessary to consider the data in light of the paleoclimatic and paleohydrologic conditions which prevailed during recharge, and

the locations of probable recharge areas. The integration of the oxygen-18 and deuterium isotopic data within a suitable paleoclimatic and geographic framework has not been presented in the SCR. The paleoclimatology of interest is that of the Quaternary Era. The necessity for consideration of Quaternary paleohydrology is provided in NRC rule 60.1.2.2.

4.4 Carbon-14 Age Dating

The carbon-14 age dating of groundwater is based on the assumption that the initial carbon-14 activity of dissolved carbon in the groundwater is established during recharge to the groundwater flow system, and since that time only radioactive decay results in a decrease in the carbon-14 activity of the carbon in the groundwater. This assumption allows the measured carbon-14 activity of a groundwater to be related to the time elapsed since recharge, or age of the groundwater. There are, however, a number of geochemical processes which can occur in the groundwater or during sampling to affect the carbon-14 activity measured in the groundwater. The processes which occur in the groundwater generally act to add carbon with low carbon-14 activity to the groundwater, and thereby reduce the carbon-14 activity of the groundwater and increase its apparent age. Consequently, a variety of corrections can be applied to "uncorrected" or analytical carbon-14 ages to account or "correct" for the effects of processes which yield dead carbon (Fritz et al., 1979). None of the geochemical models that are described in the literature were developed specifically for application to groundwater that moves through stratigraphic sequences composed primarily of basalt.

The contamination of the groundwater samples by atmospheric carbon dioxide during sampling will add carbon with a high carbon-14 activity to the groundwater, and thereby increase the carbon-14 activity of the groundwater and decrease its apparent age. It is not possible to "correct" carbon-14 ages to account for this contamination.

The carbon-14 ages presented in the SCR have been corrected to account for the addition of dead carbon to the groundwater from carbonate mineral dissolution. They have not been corrected in a manner that accounts for the effect of carbonate-mineral precipitation. The SCR suggests that carbonate precipitation occurs within some of the basalt layers. There is another geochemical process which can add dead carbon to the groundwater and increase the analytical carbon-14 ages, which has not been addressed in the SCR. Barker et al. (1979) indicate that methanogenesis by bacteria in deep groundwaters can result in a substantial dilution of the carbon-14 activity in the groundwater by the addition of "dead" carbon (low carbon-14) from geologic organic material utilized by the bacteria. This addition of dead carbon to the groundwater will result in anomalously old carbon-14 ages.

Dissolved gas analyses of the groundwaters at the Hanford site indicate significant methane production occurs in the Saddle Mountains and Wanapum Basalts. The delta carbon-13 of the methane indicates that it is of biogenic origin. Biogenic methanogenesis is further evidenced by significant enrichments (increases) in the delta carbon-13 of the dissolved carbon in the groundwaters which contain large concentrations of methane. Vertical profiles of delta carbon-13 in the dissolved carbon are shown in Figure 6.

Methane concentrations in the groundwater in the Grande Ronde are substantially lower, and there is generally no enrichment in delta carbon-13 in these groundwaters.

Based on the potential influence of methanogenesis on the analytical carbon-14 ages, it may be anticipated that the carbon-14 ages for the groundwaters from the Saddle Mountains and Wanapum Basalts could be anomalously old because of Figure 6

the high concentrations of methane in these formations, whereas the carbon-14 ages for the Grande Ronde Basalt may be more representative of the actual groundwater age. Indeed, uncorrected carbon-14 ages as young as 11,400 years were determined for groundwater in the Grande Ronde (from data collected at the BWIP Workshop, July 1982). Any corrections for the addition of dead carbon to the groundwater would tend to decrease the carbon-14 ages for the Grande Ronde groundwaters. This contradicts the carbon-14 ages reported in the SCR, which indicate a mean corrected carbon-14 age of >32,000 years for the Grande Ronde groundwater. The SCR also indicates mean corrected carbon-14 ages of 17,000 years and 25,000 years for the Saddle Mountains and Wanapum respectively.

The occurrence of the youngest carbon-14 ages in the Grande Ronde is contrary to the expected groundwater age relationships in the basalt. This casts considerable doubt on the applicability of carbon-14 ages in determining relative groundwater ages at the Hanford site. Barker et al. (1979) present several models for the correction of carbon-14 ages to account for the effects of methanogenesis, and it is suggested that application of such models be considered for use at the Hanford site.

There is the possibility that these young carbon-14 ages for the groundwaters in the Grande Ronde are due to contamination by atmospheric carbon dioxide during sampling. The low bicarbonate concentrations in the Grande Ronde groundwaters necessitate the collection and treatment of large volumes of groundwater for the carbon-14 analyses. Such contamination would result in anomalously young carbon-14 ages. The possibility of this type of contamination is an important consideration that is not addressed in detail in the SCR.

5 CONCLUSIONS

1. The hydrochemistry sections in the SCR pertaining to characterization, origin, age and mixing of groundwaters at the Hanford site are not presented in a format of the type that is normally considered to be acceptable for scientific evaluation. The most serious deficiencies in the SCR presentations include: a lack of description of methods by which the boreholes were prepared for water sampling and of the sampling and analytical methods, a lack of presentation of the basic data in the SCR even though there is not a cumbersome amount of data from the depth zones of main interest, and a lack of unbiased graphical summaries of data in a manner that is conducive to assessment of the hydrochemical conclusions in the SCR.
2. Based on informal information pertaining to the sampling and analytical methods acquired at the BWIP Hydrogeology Workshop in July 1982 and on listings obtained at this meeting of much of the basic data, it is con-

cluded that a moderate amount of useful hydrochemical data have been obtained from the Hanford site. In spite of some uncertainties relating to the influence of drilling fluids and sampling methods, it is reasonable to expect that the major ion data, stable isotope data, tritium data and gas data have adequate integrity for the main interpretive purposes.

3. In future drilling, the use of drilling mud should be avoided so that more detailed geochemical characterizations of the groundwater can be accomplished with less uncertainty.
4. Except for the shallowest basalt unit, the number of boreholes from which hydrochemical data have been obtained is small, and the geographic locations of the deep holes are not well suited for evaluation of hydrochemical conditions across the study area. The vertical positions of sampling zones in the boreholes are generally far apart relative to the spacing that would be needed to assess vertical leakage or mixing between formations. There are few or no hydrochemical data available for the least permeable zones in the stratigraphic sequence.
5. Groundwater in the basalt formations at the Hanford site varies in general chemical composition from a Na-HCO₃ type water in the Saddle Mountains to a Na-Cl type water in the Grande Ronde. In the SCR this variation is interpreted as representing a hydrochemical evolutionary sequence in which Na-HCO₃ water represents the youngest water and the Na-Cl water represents the oldest water. This type of evolutionary sequence has been used in the interpretation of many groundwater flow systems in sedimentary deposits in several regions of the world, but generally in situations where there is a large increase in the total dissolved solids and a marked increase in chloride concentrations. Such increases have not been observed at the Hanford site. The origin and release rates of chloride in deep groundwater at the Hanford site have not been established and have not been related to the hydrochemical evolutionary sequence.
6. In the hydrochemical interpretations presented in the SCR, the possible effects of matrix diffusion on the major ion and isotope distributions are not evaluated, nor are the hydrochemical influences of mineral coatings on fracture surfaces assessed.
7. The SCR makes reference to hydrochemical information on four deep boreholes at the Hanford site. The profiles of major ions and oxygen-18 and deuterium concentrations from these holes are variable from one hole to the next. In DC-14 and DC-15, there are considerable differences in concentrations between the Wanapum and the Grande Ronde Formations. The SCR concludes that these differences indicate the groundwater flow systems in these two formations are separate. It is the opinion of the NRC staff that the precise degree of leakage between formations (vertical mixing) cannot be ascertained from the existing hydrochemical data. Vertical mixing between adjacent formations will be difficult to deduce because dilution will mask the hydrochemical evidence of mixing. Interpretations regarding vertical mixing must consider hydraulic gradients and hydraulic conductivities in the formations in question in order to offer a possibility for definitive interpretations.

In the hydrochemical sections of the SCR, arguments in support of the conclusions regarding separation of groundwater zones are based only on hydrochemical data. These conclusions are very speculative. Borehole DC-12 exhibits no major shifts in major ions and isotopes from Wanapum to the Grande Ronde. This hydrochemical information, if used in the same manner as other hydrochemical borehole data are used in the SCR, could be taken as supporting a conclusion that there is little or no degree of local flow system separation between these two formations.

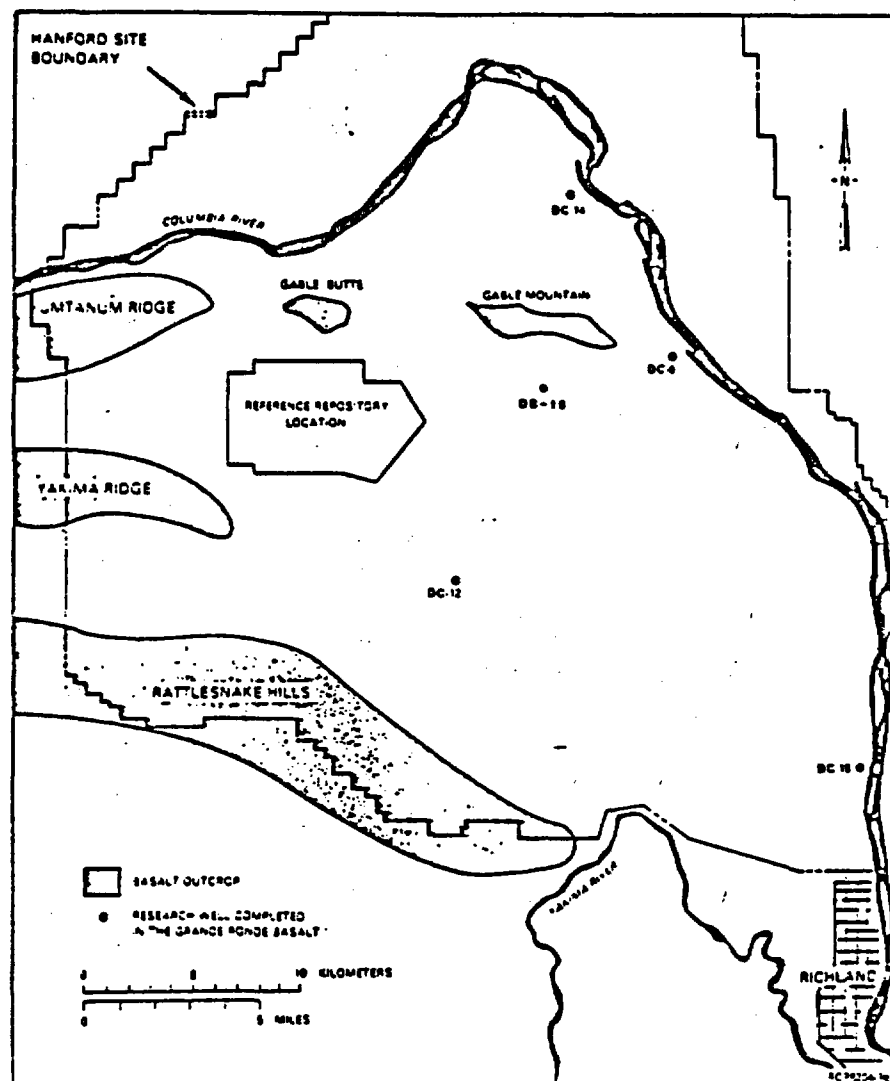
8. Uncorrected carbon-14 ages as young as 11,400 years were determined for groundwater samples from the Grande Ronde (from data received at the BWIP Hydrogeology Workshop). Correction of these dates to account for geochemical effects will tend to decrease the carbon-14 ages. This contradicts the carbon-14 ages reported in the SCR, which are listed as having a mean age of greater than 32,000 years. The SCR reported mean corrected ages of 17,000 and 25,000 years for the Saddle Mountain and Wanapum, respectively. These carbon-14 ages may be much older than the actual groundwater ages due to the effect of methanogenesis in these formations. Methanogenesis in these two formations is a process that renders the carbon-14 ages difficult or impossible to interpret in terms of actual groundwater age.

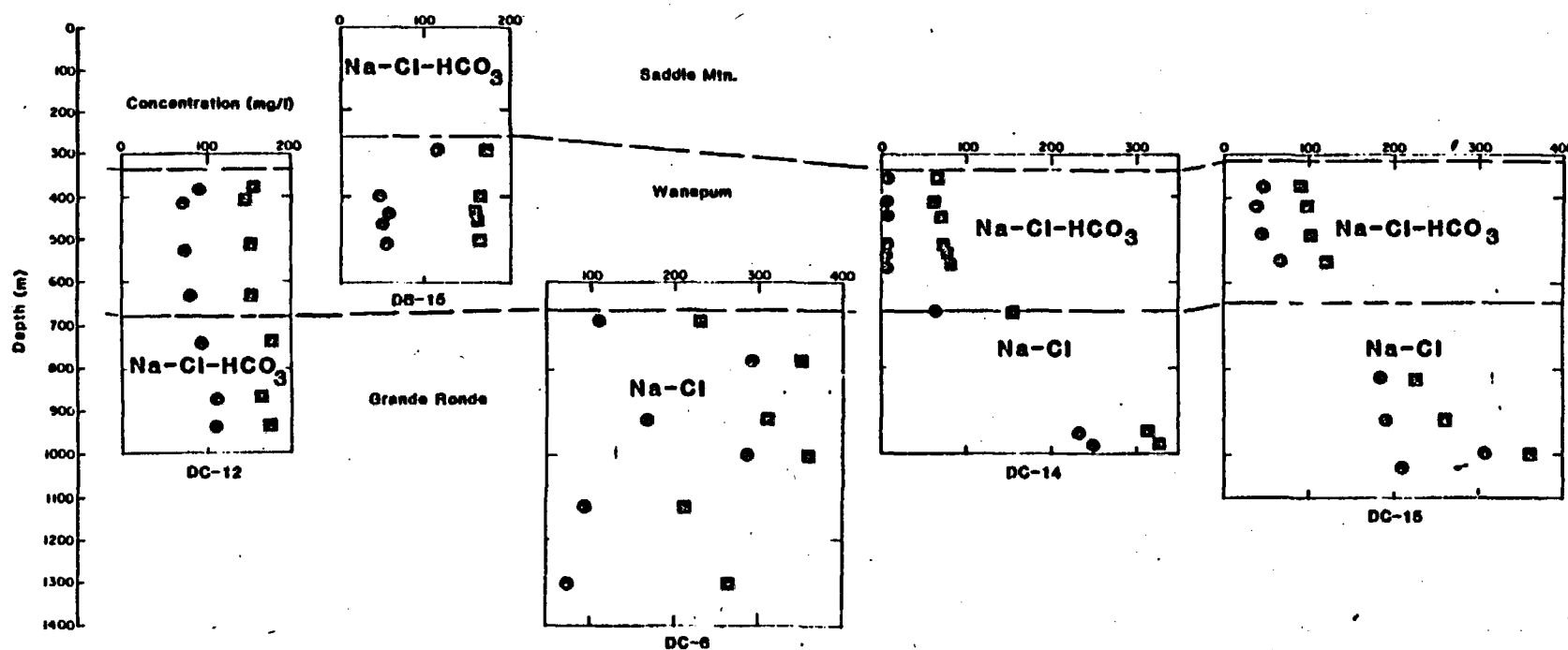
REFERENCES

- Barker, J.F., P. Fritz and R.M. Brown, "Carbon-14 Measurements in Aquifers with Methane", p. 661 in Isotope Hydrology 1978, Vol. II, International Atomic Energy Agency, Vienna, 1979.
- Barker, J.F. and P. Fritz, "The Occurrence and Origin of Methane in Some Groundwater Flow Systems," Canadian Journal of Earth Sciences, v. 18, No. 2, p. 1802-1816, 1981.
- Chebotarev, I.I., "Metamorphism of Natural Waters in the Crust of Weathering," Geochemica et Cosmochimica Acta 8, 22-48, 137-170, 198-212 (1955).
- Craig, M., "Isotopic Variations in Meteoric Waters," Science, v. 133, p. 1702-1703, 1961.
- Dansgaard, N., "Stable Isotopes in Precipitation." Tellus, v. 16, p. 436-468.
- Domenico, P.A., "Concepts and Models in Groundwater Hydrology." McGraw-Hill, New York, 1972.
- Feenstra, S., J.A. Cherry, E.A. Sudicky and Z. Haq, "The Effect of Matrix Diffusion on Contaminant Migration in a Fractured Sandstone," in preparation for submittal to Ground Water. Available from the authors.
- Fritz, P., J.E. Gale and E.J. Reardon, "Comments on Carbon-14 Dating of Groundwaters in Crystalline Environments," Geoscience Canada 6 (1), 10-15 (1979).
- Fritz, P. and S.K. Frape, "Comments on the Oxygen-18 and Deuterium, and Chemical Composition of Saline Groundwaters on the Canadian Shield," In: Isotope Studies of Hydrologic Processes, Edited by E.C. Perry Jr. and C.W. Montgomery, Northern Illinois University Press, DeKalb, Illinois, p. 57-63, 1982.
- Gat, J.R., "The Isotopes of Hydrogen and Oxygen in Precipitation," p. 21 in Handbook of Environmental Isotope Geochemistry, Vol. 1: The Terrestrial Environment, ed. P. Fritz and J.C. Fontes, Elsevier, Amsterdam, 1980.
- Grisak, G.E. and J.F. Pickens, "An Analytical Solution for Solute Migration in Fractured Media with Matrix Diffusion," J. Hydrology 52, 47-57 (1981).
- Nerentnieks, I., T. Eriksen and P. Tahtinen, "Tracer Movement in a Single Fissure in Granitic Rock," Water Resources Res. 18 (4), 849-858 (1982).

LOCATIONS OF BOREHOLES FOR WHICH DETAILED HYDROCHEMICAL DATA ARE AVAILABLE

Figure 1





NOTE: If more than one sample is taken in the same interval, data point represents an arithmetic mean.

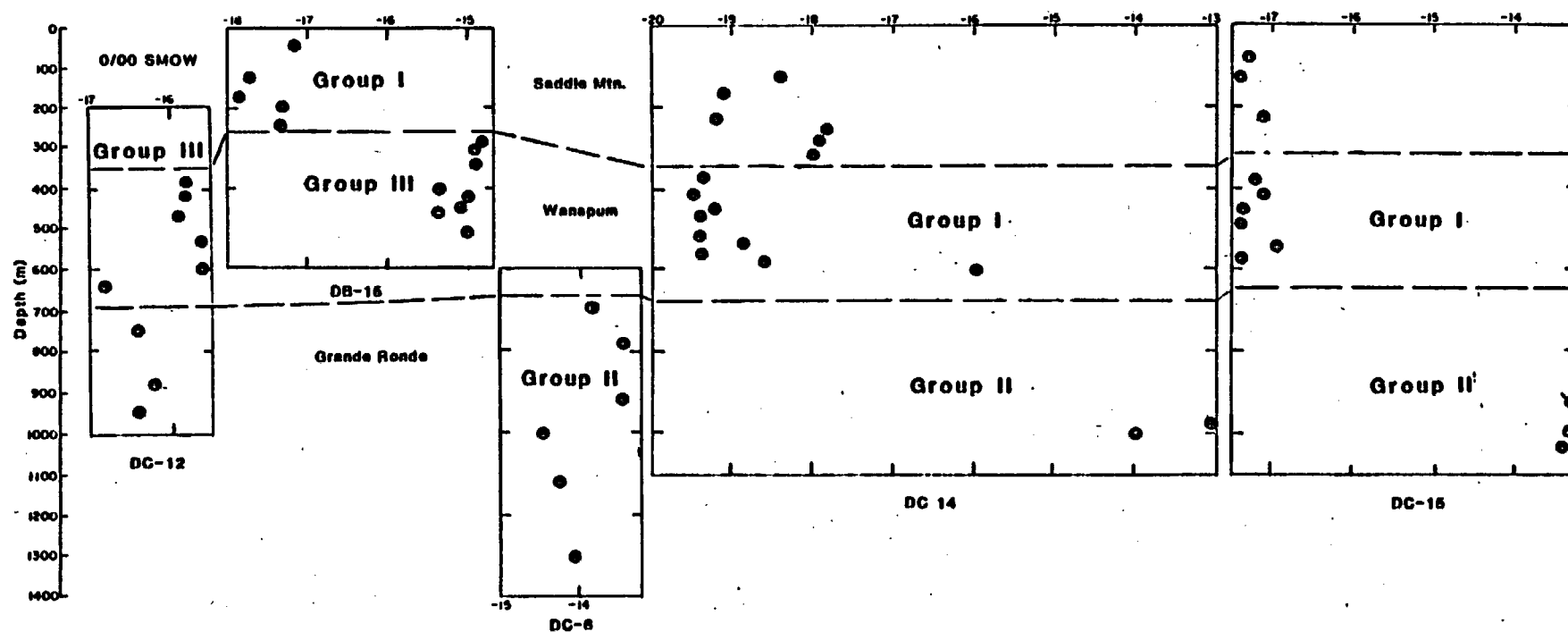
EXPLANATION

Chloride (mg/L) ●
Sodium (mg/L) ■

F-17

August 1981

1981

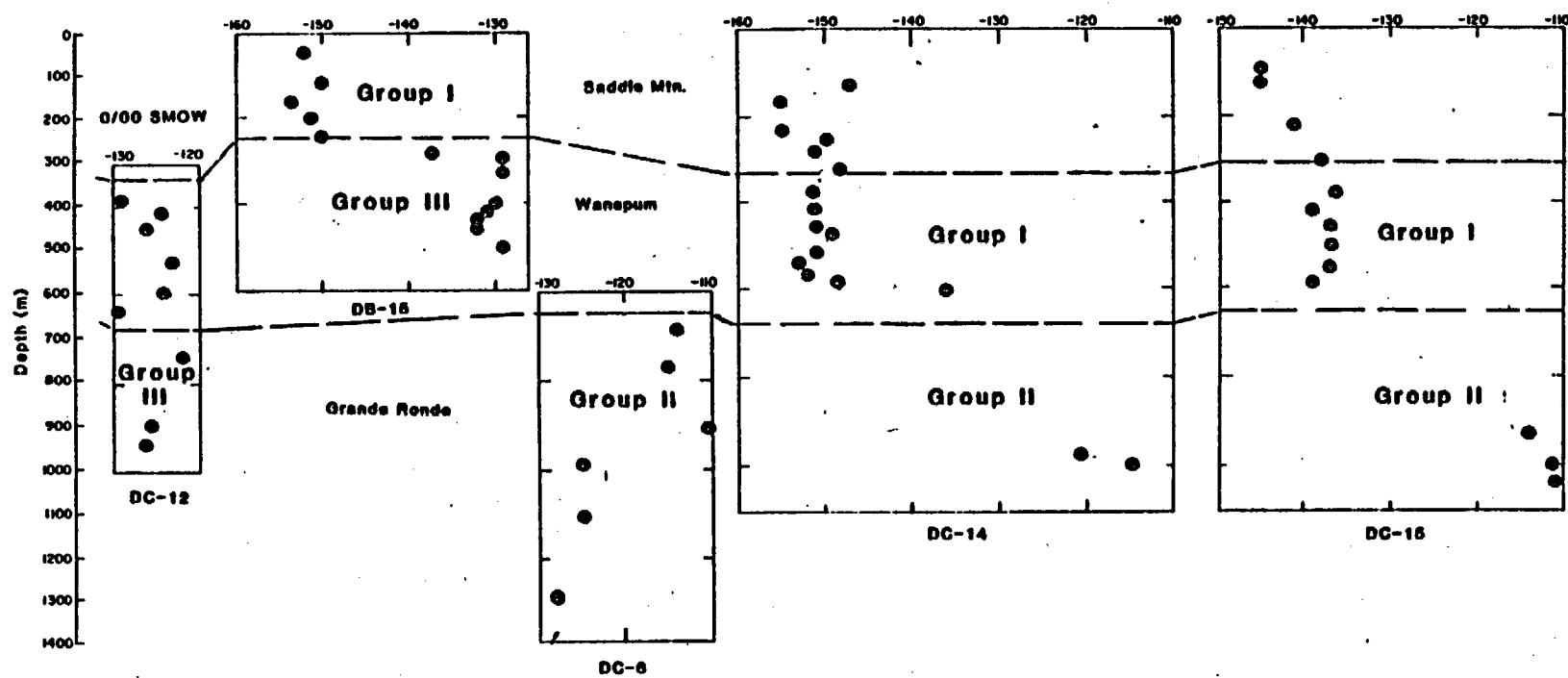


NOTE: If more than one sample is taken in the same interval, data point represents an arithmetic mean.

F-18

6/17/05/08/

1/Logsdon



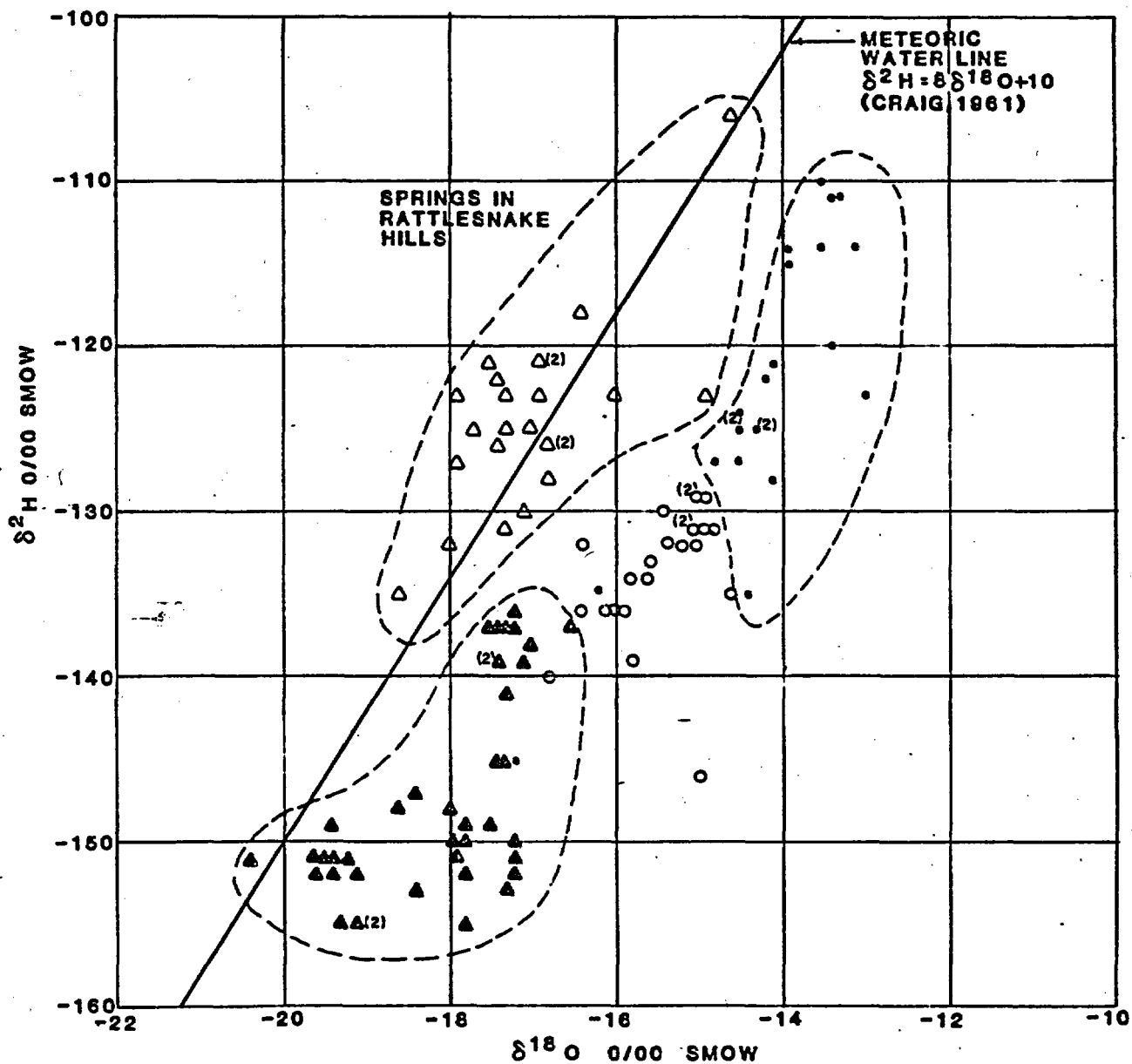
NOTE: If more than one sample is taken in the same interval,
data point represents an arithmetic mean.

F-19

05041

11/04/04

Data from Boreholes DB-15, DC-6, DC-12, DC-14, DC-15



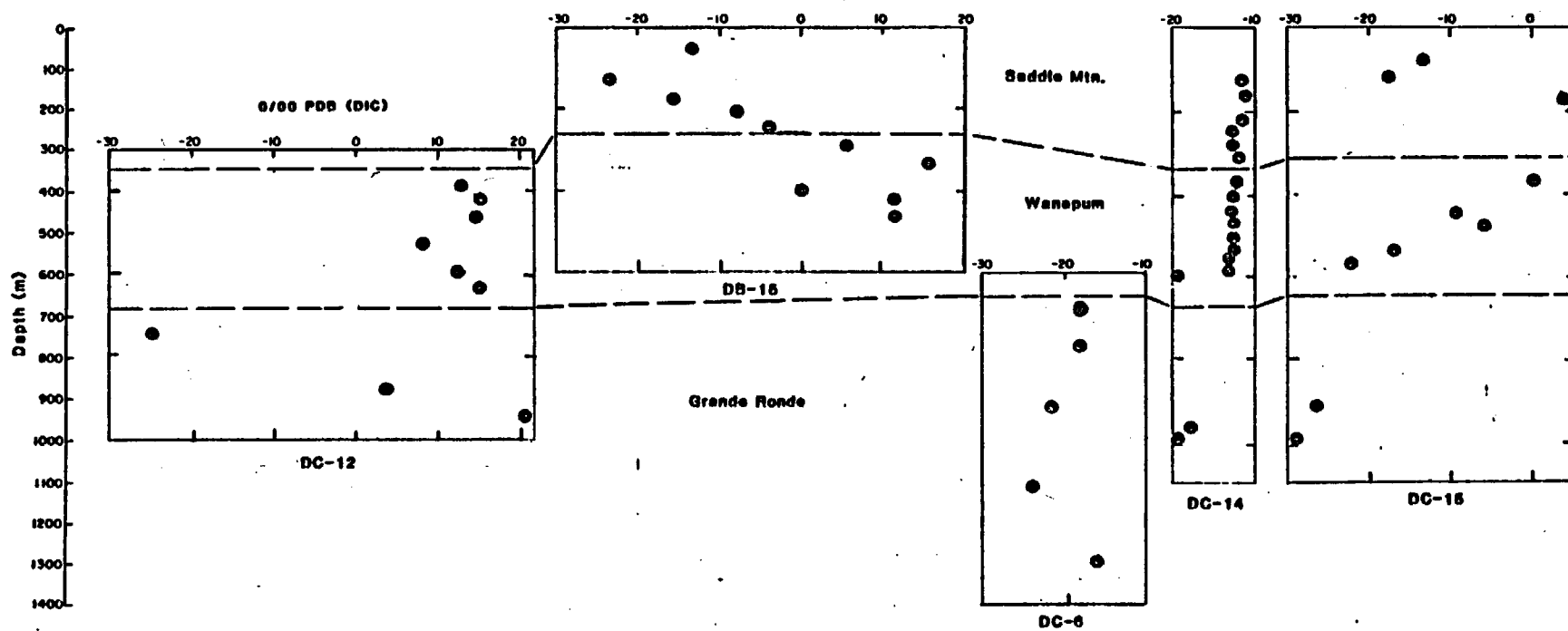
LEGEND

- ▲ Group I:
Saddle Mountains DB-15;
Saddle Mountains and Wanapum DC-14, DC-15
- Group II:
Grande Ronde DC-6, DC-14, DC-15
- Group III:
Wanapum and Grande Ronde DC-12, Wanapum DB-15
- △ Springs in Rattlesnake Hills
- (2) Indicates two samples

F-20

BIOINUSCA/

Logsdon



NOTE: If more than one sample is taken in the same interval, data point represents an arithmetic mean.

F-21

SWD 03/01/13

1/15/13

SELECTED KEY HYDROCHEMICAL DATA -
BOREHOLE DB-15

Table A-1

UNIT	SAMPLE NUMBER	DEPTH (m)	$\delta^{18}\text{O}$ (‰) (SMOW)	$\delta^2\text{H}$ (‰) (SMOW)	$\delta^{13}\text{C}$ (‰) (PDB)	^{14}C (Years)	^{14}C (%) (Modern)	^3H (T.U.)	CH_4 (Mole %)	F (mg/L)	Cl (mg/L)	Na (mg/L)	HCO_3 (mg/L)
Rattlesnake R.	79-17	46-68	-17.2	-152	-13.1			10.8					
	79-22		-17.1										
Selah	79-20		-17.6					10.6					
	79-35	113-129	-17.9	-150	-23.8			0.09					
Cold Creek	79-27	155-188	-17.8	-152				0.10					
	79-33		-17.9	-155	-15.5			0.11					
Umatilla	79-8	195-208	-17.1		-6.5								
	79-15		-17.2	-150	-8.4								
	79-38		-17.5										
	79-39		-17.3	-153		26,300	3.77						
Mabton	79-25	233-258	-17.5	-149									
	79-31	233-258	-17.2	-151	-3.9								
Priest Rpd. #1	79-51	262-295	-14.6	-135	+10.4			0.25		22	117	171	115
	79-61		-14.8	-131	+1.5								
	79-92		-15.0	-146									
Priest Rpd. #2	79-85		-14.9		+8.2			0.19					
Priest-Roza	79-99		-14.9	-129									
Roza	79-68	319-337	-15.0	-129									
	79-80		-14.8		+15.9	23,760	5.17	0.15					
Frchmn. Spr. #2	79-90	396-409	-15.4	-130					89.8	17	95	166	140
Frchmn. Spr. #3	80-35		-14.9	-131	-16.0	>32,000	1.9	0.11					
	80-41		-15.1	-131	+16.0	>32,000	< 1.95	0.17					
Frchmn. Spr. #4	80-24		-15.2	-132	+11.6	27,670	3.2						
	80-74	424-440	-15.0	-132	+11.6	27,670	3.18		94.4	20	108	160	109
Frchmn. Spr. #5	80-77	441-466	-15.4	-132	+13.3	>30,000	< 2.4	0.09					
	80-42	441-466							90.9	17	102	162	148
Frchmn. Spr. #6	80-1	479-513	-15.0	-129	+11.6	27,800	3.1	0.04	93.8	20	105	164	114

*Uncorrected

F-22

Boyle 05081

16 April

Table A-2

***Uncorrected**

14984

Table A-3

***Uncorrected**

1495 dm

SELECTED KEY HYDROCHEMICAL DATA -
BOREHOLE DC-14

Table A-4
1 of 2

UNIT	SAMPLE NUMBER	DEPTH (m)	$\delta^{18}\text{O}$ (0/00 SMOW)	$\delta^2\text{H}$ (0/00 SMOW)	$\delta^{13}\text{C}$ (0/00 PDB)	^{14}C * (Years)	^{14}C (% Modern)	^3H (T.U.)	CH_4 (Mole %)	F (mg/L)	Cl (mg/L)	Na (mg/L)	HCO_3 (mg/L)
Elephant Mtn.	80-3	119-129	-18.4	-147	-11.6	23,940	5.1	0.10					
Rattlesnake R.	80-53	150-161	-19.1	-155	-11.0	26,160	3.8	-0.08					
Selah	80-47		-19.3	-155	-11.6	24,460	4.7	0.07					
	80-85	214-233	-19.1	-155	-11.6	24,460	4.74	0.07					
Huntzinger	80-69		-17.8	-150	-12.8	>32,000	< 1.9	0.12					
	80-89		-17.8	-149	-12.6	>28,000	< 3.05	0.76					
Umatilla	80-99		-17.9	-151	-12.7	>34,000	< 1.45	0.23					
Mabton	80-71	295-330	-18.0	-148	-11.4	23,475	5.36	1.23					
Priest Rpd.	80-136		-19.1	-152	-12.2	32,150	1.82	-0.03					
	80-144		-19.6	-152	-12.2	32,150	1.82						
	80-189	365-371	-19.6	-151	-12.1	>34,000	< 1.45			1.0	6.3	65	156
Roza	80-112	394-409	-19.5	-151	-12.2	28,110	3.0	0.63					
	80-168	394-409								0.9	6.9	61	147
Squaw Cr.	80-183	451-462	-19.2	-151	-12.8	30,250	2.3	0.37					
	80-157	451-462								2.2	7.0	73	131
Frchmn. Spr. #2	80-155	480-497	-19.4	-149	-12.4	29,500	2.5	0.04	< 0.01	2.2	6.9	76	112
Frchmn. Spr. #3	80-104	500-521	-19.4	-151	-12.3	24,630	4.6			1.8	5.6	80	110
	80-148		-20.4	-151	-12.3								
Frchmn. Spr. #4	80-129	528-555	-18.8	-153	-12.5	>32,000	< 1.85	0.22		2.3	5.8	75	102
Frchmn. Spr. #5	80-170		-19.4	-152	-12.7	>30,000	< 2.4	1.45					
Frchmn. Spr. #6	80-117		-18.6	-148	-12.9	>34,000	< 1.45	0.02					
Frchmn. Spr. #7	80-213		-16.0	-136	-19.7	25,220	4.3	0.26					
Grande Ronde #7	81-44	969-983	-14.1	-121	-19.9	17,090	11.9	1.38		47	238	325	91
Grande Ronde #8	81-21		-17.2	-145	-13.9	23,600	5.4	2.13					
Umtanum	81-30	936-958	-13.1	-114	-17.3					41	231	316	71
Grande Ronde	81-20		-14.8	-127	-16.2	17,260	11.6	1.81					
	80-236	646-681								24	71	161	113

*Uncorrected

F-25

SAIT HSE/1

Logan

Table A-4
2 of 2

[illegible]

F-26

134470 05441

11095 dm

SELECTED KEY HYDROCHEMICAL DATA -
BOREHOLE DC-15

Table A-5

UNIT	SAMPLE NUMBER	DEPTH (m)	$\delta^{18}\text{O}$ (‰ SMOW)	$\delta^2\text{H}$ (‰ SMOW)	$\delta^{13}\text{C}$ (‰ PDB)	^{14}C * (Years)	^{14}C (% Modern)	^3H (T.U.)	CH_4 (Mole %)	F (mg/L)	Cl (mg/L)	Na (mg/L)	HCO_3 (mg/L)
Levey	80-56	87-95	-17.3	-145	-13.3	20,580	7.7	0.16					
Rattlesnake R.	80-54	133-150	-17.4	-145	-16.2	24,375	4.8	0.25					
Cold Creek	80-57	220-234	-17.1	-141	+4.1	>37,000	< 1.0	0.14	82.5				
Mabton	80-87	310-324	-16.8	-138	+14.5	36,200	1.10	0.35	96.7				
Priest-Roza	80-137		-17.2	-136	+0.3	26,450	3.7						
Roza	80-176	372-394	-17.1	-139		23,350	5.4	0.42	87.9				
	80-197	372-394								11	47	91	106
Frchmn. Spr. #2	80-149		-17.2	-137	-9.4			0.87					
	80-135	416-420	-17.5	-137	-9.4	27,000	3.4	0.89	80.0	9	40	98	118
Frchmn. Spr. #4	80-120	469-485	-17.4	-137	-5.2	>34,000	< 1.5	4.61	65.7	11	45	102	145
Frchmn. Spr. #5	80-108		-17.3	-137	-17.4	>32,000	< 1.85	0.44					
	80-131	529-559	-16.5	-137	-17.0	>30,000	< 2.38	0.44	0.14	12	65	117	100
Frchmn. Spr. #6	80-114	559-575	-17.4	-139	-22.1	>33,000	< 1.64	0.69	0.35				
	80-193		-17.4	-139	-22.1	>33,000	< 1.6	0.69					
Grande Ronde #2	81-2		-14.5	-124	-31.3	12,520	21.0	3.80					
	81-41		-14.2	-122	-25.5	16,010	13.6	0.90					
Grande Ronde #7	81-27	902-949	-13.5	-114	-31.5	22,450	6.2	0.63		33	189	260	51
	81-33		-13.0	-123	-20.4			0.81					
Grande Ronde #10	81-64	989-1004	-13.3	-111	-28.8	17,700	11.4	1.48		24	308	362	64
Grande Ronde #11	81-96	1006-1040	-13.4	-111				0.64		23	210	277	86
Grande Ronde	81-46	808-823								18	183	229	65

*Uncorrected

F-27

6/27/05 CH 1

Logsdon

APPENDIX G
LIMITATIONS OF PACKER TESTING FOR
HEAD EVALUATION IN HANFORD BASALTS

01/28/83

BWIP DSCA/APP G/LOGSDON

TABLE OF CONTENTS

1. INTRODUCTION
2. METHODOLOGY
 - 2.1 System Analyzed
 - 2.2 Analytical Evaluations
 - 2.3 Numerical Evaluations
3. RESULTS
 - 3.1 Steady-State Results
 - 3.2 Transient Results
4. CASE EXAMPLE
5. SUMMARY AND CONCLUSIONS

LIST OF FIGURES

Figure

- 1 Typical Packer Test System.
- 2 Hydrogeologic Model Used in Analysis
- 3 Finite-Element Mesh
- 4 Pressure in the Packed-Off Section as a Function of Time
- 5 Head Decay in the Packed-Off Stratum - No Flow Boundary Case
- 6 Head Decay in the Packed-Off Stratum - Fixed Head Boundary Case
- 7 Reequilibration During a Packer Test at BWIP
- 8 Completion in DC-1
- 9 Head Values Obtained During Drilling and Piezometer Heads in DC-1
- 10 Plot of Water Level Versus Time for Piezometers in DC-1
- 11 Results of Packer Test and Permanent Completion Head Measurements in Oil Shale

LIST OF TABLES

Table

- 1 Parameters Used in Numerical Analysis
- 2 Results of Steady-State Analyses

1 INTRODUCTION

This appendix addresses the question of the accuracy of head measurement in boreholes using packer techniques, with specific application to the Hanford basalt flows.

Accurate head measurements are of critical importance in a regional study of a geohydrologic system because they are used for the following purposes:

- o Determination of head gradients so that the direction of flow (vertically and horizontally) can be determined in the undisturbed state.
- o Calibration of steady-state models for later use in performance analysis.
- o Evaluation and calibration for the transient behavior of the system (by observing the long-term fluctuation of heads due to natural and induced changes in the system).

Because gradients and fluctuations tend to be small in locations like the Hanford site, the spot head values must be obtained with considerable accuracy.

Head measurements at the Hanford site have been made during the drill-and-test sequence by packing-off sections of corehole and measuring the fluid pressure or fluid level in a riser pipe which is open to the formation over the packed-off interval (Figure 1). If pressure rather than water level is measured, it is converted to a head by application of a conversion formula, taking fluid density into account.

There is a possibility that errors may occur in using this testing technique. Assuming that the test itself is properly conducted, two main sources of error are still possible. Measured head may differ from the head which existed before the hole was drilled because:

- o Transient head perturbations caused by drilling may not have fully dissipated.
- o Heads may be different from the original head even at steady state due to the effects of the open hole immediately above the packer.

This study considers each of these possibilities for the expected range of permeabilities at Hanford.

A wide range of other possible causes of error in this technique of head measurement are not considered in this study. These other sources of error are due to less-than-ideal test methods and include:

- o Improper packer seating
- o Equipment elasticity effects

- o Errors in pressure measurement
- o Errors in conversion of pressure to heads
- o Wellbore effects.

2 METHODOLOGY

2.1 System Analyzed

Analyses considered in this appendix have been performed on the same idealized system. This system is a horizontally layered section, with the layers alternating between low permeability (representing dense basalt) and high permeability (representing flow tops and interflows). Each layer is 10 meters thick. To simulate conditions at the most critical point (i.e., the repository horizon), a depth of 1000 meters to 1200 meters below the top of the zone of saturation has been analyzed. The system analyzed is shown in Figure 2. The hole diameter chosen for study is 0.1 m (4 in.). The packer, 4 meters in length, is set in a low-permeability unit between depths of (effectively) 1100 m to 1096 m.

2.2 Analytical Evaluation

Various analytical evaluations have been performed to bound the behavior of the system. These typically involve analyses of infinite, radial systems, using the Theis (1935) equation for nonleaky transient analyses.

2.3 Numerical Evaluation

In order to more accurately evaluate the condition around a real packer test in basalt, a series of numerical analyses have been performed using the Golder Associates' finite-element-method computer code. Each analysis used the same mesh, details of which are shown in Figure 3. Again, the hole diameter was taken a 0.1 meters, and the outer boundary was fixed at about 10,000 meters. Transient analyses were performed to simulate time-dependent behavior of the system, while steady-state analyses were performed to evaluate equilibrium conditions. Table 1 shows the ranges of parameters used in the various analyses. Assumed values of horizontal hydraulic conductivity are consistent with test results reported by DOE for the Pasco Basin. Vertical hydraulic conductivities are based on generic information relating to the anisotropic characteristics of basalt.

Two different sets of boundary conditions were used on the upper and lower planes of the modeled domain: fixed head and no flow. This set of conditions bounds the actual case.

Table 1 - Parameters Used in Numerical Analysis

HYDRAULIC CONDUCTIVITIES (meter/day)				ANALYSIS PERFORMED	
HIGH K LAYER		LOW K LAYER		Steady State	Transient
Horiz.	Vert.	Horiz.	Vert.		
1	1	1	1	X	
1	10	10 ⁻⁴	10 ⁻³	X	X
1	10	10 ⁻⁵	10 ⁻⁴	X	
1	10	10 ⁻⁶	10 ⁻⁵	X	
1	10	10 ⁻⁷	10 ⁻⁶	X	X
0.1	1	10 ⁻⁶	10 ⁻⁵	X	

3 RESULTS

3.1 Steady- State Results

The steady-state results illustrate the effect which the open drillhole above the packer has upon the head in the packed-off section. In order to stress the system in such a way as to make any effect obvious, the outer boundary of the analysis region was subjected to an upward head gradient of 1 percent. As the center of the packed-off zone is at 1105 meters below the phreatic surface, the head at this point, before the hole was drilled, would be 11.05 meters above the phreatic surface.

The head which would exist at equilibrium in the drill hole above the packer is the average of the upper 1098 meters of hole which is open. This head is approximately 5.49 meters above the phreatic surface, and this head was fixed at the hole boundary.

Results of the analyses of steady state flow are presented in Table 2. All heads are expressed as a distance above the phreatic surface.

While Table 2 does not have great generality, it does indicate that the head measured in the packed-off section represents a combination of the effects of the undisturbed head at that elevation and of the head in the open hole above. For systems with very low vertical permeabilities in dense basalt, the error induced by this effect is negligible. This would be true at Handord for dense-zone vertical permeabilities of 10⁻⁵ meters per day (10⁻¹⁰ meters per second) or less. For dense-zone vertical permeabilities above about 10⁻⁴ meters per day (10⁻⁹ meters per second), this effect becomes significant, with more than 10 percent of the difference between the head in the hole and the original head appearing in the measured head. The effect depends to some extent upon the horizontal permeability and thickness of the flow-top. This study shows that the errors induced by the open hole above the test section can be significant, even at steady state.

Table 2 - Results of Steady State Analysis

HYDRAULIC CONDUCTIVITIES (meter/day)				HEAD IN PACKED-OFF SECTION (H _p) (Meters)		PERCENTAGE INFLUENCED BY HEAD IN HOLE (P) (See Note 1)	
HIGH K LAYER		LOW K LAYER					
Horiz.	Vert.	Horiz.	Vert.	(2)	(3)	(2)	(3)
1	1	1	1	9.22	(8.45)	33	(47)
1	10	10 ⁻⁴	10 ⁻³	10.11	(8.97)	17	(37)
1	10	10 ⁻⁶	10 ⁻⁵	10.78	(10.74)	5	(6)
1	10	10 ⁻⁷	10 ⁻⁶	10.97	(10.98)	1	(1)
0.1	1	10 ⁻⁶	10 ⁻⁵	10.45	(9.80)	11	(22)

NOTES: (1) The influence of the head in the hole above the packed-off section is expressed as a percentage influence where:

$$H_p = H_b + P/100 (H_h - H_b)$$

H_p = head (above the phreatic surface) in packed-off section

H_h = head (above the phreatic surface) in hole = 5.49 m

H_b = head (above the phreatic surface) at far boundary = 11.05 m

P = percentage influence of hole.

(2) Values from analyses with no-flow boundaries at top and bottom of analyzed domain.

(3) Values in brackets taken from analyses with fixed heads at top and bottom of analyzed domain.

3.2 Transient Results

The transient analyses performed using the finite-element model began initially with the head in the drill hole elevated 100 meters above the original ground water table, with all heads at steady-state. This situation is equivalent to having an open hole filled to approximate ground surface with water, for an infinite time before the packer test was performed. The boundary condition at the outer boundary was the same 1% upward head gradient used in the steady-state analysis.

At $t = 0$, the packer is introduced into the bottom of the hole, and the water level in the hole is allowed to return to its equilibrium level. The head in the packed-off section is then monitored. The results of this decaying excess head are shown in Figure 4, for both the high and low hydraulic conductivity cases described in Table 1. The process was performed for both no-flow and fixed-head top and bottom boundaries with similar results.

The head takes about 50 days to approach equilibrium in both cases. Evaluation of the detailed printout shows that this is the time taken for the pressure reduction to reach the boundary; the equilibration time would be longer if the model boundary were further away from the drill hole. Figure 5 shows the head distribution with distance away from the well, as a function of time, for both the high and low vertical conductivity cases with no-flow top and bottom boundaries. The fixed-head boundary case is shown in Figure 6.

Clearly, the system analyzed is somewhat extreme, as it assumes that the well overpressure has been applied for infinite time before the packer is inserted. To assess the impact of shorter periods during which the hole is charged, a simple analytical solution of the system was performed assuming that nonleaky flow occurs in the high permeability strata (equivalent to zero vertical hydraulic conductivity in the dense basalts). The results of this analysis are the displayed in Figure 7, together with the finite-element analysis results for low hydraulic conductivity situation. The conclusions which can be drawn from this analysis are that the time which the hole has been charged is important, and that the value of the vertical hydraulic conductivity of the dense basalts exerts a major influence upon the rate of equilibration of the test.

4 CASE EXAMPLES

There are a few case examples which allow field evaluation of the accuracy of head measurement using packer technology in a highly-confined, layered flow system. Two examples are cited below:

- o An example of head-testing during drilling at BWIP followed by permanent completion using multiple piezometers.
- o An example of head-testing during drilling at an oil shale project in Colorado followed by a permanent completion.

4.1 Testing of Heads at Hanford Well ARH-DC-1

Well ARH-DC-1 was drilled just north of the 200E waste storage area on the Hanford Reservation to a depth of 1,725 meters. The drilling and testing is described in La Sala and Doty (1971) and was generally as follows:

- o Drilling began on April 27, 1969.
- o The drilling method was conventional rotary, using air-mist and aerated foam for cuttings removal.
- o The hole was cased to a depth of 110 meters and left open below; diameter was 250 millimeters.
- o Permeability, head, and water-quality testing took place at depths to 1,305 meters.

- o Drilling was suspended on September 23, 1969.

At a later date, the well was completed by the United States Geological Survey, at a total of five depths as shown in Figure 8. The comparison between stable heads measured in these permanent completions and the head measured during drilling is shown in Figure 9. The plot of water levels versus time for the piezometers is shown in Figure 10.

Some comments appear warranted. First, the time taken for the piezometers to settle down appears to be very long. Second, there is an apparent seasonal fluctuation of the water levels. Third, there appears to be a significant difference between the piezometer water-levels and the head found during testing. (Note that the tested heads are consistently lower than the piezometer values due to the fact that air-mist drilling continually produces water from the hole, thus lowering regional heads during drilling.) Errors vary between 1 and 15 meters. Finally, the vertical head gradients which would be estimated from the data collected during drilling are significantly different than those which would be estimated from the piezometer data.

4.2 Testing of Heads in the Piceance Basin, Colorado

This example is drawn from tests which were performed by Golder Associates during drilling as part of an evaluation of an oil shale mining project in the Piceance Basin in Colorado during 1974 through 1975 (Arco et al., 1974 et seq.). Broadly, the program involved:

- o Core drilling using an air-mist drilling technology.
- o Packer testing during drilling using a single packer. Both mechanical and inflatable packers were used.

Testing involved shut-in pressure measurement, and withdrawal and injection permeability tests. Pressures were measured downhole to avoid problems associated with water level measurements at the surface, and the tool had a downhole shut-in valve for flow control.

As is usual in an ongoing coring program, there was considerable emphasis to keep the hydrology testing short. Each test took from 12 to 24 hours, and each shut-in pressure measurement was continued until an apparently stable reading was obtained, which generally required from a few minutes to two hours.

After the hole was drilled, it was completed with two strings of galvanized iron pipe, cemented in place. Communication between the formation and the string was created by explosive perforation in specific intervals. The lower string completion failed due to blockage caused by inflow of viscous hydrocarbons (kerogen), but the upper completion remained operational. The water level in this string finally stabilized six months after completion.

The results of the permeability and head tests for this hole are shown in Figure 11. The following points are noteworthy:

- o The heads determined by the packer testing were quite variable, especially given the layered sedimentary rock system.
- o The variability has a weak negative correlation with permeability; the higher the permeability, the lower the head. Note that during air-mist drilling water is extracted from the formation, so the head transients induced in the formation serve to lower the observed head.
- o The actual static head measured in a reliable permanent completion in the top 250 meters of saturated material was about 10 meters higher than the average of the relevant packer-test values.
- o The time taken for the head to stabilize in the permanent completion was in the order of six months in this highly confined system.

On this project, the head system could not be understood or analyzed until the entire site had been vacated for six months to allow head transients to dissipate. At that time, however, the head pattern was unambiguous and entirely in accordance with expected regional groundwater flow patterns. Head data from packer testing proved to be entirely unuseable.

5. SUMMARY AND CONCLUSIONS.

This appendix has attempted to evaluate the reliability of head data obtained by packer-testing methods in single holes. Substantial errors have been shown to be possible as a result of:

- o Transient head-errors induced by drilling; these changes may take months to dissipate.
- o Steady-state head-errors in the packed-off zone due to the presence of the open hole above the packers.

Both effects can lead to substantial error in estimates of static head at the the depth. For relatively high vertical-permeability materials both effects can cause significant cumulative error, while for low vertical permeability materials the transient effects dominate. For practical ranges of permeability of Hanford basalts, it appears that enough error would be introduced to cast serious doubt on the value of packer-test results for evaluating static heads. Based on this study, an error range of ± 10 meters would appear to be likely.

The problems with this method of head measurement are illustrated with two actual case examples where packer testing was used in relatively low permeability, layered rocks (oil shale and basalt). No useful head information was obtained in either case until permanent completions were installed.

There findings are important because they suggest that the present and planned approach to head measurement at Hanford will not produce results which will be useable for the purposes of model calibration or radionuclide transport analyses.

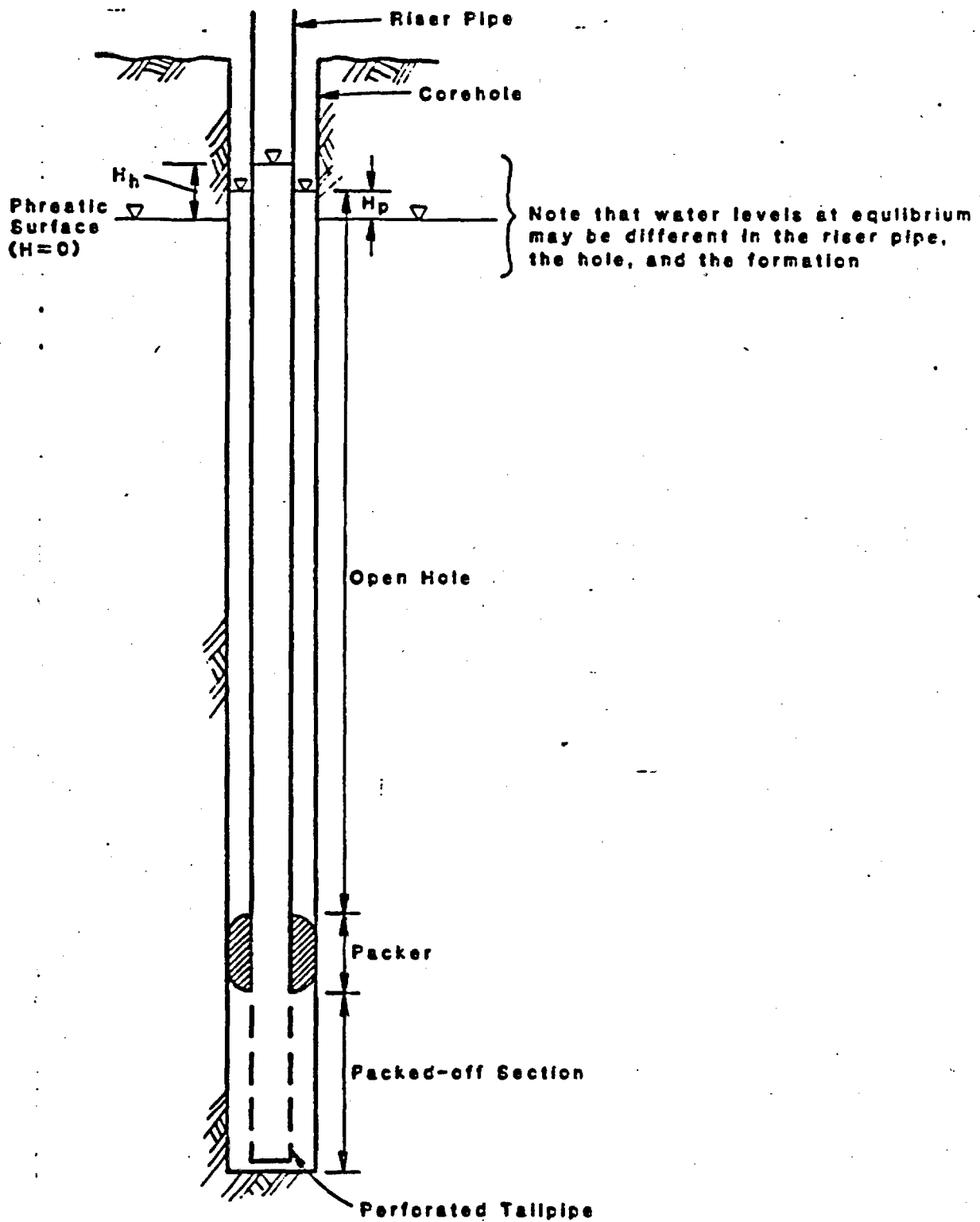
6. REFERENCES

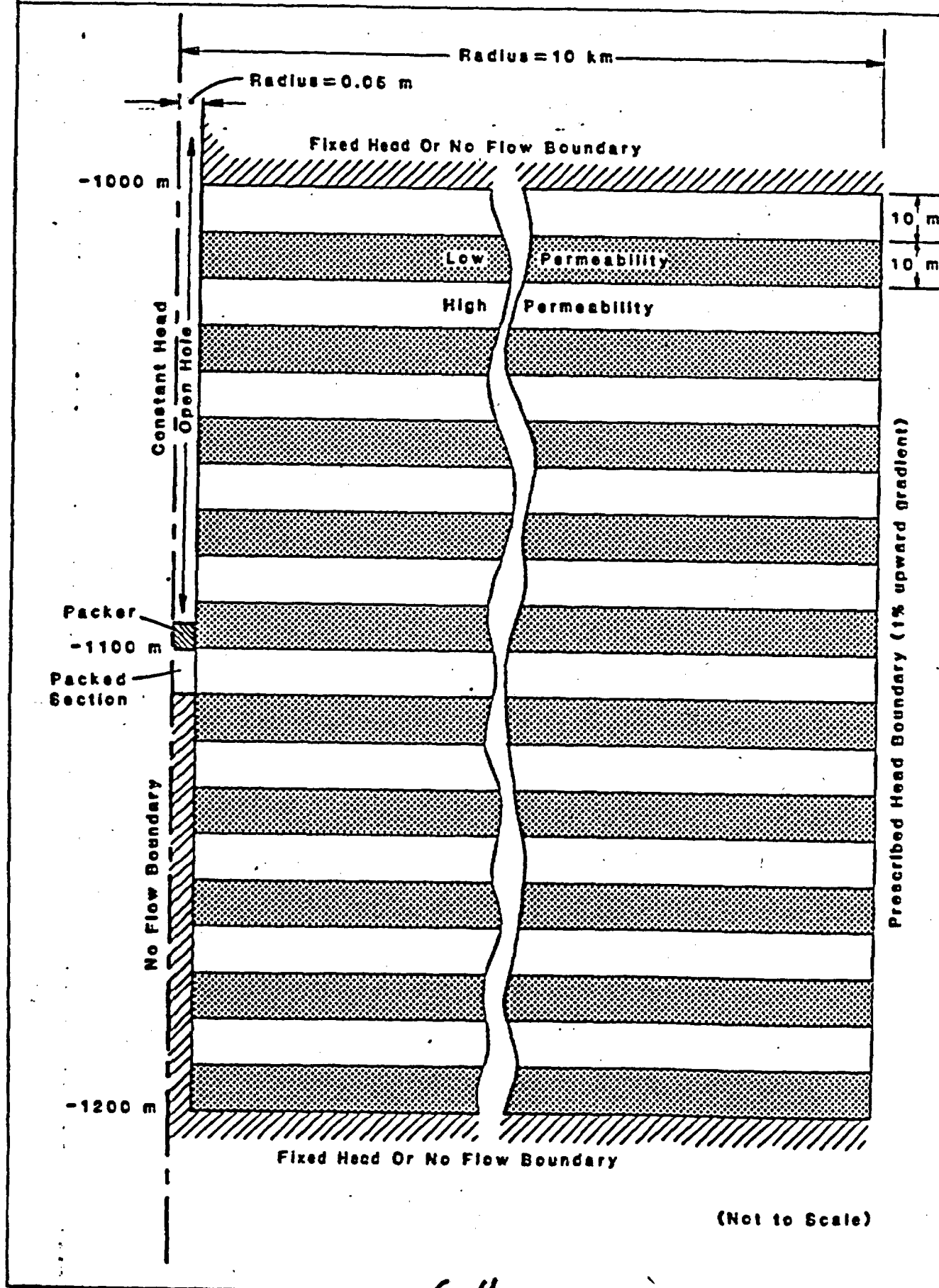
Theis, C.V., "The Relation Between the Lowering of the Piezometric Surface and the Rate and Duration of Discharge of a Well, Using Ground water Storage," Trans. Amer. Geophys. Union, 2, 519-524, 1935.

LaSala, A.M. and G.C. Doty, "Preliminary Evaluation of Hydrologic Factors Related to Radioactive Waste Storage in Basaltic Rocks at the Hanford Reservation, Washington," U.S. Geological Survey, Open File Report, Washington, D.C., 1971.

Gephart, R.E., Arnet, R.C., Baca, R.G., Leonhart, L.S., and Spane, F.A., Jr., Hydrologic Studies Within the Columbia Plateau, Washington: An Integration of Current Knowledge, Rockwell Hanford Operations, RHO-BWI-ST-5, 1979.

Atlantic Richfield Company, Quarterly Reports, Federal Oil shale Tract C-b, 1974/1975. (Available at the Area Oil Shale Supervisor's Office, Grand Junction, Colorado).

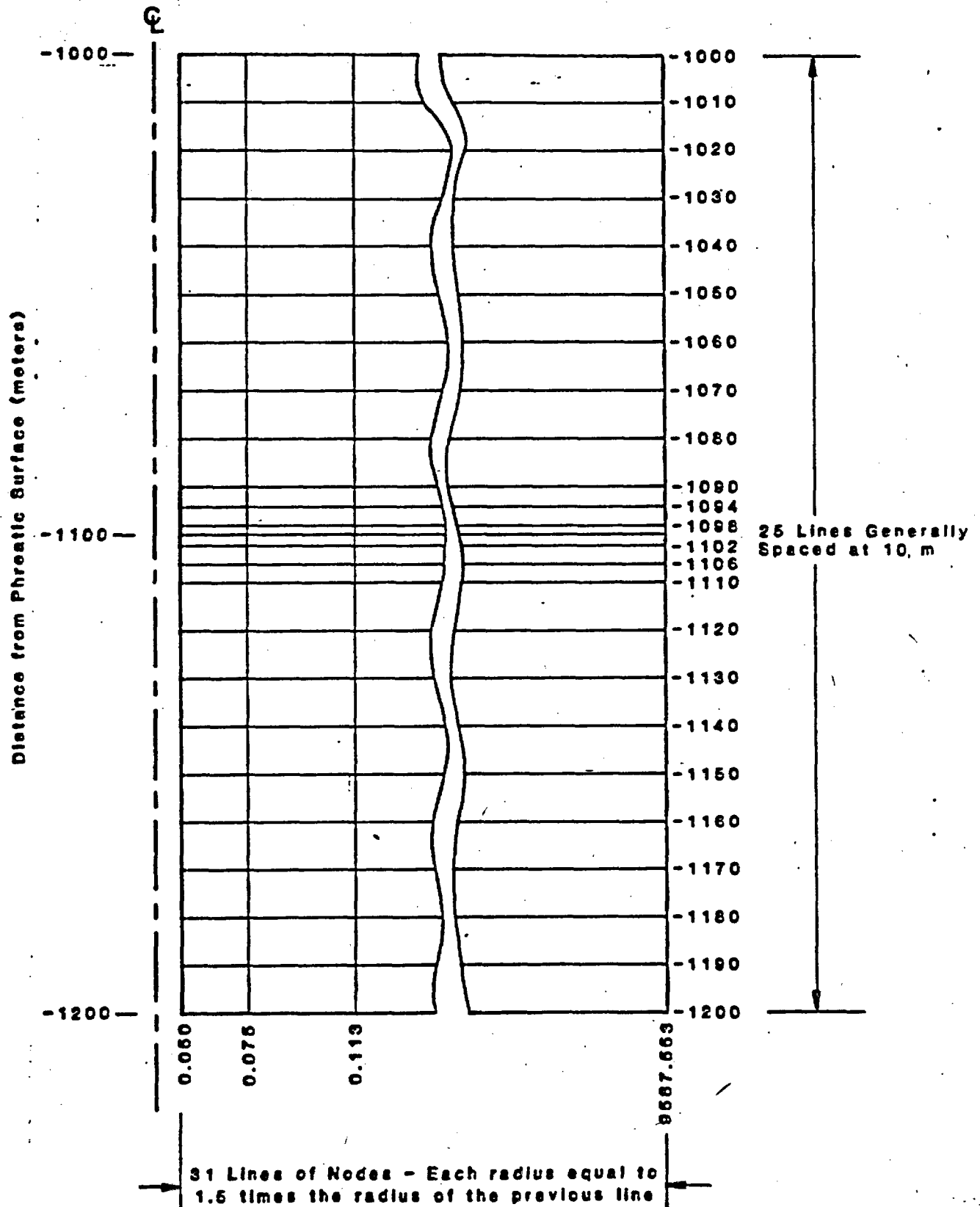




G-11

BWD OSCA 1

1/Logdon



Note: All dimensions in meters

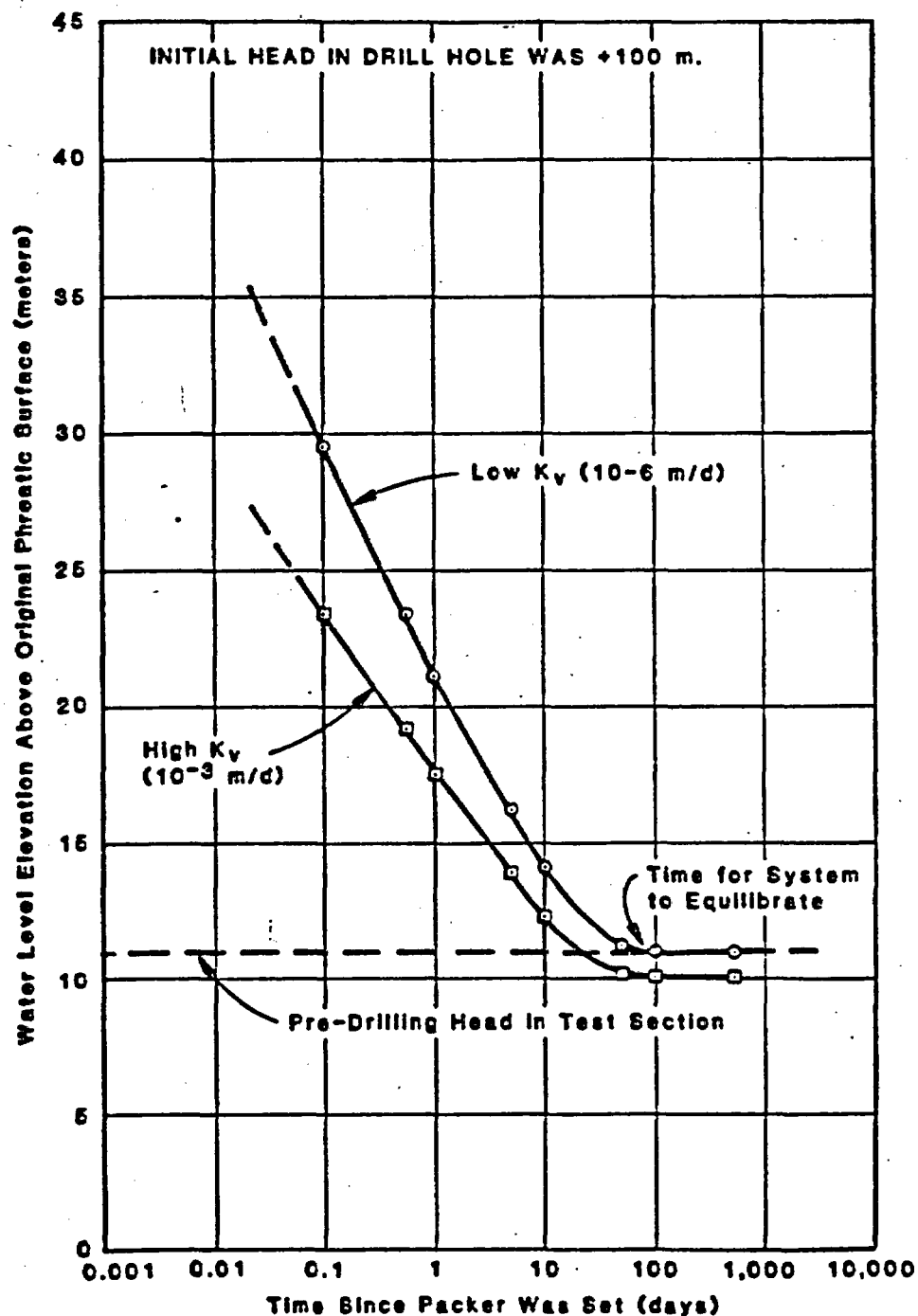
6-12

BWIP 0504/

1 Legend

PRESSURE IN THE PACKED OFF SECTION AS A FUNCTION OF TIME

Figure 4



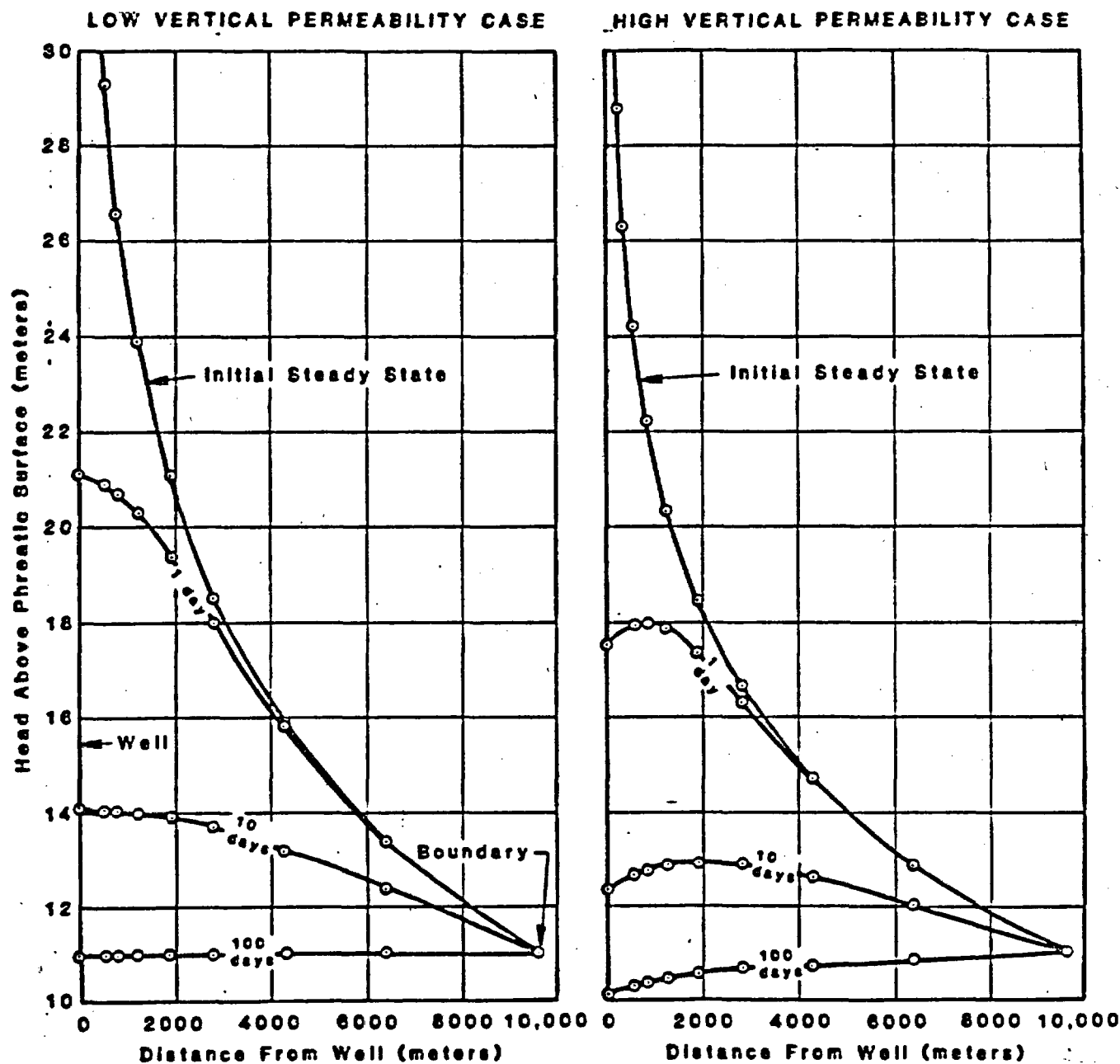
6-13

BAUTR DSCA-1

1/2 eqsdm

HEAD DECAY IN THE PACKED OFF STRATUM -NO FLOW BOUNDARY CASE

Figure 5



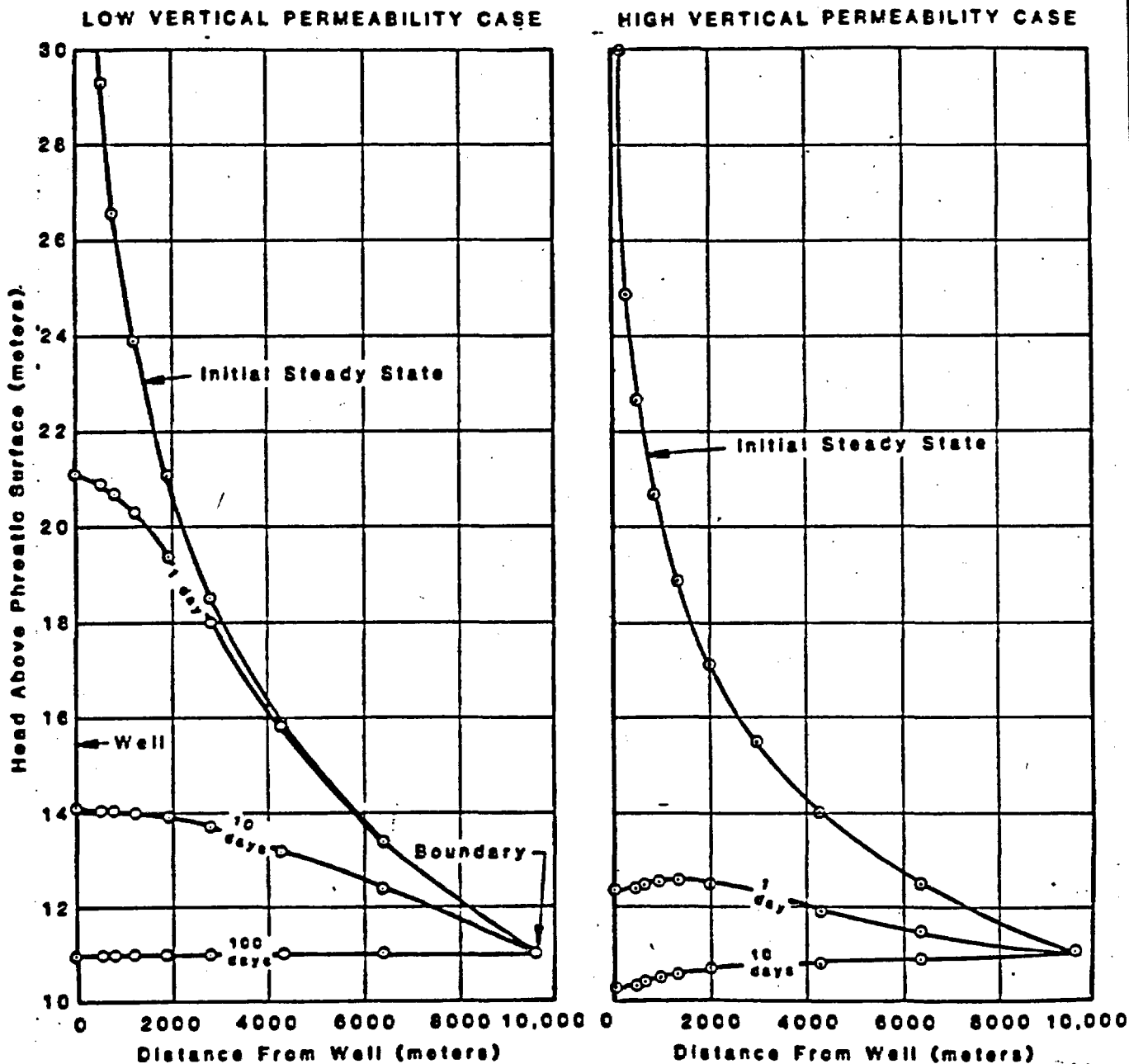
G-14

BWIA 0504/

1/29/80

HEAD DECAY IN THE PACKED OFF STRATUM -FIXED HEAD BOUNDARY CASE

Figure 6

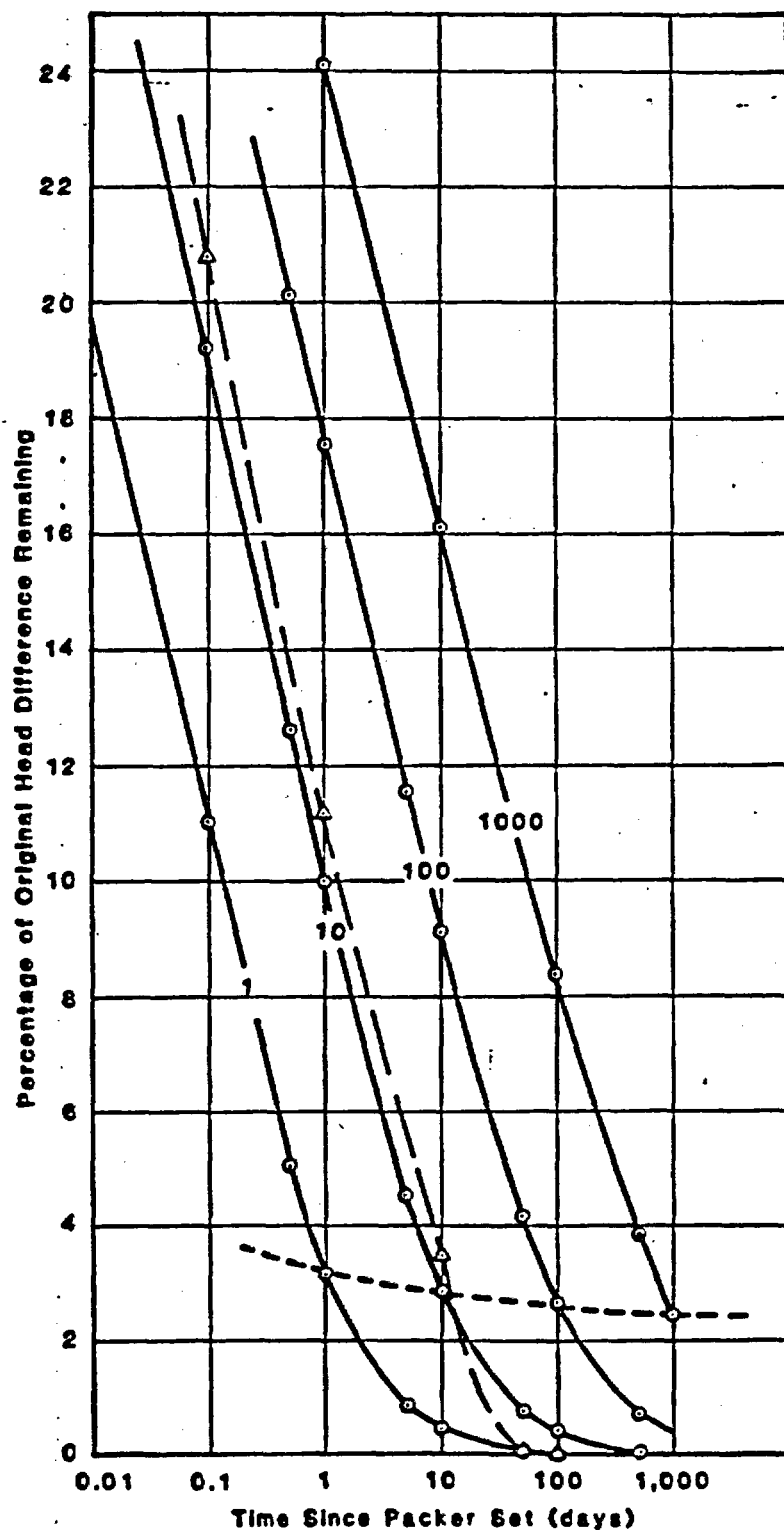


G-15

ANALYSIS

1/2 Log scale

RE-EQUILIBRATION DURING A PACKER TEST AT BWIP Figure 7

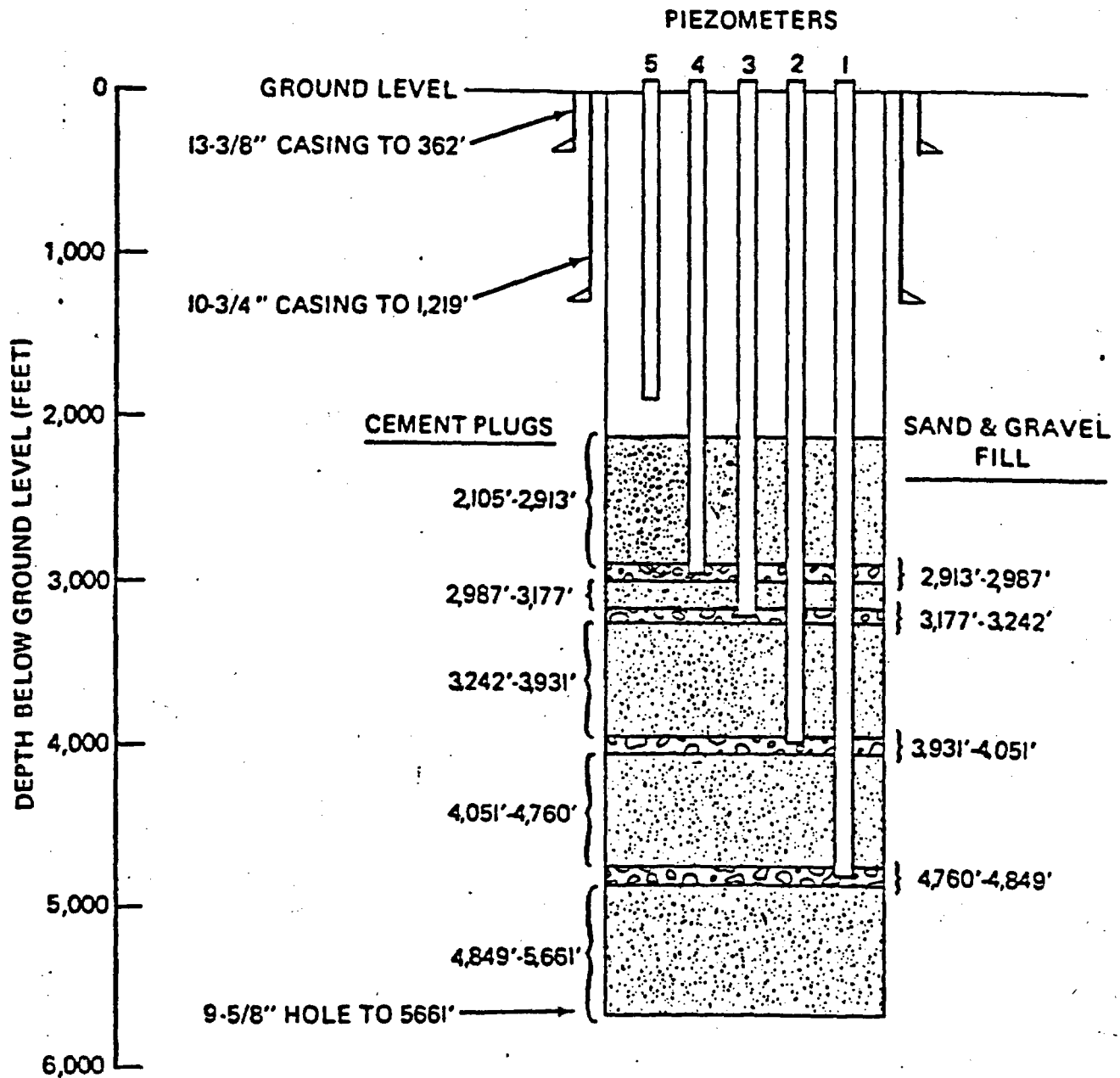


LEGEND

- △ Finite Element Analysis (low K_v)
- Analytical Solution (time hole was open before test, days)
- Time Since Packer was Set Equals Time Hole was Charged Before Test

ASSUMPTIONS

1. Hole held at constant head before test
2. $K = 1 \text{ m/d}$, $S_g = 3.3 \times 10^{-7} \text{ m}^{-1}$
3. Nonleaky (see text)
4. "Original head difference" = (pretest head) - (final head) in packed off section at infinite time



RCP 8001-296

REFERENCE: GEPHART ET AL, 1979, PAGE III-113

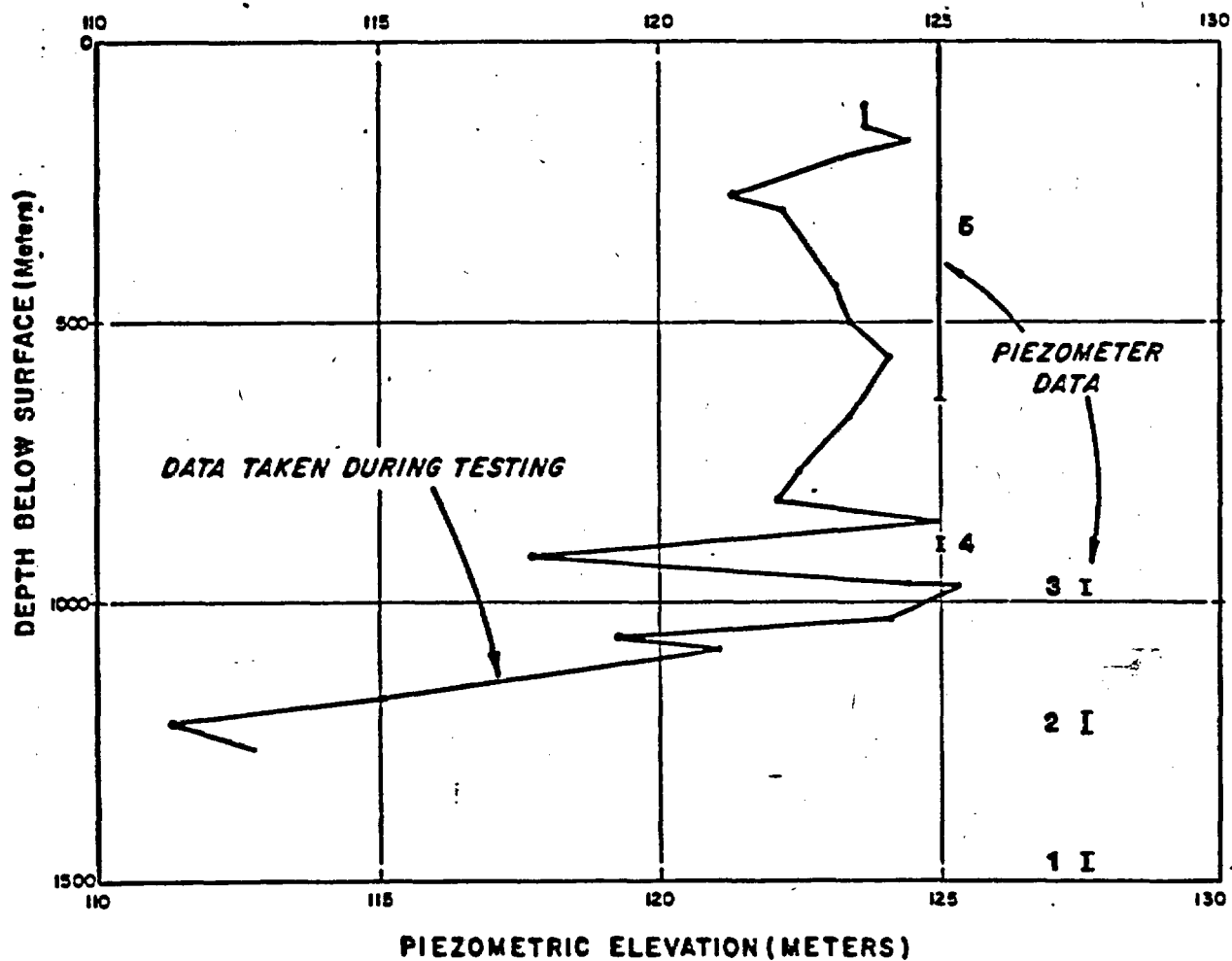
G-17

BUTIN DSCAL

1/29/80

HEAD VALUES OBTAINED DURING DRILLING, AND PIEZOMETER HEADS IN DC-1

Figure 9



SOURCES: PACKER TEST DATA, LASALA AND DOTY, 1971
PIEZOMETER DATA, GEPHART ET AL, 1979

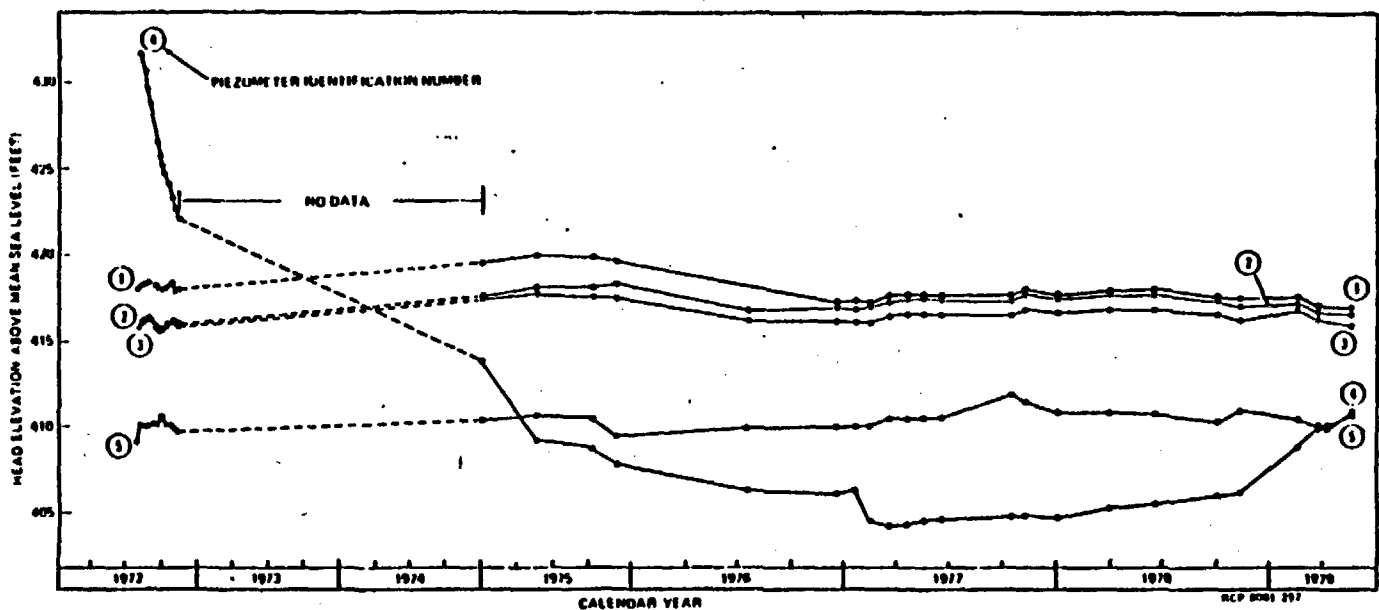
G-18

BUWA-05041

1 Logsdon

PLOT OF WATER LEVEL VERSUS TIME FOR PIEZOMETERS IN DC-1

Figure 10

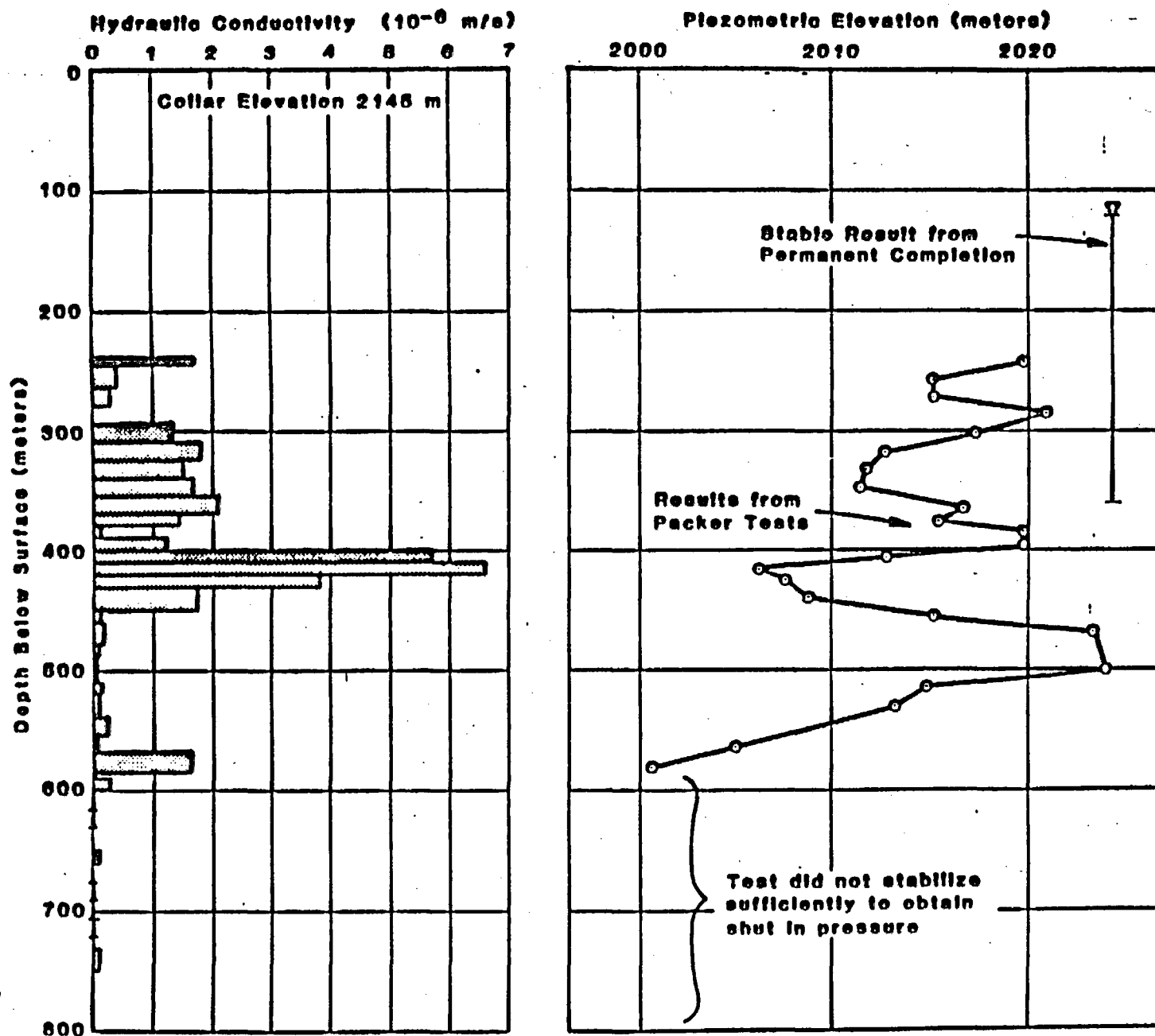


SOURCE: GEPHART ET AL, 1979, PAGE III-114

G-14

ASUIN 0504/1

16940m



Source: Quarterly Reports: Federal Oil Shale Tract C-b, Atlantic Richfield, 1974 et seq

G-20

BUIT 05041
11/1/84

APPENDIX H
HYDROGEOLOGIC DATA INTEGRATION
FOR CONCEPTUAL GROUNDWATER FLOW MODELS

01/28/83

BWIP DSCA/APP H/LOGSDON

LIST OF TABLES

Table

1

Summary of Hydrologic Data

LIST OF FIGURES

Figure ---

- 1 Assumed Hydrostratigraphic Units
- 2A Effective Horizontal Hydraulic Conductivity (m/sec) of Interflows in the Mabton
- 2B Effective Horizontal Hydraulic Conductivity (m/sec) of Interflows in the Priest Rapids
- 2C Effective Horizontal Hydraulic Conductivity (m/sec) of Interflows in the Roza
- 2D Effective Horizontal Hydraulic Conductivity (m/sec) of Interflows in the Frenchman Springs
- 2E Effective Horizontal Hydraulic Conductivity (m/sec) of Interflow in the Grande Ronde A
- 2F Effective Horizontal Hydraulic Conductivity (m/sec) of Interflows in the Grande Ronde B
- 2G Effective Horizontal Hydraulic Conductivity (m/sec) of Interflows in the Grande Ronde C
- 2H Effective Horizontal Hydraulic Conductivity (m/sec) of Interflows in the Grande Ronde D
- 2I Effective Horizontal Hydraulic Conductivity (m/sec) of Interflows in the Grande Ronde E1
- 2J Effective Horizontal Hydraulic Conductivity (m/sec) of Interflows in the Grande Ronde E3
- 2K Effective Horizontal Hydraulic Conductivity (m/sec) of Interflows in the Grande Ronde F
- 3 Total Transmissivity Histograms
- 4 Effective Hydraulic Conductivity Histograms
- 5 Distribution of Total Transmissivity Values for Assumed Hydrostratigraphic Units
- 6 Distribution of Effective Horizontal Hydraulic Conductivity Values for Assumed Hydrostratigraphic Units
- 7 Smoothed Variograms of Effective K_H for the Grande Ronde B and E1 Formations

Figure

- 8 Average Horizontal Hydraulic Conductivity Versus Depth
 Below Ground Surface**
- 9 Average Horizontal Hydraulic Conductivity Versus Thickness
 of Interflow**
- 10A Calculated Vertical Gradients Between the Mabton and Priest
 Rapids**
- 10B Calculated Vertical Gradients Between the Priest Rapids and
 Roza**
- 10C Calculated Vertical Gradients Between the Roza and Frenchman
 Springs**
- 10D Calculated Vertical Gradients Between the Frenchman Springs and
 Grande Ronde A**
- 10E Calculated Vertical Gradients Between the Grande Ronde A and
 Grande Ronde B**
- 10F Calculated Vertical Gradients Between the Grande Ronde B and
 Grande Ronde C**
- 10G Calculated Vertical Gradients Between the Grande Ronde C and
 Grande Ronde D**
- 10H Calculated Vertical Gradients Between the Grande Ronde D and
 Grande Ronde E1**
- 10I Calculated Vertical Gradients Between the Grande Ronde E1 and
 Grande Ronde E3**
- 10J Calculated Vertical Gradients Between the Grande Ronde E3 and
 Grande Ronde F**

HYDROGEOLOGIC DATA INTEGRATION FOR CONCEPTUAL GROUNDWATER FLOW MODELS

1 INTRODUCTION

The following discussion describes a preliminary attempt to integrate existing hydrogeologic data in the Pasco Basin for the purpose of formulating a conceptual flow system model. The goal is not to determine a definitive flow system model but rather to evaluate whether measured hydraulic parameters and hydraulic heads can be used to support the overall conceptual model of the Pasco Basin which has been put forward by DOE in the SCR. This overall conceptual model is based upon a horizontally-layered flow system consisting of permeable interflow zones (aquifers) separated by relatively low permeability intraflow zones (confining layers). For a conceptual model to be incorporated into a numerical model, it must be demonstrated that hydrologic properties of the system are predictable between measuring points, and that the model is consistent with measured field data.

For this study an effort is made to define hydrostratigraphic units (HSU's) based primarily upon geologic data and then to determine whether measured hydraulic parameters and heads can be used to characterize the HSU's. This process of identifying HSU's and characterizing their hydrogeologic properties is usually a prerequisite for developing mathematical flow system models which can predict processes such as radionuclide transport. Although there is no standard procedure for accomplishing this task, the overall methodology described below is generally applicable in horizontally-layered flow systems such as exist at Hanford, and is consistent with the approach taken by DOE.

2 HYDROSTRATIGRAPHIC UNITS

2.1 General Definition

The term "hydrostratigraphic unit" was proposed by Maxey (1964) to describe "bodies of rock with considerable lateral extent that compose a geologic framework for a reasonably distinct hydrologic system." Further discussion of HSU's is given by Carnahan et al. (1982) who describe several additional characteristics which an HSU should display, including:

- o hydraulic properties which contrast in a uniform way with the properties of the surrounding units;
- o for the purpose of groundwater modeling, hydraulic properties which are statistically similar (i.e., predictable) over the extent of the proposed unit;
- o for continuum analysis, each HSU must be made up of at least one Representative Elemental Volume (REV) which behaves as a continuum.

The term "geohydrologic unit" (or hydrogeologic unit) is often used synonymously with HSU, although Maxey suggests that it should be reserved for use as a more general descriptive term.

HSU's are defined primarily for the convenience of one trying to model the hydraulic behavior of porous media. The thickness, extent, hydraulic parameters, and other characteristics of an HSU will vary depending upon the particular requirements of the modeler. However, it is usually assumed that these characteristics can be determined (i.e., by field measurement) at various locations within an HSU and then predicted by some method over the remainder of the HSU. An evaluation of how this process could be applied to the Pasco Basin is discussed below.

2.2 Determination of HSU's

In the thick basalt sequence underlying the Pasco Basin, the SCR asserts that groundwater flow occurs primarily in high permeability flow tops and basal rubble (interflow zones), which are separated by dense basalt of much lower permeability (intraflow zones)(pages 5.1-198 to 5.1-203). This conceptual model predicts essentially horizontal flow with high flux rates in the interflow zones and vertical flow with low flux rates in dense basalt. Since interflow zones are stratigraphic in nature, it seems reasonable to develop a conceptual model based on identifiable stratigraphic units.

Hydrostratigraphic units which were chosen for this appendix are shown in Figure 1, along with the geostratigraphic units to which they correlate. Geologic units are well defined and can be correlated reliably within the Pasco Basin. Therefore, it is relatively easy to develop a geologic framework for the conceptual hydrogeologic model. The resulting model is conceptually similar to a layered sedimentary system model consisting of alternating aquifers and aquitards.

A number of the HSU's shown in Figure 1 consist of several basalt flows. Greater detail was retained near the proposed repository horizon, with three HSU's defined to represent the Umtanum flow top (E1), the dense Umtanum (E2), and the underlying flow top (E3). The Through Runner Unit of the Sentinel Bluffs Sequence was selected as an HSU since it is under consideration as a repository horizon.

The selection of HSU's is more or less arbitrary. Different HSU's which may be equally or more appropriate for modeling the hydrogeologic system could have been selected. However, the HSU's shown in Figure 1 are used throughout the remainder of this study. No HSU's above the Mabton (i.e. within the Saddle Mountains Basalt) are considered because the bulk of hydrogeologic data used in this study pertains to units in the Wanapum and Grande Ronde Basalts.

3 HYDRAULIC PARAMETERS

3.1 Observed Data

The data used for this study are listed in Table 1. Values of transmissivity and hydraulic conductivity were taken from RHO data examined during a July 1982 workshop and from Gephart et al. (1979a, 1979b). They generally agree with the test ranges presented in Figures 5-18 to 5-24 in the SCR, although some differences exist. Since specific test results are not presented in the SCR, it is not possible to determine why some differences between the July Workshop data and the SCR exist. The SCR contains several test intervals that

were completed in DC-16A and RRL-2 subsequent to the July workshop. These results are not included in this study. Values of hydraulic head used in this study were taken from Figures 5-34 to 5-41 in the SCR and also from Gephart et al. (1979b).

Tests to determine hydraulic parameters (primarily transmissivity and horizontal hydraulic conductivity) were performed by straddling one or more interflows with packers set in dense basalt. Since dense basalt has low permeability, a calculated value of transmissivity was assumed to represent only the characteristics of the interflow zone(s). Average horizontal hydraulic conductivity of an interflow(s) within a test interval was obtained by dividing measured transmissivity by the thickness of the interflow(s) tested. Total transmissivity of a hydrostratigraphic unit was obtained by summing the transmissivities of all interflows within the unit. The effective horizontal hydraulic conductivity (K_H) of interflows within an HSU was calculated by dividing the total transmissivity by the sum of the interflow thicknesses. In this manner, one value of hydraulic conductivity was determined to represent a particular HSU at each hole tested.

The distribution of effective hydraulic conductivity for each HSU was plotted on a base map of the Pasco Basin (see Figures 2A through 2K). Few trends in the spatial distribution of hydraulic conductivity are discernible by visual inspection. In most units the data range over several orders of magnitude and vary spatially in what appears to be an unpredictable pattern.

3.2 Statistical Tests of Differences

Figures 3 and 4 show histograms of total transmissivity and effective hydraulic conductivity for each HSU. Within most HSU's the hydraulic parameters vary by several orders of magnitude and it is difficult to visually identify distinct ranges within the different units.

Since no measurements of the vertical hydraulic conductivities of potential confining beds are currently available, it is not possible to determine HSU's on the basis of vertical isolation. However, the degree of vertical isolation between various HSU's will be an important consideration in choosing HSU's appropriate for modeling. Significant differences in total transmissivity and/or horizontal hydraulic conductivity between HSU's constitute another basis for choosing HSU's. The statistical analysis presented below was conducted to determine if the HSU's chosen on the basis of stratigraphy also have characteristic values of measured hydraulic parameters.

The data were analyzed to determine if the differences in the mean values of log (total transmissivity) and log (effective K_H) between proposed hydrostratigraphic units were significant. The means (geometric means), standard deviations and 95% confidence intervals for the means of the units are shown in Figures 5 and 6 for transmissivity and hydraulic conductivity, respectively. The 95% confidence interval is:

$$m \pm 1.96 \frac{s}{\sqrt{n}}$$

where m = sample mean
 S = sample standard deviation
 n = sample size.

The probability that the confidence interval shown for each unit contains the actual mean for the unit is 95%. Note that the confidence intervals for adjacent units overlap in many cases.

Additional methods are available to determine if mean effective hydraulic conductivities of assumed HSU's are statistically different from one another, thereby implying that it may be useful to treat the two units as separate HSU's. One method of testing differences is the t-test (Blalock, 1972). The t-test examines the null hypothesis that two population means are the same. Assuming that the population standard deviations are not different, the test statistic

$$t = \frac{m_1 - m_2}{S_{m_1 - m_2}},$$

where m_1, m_2 = means of samples 1 and 2,

$$S_{m_1 - m_2} = S \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}; \text{ and}$$

n_1, n_2 = size of samples 1 and 2;

$$S^2 = \frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2} = \text{pooled variance,}$$

where S_1, S_2 = standard deviation of samples 1 and 2;

and degrees of freedom,

$$DF = n_1 + n_2 - 2,$$

are calculated. A similar formulation can be developed for cases where it cannot be assumed that the population standard deviations are not different. If the computed value of t will occur more than α of the time, where α is the significance level of the test and refers to the probability of Type 1 error (concluding that the null hypothesis is false when in fact it is a true statement about the populations sampled), then the null hypothesis is accepted. Tables of the distribution of t can be found in many statistics references, for example, Blalock (1972).

By testing and rejecting the null hypothesis that no difference in mean values exists between adjacent HSU's, the implication is that the assumed HSU's have significantly different values of effective hydraulic conductivity. If the hypothesis is not rejected, no significant difference can be implied.

It was determined that the null hypothesis could be rejected at the 5% significance level for only two pairs of adjacent units: the Mabton and Priest Rapids units and Grande Ronde A and B units. The conclusion can be drawn that mean values of effective hydraulic conductivity for these pairs of units are different with only a 5% chance of being wrong. All other adjacent pairs tested showed no significant difference in means at the 5% confidence level. The t-test is sensitive to the sample size and standard deviation, thus the conclusions relating to statistical differences between units could change if more sample points are obtained.

In using the t-test it is assumed that the actual distribution of effective horizontal hydraulic conductivity within a unit can be described by a log-normal distribution. This assumption is commonly made in hydrology, and the histograms of log (effective K_h) shown in Figure 4 do not indicate that some other distribution would be more appropriate. However, the sample sizes are small ($n \leq 9$), so the histograms cannot confirm that the population distribution is actually log-normal. Other tests, for example the Wald-Wolfowitz runs test, the Mann-Whitney test and the Kolmogorov-Smirnov test (Blalock, 1972), do not require the normality assumption. However, since the assumptions are weaker, these tests are less powerful; that is, there is a higher risk of Type II error (not concluding that the null hypothesis is false when in fact it is not a true statement about the populations).

3.3 Variograms

Variograms are a method of relating the degree of spatial correlation between measured data points (David, 1977). In a continuously varying system, it can be expected that measured values of a particular parameter (in this case horizontal hydraulic conductivity) will correlate better as the distance between measuring points decreases. That is, it is expected that the effective horizontal hydraulic conductivity values within a particular HSU will be more similar to each other in closely-spaced holes than in widely-spaced holes. Once a variogram model relating spatial data has been established, it is possible to interpolate between measured data by a technique called Kriging (David, 1977). This technique would be valuable in interpolating the characteristics of HSU's between points at which measured values exist. An interpolative model is a necessary requirement in developing hydrogeologic models for performance assessment.

Variograms relate the average distance between test values to the average squared difference between those values:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} (Z_i(x) - Z_i(x+h))^2$$

where

$\gamma(h)$ = variogram value for distance h ,

$N(h)$ = number of combinations of values with interval distance h ,

$Z_i(x)$ = value at point x ,

$Z_i(x+h)$ = value at a point distance h away from x .

Since for unevenly spaced data only one pair of values might exist at a given distance, variograms are frequently smoothed. The smoothing method selected for BWIP data was a moving average over a distance of 20,000 feet.

Variograms graphically illustrate the variability of values in space. Where variograms can be described by an approximately monotonic function, they indicate spatial correlation, and allow development of realistic spatial models and spatial averages. Where variograms are erratic and non-monotonic, they indicate that values are not meaningful on the scale of distance used or that the actual in situ properties are not spatially correlated.

Smoothed variograms were calculated using effective horizontal hydraulic conductivity for the eleven hydrostratigraphic units. Of these, only Grande Ronde B, which is shown in Figure 7, indicated any spatial correlation. The variogram of the Grande Ronde E1 (Umtanum Flow top) shown in Figure 7 is typical of the units with no spatial correlation. Possible conclusions to be drawn from these variograms are:

- o representative elemental volumes were not tested (except possibly in the Grande Ronde B);
- o effective hydraulic conductivity is spatially uncorrelated;
- o the hydrostratigraphic units used are not appropriate for definition of effective horizontal hydraulic conductivity.

The NRC staff believes that the first factor above is the most likely cause of the lack of spatial correlation.

3.4 Regression Analysis

Two regression analyses were performed to determine whether average horizontal hydraulic conductivity (in this case for a single test interval) is related to either depth below ground surface or the thickness of the interflow in which the value was determined. Qualitatively, it can be expected that depth may be a factor, because greater depths might result in smaller fracture openings and greater secondary mineralization, resulting in lower conductivities. It is also possible that interflow thickness might be a factor if thicker interflows

have more prominent vesicular and brecciated zones than thinner interflows, resulting in greater hydraulic conductivity.

A scatter diagram of average hydraulic conductivity versus depth is shown in Figure 8. A least-squares linear regression indicates that hydraulic conductivity is related to depth by the equation:

$$\log K_H = 1.7680 - 0.00094 d,$$

where d is the depth below ground surface. The correlation coefficient r , which is a measure of the goodness of fit, is equal to -0.514 . A perfect fit would have r equal to -1.0 or 1.0 . The square of the correlation coefficient is the amount of total variation in the dependent variable, K_H , which is explained by the independent variable, d . The r^2 value of 0.26 for this case indicates that the linear relationship explains 26% of the observed variation in K_H . Thus, there appears to be a weak relationship between depth and average horizontal hydraulic conductivity.

The scatter diagram of K_H versus interflow thickness (b) is shown in Figure 9. The following equation relates the two variables:

$$\log K_H = 0.12521 - 0.00375 b$$

The correlation coefficient is equal to -0.0694 for this relationship, and the value of r^2 is 0.005 . This indicates that there is essentially no relationship between K_H and interflow thickness.

4 HYDRAULIC HEAD

Measured (uncorrected) hydraulic heads were tabulated using data from the SCR and Gephart et al. (1979b). Most measurements were made in packed-off sections of open boreholes after the hydraulic response had apparently stabilized. Vertical hydraulic gradients were calculated by dividing the difference in interpolated head values at the midpoints of two adjacent HSU's by the vertical distance separating the midpoints. A positive value indicates upward vertical flow potential (see Table 2). These apparent head gradients are shown in Figures 10A through 10K.

Hydraulic heads in the SCR are uncorrected for temperature and compressibility effects. It is expected that these effects will not significantly change the inferred direction of groundwater flow, since temperature and compressibility effects should be relatively insignificant between two adjacent HSU's. Thus, the gradients should be good qualitative indicators of the direction of potential vertical flow.

The calculated gradients are highly variable, with the indicated direction of vertical flow changing, even within the same hole. This leads one to conclude that either the vertical flow pattern between the assumed HSU's is very complex or that the measured heads are not representative of the true formation heads. In either case, it would probably prove to be a difficult task to calibrate groundwater flow models based upon the given heads.

Based upon this simple analysis of apparent vertical gradients, it appears essential to demonstrate that the measured heads reflect true formation heads (see Appendix G). This will probably require the installation of permanent head monitoring installations at varying depths within the same or adjacent holes. This would allow representative, time-coincident heads to be measured and would provide a check on the reliability of heads measured during the current drill-and-test sequence.

5 CONCLUSIONS

It is relatively easy to define hydrostratigraphic units based upon geologic units. However, it is not apparent, based on existing single-hole test data, that characteristic hydraulic parameters can be assigned to the HSU's. Existing horizontal hydraulic conductivity data indicate wide variations in values within the assumed HSU's, which are in some cases taken to be individual flow tops. A lack of correlation of measured characteristics of HSU's could be caused by several factors:

- o inappropriate choice of HSU's;
- o nonrepresentative measurements of HSU properties (i.e. measurements do not represent a representative elemental volume of the medium);
- o inaccurate measurements of HSU properties;
- o lack of spatial correlation within HSU's (i.e. interflow/intraflow characteristics vary unpredictably within individual HSU's).

This problem is possibly the result of the testing strategy used to determine hydraulic parameters. The current strategy of determining parameters from single-hole tests may not be adequate to obtain representative bulk parameter values. That is, the tests may not be of large enough scale to characterize representative elemental volumes. The variability in measured parameters could be a reflection of the variability of intraflow structures (flow tops, colonnade/entablature, fanning structures). It currently does not appear that such structures can be predicted with any confidence even over relatively short distances (i.e., several hundred meters). A strategy of large-scale hydraulic testing using pumping wells and observation wells may yield much more uniform estimates of hydraulic parameters since such tests have the capability of characterizing a large volume of the flow system.

It is also possible that the data are representative of REV's but that the flow system is highly heterogeneous. If this is the case, it will be very difficult to characterize and model the flow system for the purpose of predicting repository performance.

A simple evaluation of measured hydraulic head data also raises questions of the representativeness of existing data. Vertical head gradients do not seem to fit into any overall conceptual model of groundwater flow. Rather, they indicate a complex flow system which would appear to be extremely difficult to duplicate by a predictive flow system model. This complexity could be the result of the

method of head measurement (i.e., short-term monitoring in packed-off intervals). The installation of reliable, permanent head monitoring installations may greatly improve the head data available for calibration of flow system models. ---

6 REFERENCES

- Blalock, H.M. Jr., Social Statistics, 2nd edition, McGraw-Hill, New York, 1972.
- Carnahan, C.L., et al., "Selected Hydrologic and Geochemical Issues in Site Characterization for Nuclear Waste Disposal: Flood Basalts at the Hanford Reservation (draft)," Earth Sciences Division, Lawrence Berkeley Laboratory 1982.
- David, M., Geostatistical Ore Reserve Estimation. New York: Elsevier, Scientific Publishing Co., 1977.
- Gephart, et al., "Geophysical Logging and Hydrologic Testing of Deep Basalt Flows in the Rattlesnake Hills Well Number One," Rockwell Hanford Operations, RHO-BWI-ST-1, 1979a.
- Gephart, et al., "Hydrologic Studies Within the Columbia Plateau, Washington: An Integration of Current Knowledge," Rockwell Hanford Operations, RHO-BWI-ST-5, 1979b.
- Maxey, G.B., "Hydrostratigraphic Units," Journal of Hydrology 2, 124-129 (1964).

Table 1 Summary of Hydrologic Data

EXPLANATION

Hydrostratigraphic Units

MB	Mabton
PR	Priest Rapids
RZ	Roza
F\$	Frenchman Springs
GRA	Grande Ronde A
GRB	Grande Ronde B (Through Runner)
GRC	Grande Ronde C
GRD	Grande Ronde D
GRE1	Grande Ronde E1 (Umtanum flow top)
GRE3	Grande Ronde E3 (flow top below Umtanum)
GRF	Grande Ronde F

Calculations

- o Effective interflow thickness given by RHO or estimated from RHO borehole logs. If data not available, effective thickness set equal to thickness of test interval.
- o Average K_H of Test Interval = Transmissivity/Effective Thickness.
- o Total Transmissivity of HSU = Sum of Transmissivity for All Interflows.
- o Effective K_H of HSU = Total Transmissivity/Sum of Effective Thickness.

Sources of Data

- o NRC/BWIP Hydrogeology Workshop (July 1982): DB-15, DC-1, DC-2, DC-6, DC-7, DC-12, DC-14, DC-15, DC-16, Ford, McGee, RRL-2)
- o Gephart et al (1979a): RSH-1
- o Gephart et al (1979b): DB-12, DB-13, DC-1

4-11

Table 1 Summary of Hydrologic Data

HSU	BOREHOLE NO.	TEST INTERVAL (m below GS)		HEAD (m MSL)	TRANSMISSIVITY (m ² /day)	EFFECTIVE THICKNESS (m)	AVERAGE K _{ij} (m/s)	TOTAL TRANSMISSIVITY (m ² /day)	EFFECTIVE K _{ij} (m/s)
MB	DB-12	114.3	159.7		1.5E+02	42.1	4.2E-05	1.5E+02	4.2E-05
MB	DB-13	364.2	393.8		1.8E+02	29.0	7.1E-05	1.8E+02	7.1E-05
MB	DB-15	207.3	257.3	124.0	1.7E+02	27.4	7.1E-05	1.7E+02	7.1E-05
MB	DC-14	295.4	330.1	149.0	1.7E+00	34.7	5.6E-07	1.7E+00	5.6E-07
MB	DC-16	425.2	477.9	128.1	1.2E+01	29.3	4.6E-06	1.2E+01	4.6E-06
MB	RRL-2	415.7	469.4	127.4	2.7E-03	15.2	2.0E-09	2.7E-03	2.0E-09
PR	DB-12	156.4	199.0		3.8E+04	42.7	1.0E-02	3.8E+04	1.0E-02
PR	DB-15	261.5	295.4	125.0	2.2E+02	11.0	2.4E-04	2.2E+02	2.4E-04
PR	DC-12	370.9	382.2	123.6	1.2E+01	10.4	1.3E-05	1.2E+01	1.3E-05
PR	DC-14	359.7	363.3	150.6					
PR	DC-14	364.5	370.9	150.2	2.7E+02	4.3	7.4E-04	2.7E+02	7.4E-04
PR	DC-14	370.9	387.4	150.6					
PR	DC-15	305.7	326.7	117.0	5.0E+00	14.9	3.9E-06	5.0E+00	2.5E-06
PR	DC-15	350.2	362.4	117.6	3.5E-02	8.8	4.6E-08		
PR	DC-16	515.1	526.7	116.3	4.0E-01	.6	7.8E-06	4.0E-01	7.8E-06
PR	FORD	190.5	236.8		8.4E+03	2.7	3.5E-02	9.3E+03	7.1E-03
PR	FORD	198.1	243.8		9.3E+03	15.2	7.1E-03		
PR	MCGEE	246.9	271.3	281.4	4.3E+03	24.4	2.0E-03	4.3E+03	2.0E-03
PR	RRL-2	479.8	522.4	122.3	6.0E+01	7.6	9.2E-05	6.0E+01	9.2E-05
RZ	DB-15	318.5	336.8	124.8	1.7E+02	13.4	1.4E-04	1.7E+02	8.1E-05
RZ	DB-15	338.6	349.3		3.5E-06	10.7	3.9E-12		

H-12

Table 1 Summary of Hydrologic Data

2.

HSU	BOREHOLE NO.	TEST INTERVAL (m below GS)		HEAD (m MSL)	TRANSMISSIVITY (m ² /day)	EFFECTIVE THICKNESS (m)	AVERAGE K _{II} (m/s)	TOTAL TRANSMISSIVITY (m ² /day)	EFFECTIVE K _{II} (m/s)
RZ	DC-12	404.8	415.7	123.5					
RZ	DC-14	391.7	415.7	150.2	8.6E+02	12.8	7.8E-04	8.6E+02	7.8E-04
RZ	DC-15	371.6	394.1	118.0	3.4E+02	16.2	3.9E-04	6.0E+02	3.5E-04
RZ	DC-15	413.6	423.7	117.6	6.6E+01	3.0	2.5E-04		
RZ	DC-16	536.4	557.2	122.7	2.0E+03	4.3	5.6E-03	2.0E+03	5.6E-03
RZ	MCGEE	313.3	334.1		2.8E+01	20.7	1.6E-05	2.8E+01	1.6E-05
RZ	RRL-2	528.8	540.4	123.1	2.2E+02	7.0	3.5E-04	2.2E+02	3.5E-04
FS	DB-15	396.2	409.3	124.4	9.3E-01	10.1	1.1E-05	1.3E+02	1.8E-05
FS	DB-15	412.4	418.5	124.8	3.5E+01	4.9	8.5E-05		
FS	DB-15	424.6	439.8	125.4	1.5E+01	9.1	1.9E-05		
FS	DB-15	442.0	466.3	124.8	8.4E+00	21.0	4.6E-06		
FS	DB-15	478.5	513.0	124.8	6.6E+01	24.7	3.1E-05		
FS	DB-15	524.3	548.6	123.7	6.2E-03	3.0	2.5E-08		
FS	DB-15	548.6	588.9	123.4	8.9E-04	6.1	1.7E-09		
FS	DC-1	405.4	463.3		7.4E-01	57.9	1.5E-07	4.8E+00	4.9E-07
FS	DC-1	600.5	658.4		4.1E+00	57.9	8.1E-07		
FS	DC-12	459.6	467.6	123.6	1.0E+00	2.4	5.3E-06	1.6E+01	8.1E-06
FS	DC-12	493.2	513.3	123.8					
FS	DC-12	514.2	521.2	123.8	4.3E+00	3.0	1.6E-05		
FS	DC-12	581.9	604.7	123.8	6.6E-02	9.8	7.8E-08		
FS	DC-12	624.8	633.7	123.8	1.0E+01	6.7	1.8E-05		

H-13

Table 1 Summary of Hydrologic Data .

HSU	BOREHOLE NO.	TEST INTERVAL (m below GS)		HEAD (m MSL)	TRANSMISSIVITY (m ² /day)	EFFECTIVE THICKNESS (m)	AVERAGE K _H (m/s)	TOTAL TRANSMISSIVITY (m ² /day)	EFFECTIVE K _H (m/s)
FS	DC-14	451.1	462.1	147.8	2.5E+00	3.4	8.8E-06	2.0E+02	5.6E-05
FS	DC-14	481.6	497.4	149.4	3.1E+01	8.5	4.2E-05		
FS	DC-14	499.9	520.6	148.4	9.0E+00	10.4	1.0E-05		
FS	DC-14	524.3	554.7	148.4					
FS	DC-14	554.7	571.5	148.0	2.7E+01	3.7	8.5E-05		
FS	DC-14	571.5	604.4	133.8	1.3E+02	15.2	9.9E-05		
FS	DC-15	425.2	449.0	117.6	2.8E-01	.6	5.3E-06	7.6E+02	1.4E-04
FS	DC-15	451.4	459.0	117.6	1.8E+02	5.5	3.9E-04		
FS	DC-15	458.7	473.4	117.6	5.4E+01	14.6	4.2E-05		
FS	DC-15	469.4	485.5	117.6	1.7E+02	6.1	3.2E-04		
FS	DC-15	528.8	558.7	117.6	5.9E+00	23.8	2.9E-06		
FS	DC-15	559.0	572.1	117.6	3.6E+02	11.6	3.5E-04		
FS	DC-16	576.7	609.6	122.6	3.9E+02	2.7	1.7E-03	3.9E+02	7.4E-04
FS	DC-16	641.6	657.1	122.8	2.0E+00	3.4	7.1E-06		
FS	RRL-2	581.3	677.3	122.5	1.0E+02	9.8	1.2E-04	3.0E+02	1.2E-04
FS	RRL-2	684.0	805.9	121.9	2.0E+02	19.8	1.1E-04		
GRA	DC-1	600.5	658.4	124.1	4.1E+00	57.9	8.1E-07	4.1E+00	8.1E-07
GRA	DC-6	689.5	730.6	133.5	1.9E-01	13.7	1.6E-07	1.9E-01	1.6E-07
GRA	DC-12	676.0	688.8		2.1E-02	6.1	4.2E-08	1.0E+01	6.0E-06
GRA	DC-12	691.0	701.3		1.7E-01	6.1	3.2E-07		
GRA	DC-12	734.0	745.5	124.0	1.0E+01	8.2	1.4E-05		
GRA	DC-14	646.2	681.2	142.6	5.4E+01	12.2	5.3E-05	5.4E+01	3.3E-05
GRA	DC-14	717.8	733.0	132.6	2.4E-02	6.7	4.2E-08		
GRA	DC-15	639.8	670.0	118.6	3.0E-01	20.4	1.7E-07	2.0E+02	7.1E-05
GRA	DC-15	678.8	714.1	118.6	2.0E+02	10.1	2.3E-04		
GRA	DC-15	723.0	758.0	119.2	1.9E-01	3.0	7.1E-07		
GRA	RRL-2	812.3	826.9	121.6	1.6E-01	5.5	3.3E-07	8.0E+01	3.9E-05
GRA	RRL-2	828.8	887.9	121.0	8.0E+01	17.4	5.3E-05		

b1-H

Table 1 Summary of Hydrologic Data

4.

HSU	BOREHOLE NO.	TEST INTERVAL (m below GS)		HEAD (m MSL)	TRANSMISSIVITY (m ² /day)	EFFECTIVE THICKNESS (m)	AVERAGE K _H (m/s)	TOTAL TRANSMISSIVITY (m ² /day)	EFFECTIVE K _H (m/s)
GRB	DC-2	714.5	724.2	135.3	5.9E-03	6.4	1.1E-08	8.5E-03	6.0E-09
GRB	DC-2	724.2	734.3	128.9	2.5E-03	10.1	2.9E-09		
GRB	DC-6	730.3	822.0	129.0					
GRB	DC-12	782.7	811.1		1.4E-02	19.8	8.1E-09	1.4E-02	8.1E-09
GRB	DC-14	734.6	766.0	134.8	3.9E-01	7.6	6.0E-07	3.9E-01	6.0E-07
GRB	DC-15	759.6	776.6	119.2	1.7E+01	7.3	2.6E-05	1.7E+01	2.6E-05
GRB	RRL-2	908.6	920.5	121.0	9.3E-04	3.0	3.5E-09	9.3E-04	3.5E-09
GRB	RSH-1	588.0	611.1		1.4E-01	23.2	7.1E-08	1.4E-01	7.1E-08
GRC	DC-1	792.5	847.3	122.5	2.3E+00	54.9	4.9E-07	2.3E+00	2.9E-07
GRC	DC-1	832.1	887.0	125.3	3.0E-02	54.9	6.4E-09		
GRC	DC-6	822.0	881.8	130.0	3.3E+00	42.7	9.2E-07	3.3E+00	9.2E-07
GRC	DC-12	858.9	866.5	124.6	1.4E+02	3.7	4.6E-04	2.0E+02	3.0E-04
GRC	DC-12	865.0	872.6		5.5E+01	4.0	1.6E-04		
GRC	DC-14	809.9	876.0	132.8	3.1E-02	22.9	1.5E-08	3.1E-02	1.5E-08
GRC	DC-15	808.0	823.0	118.8				1.0E+00	2.5E-06
GRC	DC-15	820.5	842.2	118.8	7.5E-01	3.0	2.9E-06		
GRC	DC-15	857.4	874.2	119.2	3.0E-01	1.8	1.9E-06		

H-15

Table 1 Summary of Hydrologic Data

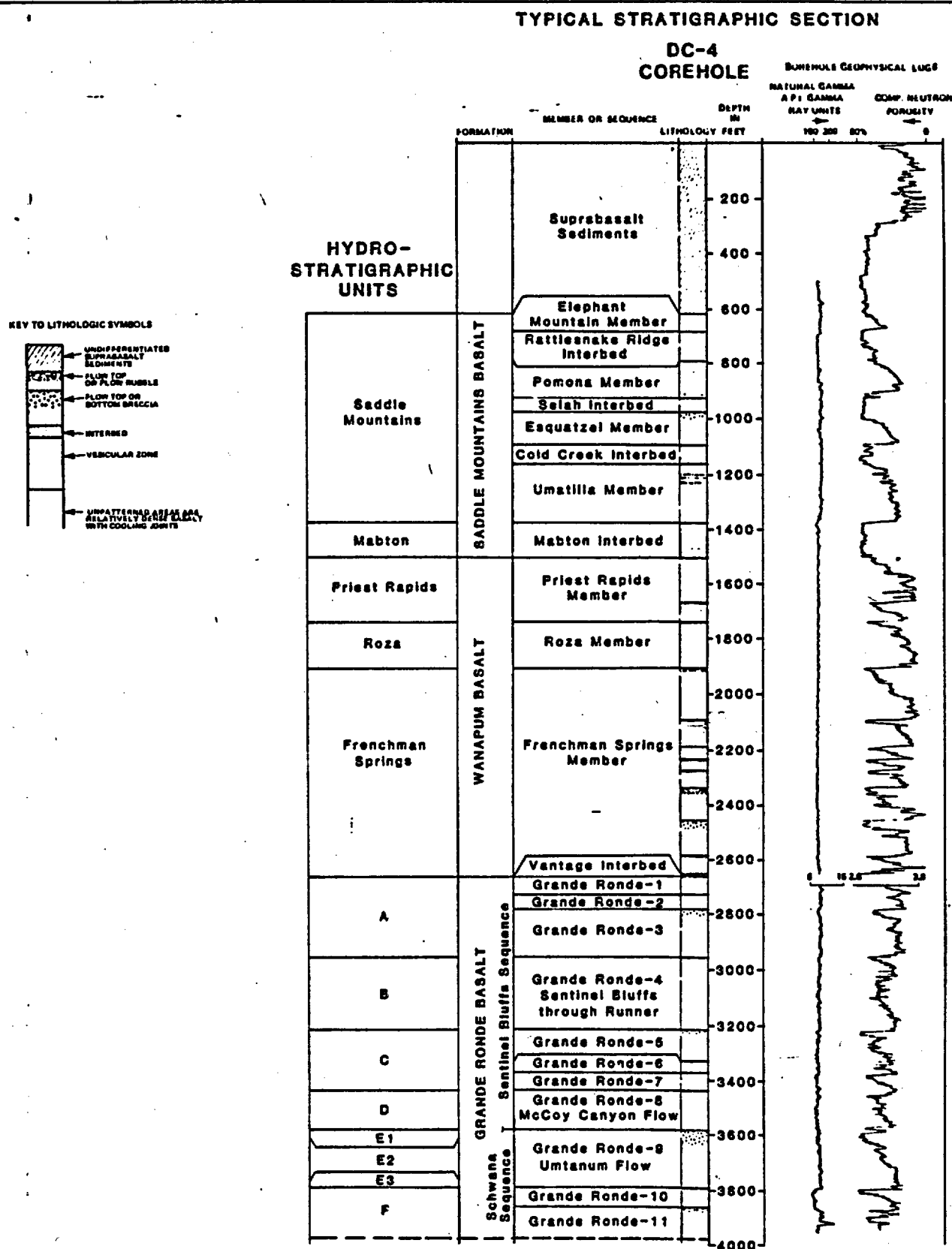
HSU	BOREHOLE NO.	TEST INTERVAL (m below GS)		HEAD (m MSL)	TRANSMISSIVITY (m ² /day)	EFFECTIVE THICKNESS (m)	AVERAGE K _H (m/s)	TOTAL TRANSMISSIVITY (m ² /day)	EFFECTIVE K _H (m/s)
GRD	DC-1	832.1	887.0	125.3	3.0E-02	54.9	6.4E-09	3.0E-02	6.4E-09
GRD	DC-12	934.8	961.0		5.9E-02	10.7	6.4E-08	5.9E-02	6.4E-08
GRD	DC-14	877.8	906.8	132.8	2.2E-02	19.2	1.3E-08	2.2E-02	1.3E-08
GRE1	DC-1	887.9	910.4	124.4					
GRE1	DC-2	900.4	916.5		5.5E-03	14.3	4.6E-09	5.5E-03	4.6E-09
GRE1	DC-6	912.0	938.2	134.5	4.6E-02	8.8	6.0E-08	4.6E-02	6.0E-08
GRE1	DC-12	975.1	1000.4	124.6					
GRE1	DC-14	932.7	958.3	134.4	5.1E-01	20.1	2.9E-07	5.1E-01	2.9E-07
GRE1	DC-15	902.5	948.8	121.4	2.3E+00	36.0	7.4E-07	2.3E+00	7.4E-07
GRE1	RRL-2				9.3E-01	45.7	2.4E-07	9.3E-01	2.4E-07
GRE1	RSH-1	796.7	819.9	595.6	1.1E-03	23.2	5.6E-10	1.1E-03	5.6E-10
GRE1	RSH-1	799.2	815.6		6.8E-05	8.2	9.5E-11		
GRE3	DC-1	958.9	986.3		7.2E+00	27.4	3.0E-06	7.2E+00	3.0E-06
GRE3	DC-1	965.0	974.1		6.7E-02	9.1	8.5E-08		
GRE3	DC-1	968.3	988.2	126.5					
GRE3	DC-14	969.3	983.0	134.4	3.9E-01	4.6	9.9E-07	3.9E-01	9.9E-07
GRE3	DC-15	989.1	1004.6	112.2	6.4E-01	2.4	2.9E-06	6.4E-01	2.9E-06
GRE3	RSH-1	861.1	871.7		3.0E-04	5.5	6.4E-10	3.0E-04	6.4E-10

71-#

Table 1 Summary of Hydrologic Data

HSU	BOREHOLE NO.	TEST INTERVAL (m below GS)		HEAD (m MSL)	TRANSMISSIVITY (m ² /day)	EFFECTIVE THICKNESS (m)	AVERAGE K _H (m/s)	TOTAL TRANSMISSIVITY (m ² /day)	EFFECTIVE K _H (m/s)
GRF	DC-1	1011.9	1051.9		6.1E-02	39.9	1.8E-08	7.1E+00	6.0E-07
GRF	DC-1	1150.3	1199.1		5.2E-02	48.8	1.2E-08		
GRF	DC-1	1191.8	1240.5		7.0E+00	48.8	1.7E-06		
GRF	DC-1	1198.2	1234.7	126.8					
GRF	DC-1	1450.8	1478.0	126.9					
GRF	DC-6	988.8	1075.9	135.0	9.3E-01	25.9	4.2E-07	1.0E+01	1.2E-06
GRF	DC-6	1073.9	1165.6	135.5	9.3E+00	61.6	1.8E-06		
GRF	DC-6	1270.7	1321.6	140.0	1.1E-01	12.8	1.0E-07		
GRF	DC-7	1255.8	1297.5	123.4	4.5E-04	24.4	2.1E-10	1.8E-01	2.4E-08
GRF	DC-7	1298.8	1351.5	123.4	8.2E-04	4.0	2.4E-09		
GRF	DC-7	1354.5	1406.7	124.4	2.5E-02	13.7	2.1E-08		
GRF	DC-7	1427.7	1471.3	122.6	1.2E-01	25.9	5.3E-08		
GRF	DC-7	1472.2	1526.4	119.2	3.0E-02	16.2	2.1E-08		
GRF	DC-12	1018.3	1240.5	124.0	7.2E+01	48.8	1.7E-05	8.7E+01	1.7E-05
GRF	DC-12	1225.6	1240.5		5.9E+01	7.3	9.2E-05		
GRF	DC-12	1324.1	1357.9	124.0					
GRF	DC-12	1244.8	1357.9		1.5E+01	12.2	1.4E-05		
GRF	DC-14	993.6	1016.5	134.4	1.7E+00	16.2	1.2E-06	1.7E+00	1.2E-06
GRF	DC-15	1006.1	1040.0	117.0	9.3E-02	14.9	7.4E-08	5.8E-01	1.3E-07
GRF	DC-15	1140.3	1172.0	121.6	4.8E-03	24.4	2.3E-09		
GRF	DC-15	1261.3	1293.3	123.0	4.7E-01	12.8	4.2E-07		
GRF	RSH-1	979.3	1002.5	414.5	4.1E-02	23.2	2.0E-08	4.2E-01	5.3E-08
GRF	RSH-1	1255.5	1278.6	291.7	2.0E-03	23.2	9.5E-10		
GRF	RSH-1	1472.8	1496.0	304.5	3.9E-03	23.2	1.9E-09		
GRF	RSH-1	1804.7	1827.9	260.6	3.7E-01	23.2	1.9E-07		

H-17



EXPLANATION

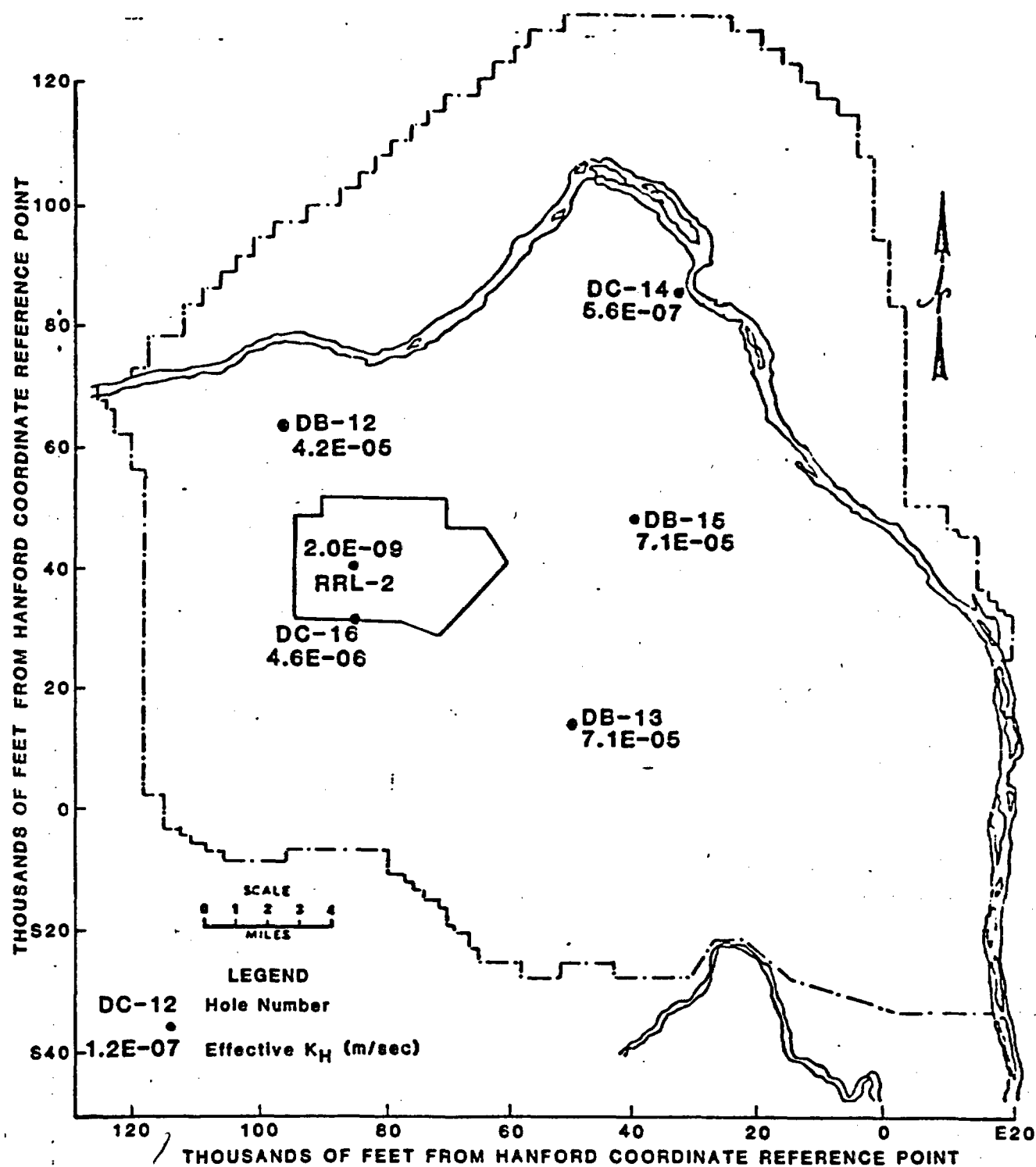
GRANDE RONDE BASALT FLOWS ARE NUMBERED FROM THE TOP OF THE FORMATION IN EACH BOREHOLE. THE NUMBERING OF FLOWS IS SPECIFIC TO EACH BOREHOLE AND THENCE GRANDE RONDE 12 IN DC 14 IS NOT NECESSARILY THE SAME AS GRANDE RONDE 12 IN DHS. NAMED FLOWS, HOWEVER, ARE EQUIVALENT FROM ONE BOREHOLE TO ANOTHER.

From: RSD-BWI-DP-038
(Rockwell Hanford Operations)

H-18

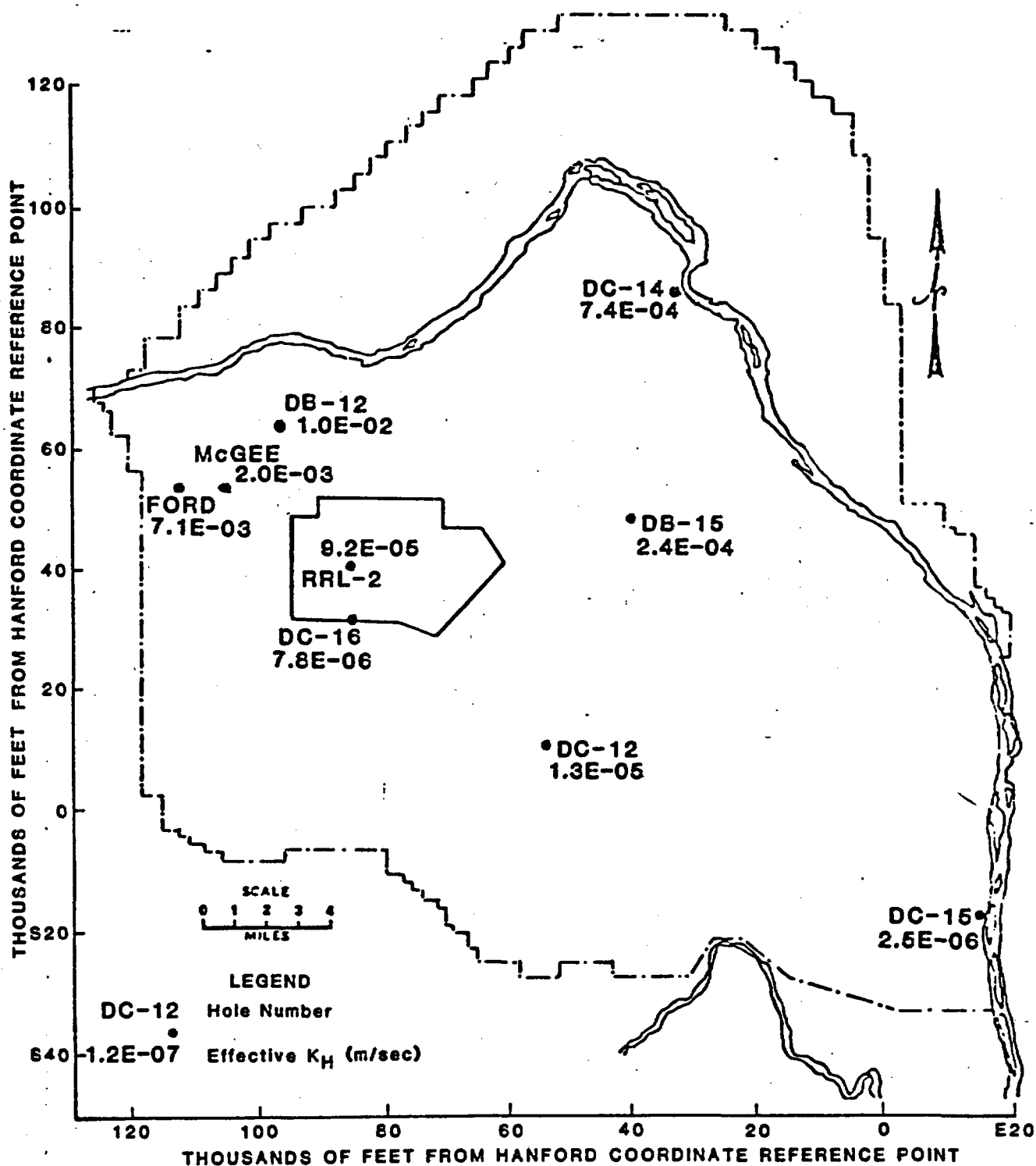
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE MABTON

Figure 2A



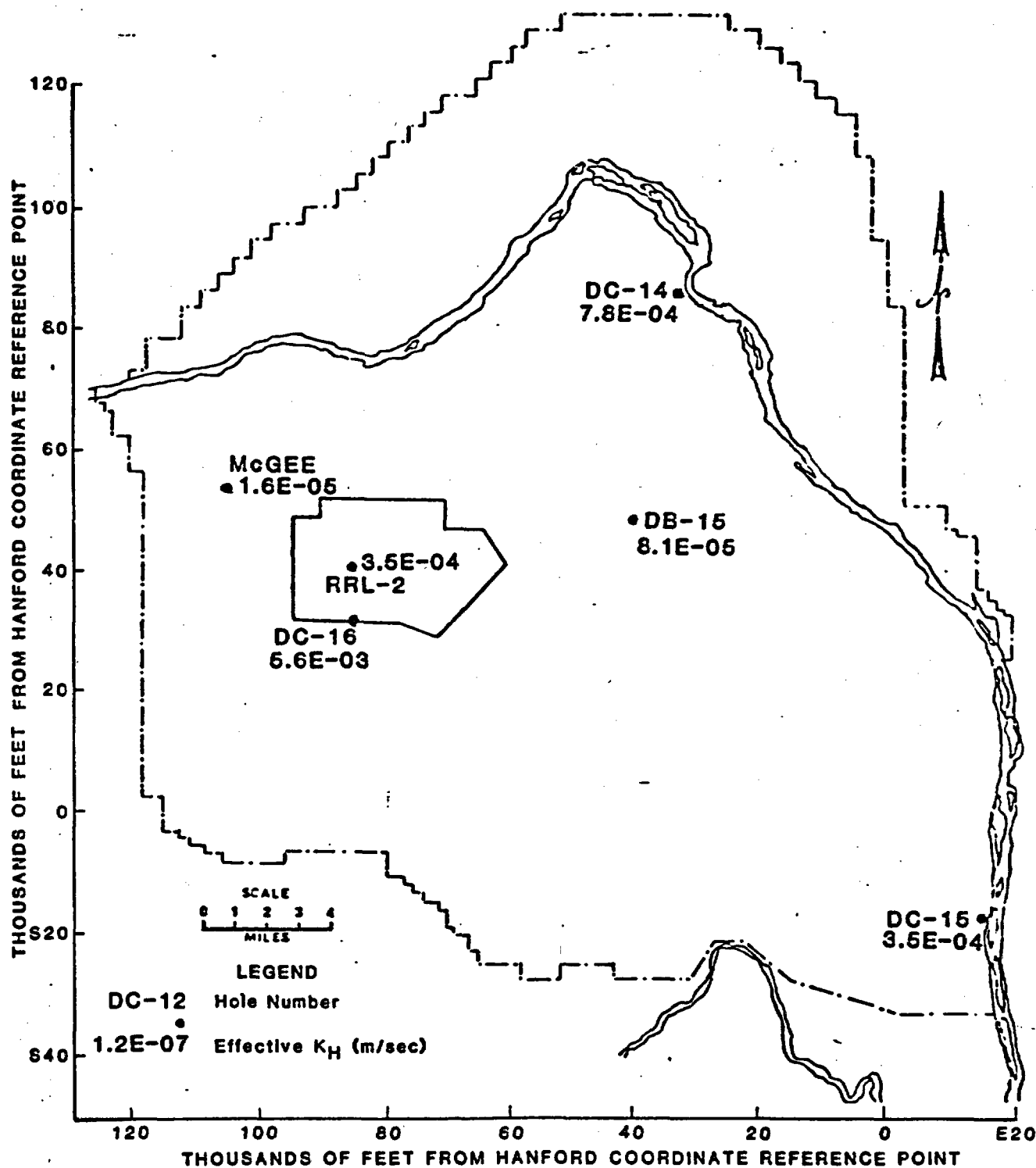
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE PRIEST RAPIDS

Figure 2B



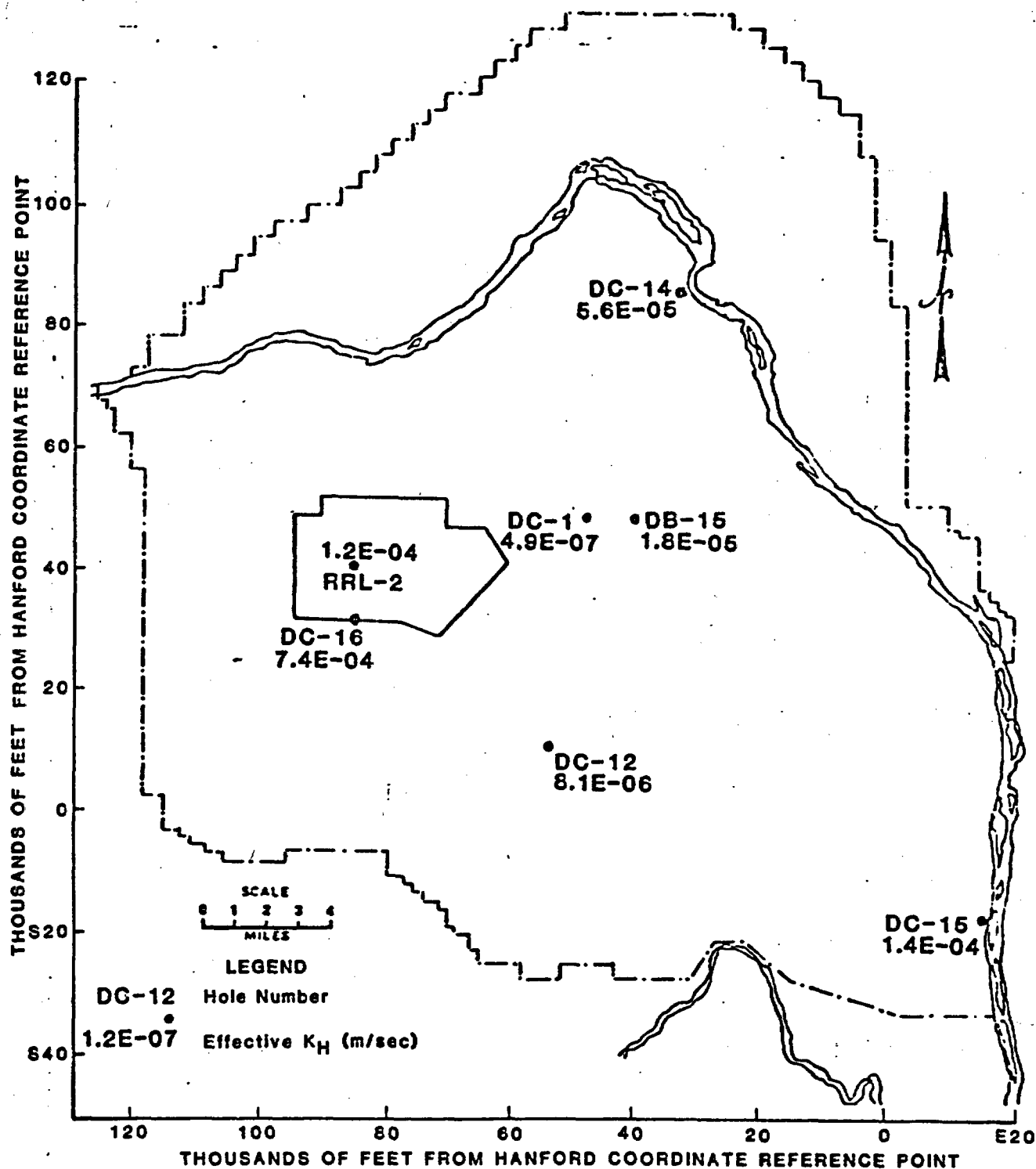
**EFFECTIVE HORIZONTAL HYDRAULIC
CONDUCTIVITY (M/SEC) OF INTERFLOWS
IN THE ROZA**

Figure 2C



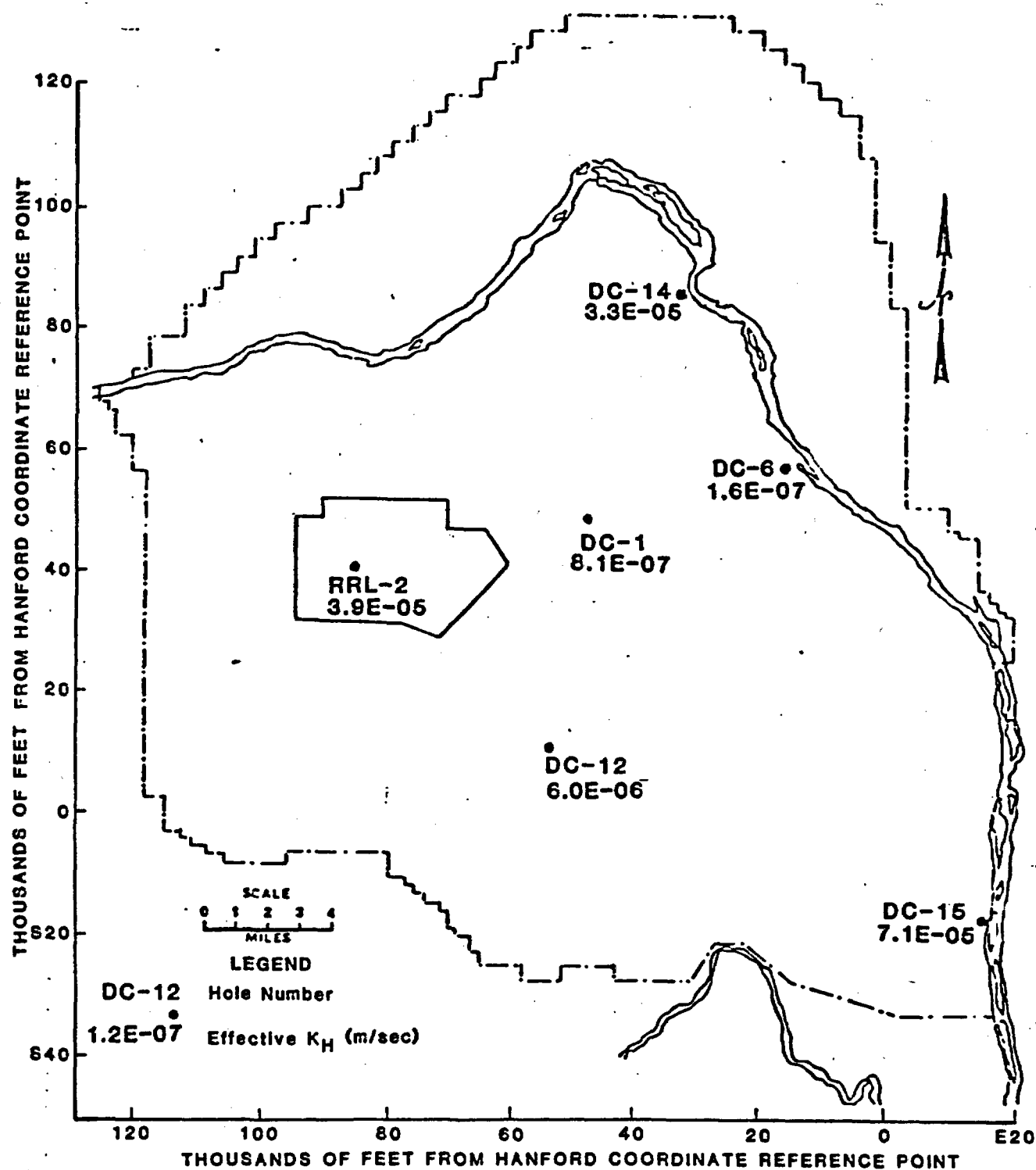
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE FRENCHMAN SPRINGS

Figure 2D



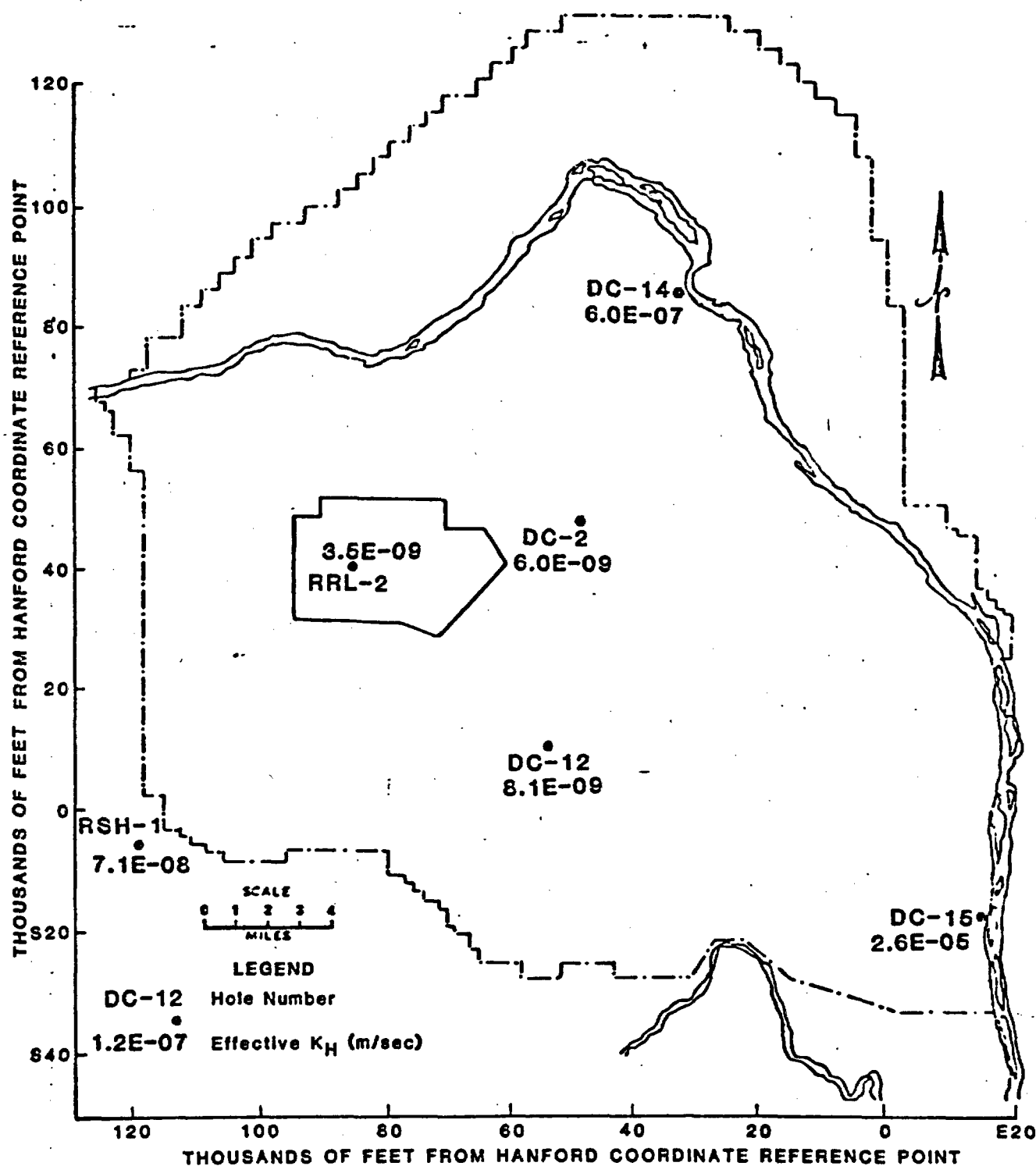
**EFFECTIVE HORIZONTAL HYDRAULIC
CONDUCTIVITY (M/SEC) OF INTERFLOWS
IN THE GRANDE RONDE A**

Figure 2E



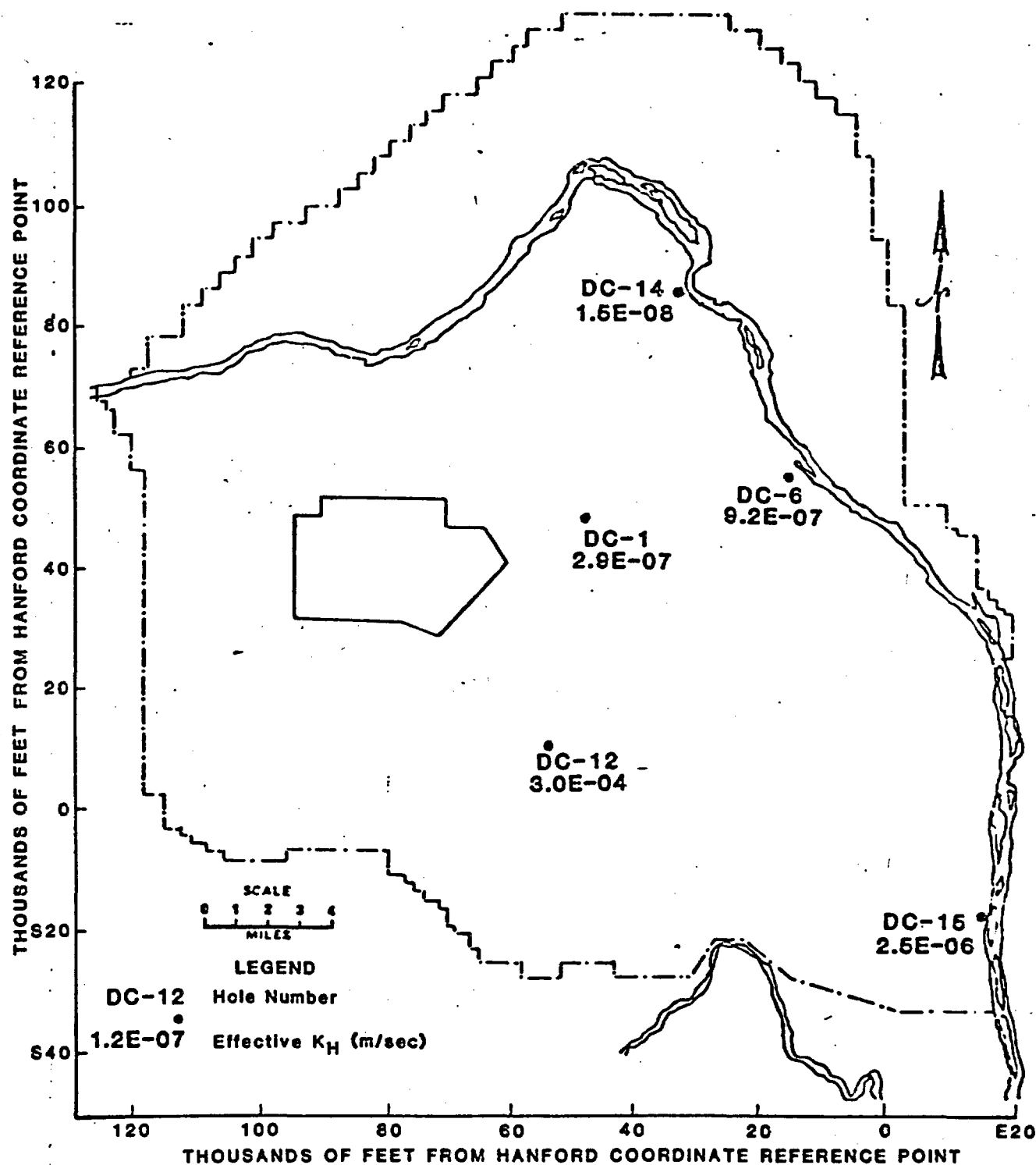
EFFECTIVE HORIZONTAL HYDRAULIC
CONDUCTIVITY (M/SEC) OF INTERFLOWS
IN THE GRANDE RONDE B

Figure 2F



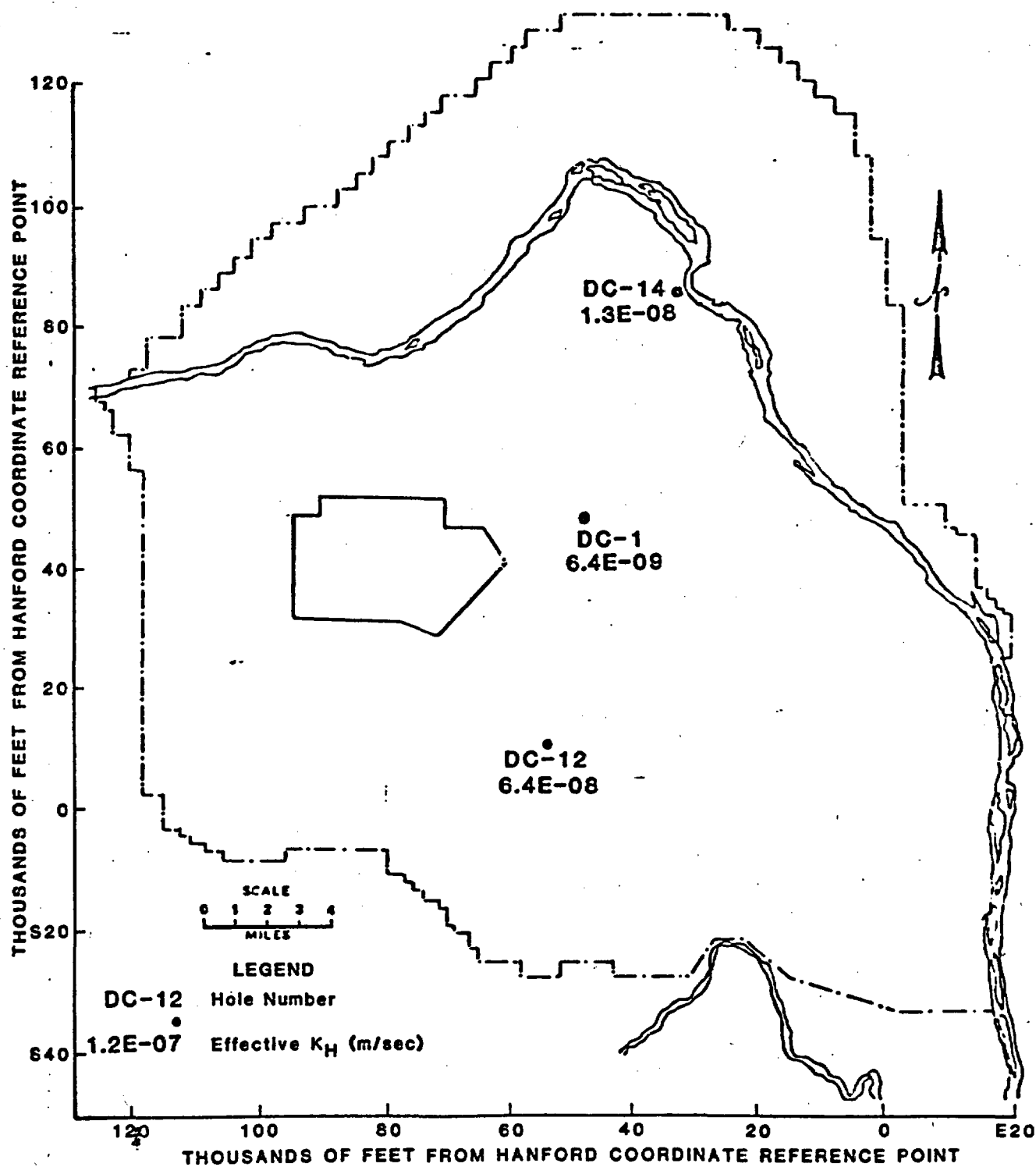
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE GRANDE RONDE C

Figure 2G



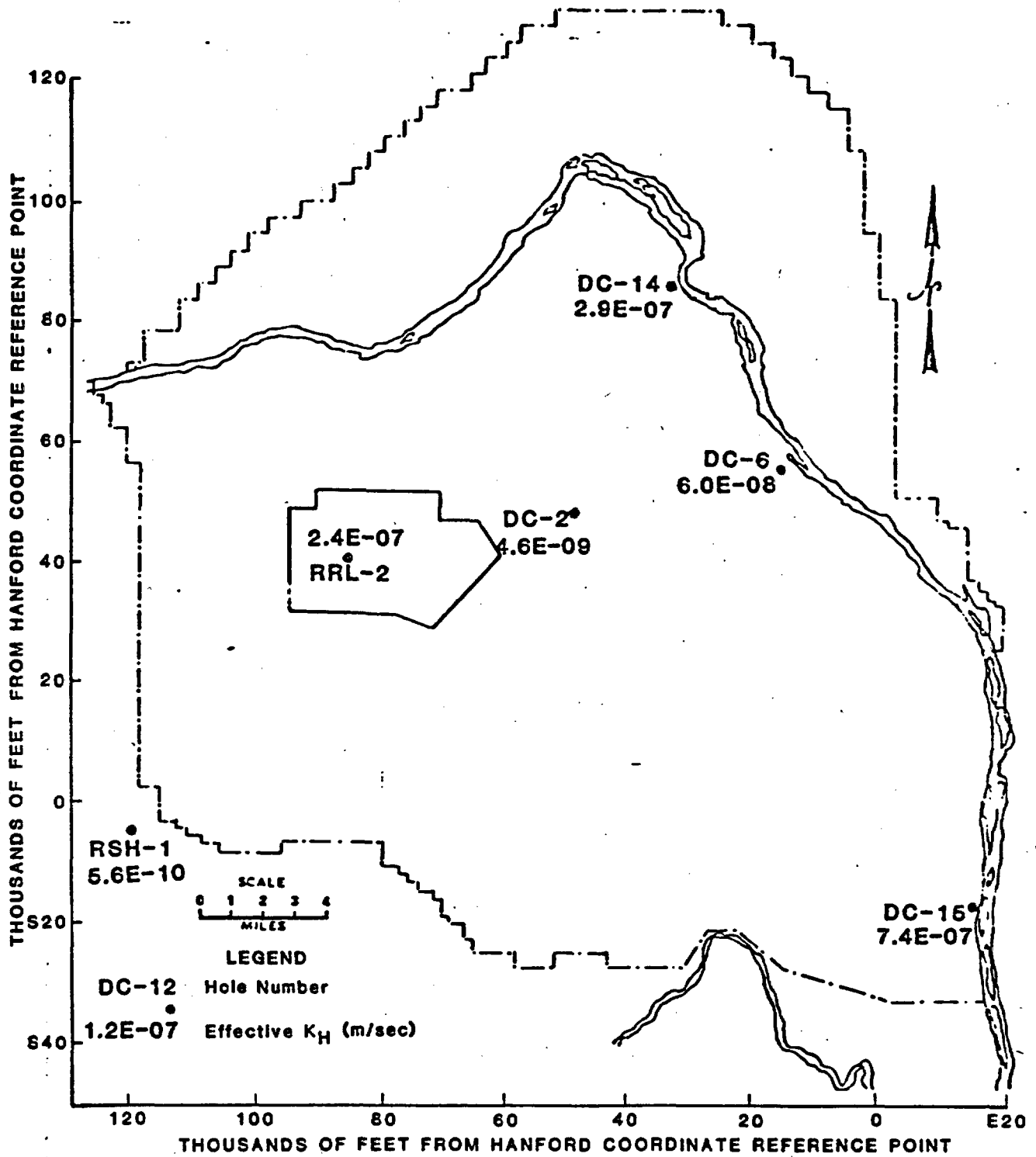
**EFFECTIVE HORIZONTAL HYDRAULIC
CONDUCTIVITY (M/SEC) OF INTERFLOWS
IN THE GRANDE RONDE D**

Figure 2H



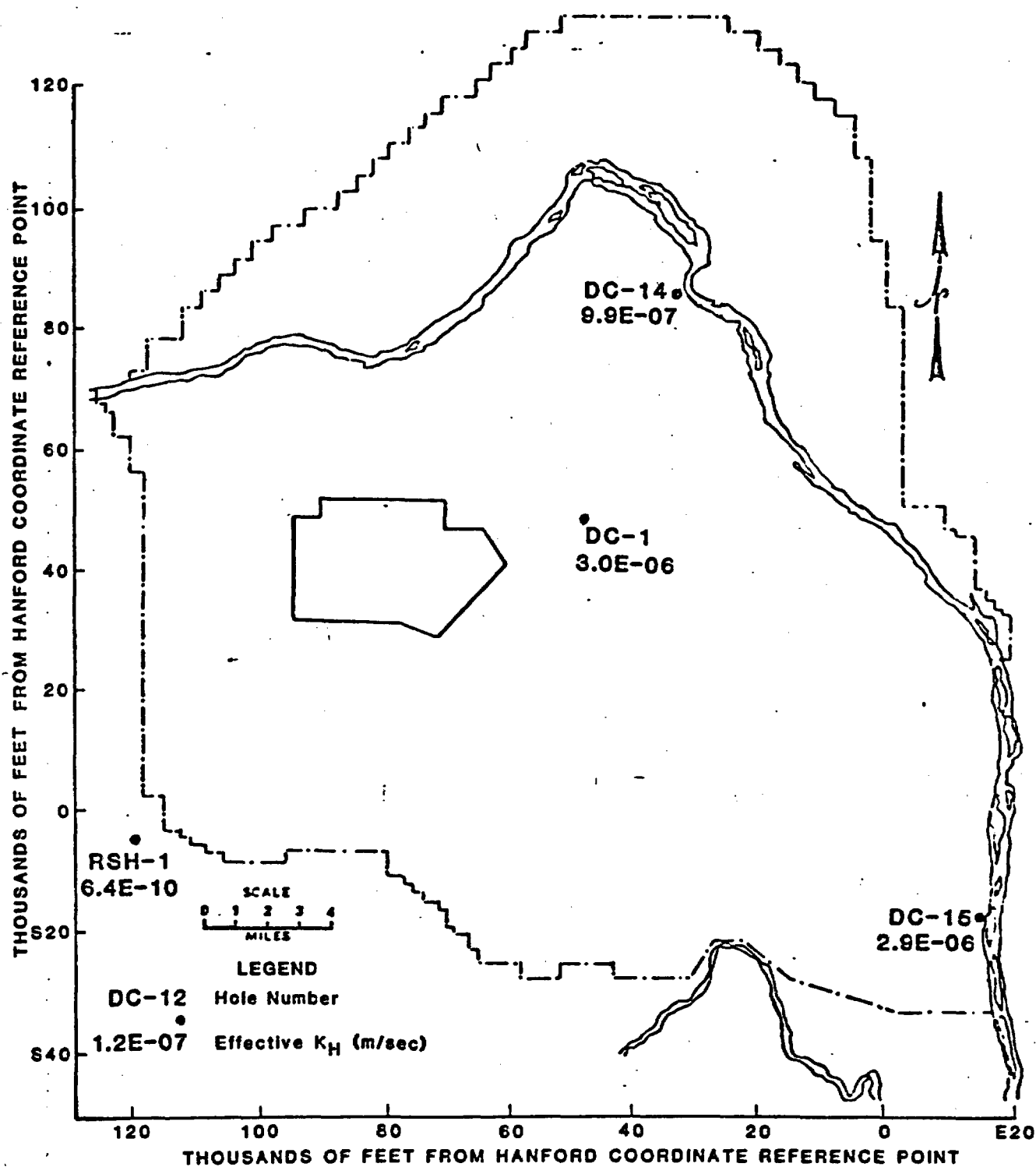
**EFFECTIVE HORIZONTAL HYDRAULIC
CONDUCTIVITY (M/SEC) OF INTERFLOWS
IN THE GRANDE RONDE E1**

Figure 2I



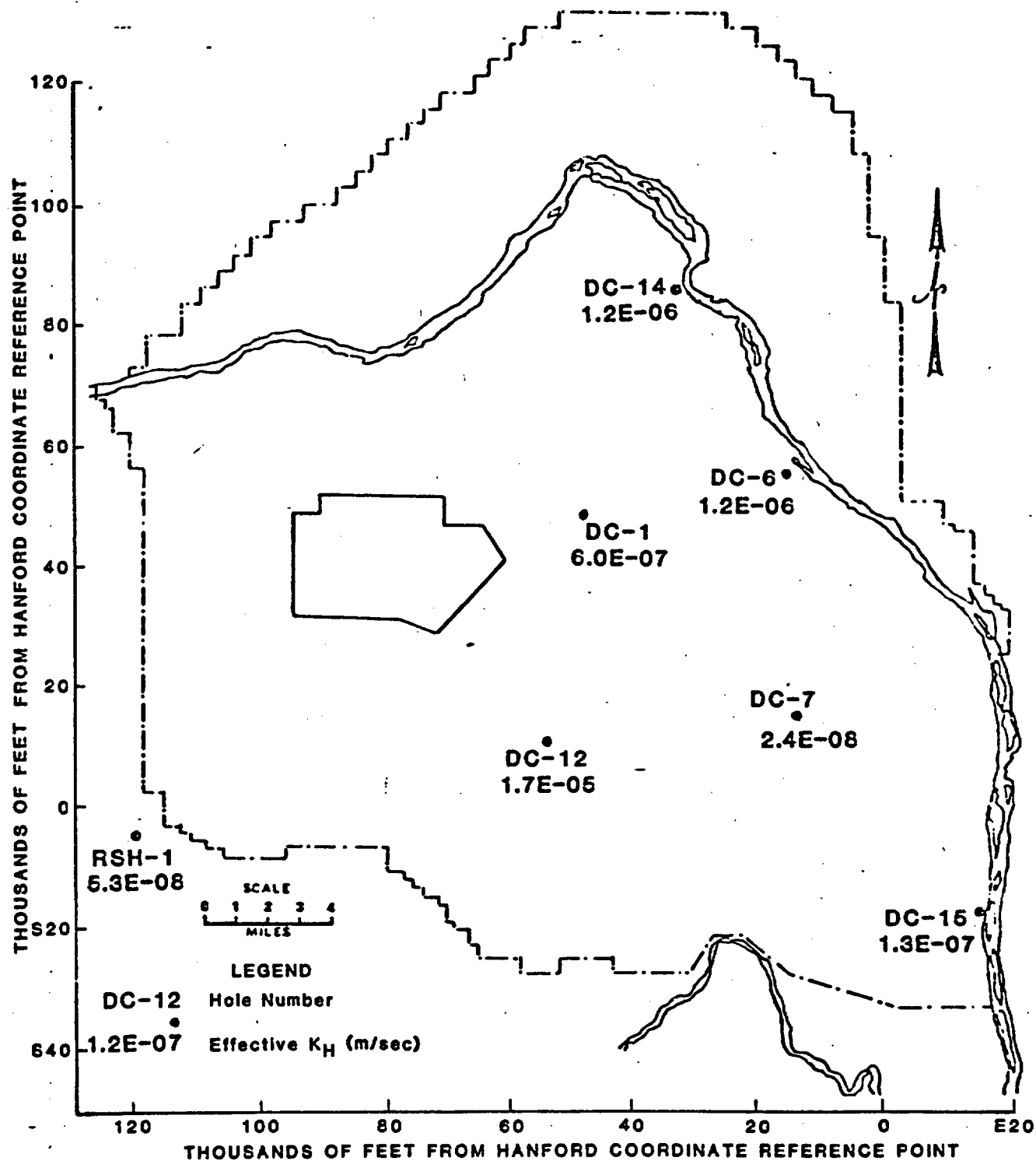
**EFFECTIVE HORIZONTAL HYDRAULIC
CONDUCTIVITY (M/SEC) OF INTERFLOWS
IN THE GRANDE RONDE E3**

Figure 2J



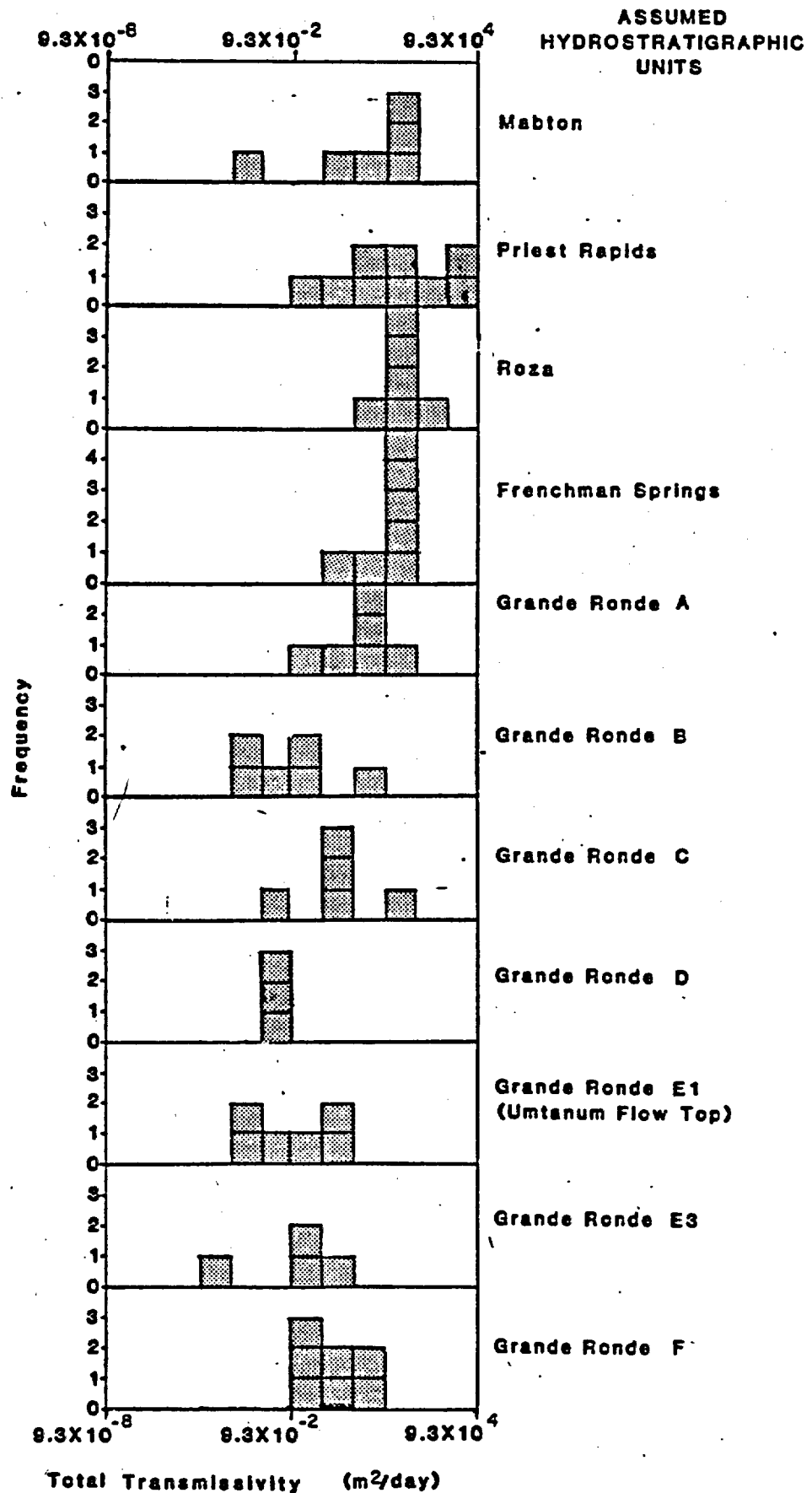
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE GRANDE RONDE F

Figure 2K



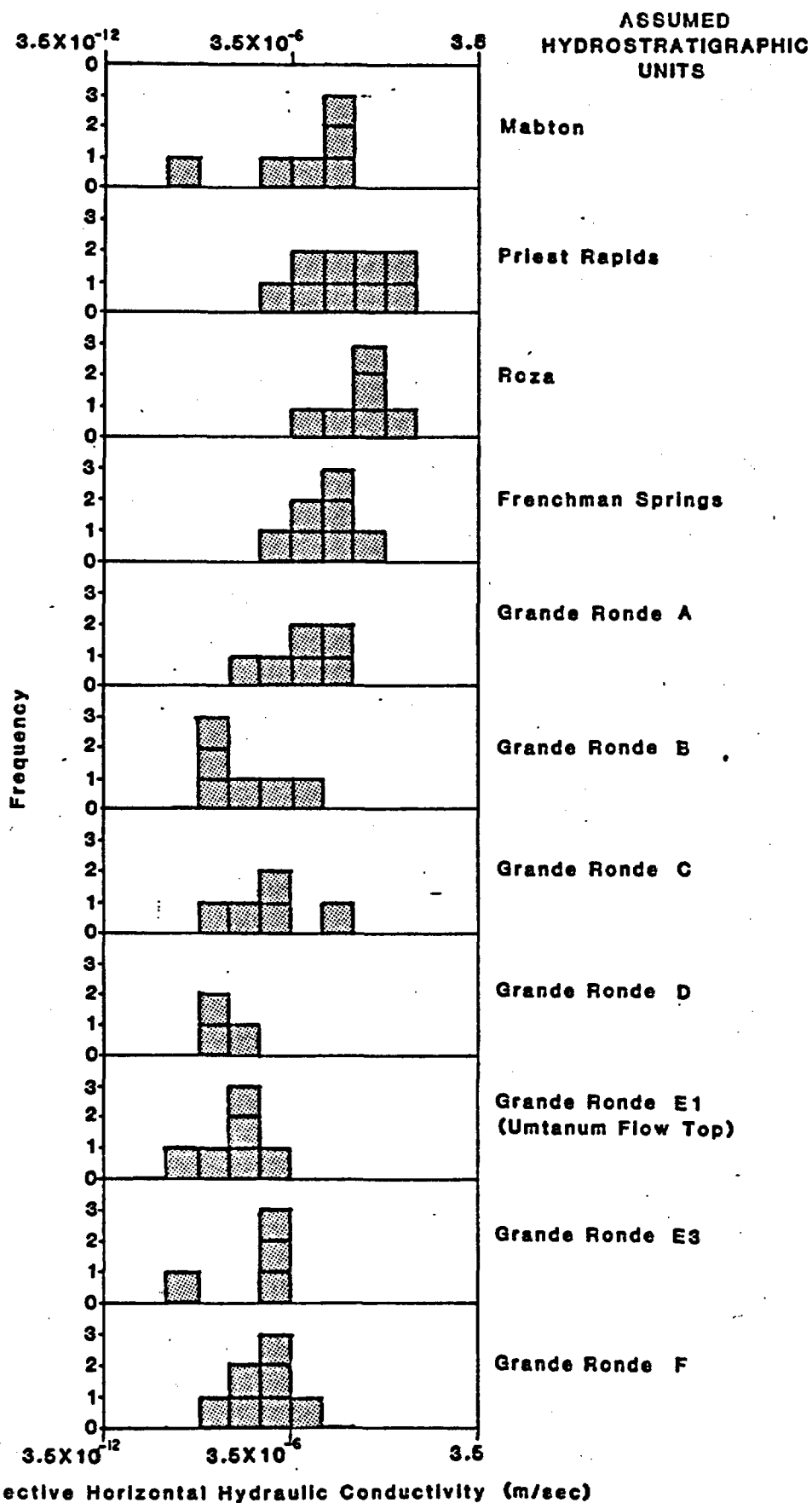
TOTAL TRANSMISSIVITY HISTOGRAMS

Figure 3



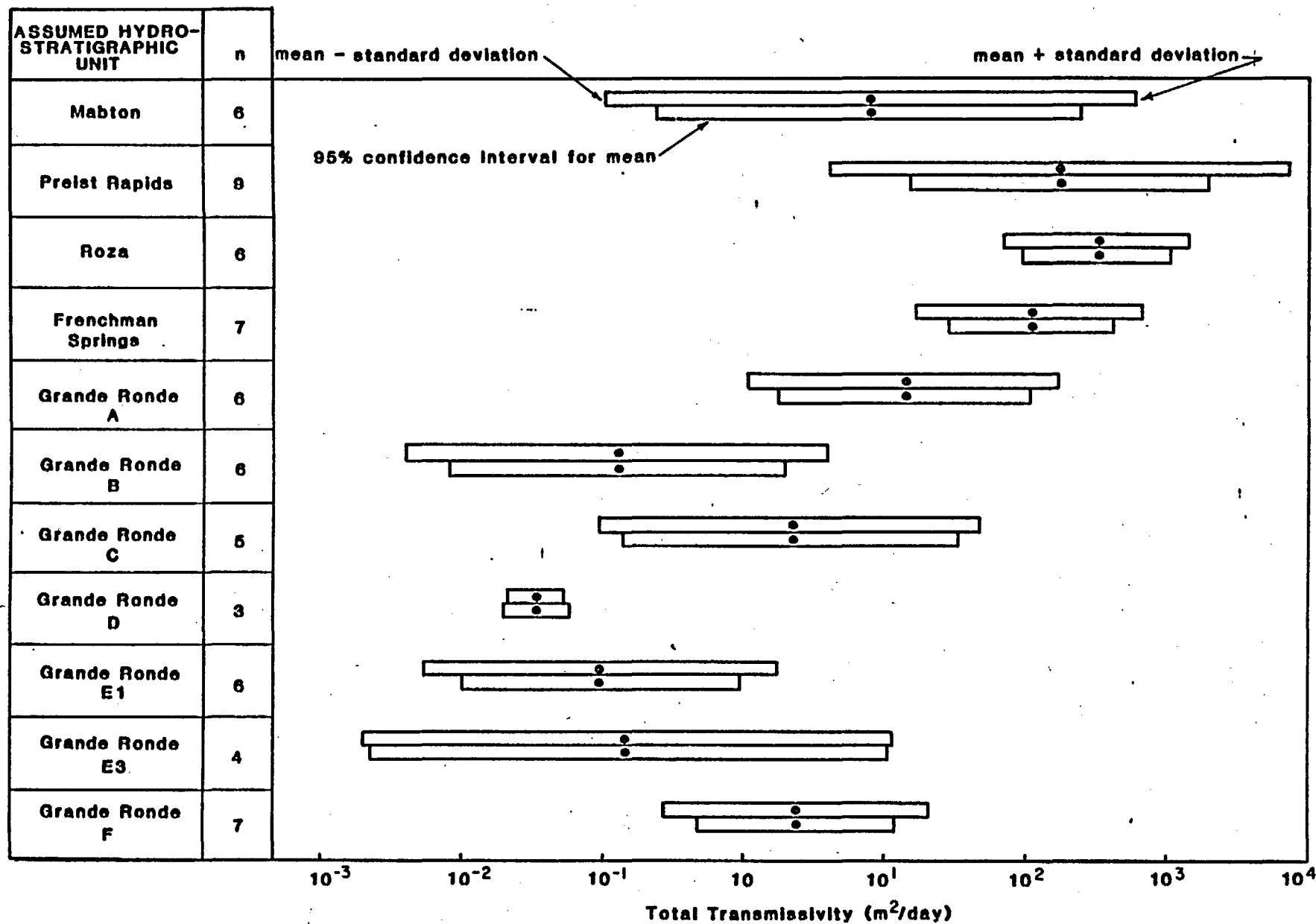
EFFECTIVE HYDRAULIC CONDUCTIVITY HISTOGRAMS

Figure 4



DISTRIBUTION OF TOTAL TRANSMISSIVITY
FOR ASSUMED HYDROSTRATIGRAPHIC UNITS

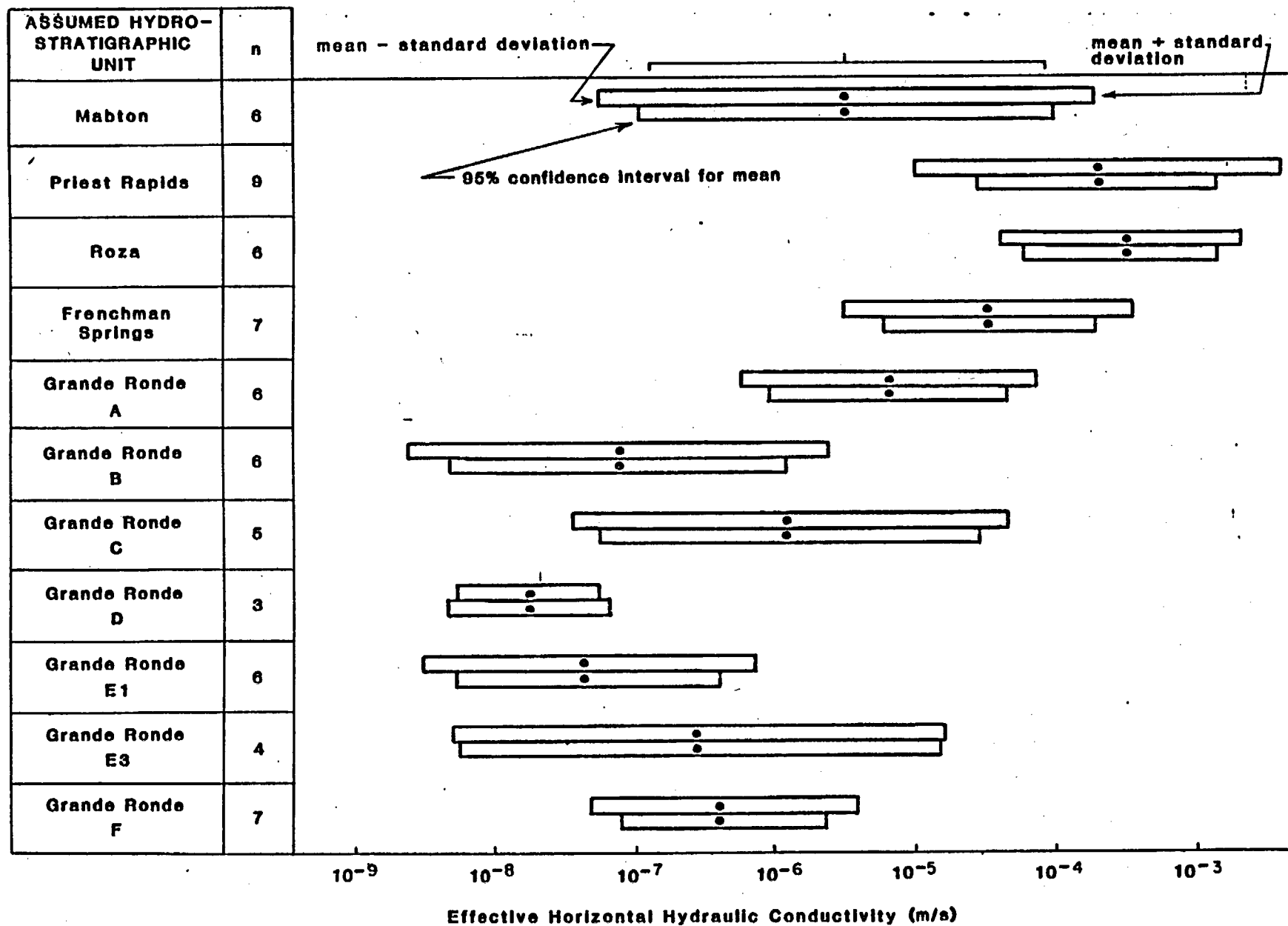
Figure 5



H-32

DISTRIBUTION OF EFFECTIVE HORIZONTAL
CONDUCTIVITY VALUES FOR ASSUMED
HYDROSTRATIGRAPHIC UNITS

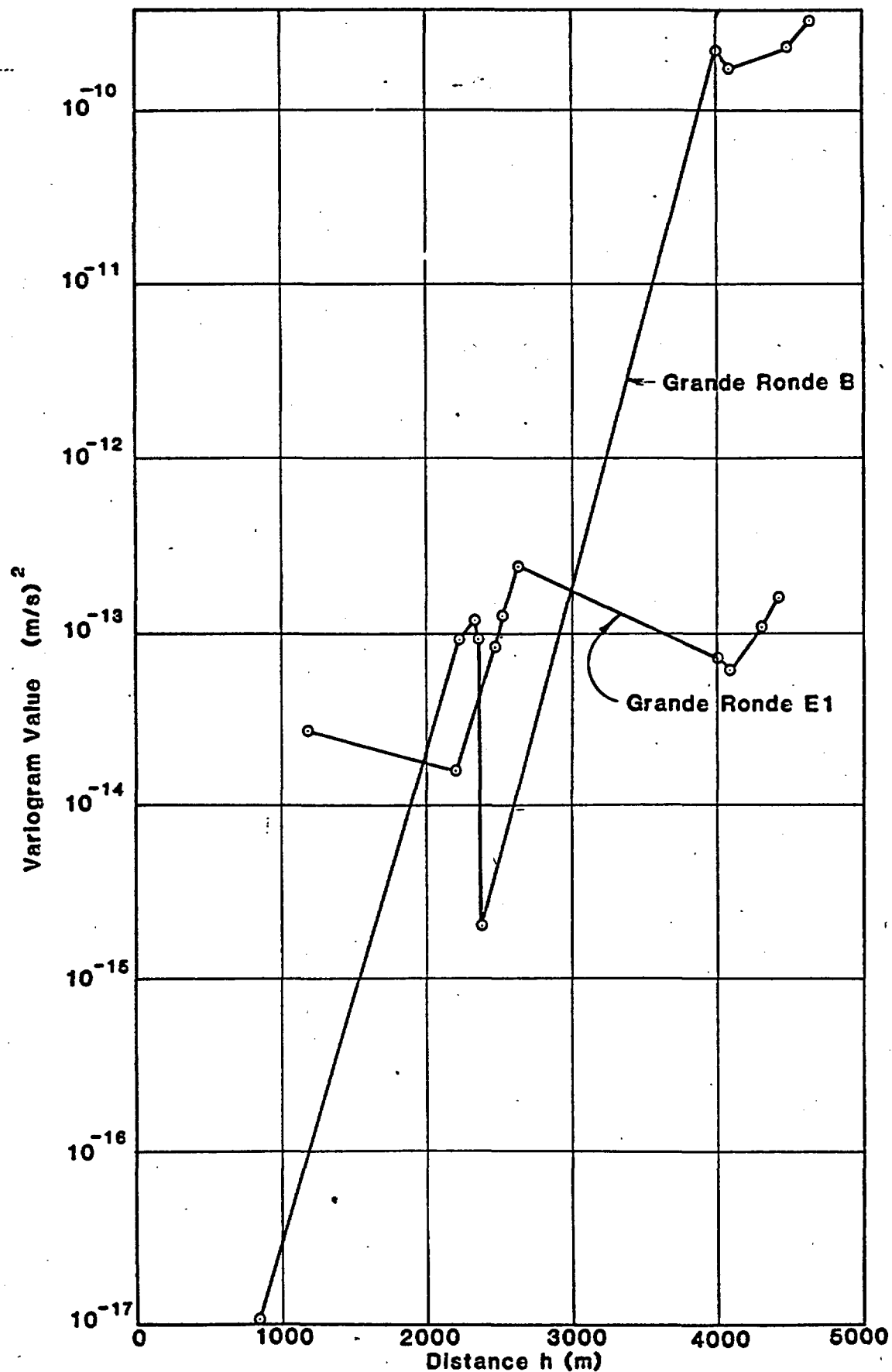
Figure 6



H-33

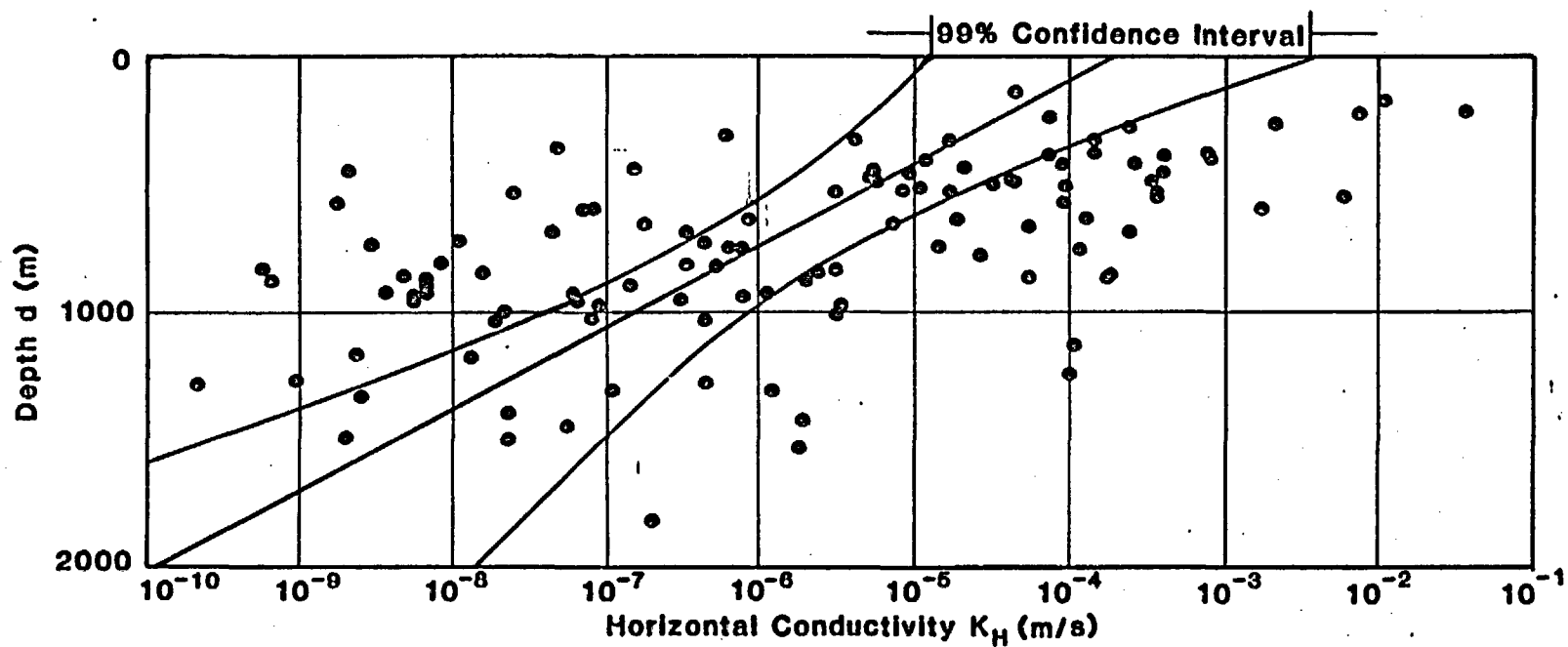
SMOOTHED VARIOGRAMS OF EFFECTIVE K_H FOR THE
GRANDE RONDE B AND E1 FORMATIONS

Figure 7



HORIZONTAL HYDRAULIC CONDUCTIVITY
VERSUS DEPTH BELOW GROUND SURFACE

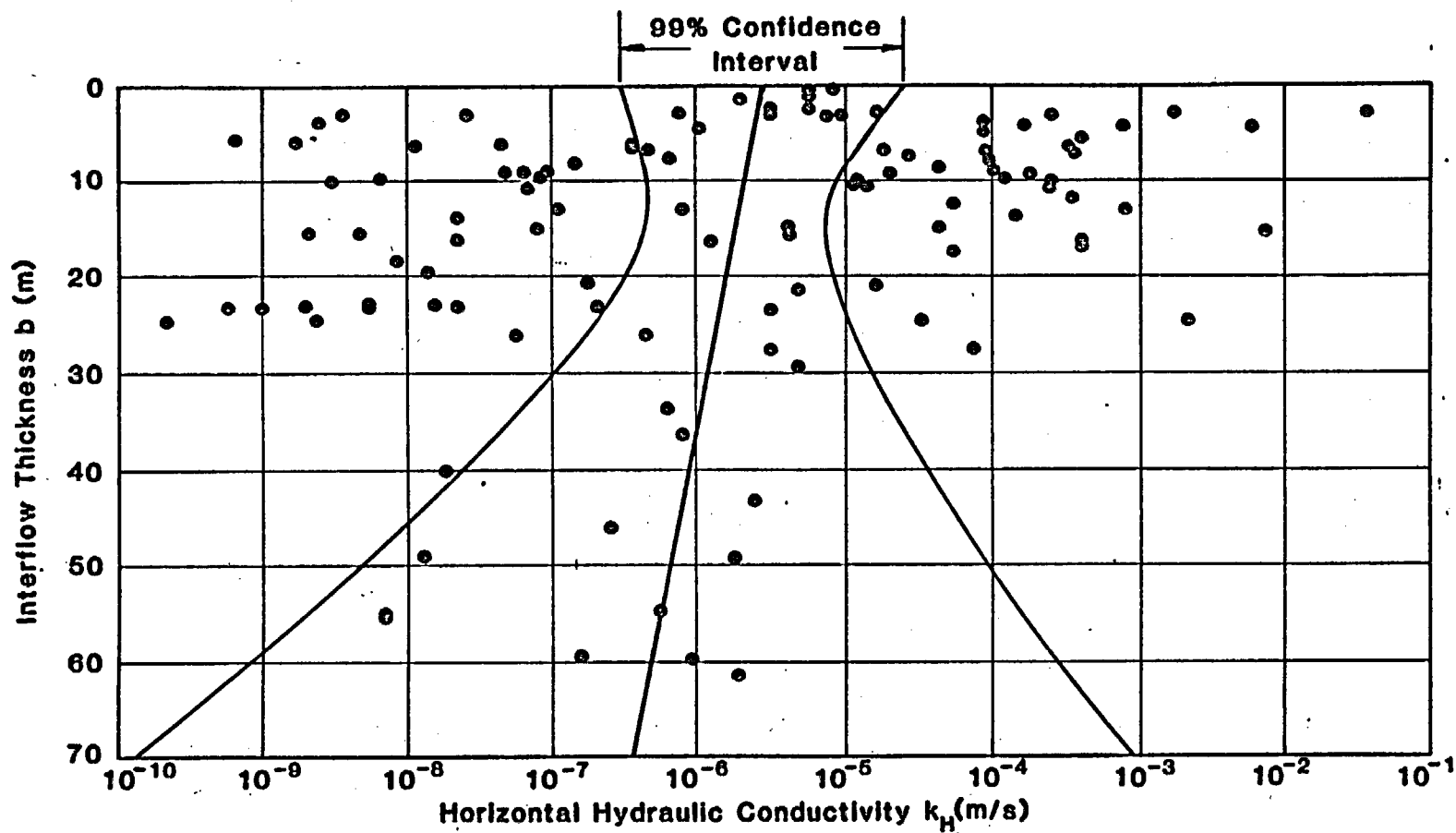
Figure 8



Correlation Coefficient -0.514

HORIZONTAL HYDRAULIC CONDUCTIVITY
VERSUS THICKNESS OF INTERFLOW

Figure 9

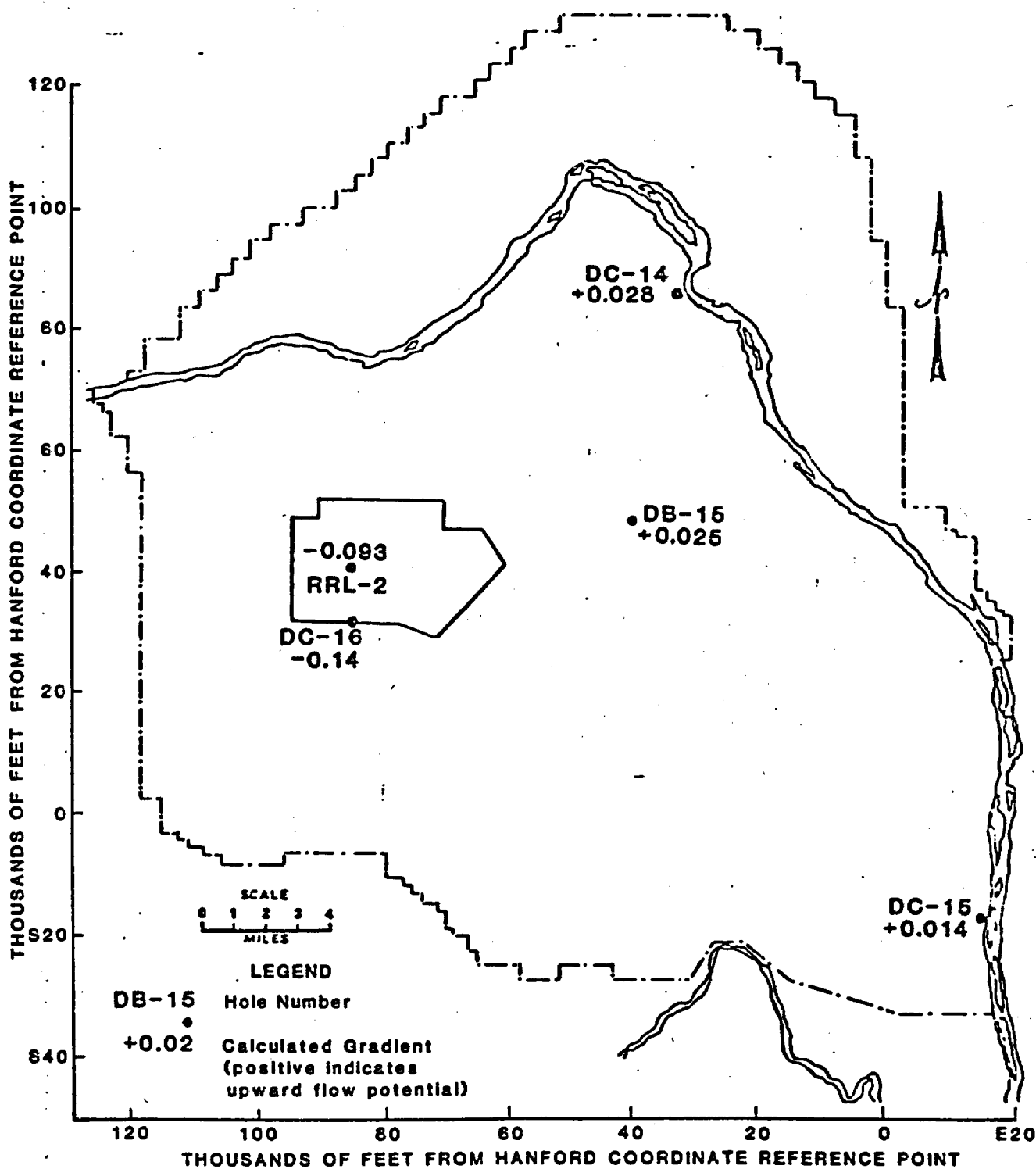


Correlation coefficient 0.0694

H-36

CALCULATED VERTICAL GRADIENTS BETWEEN THE MABTON AND PRIEST RAPIDS

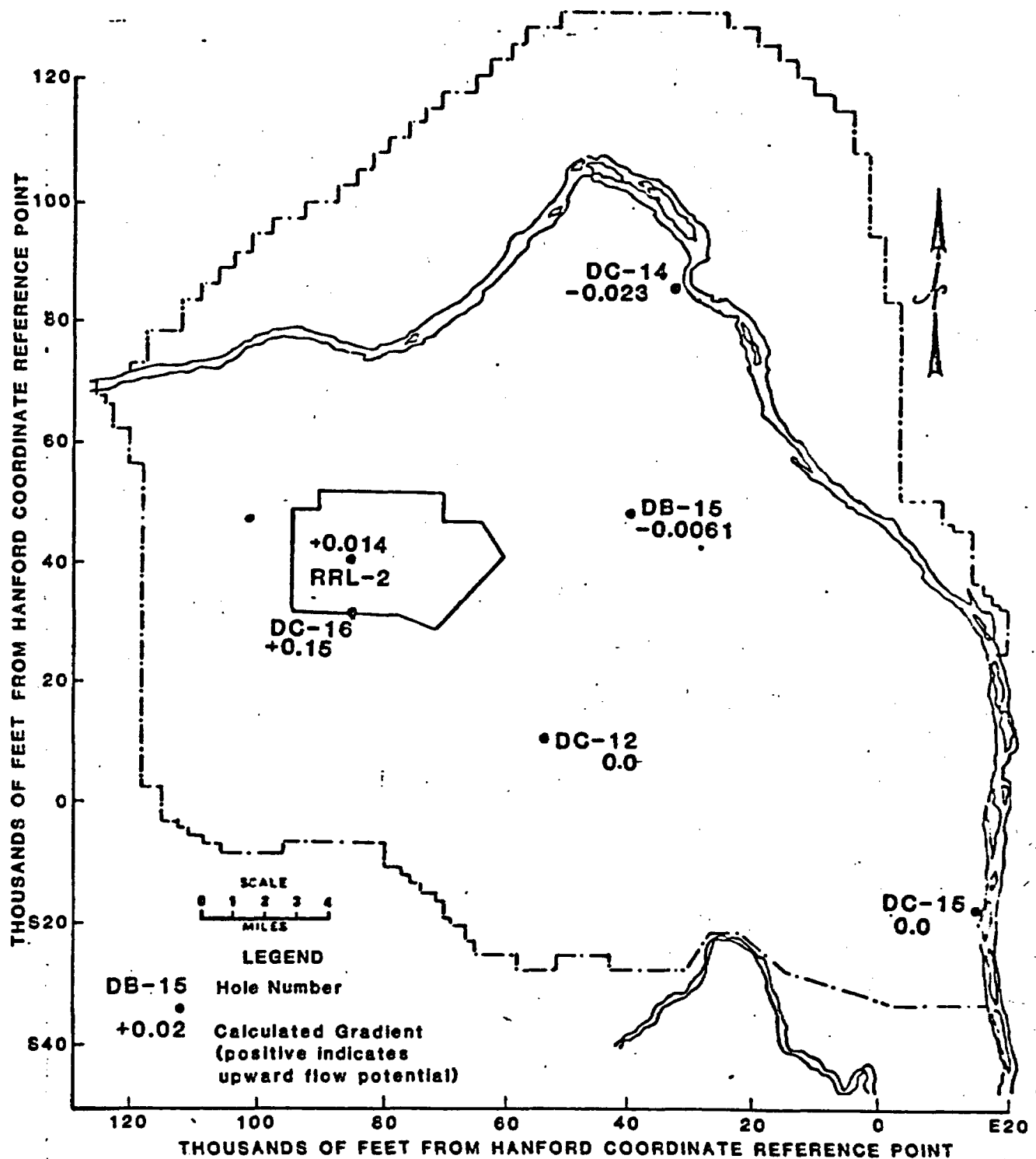
Figure 10A



Note: Positive value indicates upward flow

CALCULATED VERTICAL GRADIENTS BETWEEN THE PRIEST RAPIDS AND ROZA

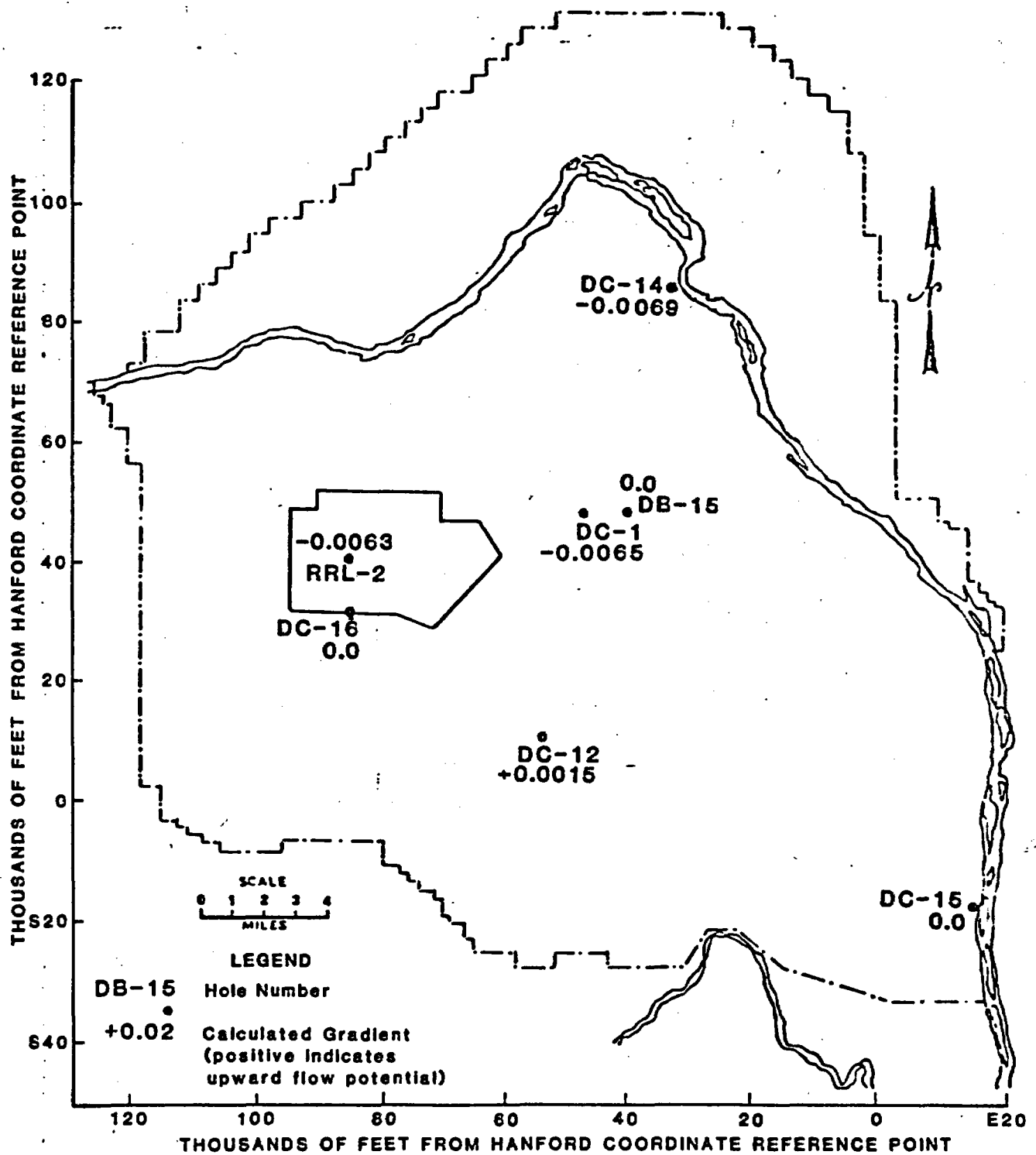
Figure 10B



Note: Positive value indicates upward flow

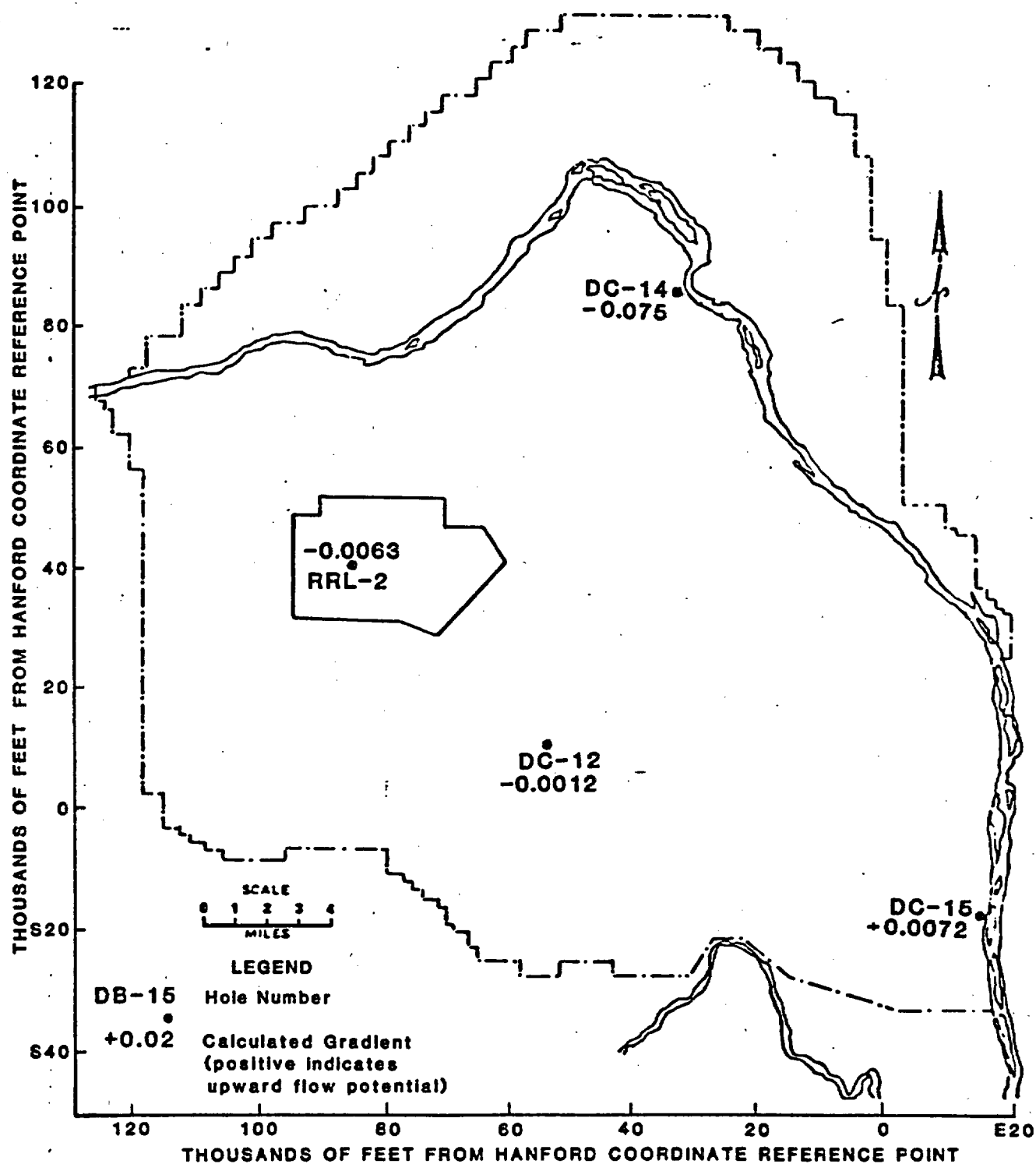
CALCULATED VERTICAL GRADIENTS BETWEEN THE ROZA AND FRENCHMAN SPRINGS

Figure 10C



CALCULATED VERTICAL GRADIENTS BETWEEN THE FRENCHMAN SPRINGS AND GRANDE RONDE A

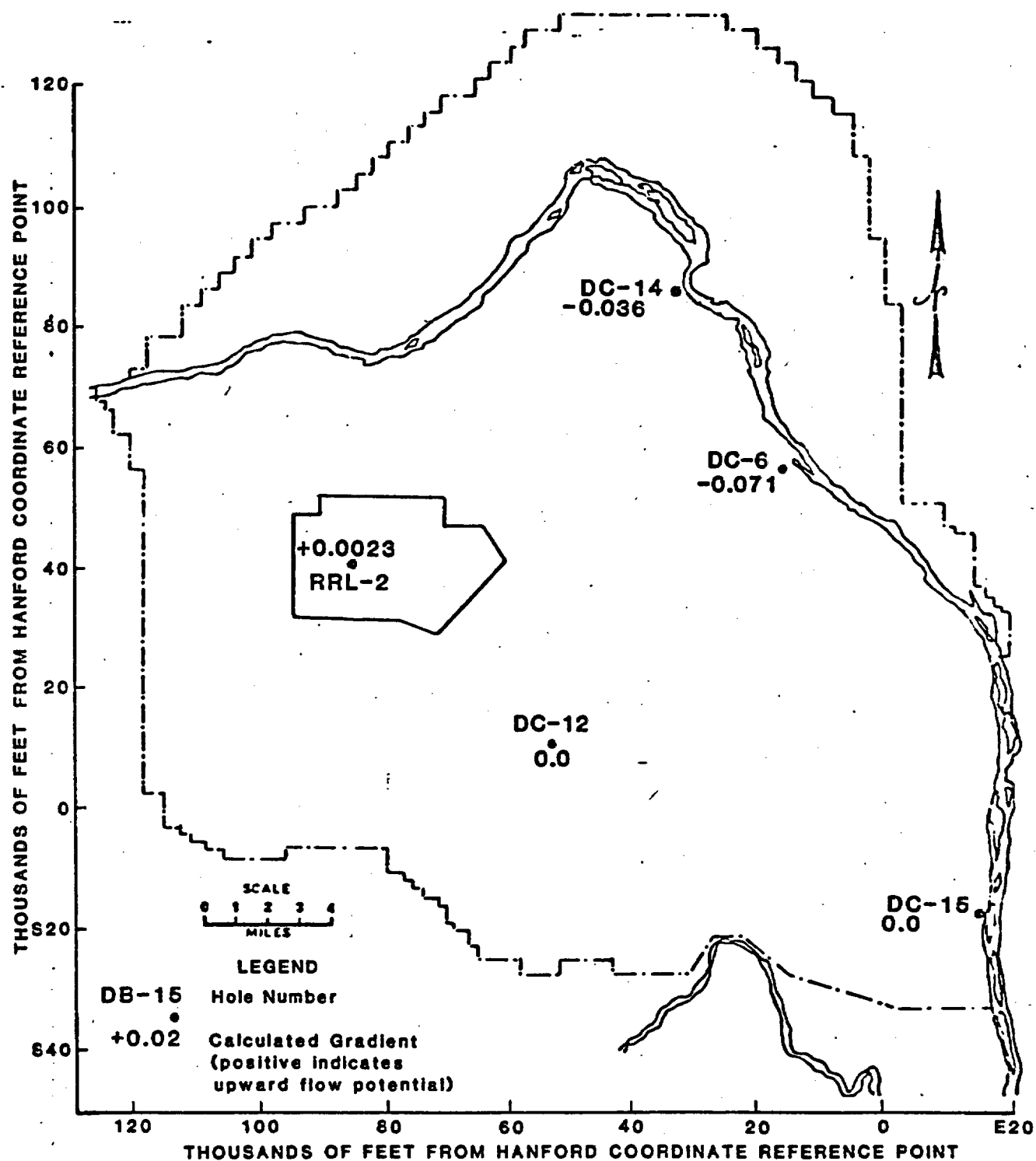
Figure 10D



Note: Positive value indicates upward flow

CALCULATED VERTICAL GRADIENTS BETWEEN THE GRANDE RONDE A AND GRANDE RONDE B

Figure 10E

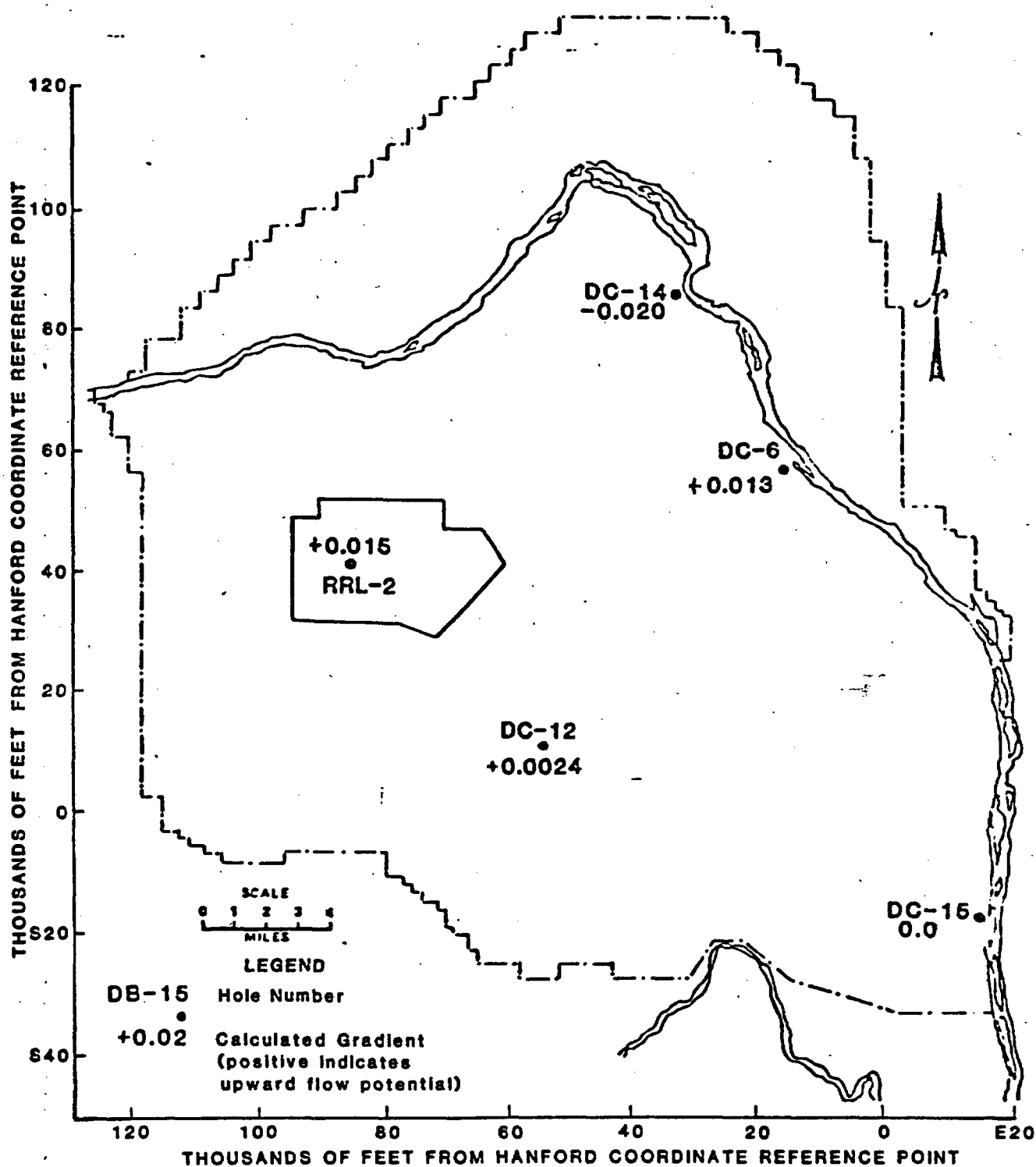


Note: Positive value indicates upward flow

H-41

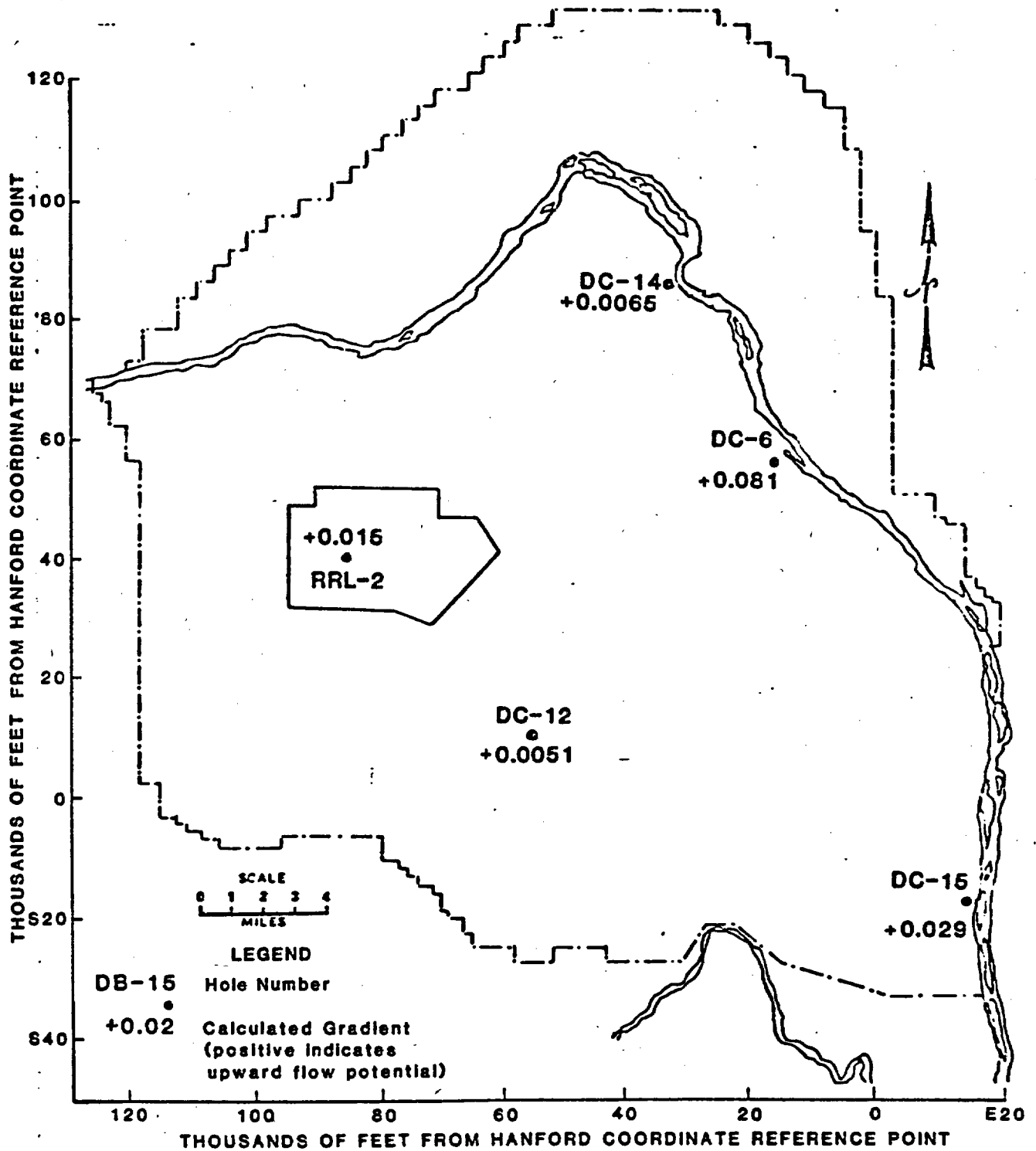
CALCULATED VERTICAL GRADIENTS BETWEEN THE GRANDE RONDE B AND GRANDE RONDE C

Figure 10F



CALCULATED VERTICAL GRADIENTS BETWEEN THE GRANDE RONDE C AND GRANDE RONDE D

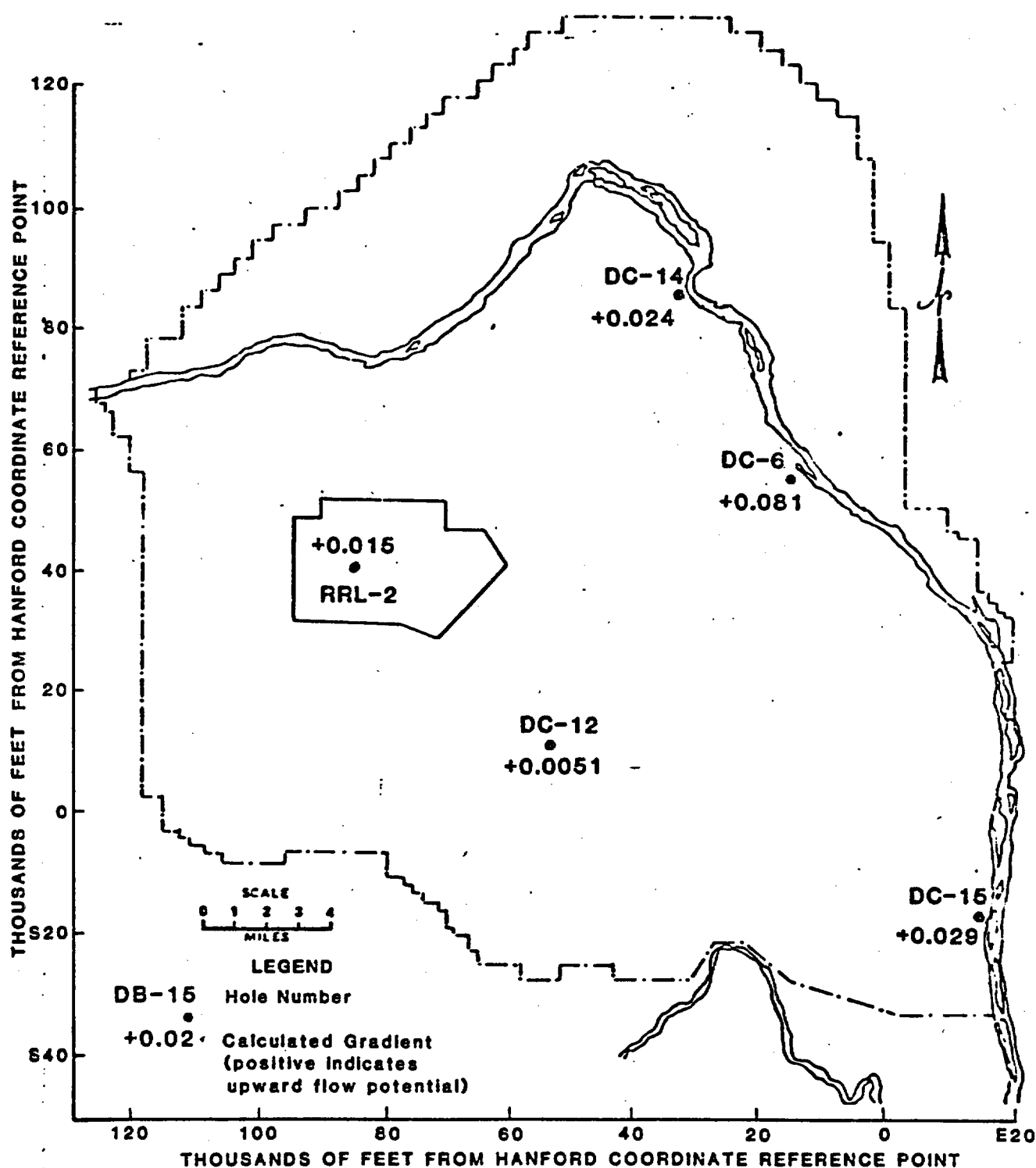
Figure 10G



Note: Positive value indicates upward flow

CALCULATED VERTICAL GRADIENTS BETWEEN THE GRANDE RONDE D AND GRANDE RONDE E1

Figure 10H

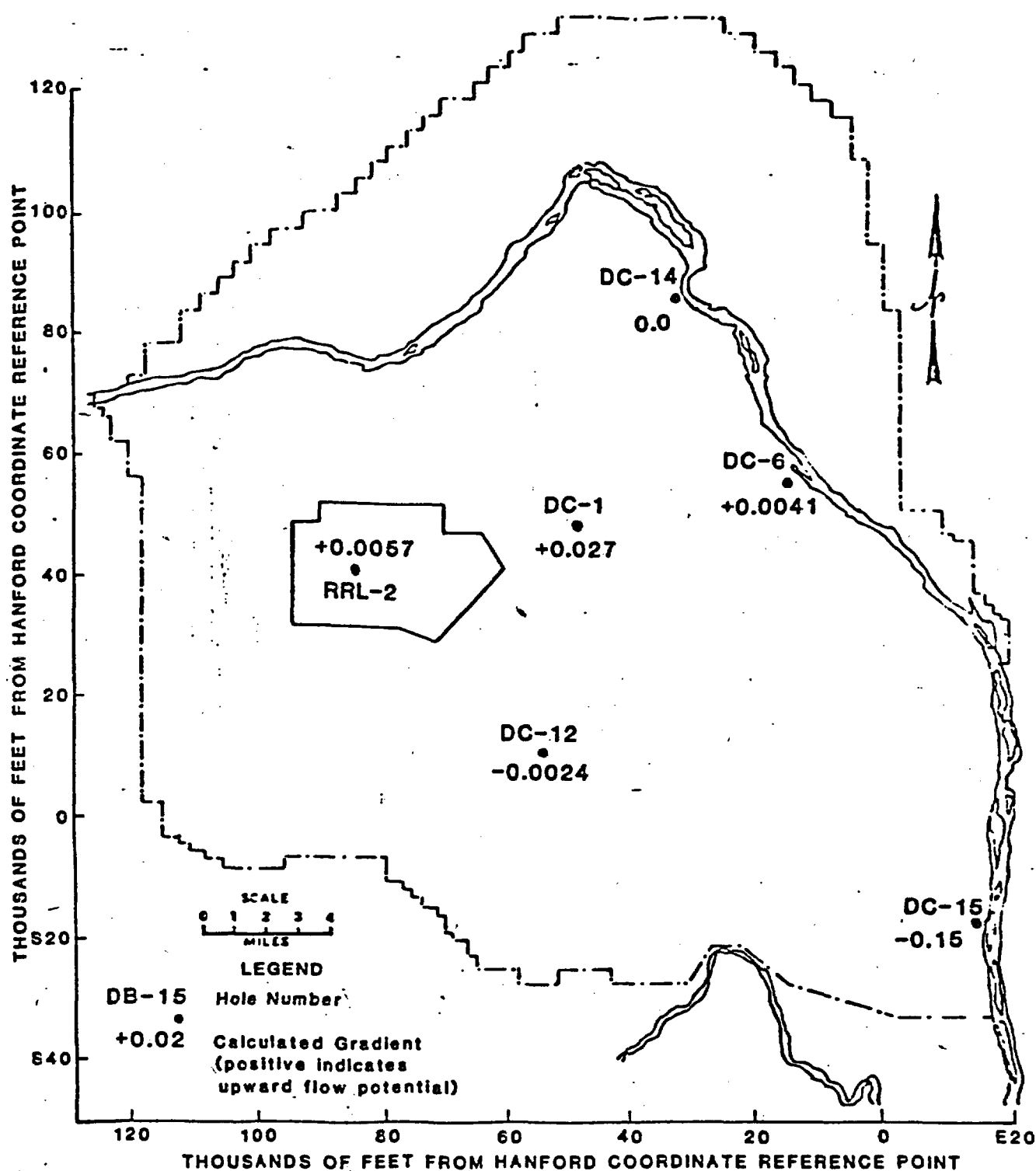


Note: Positive value indicates upward flow

H-44

CALCULATED VERTICAL GRADIENTS BETWEEN THE GRANDE RONDE E1 AND GRANDE RONDE E3

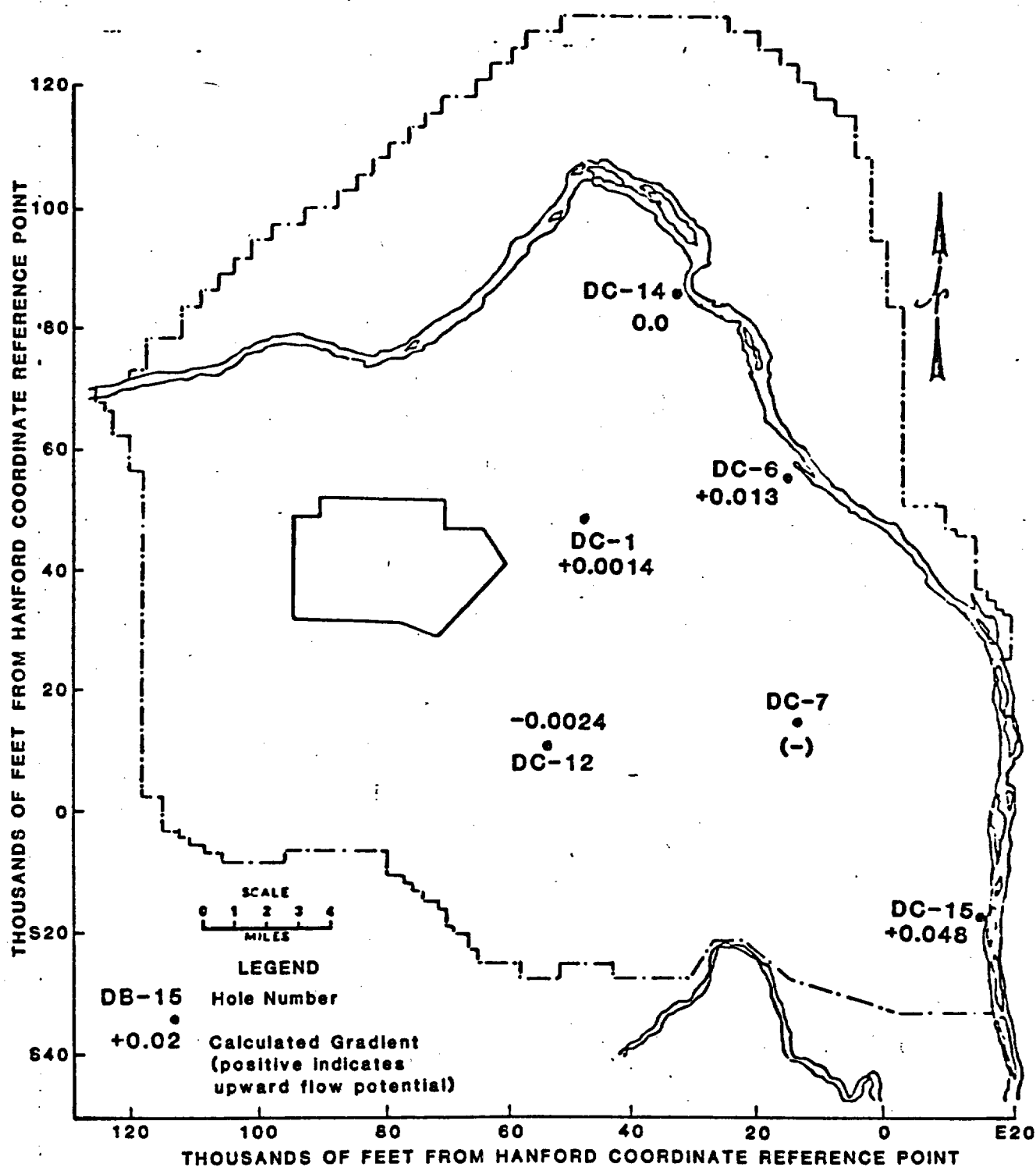
Figure 10I



H-45

CALCULATED VERTICAL GRADIENTS BETWEEN THE GRANDE RONDE E3 AND GRANDE RONDE F

Figure 10J



Note: Positive value indicates upward flow

Hydraulic head in Grande Ronde F interpolated 200 meters below Grande Ronde E3