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

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

/s/

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 nls	3/ /83	3/ /83	3/31/83			

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Site Characterization Report for the Basalt Waste Isolation Project

November 1982

Prepared by Rockwell Hanford Operations
Under Contract DE-AC06-77RL01030

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

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Volume II

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November 1982

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Prepared For:
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Assistant Secretary for Nuclear Energy
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DOE/RL 82-3
Volume III

Site Characterization Report for the Basalt Waste Isolation Project

November 1982

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Prepared For:
U.S. Department of Energy
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APPENDIX C

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

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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 interrelationships 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~~ may 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

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. For the SCR 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.

The DOE definition of issue used in the SCR 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 reposiotry 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 form 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 perperties 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

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.

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 NRC 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 Intitutional). Table C-2 lists all of the performance and specific issues. These issue statments 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), which are working papers developed during the early stages of the SCR analysis. 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.

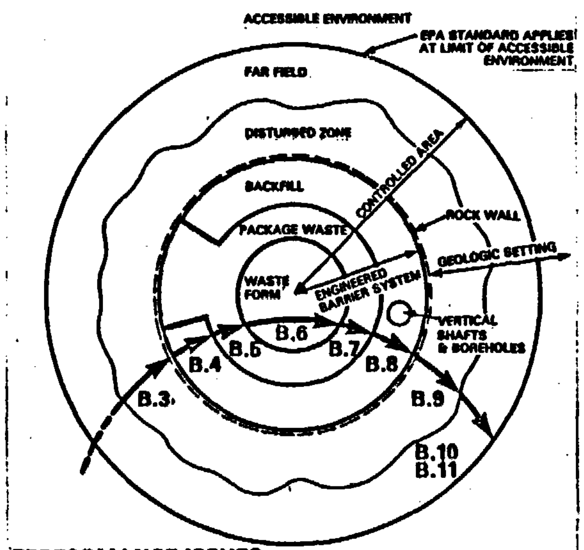
Issue ratings are given for the following four categories: 1) importance to repository performance and suitability, 2) ease of resolution, 3) current level of resolution, based on SCR contents and information gained during technical interactions with DOE and DOE contractors, and 4) likely level of resolution 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 <u>CORRELATION OF NRC AND DOE ISSUES AND WORK ELEMENTS</u>

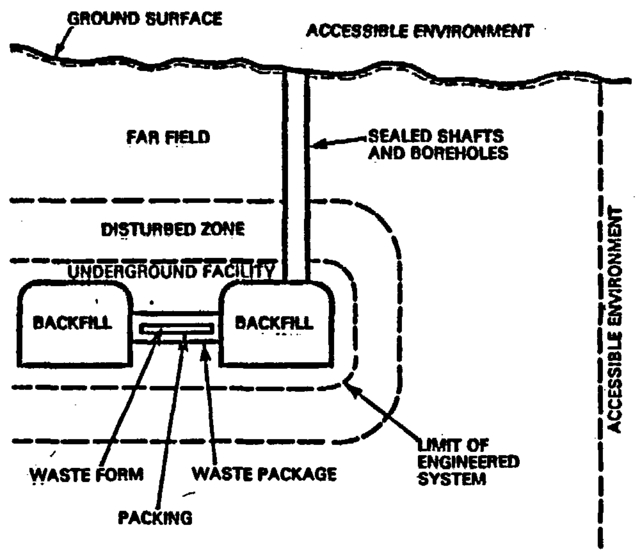
The DOE site characterization plans are organized and presented using thier issue/work element structure. Tables C-5 and C-6 list the numbered DOE issues and work elements.

The analysis of the site characterization program for each NRC issue included identifying and evaluating those DOE issues and work ~~elelemtns~~ 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 DOEs' plans in the SCR.

DIAGRAMMATIC PLAN VIEW



DIAGRAMMATIC CROSS SECTION 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?

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

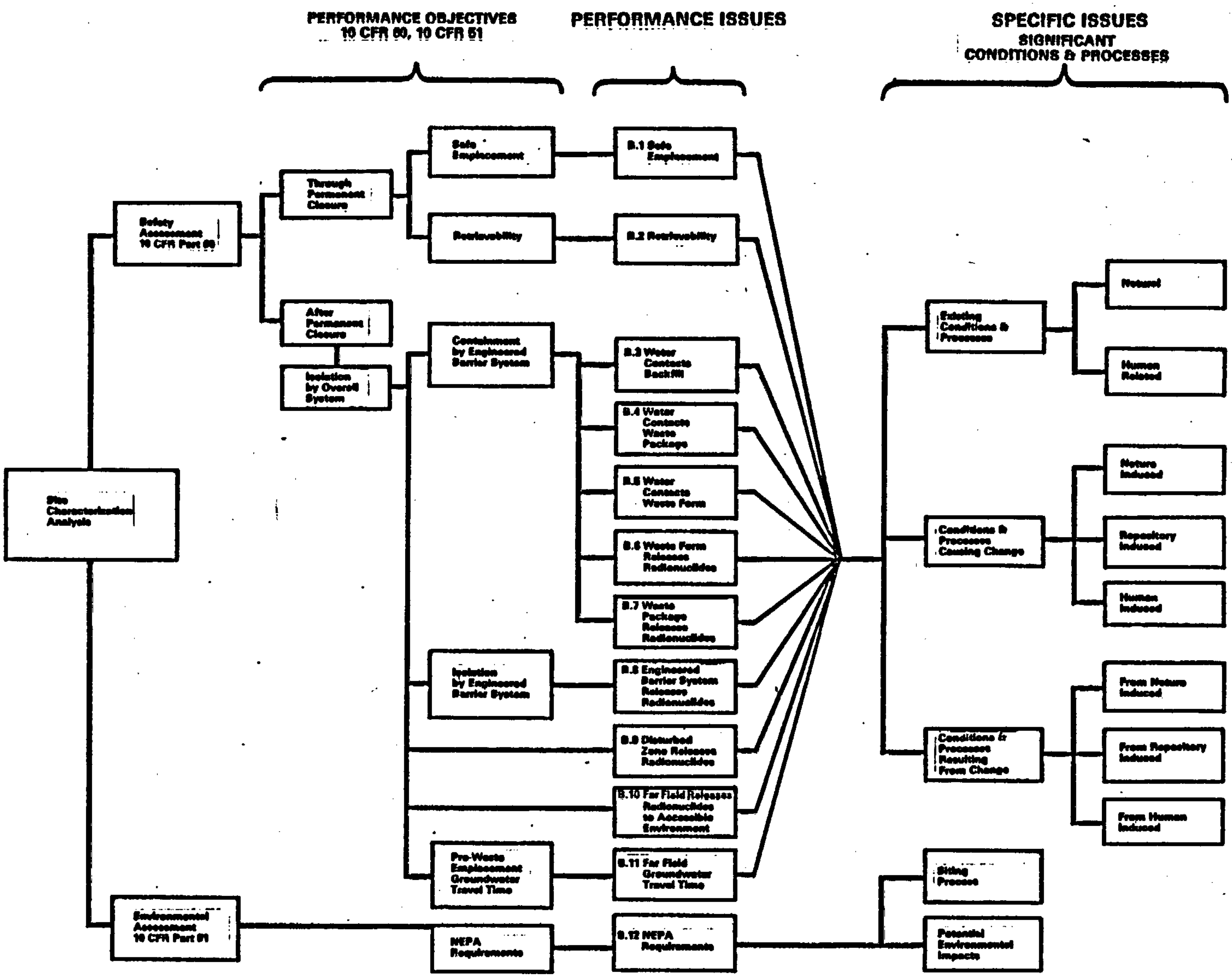


FIGURE C-2 LOGIC FOR BREAKDOWN OF NRC BWIP ISSUES

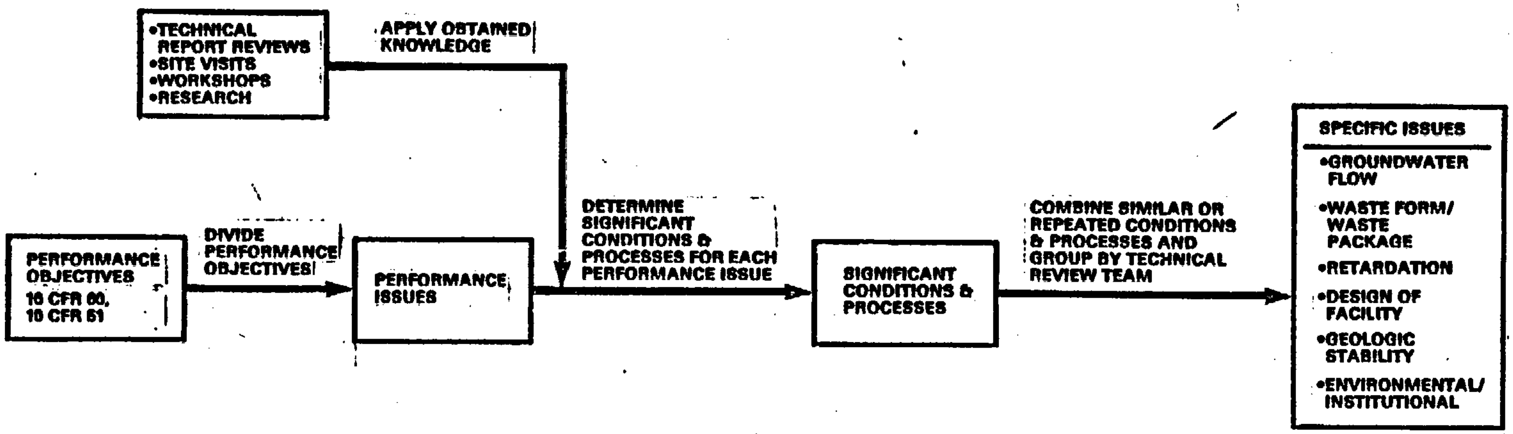


FIGURE C-3 PROCESS USED FOR IDENTIFYING NRC BWIP ISSUES

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

10 CFR PART 60 PERFORMANCE OBJECTIVES		PERFORMANCE ISSUES	
SAFETY			
• Performance of the geologic repository operations area through permanent closure 10 CFR 60.111	• Protection against radiation exposures and releases of radioactive material, 10 CFR 60.111a	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?
	• Retrievability of waste, 10 CFR 60.111b	B.2	How do the design criteria and conceptual design accommodate the retrievability option?
• Performance of the overall system after permananent Closure 10 CFR 60.112	• Containment by the engineered barrier system, 10 CFR 60.113(a)(ii)(A)	B.3	When and how does water contact the backfill?
		B.4	When and how does water contact the waste package?
	• Isolation by the engineered barrier System, 10 CFR 60.113(a)(ii)(B)	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?
	• Pre-waste emplacement groundwater travel time, 10 CFR 60.113(a)(2)	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			
• Nuclear facility NEPA requirements 10 CFR 51		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, dispersitvity, 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 ELEMENT IDENTIFIED BY DOE ISSUE NO.	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.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 radionclides 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 outermost packing material/rock/backfill 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 backfill 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 disturbed zone 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 far field 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 sorption 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 solubility/concentration 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 colloids/particulates 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> <u>Eh,</u> <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> <u>Eh,</u> <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., groundwater, species, concentration, Eh, pH and others as appropriate) anticipated in the far field 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 backfill 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 disturbed zone rock/fracture-filling materials (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 far field rock/fracture filling-materials environment through time?	W.2.A	W.2.3.A
	3.9.4 What are the geochemical reactions anticipated in seals 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 groundwater 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 radiolysis 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 Eh (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, 5.1.18.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 AND WORK ELEMENT IDENTIFIED BY DOE	
		ISSUES IDENTIFIED BY NRC	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, threatehed 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?

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	
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					●		●						

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	
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			●	●				●	●	●			

TABLE C-3 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											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	
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-~~7~~4 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 4 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	○	○	●	○	
2.7	●	○	●	○	P
2.8	○	○	●	○	
2.9	○	○	●	○	Q
2.10	○	○	●	○	
2.11	○	●	●	○	
2.12	○	○	●	●	
2.13	●	○	●	○	Q
2.14	●	○	●	○	Q
2.15	●	○	●	○	Q
2.16	●	○	●	○	Q
2.17	○	●	●	○	
2.18	○	○	●	○	Q
2.19	○	○	●	○	
2.20	●	○	●	○	
2.21	●	○	●	○	R
2.22	○	○	●	○	
2.23	○	○	●	●	
2.24	○	○	●	○	
2.25	○	○	●	○	
2.26	○	○	●	○	
2.27	○	○	●	●	
3.0 Retardation					
3.1	●	○	○	?	6,U
3.1.1	●	○	○	?	6,U
3.1.2	●	○	○	?	6,U
3.1.3	●	○	●	?	6,U
3.2	●	○	○	?	6,T
3.2.1	●	○	○	?	6,T
3.2.2	●	○	○	?	6,T
3.2.3	●	○	○	?	6,T
3.2.4	●	○	○	?	6,T
3.2.5	●	○	○	?	6,T
3.2.6	●	○	○	?	6,T
3.2.7	●	○	●	?	6,T
3.3	●	○	●	?	6
3.4	●	○	●	?	6
3.5	●	•	○	?	6
3.6	●	•	○	?	6
3.7	●	•	○	?	6
3.8	●	○	○	?	S,T,U

TABLE C-4 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

TABLE C-4 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					

TABLE C-5 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 measuremetns 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?	S.1.1.A Determine the thickness and continuity of the candidate repository horizons within the reference repository location. 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. 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. S.1.4.A Determine the primary internal structure of the candidate repository horizons within the reference repository location. 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.
	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. S.1.7.A (Related to S.1.11.B) Determine the stratigraphic characteristics of the flows above and below the candidate repository horizons. 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. 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.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	S.1.10.A (Related to S.1.27.C, S.1.28.C, S.1.29.C, and S.1.30.C) Determine the presence and characteristics of other possible anomalies that could serve as zones of greater permeability.
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.1.11.B (Related to S.1.17.B) Evaluate the regional structural and tectonic setting of the Pasco Basin. S.1.12.B (Related to S.1.11.B and S.1.29.C) Determine the location of folds and faults in the Pasco Basin area with emphasis on the reference repository location. S.1.13.B Evaluate the type and amount of displacement, geometry (width and continuous length), and age of faults within the Pasco Basin. S.1.14.B 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.
	S.1.15.B (Related to S.1.13.B, R.1.3.A, and R.1.6.A) Evaluate the geologic (long-term) and contemporary rate of deformation and stress field in the Pasco Basin and reference repository location. S.1.16.B (Related to R.1.29 and R.1.30) Determine the seismicity of the Pasco Basin and reference repository location. S.1.17.B (Related to S.1.11.B through S.1.16.B, and S.1.23.B) Develop a conceptual model that can be used to evaluate the past, present, and projected tectonic setting of the reference repository location. S.1.18.B (Included in S.1.12.B, S.1.13.B, and S.1.14.B) Determine the presence of active faults within the geologic setting; evaluate their rupture length. S.1.19.B (Included in S.1.12.B and S.1.13.B) Determine if Quaternary faulting is present within the disturbed zone.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	S.1.20.B (Included in S.1.12.B through S.1.16.B) 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.
	S.1.21.B (Included in S.1.11.B, S.1.12.B, and S.1.15.B) Evaluate the nature of structural deformation such as uplift, subsidence, folding, and fracturing during the Quaternary Period.
	S.1.22.B (Included in S.1.16.B) 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.
	S.1.23.B (Related to S.1.17.B) Determine the nature of igneous activity within the Pasco Basin.
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?	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) Determine the hydraulic properties of the groundwater flow systems.
	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) Determine the hydraulic heads of the groundwater flow systems.
	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) Determine the hydrochemistry of the basalt groundwater system.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element	Issues	Work element
	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) Determine the geometry of and interaction between the confined flow systems. 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) Determine the extent of vertical groundwater movement between the confined, unconfined, and surface water systems. 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) Determine the hydrologic characteristics and influences of structure and stratigraphic discontinuities that may shorten groundwater flow paths and solute transport times.		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.C through 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.1.31.C (Related to S.1.30.C, S.1.33.C, S.1.34.C, S.1.38.D, and S.1.39.D) Develop and/or modify numerical codes that adequately simulate groundwater flow, natural hydrochemical species transport, and travel times under pre-waste-emplacement conditions. S.1.32.C (Included in S.1.41.D) Evaluate the ranges of relevant hydrogeologic conditions since the start of the Quaternary Period. 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) Using selected models, predict groundwater travel time from the repository location to the accessible environment under pre-waste-emplacement conditions.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	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) Determine the bounds of uncertainty in model predictions of pre-waste-emplacement groundwater travel time. S.1.35.C (Included in S.1.30.C) Determine the groundwater content of the host rock. S.1.36.C (Included in S.1.30.C) Determine the nature of groundwater circulation in the host rock.
Issue 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?	
	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) 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.1.38.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) Determine the radionuclide transport, thermal, and mechanical properties of the geohydrologic system. 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) Using selected models, predict radionuclide mass fluxes to the accessible environment. S.1.40.D (Related to S.1.39.D) Determine the bounds of uncertainty in the model predictions of radionuclide fluxes to the accessible environment.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	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) 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.1.42.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) Determine whether the range of geochemical conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.
	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) Determine whether the range of hydrogeologic conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.
	S.1.44.D (Related to S.1.45.D, S.1.48.D and S.1.49.D) Determine the potential for, and effect of, failure of existing or planned man-made surface water impoundments.
	S.1.45.D (Related to S.1.16.B, S.1.41.D, S.1.46.D, and S.1.49.D) Determine the effect of potential impoundments on the groundwater flow system.
	S.1.46.D (Related to S.1.41.D, S.2.1, and S.2.4) Determine the potential for human activity to cause significant changes in the surface and groundwater hydrology.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	S.1.47.D (Related to R.1.34) Determine the potential for and the effect of occupancy and modification of the Columbia River flood plain. S.1.48.D (Included in S.1.45.D) Determine the potential for and magnitude of impoundment that could affect a change in the regional groundwater flow. 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) Evaluate the effect of possible climatic changes. S.1.50.D (Related to S.1.41.D, R.1.18.D, and R.1.20.D) Determine the potential effect of boreholes on repository performance. S.1.51.D (Included in S.1.41.D) Determine the effect on waste isolation of potential changes in such hydrologic conditions as hydraulic gradient, average interstitial

Issues	Work element
	velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points. 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) Determine whether the range in tectonic and structural conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint. S.1.53.D (Included in S.1.16.B, S.1.17.B, and S.1.52.D) Determine the historical seismicity of the geologic setting and if there are any historical earthquakes that could adversely affect the repository. S.1.54.D (Included in S.1.11.B through S.1.17.B, and S.1.52.D) Determine the effect of an active fault within the geologic setting on repository performance.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	S.1.55.D. (Included in S.1.11.B through S.1.17.B, and S.1.52.D) Determine the effect of an active fault within the disturbed zone on repository performance.
	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) Determine the effect of faults and fractures on repository performance.
	S.1.57.D (Included in S.1.16.B, S.1.17.B, and S.1.52.D) Determine the effect of seismicity on repository performance.
	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) Determine the effect of structural deformation such as uplift, subsidence, folding, and fracturing on repository performance.
	S.1.59.D (Related to S.1.17.B, S.1.23.B, S.1.41.D, and R.1.34) 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.
	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) Determine whether the range of geomorphic conditions since the start of the Quaternary Period indicates instability from a waste isolation standpoint.
	S.1.61.D (Included in S.1.60.D) Determine the likelihood of repository exhumation due to extreme erosion over the next 10,000 years.
S.2 - Environment and Socioeconomics	
None.	S.2.1 (Related to S.1.46.D, S.2.3, and S.2.4) Establish baseline ecologic, radiologic, sociopolitical, and economic conditions against which impacts can be assessed and mitigation measures proposed.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
None.	S.2.2 (Related to S.2.3) Determine if subsurface mining is present within the disturbed zone. S.2.3 (Related to S.2.1, S.2.2, and R.1.34) 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.
None.	S.2.4 Identify the distribution of land ownership, use, and control of the repository area.
None.	S.2.5 (Related to S.1.49.D) 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.

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?	R.1.1.A Determine the methodology for design and analysis of subsurface openings and their support systems. R.1.2.A Evaluate the effect of underground construction sequence on the stability of openings. 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. R.1.4.A Determine the magnitude and distribution of excavation-induced stresses for single and multiple openings. R.1.5.A Determine the magnitude and distribution of thermal stresses in the rock mass for the proposed waste package storage configuration.
	R.1.6.A (Related to R.1.7.A and R.1.48) 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. R.1.7.A (Related to R.1.6.A and R.1.48) Document occurrences of dynamic instability of test excavations at depth at the repository site. 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. R.1.9.A Determine the potential for subsidence caused by mine openings.

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.
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 wth 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
	R.1.18.D Identify performance requirements for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste.
	R.1.19.D Select materials and develop testing techniques required to meet repository room and tunnel sealing criteria.
	R.1.20.D Determine the effect of temperature, rock-mass deformation, groundwater flow, and groundwater chemistry on materials used for seals.
	R.1.21.D Develop grouts and grouting techniques that ensure acceptable sealing of the disturbed rock zone.
	R.1.22.D Determine the effects of temperature, rock-mass deformation, and time on the permeability of the sealed rock zone.
	R.1.23.D Select materials and develop testing techniques required to meet borehole sealing criteria.
	R.1.24.D Develop construction and test techniques required to meet repository tunnel and shaft sealing criteria.
	R.1.25.D Prepare final specifications for sealing boreholes, tunnels, shafts, and rooms containing nuclear waste.
	R.1.26.D Develop methods and equipment for backfilling and sealing the repository, and demonstrate their effectiveness.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
None.	R.1.27 Determine which facilities or systems within the facility will be designated and classified as high-level waste facilities.
None.	R.1.28 Assess the effects of adverse conditions on the design and performance of the repository. R.1.29 (Related to R.1.30) Assess the effects of seismic events on underground openings during construction and operations. R.1.30 (Related to R.1.29) Assess the effects of seismic events on repository tunnel and shaft seals.

Issues	Work element
	R.1.31 Develop shielding requirements, operating, and access control procedures to limit the dose to repository personnel. R.1.32 Develop the procedures and requirements for controlling access to the repository site. R.1.33 Determine the techniques to be used for limiting, monitoring, and controlling the airborne radioactivity in the repository.
None.	R.1.34 Develop a design that will protect operations personnel against the effects of natural phenomena and environmental conditions.
None.	R.1.35 Determine the impact of the dynamic effects of equipment failure on safety-related systems and components.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
None.	R.1.36 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.
None.	R.1.37 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.
	R.1.38 Define which combustible materials can be used in the design of components and equipment that have been designated as safety-related systems.
	R.1.39 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.
	R.1.40 Determine the reliability and protection required to ensure that safety-related systems operate adequately under adverse or emergency conditions.
None.	R.1.41 Define what requirements are necessary to permit evacuation of personnel under emergency conditions.
	R.1.42 Determine what facilities, equipment, and services are required to ensure a safe and timely response to any emergency conditions.
None.	R.1.43 Determine which systems require redundant power supply, uninterrupted service, or standby service in the event of loss of primary power.
None.	R.1.44 Determine which structures, systems, and components are important to safety; develop and implement appropriate inspection, testing, and maintenance programs.
None.	R.1.45 Assess the potential for criticality for the proposed waste packages and storage orientations under fully flooded storage conditions.
None.	R.1.46 Determine what instrumentation and control systems are required to monitor and control safety-related systems.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	R.1.47 (Related to R.2.5) Develop, as required, instrumentation to measure stresses, deformation, temperature, and pore pressures reliably until backfill is emplaced. R.1.48 (Related to R.1.6.A and R.1.7.A) Develop or adapt instrumentation and monitoring techniques to predict rock bursts.
None.	R.1.49 Determine the requirements necessary to assure that safety-related systems provide adequate protection to construction and operations personnel.
None.	R.1.50 Determine the requirements and procedures necessary for the safe receipt and surface storage of radioactive wastes.
None.	R.1.51 Determine the ventilation requirements for the surface facilities that will contain radioactive materials.
None.	R.1.52 (Related to R.1.33) 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.
None.	R.1.53 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. R.1.54 Determine the requirements for design of the surface waste disposal facilities to facilitate decommissioning.
None.	R.1.55 (Related to W.1.12.A) Determine that the interaction between the waste package, the underground facilities, and the geologic setting does not compromise the performance of the underground facilities.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
	R.1.56 (Related to R.1.18.D, R.1.19.D, and R.1.66). 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. R.1.57 Provide an appropriate orientation, geometry, waste placement, and layout of the repository to ensure structural stability and containment of radionuclides.
None.	R.1.58 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.

Issues	Work element
None.	R.1.59 Define the requirements necessary to allow for the emplacement or retrieval of waste packages during continuous excavation and construction of the repository. R.1.60 (Included in R.1.36) Determine what safety requirements are necessary to isolate waste package storage rooms from other areas in the event that accidents occur.
None.	R.1.61 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).
None.	R.1.62 . Define the requirements, equipment, and procedures necessary to retrieve the radioactive waste after emplacement in the repository if retrieval is ultimately required.

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

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
R.2 - Performance Confirmation	
None.	R.2.1 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.
None.	R.2.2 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. R.2.3 (Identical to R.1.11.8) Measure rock strength and deformation characteristics on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture. R.2.4 (Identical to R.1.12.8) Measure rock thermal properties on a laboratory and rock-mass scale as a function of stress, time, temperature, and moisture.

Issues	Work element
None.	R.2.5 (Related to R.1.47) Deploy instrumentation, as required, to reliably measure stresses, deformation, temperature, and pore pressures until backfill is emplaced.
None.	R.2.6 Conduct field tests, as required, of borehole plugging to demonstrate that materials and emplacement methods meet requirements.
None.	R.2.7 Conduct field tests, as required, of repository room, tunnel, and shaft backfill placement to demonstrate that materials and emplacement methods meet requirements.
None.	R.2.8 Conduct field tests, as required, of repository tunnel and shaft seals to demonstrate that materials emplacement methods meet functional requirements.
None.	R.2.9 Develop, as required, instrumentation, techniques, and procedures for monitoring the integrity of the waste package in situ. R.2.10 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.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

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

Issues	Work element
	W.1.15.B (See also W.1.16.B) Define the characteristics of the backfill materials required to retard the flow of groundwater to the canister. Identify potential backfill materials with these characteristics. W.1.16.B 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. W.1.17.B (Identical to W.1.8.A, included in W.1.3.A) Determine the effect of radiation damage on the performance of the waste form, backfill, and host rock. W.1.18.B (Identical to W.1.1.A) Determine the maximum operating temperature limits for waste form, backfill, canister, and host rock. W.1.19.B (Identical to W.1.12.A and W.2.3.A) 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. W.1.20.B (Included in W.2.13.D) Determine if a waste package backfill is required to provide acceptable containment in the event of premature canister failure.

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?)	W.1.1.A (Identical to W.1.18.B) Determine the maximum operating temperature limits for waste form, backfill, canister, and host rock. 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. 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. 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 species for key radionuclides which might be released from the waste package.
	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. 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. 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. 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. 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.

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

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

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

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 wich 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. 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.	W.3.6 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. W.3.7 Determine suitability of using nonradioactive chemical analogues for actual waste forms in the hydrothermal testing program.
None.	W.3.8 Determine requirements for monitoring. Define parameters, methodology, interpretive criteria, and actions.

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.1.1-SC (Identical to P.2.1-WA 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. 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) 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.1.31.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) Develop and/or modify numerical codes that adequately simulate groundwater flow and travel times under pre-waste-emplacement conditions.
	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) Using selected models, predict groundwater travel time from the repository location to the accessible environment under pre-waste-emplacement conditions. 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) Determine the bounds of uncertainty in model predictions of pre-waste-emplacement groundwater travel time. W.2.13.D-SC (Includes discussion of W.1.20.B and W.2.11.C) Determine to what degree the characteristics of the geologic setting complement the engineered system. P.1.2-SC (Identical to P.2.2-WA and P.3.2-SD) Conduct verification, validation, and benchmarking of all codes used for performance assessment. P.1.3-SC (Identical to P.2.3-WA and P.3.3-SD) Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979).

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

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

TABLE LIST OF DOE BWIP ISSUES AND WORK ELEMENTS

Issues	Work element
P.3 - Postclosure Performance of the Waste Isolation System	
Issue S.1.D-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 preemplacement assessment), as well as the criteria on which they are based.
	S.1.41.D-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
	S.1.40.D-SD (Related to S.1.39.D) Determine the bounds of uncertainty in the model predictions of radionuclide fluxes to the accessible environment. P.3.2-SD (Identical to P.1.2-SC and P.2.2-WA) Conduct verification, validation, and benchmarking of all codes used for performance assessment. P.3.3-SD (Identical to P.1.3-SC and P.2.3-WA) Document codes and prepare user manuals in accordance with regulatory guides and national quality assurance standards (ANSI/ASME, 1979). P.3.4-SD Perform a postclosure performance assessment for the waste isolation system for inclusion in the License Application.

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

Appendix D

Reserved

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

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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 comonly 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.

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

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

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

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:

$$\frac{K_i b_i}{Kb} > 100 \quad , \qquad i = 1,2. \tag{2}$$

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

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

3.1 Hantush-Jacob Solution

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

$$s(r,t) = \frac{Q}{4\pi Kb} W\,(u,r/B) = \frac{Q}{4\pi Kb} L\,(u,\nu) \tag{4}$$

Values of W (u,r/B) are tabulated in Hantush (1956), and type curves for the function $L(u,\nu)$ are presented in Lohman (1972) and Reed (1980). Lohman (1972) describes a curve matching procedure whereby values of K, S_s, and ν 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:

$$\beta < 0.01, \tag{5}$$

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:

$$s(r,t) = \frac{Q}{4\pi Kb} H\,(u,\beta) \tag{6}$$

for:

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

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:

$$s(r,t) = \frac{Q}{4\pi Kb} L\ (u\delta,\nu) \tag{7}$$

for

$$t > \frac{5\ S'_{si}\ (b'_i)^2}{K'_i},\quad i = 1,2 \tag{8}$$

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:

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

$K'_1 = K'_2 = K' = 2.8\text{x}10^{-3}$ to $2.8\text{x}10^{-6}$ ft/day (10^{-8} to 10^{-11} m/s)
$S_{s1}' = S_{s2}' = S_s' = 10^{-8}$ ft^{-1} ($3.3\text{x}10^{-8}$ 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 ($1.7\text{x}10^{-5}$ m/s): Upper Umpumped Aquifer B
b_1 = 175 ft (53 m)

$K_2 = 2.6\text{x}10^{-1}$ ft/day ($9.2\text{x}10^{-7}$ m/s): Lower Umpumped 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_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^{-10} 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:

$K = 4.9$ ft/day (1.7×10^{-5} m/s); Aquifer B
$S_s = 10^{-7}$ ft^{-1} (3.3×10^{-7} m^{-1})
$b = 175$ ft (53 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})

$b_1' = 100$ ft (30 m); Upper Aquitard A
$b_2' = 360$ ft (110 m); Lower Aquitard C

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

$Q = 1000$ gpm (63 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_s, and the ratio (K'/S_s'), from time-drawdown data using piezometers in both the aquifer and aquitard.

The ratio method is valid for the following conditions:

$$\beta < 1.0 \tag{9}$$

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

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:

$$S'(r,z,t) = s(r,t)\, F(t_D, t'_D) \tag{10}$$

The function $F(t_D, t'_D)$ 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.

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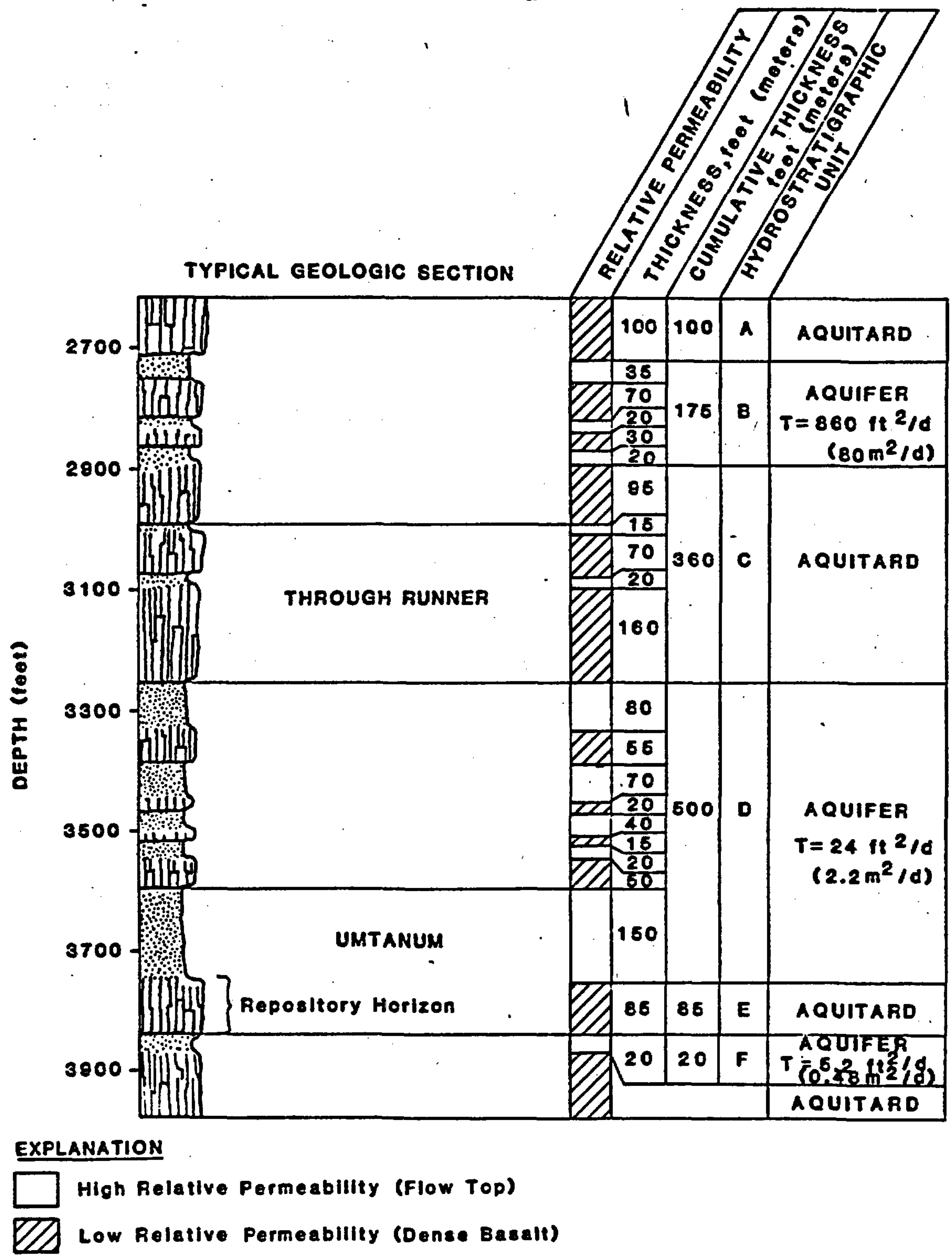
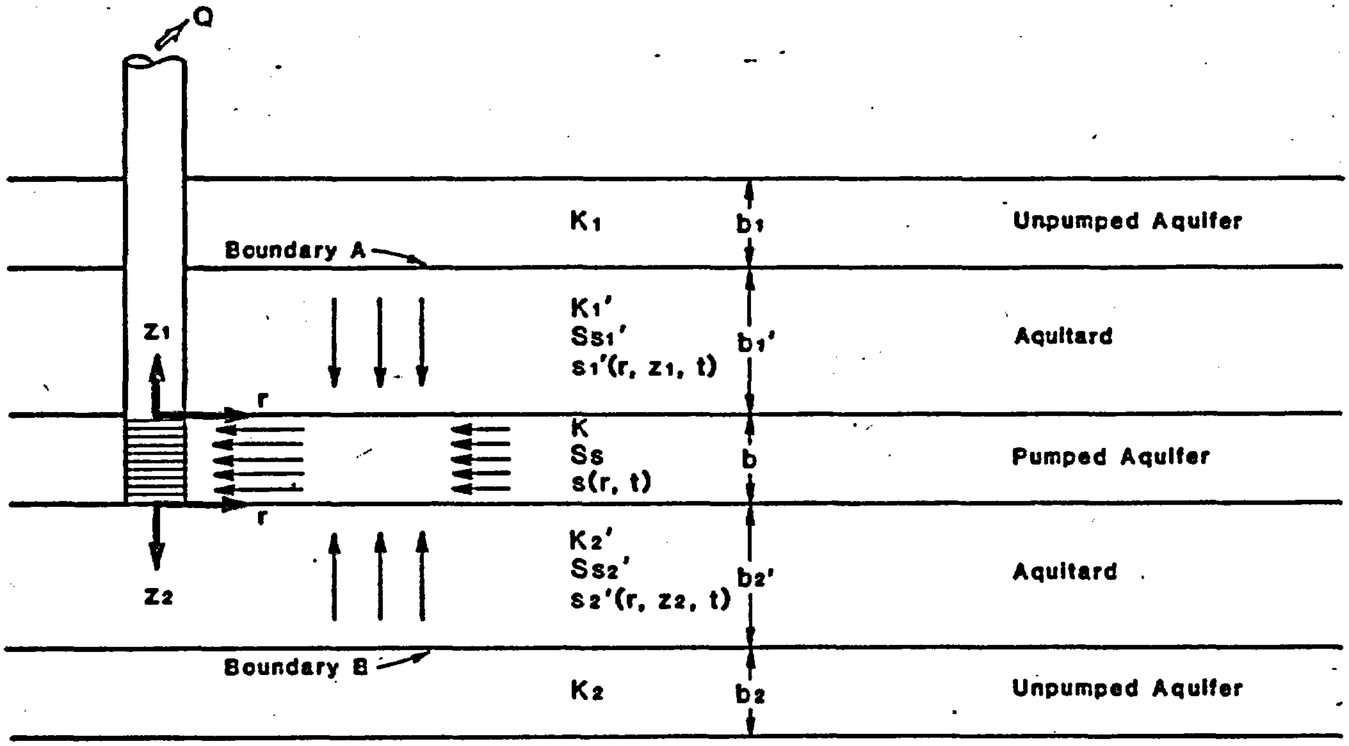
ASSUMED HYDROSTRATIGRAPHY AT THE RRL SITE Figure 1



BWIP OSCA/[illegible]/Logsdon

MATHEMATICAL MODEL

Figure 2



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_i = unpumped aquifer horizontal hydraulic conductivity ($L\ T^{-1}$)

b_i = unpumped aquifer thickness (L)

DIMENSIONLESS PARAMETERS

$$\frac{r}{B} = r\left(\sqrt{\frac{1}{Kb}\left(\frac{K_1'}{b_1'} + \frac{K_2'}{b_2'}\right)}\right)$$

$$\nu = \frac{1}{2}\left(\frac{r}{B}\right)$$

$$\beta = \frac{r}{4b}\left(\sqrt{\frac{K_1'Ss_1'}{K\ Ss}} + \sqrt{\frac{K_2'\ Ss_2'}{K\ Ss}}\right)$$

$$u = \frac{Ss\,r^2}{4Kt}$$

$$\delta = 1 + \left(\frac{Ss_1'\,b_1' + Ss_2'\,b_2'}{3\ Ss\ b}\right)$$

$$t_D = \frac{1}{4u} = \frac{Kt}{Ss\,r^2}$$

$$t_D' = \frac{K't}{Ss'\,z^2}$$

BWIP OSCA/[illegible] Logsdon

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

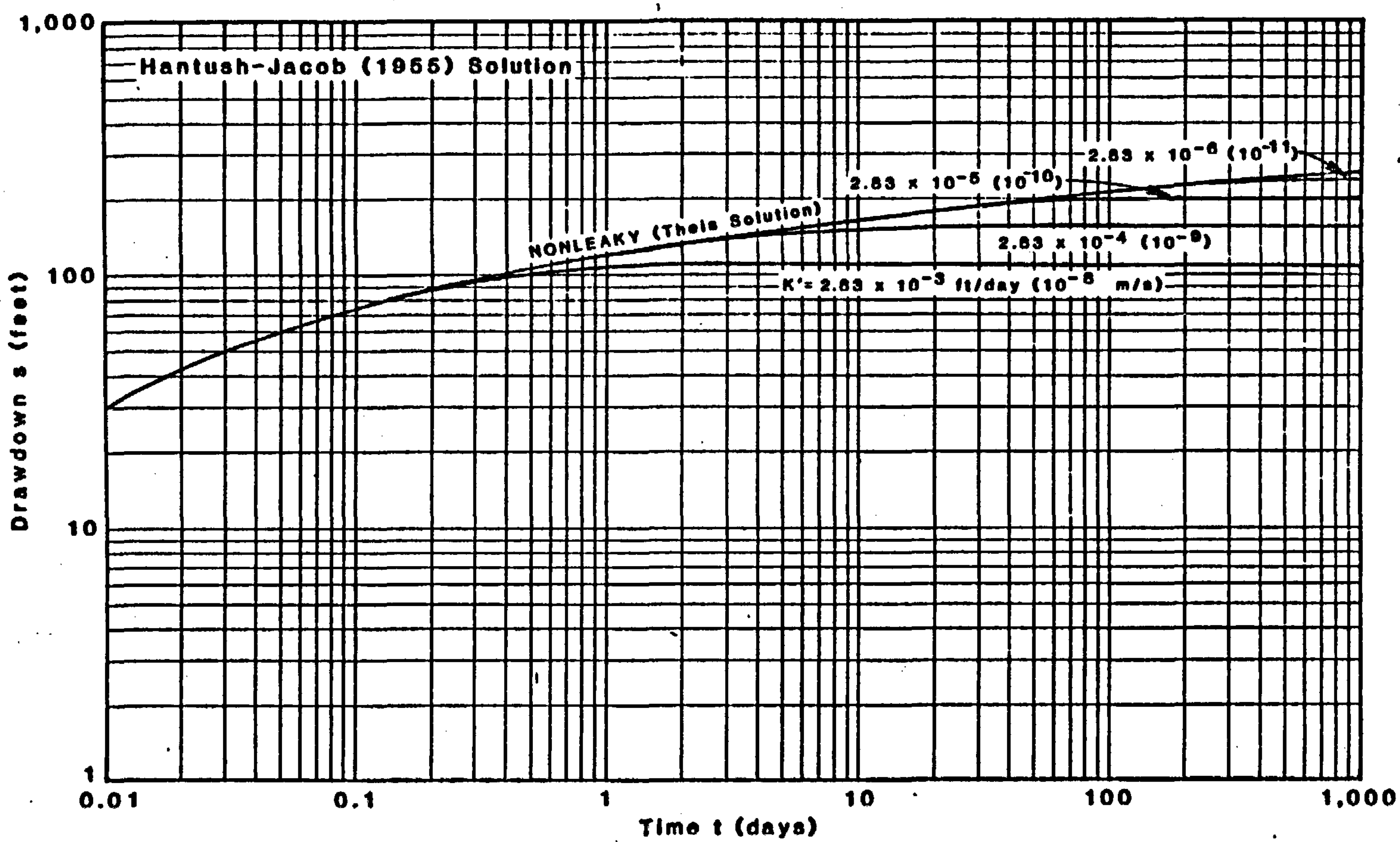


Figure 3

E-13

BWIP 0354/ /Logsdon

CASE I: PREDICTED HYDRAULIC RESPONSE IN AQUIFER D; r=500 FEET

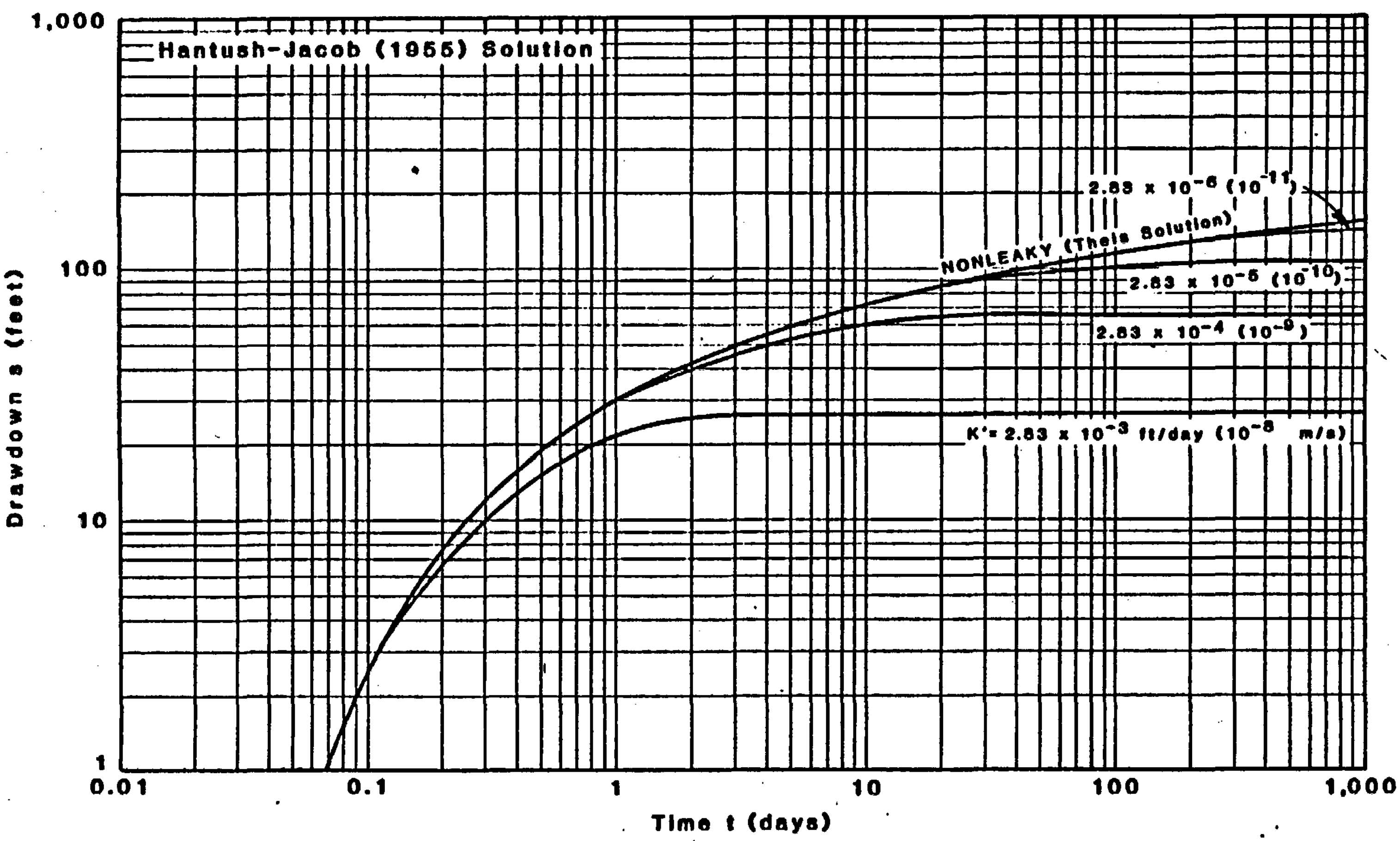


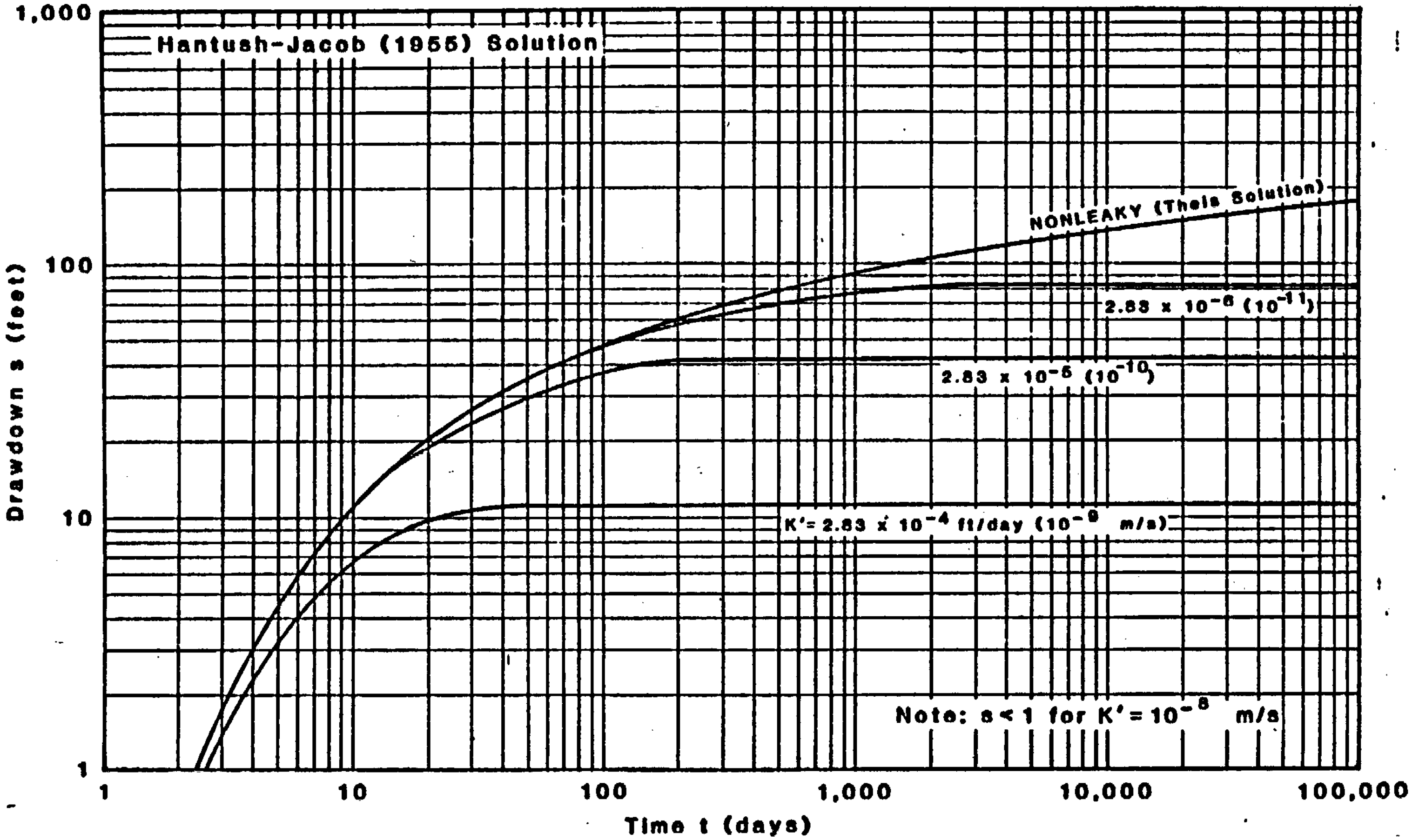
Figure 4

E-14

BKEA OSCA/[illegible]/Logsdon

CASE 1: PREDICTED HYDRAULIC RESPONSE
IN AQUIFER D; r=3000 FEET

Figure 5

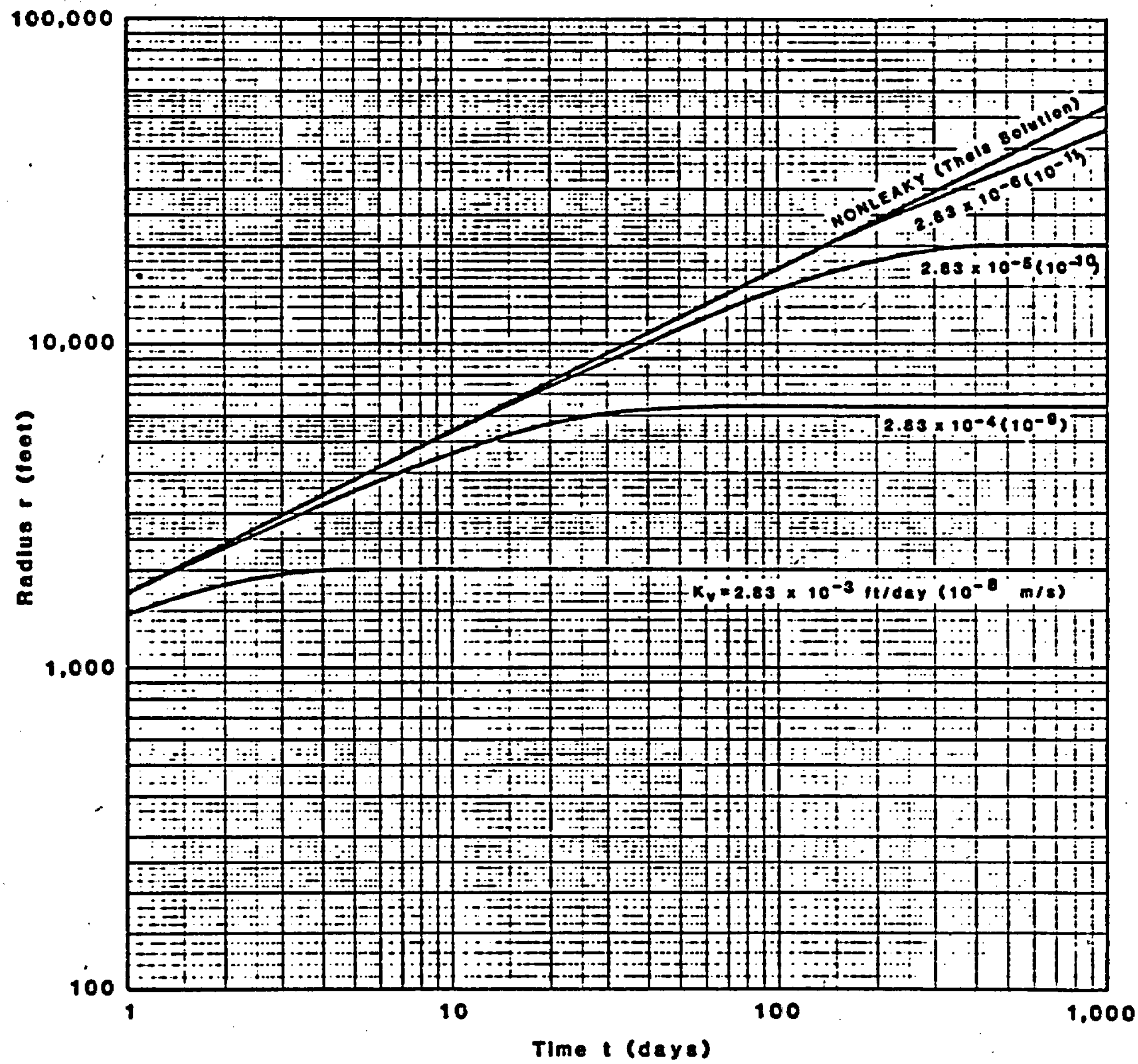


E-15

BWTP ...

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

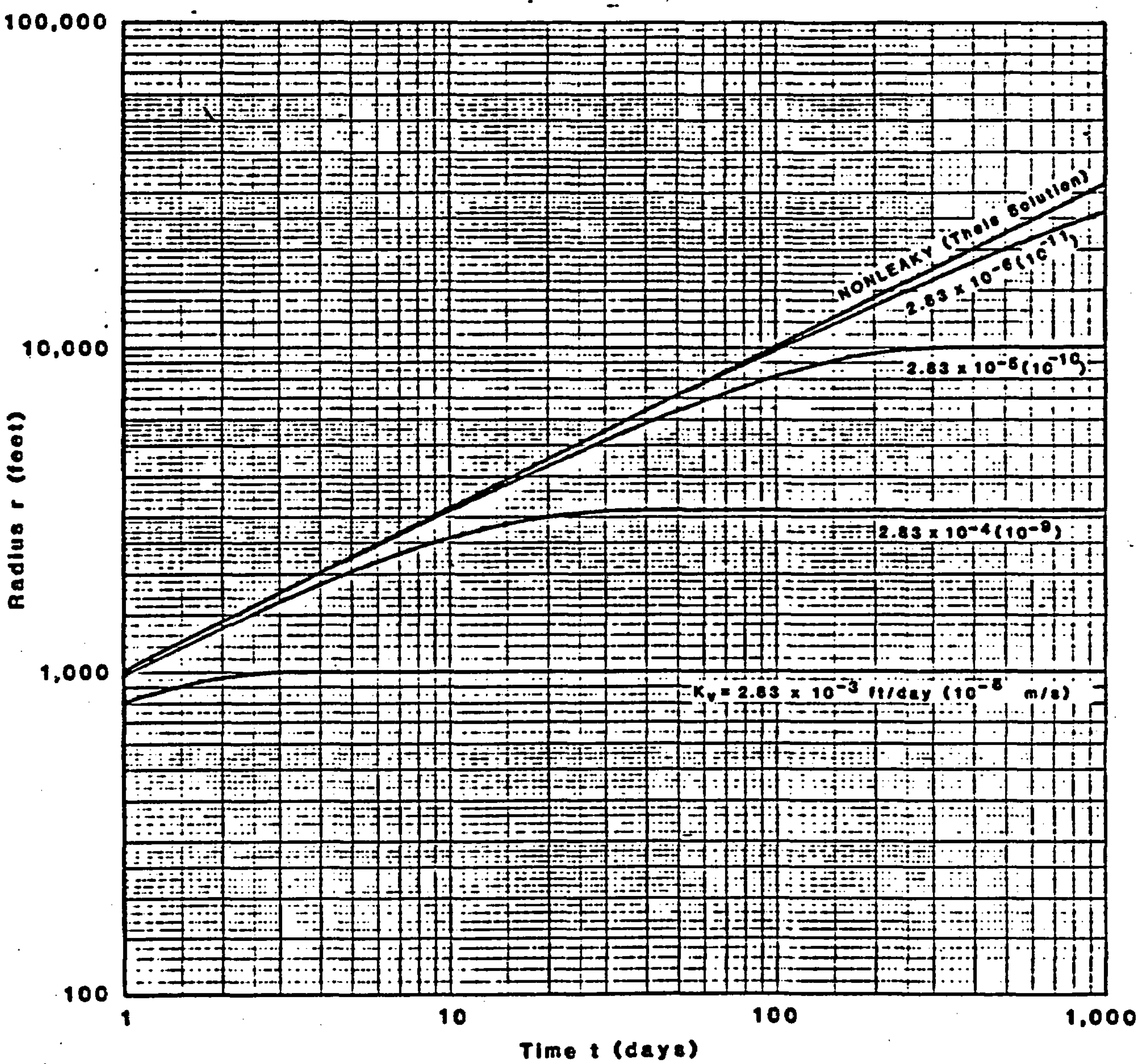
Figure 6

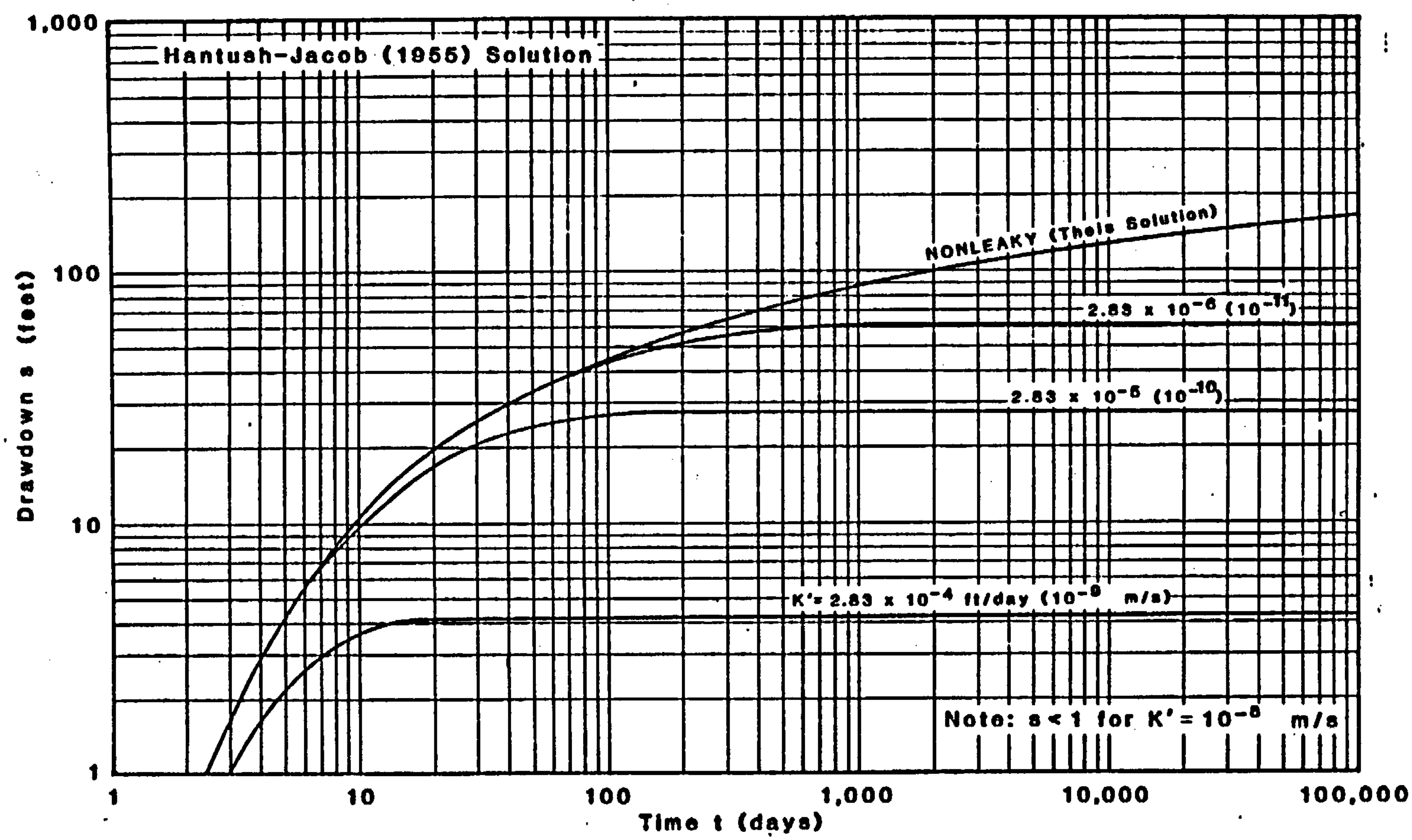


BWIP OSCA/[illegible]/Logsdon

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

CASE II: PREDICTED HYDRAULIC RESPONSE IN AQUIFER B; r = 100,000 FEET

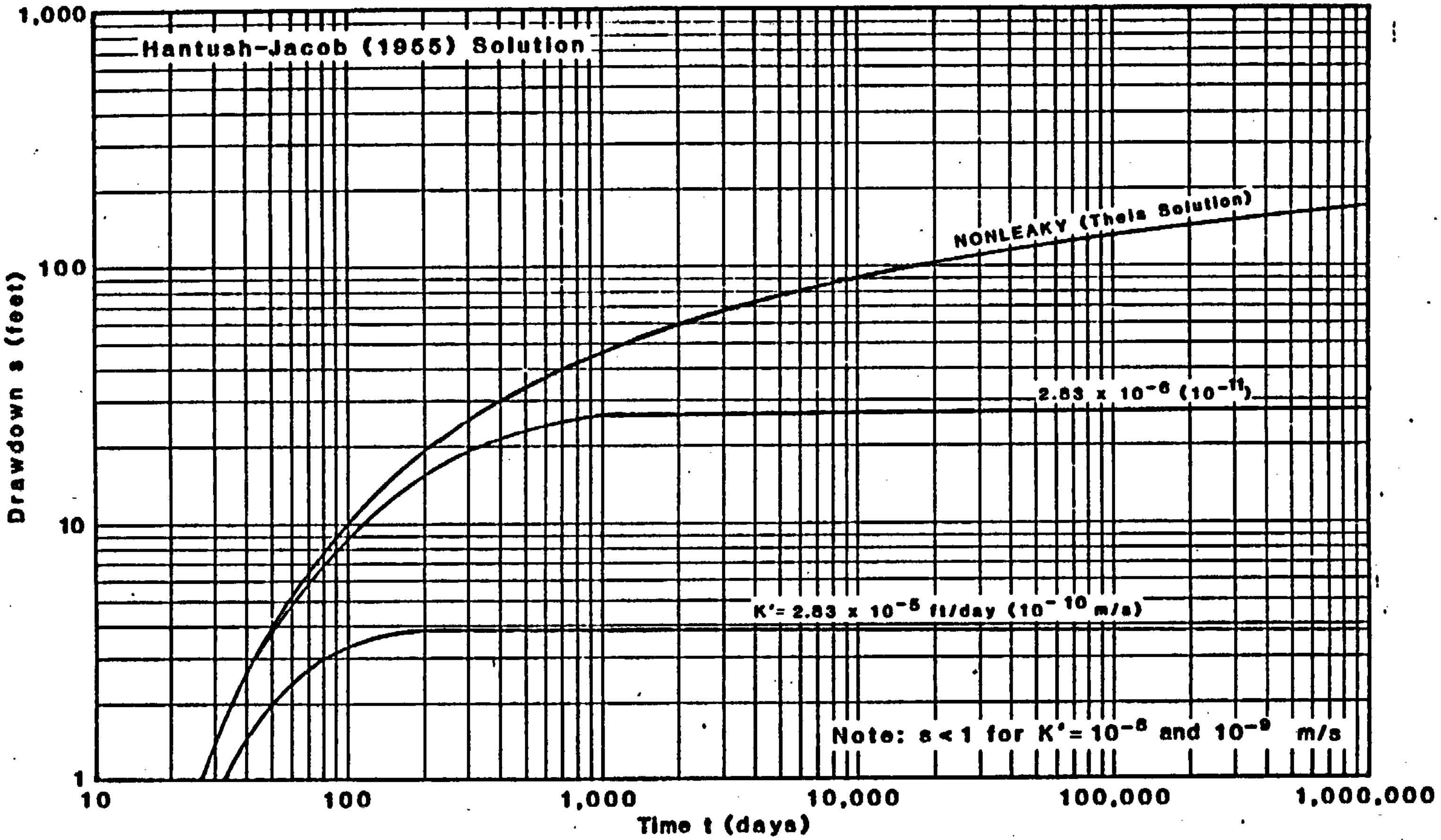


Figure 9

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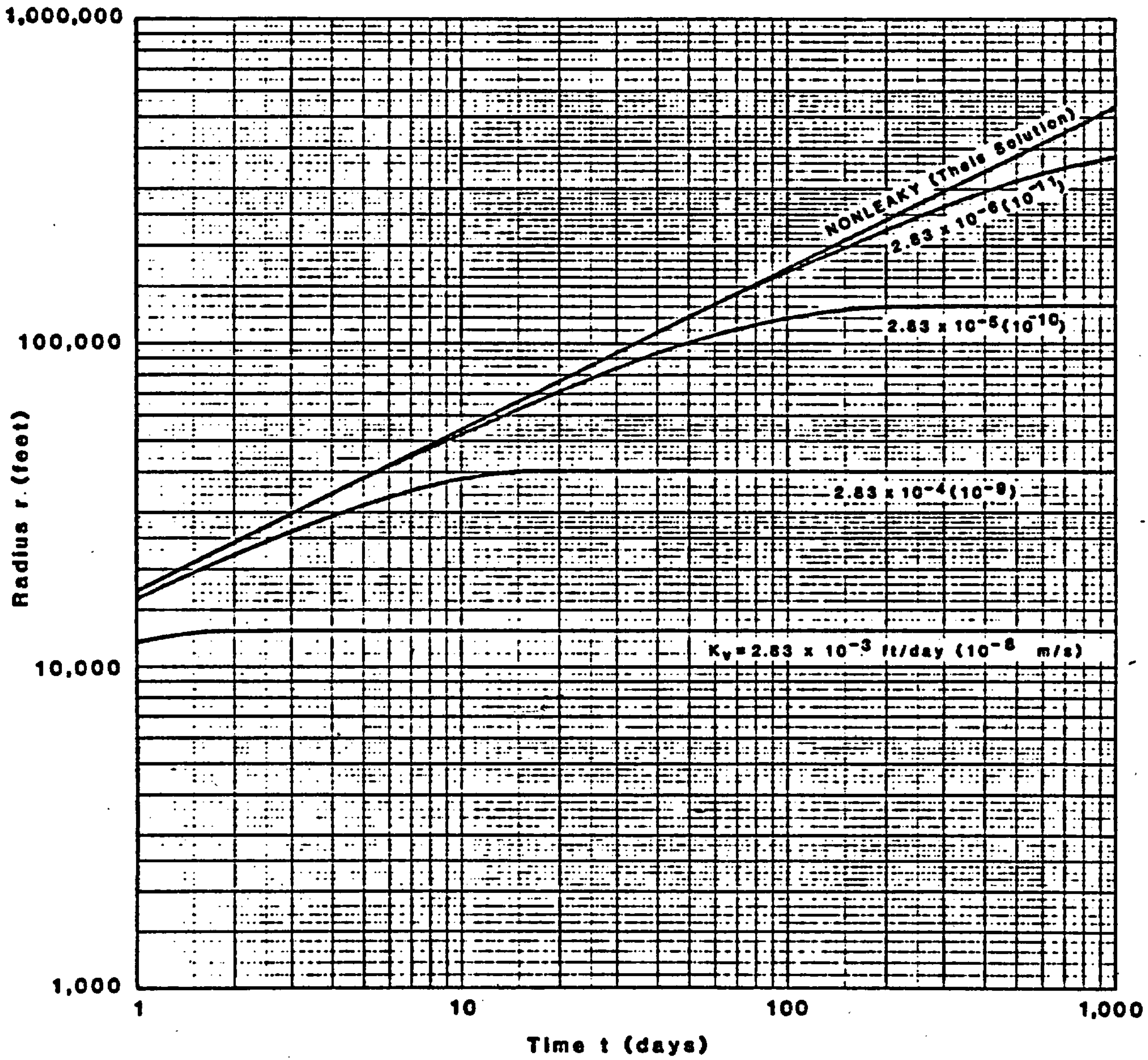
Bo... 0S... /Logsdon

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

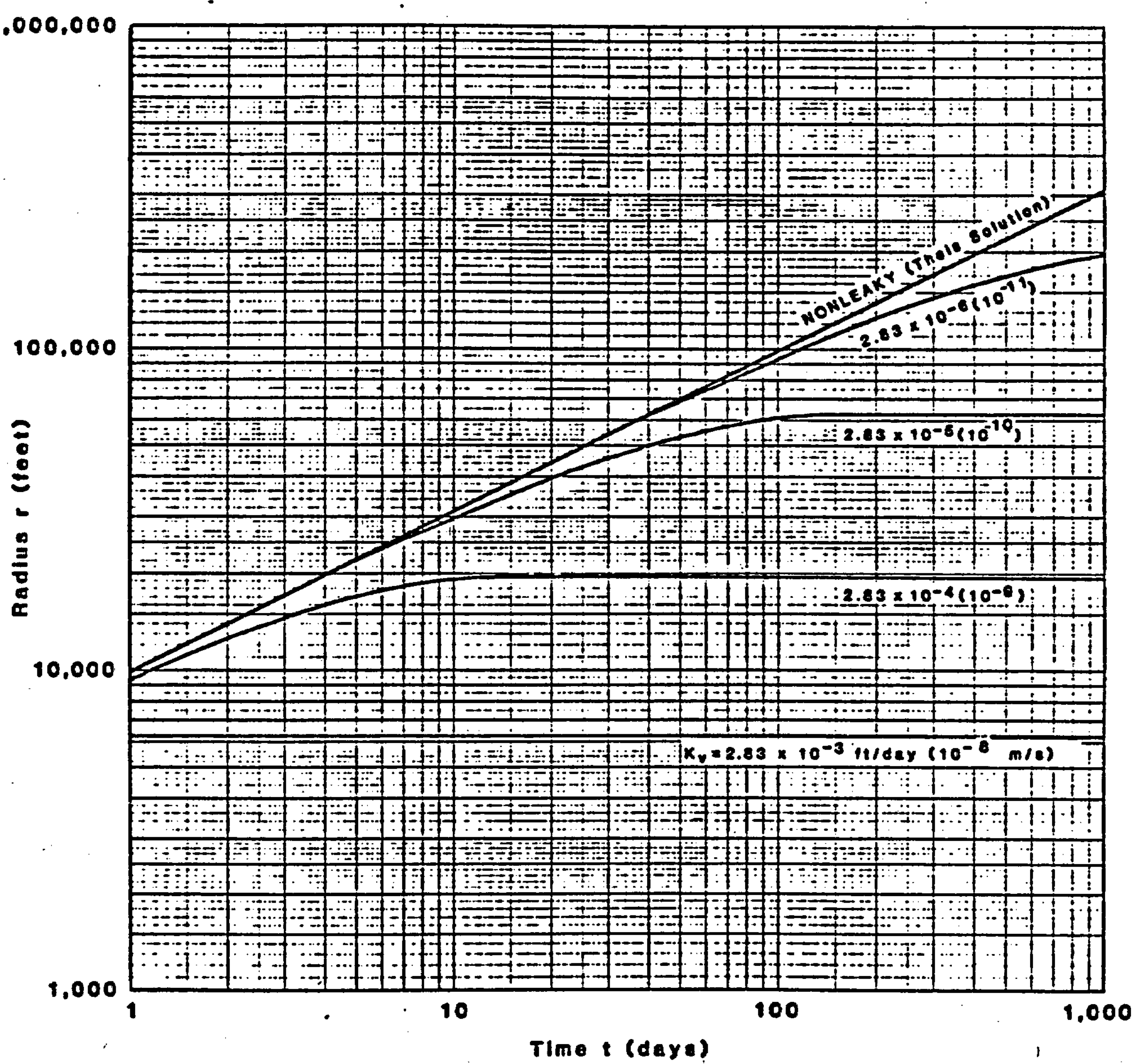
Figure 10



BWIP OSCA/[illegible]/Logsdon

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

Figure 11



BWLA OSCA/[illegible]/Logsdon

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

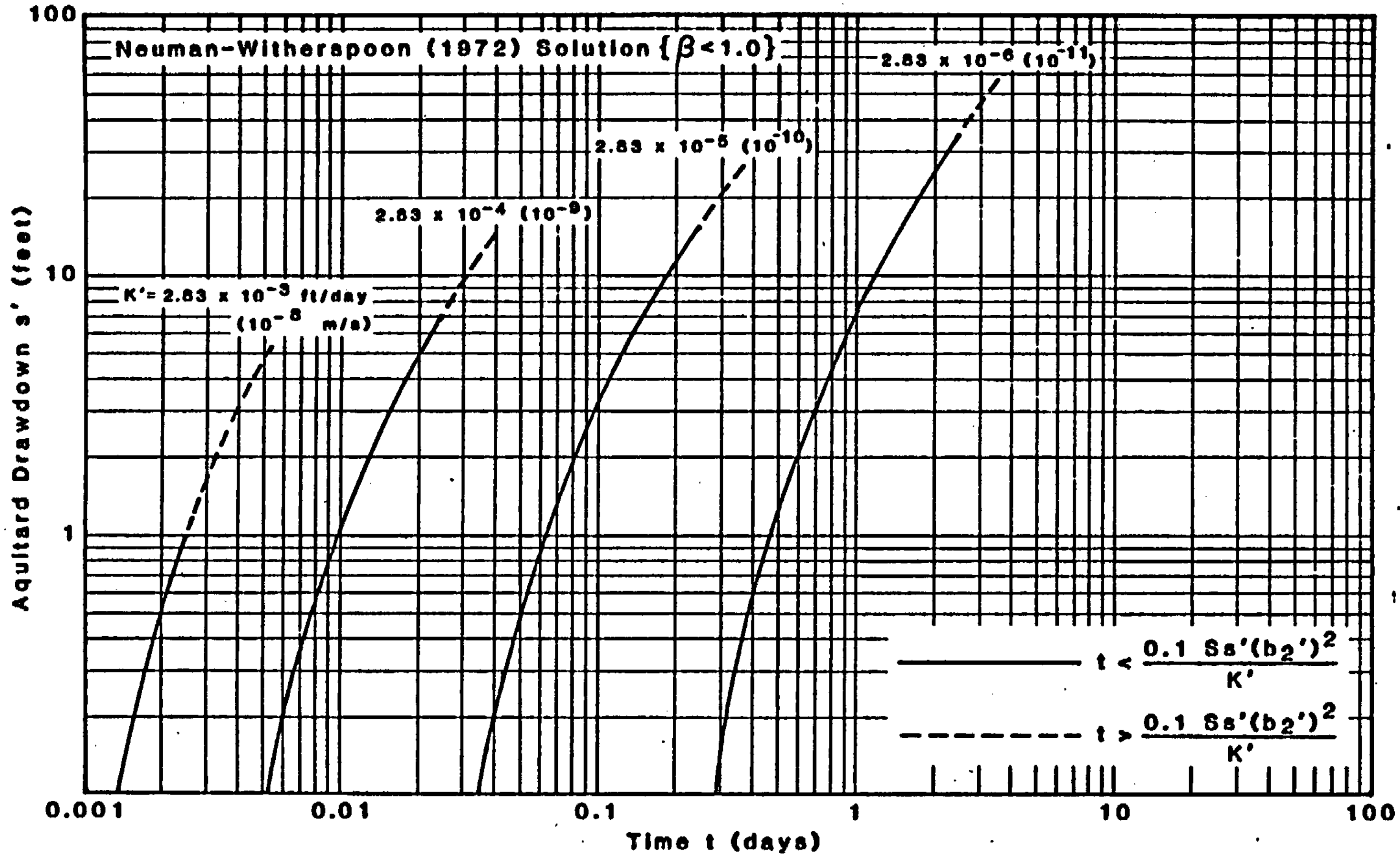
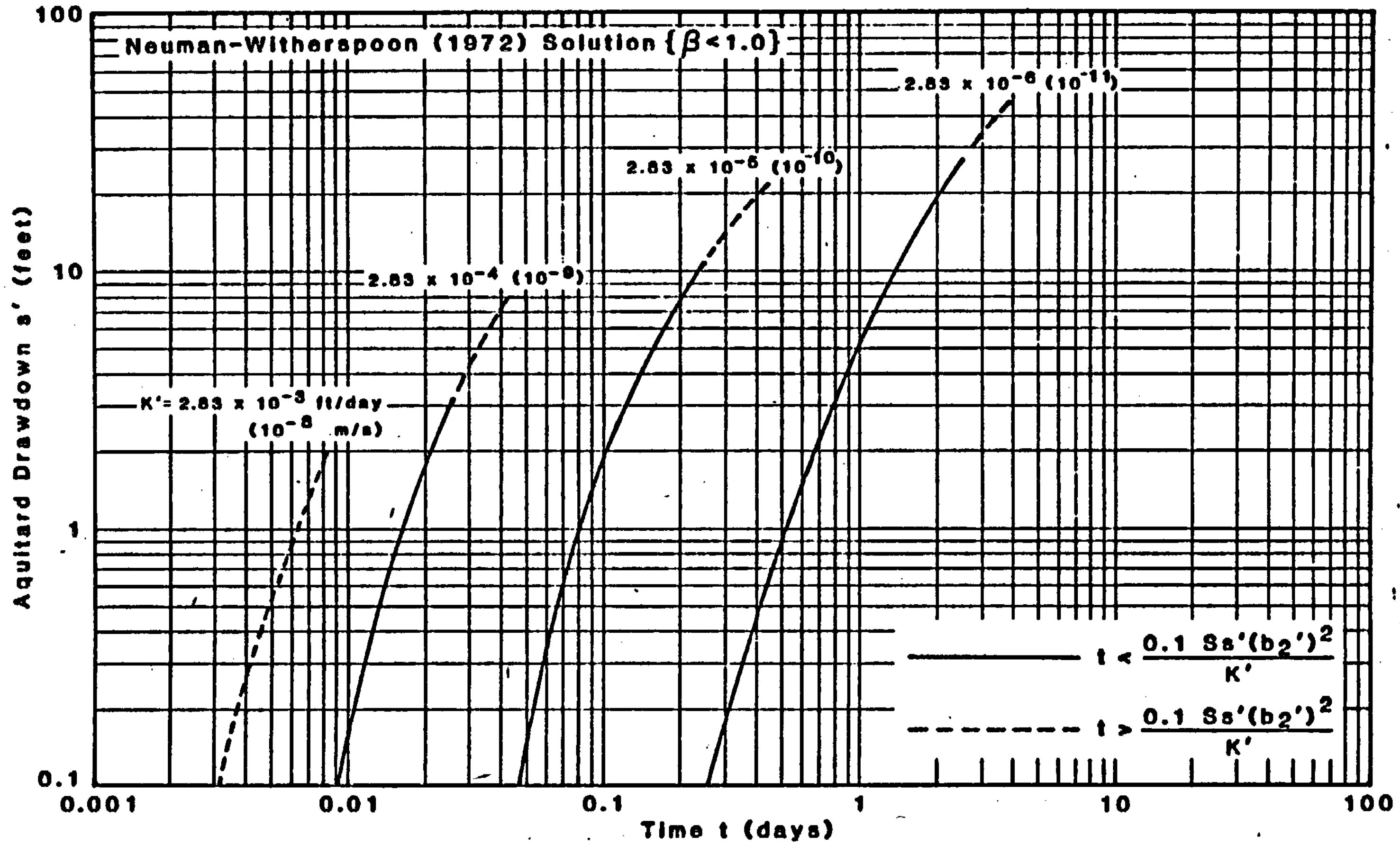


Figure 12.

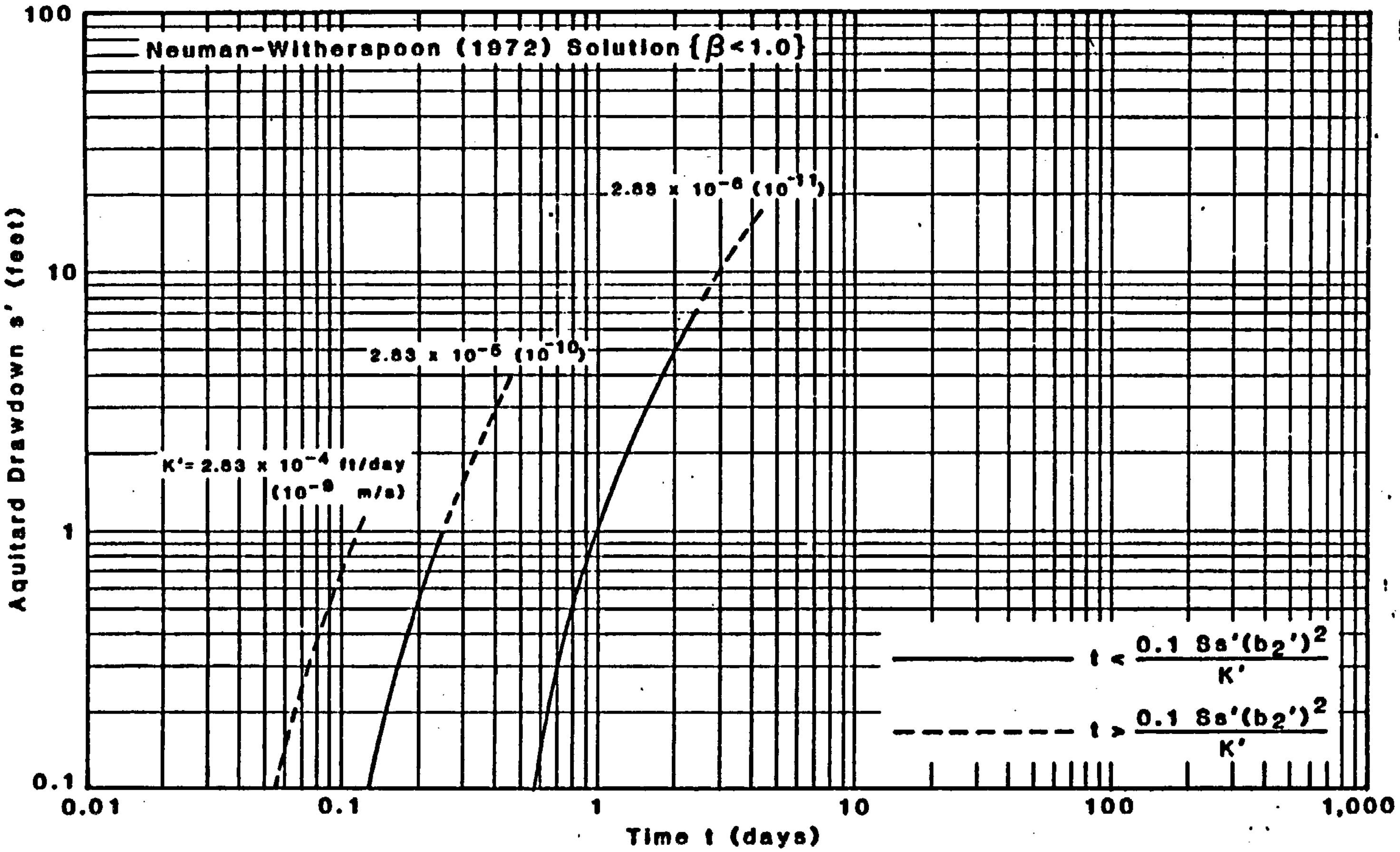
E-22



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

Figure 13

E-23



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

Figure 14

E-24

APPENDIX F

REVIEW OF HYDROCHEMICAL CHARACTERIZATION RELATED TO FLOW SYSTEM INTERPRETATION IN HANFORD BASALTS

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LIST OF FIGURES

LIST OF TABLES

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 SCR, 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 F ±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:

- 45 groundwater samples from 21 boreholes in the Saddle Mountains Basalt
- 27 groundwater samples from six boreholes in the Wanapum Basalt
- 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:

- Na - HCO_3
- Na - Cl - HCO_3
- 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-HCO_3 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-HCO_3 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 ft^2/day compared to 6550 ft^2/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 $Na\text{-}HCO_3$ 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 $Na\text{-}Cl\text{-}HCO_3$ 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 $Na\text{-}Cl\text{-}HCO_3$ groundwater in the Wanapum in boreholes DC-14 and 15 is characteristic of Group I, whereas the $Na\text{-}Cl\text{-}HCO_3$ 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 sytem. In theory, it should be possible therefore to use

the delta oxygen-18 and deuterium data to assist in the intrepretation 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 methanogensis 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 $Na\text{-}HCO_3$ 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 $Na\text{-}HCO_3$ 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.

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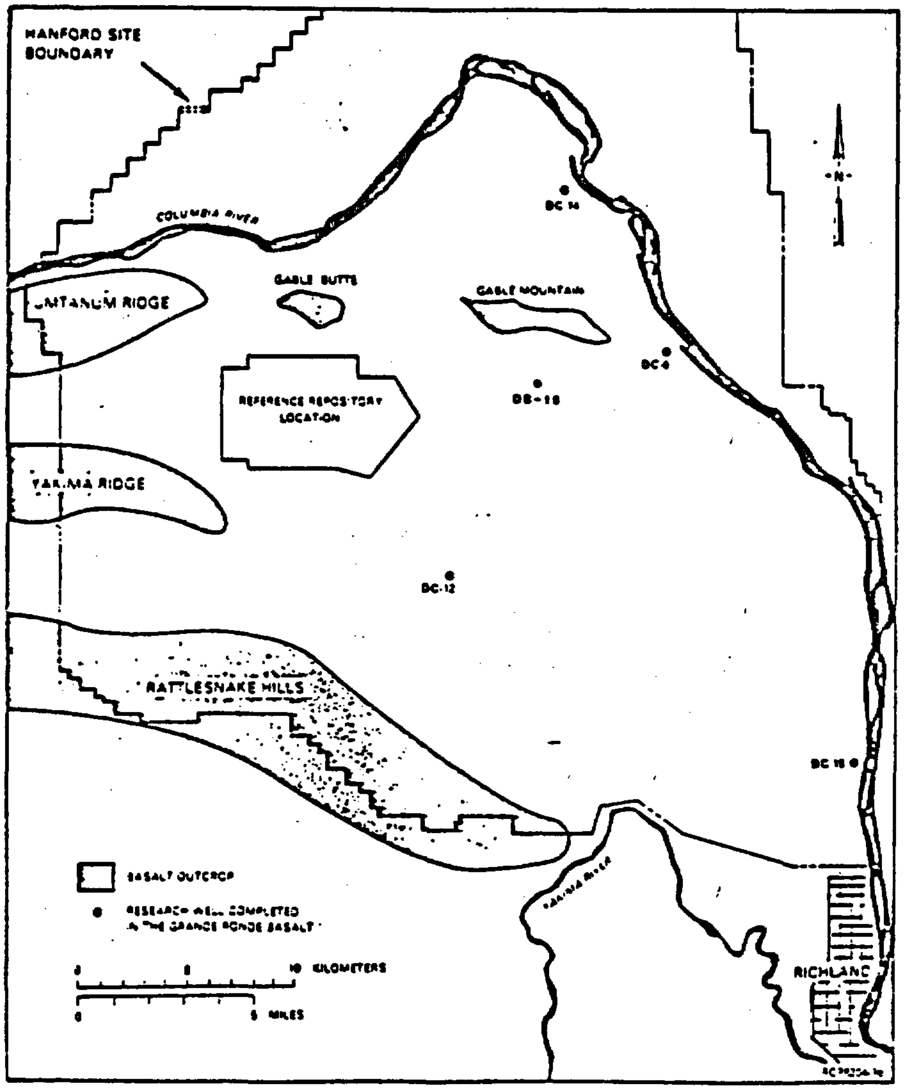
LOCATIONS OF BOREHOLES FOR WHICH DETAILED HYDROCHEMICAL DATA ARE AVAILABLE

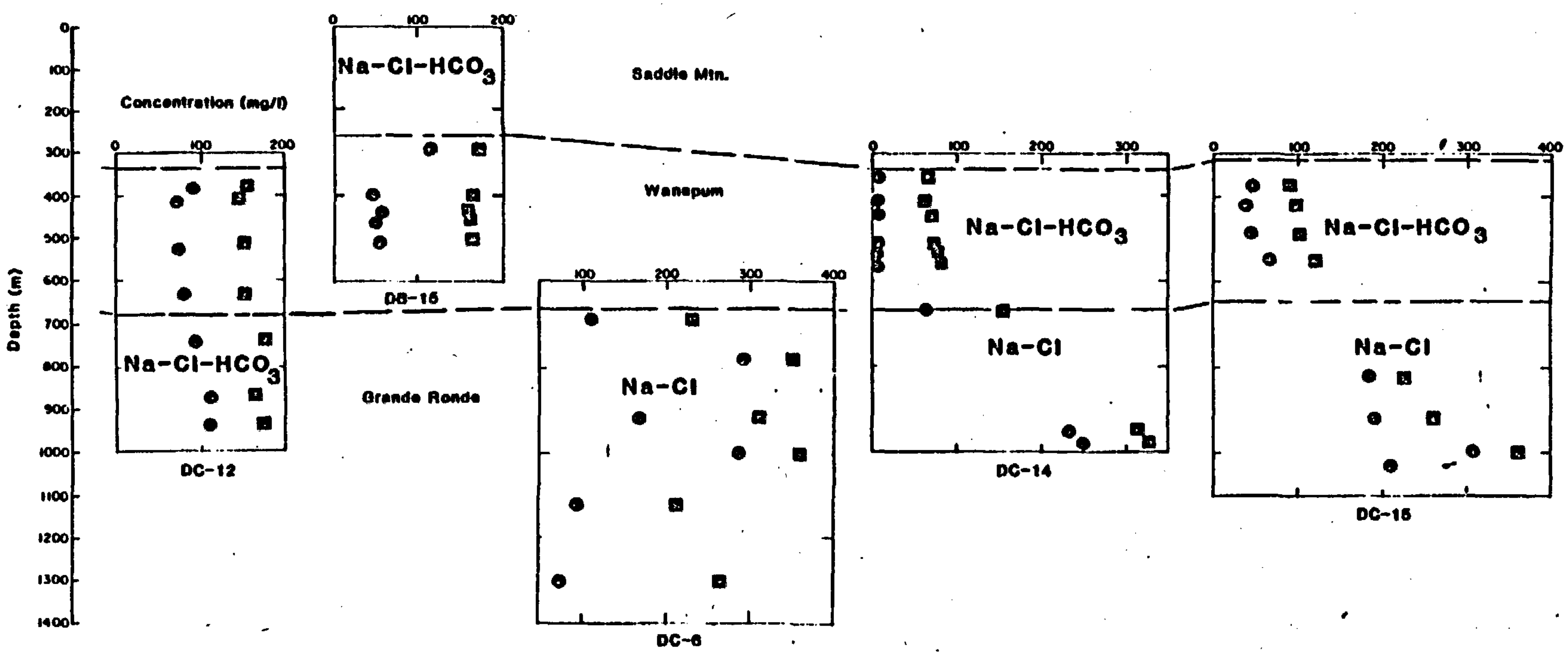
Figure 1



BWIP OSCA/ /Logsdon

GEOCHEMICAL PROFILES: CHLORIDE, SODIUM

Figure 2



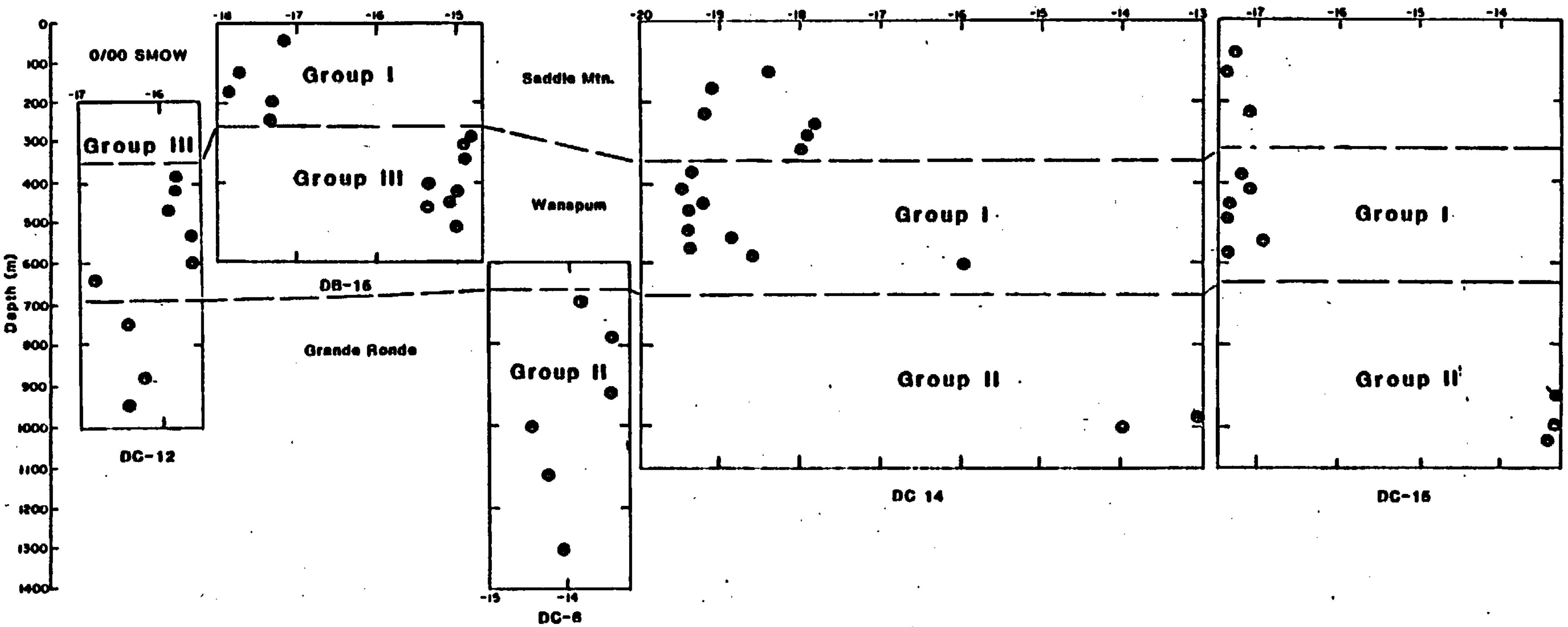
NOTE: If more than one sample is taken in the same interval, data point represents an arithmetic mean.

EXPLANATION

Chloride (mg/L) ●

Sodium (mg/L) ▣

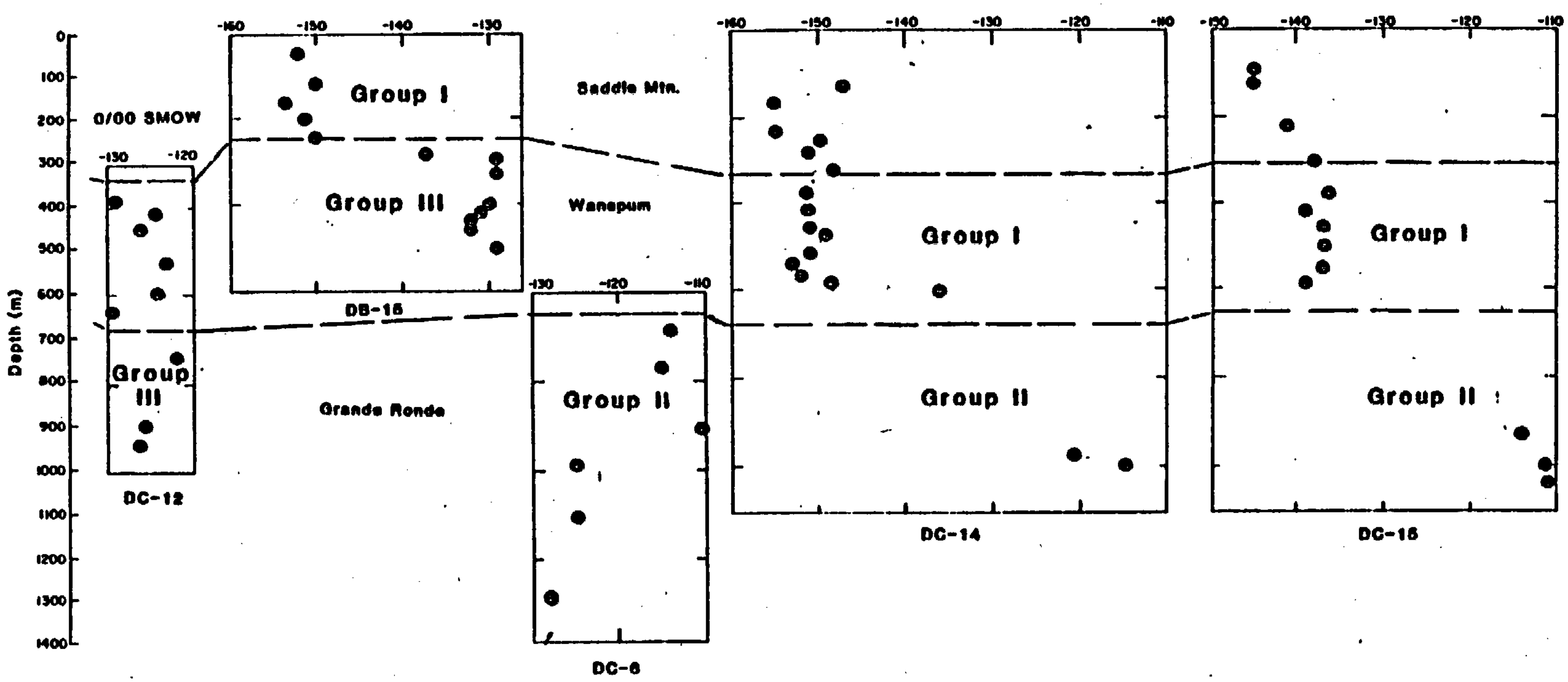
GEOCHEMICAL PROFILES: OXYGEN - 18



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

Figure 3

GEOCHEMICAL PROFILES: DEUTERIUM



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

Figure 4

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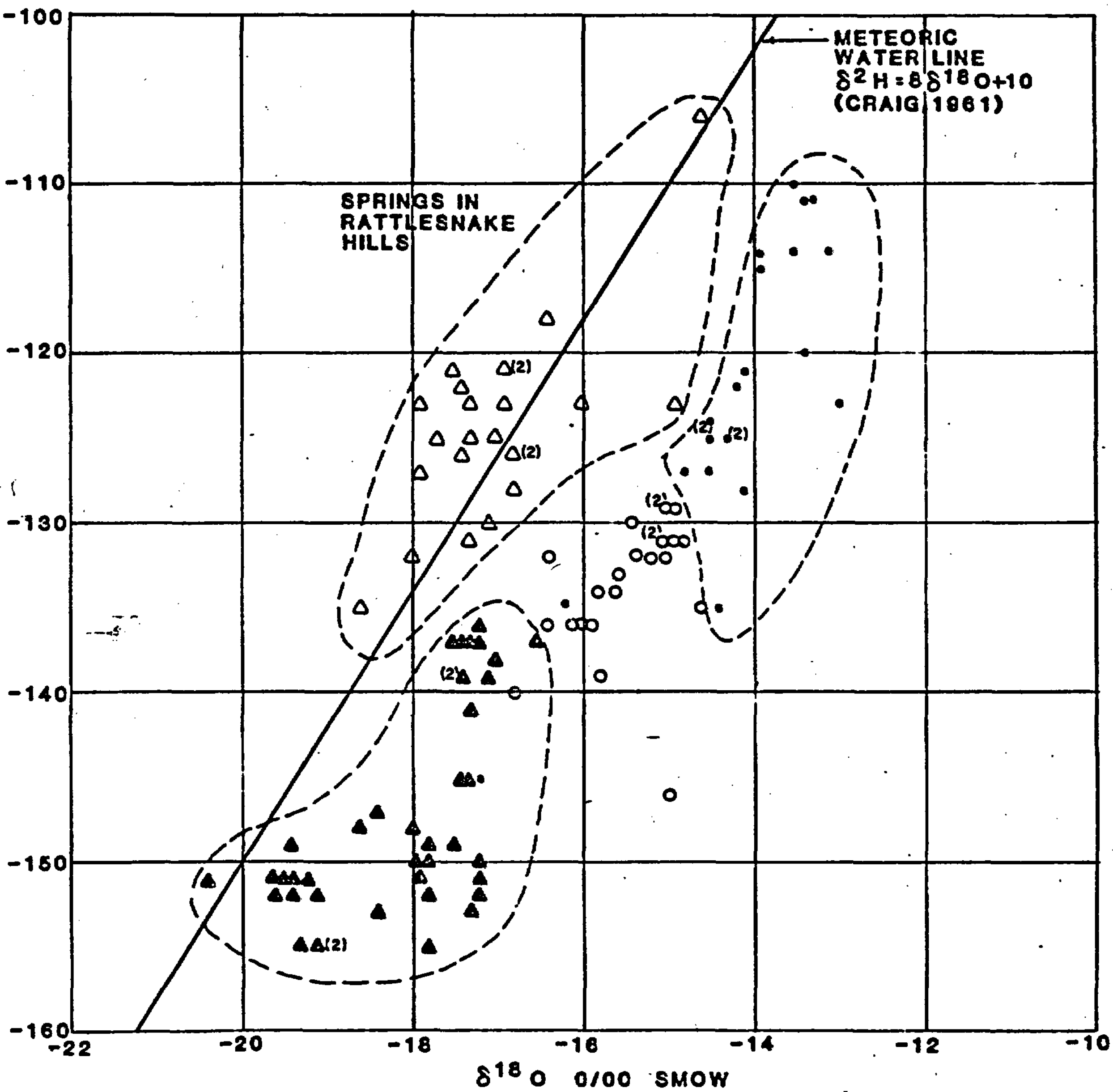
Rud OSUA / Logsdon

^{18}O - ^{2}H RELATIONSHIP

Figure 5

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

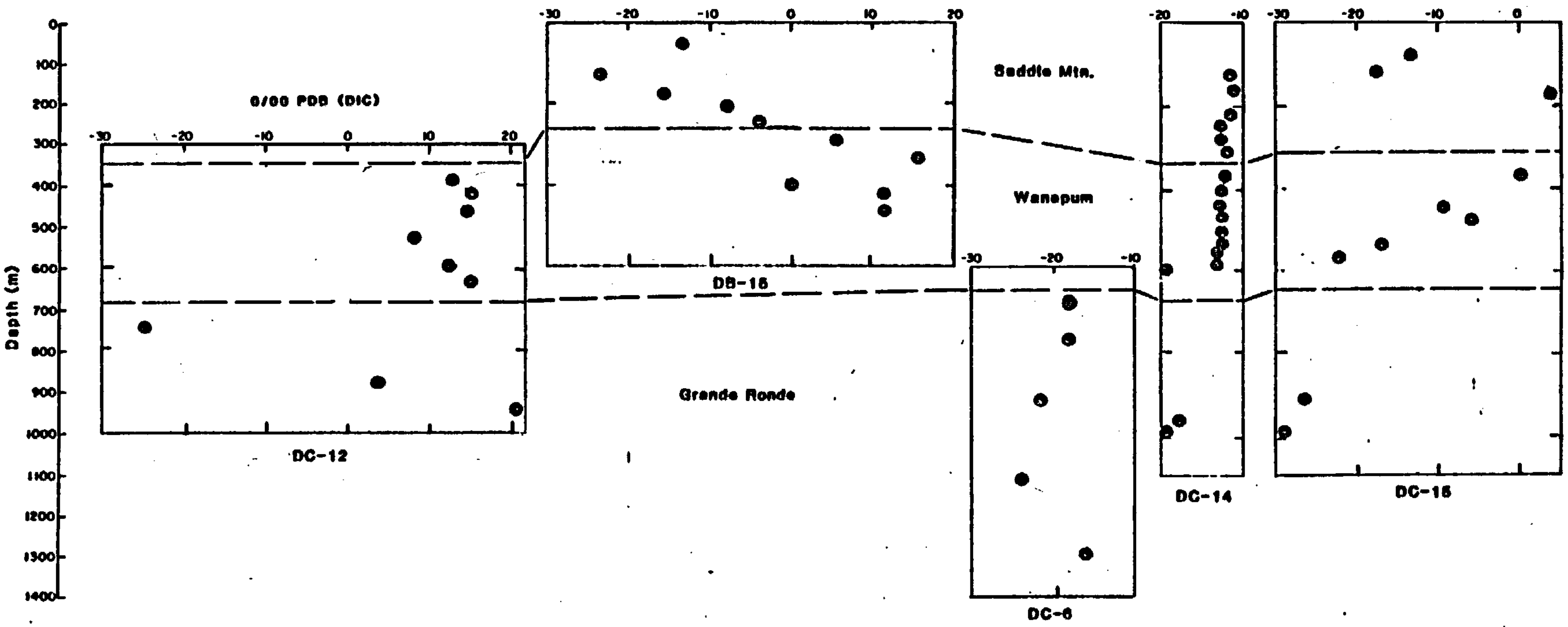
○ Group III:
Wanapum and Grande Ronde DC-12, Wanapum DB-15

△ Springs in Rattlesnake Hills

(2) Indicates two samples

BWIP USGS / Logsdon

GEOCHEMICAL PROFILES: CARBON - 13



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

Figure 6

Table A-1

SELECTED KEY HYDROCHEMICAL DATA – BOREHOLE DB-15

UNIT	SAMPLE NUMBER	DEPTH (m)	$\delta^{18}O$ (0/00 SMOW)	$\delta^{2}H$ (0/00 SMOW)	$\delta^{13}C$ (0/00 PDB)	^{14}C* (Years)	^{14}C % (Modern)	^{3}H (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

Table A-2

SELECTED KEY HYDROCHEMICAL DATA – BOREHOLE DC-6

UNIT	SAMPLE NUMBER	DEPTH (m)	$\delta^{18}O$ (0/00 SMOW)	$\delta^{2}H$ (0/00 SMOW)	$\delta^{13}C$ (0/00 PDB)	^{14}C* (Years)	^{14}C (% Modern)	^{3}H (T.U.)	CH_4 (Mole %)	F (mg/L)	Cl (mg/L)	Na (mg/L)	HCO_3 (mg/L)
Grande Ronde	80-161	657-730								35	113	229	61
	80-191	730-822	-13.9	-114	-18.0	19,070	9.3	0.09		22	297	350	85
	80-186	730-822	-13.9	-115	-18.0			0.04					
	80-118	912-938	-13.5	-110	-21.3			-0.06		42	166	310	62
	81-82	988-1075	-14.5	-125				0.01		36	289	360	42
	80-37	1076-1166	-14.3	-125	-23.8	>20,000	< 8.26	-0.01		39	96	219	
	79-57	1125-1133	-14.3	-125	-23.3	>23,000	< 5.69	-0.01		31	108	212	17
	81-45	1269-1321	-14.1	-128	-15.8	11,440	21.0	-0.20				242	
	79-58		-14.4	-135	-23.2	16,790	12.32	+0.1					
	79-91		-14.5	-127									
	80-29		-14.5	-125	-23.8	>20,000	< 8.3	-0.01					
	80-15		-13.4	-120				0.12					
	80-238		-15.1	-131	-26.4	13,380	18.8	-0.13					
	81-18		-16.2	-135				0.04					

*Uncorrected

Table A-3

SELECTED KEY HYDROCHEMICAL DATA – BOREHOLE DC-12

UNIT	SAMPLE NUMBER	DEPTH (m)	$\delta^{18}O$ (0/00 SMOW)	$\delta^{2}H$ (0/00 SMOW)	$\delta^{13}C$ (0/00 PDB)	^{14}C* (Years)	^{14}C (% Modern)	^{3}H (T.U.)	CH_4 (Mole %)	F (mg/L)	Cl (mg/L)	Na (mg/L)	HCO_3 (mg/L)
Priest Rpd.	80-80	371-382	-15.8	-139	+12.8	27,750	3.2	-1.71					
	80-62	371-382							95.9	10	103	142	115
Priest-Roza	80-100	405-416	-15.8	-134	+15.2	> 32,000	< 1.9	0.42					
	80-63	405-416							94.1	9	97	123	115
Roza-Frchmn.	80-97	493-513	-15.9	-136	+14.8	> 34,000	< 1.45	0.34					
	80-73	493-513								8	105	126	118
Frchmn. Spr. #2	80-32		-15.6	-133	+8.0	26,415	3.7	1.16					
Frchmn. Spr. #5	80-82		-15.6	-134	+12.8	27,660	3.18	0.59					
Frchmn. Spr. #8	80-124	625-634	-16.8	-140	+15.2	29,300	2.60						
	80-102	625-634								10	102	135	117
Grande Ronde	80-234		-16.1	-136	+2.5	15,030	15.3	9.27					
Grande Ronde #4	80-174	733-746	-16.4	-132	-24.8	22,670	5.9	4.10		14	128	148	114
Grande Ronde #6	80-209	859-867	-16.2	-135	+3.6	19,440	8.9	2.10					
	80-233	859-867								11	117	163	123
Grande Ronde #10	81-61	935-961	-16.4	-136	+20.7	17,240	11.7	0.16		13	131	161	74

*Uncorrected

SELECTED KEY HYDROCHEMICAL DATA - BOREHOLE DC-14

Table A-4

UNIT	SAMPLE NUMBER	DEPTH (m)	$\delta^{18}O$ (0/00 SMOW)	$\delta^{2}H$ (0/00 SMOW)	$\delta^{13}C$ (0/00 PDB)	^{14}C* (Years)	^{14}C (% Modern)	^{3}H (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

SELECTED KEY HYDROCHEMICAL DATA - BOREHOLE DC-14

UNIT	SAMPLE NUMBER	DEPTH (m)	$\delta^{18}O$ (0/00 SMOW)	$\delta^{2}H$ (0/00 SMOW)	$\delta^{13}C$ (0/00 PDB)	^{14}C* (Years)	^{14}C (% Modern)	^{3}H (T.U.)	CH_4 (Mole %)	F (mg/L)	Cl (mg/L)	Na (mg/L)	HCO_3 (mg/L)
Grande Ronde	80-141	973-984								50	258	343	38
	80-42									44	247	316	54

Table A-5

SELECTED KEY HYDROCHEMICAL DATA – BOREHOLE DC-15

UNIT	SAMPLE NUMBER	DEPTH (m)	$\delta^{18}O$ (‰ SMOW)	$\delta^{2}H$ (‰ SMOW)	$\delta^{13}C$ (‰ PDB)	^{14}C* (Years)	^{14}C % (Modern)	^{3}H (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

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

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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 Evaluaiton and calibration fo 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 ranged 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

- Errors in pressure measurement
- Errors in conversion of pressure to heads
- 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 dence 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			
Horiz.	Vert.	Horiz.	Vert.	Steady State	Transient
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 fo 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 apperaring 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 (Hp) (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 influene 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 in the time taken for the pressure reduction to reach the boundary; the equilibration time would be longer if the model boundary were further way 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:

- An example of head-testing during drilling at BWIP followed by permanent completion using multiple piezometers.
- 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:

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

- 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 comparision 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 that 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 drillign 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:

- Core drilling using an air-mist drilling technology.
- 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 unitl 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:

- The heads determined by the packer testing were quite variable, especially given the layered sedimentary rock system.

- 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.

- 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.

- 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:

- Transient head-errors induced by drilling; these changes may take months to dissipate.

- 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 transprot analyses.

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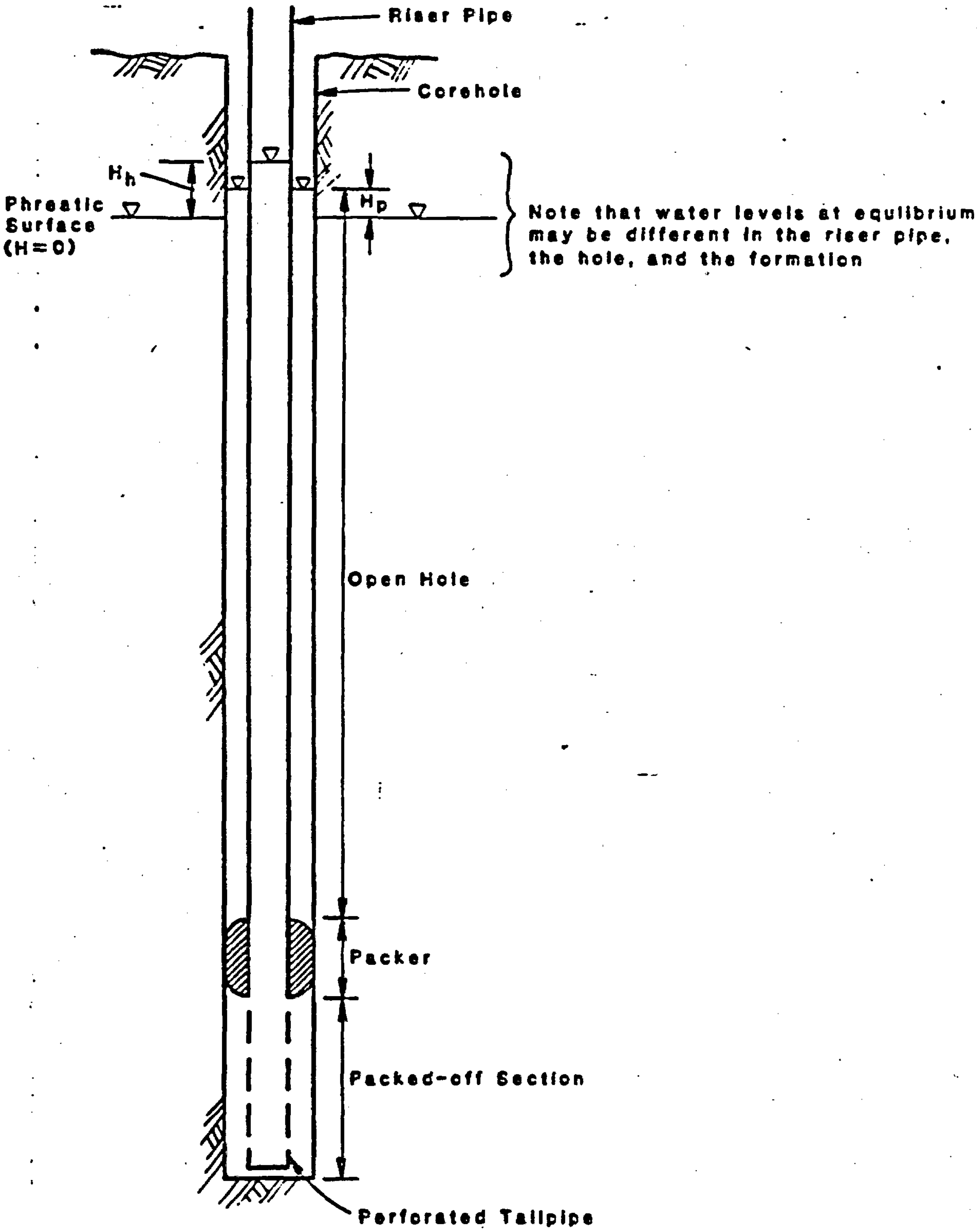
TYPICAL PACKER TEST SYSTEM

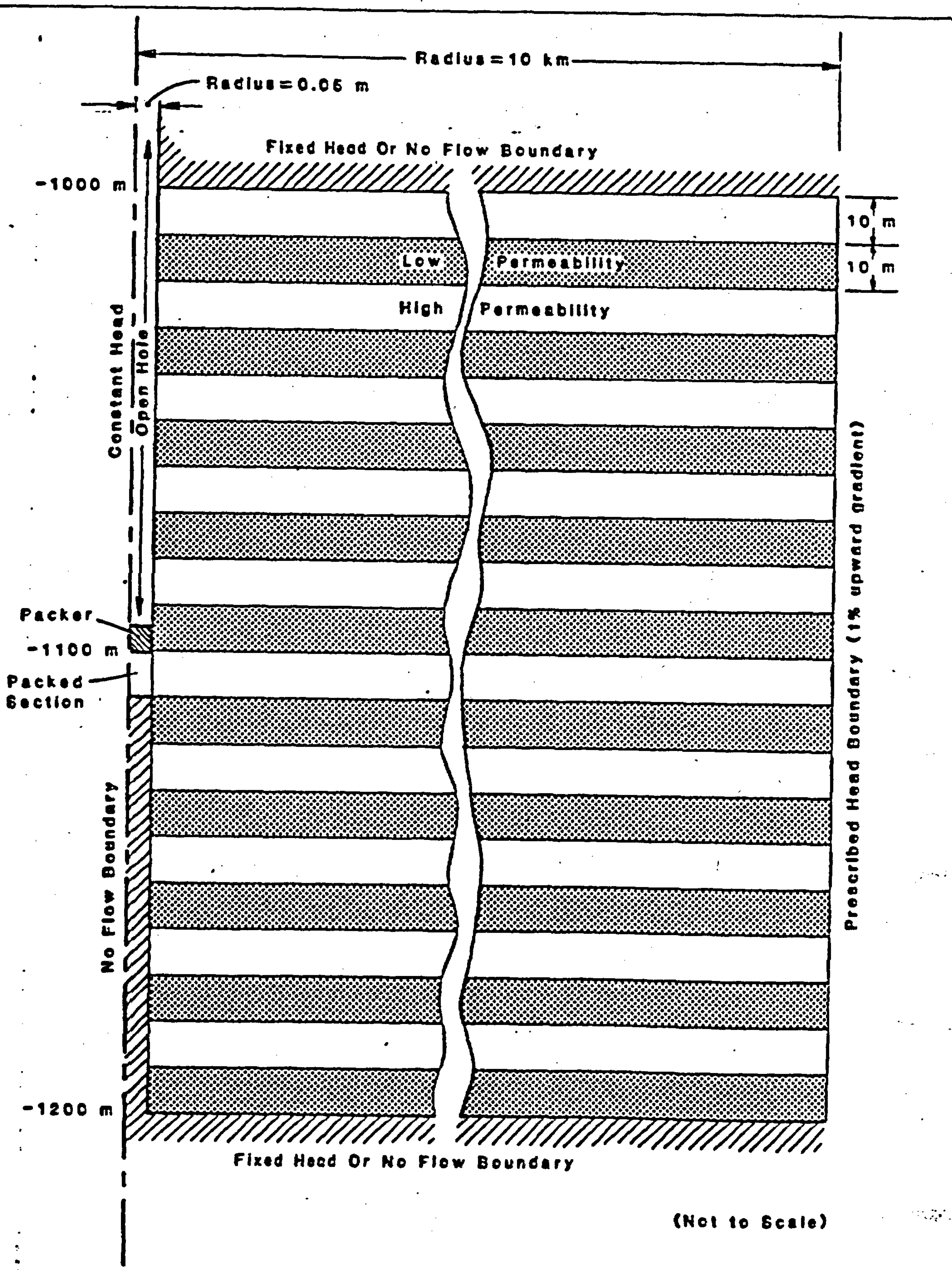
Figure 1



BWIP OSCAI /Legsdon

HYDROGEOLOGIC MODEL USED IN ANALYSIS

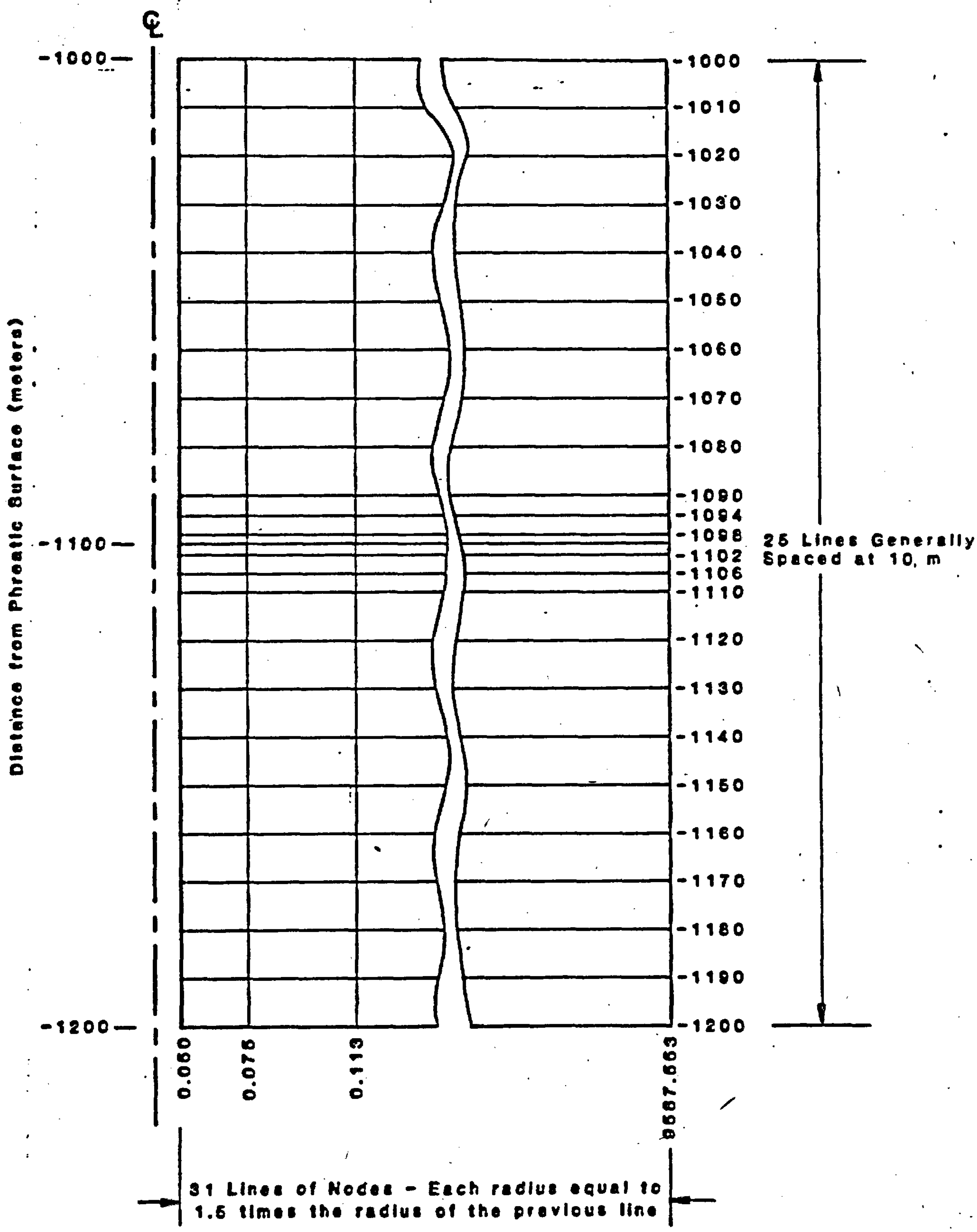
Figure 2



BWIP OSCA / /Logsdon

FINITE ELEMENT MESH

Figure 3

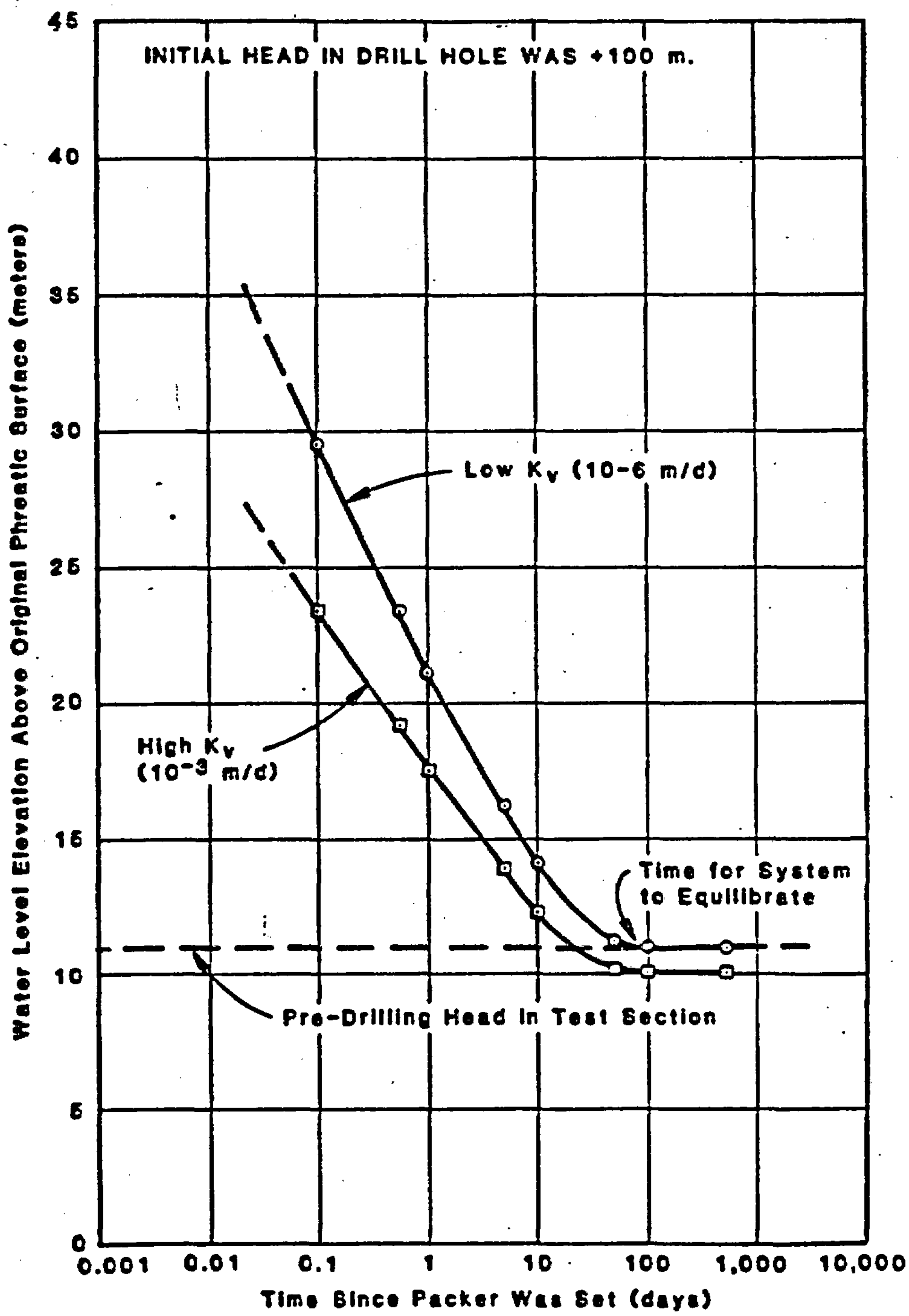


Note: All dimensions in meters

BWIP OSCA / 1 Logsdon

PRESSURE IN THE PACKED OFF SECTION AS A FUNCTION OF TIME

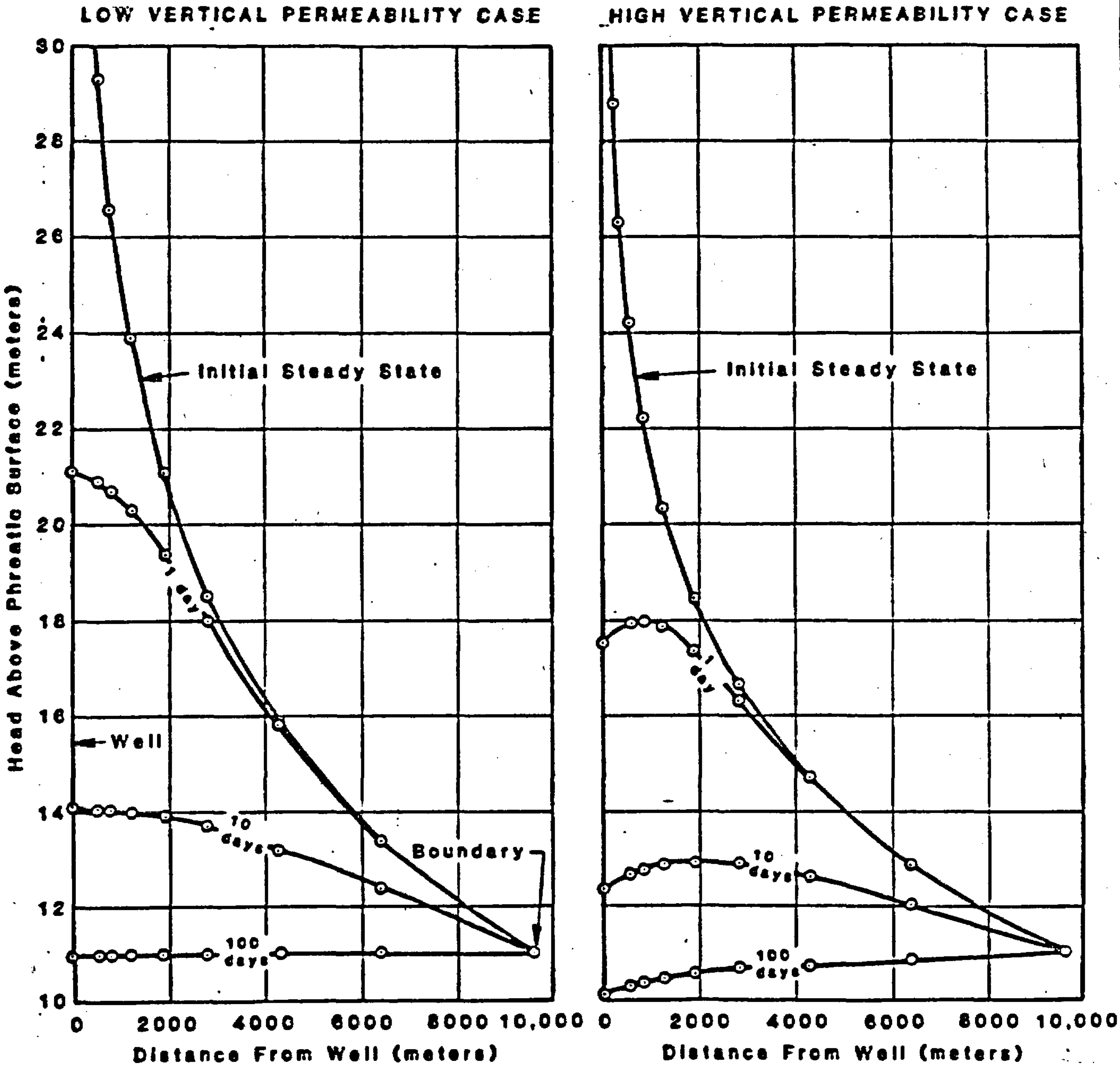
Figure 4



BWIP DSCA1 / Logsdon

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

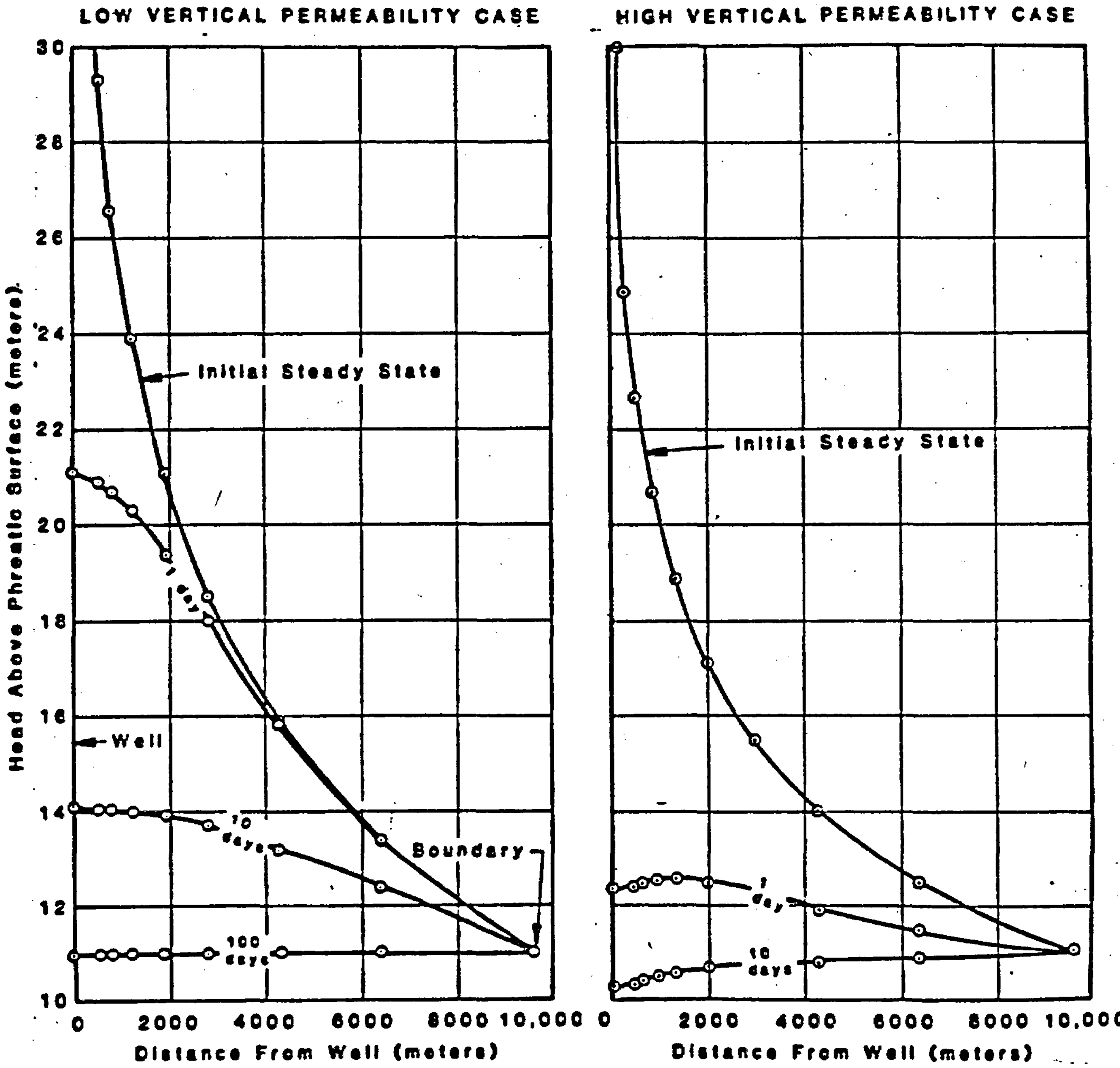
Figure 5



BWIA OSUA / Logsdon

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

Figure 6



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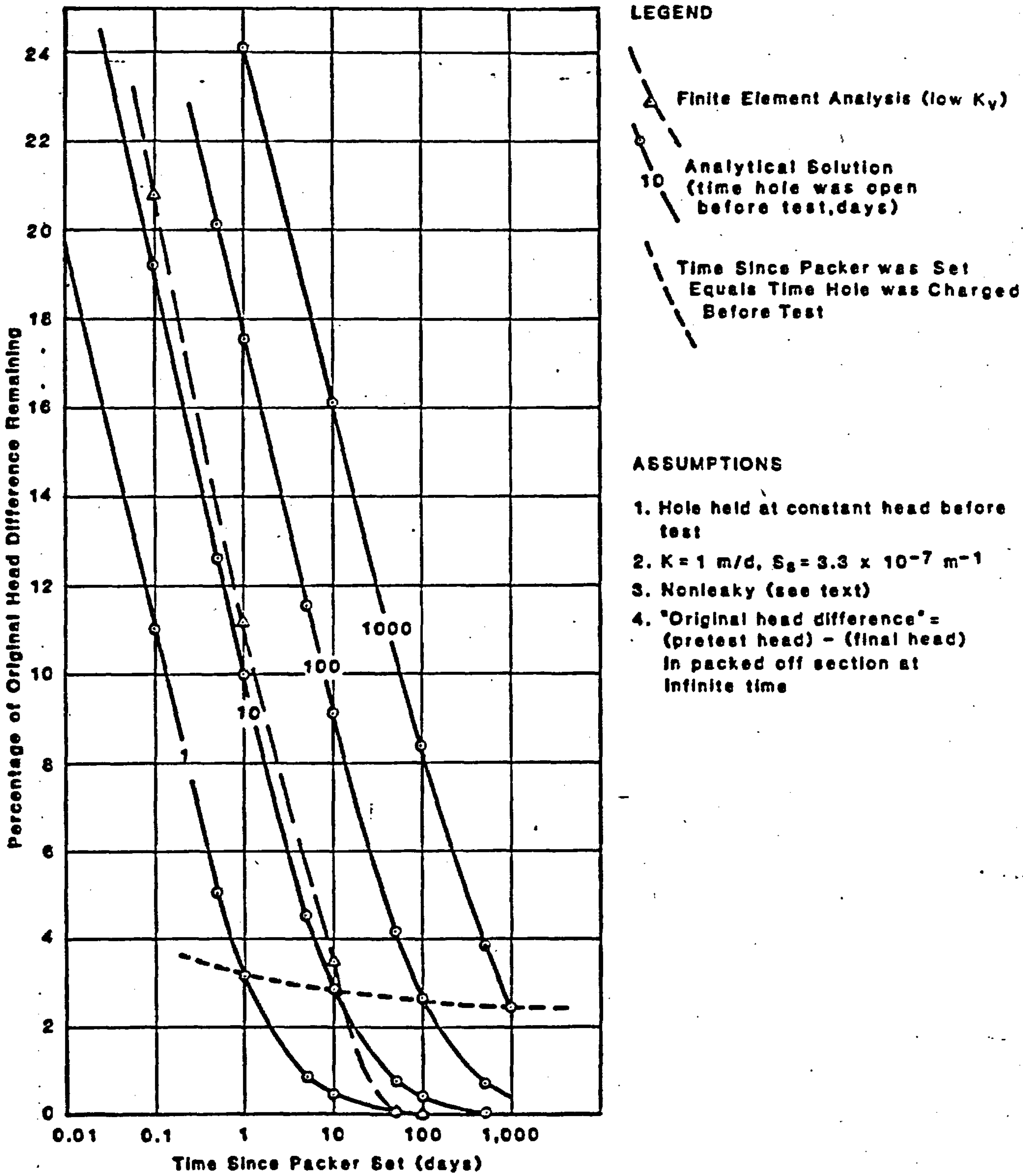
BWIP DSCA / ILogsdon

RE-EQUILIBRATION DURING A PACKER TEST AT BWIP Figure 7



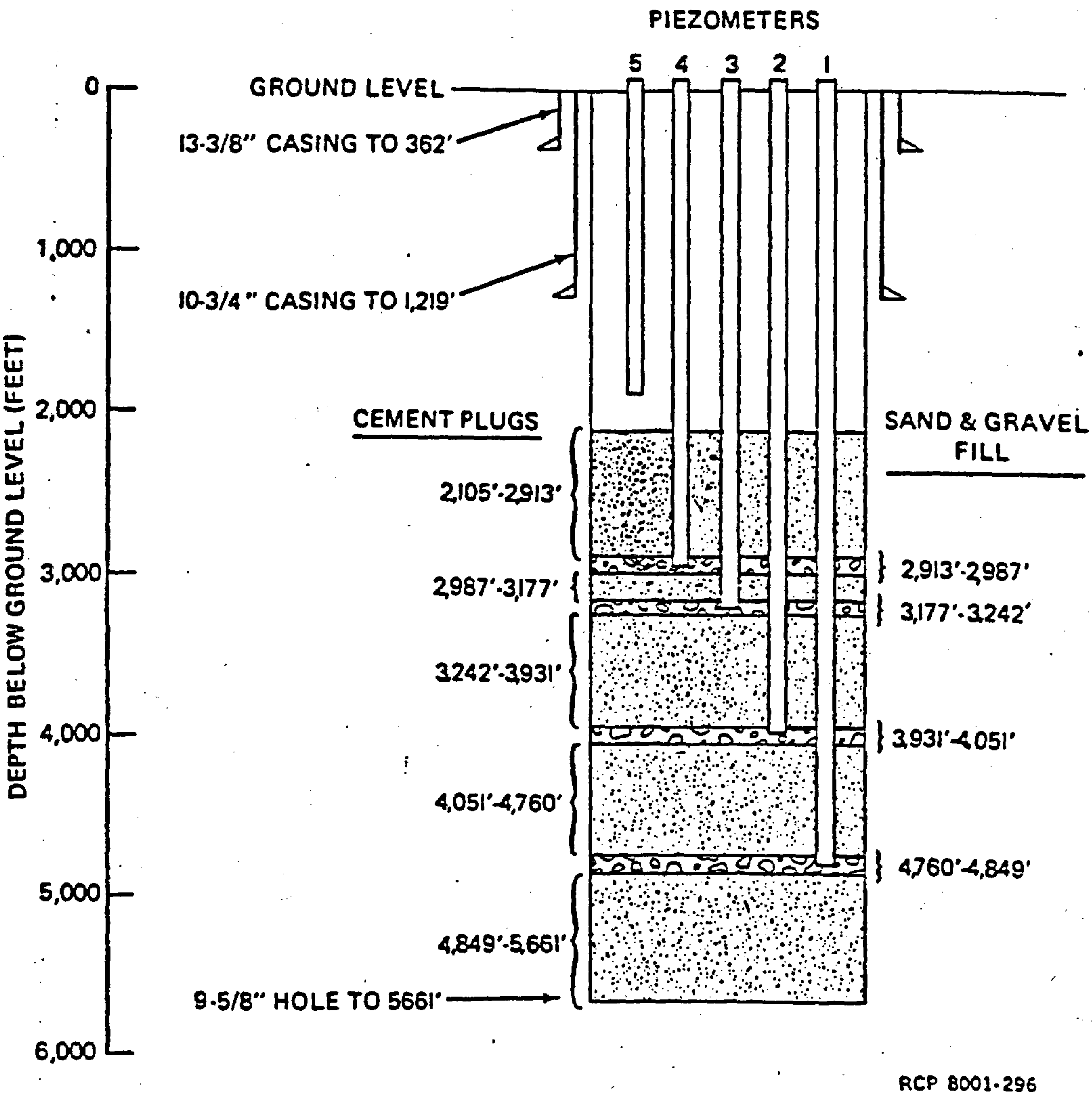
ASSUMPTIONS

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

BWIP OSCAI Logsdon

COMPLETION IN DC-I

Figure 8

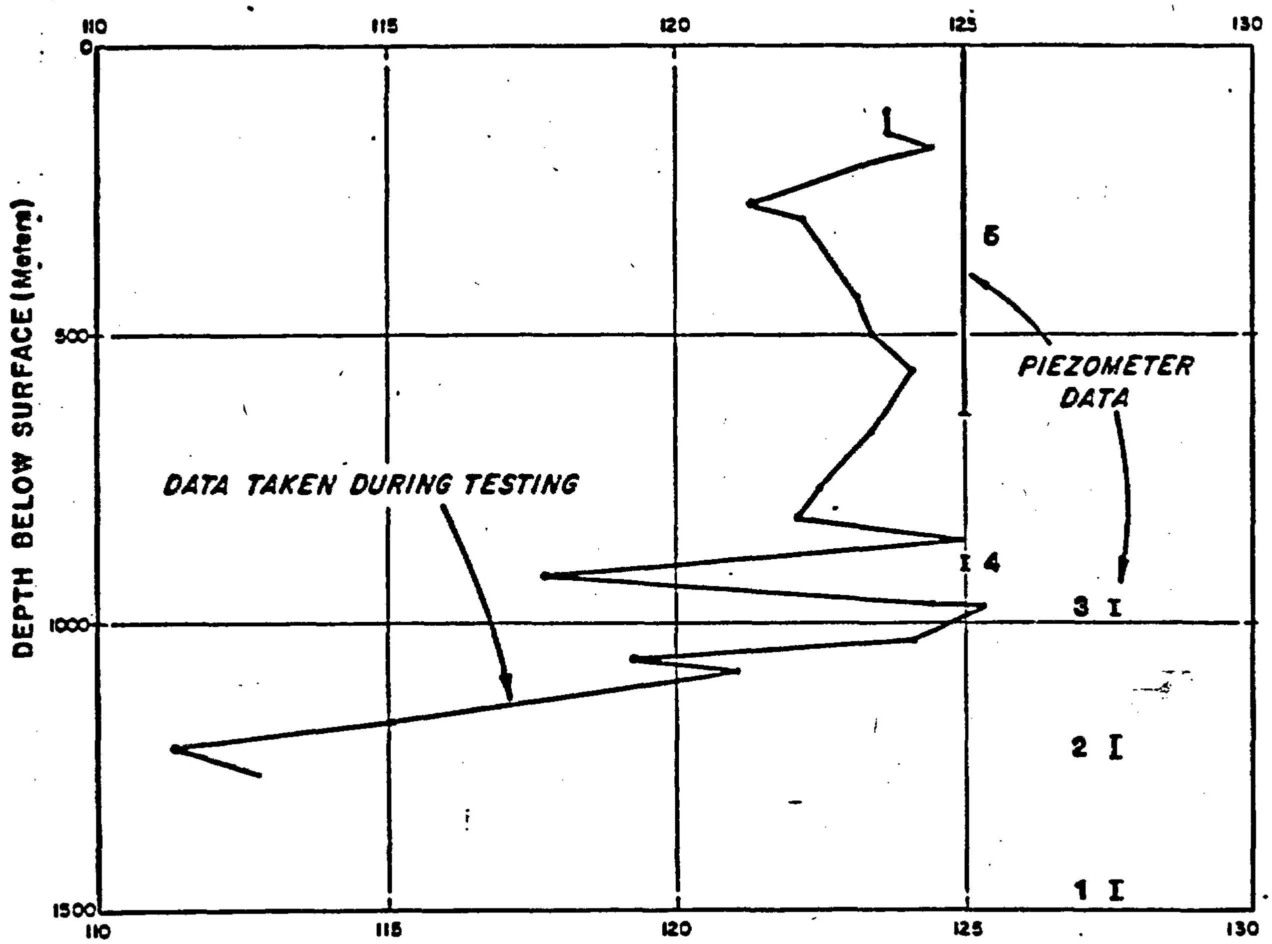


REFERENCE: GEPHART ET AL, 1979, PAGE III-113

BWIP BSCH1 ILogsdon

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

Figure 9

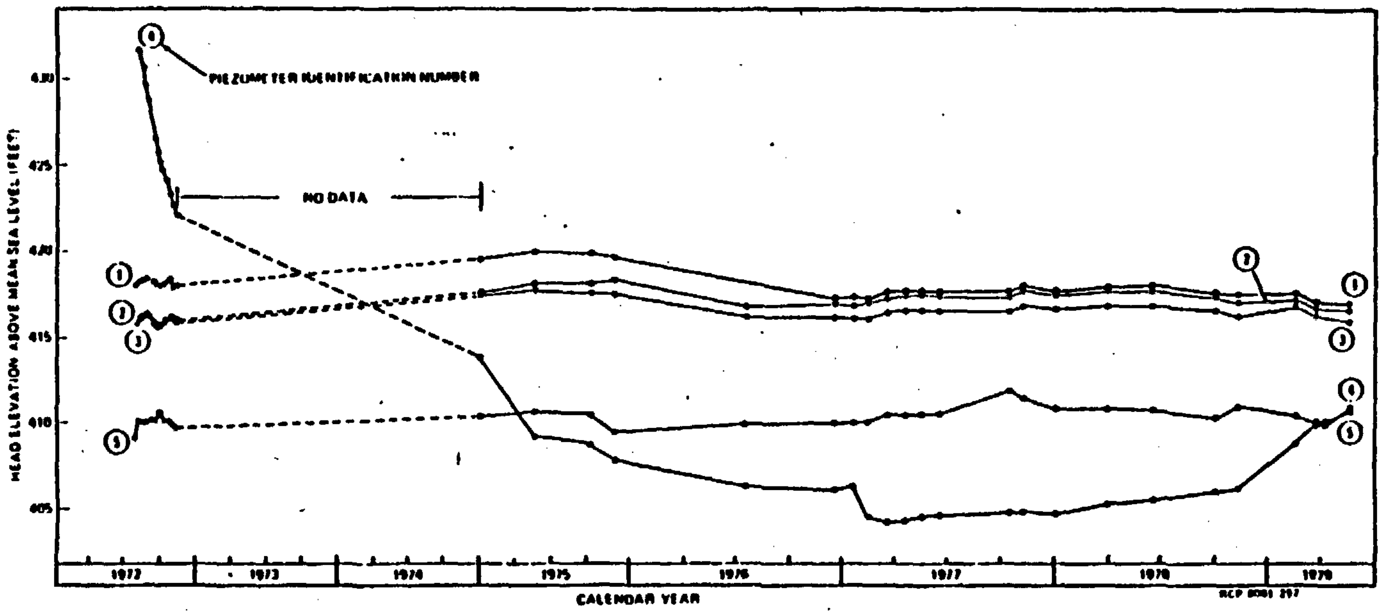


SOURCES: PACKER TEST DATA, LASALA AND DOTY, 1971
PIEZOMETER DATA, GEPHART ET AL, 1979

BWIP-OSCA / /Legislm

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

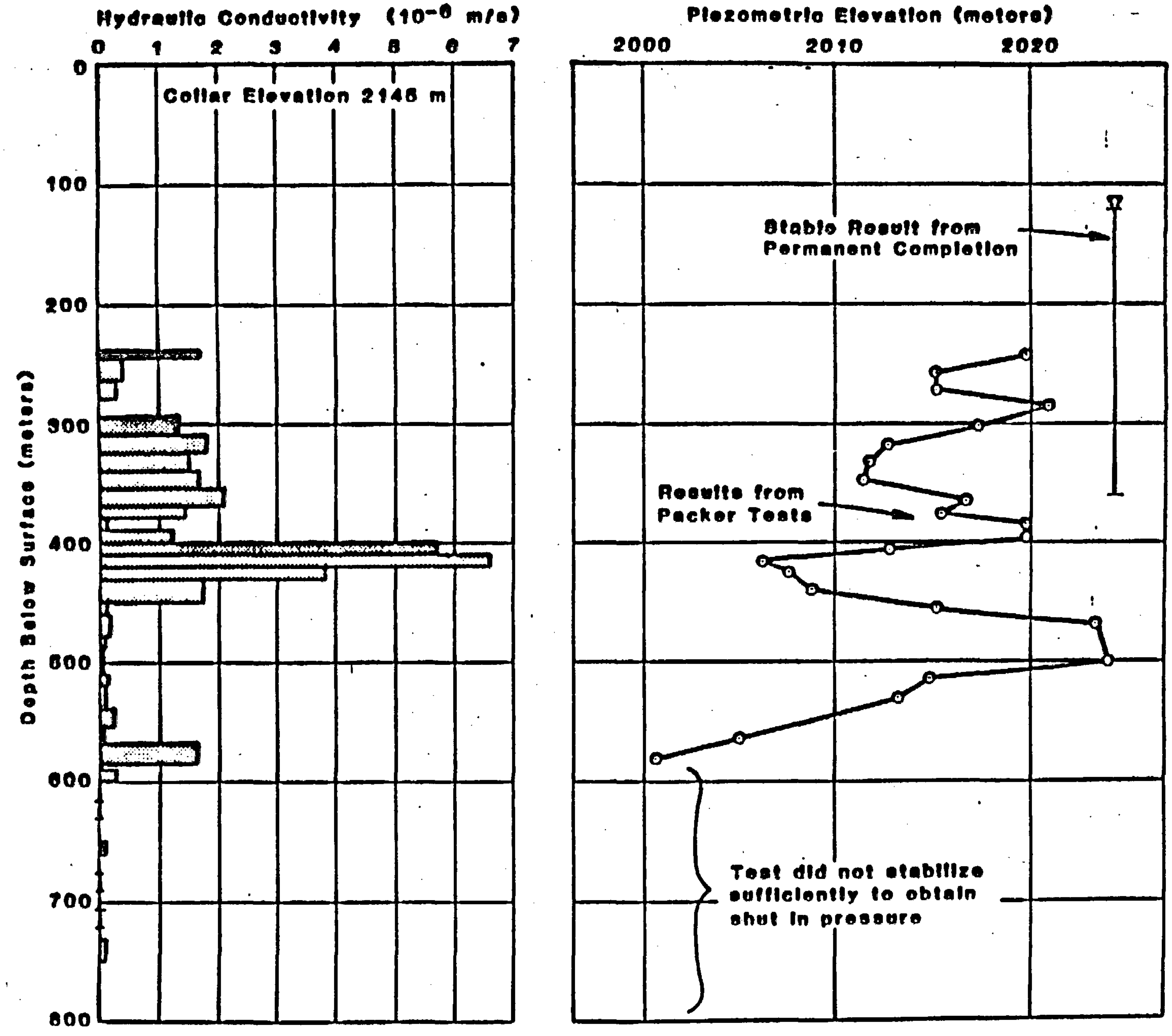
Figure 10



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

Figure 11

RESULTS OF PACKER TEST AND PERMANENT COMPLETION HEAD MEASUREMENTS IN OIL SHALE



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

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APPENDIX H

HYDROGEOLOGIC DATA INTEGRATION FOR CONCEPTUAL GROUNDWATER FLOW MODELS

LIST OF TABLES

LIST OF FIGURES

Figure

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:

$$m \leq 1.96 \frac{S}{\sqrt{n}}$$

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,

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

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 hyothesis 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 intervalue 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 hydrostatigraphic 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:

- representative elemental volumes were not tested (except possibly in the Grande Ronde B);
- effective hydraulic conductivity is spatially uncorrelated;
- 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:

- inappropriate choice of HSU's;
- nonrepresentative measurements of HSU properties (i.e. measurements do not represent a representative elemental volume of the medium);
- inaccurate measurements of HSU properties;
- 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.

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Table 1 Summary of Hydrologic Data

EXPLANATION

Hydrostratigraphic Units

MB	Mabton
PR	Priest Rapids
RZ	Roza
FS	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

- 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.
- Average K_H of Test Interval = Transmissivity/Effective Thickness.
- Total Transmissivity of HSU = Sum of Transmissivity for All Interflows.
- Effective K_H of HSU = Total Transmissivity/Sum of Effective Thickness.

Sources of Data

- 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)
- Gephart et al (1979a): RSH-1
- Gephart et al (1979b): DB-12, DB-13, DC-1

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)
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		

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)
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	5.4E+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		

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		

H-14

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)
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		

Table 1 Summary of Hydrologic Data

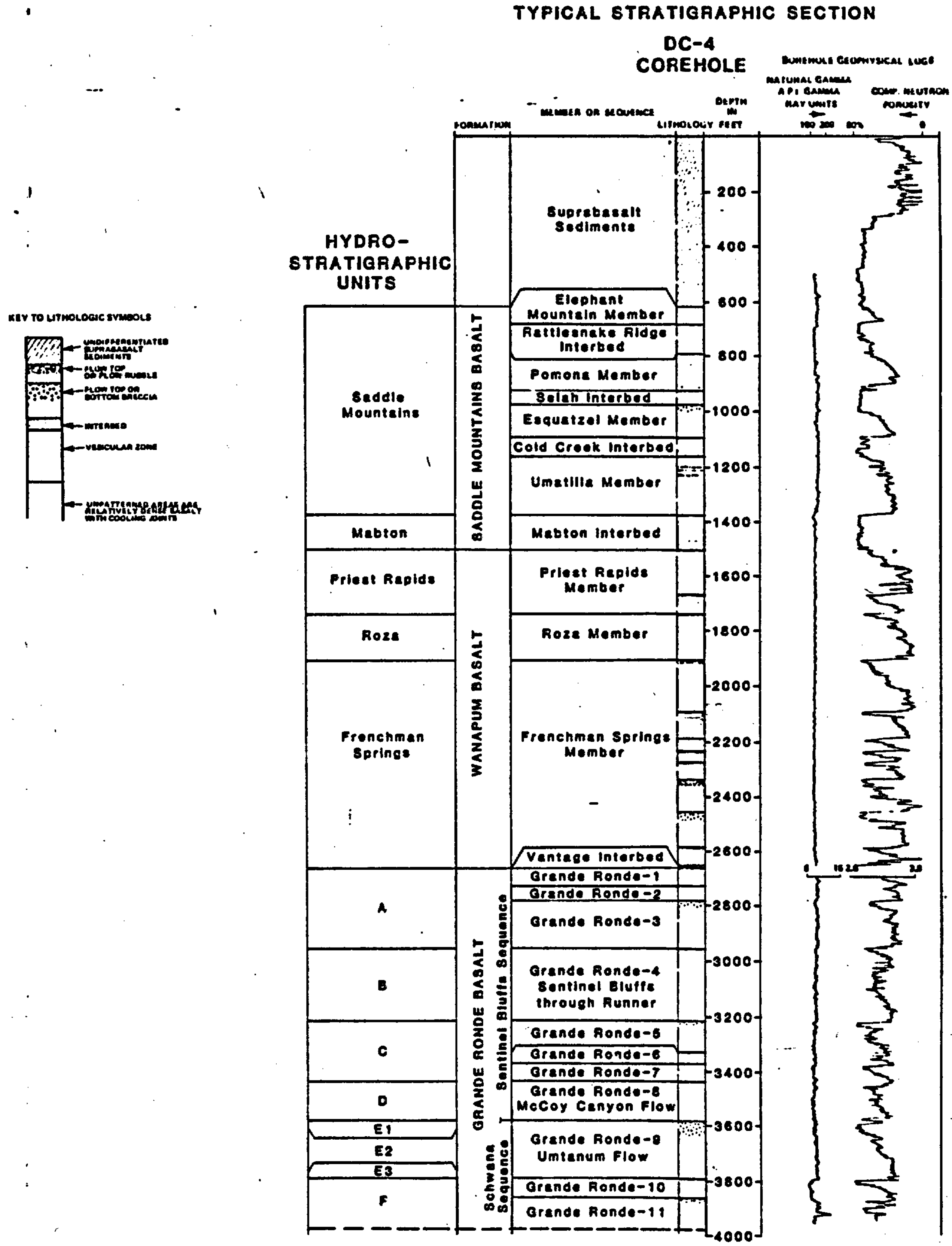
HSU	BOREHOLE NO.	TEST INTERVAL (m below GS)		HEAD (m MSL)	TRANSMISSIVITY (m^2/day)	EFFECTIVE THICKNESS (m)	AVERAGE K_H (m/s)	TOTAL TRANSMISSIVITY (m^2/day)	EFFECTIVE K_H (m/s)
GRD	DC-1	832.1	887.0	125.3	3.0E-02	54.9	6.4E-09	3.0E-02	6.4E-09
GRD	DC-12	934.8	961.0		5.9E-02	10.7	6.4E-08	5.9E-02	6.4E-08
GRD	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

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	1075.9	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		

ASSUMED HYDROSTRATIGRAPHIC UNITS

Figure 1



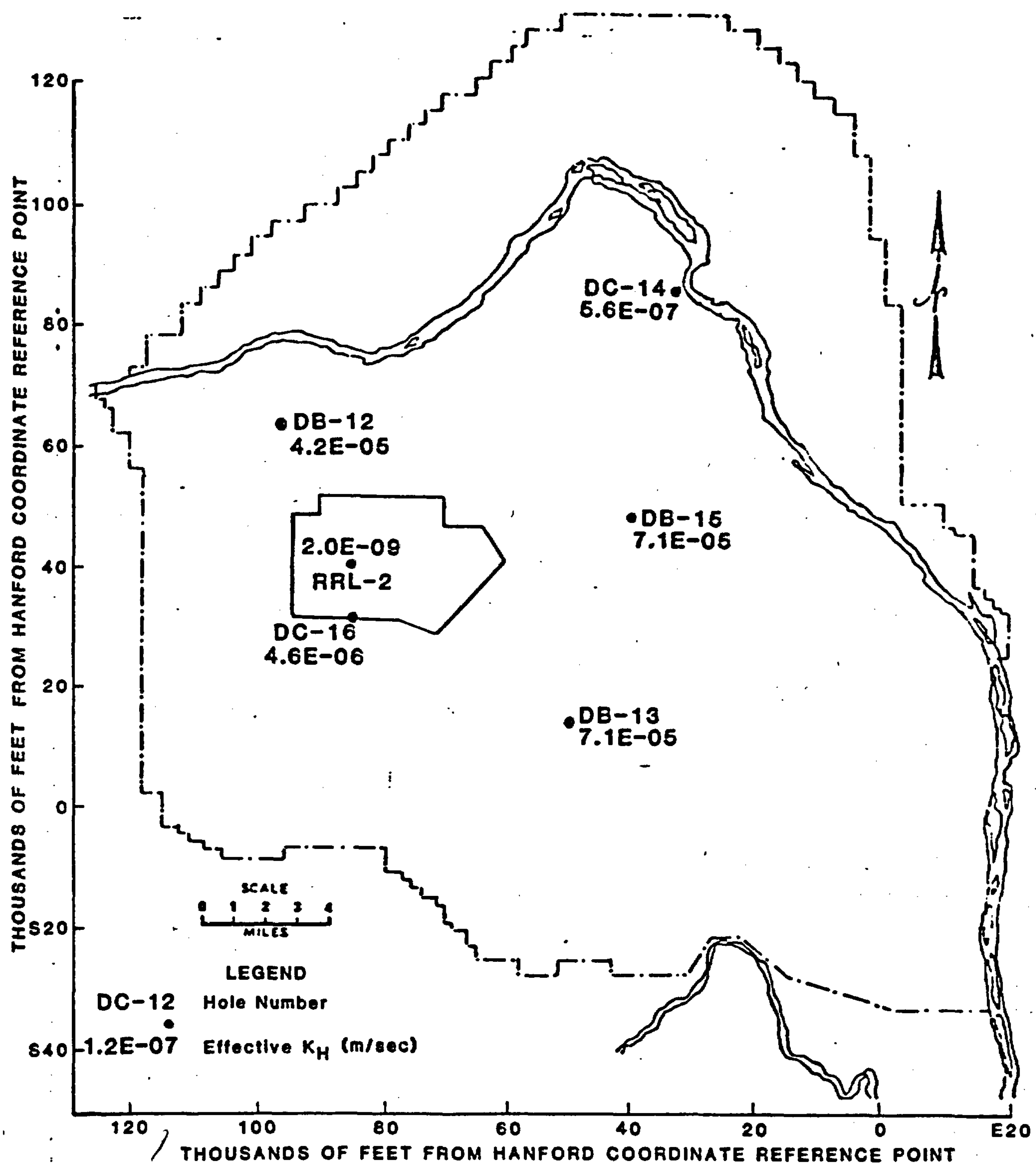
EXPLANATION

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 HENCE GRANDE RONDE 12 IN DC 14 IS NOT NECESSARILY THE SAME AS GRANDE RONDE - 12 IN DH-5. NAMED FLOWS, HOWEVER, ARE EQUIVALENT FROM ONE BOREHOLE TO ANOTHER.

From: RSD-BWI-DP-035
(Rockwell Hanford Operations)

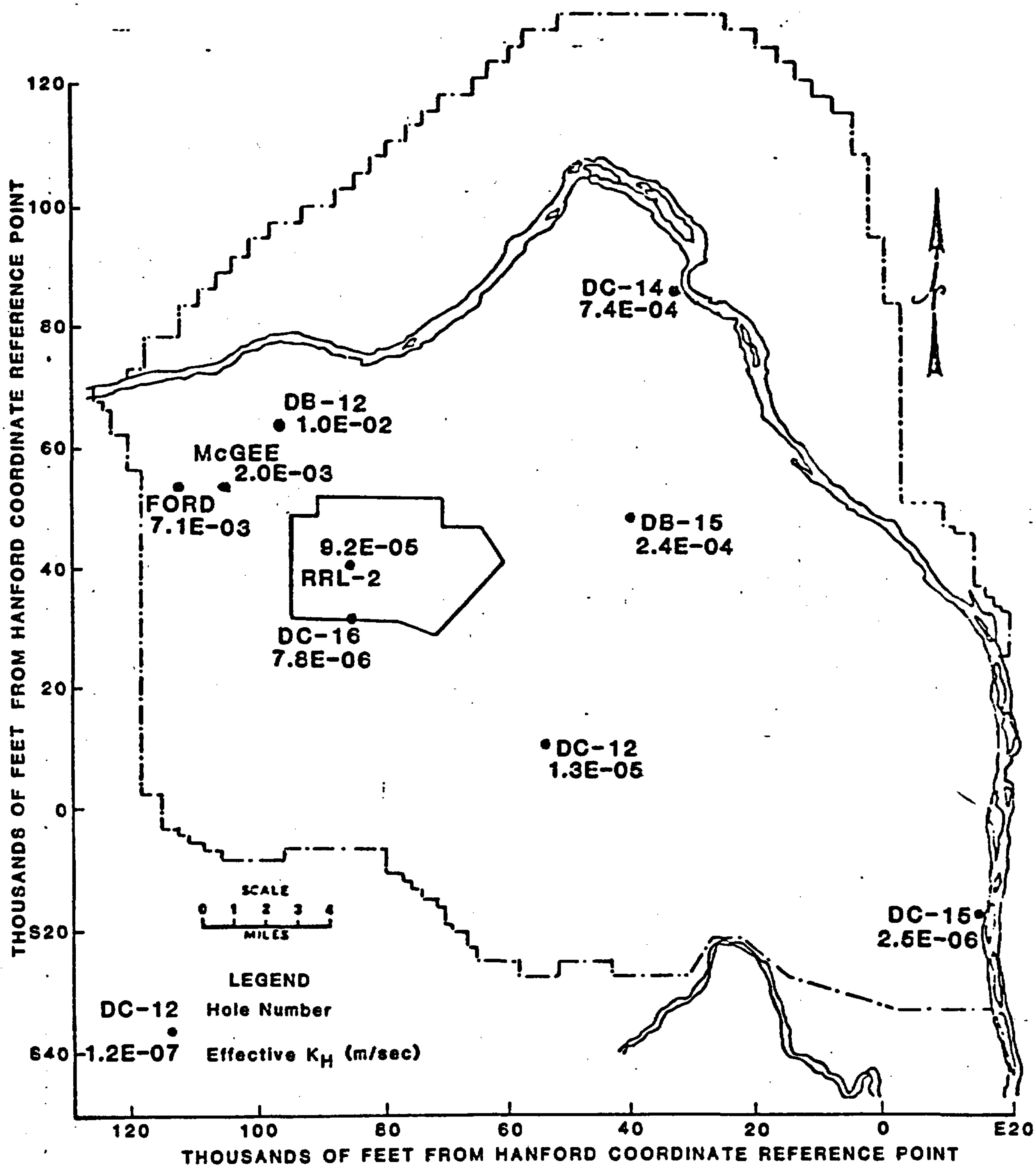
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE MABTON

Figure 2A



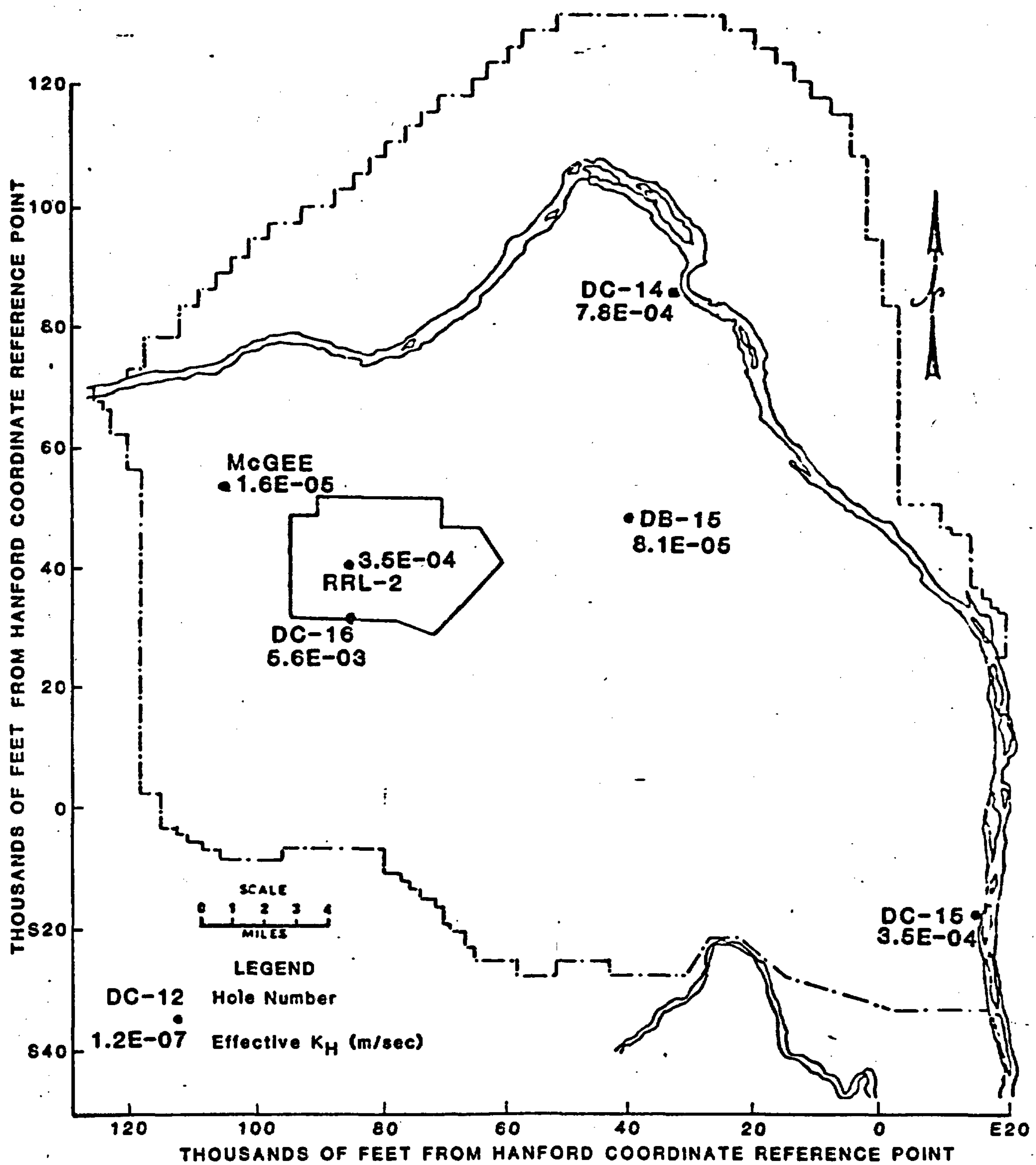
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE PRIEST RAPIDS

Figure 2B



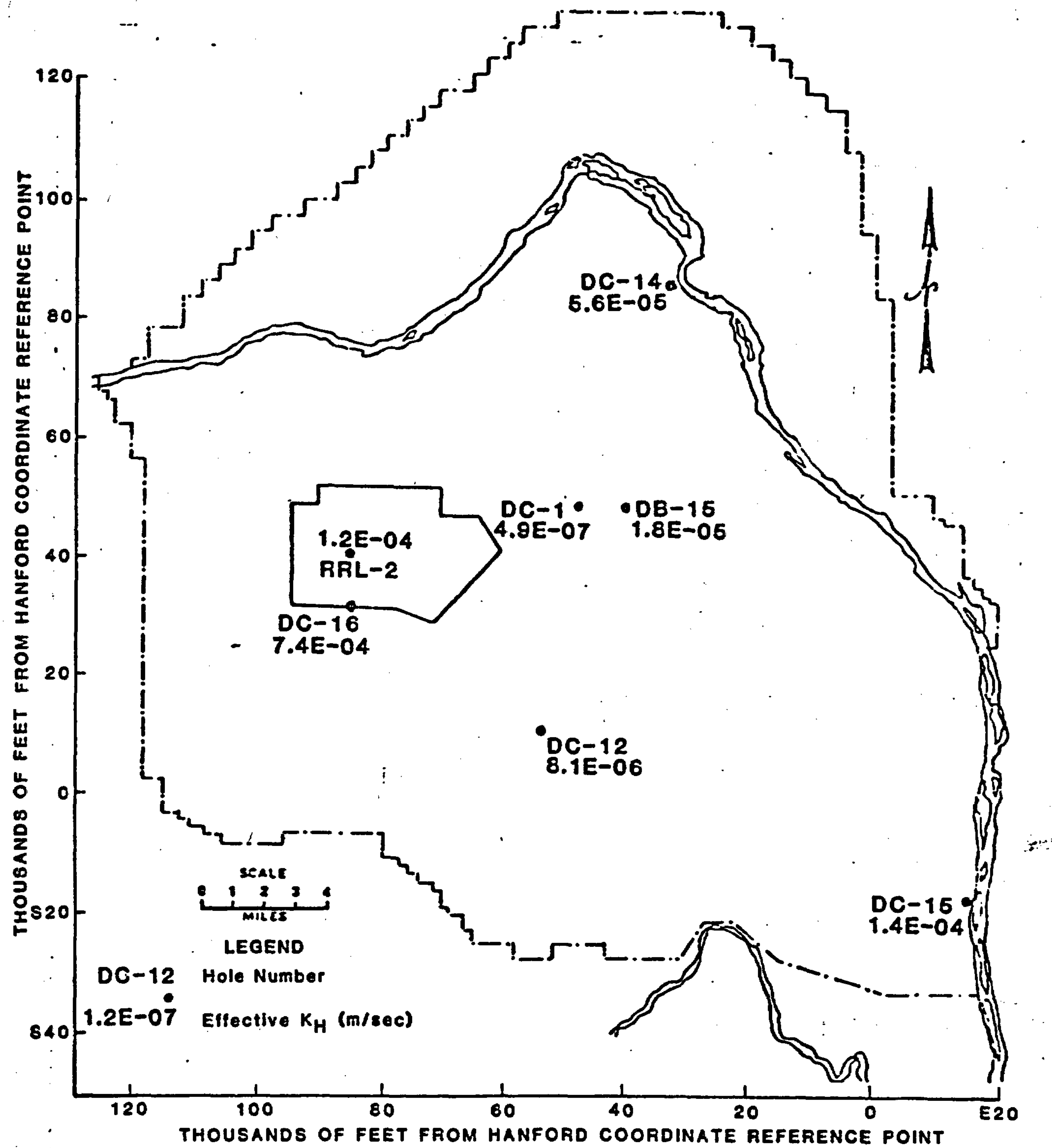
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE ROZA

Figure 2C



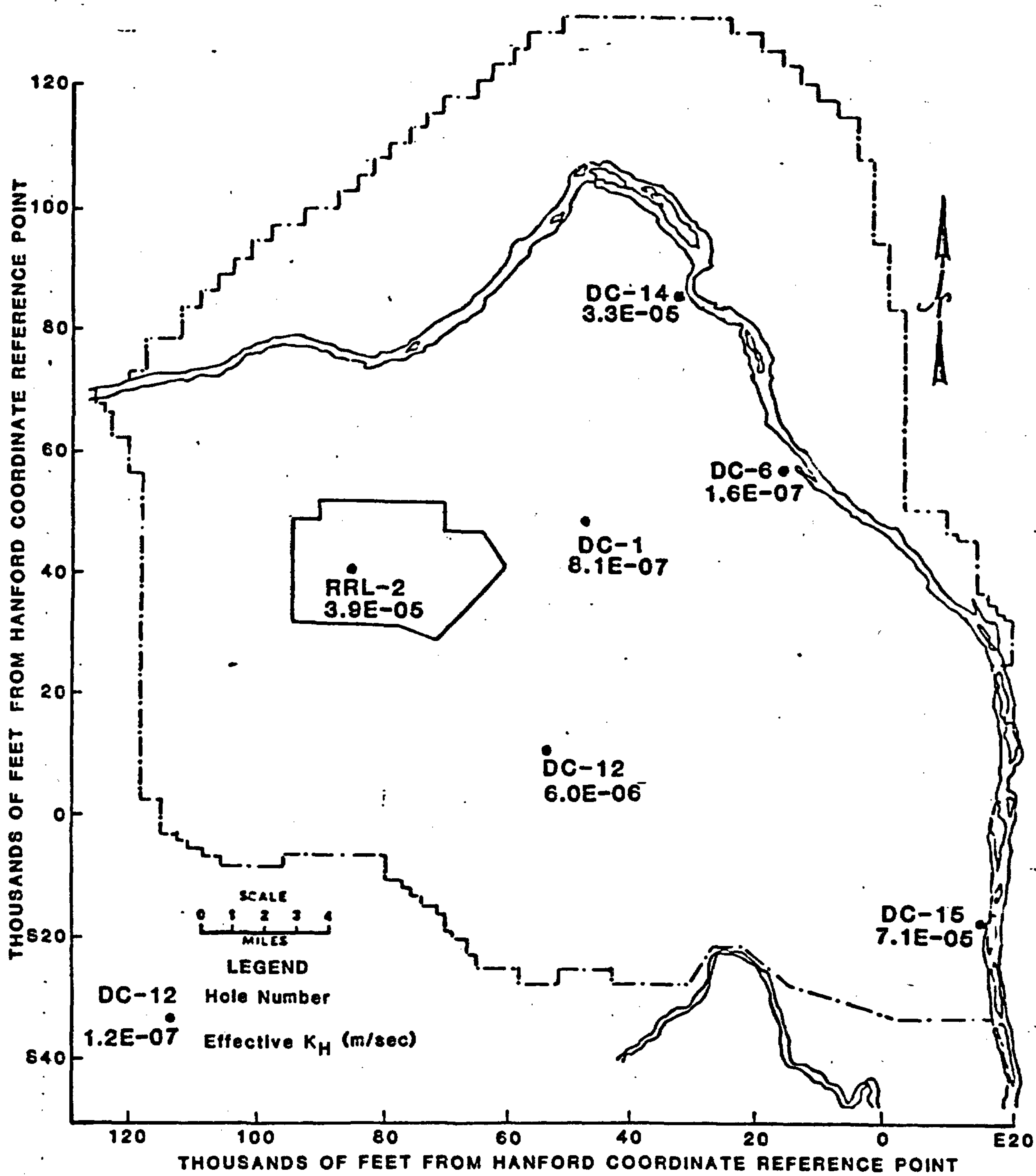
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE FRENCHMAN SPRINGS

Figure 2D



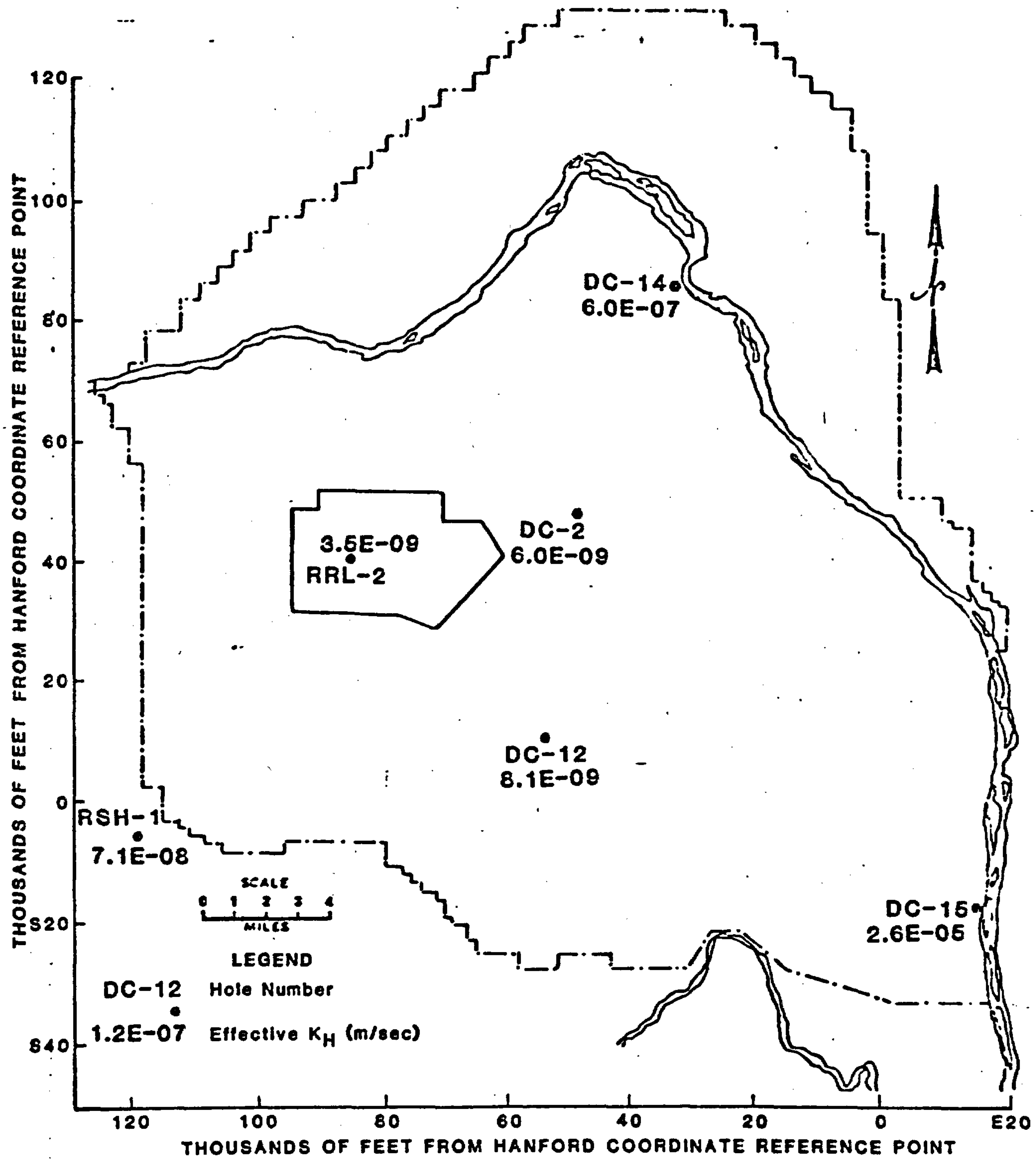
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE GRANDE RONDE A

Figure 2E



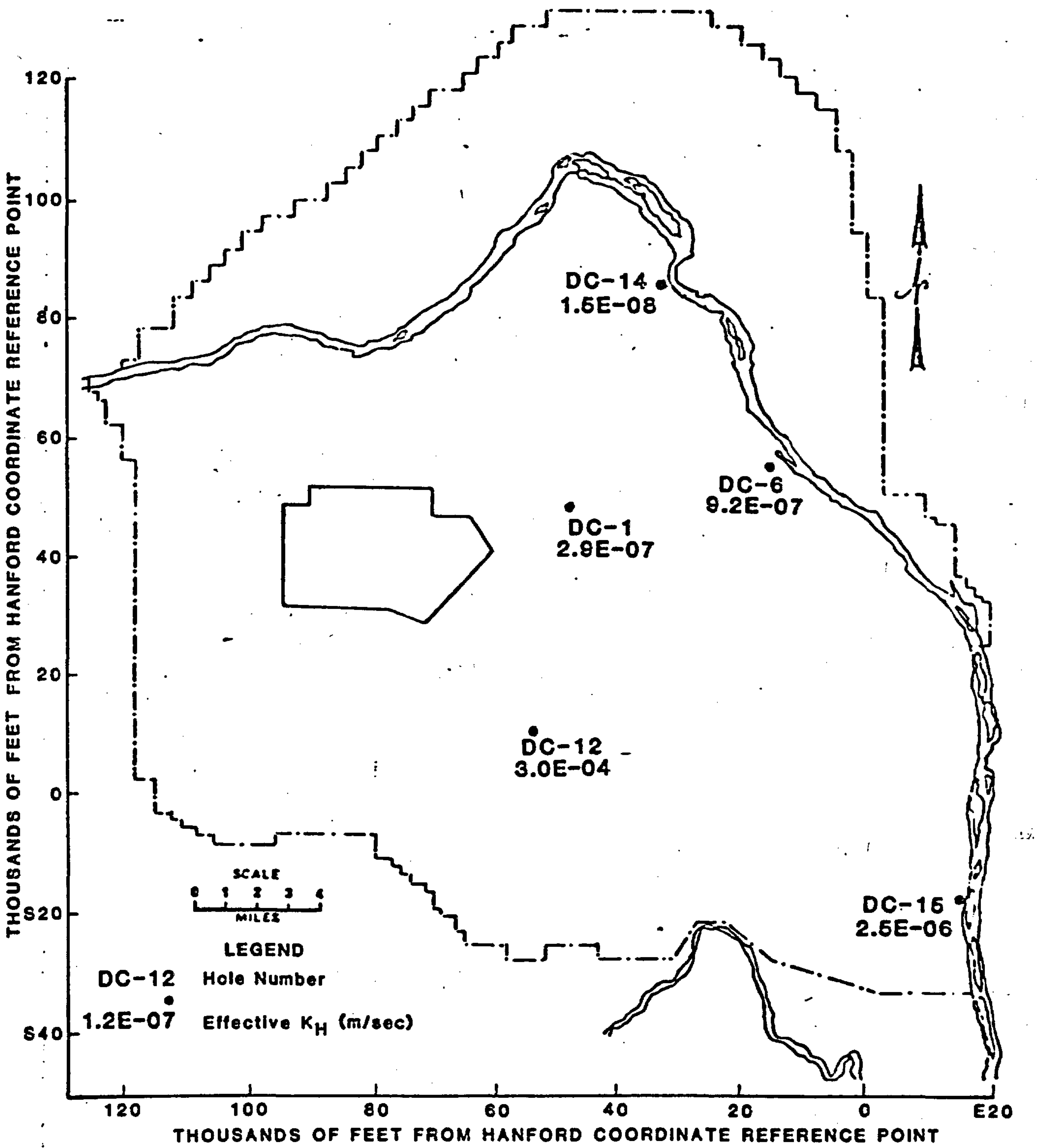
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE GRANDE RONDE B

Figure 2F



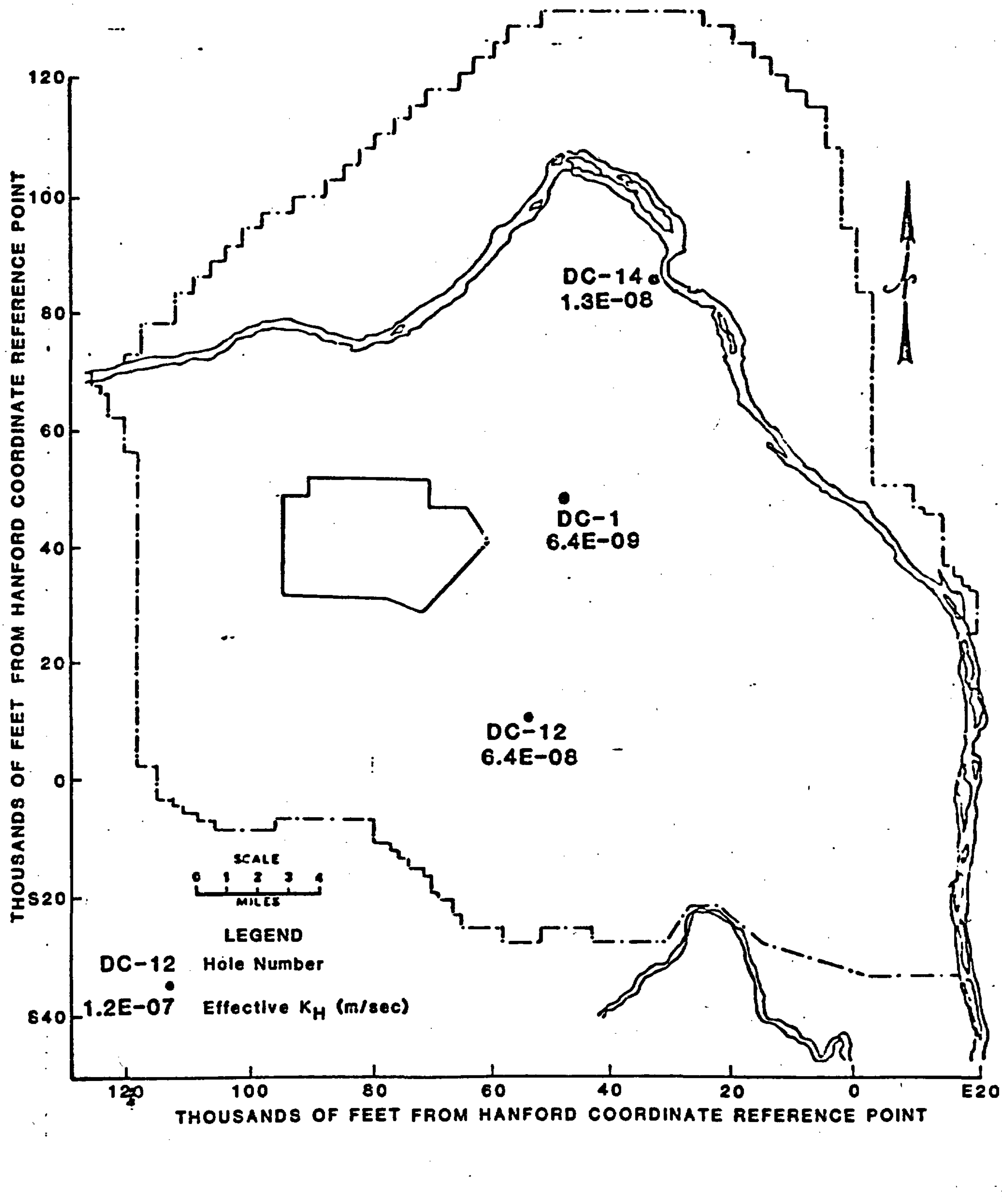
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE GRANDE RONDE C

Figure 2G



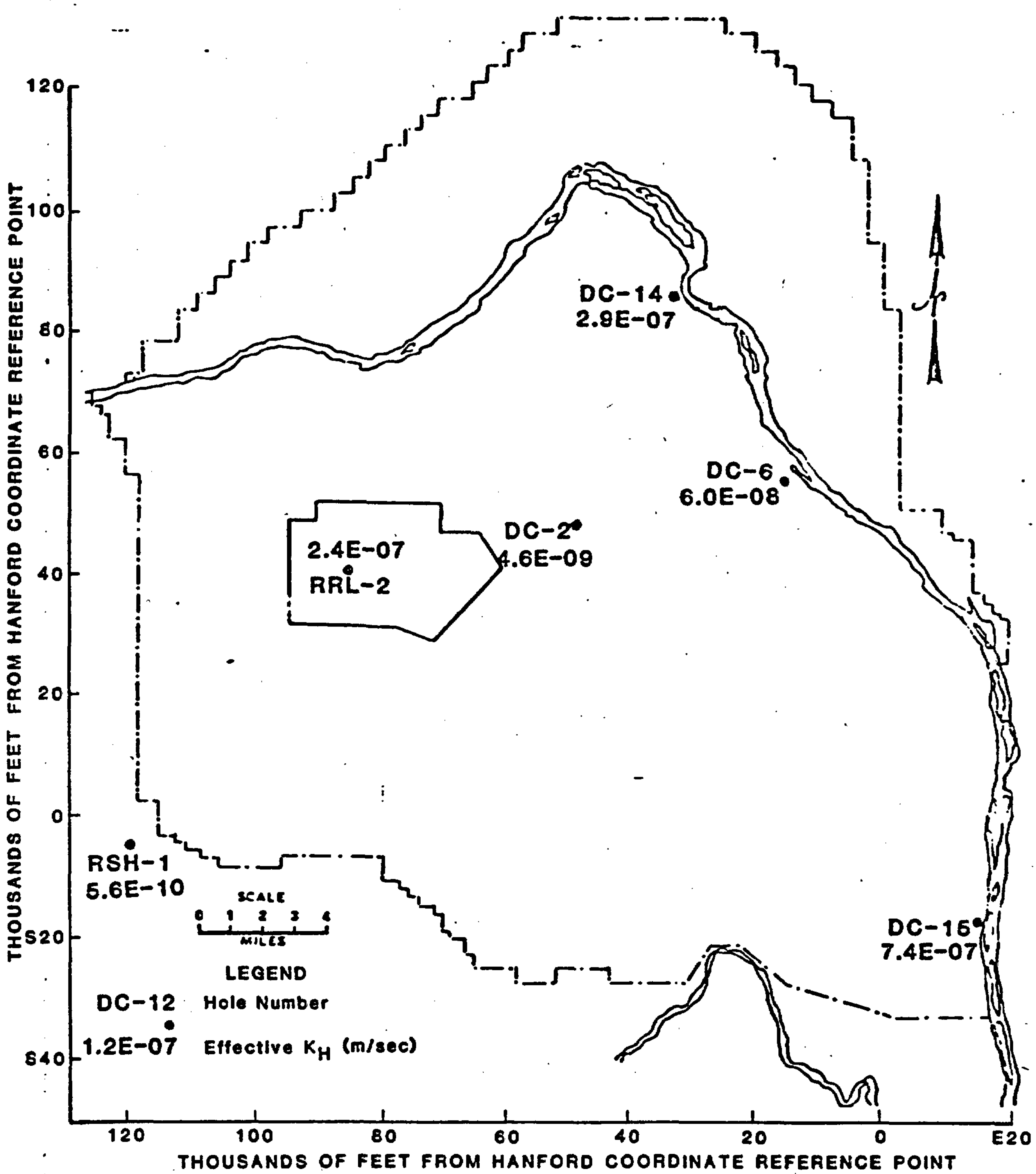
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE GRANDE RONDE D

Figure 2H



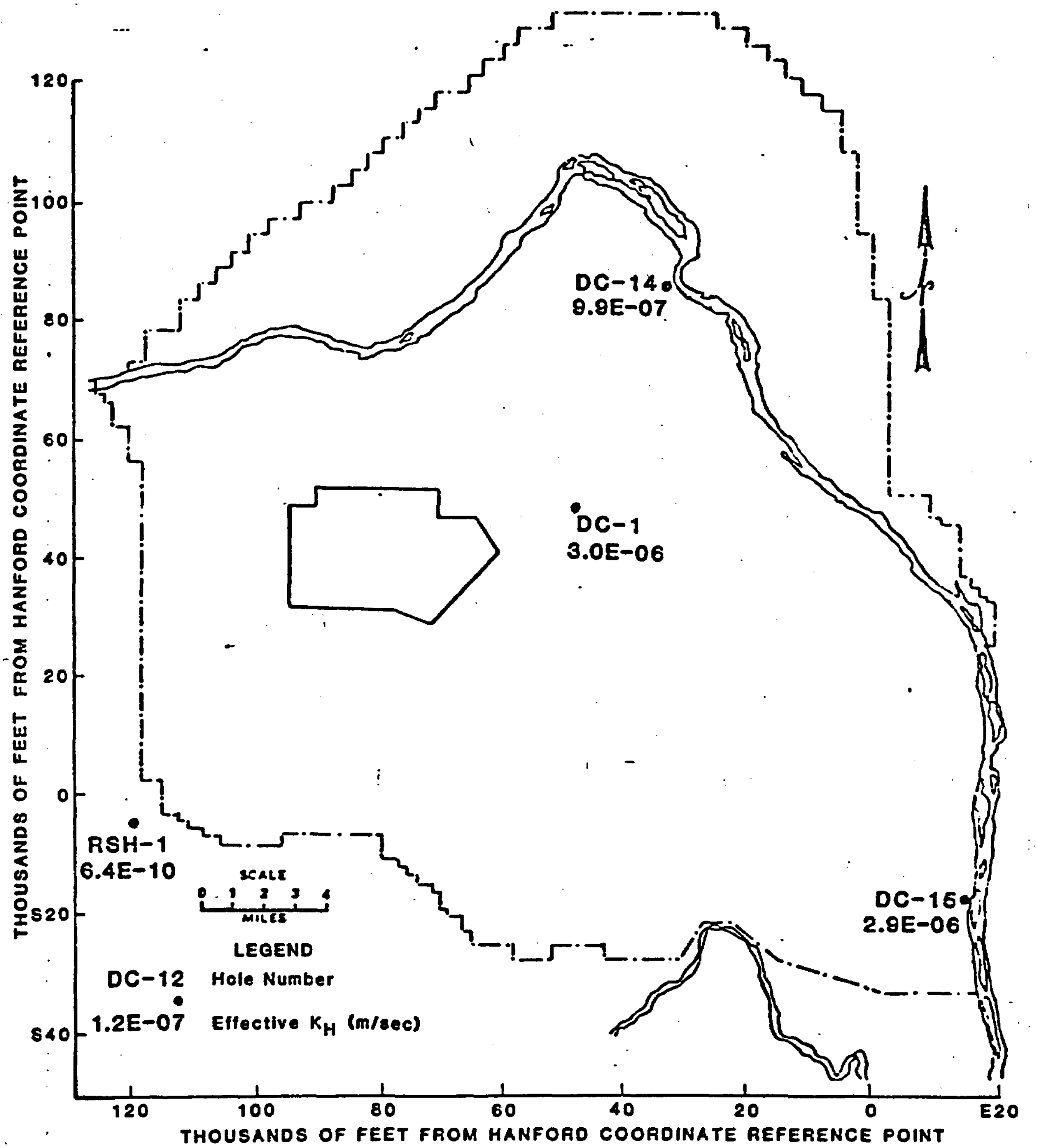
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE GRANDE RONDE E1

Figure 2I



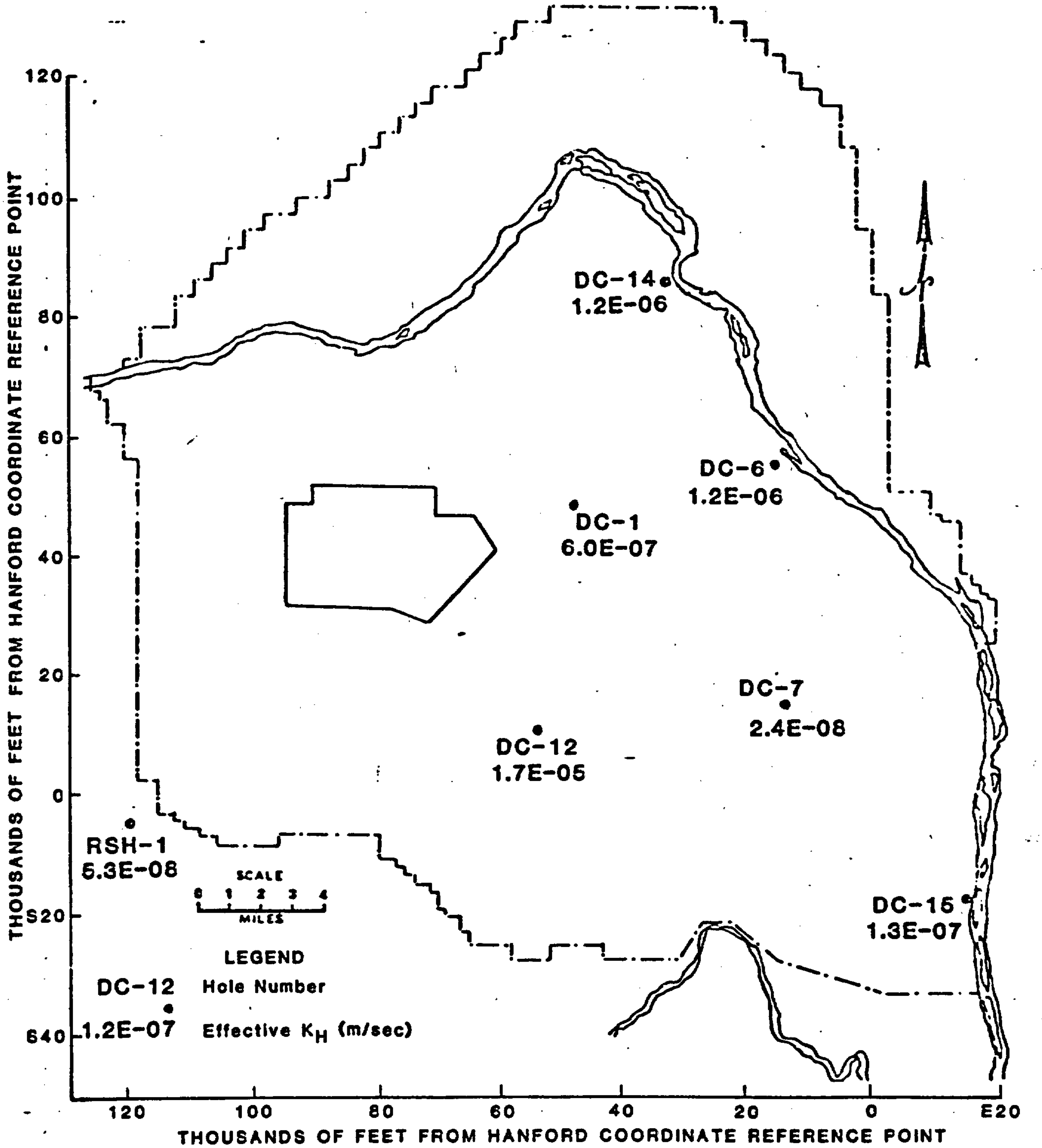
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE GRANDE RONDE E3

Figure 2J



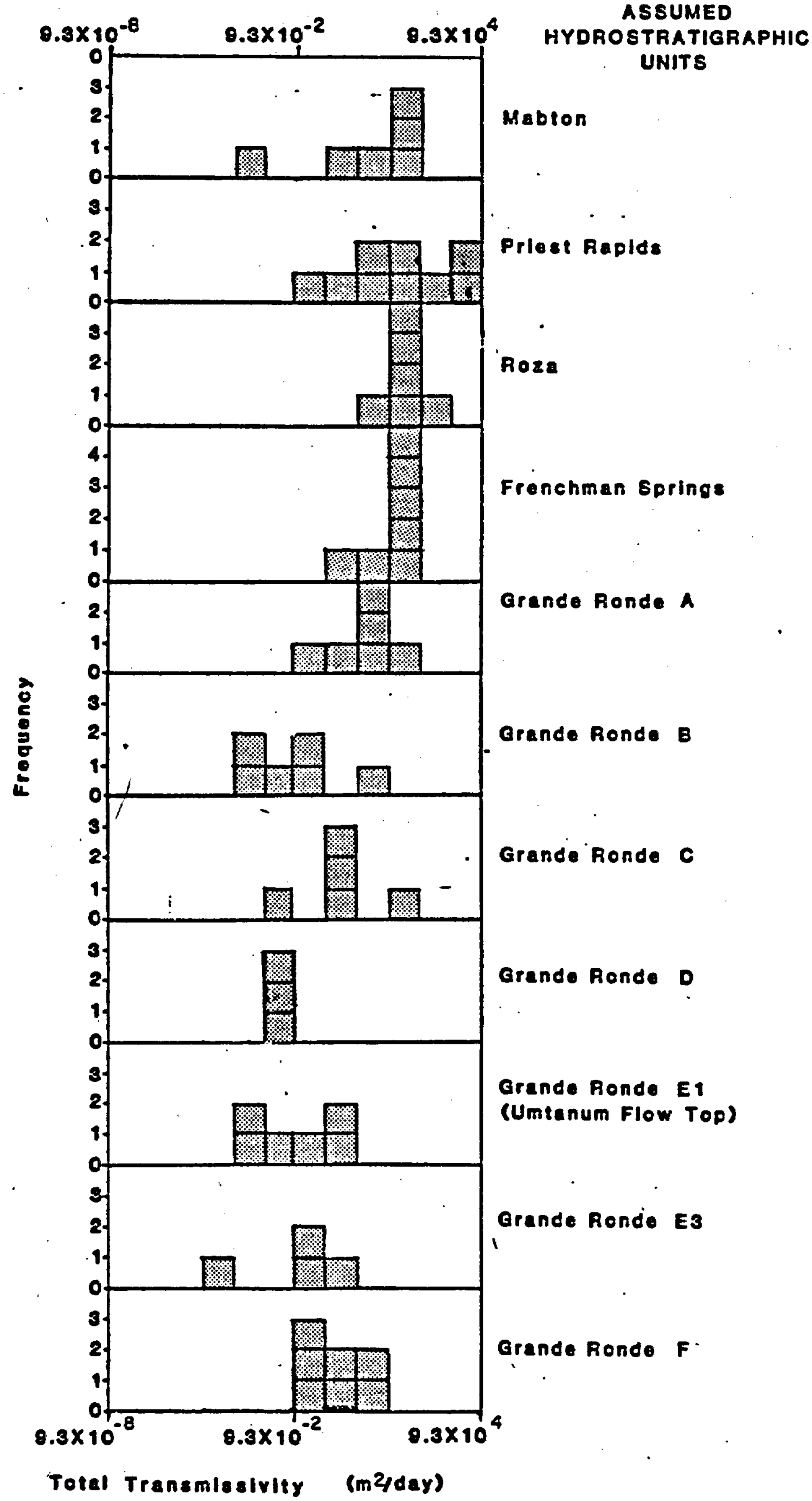
EFFECTIVE HORIZONTAL HYDRAULIC CONDUCTIVITY (M/SEC) OF INTERFLOWS IN THE GRANDE RONDE F

Figure 2K



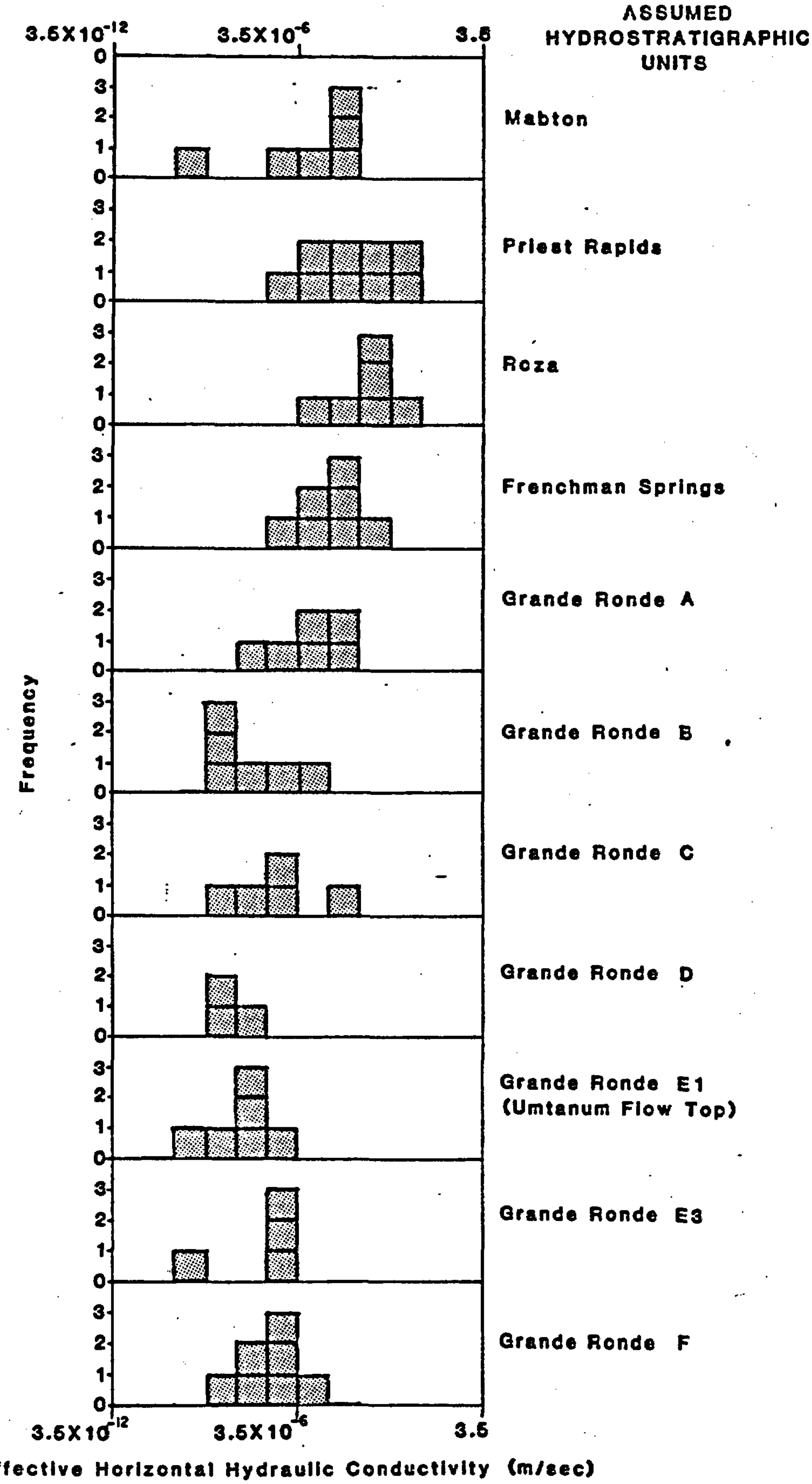
TOTAL TRANSMISSIVITY HISTOGRAMS

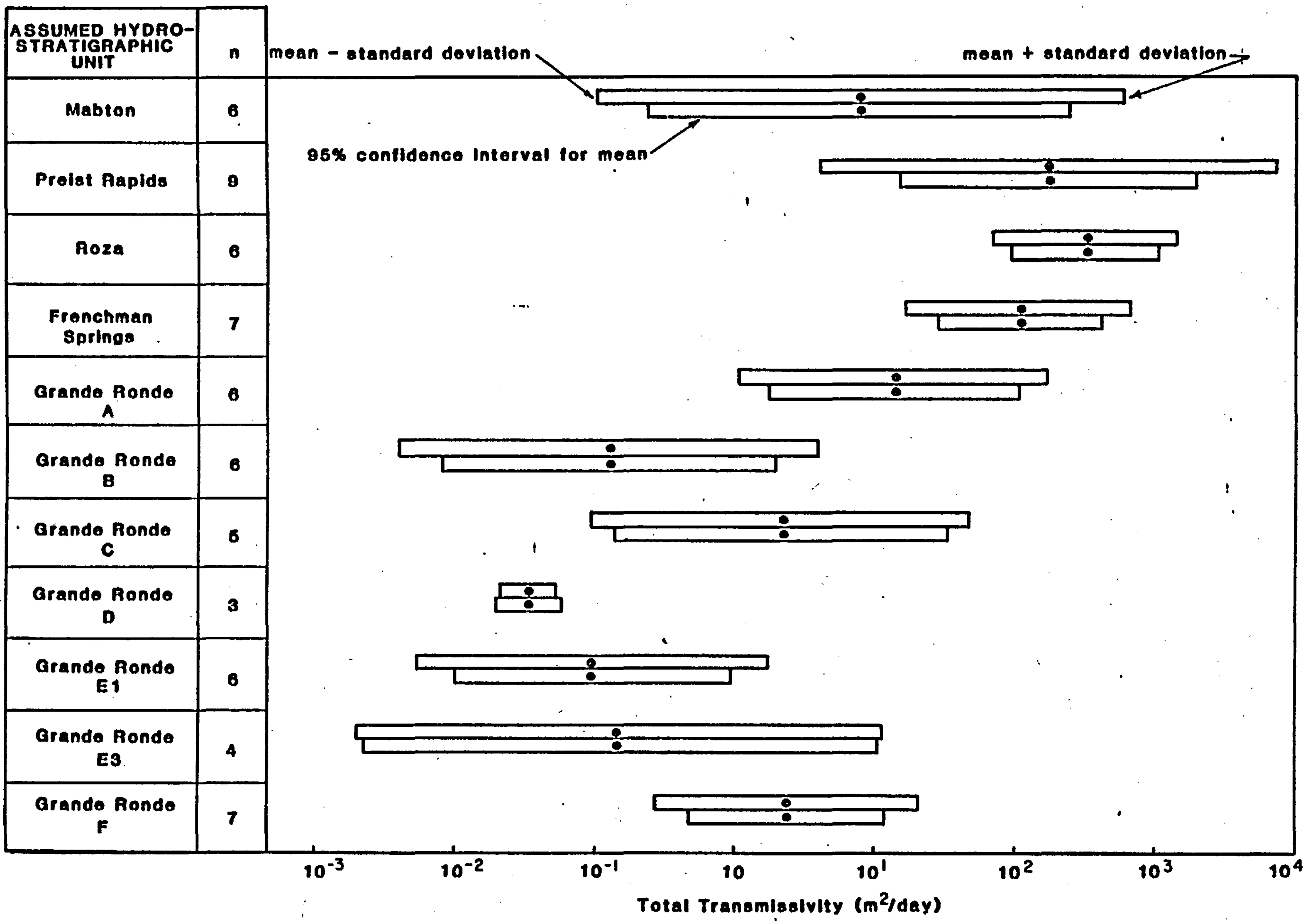
Figure 3



EFFECTIVE HYDRAULIC CONDUCTIVITY HISTOGRAMS

Figure 4

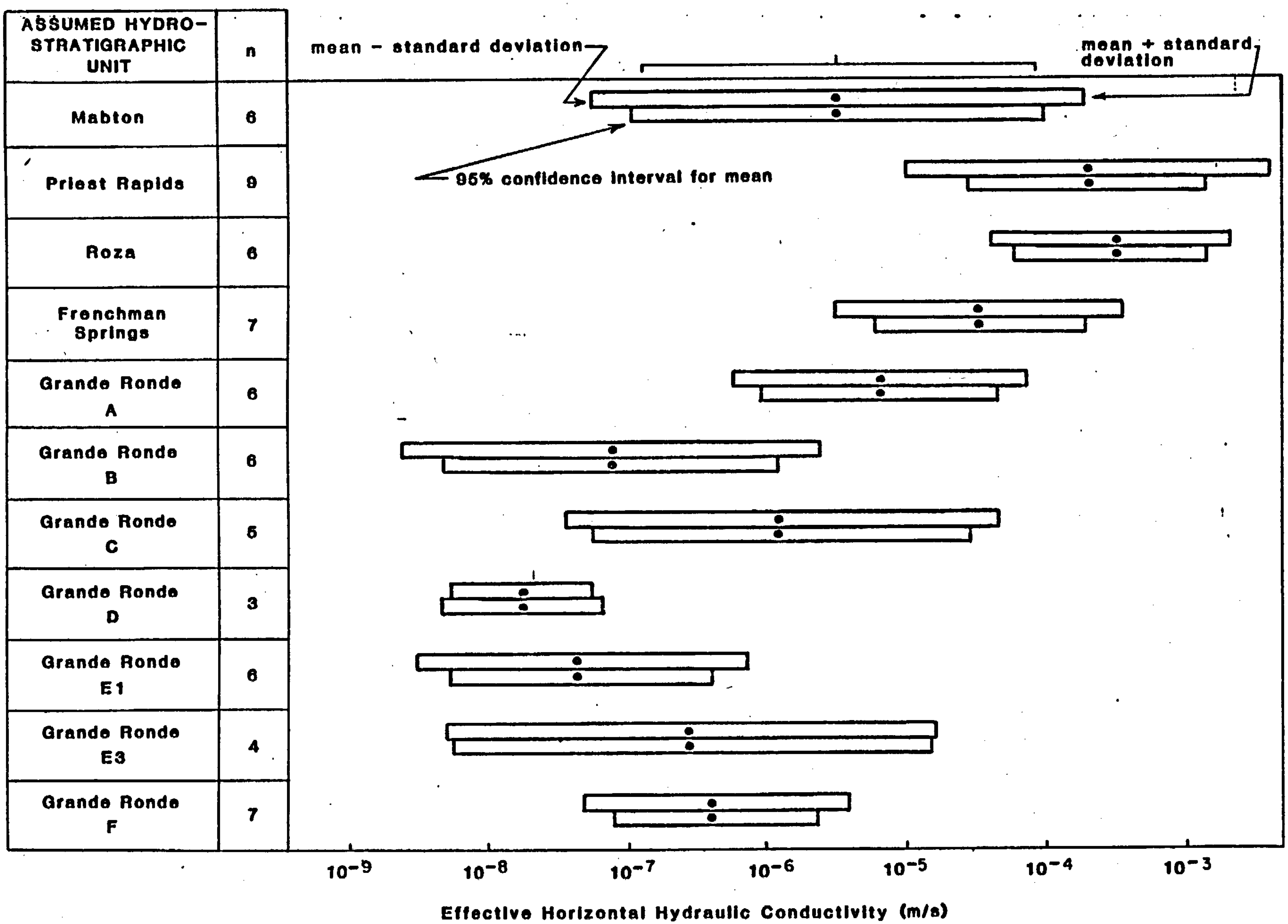




DISTRIBUTION OF TOTAL TRANSMISSIVITY FOR ASSUMED HYDROSTRATIGRAPHIC UNITS

Figure 5

#-33

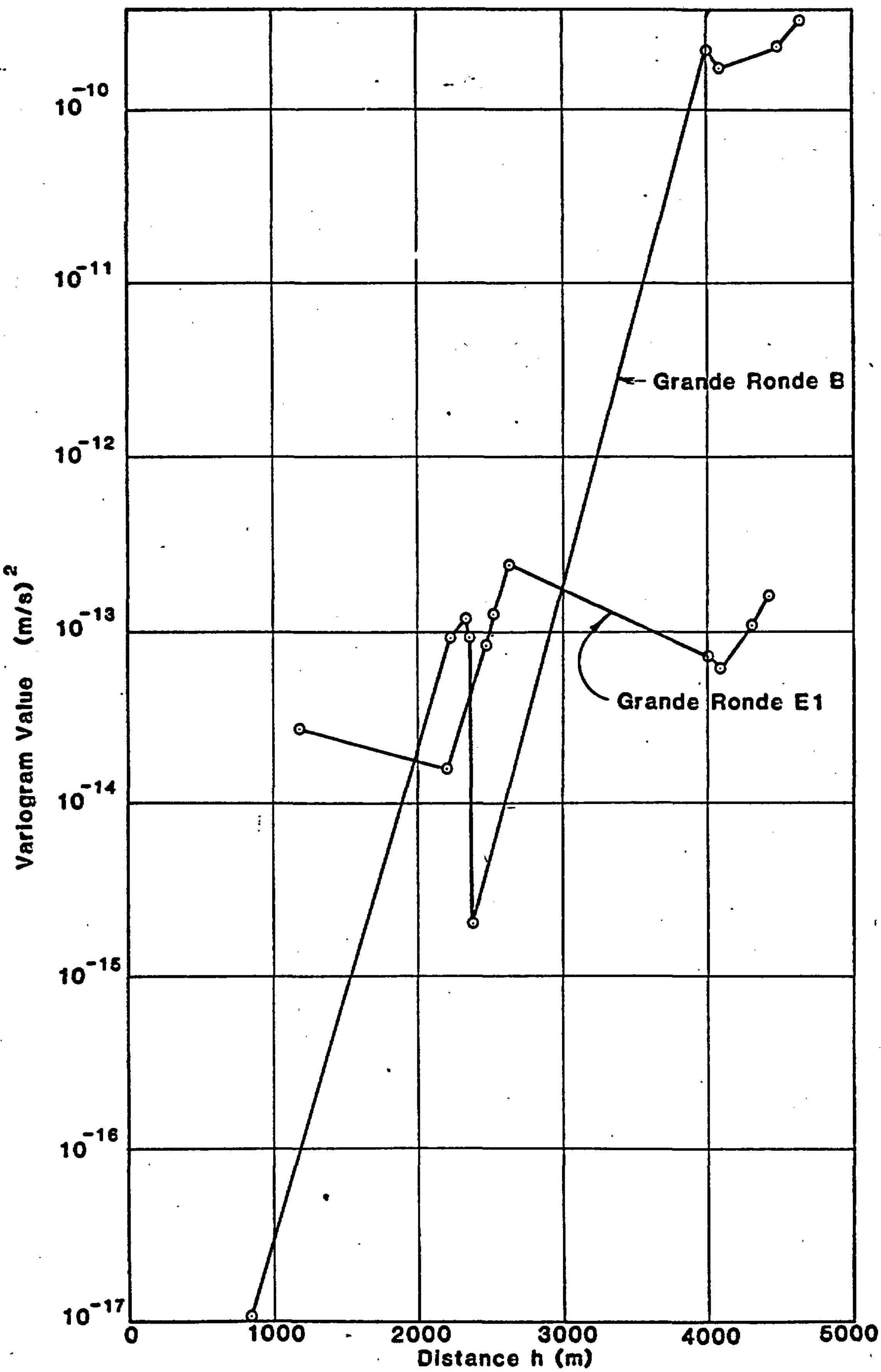


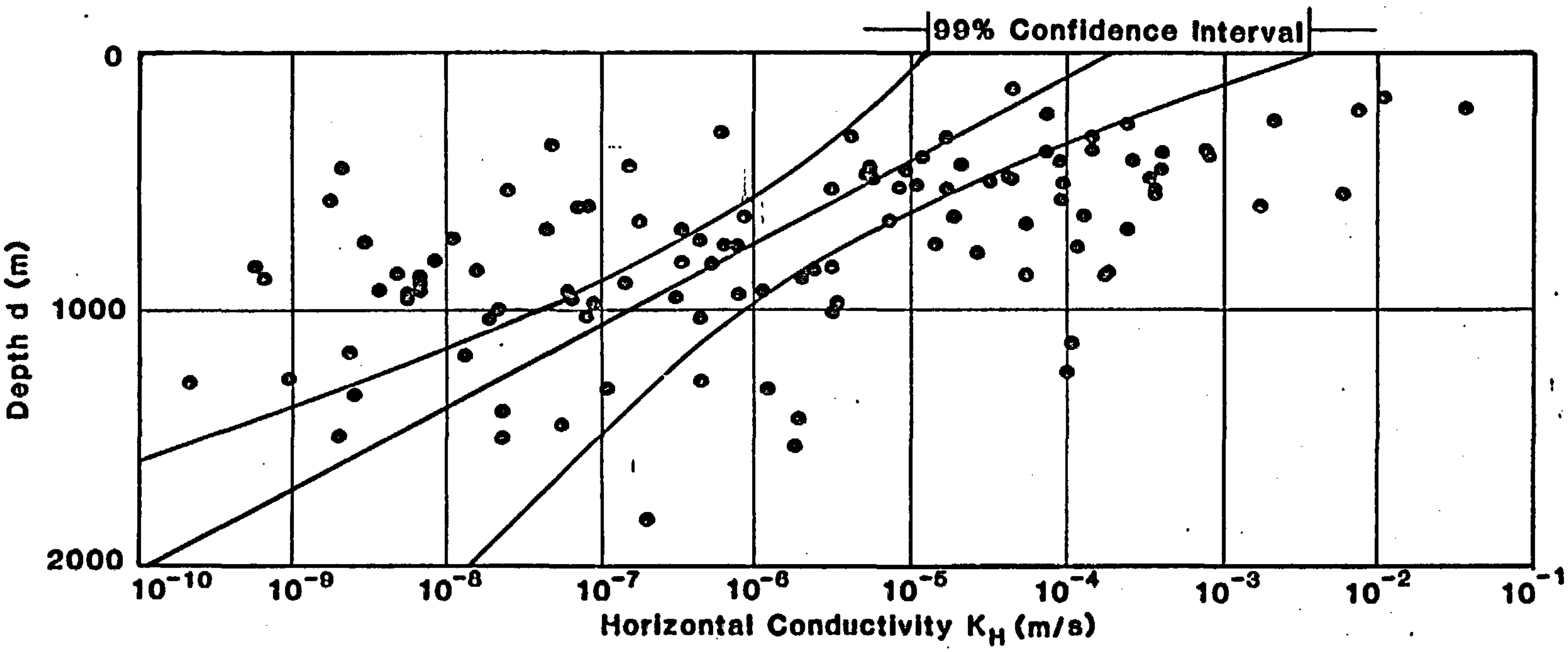
DISTRIBUTION OF EFFECTIVE HORIZONTAL CONDUCTIVITY VALUES FOR ASSUMED HYDROSTRATIGRAPHIC UNITS

Figure 6

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

Figure 7

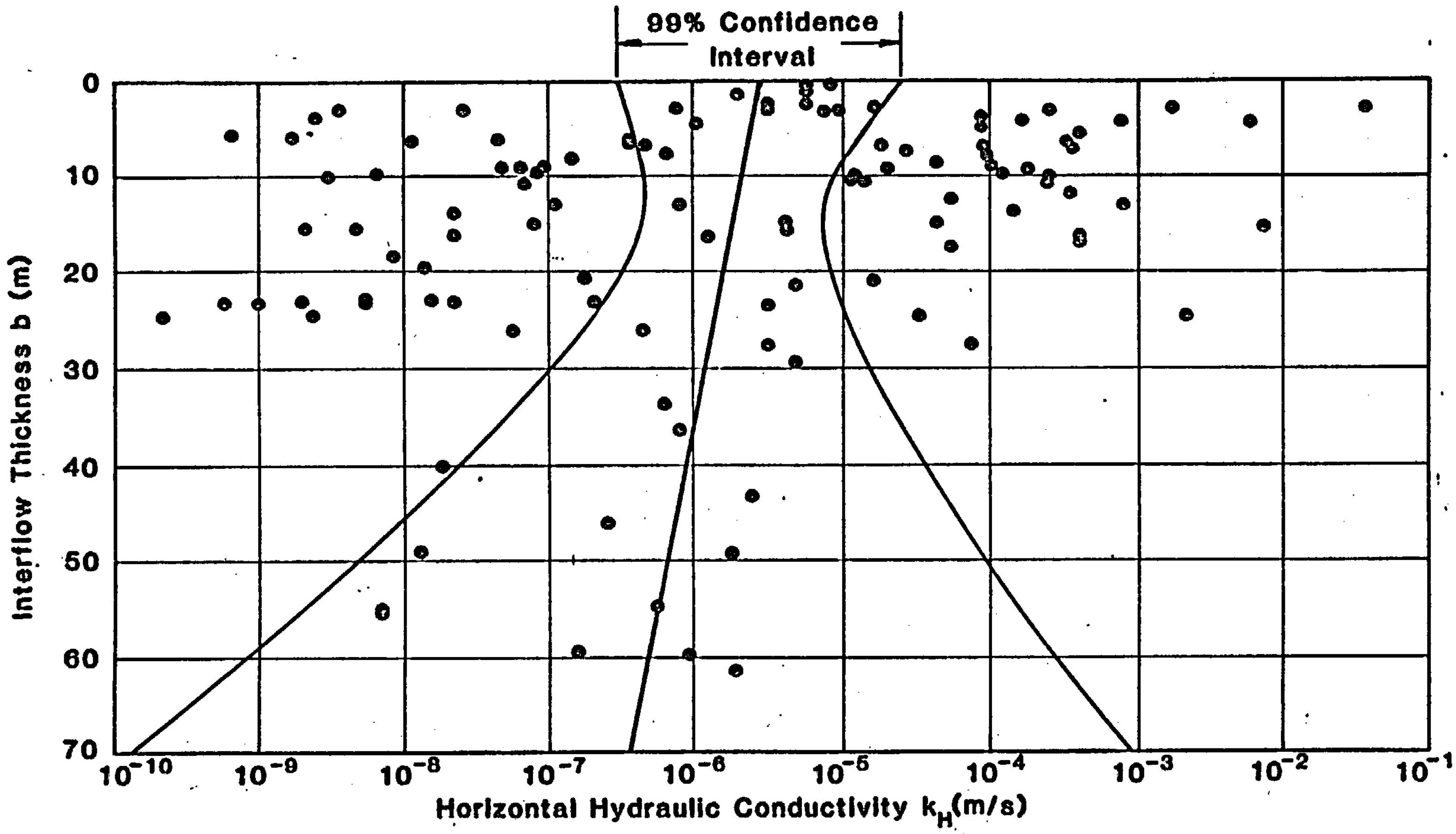




Correlation Coefficient -0.514

HORIZONTAL HYDRAULIC CONDUCTIVITY VERSUS DEPTH BELOW GROUND SURFACE

Figure 8



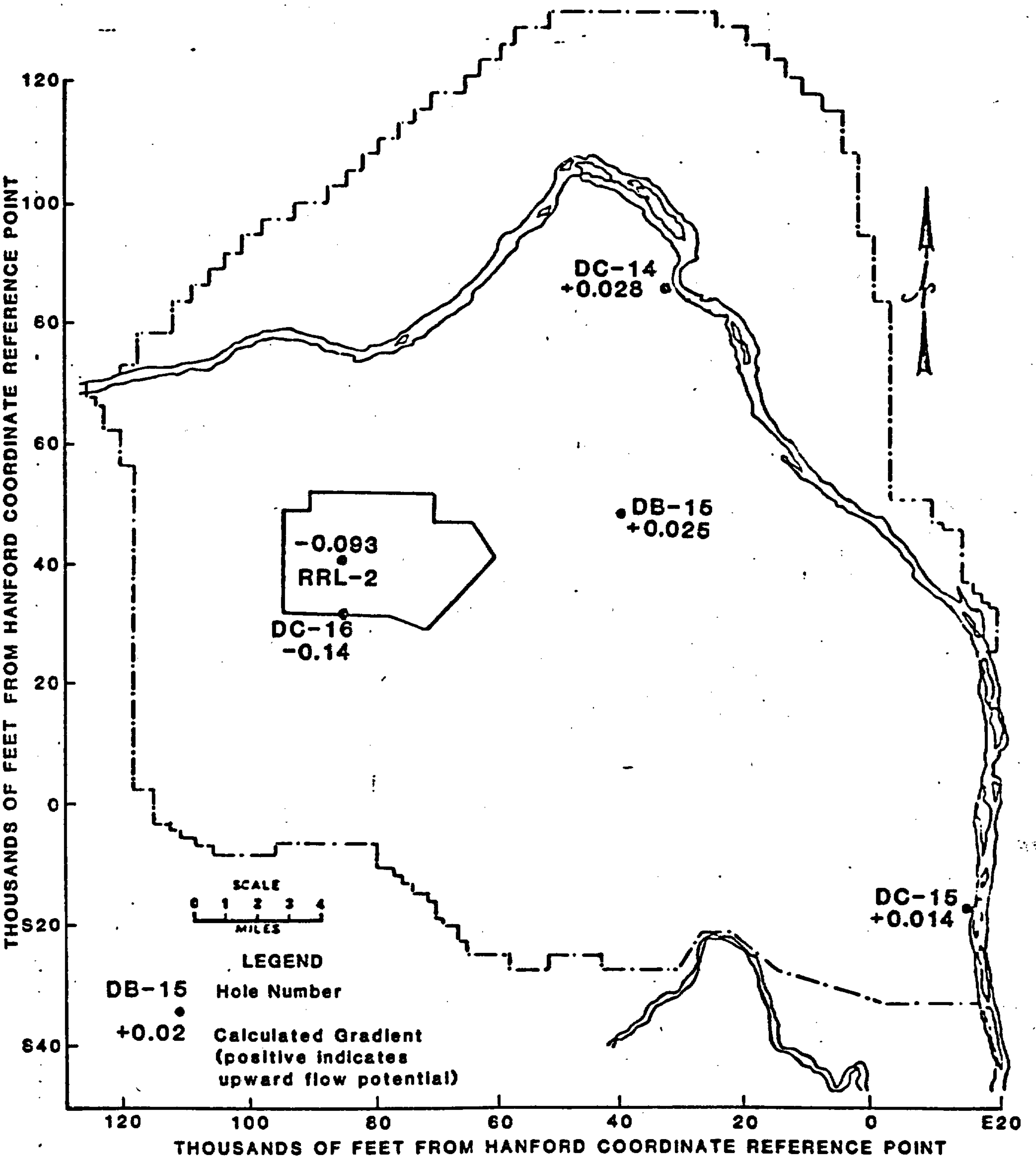
Correlation coefficient 0.0694

HORIZONTAL HYDRAULIC CONDUCTIVITY VERSUS THICKNESS OF INTERFLOW

Figure 9

CALCULATED VERTICAL GRADIENTS BETWEEN THE MABTON AND PRIEST RAPIDS

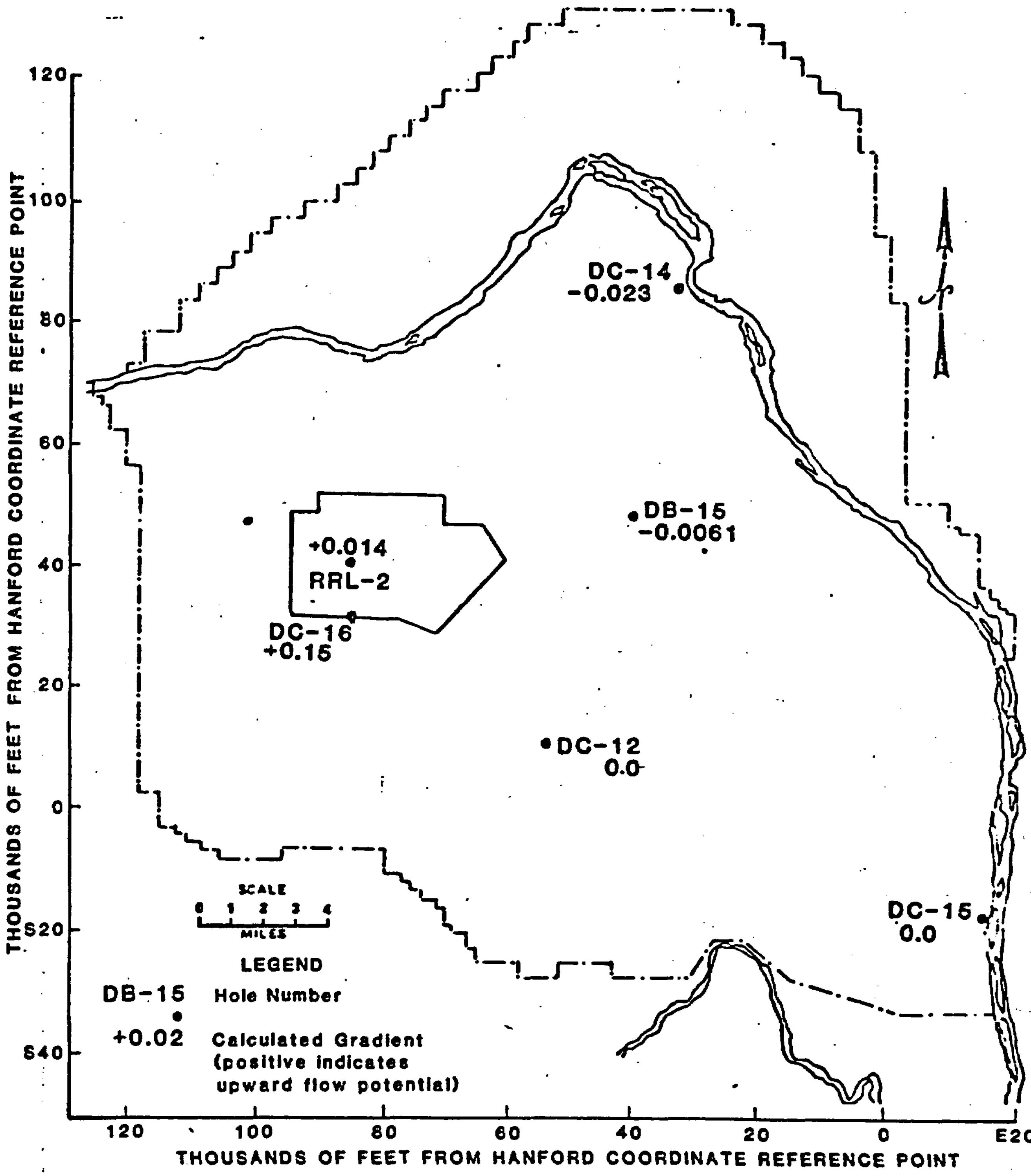
Figure 10A



Note: Positive value indicates upward flow

CALCULATED VERTICAL GRADIENTS BETWEEN THE PRIEST RAPIDS AND ROZA

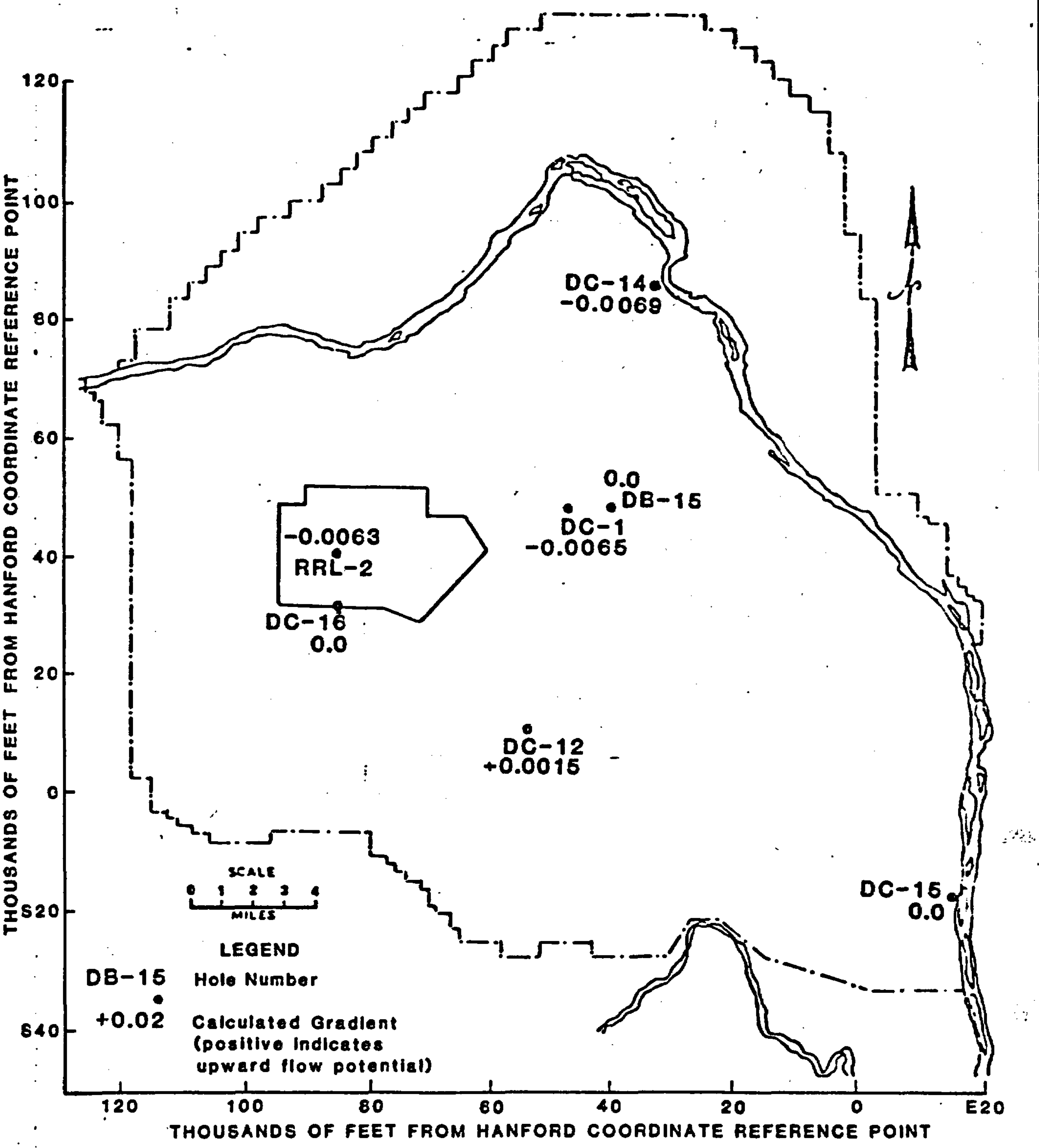
Figure 10B



Note: Positive value indicates upward flow

CALCULATED VERTICAL GRADIENTS BETWEEN THE ROZA AND FRENCHMAN SPRINGS

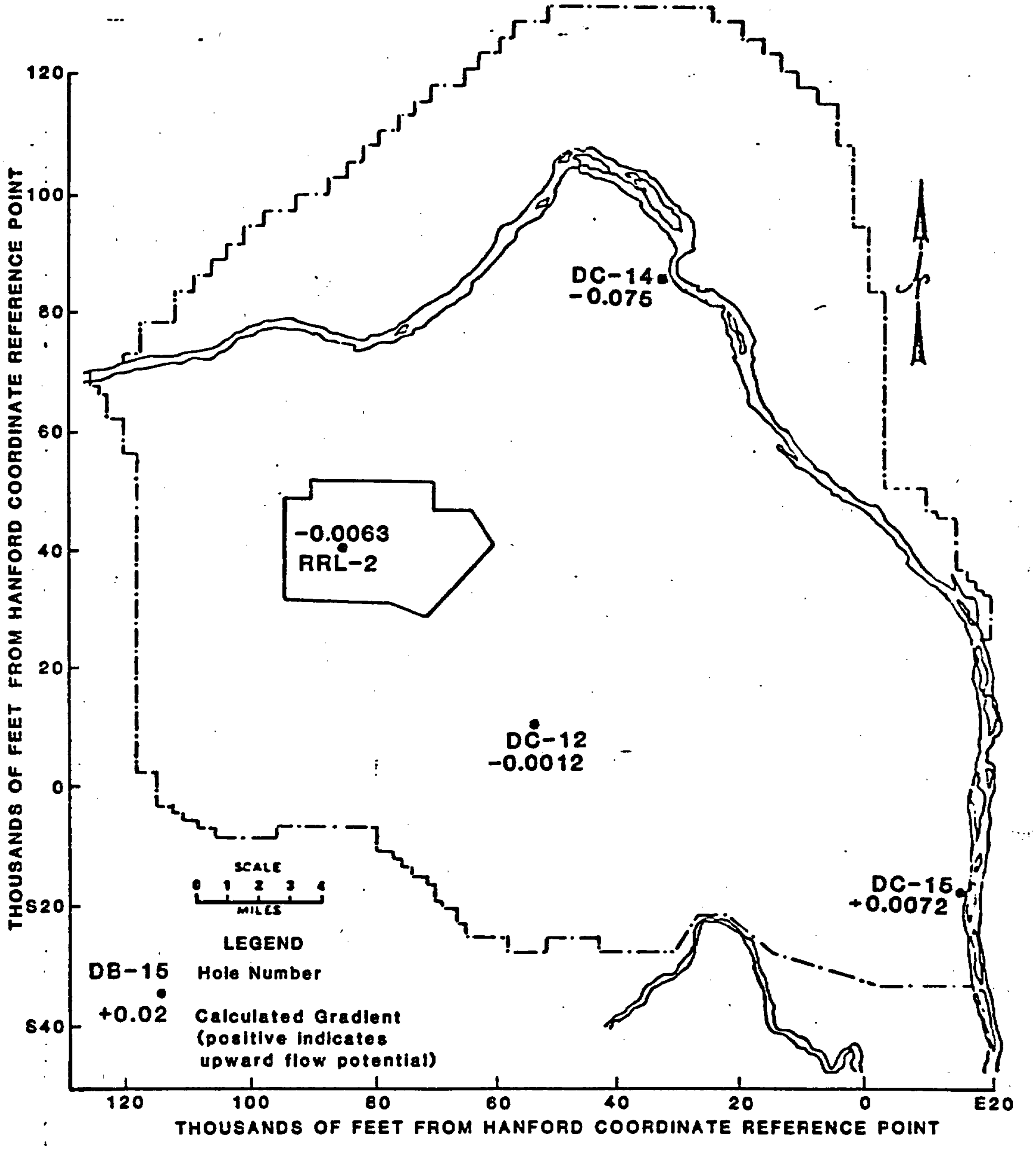
Figure 10C



Note: Positive value indicates upward flow

CALCULATED VERTICAL GRADIENTS BETWEEN THE FRENCHMAN SPRINGS AND GRANDE RONDE A

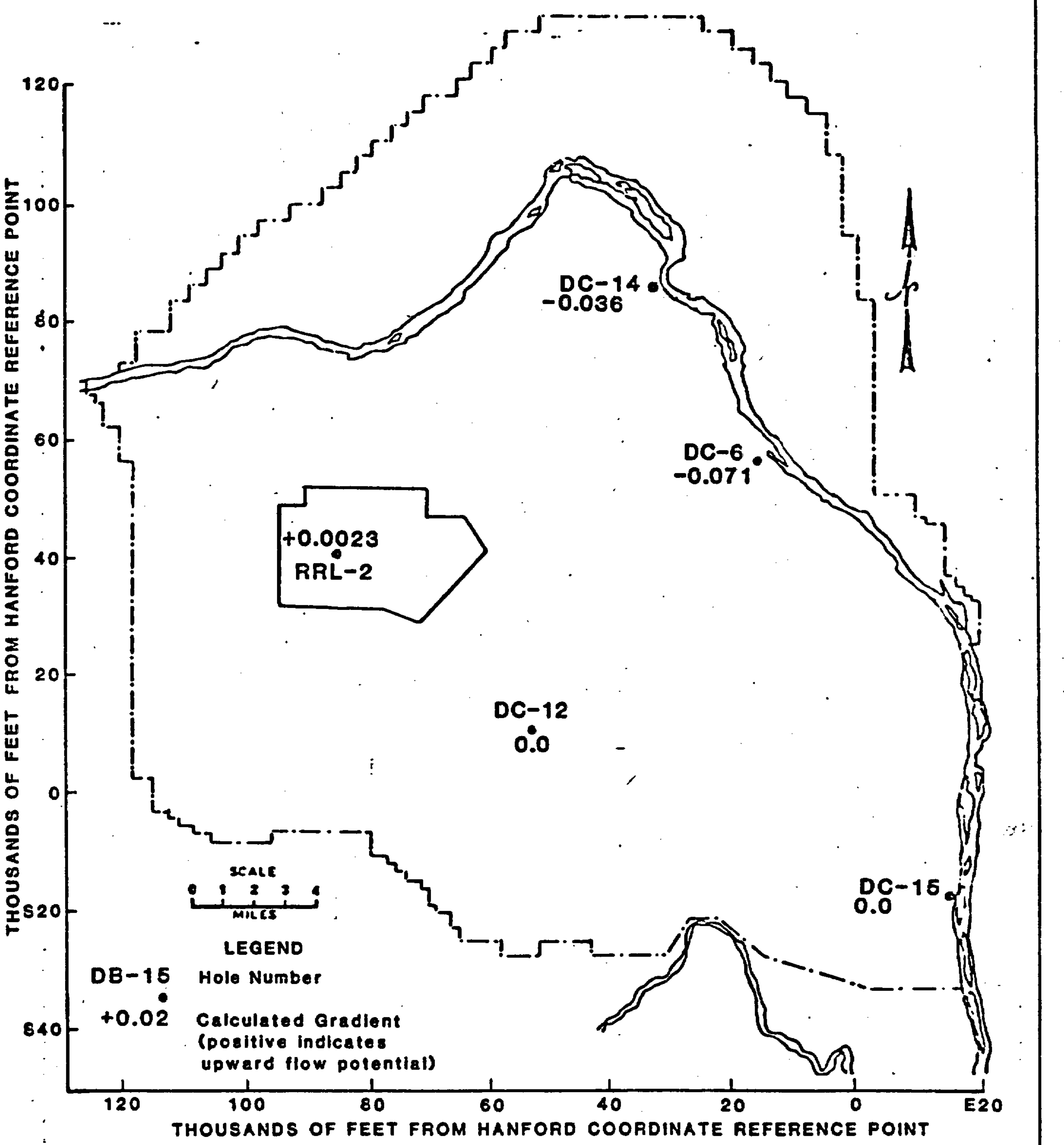
Figure 10D



Note: Positive value indicates upward flow

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

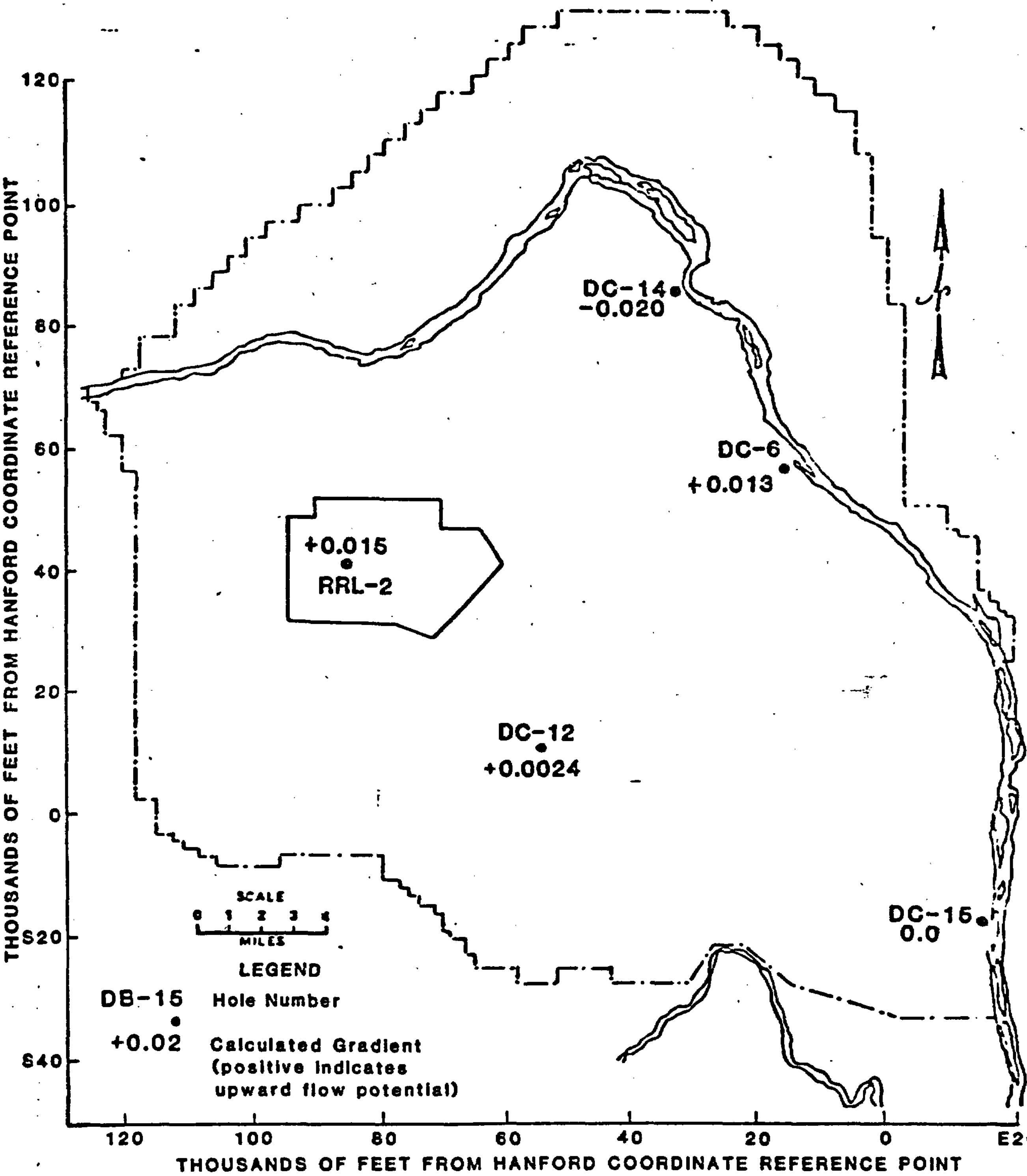
Figure 10E



Note: Positive value indicates upward flow

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

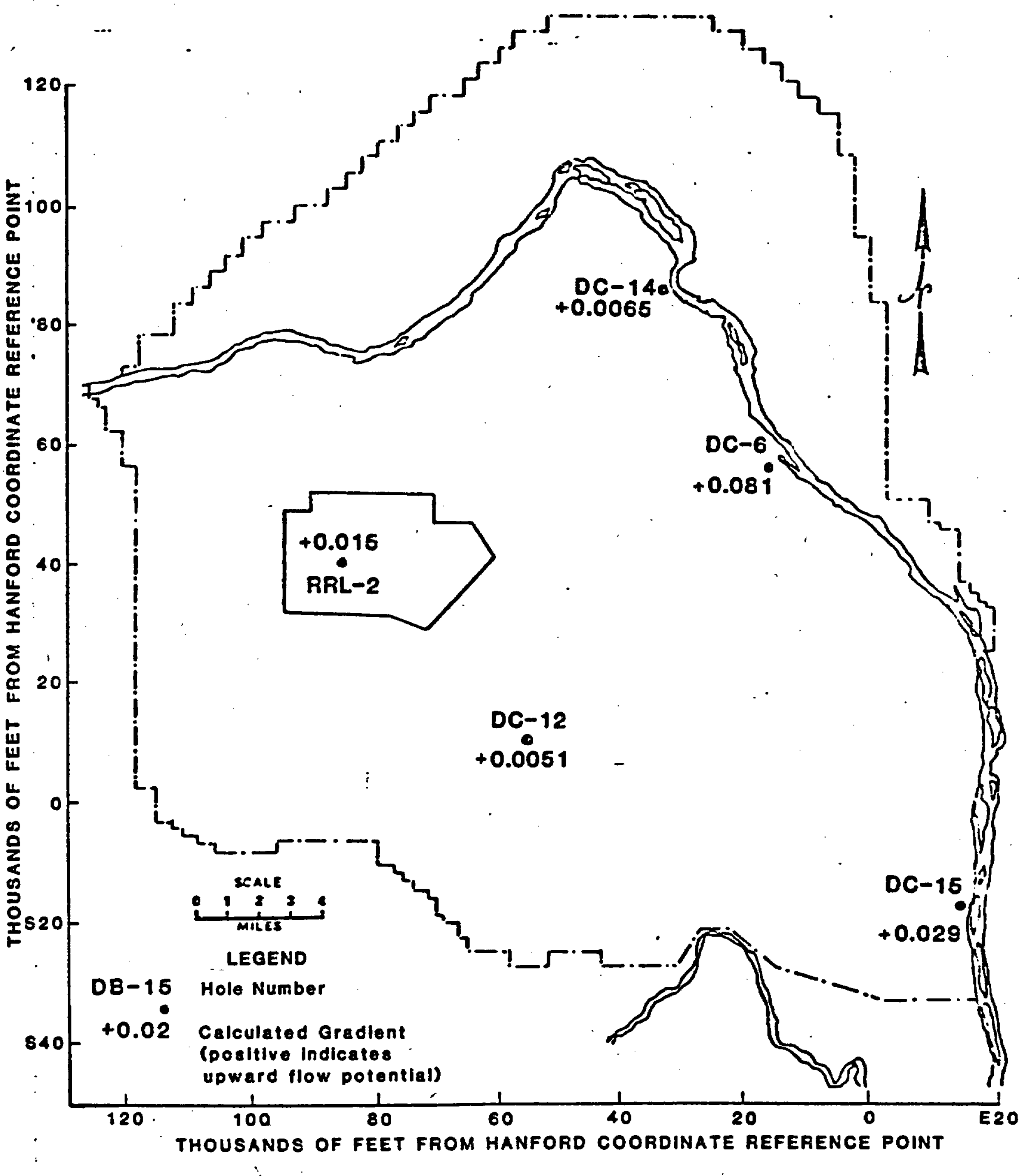
Figure 10F



Note: Positive value indicates upward flow

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

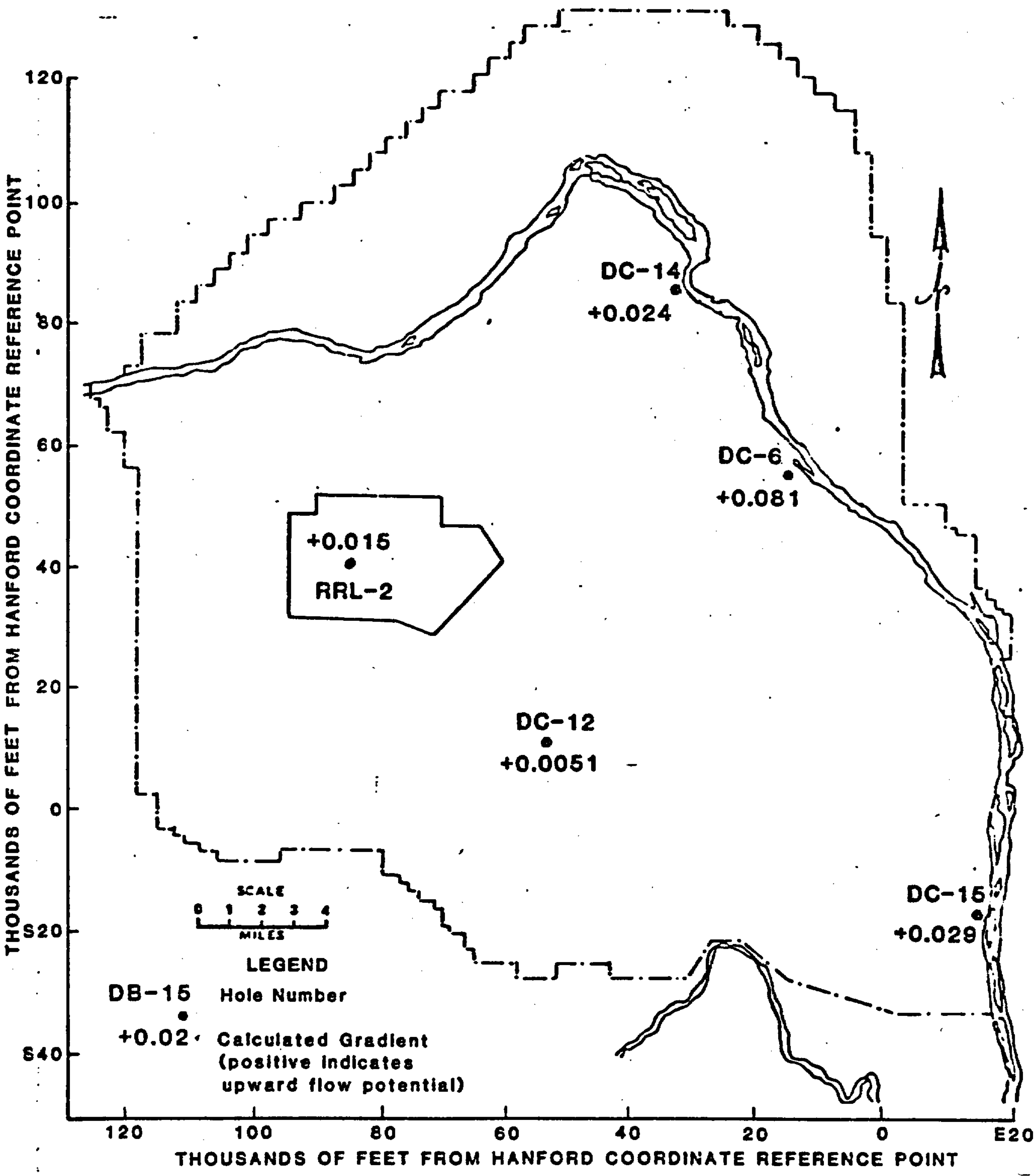
Figure 10G



Note: Positive value indicates upward flow

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

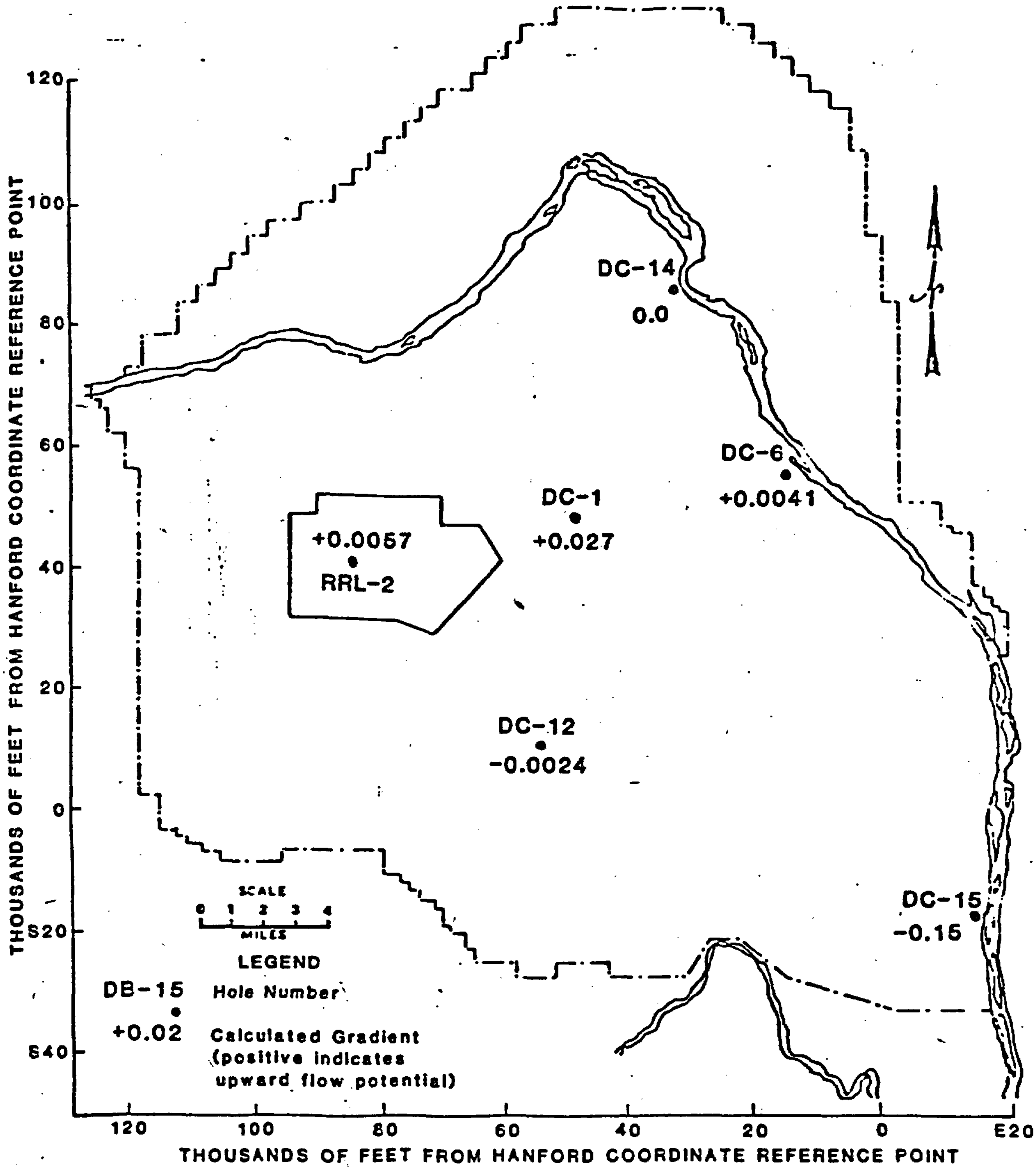
Figure 10H



Note: Positive value indicates upward flow

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

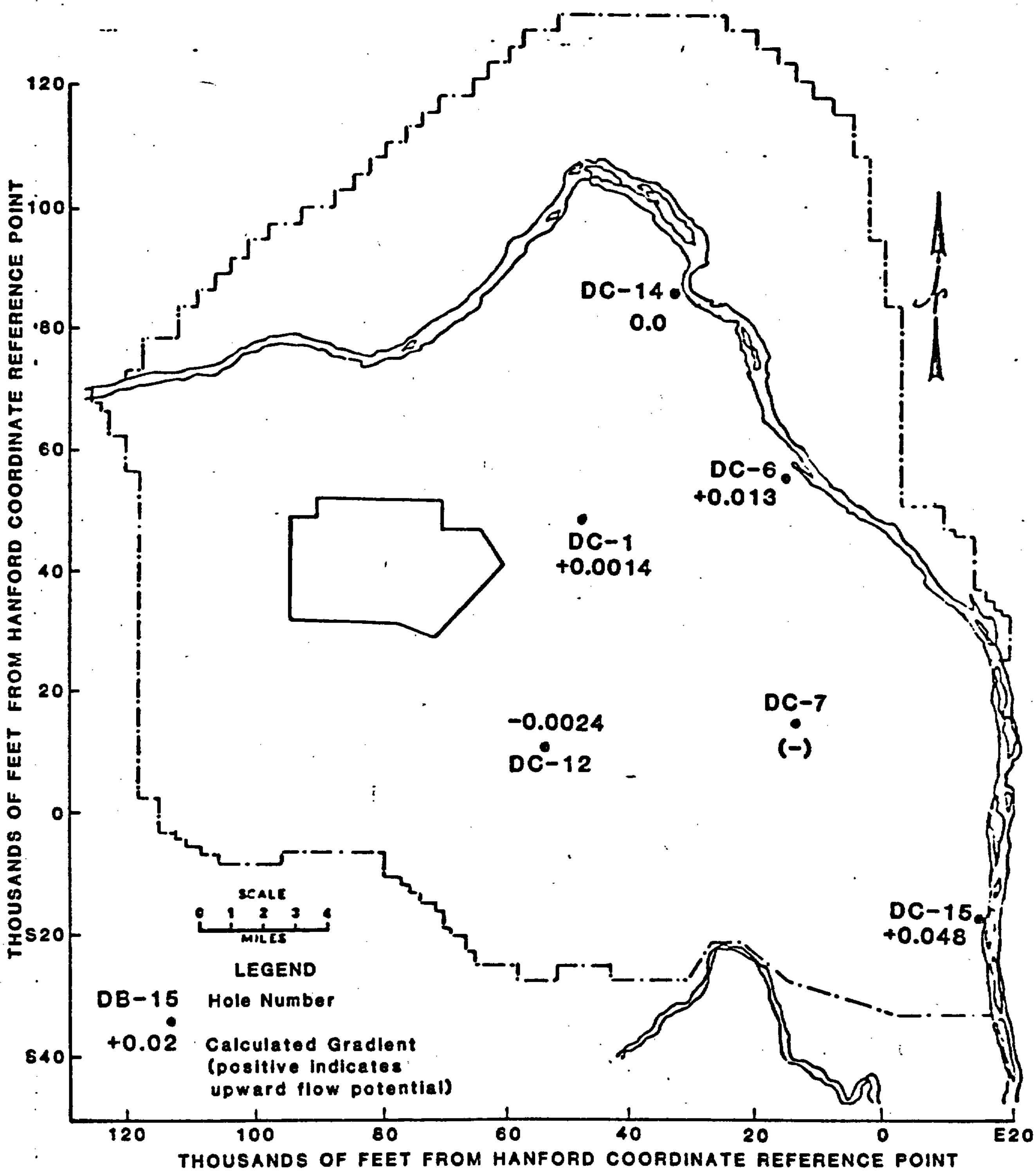
Figure 10I



Note: Positive value indicates upward flow

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