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YUCCA MOUNTAIN

YUCCA MOUNTAIN
SITE CHARACTERIZATION
PROJECT

SITE CHARACTERIZATION PROGRAM BASELINE

REVISION 1

VOLUME 1 OF 5

MARCH 1991
UNITED STATES DEPARTMENT OF ENERGY

U.S. DEPARTMENT OF ENERGY

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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

Document No. YMP/CM-0011
Revision 1
CI No. CI.11.0000/CI.13.0000
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PROJECT BASELINE DOCUMENT

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YUCCA MOUNTAIN SITE CHARACTERIZATION PROGRAM BASELINE (SCPB) VOLUME 1

CHANGES TO THIS DOCUMENT REQUIRE PREPARATION AND APPROVAL OF A CHANGE REQUEST IN ACCORDANCE WITH PROJECT AP-3.3Q

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

UNITED STATES DEPARTMENT OF ENERGY
YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT OFFICE

Y-AD-057
9/90

YUCCA MOUNTAIN PROJECT CHANGE DIRECTIVE (CD)

1 CR No. 91/052
Page 1 of 2

SECTION I. IDENTIFICATION

Title of Change:

Submittal of the "Site Characterization Program Baseline, Rev. 1," for CCB Control

3 Change Classification:

☐ Class 1 ☐ Class 3
☒ Class 2

SECTION II. DISPOSITION

4 CR Disposition:

☐ Approved ☐ Disapproved
☒ Approved with Conditions

5 Conditions: *(if applicable)*

The next revision of this document should incorporate the following items:

1. The term "Exploratory Shaft Facility" should be replaced by "Exploratory Studies Facility" throughout the document.

2. The term "repository" should be replaced by "potential repository" throughout the document.

(See Change Documentation Continuation Page ___)

Implementation Direction: *(if applicable)*

1. This Change Request (CR) is approved for CCB Baselining as the "Site Characterization Program Baseline, Revision 1," and is assigned Controlled Document number YMP/CM-0011.

2. The Director, Regulatory and Site Evaluation Division is responsible for ensuring the above listed conditions are incorporated into the next revision of Document YMP/CM-0011.

(See Change Documentation Continuation Page 2)

SECTION III. CONCURRENCE

7 Quality Assurance Organization Concurrence

Name: D. G. Horton *(print)* Org.: PQA *(print)*

Signature: [signature: N. Ventura for DG Horton] Date: 3/28/91

8 Disposition Authority

Name: M. B. Blanchard *(print)* Title: CCB Chrprsn *(print)*

Signature: [signature] For Maxwell Blanchard Date: 3/28/91

9 Effective Date:

3/28/91

6 Implementation Direction (continued)

3. The CCB Secretary shall ensure that the Cover Page and the Title Page for Document YMP/CM-0011, Revision 1, are prepared.

4. The Document Originator shall provide a Print Ready Copy of YMP/CM-0011, Revision 1, to the CCB Secretary. The Document Number and Revision Number will be identified on each page of the Publication Ready Document, YMP/CM-0011.

5. The CCB Secretary shall ensure that YMP/CM-0011, Revision 1, is prepared in accordance with this Change Directive (CD). The CCB Secretary shall ensure the Document Change Notice (DCN), indicating changes made in the document, is prepared. The DCN will be attached to the front of the Print Ready Copy of the document. The CCB Secretary shall also prepare a Controlled Document Issuance Authorization (CDIA) to transmit this CD, the DCN, and YMP/CM-0011, Revision 1, to the Project Document Control Center (DCC) in accordance with AP-1.5Q.

6. Per AP-3.3Q, each TPO and Project Office Division Director will complete an Affected Document Notice (ADN) as notification of completion of implementation planning for this CD.

7. The CCB Secretary shall ensure that the Configuration Information System (CIS) and the CCB Register are updated to reflect Revision 1 to YMP/CM-0011.

8. Any changes to document YMP/CM-0011, Revision 1, will require submittal of a CR to the Project CCB.

9. Upon release of YMP/CM-0011, Revision 1, all Project Participants will be required to use YMP/CM-0011, Revision 1, in performing duties applicable to this document.

Y-AD-059
9/90

YUCCA MOUNTAIN PROJECT
DOCUMENT CHANGE NOTICE (DCN) RECORD

Document Title:

Site Characterization Program Baseline

2 Document Number:
YMP/CM-0011

The document identified in Blocks 1 and 2 has been changed. The changed pages attached to this DCN are identified in Block 7 opposite the latest DCN number in Block 3. The original issue of this document as modified by all applicable DCN's constitutes the current version of the document identified in Blocks 1 and 2.

3 DCN NO.	4 CR NO.	5 DOCUMENT Rev./ICN #	6 CR TITLE	7 AFFECTED PAGES	CHANGE	ADD	DELETE	8 DATE
001	91/052	Rev. 1	Submit SCPB, Rev. 1 for CCB Control (complete revision of information related to ESF design)	All	X			4/5/91

Department of Energy
Yucca Mountain Site Characterization
Project Office
P. O. Box 98608
Las Vegas, NV 89193-8608

WBS 1.2.9
QA: N/A

MAR 20 1991

Distribution

RENAMING OF EXPLORATORY SHAFT EFFORT

As a consequence of the instructions from Dr. John W. Bartlett, Director of the Office of Civilian Radioactive Waste Management, on February 12, 1991, about the redirection of Yucca Mountain Site Characterization Project efforts associated with the Exploratory Shaft Facility design effort, it has become apparent that retaining the name of Exploratory Shaft would be somewhat misleading when the current design studies are focusing upon ramps, and a shaft is only being considered as a possible backup.

Therefore, after considerable discussion with many parties about selecting a new name, I have concluded that the most appropriate approach for now is to change the name of Exploratory Shaft Facility (ESF) to Exploratory Studies Facility (ESF). As you can observe, the acronym remains the same but "Shaft" becomes "Studies."

For all future communication, I request that you use this new name for this very important facility. We do not plan on modifying any completed documents or sending out errata sheets. I do request that all new communications within the U.S. Department of Energy's program now refer to this facility as the Exploratory Studies Facility. I thank you for your cooperation.

Carl P. Gertz
Project Manager

YMP:MBB-2814

YMP-5

Distribution—Memorandum dated MAR 20 1991

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YMP/CM-0011, Rev. 1

The numbering scheme used in this table of contents reflects that the numbering of the Site Characterization Plan has been preserved to maintain consistency among related documents. Sections 8.5 and 8.6 have been intentionally excluded.

SITE CHARACTERIZATION
PROGRAM BASELINE

REVISION 1

Submitted:

John H. Nelson
Technical and Management
Support Services Project Manager

Date 3/26/91

Approved:

D.C. Dobson
Division Director, Regulatory and
Site Evaluation Division

Date 3/27/91

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8.0 INTRODUCTION

This chapter presents the Department of Energy's (DOE) plans for the site characterization program to be conducted at the Yucca Mountain site in the State of Nevada. Such a program is required by the Nuclear Waste Policy Act of 1982, by the regulations promulgated for geologic repositories by the U.S. Nuclear Regulatory Commission (NRC) in 10 CFR Part 60, and by the DOE's general guidelines for siting repositories, promulgated as 10 CFR Part 960. These legal requirements are summarized in the general introduction to this document, which also discusses the DOE's compliance with them.

The DOE expects to modify these plans as more information about the potential repository system becomes available. (NOTE: Throughout this document, the use of the term "repository" refers to a potential repository at the Yucca Mountain site, assuming the site is found to be suitable.) The data collected during site characterization will be used in the design of the repository and the waste package, as well as in the analyses of system performance. Characterization, design, and performance assessment activities will all be conducted during site characterization. These activities will depend on each other; for example, the data collected from the site will be used in designing the repository, while the design of the repository will be considered in determining the needed tests and analyses. The site characterization program will be modified, as needed, to meet newly developed design and performance requirements and in response to the data obtained from site characterization itself.

As site characterization proceeds, the results of investigations and any changes to plans will be reported to the NRC, the State of Nevada, and the general public through semiannual progress reports and technical reports. As the DOE revises its plans, it will do so in consultation with the NRC, the State of Nevada, and the general public. The DOE expects that this process will help to develop a consensus among the DOE, the NRC, the State of Nevada, and the general public that will lead to the early resolution of issues as part of the siting and licensing process.

The remainder of this introduction is devoted to two topics: the organization and content of Chapter 8 and the top-level strategy that describes the role the features of the site are expected to play in accomplishing the general objectives for the disposal system.

Organization and content of Chapter 8

Chapter 8, called Part B of the SCP, builds on the existing information about the site (the information that is reported in Chapters 1 through 5 of Part A) and on information about the conceptual designs of the repository and the waste package (the designs of the repository and the waste package are described in Chapters 6 and 7 of Part A, respectively). The information presented in Part A not only summarizes the current technical knowledge about the site, but also constitutes part of the basis for defining the information that needs to be obtained during site characterization. Chapter 8 describes the DOE's plans for the characterization of the Yucca Mountain site.

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The first three sections of Chapter 8 present the rationale for the site characterization program and develop from that rationale a detailed description of the tests to be conducted during the program. The discussion that follows describes the content of those sections.

The site characterization program has three principal purposes:

- To provide the data to be used to determine the suitability of a site.
- To provide the data needed for licensing.
- To provide the data for design of the repository and the waste package.

In planning a program to achieve these purposes, the DOE has adopted an approach that starts with the regulatory requirements that must be satisfied in siting and licensing the repository, identifies the performance and design information needed to address those requirements, and then develops specific investigations to obtain the needed information. This approach is embodied in an issue resolution strategy, which is discussed in some detail in Section 8.1. An important part of this strategy is an issues hierarchy (Section 8.1.1) that consists of key issues, issues, and information needs. The key issues and issues are based on the regulatory requirements that govern a repository. The information needs define the data and analytical techniques that are needed to resolve each issue. The DOE expects that satisfying the information needs will resolve the issues and that the resolution of the individual issues will lead to resolution of the key issues. Issue resolution is not likely to provide complete assurance that performance of the repository system will be acceptable. A reasonable assurance of acceptable performance is the general standard that will be met. The strategy described here and in Section 8.1 will be applied in an iterative manner to develop confidence throughout the licensing phases. The concept of reasonable assurance is discussed later in this section.

Another important part of the issue resolution strategy and the development of information needs for the issues is the "performance allocation" process, discussed in Section 8.1.2. Performance allocation consists of deciding which repository-system elements will be relied on in resolving an issue, identifying the functions that the elements will be expected to perform and the processes that will affect the performance of each element, making specific quantitative statements about the expected performance, and developing a testing program to obtain the needed information about the performance. The issue resolution strategy will guide the development of the programs for testing and analysis; it will help to make clear what tests and analyses are necessary. As the characterization of the site proceeds and more information becomes available, the strategy will be refined to support site selection and licensing.

Section 8.2 serves both as a summary of the overall strategy for resolving the issues and an introduction to the individual issues. It presents the issues to be resolved and their information needs. Section 8.3 then presents the complete strategies for issue resolution and describes the planned investigations to be conducted during site characterization. This section is

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organized into five sections around the major programs: site, repository, seals, waste package, and performance assessment.

The site program is discussed in Section 8.3.1. Organized by technical disciplines, this section describes the investigations, studies, and activities to be carried out to resolve the design and performance issues in the issues hierarchy. The site program is designed to reduce uncertainty about site properties and conditions and to reduce uncertainty in the conceptualization of the site physical system. Systematic hypothesis testing is being used to discriminate between alternative conceptual models by eliminating untenable or nonviable hypotheses.

The repository program is described in Section 8.3.2, which provides detailed resolution strategies for the repository design issues. The section identifies the site information and the design activities needed for issue resolution.

The seal program is covered in Section 8.3.3, which identifies the activities required to develop designs and demonstrate the performance of seals to be placed in shafts, ramps, drifts, and boreholes.

The waste package program is discussed in Section 8.3.4. This section presents the detailed issue resolution strategies for the issues that deal with the design of the waste package. The section identifies the site information and the design activities needed for issue resolution.

Section 8.3.5 presents the performance assessment program. Strategies to address the preclosure and postclosure performance issues and discussions of the analytic techniques needed for the safety and performance assessments for these strategies are presented. The section identifies the site information and the performance assessment activities needed for resolving the issues.

Much of the information presented in Section 8.3 is summarized in performance allocation and hypothesis testing tables. A careful study of these tables will provide an understanding of the information to be provided by the site program and the intended use of this information for resolving the design and performance issues.

The plans for surface-based activities and for subsurface excavations related to implementing the site characterization program described in Section 8.3 are presented in Section 8.4. This section also discusses the potential impacts on the integrity of the site as a result of conducting these activities. Section 8.4 is divided into three parts. The first section, 8.4.1, presents background information on the approach adopted by the DOE to guide the characterization program, gives the approach to incorporating the requirements of 10 CFR Part 60 into the development of the testing program, and discusses the concepts of flow in the unsaturated zone. The rationale for the planned testing is presented in Section 8.4.2, which also describes the surface testing and the underground test facility and evaluate whether construction or operation of facilities or the conduct of the tests is likely to adversely impact the results of site characterization activities. Section 8.4.3 evaluates the impact of the testing program on the

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integrity of the site by considering its potential impacts on the postclosure performance objectives.

Section 8.7 presents general plans for decontamination and decommissioning of the Yucca Mountain site in the event the site were found to be unsuitable for a repository. That section also contains general plans for mitigation of any significant adverse environmental impacts that may be caused by site characterization.

Top-level strategy

This section presents the "top-level strategy," that is, a brief explanation of the role the features of the Yucca Mountain site are expected to play in achieving the general objectives for the system. As a consequence of this role, which will be explained, the program for characterizing the site places considerable emphasis on the range of expected flow conditions in the unsaturated rocks in which the waste would be emplaced. The program also emphasizes the geochemistry and other characteristics of the unsaturated rocks. These characteristics could affect performance of the waste packages and radionuclide transport through the unsaturated rocks. In addition, the geohydrology of the saturated rocks deep beneath the site will be characterized. Reliance on these features requires the investigation of any disruptive processes and events that might alter the features. The top-level strategy also emphasizes pre-closure radiation safety and the effects of seismicity on the surface and underground facilities. This section discusses the basis for the emphasis on these features in the site characterization program.

The principal role of a disposal system is to isolate waste for a long period into the future. Therefore, the general objective for the entire system is to limit any radionuclide releases to the accessible environment. This objective will be achieved by selecting a site that contains natural barriers against radionuclide releases and by providing an appropriate system of engineered barriers. To provide additional insurance that the system will perform adequately, individual objectives have also been defined for the engineered and natural barriers to radionuclide release and for the design of the disposal system. The general objective for the engineered barriers is that they should limit the release of radionuclides to the natural barriers. The general objective for the natural barriers is that the time of travel of significant quantities of radionuclides through these barriers to the accessible environment should be very long. In particular, since ground water may transport radionuclides, the ground-water travel time should be very long. The general objectives for the design of the disposal system are that its operation should be safe and that its construction should not compromise its ability to meet the other general objectives.

These general objectives are compatible with the regulations promulgated by the NRC in 10 CFR Part 60. In the regulations, the NRC specifies postclosure performance objectives, including the environmental standards anticipated to be set by the Environmental Protection Agency for releases to the accessible environment, individual protection, and ground-water protection; requirements on the containment to be provided by the set of waste packages and on the rate of release of radionuclides from the engineered-barrier system; and an objective for the pre-waste-emplacement ground-water travel time. The regulations also specify design criteria for the disposal system to ensure the postclosure performance objectives would be met, and they set preclosure objectives for radiation protection. Detailed strategies that explicitly address the NRC regulations are presented in Sections 8.1, 8.2, and 8.3. The remainder of this section describes the top-level strategy to address the general objectives for the disposal system.

General objective for the disposal system

The major system elements that are expected to affect waste isolation at the Yucca Mountain site can be seen in Figure 8.0-1. As explained in detail in Chapter 3, the currently available information suggests that only small amounts of water are available to percolate slowly downward through Yucca Mountain. If the Yucca Mountain site is developed for a repository, water that moves through the unsaturated rock above the repository could continue down to the unsaturated rock unit in which the underground repository would be constructed. If any of this water could reach the emplaced waste, it might dissolve radionuclides and carry them in solution through the unsaturated rock below the repository to the saturated rock that underlies the unsaturated zone. After reaching saturated rock (Figure 8.0-1), the water joins the much larger, horizontal flow there. Radionuclides that are carried by the water could therefore be transported by the flow in the saturated zone and move toward the accessible environment.

To reach the emplaced waste, the water would have to penetrate the engineered-barrier system. For the purposes of defining the top-level strategy, the major elements of this system are the container and the waste form inside the container. There would also be an air gap between the container and the wall of the borehole in which the container would be emplaced.

This sequence of events--downward water movement, water penetration into the engineered-barrier system, downward transport of radionuclides to saturated rock, and horizontal transport--provides a way by which radionuclides could move from the Yucca Mountain repository to the accessible environment. According to the available evidence, the percolation flux at and below the repository horizon is very low. Furthermore, it appears that the percolation of water through the unsaturated rock units at this depth is primarily in the rock matrix rather than through fractures. If the water is retained within the rock matrix, as it appears to be, the water would not be expected to move from the rock across the air gap to the waste container; the water would, therefore, not be expected to reach the waste. Furthermore, the results of preliminary studies have suggested that the quantity of moving water is so small that any corrosion of the disposal container and dissolution of radionuclides would be limited even if the water could cross the air gap. The evidence also suggests that the movement of water in the rock matrix is very slow and that, therefore, the transport of any radionuclides dissolved in this water downward through the unsaturated rocks below the repository would be very slow. An additional characteristic of the unsaturated rock and the water is their geochemistry, which will determine the radionuclide dissolution and the retardation of radionuclide transport.

Therefore, the elements of the system that the DOE will investigate in the site characterization program to evaluate the system with respect to the general objective are

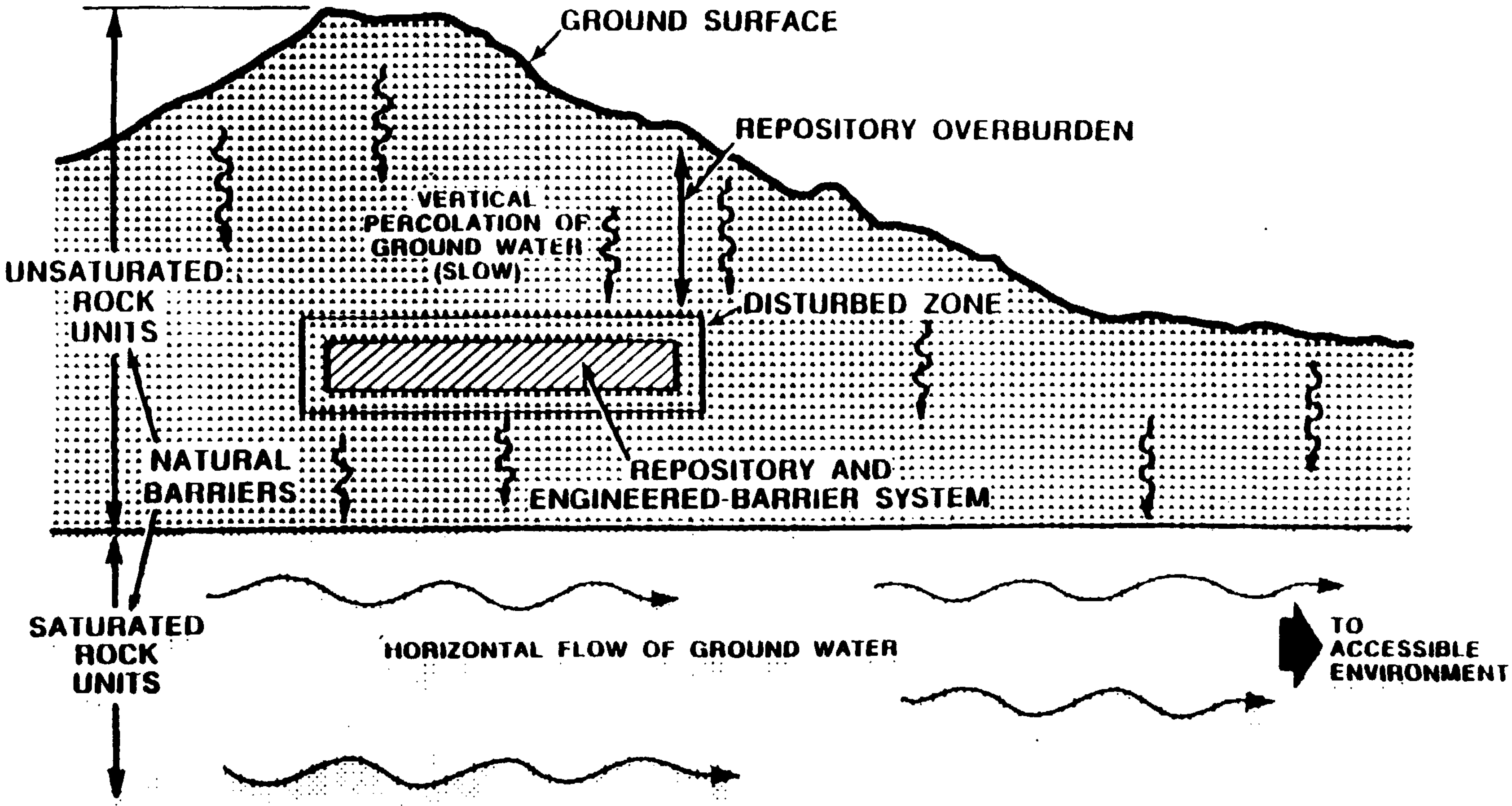

Figure 8.0-1. Major system elements exp[illegible] to affect waste isolation at the Yucca Mountain site

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- o The unsaturated rock units.
- o The saturated rock that lies below the unsaturated rock.
- o The engineered-barrier system.

Concentrating on the characteristics of only one of these features, such as the slow movement of water through the unsaturated rocks below the repository, could reduce the cost of the site characterization program. The DOE has decided, however, that it is prudent to consider initially the characteristics of all three of these features. Future evidence may show, for example, that the current estimates of ground-water travel time are too long. If so, the DOE's strategy may need to focus on the other features. Choosing all of these features is a way of dealing with the uncertainties in each of them; it ensures that the site characterization activities, guided by the strategy, will collect the data needed to evaluate the site with respect to the general objective. Analyses conducted during site characterization may indicate that other features may need to be considered as well. Conversely, information obtained during site characterization may show that fewer features need to be taken into account. In either case, the top-level strategy can be revised appropriately.

One further sequence of events might contribute to a release under the current conditions at Yucca Mountain. If the waste containers were breached, radionuclides that exist in the waste in gaseous form might move upward through the air spaces in the unsaturated rock above the repository. They might then reach the accessible environment at the ground surface above the repository. The available information is not complete enough to decide definitively whether this sequence is capable of producing significant releases. It is not clear, for example, that the waste form can release gaseous radionuclides rapidly enough or in sufficient quantities to be important. The DOE will evaluate the potential for gaseous release to determine the significance of this mode of release. The elements of the system that may affect gaseous releases at the site are the unsaturated rock above the repository and the engineered-barrier system. The current evidence is not sufficient to indicate if the unsaturated rock would be effective. The available evidence does suggest, however, that the waste form is likely to allow only negligible amounts of volatile radionuclides to escape. The top-level strategy, therefore, focuses primarily on the ability of the engineered-barrier system to limit the rate of release of gaseous radionuclides.

<u>General objective for performance of the engineered-barrier system</u>

The general objective for the engineered-barrier system is to limit release of radionuclides to the natural barriers. In the top-level strategy, the DOE has chosen to focus on three particular components to evaluate the performance of the engineered-barrier system.

- o The air gap between the container and the host rock.
- o The container.
- o The waste form.

The container is expected to provide the principal barrier to the release of radionuclides from the engineered-barrier system. This barrier will be designed to provide substantially complete containment of the wastes during the early period when the heat and radiation emitted by the waste are

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at their peak. The limited availability of water in the unsaturated zone is expected to contribute to the ability of the container to limit the release of radionuclides to the natural barriers. In addition, the container materials will be chosen to be compatible with the geochemistry of the water in order to limit degradation of the containers in contact with any water.

The air gap between the container and the host rock is expected to increase the ability to limit the release of radionuclides. That is, because the percolation flux is expected to be low and because the water is expected to be retained in the rock matrix, little water would be available to leave the rock and cross this air gap. Therefore, the amount of water available to contact the waste packages is expected to be even less than the small amount in the host rock.

The waste form is chosen as an additional barrier to limit the rate of radionuclide release from the engineered-barrier system. Because of the low probability of early container failure and because of the small quantities of water available for waste-form dissolution and the leaching of radionuclides, the spent fuel or glass matrix is expected to limit the rate of release.

General objective for the performance of the natural barriers

As explained above, one natural barrier within the geologic setting that can contribute to the isolation of the waste and to the overall system performance is the long ground-water travel time to the accessible environment. The DOE has chosen to focus on two barriers to determine the ground-water travel time:

- The unsaturated rock units below the repository.
- The saturated rock below the unsaturated rock.

The current evidence suggests that the travel time from the repository through the unsaturated units to the saturated zone is longer than 10,000 yr. Furthermore, many of the radionuclides important for waste isolation will have an even longer travel time than the ground water because of geochemical and mechanical retardation processes. Therefore, these units are expected to provide an effective barrier to radionuclide transport. According to the available evidence, the saturated rock units can add at least a few hundred years and possibly a few thousand years to the total time that radionuclides would take to move to the accessible environment.

General objectives for the design of the disposal system

The general design objectives to ensure safe operation without compromising the ability to meet the other general objectives have a number of implications for the site characterization program. In particular, the surface and underground facilities must be designed to withstand potential ground motion or surface rupture at the site. The available evidence suggests that the design can accommodate the range of seismic activity expected at the site. Information regarding the expected frequency and magnitude of earthquake-related activity at the site will be needed to support the detailed design.

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The design of the repository system must also address radiation protection of the surface and underground facilities. It is expected that standard techniques will be adequate to assess preclosure radiation safety. Although these assessments will not rely heavily on features of the site, some investigations will be conducted to support them.

Priorities for the site characterization program

Priorities for the testing program can be inferred from the choices made for the top-level strategy, that is, the elements identified and the expected role of these elements with regard to the general objectives suggest the priorities for the investigations in the site characterization program. The top-level strategy to address these objectives at the Yucca Mountain site leads to the following areas of emphasis:

- Unsaturated-zone flow characteristics.
- Site characteristics (e.g., geochemistry) affecting performance of the container and the waste form and transport of the radionuclides in the unsaturated zone and the geohydrologic characteristics of the saturated rocks that underlie the unsaturated zone.
- Unlikely processes or events that disturb site characteristics.
- Preclosure radiation safety and the effects of seismicity on the surface and underground facilities.

The top-level strategy focuses strongly on the investigations of the characteristics of the flow in the unsaturated zone, relying heavily on the current view that the percolation flux is low and that the water in the unsaturated zone is tightly confined within the rock matrix. If these concepts can be confirmed, then the general objective for the system and for the postclosure performance of the engineered and natural barriers are very likely to be met. Therefore, the investigations of these concepts have the highest priority in the program. As part of these investigations, the program will address alternative concepts including flow in fractures, lateral movement of water at rock interfaces in the unsaturated zone, and the effect on the flow of structural features such as faults. The ability of the unsaturated rock to hold water and limit contact of water with the waste packages will also be investigated.

Because of uncertainties in these concepts and to add confidence that the general objective will be met, other site characteristics will also be investigated. The top-level strategy also places emphasis on other characteristics of the site as discussed above. Therefore, at a somewhat lower level of priority, the program will give attention to the geochemistry and other characteristics of the unsaturated rocks that may affect the performance of the waste packages and the transport of radionuclides in the unsaturated rocks and the geohydrology of the saturated rocks deep below the site.

The design of the repository system must address preclosure concerns such as the effect of seismic activity. Accordingly, an extensive program to investigate seismicity affecting the site is planned. This program will

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evaluate the probability and magnitude of ground motion and potential surface rupture at the Yucca Mountain site.

The site characterization program must also address those processes and events that might occur in the future and disrupt the site characteristics important to waste isolation. For example, the possibilities for extreme climatic changes or faulting will be investigated to evaluate effects on percolation, local flux, and the altitude of the water table in relation to the repository horizon. The probability of occurrence and the potential effects of volcanism on the characteristics of the site will also be investigated. The following is a general list of the disruptive processes and events that present data suggest are sufficiently credible to warrant consideration:

1. Extreme climate change.
2. Stream erosion.
3. Faulting and seismicity.
4. Magmatic intrusion.
5. Extrusive magmatic activity.
6. Extensive irrigation.
7. Intentional ground-water withdrawal.
8. Exploratory drilling.
9. Resource mining.
10. Climate control.
11. Surface flooding and impoundments.
12. Regional changes in tectonic regime.
13. Folding, uplift, and subsidence.

This description of the general priorities that the top-level strategy leads to serves primarily as a broad introduction to the detailed discussions in Sections 8.1. through 8.4. Readers who wish to understand fully the planned investigations and the reasons for them must consult those sections, which provide complete strategies, derive investigation plans from the strategies, and explain the investigations in detail.

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8.1 RATIONALE FOR THE SITE CHARACTERIZATION PROGRAM

The site characterization program and Chapter 8 follow two organizing principles. The first is the issues hierarchy, which states the questions the DOE feels must be resolved about the performance of the mined geologic disposal system (i.e., the waste package, the engineered repository, and the natural system at the site) to demonstrate compliance with the applicable Federal regulations. The second principle is a general procedure, or "strategy," for determining how those issues are to be resolved. This general strategy can be used to develop a specific strategy for the resolution of each issue. One step in the application of the specific strategies results in the identification of the site information needed to support the resolution of the issues. An understanding of these principles is helpful in following the discussions in the rest of this document; this section therefore discusses them briefly.

8.1.1 THE ISSUES-BASED APPROACH TO PLANNING SITE CHARACTERIZATION

The issues hierarchy states questions about the performance of the disposal system and identifies the information that must be known before a site can be selected and licensed. It is based on the issues-hierarchy concept presented in the Mission Plan (DOE, 1985b). The discussion that follows explains the derivation, structure, scope, and objectives of the issues hierarchy. More information can be found in the Issues Hierarchy for a Mined Geologic Disposal System (DOE, 1986d).

8.1.1.1 Derivation, structure, and scope

The issues hierarchy is a three-tiered framework consisting of key issues, issues, and information needs. On the first, or highest, tier there are four key issues, which embody the principal requirements established by the regulations governing geologic disposal. Each of the key issues is followed, in the second tier, by a group of several issues that expand on the requirements stated in the key issue they represent. The third tier consists of still more detailed sets of information called the "information needs"--one set for each issue. This framework provides a convenient means for distinguishing broad questions of overall performance and suitability (key issues) from more specific questions about the characteristics of the site, the design of the repository and the waste package, and the performance of the total geologic disposal system. It also distinguishes the key issues and issues from requirements for the basic information needed to resolve the issues.

The issues hierarchy, then, defines issues that must be resolved to demonstrate compliance with key regulatory requirements. Other, detailed requirements that the disposal system must satisfy, such as functional requirements, are included in the specifications given in the Generic Requirements for a Mined Geologic Disposal System (DOE, 1986c), the Waste Management System Requirements and Descriptions (DOE, 1986f), and in the requirements document that will be issued for a repository at the Yucca

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Mountain site. As the definition of requirements progresses, the requirements and the issues hierarchy will be compared and correlated to ensure consistency and completeness in each. The role of the system requirements and descriptions in the issue resolution strategy is described in Section 8.1.2.

The information needs supporting the key issues and issues have been developed. The entire issues hierarchy for the Yucca Mountain site is presented in Section 8.2.1.1. Although care has been taken to ensure that this issues hierarchy contains a comprehensive list of siting and licensing issues, it will be revised as necessary during site characterization to encompass any additional issues that may arise.

Key issues

The key issues embody the principal requirements established by the regulations governing repositories and have been adopted nearly verbatim from the key issues in the Mission Plan. They are stated as questions that must be answered affirmatively if a site is to be selected for development, licensing. The key issues are derived from the four system guidelines of the DOE siting guidelines promulgated in 10 CFR Part 960 and are, therefore, concerned with (1) the performance of the repository system after closure; (2) radiological safety before closure; (3) the environmental, socioeconomic, and transportation impacts of the repository; and (4) the ease and cost of repository siting, construction, operation, and closure.

Key Issue 1 (postclosure performance) is derived directly from the postclosure system guideline (10 CFR 960.4-1), which defines the general long-term performance requirements for the disposal system as a whole. These performance requirements reflect the general objectives of protecting the health and safety of the public and the quality of the environment; they are based specifically on the standards promulgated by the Environmental Protection Agency (EPA) in Subpart B of 40 CFR Part 191, and adopted by the Nuclear Regulatory Commission (NRC) of 10 CFR Part 60.

Key Issue 2 (preclosure radiological safety) is derived from the preclosure system guideline (10 CFR 960.5-1(a)(1)). It requires compliance with the applicable requirements of the EPA standards in Subpart A of 40 CFR Part 191, and the NRC criteria in 10 CFR Part 60 and 10 CFR Part 20. Because compliance with these regulatory requirements depends mainly on the design and operating procedures of the repository rather than on the geologic characteristics of the site, not all aspects of Key Issue 2 are directly addressed in the site characterization plan (SCP). Little information from the site characterization program is required for the resolution of Key Issue 2. Instead most of the information needed to resolve this issue will be obtained from design studies for the repository and the waste package and from studies conducted concurrently with site characterization. (Plans for such studies will be presented in an environmental program plan and a repository design plan for the Yucca Mountain site.)

Key Issue 3, which is concerned with the environmental, socioeconomic, and transportation impacts associated with a repository, is derived from the preclosure system guideline (10 CFR 960.5-1(a)(2)). The resolution of this issue does not directly depend on information from site characterization

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activities and, therefore, this key issue is not addressed in the SCP. The information needed to resolve this issue will be collected during the environmental and socioeconomic investigations performed concurrently with site characterization. Plans for these studies will be presented in environmental and socioeconomic program plans, prepared concurrently with the SCP.

Key Issue 4 (the ease and cost of repository siting, construction, operation, and closure) is derived from the preclosure system guideline (10 CFR 960.5-1(a)(3)). The requirements of this issue are derived from those of the referenced preclosure system guideline, which requires that the technical feasibility and cost of repository siting, construction, operation, and closure be evaluated in light of the site characteristics and related design requirements. The resolution of this issue depends in part on site conditions and in part on information that can be developed independently of the description of site conditions. Plans to acquire this independent information will be presented in a repository-design plan; these plans are not presented in this SCP, because the activities they describe do not fall within the definition of site characterization in the Nuclear Waste Policy Act (NWPA, 1983).

Matrices that correlate each issue with specific regulatory requirements are presented in Section 8.2.1.2, which also discusses the relationship of the issues hierarchy to other sets of issues--for example, those proposed by the NRC in the draft issue-oriented site technical positions.

Issues

The issues defined for each key issue are also stated as questions (Section 8.2.1.1). When each group of issues was constructed, an effort was made to include in the group all the questions that must be answered to resolve the key issue. Taken together, the issues, therefore, provide a conceptual strategy for resolving each key issue. The issues defined for each key issue are identical in overall scope to the issues in the Mission Plan, but the structure and the wording are different. The issues are derived, in part, from the DOE siting guidelines of 10 CFR Part 960, from the NRC performance objectives and design criteria of 10 CFR Part 60, and from the EPA requirements of 40 CFR Part 191.

To accommodate the structure and the intent of the regulations in 10 CFR Part 60 and 10 CFR Part 960, the issues are divided into performance issues and design issues. The NRC criteria in 10 CFR Part 60 clearly make a distinction between performance objectives and design criteria; though obviously related, performance objectives and design criteria have different purposes and must be addressed from different perspectives.

The performance issues generally address questions about compliance with regulatory requirements for the performance of the disposal system. They are generally related directly to the highest level of regulatory requirements to be satisfied. For example, there are performance issues that correspond to each of the postclosure performance objectives stated in 10 CFR 60.113. There are also performance issues that correspond to the requirement to make higher-level findings for the postclosure guidelines and for each set of preclosure guidelines in 10 CFR Part 960.

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The design issues address questions about the design of the repository, the shaft and borehole seals, and the waste package. They address the design criteria specified in 10 CFR 60.130 through 60.135, the design-related considerations of preclosure guideline 10 CFR 960.5-1(a)(3), and information required to support the resolution of performance issues.

The resolution of both the performance and the design issues requires information about the site, and to provide this information the site program described in Section 8.3.1 has been developed. This program will evaluate the site characteristics, processes, and events that may affect the design and the performance of the waste package and the repository; the results will provide the detailed site information that will be used to develop site descriptions and to support the resolution of design and performance issues, including the demonstration of compliance with the siting guidelines. The site program is organized by technical discipline (e.g., geohydrology, geochemistry, and rock characteristics), and it provides a means of controlling and integrating the investigations in each technical discipline..

The relationship among the two categories of issues and the site program can be summarized as follows: the performance and the design issues establish requirements and priorities for the site program, while the site program produces data for the analyses needed to address design and performance issues. An investigation or other type of activity in the site program will take place only if it is necessary to provide information needed to resolve a design or a performance issue.

Information needs

On the third tier of the issues hierarchy is a set of statements called "information needs." Unlike the key issues and issues, the information needs are stated as requirements for technical information rather than as questions. In developing the information needs, an attempt was made to list the categories of information needed for resolving the issues. In principle, then, acquiring all the information called for at the third tier of the hierarchy will allow all the issues to be resolved through analyses and evaluations that use the information. If the issues are resolved affirmatively, the key issues will also have been resolved.

Site-specific information needs for the Yucca Mountain site have been identified and are listed in Section 8.2.1.1.

8.1.1.2 Application in the site characterization plan

The issues hierarchy, which is presented in Section 8.2.1.1, is useful in the SCP because it is a framework for developing the site characterization program described in Section 8.3 and for explaining why the proposed program is adequate and necessary. In simple terms, the site characterization program will be adequate if it addresses all the information needs in the third tier of the issues hierarchy. And the necessity for any particular planned study can be established by determining its role in supplying an information need. For these reasons, the issues hierarchy in Section 8.2.1.1 is used as

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an organizing principle for many parts of the SCP. In particular, Section 8.3, which describes the characterization program, is organized around the investigations and studies that are required to satisfy the information needs in the issues hierarchy. The defining of these issues was itself a part of the issues-based approach to site characterization described in this section and the issue resolution strategy described in the next section.

8.1.2 ISSUE RESOLUTION STRATEGY

To resolve the issues in the issues hierarchy, the DOE has adopted a general "issue resolution strategy" that guides the development of specific plans for resolving each issue. This general strategy is a procedure consisting of four distinct processes: issue identification, performance allocation, data collection and analysis, and issue resolution documentation. The steps in these processes are outlined in Figure 8.1-1. The first two processes, applied separately to each issue, lead to the identification of the information necessary to resolve the issue and the development of plans for acquiring that information. The reasoning used in carrying out those two processes is, then, the basis for the rationale for the particular site characterization activities that are intended to resolve the issue. The rationale and the plans for these activities are described in Sections 8.2 and 8.3. An understanding of the general issue resolution strategy is important for understanding these four steps and the site characterization program presented in Section 8.3.

8.1.2.1 Issue identification

The first process in the issue resolution strategy, labeled "issue identification" in Figure 8.1-1, consists of three steps. Two of these steps (1 and 2) are the development of the issues hierarchy itself. Step 1 identifies the regulatory requirements; from them the issues are derived (step 2), as explained in Section 8.1.1. The plans for resolution of each issue will be affected by the current understanding of the site. Therefore, a step (step 1a) is needed to describe to the extent to which it is known. In this step conceptual models and working hypotheses for the site are identified and preliminary designs for these concepts are specified. This description for a repository system at the Yucca Mountain site will be presented in site-specific requirements and system-description documents.

8.1.2.2 Performance allocation

The second process in the strategy, called "performance allocation," consists of the steps that provide the rationale for the establishment of particular site characterization activities. In the issue resolution strategy the term "performance allocation" refers only to the four steps, steps 3 through 6, shown in Figure 8.1-1. Applied separately to each issue in the hierarchy, this process produces the principal guidance for planning the

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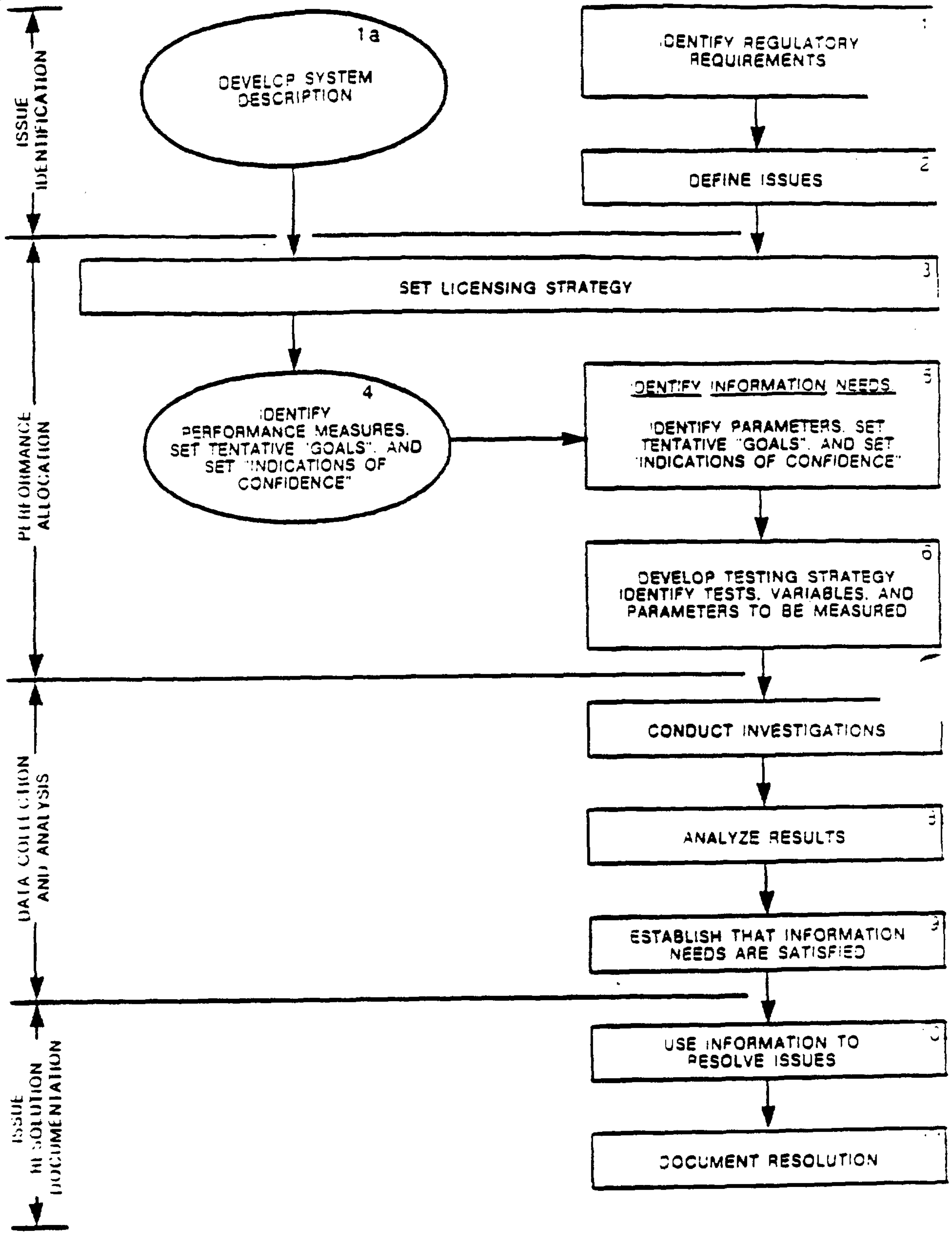

Figure 8.1-1. Issue resolution strategy

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activities needed to resolve the issue. The performance-allocation concept was developed in open meetings between the DOE and the NRC and documented in the minutes of those meetings.

Licensing strategy

For each issue, the first step in performance allocation (step 3 in Figure 8.1-1) is the adoption of a "licensing strategy." This step uses available information to develop, for planning purposes, a statement of the site features, engineered features, conceptual models, and analyses that the DOE expects to be important in resolving the issue. The statement is called a licensing strategy because the combined statements developed in step 3 for all the issues are the basis for the current DOE plans to show compliance with regulatory requirements. Eventually, information developed from the current plans is intended to support the recommendation of a site for development and the demonstration of compliance with NRC requirements for the construction, operation, closure, and decommissioning of a repository.

In this document, the licensing strategy is necessarily preliminary because site characterization is only beginning. But the strategy is developed well enough to guide the preparation of the plans for tests and analyses and to make clear what activities are considered to be necessary and whether they will be sufficient to resolve the issue. As site characterization proceeds and additional information becomes available, the licensing strategy may be revised. In fact, the licensing strategies described in this document are likely to change before the submission of the license application to the NRC; for the purposes of this SCP, they are simply the basis for initial planning.

For guiding the development of the SCP, the principal product of step 3 is a statement of the disposal-system components on which the DOE currently intends to rely in resolving the issue; if these components perform as the licensing strategy indicates they are expected to perform, the issue is likely to be resolved. The statement may also identify, for each of the components, specific features or characteristics that the DOE expects will contribute to the performance of the component and, hence, to the resolution of the issue. The performance and design issues provide the statement of disposal-system components for use in later steps as a basis for deciding what specific information is needed for resolving the issue.

Performance measures and tentative goals

Step 4 carries the strategy further by establishing "performance measures" for each of the components identified in step 3. A performance measure is a physical quantity that describes the performance of the component. The measure may be a directly measurable quantity, or it may be a quantity derived from other, more directly measurable quantities.

For each performance measure, step 4 establishes a tentative "goal." The word "goal" is enclosed within quotation marks in Figure 8.1-1 to show that it has a special meaning in performance allocation. The tentative goal is not a target that the performance measure must attain if the repository is to perform properly, and therefore it does not have to be met. Instead, it is simply a guide for the development of a testing program--a guide that

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states the licensing strategy quantitatively and can be changed or discarded once the testing program has been established. In assigning goals to the performance measures, the DOE will specify values that are consistent with the licensing strategy for the issue. If the tests and analyses can demonstrate that a goal is attained, the licensing strategy for the issue will be satisfied, and the issue will likely be resolved. The goals are, therefore, guides for deciding, in the later steps of performance allocation, what information must be provided by the testing program. Whenever a goal is identified, the reasoning that led to its selection is also presented.

As a further guide for testing, step 4 accompanies each tentative goal with an "indication of confidence," a statement that further clarifies the role of the component in the licensing strategy. The indication of confidence expresses, as quantitatively as possible, the confidence with which the licensing strategy desires the testing program to show that the goal has been attained.

For some goals, it is possible to use statistically rigorous numerical values as indications of confidence; for most of them, however, only a qualitative expression is now possible. When qualitative indicators are assigned, they are accompanied by further explanation of their intended meaning.

Because they depend on a licensing strategy that is preliminary, the goals and indications of confidence are also preliminary. As site characterization progresses and more information is acquired, these goals and indicators will probably be changed to guide continued testing toward the collection of the needed information.

Information needs

The performance allocation process now proceeds to develop specific requirements for future work. Step 5 identifies "information needs," which state, for each issue, the categories or types of information needed to resolve the issue. The information needs identified for the Yucca Mountain site are listed in Section 8.2. Section 8.3 explains how these information needs were derived from the licensing strategy developed earlier in the performance allocation process.

Part of the development of an information need is the identification of the "parameters" needed to evaluate the performance measures. As already mentioned, many performance measures (e.g., the time of ground-water travel through a particular geohydrologic unit) are not directly measurable quantities. Often, however, they can be expressed by an equation in which quantities that can be measured more directly appear as parameters (e.g., hydraulic conductivity). Step 5 furthers the development of plans for testing by listing these parameters. Sometimes the performance measures cannot be expressed simply as an equation containing associated parameters; then in step 5, by an extension of the notion of mathematical parameters, lists are made of whatever quantities must be measured to demonstrate that the goal associated with the performance measure has been met. The performance allocations reported in later sections of this chapter call these quantities, as well as the quantities derived from rigorous equations, "parameters." Parameters derived for the resolution of design issues are usually called "design parameters"; those for performance issues are "performance parameters."

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In step 5 a tentative goal is assigned to each parameter. Like the goals for performance measures, these goals are not values that must be achieved by the disposal system. They are simply quantitative statements about the values that the licensing strategy expects to use for the parameters in showing that the issue has been resolved. Frequently, the goals are expressed as inequalities because the licensing strategy may require only that the value of a parameter be shown to lie within a stated range or to be greater or smaller than some stated value.

If the results of site characterization can successfully demonstrate that the tentative goal has been met, the DOE plans for getting a license will be fulfilled as far as that parameter's contribution to the associated performance measure is concerned. The demonstration will not, of course, guarantee a successful license application because many other parameters will enter the calculations in support of the license. Moreover, failure to meet the goal would not be reason to suspect that the license application will be unsuccessful because the goals are not values that, by themselves, are essential to the performance of a disposal system. The reason for setting the goals is simply to guide the specification of tests in the characterization program--to tell quantitatively what information will lead to the resolution of the performance and the design issues.

As a further guide to the detailed specification of tests, step 5 also specifies two indications of confidence for the goal assigned to each parameter. Like the indicators for goals for performance measures, these indicators are not numerically rigorous but are expressed in qualitative terms: high, medium, and low.

The first of these two indications, called "needed confidence" in the performance allocation tables in this chapter of the SCP, answers the following question: When the DOE presents its license application, how confident must it be that the goal has been met? In other words, what confidence does the licensing strategy require for the demonstration that the goal has been met? In assigning the indicators of needed confidence, the DOE is guided primarily by two considerations:

1. Importance. How important to the licensing strategy is the associated goal? Usually the goal is so important that a value of "high" is assigned to the needed confidence. When the goal is a request for information that is not crucial to the license application, an assignment of low or medium confidence is usually appropriate.

2. Sensitivity of the parameter associated with the goal. In addition to considering the importance of a goal, the DOE may examine the sensitivity with which the associated parameter contributes to performance measures and other parameters. If a performance measure or another parameter is highly sensitive to the likely or expected variations in the parameter for which a goal is assigned, the needed confidence may be higher than it would be for a parameter whose variations make little difference.

The second indication of confidence, called "current confidence" in the performance allocation tables, answers the following question: If the DOE were to present its license application today and could use only currently availa-

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ble data in the presentation, how confident would it feel that the associated goal has been met? In assigning the indicators of current confidence, the DOE is guided by considering the amount and the quality of the available data and the uncertainties in any models used to interpret those data.

Testing strategy

Step 6 in Figure 8.1-1 uses the information needs, expressed in the terms adopted during step 5, to define the work that will produce the needed information. The parameters derived in step 5 are usually not directly measurable quantities, but must be derived from other quantities that can be measured through testing. For example, hydraulic conductivity, mentioned previously as a possible parameter for calculations of ground-water travel time, is not directly measurable in a field test. Step 6, then, identifies additional, more directly measurable, quantities that can contribute to determining values for the performance and design parameters derived in step 5. These additional quantities are generally called "characterization parameters." Some of the SCP sections describing the site program also use other kinds of parameters, called by different names, in explaining how characterization parameters are being developed.

Step 6 also defines a "testing basis," whose purpose is to give further information about the way in which the characterization parameters need to be measured. Some of the testing bases appearing in the later sections of this chapter describe the accuracy with which the associated characterization parameters need to be measured; some describe the confidence that the measurements should produce for licensing. As the later sections explain, the particular descriptions of a testing basis are tailored to the parameters they explain and to the development status of those parameters.

The parameters, confidences, and testing bases are the foundation for the strategy detailed in Section 8.3 in the descriptions of the planned site characterization work. That section describes the planned tests; it identifies the experimental variables and the parameters (from steps 5 and 6) that the tests will measure. It also describes plans for developing the needed analytical models and design information.

Conceptual model uncertainties

The performance allocation approach relies heavily on the current conceptual models of the site to set the licensing strategies, to identify performance measures, to set tentative performance goals and indications of confidence, and to identify information needs. Therefore, it is also important that the site characterization program address the uncertainties in these conceptual models. The investigations to test the conceptual models that have significant uncertainties are described in the characterization programs in Section 8.3. Detailed tables are presented in the discussion of these programs that identify the conceptual models of concern, the uncertainties in these conceptual models, the significance of these uncertainties relative to the resolution of the performance and design issues, alternative hypotheses consistent with existing data, and the planned activities to address the uncertainties.

8.1.2.3 Data collection and analysis

The data collection and analysis process of the issue resolution strategy will continue after issuance of the SCP. The steps in this process are to conduct the investigations dictated by the testing strategies in the SCP, to analyze the results of these investigations, and to check that the information obtained satisfies the information needs in these strategies. These are steps 7, 8, and 9 of the issue resolution strategy of Figure 8.1-1.

The review establishing whether the information needs are satisfied (step 9) involves a comparison of the data with the goals established in the testing strategy and an evaluation of the usefulness of additional testing. Therefore, this review provides the technical information for the decision to continue or terminate testing.

The process associated with the determination if the data are sufficient is suggested in the logic diagram shown in Figure 8.1-2. The three steps of this process (steps 7, 8, and 9) are also noted in this diagram.

Two fundamental premises should be mentioned before the steps in the process are discussed. First, a full performance assessment cannot be conducted after each study to determine if the information obtained is sufficient to resolve issues. The site characterization program is extremely complex and comprehensive. While many of the critical elements needed for the full performance assessments will be completed early, others that will be needed will not be completed until much later, and some not until the end of site characterization. To wait until the complete set of information is available to evaluate the testing is not prudent. Therefore, elements of this program will be evaluated individually with respect to adequacy of the information obtained without resorting to full performance assessments. Part of this evaluation will involve some analysis. The extent of such analysis is discussed below.

The second premise behind the data collection process is that the investigations specified in the SCP define all the testing needed to confirm the conceptual models and hypotheses serving as the basis for the current licensing strategies. That is, if all of these models and hypotheses are indeed confirmed, the testing dictated in the testing strategies should be sufficient to resolve all the performance and design issues. However, it is not likely that all of these hypotheses, most of which are based on preliminary information, will be confirmed. Therefore, it is expected that some of the conceptual models for the site will be modified as a result of the site characterization, and that the strategies may need to change. Accordingly, analysis of the results of the testing will be conducted as the testing proceeds to determine if the investigations set forth in the SCP need to be completed or if the testing strategies need to be modified.

Therefore, the first steps in the process are to initiate the studies under the various investigations (step 7) and to conduct analyses as the data become available (steps 8a and 8b). For the purpose of deciding if the data are sufficient, the principal result of these analyses is an estimate of the confidence that the particular parameter goals specified for the study are met. This estimate will depend not only upon the uncertainties in those parameters, but also the uncertainties in the models and hypotheses upon which the parameters are based, and these uncertainties must be taken into account

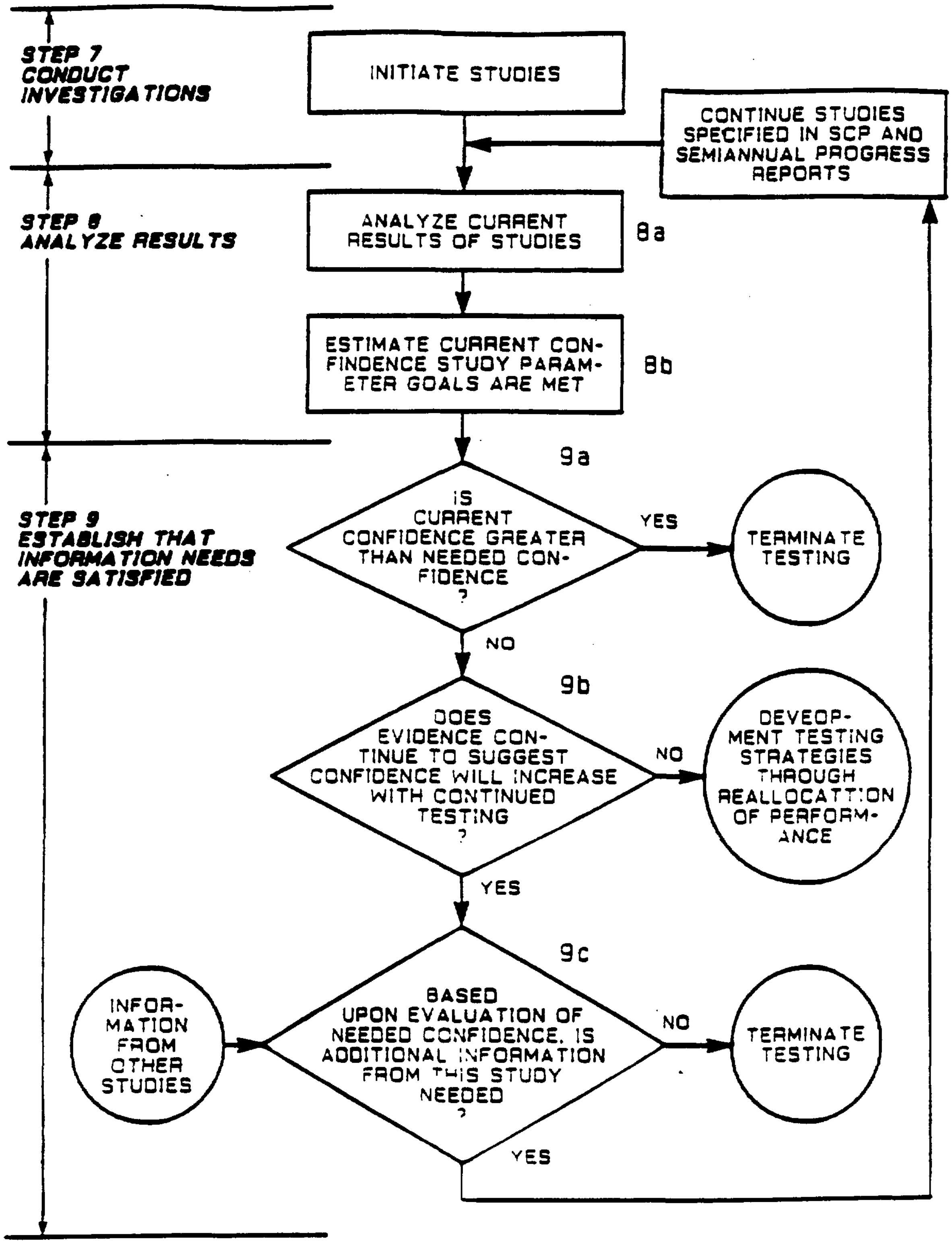

Figure 8.1-2. Data collection and analysis process.

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in making the estimates. In some cases, the estimates may be quantitative; but in many cases judgment, supported with appropriate documentation, will be the principal basis for the estimates. All reviews and documentation will be performed in accordance with established quality assurance procedures as described in Section 8.6.

The current confidence in the parameter goals will be compared with the needed confidences expressed in the SCP and the semiannual progress reports (step 9a). Because the needed confidences are qualitative and subjective in many cases, this comparison will also require judgment and technical review. If it is concluded that the needed confidences are exceeded, the testing can be terminated.

It may not be possible to conclude that the needed confidences have been achieved, and in most cases, the testing would then continue until the next review or even until the full set of tests specified in the SCP has been completed. However, there are conditions under which such testing may be terminated without increasing the confidence that the parameter goals are met. One such condition is indicated in step 9b; in this case, information from the testing program may suggest that additional testing will not increase the confidence. For example, it may be discovered that site characteristics are actually much different than originally thought and that there is now a high confidence that the original goals will not be met. In this case, the testing associated with this strategy would be terminated and new strategies could be developed, consistent with the new information. Any new strategies would be reported in the semiannual progress reports.

Another condition, illustrated in step 9c of the logic diagram, is the case in which information from other studies may suggest that the information from the testing being evaluated is less important than originally thought; that is, the needed confidence is less than originally proposed. In this case, the testing may also be terminated. Because such a decision will usually involve judgment, the basis for such a decision will also be technically reviewed. This review will be conducted both at the technical level and at the management level of DOE and its contractors. The final review and acceptance of the need for continuing testing will be reviewed and approved by DOE program management.

The review of the data collection and analysis process will involve judgments at three levels of detail: the study level, the investigation level, and the issue level. The judgments at the study level involve the technical evaluations of the current confidence that the parameter goals are met (step 9a of the logic diagram) and the evaluation of whether the current confidence can be increased by additional testing (step 9b). On the basis of these technical evaluations, recommendations are made to continue the testing program or to terminate some of the testing.

There is a level of both technical and management judgment at the investigation level to ensure that the objectives of the investigations are met and that the information needs are being satisfied. For example, recommendations to terminate testing because of the technical considerations at the study level will be reviewed from both a technical and management perspective to ensure that the investigation objectives are not jeopardized by such an action. In addition, the information from all of the studies is reviewed at

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the investigation level to determine if information from particular studies is no longer needed and whether those studies should be terminated as a result (step 9c of the logic diagram).

Finally, there is a level of management judgment at the issue level to ensure that proper steps are being taken for issue resolution. The recommendations made at the study level, which are considered to be consistent with the objectives of the investigations, and the recommendations made at the investigation level to extend or curtail any of the testing originally planned will be reviewed at the issue level by DOE technical management for this purpose. This review will address the adequacy of the information obtained in the site characterization program with regard to issue resolution and will consider the concerns of outside organizations, such as the NRC, in this regard.

8.1.2.4 Issue resolution documentation

The purpose of the issue resolution documentation process of the issue resolution strategy is to use the information obtained from site characterization to determine if there is sufficient data to support successful license application. This will be accomplished by evaluating the available information, developing positions on each of the issues and technical concerns for the site, providing for independent review of these positions as appropriate, and by documenting the reviewed positions to finalize them. This section discusses the approach that the DOE intends to use to carry out these activities.

The approach that is described here recognizes the fact that some uncertainties are likely to remain even after site characterization. These residual uncertainties do not necessarily preclude the reasonable assurance that is the objective of the site characterization program; indeed, the NRC itself recognized in its statements of considerations in support of the regulation (NUREG-0804) that such uncertainties would be expected to remain. Nevertheless, these uncertainties must be addressed in the issue closure process.

The discussion below describes the approach to addressing these uncertainties through the development of positions that are based upon the design, testing, and analysis planned for the site characterization program. The DOE recognizes that its judgments in developing these positions will be carefully scrutinized and questioned. The DOE expects to interact with independent reviewers, including the NRC, regarding some of these questioned items before formal licensing activities. The role of such review and interactions in the issue closure process is described below.

The steps of this process are shown in Figure 8.1-3. These are steps 10 and 11 of the issue resolution strategy of Figure 8.1-1. The first of these steps (step 10) is to use the information collected during site characterization to resolve the issue. This process begins by assembling the available data (step 10a). Although in many cases, this assembly could occur after all testing and design associated with a given issue are completed, it may be appropriate to begin to develop a position on an issue as the information is

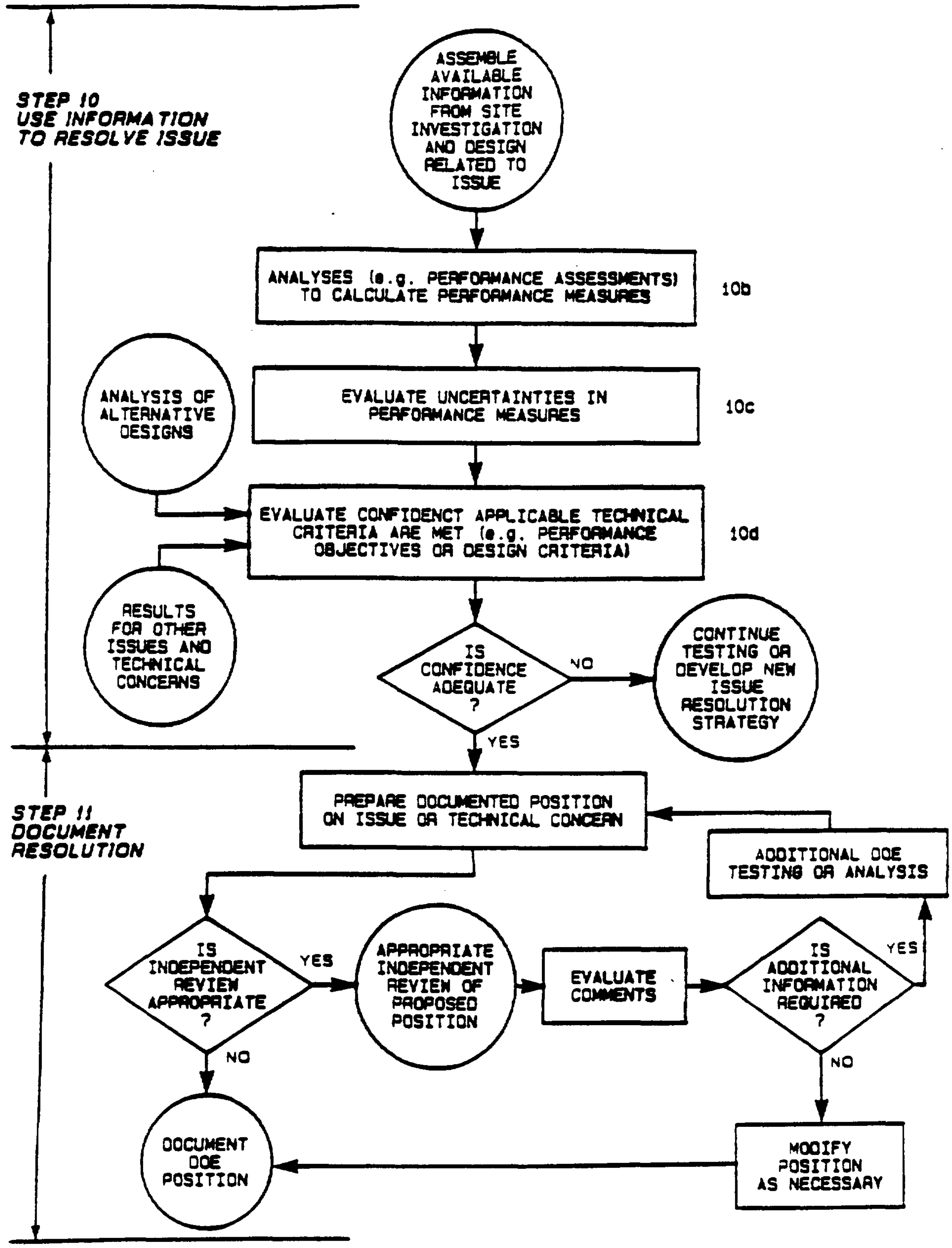

Figure 8.1-3. Issue resolution documentation

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obtained. It may, for example, be found that a position can be taken even before all the information originally envisioned to be necessary is acquired. This would be the case if it were found that one barrier were to perform so well that less information about another barrier would be necessary.

Periodic performance assessments will be conducted to evaluate the performance measures for the issue on the basis of the available information (step 10b). The full range of uncertainties in these performance measures will be evaluated (step 10c). This evaluation will involve sensitivity and uncertainty analysis of the parameters of the models and analysis of the validity of the models. Alternative conceptual models will also be evaluated. In addition, information that is not yet available will be taken into account in assessing these uncertainties. Then, using the analyses of performance measures, the confidence that the applicable technical criteria are met will be evaluated (step 10d). This confidence will depend upon the range of uncertainties that still exists.

The remaining uncertainties will be addressed in several ways. First, analyses of alternative designs will be conducted. From such analyses, it may be learned that one design is superior to others for the resolution of the issue or that issue resolution is not sensitive to the design options being considered. In addition, the impacts of the resolution of other issues will be taken into account; that is, the results of the analyses for all issues will be used in evaluating the level of confidence that the technical criteria are met.

The next step (10e) is to decide if the current level of confidence that the technical criteria are met is adequate or not. This determination will be a judgment based upon the information available and not upon pre-set criteria; however, the performance goals and needed confidences in those goals for the performance measures will provide useful guides for the kinds of judgments that will be made.

The information from these analyses is then used to develop a documented position on the issue or technical concern in a position paper. The position papers would then be available for independent review as appropriate. For those instances where independent reviews have been sought, the DOE will review the comments resulting from these independent reviews and interact with the reviewers to account for differences (step 10g). From this evaluation, the DOE will determine what actions should be taken. For example, the DOE may be able to resolve significant differences and determine that it is appropriate to move forward with the position. On the other hand, the DOE may decide that the current level of uncertainty is too large and develop plans to acquire additional information to reduce this uncertainty. Alternatively, the DOE may decide to modify the position as a result of the comments.

The next step of the issue resolution strategy (step 11) is to formally document the issue resolution to support licensing. The resolution of the issues would be documented in Issue Resolution Reports (IRRs). The positions on the technical criteria of Subpart E of 10 CFR Part 60 will be documented as a part of the safety analysis report (SAR) that will be a part of DOE's license application. Throughout the issue resolution process, the DOE will be

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soliciting the views of and interacting with outside organizations, such as the NRC, on selected key topics. As already mentioned, the current versions of the strategies are preliminary and intended simply as a basis for initial planning.

8.1.2.5 Application of the issue resolution strategy

The entire issue resolution strategy is intended to be iterative. Section 8.3 reports the current DOE issue resolution strategies. As explained previously, the licensing strategy, as well as the tentative goals and the indications of confidence for the performance measures and related parameters, may be changed to reflect new information or in response to comments about plans or test results. If they are changed, the steps that follow in the issue resolution strategy will also be reexamined and their products revised. The analyses of the results of the investigations (step 8) may produce new understandings that require the rethinking of earlier steps. Any of the steps may, in fact, lead to revisions of the issue resolution strategy.

The rationale for future changes to the issue resolution strategies (e.g., revised licensing strategies and performance allocations) will be documented in the site characterization progress reports, which will also report the results of site characterization studies. The reviews, interactions, and reports will continue until the license application is submitted to the NRC.

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8.2 ISSUES TO BE RESOLVED AND INFORMATION REQUIRED DURING SITE CHARACTERIZATION

As described in Section 8.1, the concept of the issues hierarchy is one of the two themes underlying the site characterization program that has been developed for the Yucca Mountain site. The key issues, making up the highest tier in the hierarchy, are the key issues identified in the Mission Plan (DOE, 1985b). Statements of these issues, which are derived from the four system guidelines of the DOE general siting guidelines (10 CFR Part 960), are provided in Table 8.2-1. Key Issue 1 addresses the requirements related to containment and isolation; Key Issue 2 covers protection of the general public and workers from radiological exposures; Key Issue 3 addresses the protection of the quality of the environment; and Key Issue 4 covers the DOE concerns that the mined geologic disposal system is cost effective and can be constructed, operated, closed and decommissioned on the basis of reasonably available technology. The key issues address the primary NRC postclosure requirements for containment and isolation, and the preclosure radiological safety requirements.

8.2.1 ISSUES TO BE RESOLVED

The issues within each key issue in the Office of Geologic Repositories (OGR) Issues Hierarchy (DOE, 1986d) represent the current DOE understanding of the questions that should be answered in order for the key issue to be resolved. Issues are often correlated with the principal NRC requirements addressing a specific repository design or site feature, and thus final resolution of an issue may be confirmed only at the time of licensing. As described in Section 8.1.2, issue resolution strategies have been developed for each issue in the issues hierarchy. From these strategies, preliminary site-specific data needs have been derived and a site characterization program has been designed to obtain sufficient data to satisfy the information requirements. The issues in Key Issue 3 are not included in the SCP, because the definition of site characterization in the Nuclear Waste Policy Act (NWPA) excludes socioeconomic, transportation, and environmental studies. Details of the information requirements for environment-related topics will be presented in other DOE documents.

Table 8.2-2 lists all performance and design issues associated with Key Issues 1, 2, and 4, arranged by issue. Site-specific information needs, relevant to resolution of each issue, are also presented in Table 8.2-2. Identification of these information needs is described later in this section.

Figures 8.2-1, 8.2-2, and 8.2-3 display the relationships between the regulatory requirements of 10 CFR Part 60, 10 CFR Part 20, 40 CFR 191, Subpart A, and 10 CFR Part 960 and the performance and design issues. These relationships are explained more fully in DOE (1986d).

In parallel with the development of issue resolution strategies for each of the issues, the physical elements of the repository system were defined. This system definition is called the Yucca Mountain mined geologic disposal system (MGDS) (Figure 8.2-4) and serves as a basis for a functional description of the repository. The physical elements of the Yucca Mountain MGDS are

Table 8.2-1. Statements of the key issues in the Office of Geologic Repositories issues hierarchy

Issue	Statement of key issue
Key Issue 1	Will the mined geologic disposal system at Yucca Mountain isolate the radioactive waste from the accessible environment after closure in accordance with the requirements set forth in 40 CFR Part 191, 10 CFR Part 60, and 10 CFR Part 960?
Key Issue 2	Will the projected releases of radioactive materials to restricted and unrestricted areas and the resulting radiation exposures of the general public and workers during repository operation, closure and decommissioning at Yucca Mountain, meet applicable safety requirements set forth in 10 CFR Part 20, 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191?
Key Issue 3	Can the mined geologic disposal system at Yucca Mountain be sited, constructed, operated, closed, and decommissioned, and can the associated transportation system be sited, constructed, and operated so that the quality of the environment will be protected and waste-transportation operations can be conducted without causing unacceptable risks to public health or safety?
Key Issue 4	Will the construction, operation (including retrieval), closure, and decommissioning of the mined geologic disposal system be feasible at Yucca Mountain on the basis of reasonably available technology, and will the associated costs be reasonable in accordance with the requirements set forth in 10 CFR Part 960?

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 1 of 9)

Issues	Information Need No.	Statement of information need
	KEY ISSUE 1	
Performance issues		
Issue 1.1: Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13?	1.1.1	Site information needed to calculate releases to the accessible environment
	1.1.2	A set of potentially significant release scenario classes that address all events and processes that may affect the geologic repository
	1.1.3	Calculational models for predicting releases to the accessible environment attending realizations of the potentially significant release scenario classes
	1.1.4	Determination of the radionuclide releases to the accessible environment associated with realizations of potentially significant release scenario classes
	1.1.5	Probabilistic estimates of the radionuclide releases to the accessible environment considering all significant release scenarios
Issue 1.2: Will the mined geologic disposal system meet the requirements for limiting individual doses in the accessible environment as required by 40 CFR 191.15?	1.2.1	Determination of doses to the public in the accessible environment through liquid pathways
	1.2.2	Determination of doses to the public in the accessible environment through gaseous pathway
Issue 1.3: Will the mined geologic disposal system meet the requirements for the protection of special sources of ground water as required by 40 CFR 191.16?	1.3.1	Determination whether any Class I or special sources of ground water exist at Yucca Mountain, within the controlled area, or within 5 km of the controlled area boundary
	1.3.2	Determine for all special sources whether concentrations of waste products in the ground water during the first 1,000 years after disposal could exceed the limits established in 40CFR191.16.

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 2 of 9)

Issues	Information Need No.	Statement of information need
		KEY ISSUE 1 (continued)
Performance issues (continued)		
Issue 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113?	1.4.1	Waste package design features that affect the performance of the container
	1.4.2	Material properties of the container
	1.4.3	Scenarios and models needed to predict the rate of degradation of the container material
	1.4.4	Estimates of the rates and mechanisms of container degradation in the repository environment for anticipated and unanticipated processes and events, and calculation of the failure rate of the container as a function of time
	1.4.5	Determination of whether the requirement for substantially complete containment of the waste packages is met for anticipated processes and events
Issue 1.5: Will the waste package and repository engineered barrier systems meet the performance objective for limiting radionuclide release rates as required by 10 CFR 60.113?	1.5.1	Waste package design features that affect the rate of radionuclide release
	1.5.2	Material properties of the waste form
	1.5.3	Scenarios and models needed to predict the rate of radionuclide release from the waste package and engineered barrier system
	1.5.4	Determination of the release rates of radionuclides from the waste package and engineered barrier system for anticipated and unanticipated events
	1.5.5	Determination of the amount of radionuclides leaving the near-field environment of the waste package

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 3 of 9)

Issues	Information Need No.	Statement of information need
KEY ISSUE 1 (continued)		
Performance issues (continued)		
Issue 1.6: Will the site meet the performance objective for pre-waste-emplacement ground-water travel time as required by 10 CFR 60.113?	1.6.1	Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path
	1.6.2	Calculational models to predict ground-water travel times between the disturbed zone and the accessible environment
	1.6.3	Identification of the paths of likely radionuclide travel from the disturbed zone to the accessible environment and identification of the fastest path
	1.6.4	Determination of the pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment
	1.6.5	Boundary of the disturbed zone
Issue 1.7: Will the performance-confirmation program meet the requirements of 10 CFR 60.137?		Information needs to be determined
Issue 1.8: Can the demonstrations for favorable and potentially adverse conditions be made as required by 10 CFR 60.122?		No additional information needs identified
Issue 1.9: (a) Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the postclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for geohydrology, geochemistry, rock characteristics, climate changes, erosion, dissolution, tectonics, and human interference; and (b) can the comparative evaluations required by 10 CFR 960.3-1-5 be made?		No information needs identified.

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 4 of 9)

Issues	Information Need No.	Statement of information need
		KEY ISSUE 1 (continued)
<u>Design issues</u> Issue 1.10: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.135, and (b) provide information for the resolution of the performance issues?	1.10.1	Design information needed to comply with postclosure criteria from 10 CFR 60.135 (a) for consideration of the interactions between the waste package and its environment
	1.10.2	Reference waste package designs
	1.10.3	Reference waste package emplacement configurations
	1.10.4	Postemplacement near-field environment
Issue 1.11: Have the characteristics and configurations of the repository and repository engineered barriers been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.133 and (b) provide information for the resolution of the performance issues?	1.11.1	Site characterization information needed for design
	1.11.2	Characteristics of waste package needed for design of the underground facility
	1.11.3	Design concepts for orientation, geometry, layout, and depth of the underground facility to contribute to waste containment and isolation, including flexibility to accommodate site-specific conditions
	1.11.4	Design constraints to limit water usage and potential chemical changes
	1.11.5	Design constraints to limit excavation-induced changes in rock mass permeability
	1.11.6	Repository thermal loading and predicted thermal and thermomechanical response of the host rock
	1.11.7	Reference postclosure repository design
Issue 1.12: Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.134 and (b) provide information for the resolution of the performance issues?	1.12.1	Site, waste package, and underground facility information needed for design of seals and their placement methods
	1.12.2	Materials and characteristics of seals for shafts, drifts, and boreholes
	1.12.3	Placement method for seals for shafts, drifts, and boreholes
	1.12.4	Reference design of seals for shafts, drifts, and boreholes

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 5 of 9)

Issues	Information Need No.	Statement of information need
	KEY ISSUE 2	
<u>Performance issues</u>		
Issue 2.1: During repository operation, closure, and decommissioning (a) will the expected average radiation dose received by members of the public within any highly populated area be less than a small fraction of the allowable limits and (b) will the expected radiation dose received by any member of the public in an unrestricted area be less than the allowable limits as required by 10 CFR 60.111, 40 CFR 191 Subpart A, and 10 CFR Part 20?	2.1.1	Site and design information needed to assess preclosure radiological safety
Issue 2.2: Can the repository be designed, constructed, operated, closed, and decommissioned in a manner that ensures the radiological safety of workers under normal operations as required by 10 CFR 60.111 and 10 CFR Part 20?	2.2.1	Determination of radiation environment in surface and subsurface facilities due to natural and man-made radioactivity
	2.2.2	Determination that projected worker exposures and exposure conditions under normal conditions meet applicable requirements
Issue 2.3: Can the repository be designed, constructed, operated, closed, and decommissioned in such a way that credible accidents do not result in projected radiological exposures of the general public at the nearest boundary of the unrestricted area, or workers in the restricted area, in excess of applicable limiting values?	2.3.1	Determination of credible accident sequences and their respective frequencies applicable to the repository
	2.3.2	Determination of the predicted releases of radioactive material and projected public and worker exposures and exposure conditions under accident conditions and that these meet applicable requirements

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 6 of 9)

Issues	Information Need No.	Statement of information need
		KEY ISSUE 2 (continued)
Performance issues (continued)		
Issue 2.4: Can the repository be designed, constructed, operated, closed, and decommissioned so that the option of waste retrieval will be preserved as required by 10 CFR 60.111?	2.4.1	Site and design data required to support retrieval
	2.4.2	Determination that access to the waste emplacement boreholes can be provided throughout the retrievability period for normal and credible abnormal conditions
	2.4.3	Determination that access to the waste packages can be provided throughout the retrievability period for normal and credible abnormal conditions
	2.4.4	Determination that the waste can be removed from the emplacement boreholes for normal and off-normal conditions
	2.4.5	Determination that the waste can be transported to the surface and delivered to the waste-handling surface facilities for normal and credible abnormal conditions
	2.4.6	Determination that the retrieval requirements set forth in 10 CFR 60.111(b) are met using reasonably available technology
Issue 2.5: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for population density and distribution, site ownership and control, meteorology, and offsite installations and operations?		No additional information needs identified

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 7 of 9)

Issues	Information Need No.	Statement of information need
		KEY ISSUE 2 (continued)
Design issues		
Issue 2.6: Have the characteristics and configurations of the waste packages been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.135 and (b) provide information for the resolution of the performance issues?	2.6.1	Design information needed to comply with preclosure criteria from 10 CFR 60.135(b) for materials, handling, and identification of waste packages
	2.6.2	Design information needed to comply with preclosure criteria from 10 CFR 60.135(c) for waste forms
	2.6.3	Waste acceptance specifications
Issue 2.7: Have the characteristics and configurations of the repository been adequately established to (a) show compliance with the preclosure design criteria of 10 CFR 60.130 through 60.133 and (b) provide information for the resolution of the performance issues?	2.7.1	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate design objectives pertaining to radiological protection have been met
	2.7.2	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any additional appropriate design objective pertaining to the design and protection of structures, systems, and components important to safety have been met
	2.7.3	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to criticality control have been met
	2.7.4*	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to compliance with mining regulations have been met
	2.7.5*	Determination that the design criteria in 10 CFR 60.131 through 60.133 and any appropriate additional design objectives pertaining to waste treatment have been met

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 8 of 9)

Issues	Information Need No.	Statement of information need
	KEY ISSUE 4	
Performance issues		
Issue 4.1: Can the higher-level findings required by 10 CFR Part 960 be made for the qualifying condition of the preclosure system guideline and the disqualifying and qualifying conditions of the technical guidelines for surface characteristics, rock characteristics, hydrology, and tectonics?		No additional information needs identified
Design issues		
Issue 4.2: Are the repository design and operating procedures developed to ensure nonradiological health and safety of workers adequately established for the resolution of the performance issues?	4.2.1	Site and performance assessment information needed for design
Issue 4.3: Are the waste package production technologies adequately established for the resolution of the performance issues?	4.3.1	Identification and evaluation of production technologies for fabrication, closure, and inspection of the waste package
Issue 4.4: Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues?	4.4.1	Site and performance assessment information needed for design
	4.4.2	Characteristics and quantities of waste and waste packages needed for design
	4.4.3	Plan for repository operations during construction, operation, closure, and decommissioning
	4.4.4	Repository design requirements for construction, operation, closure, and decommissioning
	4.4.5	Reference preclosure repository design
	4.4.6	Development and demonstration of required equipment
	4.4.7	Design analyses, including those addressing impacts of surface conditions, rock characteristics, hydrology, and tectonic activity

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Table 8.2-2. Site-specific information needs for the Yucca Mountain site (page 9 of 9)

Issues	Information Need No.	Statement of information need
		KEY ISSUE 4 (continued)
Design issues (continued)		
	4.4.8	Identification of technologies for surface facility construction, operation, closure, and decommissioning
	4.4.9	Identification of technologies for underground facility construction, operation, closure, and decommissioning
	4.4.10	Determination that the seals for shafts, drifts, and boreholes can be emplaced with reasonably available technology
Issue 4.5: Are the costs of the waste packages and the repository adequately established for the resolution of the performance issues?[b]	4.5.1	Estimate the costs of the reference and alternative waste packages
	4.5.2	Estimate the costs of the reference and alternative repository designs
	4.5.3	Estimate the life cycle costs of the reference and alternative total system design

[a]Information need does not require site-specific data.
[b]Resolution of Issue 4.5 is not required as the Yucca Mountain site is the only site under consideration for development as a repository as designated by the Nuclear Waste Policy Amendments Act of 1987 (NWPAA, 1987).

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KEY ISSUE 1
(POSTCLOSURE PERFORMANCE)

		REGULATION \ ISSUE	PERFORMANCE									(POSTCLOSURE) DESIGN		
			1.1 TOTAL SYSTEM PERFORMANCE	1.2 INDIVIDUAL PROTECTION	1.3 GROUND WATER PROTECTION	1.4 WASTE PACKAGE CONTAINMENT	1.5 EBS RELEASE RATE	1.6 GROUND WATER TRAVEL TIME	1.7 PERFORMANCE CONFIRMATION	1.8 NRC SITING CRITERIA	1.9 DOE GUIDELINE FINDINGS	1.10 WASTE PACKAGE CHARACTERISTICS	1.11 UNDERGROUND FACILITIES	1.12 SEAL CHARACTERISTICS
10 CFR 960	960.3-1-6	SITE EVALUATIONS									●			
10 CFR 960	960.4-1	POSTCLOSURE SYSTEM									●			
10 CFR 960	960.4-2-1	GEOHYDROLOGY									●			
10 CFR 960	960.4-2-2	GEOCHEMISTRY									●			
10 CFR 960	960.4-2-3	ROCK CHARACTERISTICS									●			
10 CFR 960	960.4-2-4	CLIMATIC CHANGES									●			
10 CFR 960	960.4-2-5	EROSION									●			
10 CFR 960	960.4-2-6	DISSOLUTION									●			
10 CFR 960	960.4-2-7	TECTONICS									●			
10 CFR 960	960.4-2-8	HUMAN INTERFERENCE									●			
10 CFR 60	60.112	SYSTEM PERFORMANCE OBJECTIVE	●											
10 CFR 60	60.113	SUBSYSTEM PERFORMANCE OBJECTIVES				●	●	●						
10 CFR 60	60.122	SITING CRITERIA								●				
10 CFR 60	60.133	UNDERGROUND FACILITY DESIGN CRITERIA											●	
10 CFR 60	60.134	SEAL DESIGN CRITERIA												●
10 CFR 60	60.135	WASTE PACKAGE DESIGN CRITERIA										●		
10 CFR 60	60.137	PERFORMANCE CONFIRMATION REQUIREMENTS							●					
40 CFR 191	191.13	CONTAINMENT REQUIREMENTS	●											
40 CFR 191	191.15	INDIVIDUAL PROTECTION REQUIREMENTS		●										
40 CFR 191	191.16	GROUND-WATER PROTECTION REQUIREMENTS			●									

Figure 8.2-1. Correlation of performance and design issues for Key Issue 1 (postclosure performance) with regulatory requirements

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KEY ISSUE 2
(PRECLOSURE RADIOLOGICAL SAFETY)

REGULATION			ISSUE: PERFORMANCE — 2.1 PUBLIC RADIOLOGICAL EXPOSURES-NORMAL CONDITIONS	PERFORMANCE — 2.2 WORKER RADIOLOGICAL SAFETY-NORMAL CONDITIONS	PERFORMANCE — 2.3 ACCIDENTAL RADIOLOGICAL RELEASES	PERFORMANCE — 2.4 RETRIEVABILITY	PERFORMANCE — 2.5 DOE GUIDELINE FINDINGS-RADIOLOGICAL SAFETY	PRECLOSURE DESIGN — 2.6 WASTE PACKAGE CHARACTERISTICS	PRECLOSURE DESIGN — 2.7 REPOSITORY DESIGN CRITERIA FOR RADIOLOGICAL SAFETY
10 CFR 960	960.5-1	PRECLOSURE SYSTEM--RADIOLOGICAL SAFETY					●		
10 CFR 960	960.5-2-1	POPULATION					●		
10 CFR 960	960.5-2-2	SITE OWNERSHIP					●		
10 CFR 960	960.5-2-3	METEOROLOGY					●		
10 CFR 960	960.5-2-4	OFFSITE INSTALLATIONS					●		
10 CFR 60	60.111	RADIOLOGICAL PROTECTION AND RETRIEVABILITY	●	●		●			
10 CFR 60	60.131	GENERAL DESIGN CRITERIA							●
10 CFR 60	60.132	PRECLOSURE RADIOLOGICAL DESIGN							●
10 CFR 60	60.133	UNDERGROUND FACILITY DESIGN CRITERIA							●
10 CFR 60	60.135	WASTE PACKAGE DESIGN CRITERIA						●	
	40 CFR 191, SUBPART A	STANDARDS FOR MANAGEMENT	●						
	10 CFR 20	RADIATION PROTECTION STANDARDS	●	●					

Figure 8.2-2. Correlation of performance and design issues for Key Issue 2 (preclosure radiological safety) with regulatory requirements

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KEY ISSUE 4
(PRECLOSURE PERFORMANCE)

10 CFR 960	REGULATION	PERFORMANCE: 4.1 DOE GUIDELINE FUNDINGS-PRECLOSURE	DESIGN: 4.2 NONRADIOLOGICAL HEALTH AND SAFETY	DESIGN: 4.3 WASTE PACKAGE PRODUCTION TECHNOLOGIES	DESIGN: 4.4 PRECLOSURE DESIGN AND TECHNICAL FEASIBILITY	DESIGN: 4.5 TOTAL SYSTEM COSTS
960.5-1	PRECLOSURE SYSTEM-EASE AND COST	●	●	●	●	●
960.5-2-8	SURFACE CHARACTERISTICS	●				
960.5-2-9	ROCK CHARACTERISTICS	●				
960.5-2-10	HYDROLOGY	●				
960.5-2-11	TECTONICS	●				

Figure 8.2-3. Correlation of performance and design issues for Key Issue 4 (preclosure performance) with regulatory requirements

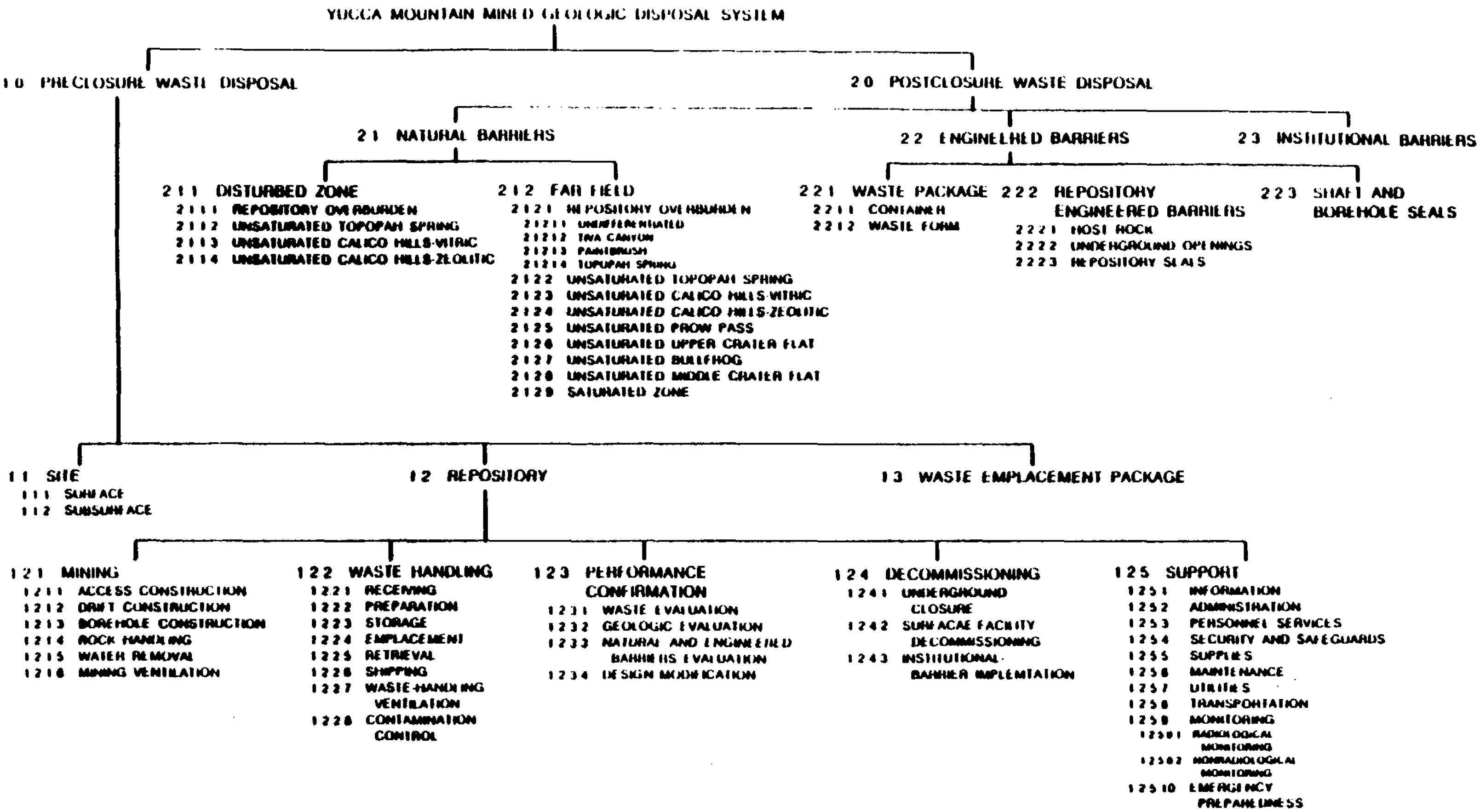

Figure 8.2 4. Hierarchy of functions and components that make up the Yucca Mountain mined geologic disposal system

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the natural site features, engineered features, and institutional features arranged in a hierarchical format. These elements are the components of the system that are used as the basis for developing issue resolution strategies. As shown in Figure 8.2-4, the highest level categorization of the MGDS results in elements related to either the preclosure or postclosure waste disposal systems. Within the preclosure element, the next level in the hierarchy is composed of three elements--site, repository, and waste emplacement package. At a similar level within the postclosure waste disposal element are natural barriers, engineered barriers, and institutional barriers. Further subdivisions of the MGDS are shown in Figure 8.2-4.

As described in Section 8.1.2, the first step in developing an issue resolution strategy for a performance or design issue is to select the system element upon which reliance will be placed. As a part of issue resolution, performance allocation has been used as a means for focusing site characterization on acquisition of data that will be most useful in demonstrating that reliance on a particular element of the MGDS will result in acceptable repository designs and performance. Sections 8.3.2 through 8.3.5 provide complete discussions of each issue resolution strategy summarized in this section.

8.2.1.1 Site-specific issues hierarchy

Table 8.2-2 provides the Yucca Mountain Project site-specific information needs within the context of the OGR issues hierarchy. Information needs were developed as convenient categories of data, parameters, and other information items necessary to support resolution of performance and design issues. Information needs include calculational models, descriptions of processes, and information about conditions and characteristics of the site and the engineered repository system. Those information needs requiring site data are described in detail in Sections 8.3.2 through 8.3.5. Site data will be, in turn, provided by site programs described in Sections 8.3.1.2 through 8.3.1.17.

8.2.1.2 Other issues

The wording of the OGR issues (DOE, 1986d) differs slightly from the wording of issues in the DOE Mission Plan (DOE, 1985b). A correlation matrix provided in Figure 8.2-5 shows that all issues in the DOE Mission Plan are addressed by one or more of the OGR issues.

Although this site characterization plan has been developed and is organized on the basis of the OGR issues, specific technical concerns related to site suitability for repository development and repository performance that have been raised by the public and the NRC have been addressed. The matrices in Tables 8.2-3 and 8.2-4 provide a correlation to the appropriate section in this document where specific technical concerns are addressed.

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OGR ISSUES \ MISSION PLAN ISSUES	1.1 GEOHYDROLOGY	1.2 GEOCHEMISTRY	1.3 ROCK CHARACTERISTICS	1.4 EROSION	1.5 CLIMATE	1.6 DISSOLUTION	1.7 TECTONICS	1.8 HUMAN ACTIVITIES	1.9 WASTE PACKAGE & ENGINEERED BARRIER SYSTEM	2.1 RADIOLOGICAL SAFETY PUBLIC	2.2 METEOROLOGY	2.3 OFFSITE ACTIVITIES	2.4 WORKER RADIOLOGICAL SAFETY	4.1 WASTE PACKAGE COST EFFECTIVENESS	4.2 SURFACE CHARACTERISTICS	4.3 ROCK THERMAL & MECHANICAL CHARACTERISTICS	4.4 PRECLOSURE HYDROLOGY	4.5 PRECLOSURE TECTONICS	4.6 OVERALL REPOSITORY COST EFFECTIVENESS	4.7 COST EFFECTIVE CLOSURE
1.1 RELEASES TO ACCESSIBLE ENVIRONMENT	●	●			●		●	●	●											
1.2 INDIVIDUAL PROTECTION	●																			
1.3 GROUND-WATER PROTECTION	●																			
1.4 WASTE PACKAGE CONTAINMENT									●											
1.5 RELEASE RATE		●							●											
1.6 GROUND-WATER TRAVEL TIME	●																			
1.7 PERFORMANCE CONFIRMATION									●							●				
1.8 NRC SITING CRITERIA	●	●	●	●	●	●	●	●												
1.9 DOE GUIDELINE FINDINGS - POSTCLOSURE	●	●	●	●	●	●	●	●	●											
1.10 WASTE PACKAGE		●					●		●							●				
1.11 REPOSITORY	●		●				●									●				
1.12 SEALS	●																●			
2.1 PUBLIC SAFETY NORMAL OPERATION										●	●	●								
2.2 WORKER SAFETY											●	●	●							
2.3 PUBLIC SAFETY DURING ACCIDENTS										●	●	●	●							
2.4 RETRIEVABILITY			●										●			●				
2.5 DOE GUIDELINE FINDINGS - RADIOLOGICAL SAFETY										●	●	●	●							
2.6 WASTE PACKAGE DESIGN		●												●						
2.7 REPOSITORY DESIGN										●	●	●	●		●	●	●	●		
4.1 DOE GUIDELINE FINDINGS - AVAILABLE TECHNOLOGY														●	●	●	●	●	●	●
4.2 NONRADIOLOGICAL WORKER SAFETY															●	●	●	●		
4.3 WASTE PACKAGE PRODUCTION									●					●						
4.4 ADEQUACY OF TECHNOLOGY											●			●	●	●	●	●	●	●
4.5 COSTS														●	●	●	●	●	●	●

Figure 8.2-5. Correlation of the Department of Energy Mission Plan issues and Office of Geologic Repositories (OGR) issues.

Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 1 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY		
EA CRD[a]	3.1.1.3	Hydraulic features	Impacts of hydraulic features on system performance	2.2.2 Mechanical properties of discontinuities in rocks	Covers fractures, joints, and effects of water
				8.3.1.4.2 Spatial distribution of thermal and mechanical properties	References thermal and mechanical properties needed for other information needs
EA CRD	3.1.1.4	Intention of guidelines	Technical approach	8.3.5.6, 8.3.5.7, 8.3.5.18 Technical basis for DOE higher level findings issues 1.9, 2.5, 4.1	Technical basis addressed individually for issues throughout Chapter 8
EA CRD	5.3	Matrix and fracture flow	Proportion of fractures vs matrix flow unknown	3.9.2.2.2 Transmissivity and hydraulic conductivity	Contains existing material on fracture vs matrix flow

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 2 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
EA CRD (continued)				8.3.1.2.1.3 Characterization of regional ground-water flow system	Activities including fracture vs matrix flow
EA CRD	5.4	Basin boundary	Effects of climatic on hydrologic conditions due to boundary conditions of basins	1.1 Geomorphology	Discusses Great Basin geology
ISTP(1)[b]	1.5	Effects on ground water	Natural changes affecting ground-water flow	8.3.1.5.2.2 Climatic effects on hydrology	Studies on the effects of climate on hydrologic characteristics
EA CRD	3.1.3.2	Unsaturated zone hydrology	Unsaturated zone data base is inadequate	3.9 Site hydrogeologic system	Includes unsaturated zone monitoring and characteristics
EA CRD	4.1.2.2	Ground-water travel time (GWTT)	Tritium analyses	8.3.1.2.2.1 Characterization of unsaturated zone infiltration	Studies include hydrologic characteristics and future infiltration

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 3 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
EA CRD (continued)			Determine flux value	3.9.4 GWTT in the unsaturated zone	Contains preliminary unsaturated zone travel-time calculation and basis for flux estimate
EA CRD	8.3	Perched water	Improve data base on perched water	8.3.1.2.2.3, 8.3.1.2.2.4 Characterization of percolation in the unsaturated zone	Activities include drilling (locating perched water zones) and testing any perched water encountered
NRC comment Final EA[c]	7	Uniform infiltration	Uniform infiltration does not allow for preferential paths	8.3.1.2 Geohydrology	Contains summary of current hypotheses, uncertainties, and alternative hypotheses
NRC comment Final EA	7	Flux values	Adequate evaluation of flux values	3.9.4 GWTT in the unsaturated zone	Contains preliminary unsaturated-zone travel-time calculation and basis for flux estimate

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 4 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
NRC comment draft EA[d]	3	Ground-water travel time	Uncertainties, alternative models	8.3.1.2 Geohydrology	Contains summary of current hypotheses, uncertainties, and alternative hypotheses
EA CRD	5.1	Saturated and unsaturated zone hydrology	Further characterization of the saturated and unsaturated zone hydrology	3.6 to 3.8 Hydrology	Includes existing information on regional ground water of the site
EA CRD	5.1	Ghost Dance fault	Potential for Ghost Dance fault as a fluid conduit	8.3.1.2 Geohydrology (postclosure)	Contains studies of the regional, unsaturated, and saturated zones of the site
EA CRD	5.1	Water table	Water table profile	8.3.1.2.1.3.2, 8.3.1.2.3.1.2 Regional and site potentiometric-level studies	Activities include monitoring and assessment of potentiometric level

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 5 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
EA CRD	7.2	Ground-water basins	Further characterization of Devils Hole basin	8.3.1.16.2.1 Location of adequate water supply	Activities include evaluation of potential effects of ground-water withdrawals on the flow system
PHPR[a]	1.02.02	Hydrologic system	Identify ground-water flow paths, rates, and fluxes	3.9 Site hydrogeologic system	Covers material on flow paths, rates, and fluxes
ISTP(1)	1.1	Hydrology	Nature of present hydrology	Chapter 3 Hydrology	Current information on hydrology
NRC comment Final EA	4	Hydrothermal activity	Hydrothermal activity affecting flow paths	1.5.2.1 Effects of faulting	Potential effects of faulting
PHPR	1.02.03	Hydrologic system	Effects of fractures and structural features on flow paths	3.7.2 Principal ground-water flow paths	Covers existing material on ground-water flow paths
				8.3.1.8.3 Studies of changes in hydrology due to tectonic processes	Activities include evaluation of effects of igneous and tectonic processes on hydrology

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 6 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
PHPR (continued)				8.3.1.3.2 Mineralogy, petrology, and rock chemistry	Activities include analyses of fracture mineralogy
EA CRD	4.1.2.2	Aquifers	Flow between aquifers	3.6 Regional hydrology	Includes existing information on hydrogeologic units and their interrelationships
NRC comment Final EA	7(4)	Hydrogeologic properties	Interrelationships of hydrogeologic properties	3.6 Regional hydrology	Includes existing information on hydrogeologic units and their interrelationships
PHPR	1.02.04	Aquifer flow	Flow between aquifers	8.3.1.2.1 Regional hydrology	Includes studies for hydraulic head and gradient
PHPR	1.02.05	Discharge and recharge	Location of natural discharge and recharge areas	3.7.1 Identification of discharge and recharge areas	Contains current information on recharge and discharge areas

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 7 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
PHPR	1.02.09	Amargosa Valley	Hydrologic relationship with the Amargosa Valley River system	8.3.1.2 Studies of of the hydrologic system	Includes studies of discharge and recharge areas
PHPR	1.02.06	Flow paths and rates	Identify the flow paths and rates to the accessible environment	3.9 Site hydrogeologic system	Covers material on flow paths, rates, and fluxes
PHPR	1.02.11	Hydrology transport model	Information necessary for the hydrologic transport model	8.3.1.2, 8.3.1.3 Geohydrology, geochemistry	Includes studies to provide information on hydrology, geochemistry, and transport characteristics
PHPR	1.02.29	Tectonic alteration	Potential for tectonic alteration of ground-water flow path	8.3.1.8.3 Studies of changes in hydrology due to tectonic processes	Activities include evaluation of effects of igneous and tectonic processes on hydrology

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 8 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
PHPR	1.02.07	Seismic effects on ground-water travel time	Effects of seismicity on ground-water travel time	1.5.2.1 Effects of faulting	Discusses the potential effects of faulting
				8.3.5.12 Assessment of ground-water travel time	Activities include calculation of ground-water travel time
PHPR	1.02.08	Effects of exploration	Effects of exploratory drilling on ground-water travel time	3.7 Regional ground-water flow system	Describes flow system
				8.3.1.9.3 Human intrusion	Studies exploration effects on hydrology
PHPR	1.02.18	Human intrusion	Potential of mining intrusion of repository	8.3.1.9.3 Human intrusion	Studies exploration effects on hydrology
ISTP(1)	1.6	Human intrusion	Effects of human intrusion on hydrology	8.3.1.9.3 Human intrusion	Studies exploration effects on hydrology

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 9 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
PHPR	1.02.10	Radionuclide transport	Potential for radionuclide transport through the flow system	8.3.5.13 Radionuclide releases	Assesses radiological releases to accessible environment
PHPR	1.09.11	Site characterization information	Benefit of site characterization information to surrounding area	Chapters 1 to 5	Contains existing site information
PHPR	1.11.04	Site characterization activities	Detailed descriptions of site characterization activities	8.3.1 Site program	Contains site information needed
PHPR	1.12.01	Detailed information	Development of detailed site information	8.3.1 Site program	Contains site information needed
PHPR	1.12.03	Issue resolution	Description of issues to be resolved during site characterization	8.3.5 Performance assessment	Contains strategies for issues resolution

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 10 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			HYDROLOGY (continued)		
PHPR	1.02.01	Site-qualifying hydrologic issues	Identify site-qualifying hydrologic issues examined during site characterization	Chapter 3 Hydrology	Current information on hydrology
				8.3.5.18 Higher-level findings	Findings required for technical guidelines
PHPR	1.02.17	Pluvial conditions	Effects of pluvial climate on unsaturated zone	5.2.2 Future climate variation	Includes climate prediction and model validation
ISTP(1)	1.3	Natural changes	Natural (climatic) changes altering ground-water flow	8.3.1.5 Climatic change	Includes effects of climate on site elements
PHPR	1.02.27	Ground-water migration	Ground-water migration in the Great Basin	1.1 Geomorphology	Discusses Great Basin geology
				8.3.1.2.1.3 Regional ground-water flow system	Includes recharge and potentiometric level studies

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 11 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: MECHANICS		
PHPR	1.02.28	Radionuclide migration	Characterization of radionuclide migration in the unsaturated zone	8.3.5.13.5 Probabilistic radiological releases to the accessible environment	Radiological releases from anticipated and unanticipated scenarios
EA CRD	3.4.1.4	Porosity	Large-scale porosity tests	2.4.2.4 Porosity and density	Provides existing information on porosity and density
				8.3.1.15.1.1 Density and porosity characterization	Includes studies characterizing rock density and porosity
EA CRD	3.4.1.4	Fracturing	Thermally induced fracturing	2.4 Thermal and thermomechanical properties--intact rock	Provides existing information on thermal properties of intact rock
				8.3.1.15.1.6 Thermal properties from in situ experiments	Thermal properties from in situ experiments

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 12 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: MECHANICS (continued)		
EA CRD	4.1.1	Regional stress regime	Lack of information on the regional stress regime	2.6 Existing stress regime	Regional and site stress regime
EA CRD	8.2	Rock properties	In situ rock properties and stress	8.3.1.15.2 Ambient stress	Studies cover in situ stress testing
EA CRD	5.3	Thermo-mechanical properties of rock	Limitations of models	2.4 to 2.5 Thermal and thermomechanical properties of rock	Includes existing material on thermo-mechanical properties of rock
			Effects of percentages of lithophysae on thermomechanical properties of the in situ rock	8.3.1.15.1 Thermal and mechanical properties of rock	Studies to determine the thermal and mechanical properties of the in situ rock
EA CRD	8.2	Rock properties	Topopah Spring vs Grouse Canyon rock properties	1.8.2.1 Relation of geology to repository design	Includes repository operations
PHPR	1.01.08	Tuff properties	Integrity of tuff maintained during repository operations	Chapter 2 Geoengineering	Provides existing material on large scale rock properties

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 13 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: MECHANICS (continued)		
PHPR (continued)				8.3.1.15.1 Thermal and mechanical properties	Studies provide information on thermal and mechanical properties
PHPR	1.02.30	Characterization effects	Effects of characterization on the integrity host rock	8.3.3.2 Borehole seals	Designs for borehole seals
				8.3.5.12.3 Disturbed zone ground-water travel time	Ground-water travel time resulting from characterization
			GEOLOGY: SURFACE CONDITIONS		
EA CRD	4.1.1	Surface conditions	Soil conditions, wind and water erosion	1.1.3.2 Erosion rates	Provides information on average erosion rates at the site
				8.3.1.14.2 Soil and bedrock properties	Studies include physical properties of soil

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 14 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
GEOLOGY: SURFACE CONDITIONS (continued)					
EA CRD (continued)				8.3.1.6.2.1 Future climatic conditions on the nature and rate of erosion	Studies include wind and water erosion
				8.3.1.6 Erosion	States erosion will not affect the minimum burial depth
EA CRD	5.4	Erosion	Further data on erosion rates needed	1.1.3.2 Erosion rates	Existing material on erosion rates of site and area
EA CRD	4.1.2.1	Flooding	Maximum probable flood	3.2.1 Floods	Contains flood history and potential for future flooding
EA CRD	8.1	Flooding	Probable maximum flood	8.3.1.16.1 Flood recurrence levels and intervals	Includes studies for the characterization of flood potential

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 15 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: SURFACE CONDITIONS (continued)		
EA CRD	4.1.3.3	Precipitation and evapo-transpiration	Annual precipitation and evapotranspiration rates and variations	3.9.3.3 Recharge and discharge	Includes information on evapotranspiration and precipitation
				8.3.1.2.1 Regional hydrology	Contains studies for precipitation and evapotranspiration data
EA CRD	4.1.3.3	Climatic regime	Detail of the climatology and meteorology of the site	5.1 to 5.2 Recent and long-term climate and meteorology	Provides existing information on climatic regime
EA CRD	7.2	Climatic regime	Further study of the climatic regime	8.3.1.5.1 Future climatic conditions	Studies provide information required for prediction of future climatic conditions
				8.3.1.12.1 Meteorological conditions at the site	Studies provide data on regional meteorological conditions

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 16 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: SURFACE CONDITIONS (continued)		
EA CRD	6.3	Meteorology	Data on extreme weather conditions	5.1 to 5.2 Recent and long-term meteorology and climate	Provides existing information on meteorological conditions
				8.3.1.12.1 Meteorological conditions at the site	Includes studies on extreme weather
				8.3.1.12.4 Recurrence intervals of extreme weather	Activities provide data on extreme weather and their recurrence intervals
EA CRD	4.1.3.7	Background radiation	Radiation levels in soil and water	4.1.2.6 Background radioactivity	Includes information on ground-water background radioactivity
EA CRD	6.5	Natural radiation	Natural radiation hazard	8.3.5.4.1 Natural radiation environment	References studies to determine the natural radiation environment

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 17 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: SURFACE CONDITIONS (continued)		
EA CRD	4.1.3.1	Land use	Detailed studies of land use	8.3.1.11.1.2 Land ownership and control	Includes interactions with the Department of Interior and Bureau of Land Management
EA CRD	5.8	Future communities	Development of future communities	8.3.1.10 Population patterns and forecasts	Includes studies on population pattern development
PHPR	1.02.25	Drainage patterns	Effects of alteration of drainage pattern	8.3.1.2.1 Descriptions of surface hydrology	Includes recharge and discharge flooding
ISTP(1)	1.2	Surface water	Nature of present surface water system	3.1 Surface hydrology	Current information on surface hydrology
			GEOLOGY: TECTONICS AND MINERALOGY		
EA CRD	5.7	Seismic patterns	Increase seismic pattern data base	1.4 Seismology of the site	Provides existing material on seismic patterns of the area

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 18 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: TECTONICS AND MINERALOGY (continued)		
EA CRD (continued)				8.3.1.17.4.1 Seismology	Contains seismologic data compilation
EA CRD	5.6	Secondary volcanism	Significance of secondary volcanic processes	1.3.2.1 Volcanic history	Includes the volcanic history and petrology of the site
				8.3.1.8.1 Studies on releases resulting from volcanic activity	Studies to provide information on releases resulting from volcanic activity
EA CRD	5.2	Lateral and vertical extent	Inadequate information on the usability of areas outside the primary area	1.2 Stratigraphy and lithology	Provides existing material on stratigraphy and lithology
				8.3.1.4.2 Stratigraphy and structure	Contains activities on the extent of lithologic units
EA CRD	5.2	Fracture mineralogy	Lack of information on fracture mineralogy	4.1.1.3.1.2 Mineralogy of fractures	Contains existing information on fracture mineralogy

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 19 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (continued)		
EA CRD	3.1.3.2	Postclosure tectonics	Tilting and warping rates and directions	1.1.3 Geomorphic processes	Covers significant late Quaternary geomorphic processes
NRC comment Final EA	1	Fault activity	Movement of north trending faults within the last 1,000 yr	1.3.2.2.2. Structure of Yucca Mountain	Current information on structural history of Yucca Mountain
NRC comment Final EA	2	Northeast trending faults	Relationship of northeast trending faults to younger basaltic activity	8.3.1.17.4.5 Detachment faults	Activities to provide data on detachment faults
NRC comment Draft EA	1	Northeast trending and fault activity	Northeast trending faults and fault activity	8.3.1.17.4.7 Geometry of faults	Activities to provide data on subsurface geometry and concealed extensions of faults
				8.3.1.8.1.2 Effects of eruptions	Activities provide analyses of effects of volcanic eruptions

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 20 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (continued)		
EA CRD	3.4.1.8	Seismic hazards	Site-specific estimates of seismic hazards	1.4.1.5 Seismic hazards at the candidate site	Provides existing information on seismic hazards
PHPR	1.01.03	Seismic activity	Potential for and associated uncertainties of seismic activity	8.3.1.17 Tectonic and igneous events	Studies include estimates of the probability of future earthquakes and faulting
PHPR	1.01.04	Seismic disruption	Estimated potential for seismic disruption of the repository	8.3.1.17.3 Ground motion	Studies to provide information on the effects of vibration ground motion on the repository
PHPR	1.01.05	Distance to fault	Determine a safe distance to a fault	8.3.1.8.2 Tectonic processes	Studies include probilities of rupture
				8.3.1.17.2 Potential fault movement	Studies include assessment of faulting potential
NRC comment Draft EA	2	Volcanism and hydrothermal activity	Origin of calcite-silicate vein deposits	8.3.1.3.2.1 Fracture mineralogy	Contains activity on determining fracture mineralogy

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 21 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (continued)		
NRC Comment Draft EA (continued)				8.3.1.5.2 Future climate	Contains studies on calcite and silicates
				1.3.2.2.2 Structure of Yucca Mountain	Contains information on the structural history of Yucca Mountain
EA CRD	5.3	Fault density	Actual fault density	1.5.2.1 to 1.5.2.3 Faulting effects, likelihood, and relation to weapons tests	Contains information on fault types, locations, and effects
NRC comment Final EA	3	Detachment faulting	Potential for the presence of detachment faults and other fault movement	8.3.1.17 Tectonic and igneous events	Includes studies on detachment faults and potential fault movement
		Faulting styles	Fault movement styles of Yucca Mountain	8.3.1.17.4 Tectonics data collection	Studies to provide data on past and present faulting and seismicity

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 22 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: TECTONICS AND MINERALOGY (continued)		
NRC comment Draft EA	1	Detachment faulting	Studies addressing detachment faulting	8.3.17.4.5 Detachment faults	Activities to provide data on detachment faults
PHPR	1.01.06	Fault source	Faulting resulting from weapons tests	8.3.1.13.2 Impact of nearby installations and operations	Includes effects of weapons testing
PHPR	1.07.03	Dust generated	Potential for hazardous fibers within dust	4.1 Geochemistry of the host rock	Discusses mineralogy of host rock
				8.3.1.3.2 Mineralogy petrology, chemistry of the host rock	Determines material constituency of host rock
EA CRD	5.8	Mineral resource	Further mineral resource evaluations	1.7 Mineral and hydrocarbon resources	Provides existing information on mineral resources
		Geothermal	Potential for extraction of geothermal resources	8.3.1.9.2 Value of resources	Includes studies on resource value

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 23 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (continued)		
NRC Comment Final EA	5	Economic deposits	Potential for economic deposits associated with calderas	8.3.1.9.3 Effects of exploiting natural resources	Studies to provide information on the potential effects of exploiting natural resources
		Breccia deposits	Potential for economic deposits associated with breccias	8.3.1.9.2.1 Present and future value of natural resources	Includes activities to assess natural resources
NRC comment Draft EA	2	Natural resources	Potential for undiscovered mineral resources	8.3.1.5.2 Future climate	Contains studies on calcite and silicate deposits
PHPR	1.01.07	Mineral resources	Presence of mineral resources	8.3.1.16.2 Identification of water supplies	Includes identification, assessment, and effects of water supply exploitation
ISTP(1)	1.4	Ground-water withdrawal	Water resource development	8.3.1.16.2 Identification of water supplies	Includes identification, assessment, and effects of water supply exploitation

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 24 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (continued)		
PHPR	1.01.01	Geologic system	Present nature of geologic system	Chapter 1 Geology	Chapter 1 contains current geology material
ISTP(5)[f]	5.1	Site-qualifying geology issues	Determine site-qualifying issues examined during site characterization	8.3.5.18 Higher level findings	Issue resolution strategy for higher-level findings on qualifying and disqualifying conditions
	5.2	Future geology	Future changes altering geology	8.3.5.18 Higher-level findings	Issue resolution strategy for higher-level findings on qualifying and disqualifying conditions
	5.3	Geologic system	Human-induced changes altering geology	8.3.5.18 Higher-level findings	Issue resolution strategy for higher-level findings on qualifying and disqualifying conditions

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 25 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
			GEOLOGY: TECTONICS AND MINERALOGY (continued)		
ISTP(5)[f] (continued)	5.4	Geologic system	Repository-induced geologic alterations	8.3.5.18 Higher-level findings	Issue resolution strategy for higher-level findings on qualifying and disqualifying conditions
	5.5	Future geology	Natural changes affecting future geology	8.3.5.18 Higher-level findings	Issue resolution strategy for higher-level findings on qualifying and disqualifying conditions
	5.6	Future geology	Future human-induced changes altering geology	8.3.5.18 Higher-level findings	Issue resolution strategy for higher-level findings on qualifying and disqualifying conditions
	5.7	Future geology	Future repository-induced alterations to geology	8.3.5.18 Higher-level findings	Issue resolution strategy for higher-level findings on qualifying and disqualifying conditions

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns a addressed (page 26 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (continued)		
PHPR	1.01.09	Physical processes	Physical processes in the unsaturated zone affecting repository behavior	1.8.2.1 Relation of geology to repository design	Contains information on the relation of geology to repository design
PHPR				8.3.1.2 Geohydrology	Includes processes occurring in the unsaturated zone
EA CRD	5.1	Ground-water chemistry	Unsaturated vs saturated zone chemistry	3.7.3, 3.9.1.3, 4.1.2 Ground-water geochemistry	Contains existing information on ground-water geochemistry
				8.3.1.3.1 Water chemistry	Development includes model of unsaturated and saturated zone water composition
EA CRD	4.2.2	Vadose water	Analysis of vadose water	8.3.1.2.2 Description of the unsaturated zone	Includes studies on hydrochemical characterization of the unsaturated zone

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 27 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (continued)		
EA CRD	5.6	Dissolution	Equilibrium of mineralogy and aqueous chemistry	8.3.1.7 Dissolution	Studies to provide rates of rock dissolution
		Topopah Spring Member	Dissolution potential of Topopah Spring Member	4.1.2 Ground-water geochemistry	Provides existing material on ground-water chemistry
				8.3.1.7.1 Dissolution rates	Studies to provide rates of rock dissolution
EA CRD	5.1	Sorption	Sorption and varying water compositions	4.1.3.3. Sorption	Provides current information on sorption
				8.3.1.3.4.1 Geochemistry sorption	Includes studies of sorption as a function of ground-water composition
EA CRD	5.1	Particulates, colloids, complexes	Formation and transport of particulates, colloids, and complexes	4.1.2.7 Particulates and colloids	Provides existing information on particulates and colloids

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 28 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY: TECTONICS AND MINERALOGY (continued)			
EA CRD (continued)				4.1.3.5 to 4.1.3.6 Diffusion and radionuclide transport	Provides existing information on diffusion and transport
				8.3.1.3.4.1.4 Sorption on particulates and colloids	Activity to provide data on sorption on particulates and colloids
				8.3.1.3.5.2 Colloid behavior	Activity to provide data on colloid behavior
				8.3.1.3.6.1.5 Filtration	Activity to provide data on filtration
EA CRD	5.2	Actinide complexes	Effects of carbon-rich waters on actinide complexing	4.1 Geochemistry	Contains geochemistry background information
				8.3.1.3.5 Studies for radionuclide retardation	Contains studies and activities on carbonate waters and actinide speciation

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 29 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (continued)		
EA CRD	4.1.1	Gaseous radionuclide	Gaseous transport of radionuclide	4.1.3 ·, Radionuclide transport	Includes radionuclide transport by gas
				8.3.1.3.8.1 Retardation of gaseous radionuclides	Study to provide data on retardation of gaseous radionuclides
EA CRD	3.4.1.3	Geochemistry data base	Insufficient geochemistry data base	4.1 Geochemistry of the host rock and surrounding units	Provides background on site geochemistry
				8.3.1.3 Geochemistry	Includes studies to provide data on present and expected geochemical conditions
EA CRD	7.1.1	Geochemistry	Composition of percolating waters	8.3.1.2.2.8 Hydrochemistry of the unsaturated zone	Study to provide data on the composition of water in the unsaturated zone

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 30 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (CONTINUED)		
NRC comment Draft EA	3	Geochemical environment	Oxidation-reduction conditions	8.3.1.3 Geochemistry	Includes studies to provide data on present and expected geo-chemical conditions
ISTP(3)[9]	3.1	Geochemistry	Present geochemistry	Chapter 4 Geochem-istry	Current information on geochemistry
NRC comment Draft EA	8	Radionuclide transport	Radionuclide trans-port increases due to geohydrologic changes resulting from climatic alterations	3.7 Regional ground-water flow system	Provides existing information on recharge systems
				8.3.1.5.2 Climatic effects on hydro-logic character-istics	Studies to provide information on the effects of future climatic conditions on hydrology
				8.3.1.3.7.1 Retarda-tion sensitivity analysis	Activities providing information on radionuclide transport

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 31 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (CONTINUED)		
NRC comment Final EA	6	Matrix retardation	Can matrix retardation overcome increases in groundwater flow due to climate change?	4.1.3.5 Matrix diffusion	Current information on matrix diffusion
				8.3.1.3.7.1 Retardation sensitivity analysis	Activities providing information on radionuclide transport
NRC comment Draft EA	6	Retardation	Retardation of radionuclides	8.3.1.3.6.1 Dynamic transport column experiments	Activities to provide data on retardation of radionuclides
NRC Comment Final EA	8	Retardation	Value of matrix diffusion and colloid sorption on the retardation of radionuclides	8.3.1.3.6.2 Diffusion	Activities to provide data on diffusion
				8.3.1.3.4.1.4 Sorption on particulates and colloids	Activity to provide sorption data on particulates and colloids
ISTP(3)	3.3	Retardation	Future geochemistry affecting retardation	8.3.1.3 Geochemistry	Includes studies to provide data on expected geochemical conditions

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Table 8.2-3. Correlation of site-related technical concerns and site characterization plan (SCP) sections where concerns are addressed (page 32 of 32)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
		GEOLOGY:	TECTONICS AND MINERALOGY (CONTINUED)		
PHPR	1.05.02	Water courses	Chemical composition of water courses	4.1 Geochemistry of the host rock	Discusses mineralogy and retardation
				8.3.1.3.2 Mineralogy, petrology, chemistry of the host rock	Includes material along water courses
				8.3.1.3.4-8 Radionuclide retardation	Studies the chemical composition along flow paths

[a]EA CRD = Site specific comment response document for the environmental assessment for the Yucca Mountain site (DOE, 1986b).

[b]ISTP(1) = Draft Issue-Oriented State Technical Position (ISTP) for Nevada Nuclear Waste Storage Investigations (NNWSI) Project--Hydrology (NRC,1984).

[c]NRC comment = NRC Comments on the final environment assessment, Yucca Mountain site (Kale, 1986).

[d]NRC comment = NRC comments on the draft environmental assessment for the Yucca Mountain site (NRC, 1987).

[e]PHPR = These comments are taken from the Public Hearings Panel Report, NVO 263, dated November 1983 (DOE/NVO, 1983).

[f]ISTP(5) = Draft ISTP for NNWSI Project--Geology/Geophysics, (NRC, 1984).

[g]ISTP(3) = Draft ISTP for NNWSI Project--Geochemistry, (NRC, 1984).

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (1 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
EA CRD[a]	4.1.1	Seismic effects	Potential effects of seismic activity on repository operation and performance	8.3.2.1.4 Repository modeling	Includes design considerations for seismic activity
EA CRD	5.4	Sealing program	Detailed description of sealing program	6.2.8 Shaft and borehole seals	Contains existing material on shaft and borehole seals
ISTP (4)[b]	4.6	Seal design	Will seal design meet 10 CFR 60.112	8.3.2.5.10 Construction of seals	States the results from other seals development tests
				8.3.3.1. Seal system	Contains planned seals design and modeling
EA CRD	5.11	Radionuclide releases to ground water	Predicted radionuclide releases to accessible environment at 100,000 yr	6.4. Design issues	Covers preliminary analysis of repository performance
				8.3.5.13.2 Postclosure system performance	Includes design concepts and calculational models for releases

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (2 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
EA CRD	5.11	Waste package corrosion	Corrosion testing	7.4 Waste package design and geochemical interactions	Provides existing material on waste package design
PHPR[c]	1.02.12	Water chemistry	Water chemistry and effect on corrosion	8.3.4.2, 8.3.4.3 Waste package characterisitics	Includes activities to provide information on waste package and interactions with the environment
PHPR	1.02.14	Ground-water effects	Effects of ground water on repository components	8.3.4.2, 8.3.4.3 Waste package characteristics	Includes activities to provide information on waste package and interactions with the environment
				8.3.5.9-10 Assessment of containment within waste package	Contains waste package design information and containment assessment
NRC Comment Draft EA[d]	10	Waste package	Detailed materials plan	7.2-7.3 Waste package design basis, reference designs, and alternative designs	Contains information on waste package design and design basis

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (3 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
ISTP(2)*	2.5	Waste package	Waste package releases within 10 CFR 20	8.3.4.3 Waste package	Issue resolution strategy for design of the waste package
ISTP(2)	2.6	Waste package	Waste package retrievability design	8.3.5.2 Waste retrievability	Contains design information and assessments relevant to retrievability
ISTP(2)	2.7	Waste package	Waste package design	8.3.5.9 Assessment of containment within waste package	Contains waste package design information and containment assessment
ISTP(2)	2.9	Waste package	Waste package monitoring	8.3.5.9 Assessment of containment within waste package	Contains waste package design information and containment assessment
PHPR	1.01.13	Resulting radiation doses	Potential for radiation releases to jeopardize individuals	8.3.5.13.5 Probabilistic radiation releases	Radionuclide releases from anticipated and unanticipated scenarios

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (4 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
ISTP(4)	4.1	10 CFR 60.111	Repository design to maintain 10 CFR 60.111	8.3.5.14 Doses to individuals	Describes allowable doses
PHPR	1.03.13	Weapons testing	Safety factors provided against weapons testing or impact	6.1.2 Reference repository design	Contains current information on repository design
				8.3.1.13.2 Offsite installations	Provides offsite impact data to repository data base
PHPR	1.08.03	Weapons testing	Compatibility of weapons testing and waste disposal	8.3.1.13.2 Offsite installations	Provides offsite impact data to repository data base
PHPR	1.02.20	Flood protection	Identify flood protection measures for repository (surface)	8.3.2.5.8 Technology of surface facility construction	Design parameters include climate and flooding
PHPR	1.03.14	Nuclear criticality	Potential for waste to go critical	7.2.2 Waste forms 8.3.4.3.2 Waste form criteria	Describes considerations of waste form

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (5 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	1.03.19	Integrity of openings	Engineering methods used to maintain openings	6.1.1 Repository design requirements	Includes operation and decommissioning as design requirements
				8.3.2.5.9 Techniques for underground construction	Includes construction of safe openings
PHPR	1.03.20	Mining effects	Potential for continual mining affecting emplaced waste	6.4.10.2.2 Repository operations	Discusses expected repository operations
PHPR	1.03.23	Repository stability	Stability of repository maintained during coupled effects of excavation and thermal stress from emplaced waste	8.3.2.5.3 Repository operations plan	Includes considerations for operation during construction
ISTP(2)	2.8	Stability	Vicinity conditions affecting waste criticality	7.2.2 Waste forms	Describes considerations of waste forms

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (6 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
ISTP(2) (continued)				8.3.4.3.2 Waste form criteria	Includes design information needed to comply with preclosure criteria for waste forms
PHPR	1.03.21	Weapons testing	Effects of weapons-induced seismicity on the repository	6.1.2 Reference repository design basis	Contains current information on repository design
				8.3.2.5.4 Repository design requirements	Includes requirements from 10 CFR 60 and 10 CFR 960
PHPR	1.03.25	Interaction effects	Results of long-term interaction between the barrier and host rock	8.3.5.13 Assessment of postclosure system performance	Includes models and scenarios of postclosure performance
PHPR	1.03.26	Waste package degradation	Degradation of waste package adversely altering the waste package environment	7.4.1 Waste package environment modification	Discusses interaction of waste package with emplacement environment

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (7 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
ISTP (2)	2.2	Waste package	Ground-water penetration of waste package	8.3.4.2.4 Postemplacement near field	Studies the changes in the near field
ISTP (3)[f]	3.2	Waste package environment	Changes in geochemistry due to waste package	8.3.2.1.2 Coupled-interaction tests	Studies include interactions between waste package and environment
PHPR	1.03.27	Backfilling	Complications due to backfilling	6.2.7 Backfilling	Discusses backfilling and techniques
ISTP (2)	2.1	Backfill	Ground-water penetration of backfill	8.3.2.2.7 Postclosure repository design	Studies to provide information necessary to develop the postclosure repository design
ISTP (4)	4.3	Backfill	Retardation ability of backfill	8.3.2.2.7 Postclosure repository design	Studies to provide information necessary to develop the postclosure repository design
ISTP (4)	4.4	Backfill	Does backfill compromise waste package?	8.3.2.2.7 Postclosure repository design	Studies to provide information necessary to develop the postclosure repository design

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (8 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
ISTP(4)	4.5	Backfill	Does backfill control radiological releases?	8.3.2.2.7 Postclosure repository design	Studies to provide information necessary to develop the postclosure repository design
PHPR	2.04.02	Suitability	Suitability of Yucca Mountain resulting from factual evidence	8.3.5.18 Assessment of postclosure system and technical guidelines	Issue resolution strategy for higher-level findings on qualifying and disqualifying conditions
PHPR	3.01.03	Human engineering	Replacement of nonexistent favorable geologic conditions with engineered components	8.3.5.18 Assessment of postclosure system and technical guidelines	Issue resolution strategy for higher-level findings on qualifying and disqualifying conditions
PHPR	3.04.18	Existing technology	The use of existing international experience with waste disposal	Chapters 6,7 Conceptual design and waste package	Contain existing information and technology on repository and waste package design

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (9 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	3.04.18	Existing technology (continued)		8.3.2.1.3 Design optimization	Studies improving the design to better meet performance objectives
PHPR	3.03.03	Storage	Long-term storage experiments	8.3.4.1 Waste package program	Includes waste form testing
PHPR	1.03.17	Licensing requirements	Identify the licensing requirements for the repository and their limitations	8.1.1 to 8.1.2 Rationale for the site characterization program	Derivation of site characterization and issue resolution strategy
				8.2 Issues to be resolved through site characterization	Issues hierarchy
PHPR	1.01.10	Model uncertainties	Level of confidence of uncertainties in models	6.4.10.3 Future work	Planned work for model validation
				8.3.2.5 Adequate techniques	Assigns level of confidence

Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (10 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
PHPR	1.03.05	Waste package performance	Long-term performance characteristics of the waste package	7.4.2.3 Degradation modes of waste package materials	Provides information on corrosion and embrittlement phenomena
PHPR	1.03.06	Waste package performance	Waste package integrity under corrosive or thermal conditions	8.3.4.1.3 Waste package designs	Describes performance objectives of waste package
PHPR	1.03.22	Waste package design	Methods for waste stabilization	8.3.4.2.2 Reference waste package designs	Includes long-term corrosive and thermal properties
NRC comment Final EA[g]	9	Waste package performance	Uncertainties in performance models or parameters of waste package design	8.3.5.9 Waste package performance assessment	Includes discussion of uncertainty in waste package design and performance
ISTP(2)	2.3	Waste package releases	Radiological release rates from waste package	8.3.5.10 Assessment of waste package containment	Includes assessment of releases from waste package
ISTP(2)	2.4	Waste package releases	Radiological migration rates through failed waste package	8.3.5.10 Assessment of waste package containment	Includes assessment of releases from waste package

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Table 8.2-4. Correlation of engineered system related technical concerns and site characterization plan (SCP) sections where concerns are addressed (11 of 11)

Source	Comment ID number	Major concern	Specific concern	SCP cross-reference	Content
ISTP(4)	4.2	Retrieval	Will underground facility allow retrieval	8.3.5.2 Issue resolution strategy for Issue 2.4; retrievability	Includes assessment of retrievability

[a]EA CRD = Site specific comment response document for the environmental assessment for the Yucca Mountain site (DOE, 1986b).

[b]ISTP(4) = Draft ISTP for Nevada Nuclear Waste Storage Investigations (NNWSI) Project--Geologic Repository Operations Area Design/Rock Mechanics, (NRC, 1984).

[c]PHPR = These comments are taken from the Public Hearings Panel Report, NVO 263, dated November 1983 (DOE/NVO, 1983).

[d]NRC Comment = NRC comments on the draft environmental assessment for the Yucca Mountain site (NRC, 1985a).

[e]ISTP(2) = Draft ISTP for NNWSI Project--Waste Package, (NRC, 1984).

[f]ISTP(3) = Draft ISTP for NNWSI Project--Geochemistry, (NRC, 1984).

[g]NRC Comment = NRC comments on the Final Environmental Assessment, Yucca Mountain site (Kale, 1986).

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8.2.2 APPROACH TO ISSUE RESOLUTION

As explained in Sections 8.1.1 and 8.1.2, the performance and design issues were used as a convenient framework for structuring this document. Each of the sections in Sections 8.3.2 through 8.3.5 covering a performance or design issue contains an issue resolution strategy explaining the performance allocation developed for the issue and describing the site data needed to resolve the issue. The site data needs identified by the performance and design issues are also categorized into a series of specific site programs. Site characterization programs are presented in detail in Sections 8.3.1.2 through 8.3.1.17. Each program section is divided into a number of site investigations containing related studies and activities. Table 8.2-5 provides an overview of the arrangement of the performance and design issues and the site programs in Section 8.3. This table should allow a reader to more readily locate information of interest.

The overall approach the DOE has developed for issue resolution is described in Section 8.1.2. This approach leads to the identification of the information needed to resolve an issue, and to the development of plans for acquiring that information. The process of performance allocation was used to provide the rationale for conducting particular site characterization activities. The issue resolution process is intended to be iterative, in that information acquired during site characterization may cause revision to earlier plans and strategies. All changes to issue resolution strategies and site characterization plans will be reported in semiannual progress reports.

Throughout site characterization, a number of reports, currently called position papers, will be prepared, documenting the DOE's technical and regulatory positions. Position papers will be developed by assimilating data and information from published reports documenting the results of site program activities and analyses, performance assessment activities, and the design of the waste package and repository. The schedules presented in Sections 8.5.1 through 8.5.4, as well as the schedule sections of Section 8.3, include some reports that will serve as input to the position papers. Other documents, currently called issue resolution reports, will be prepared to document the implementation of the issue resolution strategies defined for performance and design issues in Sections 8.3.2 through 8.3.5. These reports may also be used to document positions on other technical issues of concern to the NRC, State, or public, such as an assessment of the seismic hazards at the Yucca Mountain site or the significance of calcite-silica deposits in faults near the site.

Throughout the issue resolution process, the DOE will be soliciting the views of and interacting with outside organizations, such as the NRC, on selected key topics. Additional information on issue resolution documentation can be found in Section 8.1.2.4. Potential topics to be covered in issue resolution reports are presented in Table 8.2-6.

The ultimate purpose of the issue resolution strategy is to provide the information necessary for issue closure. Issue closure will be possible when the level of confidence in the site processes and conditions, as well as in the engineered barriers relied upon to meet the regulatory requirements, has reached a level of reasonable assurance. After NRC staff and other technical

Table 8.2-5. Overview of contents of Section 8.3 showing order of presentation of site programs and performance and design issues within major programs

Section 8.3.1 Site Program	Section 8.3.2 Repository Program	Section 8.3.3 Seal Program	Section 8.3.4 Waste Package Program	Section 8.3.5 Performance Assessment Program
8.3.1.2 Geohydrology	8.3.2.2 Configuration of underground facilities (postclosure), Issue 1.11	8.3.3.2 Seal characteristics (postclosure), Issue 1.12	8.3.4.2 Waste package characteristics (postclosure) Issue 1.10	8.3.5.2 Waste retrievability, Issue 2.4
8.3.1.3 Geochemistry	8.3.2.3 Repository design criteria for radiological safety, Issue 2.7		8.3.4.3 Waste package characteristics (preclosure), Issue 2.6	8.3.5.3 Public radiological exposures--normal conditions, Issue 2.1
8.3.1.4 Rock characteristics	8.3.2.4 Nonradiological health and safety, Issue 4.2		8.3.4.4 Waste package production technologies, Issue 4.3	8.3.5.4 Worker radiological safety--normal conditions, Issue 2.2
8.3.1.5 Climate	8.3.2.5 Preclosure design and technical feasibility, Issue 4.4			8.3.5.5 Accidental Radiological releases, Issue 2.3
8.3.1.6 Erosion				8.3.5.6 Higher level findings--preclosure radiological safety, Issue 2.5
8.3.1.7 Rock dissolution				8.3.5.7 Higher level findings--preclosure system and technical guidelines, Issue 4.1
8.3.1.8 Postclosure tectonics				8.3.5.9 Waste package containment, Issue 1.4
8.3.1.9 Human interference				8.3.5.10 Engineered barrier system release rates, Issue 1.5
8.3.1.10 Population density				8.3.5.12 Ground-water travel time, Issue 1.6
8.3.1.11 Site ownership				8.3.5.13 Total system performance, Issue 1.1
8.3.1.12 Meteorology				8.3.5.14 Individual protection, Issue 1.2
8.3.1.13 Offsite installations				8.3.5.15 Ground-water protection, Issue 1.3
8.3.1.14 Surface characteristics				8.3.5.16 Performance confirmation, Issue 1.7
8.3.1.15 Thermal and mechanical rock properties				8.3.5.17 NRC Siting Criteria, Issue 1.8
8.3.1.16 Preclosure hydrology				8.3.5.18 Higher level findings--postclosure system and technical guidelines, Issue 1.9
8.3.1.17 Preclosure tectonics				

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Table 8.2-6. Potential topics for issue resolution reports

Topic for issue resolution	Corresponding issue (SCP section)	Regulation
Requirement for protection of special sources of ground water	1.3 (8.3.5.15)	40 CFR 191.16
Design criteria for the shaft and borehole seals	1.12 (8.3.3.2)	10 CFR 60.134
General design criteria for the geologic repository operations area	2.7 (8.3.2.3)	10 CFR 60.131
Additional design criteria for surface facilities in the geologic repository operations area	2.7 (8.3.2.3)	10 CFR 60.132
Additional design criteria for the underground facility (preclosure)	2.7 (8.3.2.3)	10 CFR 60.133
Nonradiological health and safety requirements for repository workers	4.2 (8.3.2.4)	10 CFR 60.131
Final production technologies for fabrication, closure, and inspection of the waste package	4.3 (8.3.4.4)	10 CFR 60.135
Reasonable availability of technologies for repository construction, operation, closure, and decommissioning	4.4 (8.3.4.4)	10 CFR 60.135
Radiation exposure, radiation levels, and releases of radioactive material to the repository workers and the public under accidental conditions	2.3 (8.3.5.5)	10 CFR 960.5-1 10 CFR 60.2 10 CFR 60.131-133 10 CFR 72.68 10 CFR 50, Appendix A
Design criteria for the waste package and its components	2.6 (8.3.4.3)	10 CFR 60.135
Additional design criteria for the underground facility (postclosure)	1.11 (8.3.2.2)	10 CFR 60.133

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Table 8.2-6. Potential topics for issue resolution reports (continued)

Topic for issue resolution	Corresponding issue (SCP section)	Regulation
Requirement for limiting individual doses in the accessible environment	1.2 (8.3.5.14)	40 CFR 191.15
The performance objective for protection against radiation exposures and releases of radioactive materials	2.1 (8.3.5.3) 2.2 (8.3.5.4) 2.3 (8.3.5.5) 2.7 (8.3.2.3)	10 CFR 60.111 10 CFR 60.131 10 CFR 60.132 10 CFR 60.133
Radiation exposures, radiation levels, and releases of radioactive material to the public under normal conditions	2.1 (8.3.5.3)	10 CFR 60.111 10 CFR Part 20 40 CFR 191, Subpart A
Radiation exposures, radiation levels, and releases of radioactive material to repository workers under normal conditions	2.2 (8.3.5.4)	10 CFR 960.5-1 10 CFR Part 20
The performance objective for preserving the option of waste retrievability	2.4 (8.3.5.2)	10 CFR 60.111(b)
Evaluation of the Yucca Mountain site against NRC Siting Criteria	1.8 (8.3.5.17)	10 CFR 60.122
The design criteria for the waste package considering its interactions with the emplacement environment	1.10 (8.3.4.2)	10 CFR 60.135
The performance objective for substantially complete containment by the waste package	1.4 (8.3.5.9)	10 CFR 60.113
The performance objective for controlled radionuclide release by the engineered barrier system	1.5 (8.3.5.10)	10 CFR 60.113
The performance objective for pre-waste-emplacement ground-water travel time	1.6 (8.3.5.12)	10 CFR 60.113

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Table 8.2-6. Potential topics for issue resolution reports (continued)

Topic for issue resolution	Corresponding issue (SCP section)	Regulation
The performance objective for overall system performance	1.1 (8.3.5.13)	10 CFR 60.112
The prediction of cumulative radionuclide releases over 100,000 years	1.9 (8.3.5.18)	10 CFR 960.3
The requirements for performance confirmation	1.7 (8.3.5.16)	10 CFR 60.137
Evaluation of potential hazards at the Yucca Mountain site resulting from underground nuclear explosions at the Nevada Test Site	NA[a]	NA[a]
Mode of origin of calcite-silica deposits and the potential effects on repository performance	NA	NA
Assessment of volcanic hazards at the site	NA	NA
Assessment of potential hazards at the site due to faulting and vibratory ground motion	NA	NA
Evaluation of potential impacts at the site due to natural resource extraction	NA	NA
Potential for coupling of tectonic and hydrologic processes and events	NA	NA

[a]NA = not applicable.

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reviews of the DOE's information supporting reasonable assurance, the DOE would then determine either that the level of uncertainty is too large, and propose to acquire additional information to reduce the uncertainty, or alternatively, the DOE may decide to move forward with the proposed position.

8.2.3 ISSUE TRACKING

As described in Section 8.2.1, the performance and design issues were derived from NRC and DOE requirements. The information needs that have been identified under each issue represent the site data and other technical information to be used to support the resolution of the issue. The site programs described Section 8.3.1 were structured to acquire the data on present and expected site characteristics, processes, and events needed to develop site descriptions and to support the resolution of the performance and design issues. The general plan for issue tracking and resolution is depicted schematically in Figure 8.2-6. Site information, obtained from tests in the exploratory shaft facility and from surface-based site studies, will be used as required to design a suitable waste package and the surface and underground repository facilities. On the basis of the engineered system designs and the site characteristics and conditions, performance assessment calculations will be made to predict preclosure performance for normal and accident conditions, and to predict postclosure performance under both nominal (undisturbed) and disturbed conditions. The DOE will use these predictions as a part of the basis for selecting a repository site according to the process described in 10 CFR Part 960. The repository designs and the performance assessment predictions will also serve as the basis for determinations of compliance with the NRC requirements for permanent disposal of high-level radioactive waste as specified in 10 CFR Part 60.

As shown in Figure 8.2-6, site investigation reports will document the completion of various site activities. These reports will continue to update and extend the data base available for use in repository design and performance assessment activities. When designs and calculations are sufficiently mature, a variety of topical reports, and finally, issue resolution reports will document the preliminary basis upon which the DOE will seek NRC's concurrence with various regulatory and technical requirements. Thus, by acquiring the site data and other information necessary to support resolution of the performance and design issues, the DOE will systematically establish the information necessary to support demonstrations of compliance with the major technical and regulatory requirements.

An integrated system for monitoring and tracking progress toward issue resolution is under development. The technical basis derived from Section 8.3 provides the list of site activities planned to develop the data base for use in repository and waste package design and performance assessment calculations. Study plans for the site activities will describe the tests and experiments in more detail. Descriptions of repository and waste package design activities that do not require site data will be provided in other documents. These activities will also be monitored through the issue resolution tracking system. As site information and results of design analyses and activities becomes available, the baseline information will be updated. This process will continue until final designs have been

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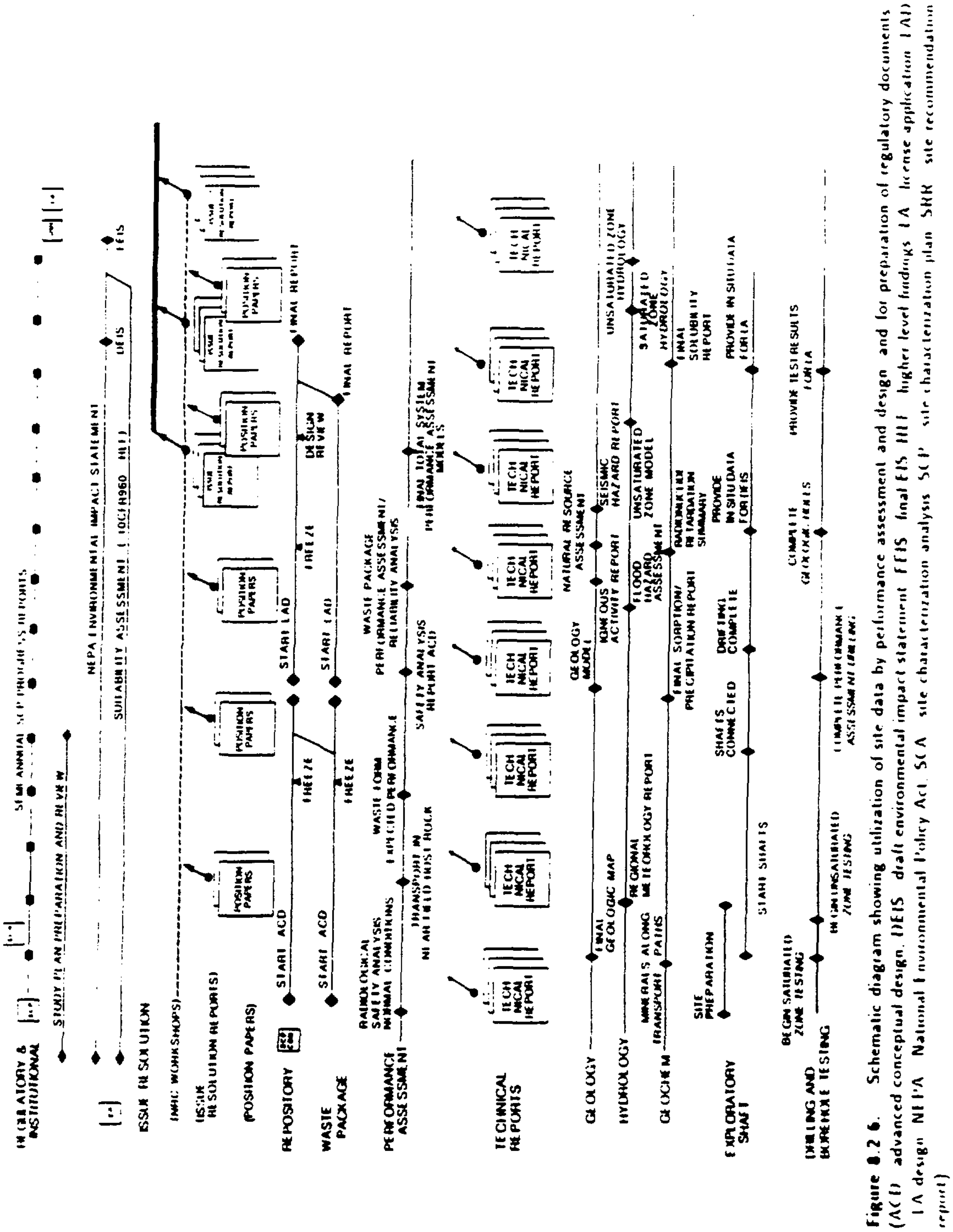
Figure 8.2-6. Schematic diagram showing utilization of site data by performance assessment and design, and for preparation of regulatory documents (ACD - advanced conceptual design; DEIS - draft environmental impact statement; FEIS - final environmental impact statement; HLF - higher level findings; LA - license application; LAD - LA design; NEPA - National Environmental Policy Act; SCA - site characterization analysis; SCP - site characterization plan; SRR - site recommendation report).



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developed and credible performance assessment predictions have been prepared on the basis of those designs. Resolution of those issues that address the DOE's siting guidelines (10 CFR Part 960) will occur when the DOE determines that the requirements of these guidelines have been met in support of the site-selection process. Resolution of those issues that address the NRC's requirements for repository performance and issuance of construction authorization cannot occur until the NRC determines that there is reasonable assurance, at that time, that all requirements are likely to be met.

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8.3 PLANNED TESTS, ANALYSES, AND STUDIES

This section describes the planned site characterization studies, and the design and performance assessment activities to be conducted during site characterization at the Yucca Mountain site. Additional details on the planned field tests and laboratory tests will be provided in study plans. The current list of study plans with estimated dates for completion is provided in Section 8.5.1.

For the repository, seal, and waste package programs, only those activities requiring site data are described in detail in this document. Additional detail will be provided in appropriate design-related documents. In the case of performance assessment activities, sufficient detail is provided to document the site-data requirements. As described in Sections 8.1 and 8.2, performance allocation was used to identify both design and performance assessment data needs.

Table 8.3-1 provides an overview of the structure of Section 8.3 showing the order of the specific site programs in Section 8.3.1, and the performance and design issues covered in Sections 8.3.2 through 8.3.5.

Table 8.3-1. Overview of contents of Section 8.3 showing order of presentation of site programs and performance and design issues within major programs

Section 8.3.1 Site Program	Section 8.3.2 Repository Program	Section 8.3.3 Seal Program	Section 8.3.4 Waste Package Program	Section 8.3.5 Performance Assessment Program
8.3.1.2 Geohydrology	8.3.2.2 Configuration of underground facilities (postclosure), Issue 1.11	8.3.3.2 Seal characteristics (postclosure), Issue 1.12	8.3.4.2 Waste package characteristics (postclosure) Issue 1.10	8.3.5.2 Waste retrievability, Issue 2.4
8.3.1.3 Geochemistry	8.3.2.3 Repository design criteria for radiological safety, Issue 2.7		8.3.4.3 Waste package characteristics (preclosure), Issue 2.6	8.3.5.3 Public radiological exposures--normal conditions, Issue 2.1
8.3.1.4 Rock characteristics	8.3.2.4 Nonradiological health and safety, Issue 4.2		8.3.4.4 Waste package production technologies, Issue 4.3	8.3.5.4 Worker radiological safety--normal conditions, Issue 2.2
8.3.1.5 Climate	8.3.2.5 Preclosure design and technical feasibility, Issue 4.4			8.3.5.5 Accidental Radiological releases, Issue 2.3
8.3.1.6 Erosion				8.3.5.6 Higher level findings--preclosure radiological safety, Issue 2.5
8.3.1.7 Rock dissolution				8.3.5.7 Higher level findings--preclosure system and technical guidelines, Issue 4.1
8.3.1.8 Postclosure tectonics				8.3.5.9 Waste package containment, Issue 1.4
8.3.1.9 Human interference				8.3.5.10 Engineered barrier system release rates, Issue 1.5
8.3.1.10 Population density				8.3.5.12 Ground-water travel time, Issue 1.6
8.3.1.11 Site ownership				8.3.5.13 Total system performance, Issue 1.1
8.3.1.12 Meteorology				8.3.5.14 Individual protection, Issue 1.2
8.3.1.13 Offsite installations				8.3.5.15 Ground-water protection, Issue 1.3
8.3.1.14 Surface characteristics				8.3.5.16 Performance confirmation, Issue 1.7
8.3.1.15 Thermal and mechanical rock properties				8.3.5.17 NRC Siting Criteria, Issue 1.8
8.3.1.16 Preclosure hydrology				8.3.5.18 Higher level findings--postclosure system and technical guidelines, Issue 1.9
8.3.1.17 Preclosure tectonics				

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8.3.1 SITE PROGRAM

This section describes the site characterization investigations currently thought to be necessary to adequately characterize the Yucca Mountain site. The investigations are subdivided into studies and activities. The studies will be described in further detail in study plans; a list of study plans is provided in Section 8.5.1. The site data base developed by the planned studies will be used to meet the requirements specified in the issue resolution strategies for the performance and design issues presented in Sections 8.3.2 through 8.3.5. The site information to be collected in this program will serve as a part of the basis for determining if the regulatory requirements for licensing a geologic repository can be met at the Yucca Mountain site.

The exact locations where the site investigations described in this section will be conducted are tentative. Specific boundaries for the Yucca Mountain site have not been determined and site boundaries shown on maps in this document should be considered preliminary and subject to change. Because Section 8.3.1 was completed before Section 8.4, some activity descriptions in Section 8.3.1 may not be totally consistent with the descriptions in Section 8.4. Some inconsistencies may not have been identified, such as drilling locations and the general approach to surface-based drilling. Changes to the affected activities will be described in the study plans and semiannual progress reports.

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8.3.1.1 Overview of the site program: Role of alternative conceptual models

The site program is designed to acquire the information about the site that is needed to resolve the design and performance issues in the issues hierarchy. (The issues hierarchy is described in Sections 8.1.1 and 8.2.1.) This objective will be met by the strategy that is illustrated in Figure 8.3.1.1-1. The site program is part of the overall issue resolution strategy that is described in Section 8.1.2.

As indicated in Figure 8.3.1.1-1, performance allocation is used to identify information needs and to develop the testing strategy of the site program. Performance allocation specifies the elements of the site that must be investigated to resolve the issues and indicates the relative degree of testing that must be done to reduce the uncertainties to levels consistent with resolution of the issues. For each issue, information needs are developed based on the current description of the physical characteristics of the site (the system description) and the associated uncertainties. The process of performance allocation is outlined later in this section and is described in detail in Section 8.1.2.2.

Investigations that address the information needs will be conducted and the results will be analyzed. The resulting information will be used in the resolution of issues as described in Section 8.1.2.

The site program testing strategy may evolve during site characterization. For example, if information gained during site characterization leads to a significant change in the conceptualization of the Yucca Mountain physical system, it may be appropriate to redefine the information needs and modify the associated testing strategy. Information needs may also change if it is found that information from the site program is not adequate to resolve all of the issues. For example, meeting some of the information needs as currently defined may be unfeasible because of limitations in measurement or analysis techniques or because the scientific findings differ significantly from current understanding. The testing strategy may also be modified if significantly improved investigative or analysis techniques become available, which permit reducing uncertainties previously considered to be irreducible. If the level of confidence in site information is inadequate and alternative tests cannot be identified, it will be necessary for the DOE to reevaluate site suitability.

The following subsections of this overview describe the elements of the Yucca Mountain system description and associated uncertainties, current site information and design, sources of site information, aspects of the site program that are designed to provide confidence that the needed data will be acquired, and, finally, the organization of the the major programs within the overall site program.

Elements of the system description and uncertainties

The Yucca Mountain site is a complex and dynamic natural physical system whose state is determined by (1) the external environmental setting (i.e., the boundary conditions); (2) the internal geometry of the system; and

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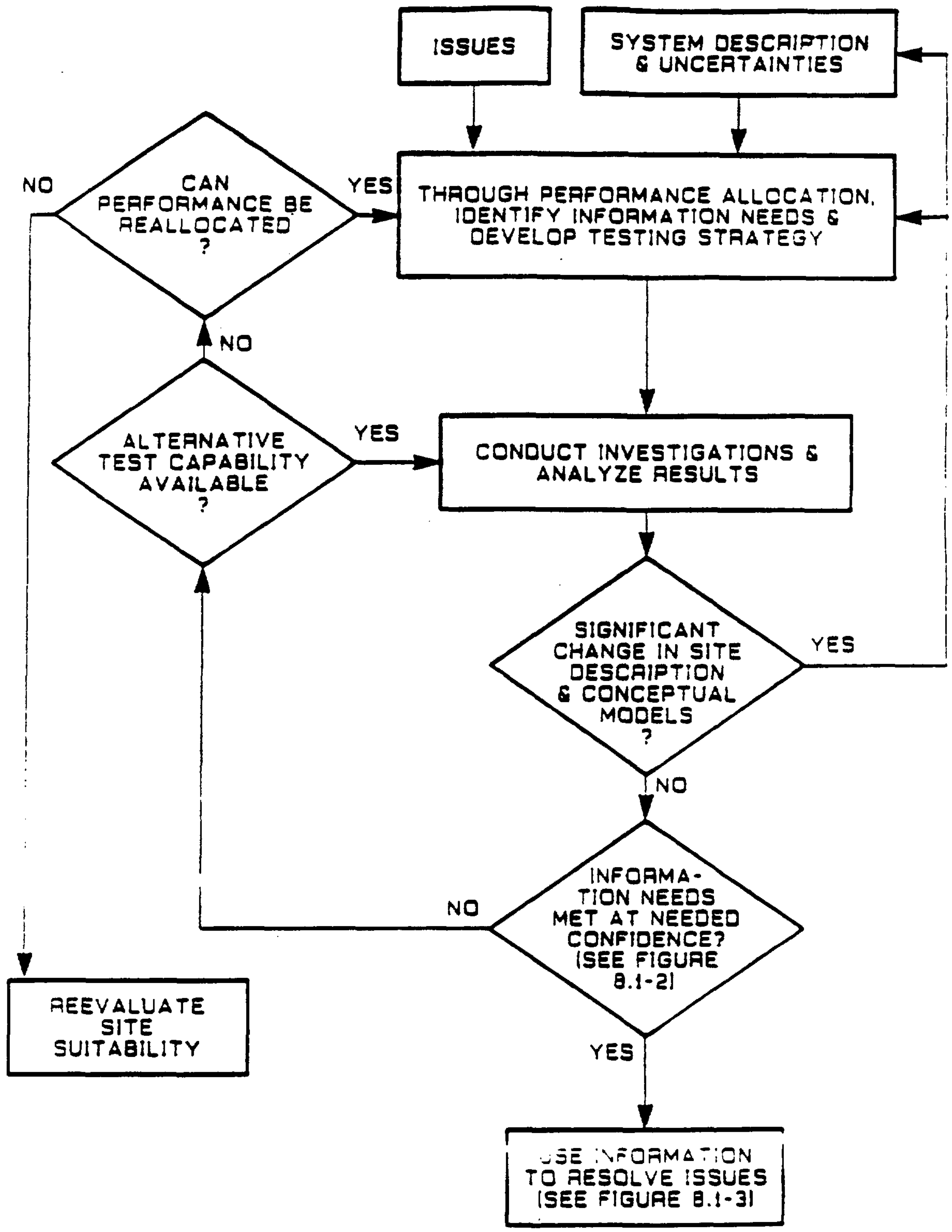

8.3.1.1-10.SCP

Figure 8.3.1.1-1. Strategy for the conduct of the site program

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(3) the physical processes acting within the system. The external environmental setting includes the regional climatic, tectonic, geothermal, and ground-water hydrogeologic systems. The internal geometry of the site is determined by the geologic framework and is defined by local structural features and stratigraphy. The processes operating within the system include hydrologic processes controlling liquid-water storage and flow and watervapor storage and flow; geothermal heat flow; processes controlling tectonic, lithostatic, and hydrostatic stress fields; geochemical and solutional kinematics; and pore-gas storage and flow.

Conceptual models must be developed to provide a description of the site physical system and to develop numerical models that can be used to quantitatively predict the system's behavior. Each conceptual model comprises a set of hypotheses regarding the environmental setting, internal geometry, and governing internal processes that are consistent with each other and that are compatible with available data. There is uncertainty in eacn conceptual and numerical model and, even after site characterization, some degree of uncertainty is expected to remain. The parameterization of numerical models involves uncertainty because of data limitations. Conceptual model uncertainty is indicated by the admissibility of alternative conceptual models, that is, there may be more than one set of hypotheses that is internally consistent and compatible with the available data.

As described below, the site program is designed to reduce both parameter uncertainty and conceptual uncertainty to the degree needed to satisfy the information needs.

Current site information and design

Considerable information about the Yucca Mountain site is already available and a preliminary conceptual design of the surface and underground repository facilities has been developed. Together, the site information and preliminary design serve to constrain and guide the plans for characterizing the site.

The present state of knowledge about the site and the surrounding area is summarized in Chapters 1 through 5. Considerable data have been collected for the specific purpose of making preliminary assessments of the suitability of Yucca Mountain for a mined geologic disposal system. Data have also been collected for other purposes, most notably in support of operations at the Nevada Test Site, adjacent and east of Yucca Mountain. These data provide information on the geologic and tectonic conditions (Chapter 1), the geoengineering properties relevant to repository construction (Chapter 2), the hydrologic environment (Chapter 3), the geochemical properties relevant to repository performance (Chapter 4), and the local meteorology and long-term variations in climate (Chapter 5).

The preliminary conceptual designs of the surface and underground repository facilities are described in Chapter 6, and information on conditions that affect waste-package design and performance is presented in Chapter 7.

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Sources of site information

The geology of Yucca Mountain reflects the formation and subsequent alterations of the site up to the present. The mountain was formed more than ten-million years ago and the local geologic record is about one-thousand times longer than the time frame of primary concern for waste isolation (10,000 yr). Thus, the local geologic record might be expected to contain an adequate sampling of those identifiable processes and disturbances that are reasonably likely to occur during the period important to waste isolation, as well as information on disturbances that would not be likely to occur during the geologically short period of concern.

The geologic processes that are reflected in the local geologic record, as discussed in Chapters 1 through 5, have all been observed elsewhere. These include volcanic processes, active faulting and related earthquake effects, weathering and erosional processes, and a variety of geochemical processes. Knowledge about ground-water processes is available from observations at many sites under a variety of conditions, including observations of earthquake- and explosion-induced effects. There are many observations elsewhere of the effects of earthquakes and explosions on engineered structures. This body of outside knowledge, a portion of which is described and referenced in Chapters 1 through 5, provides an understanding of the processes that may be acting locally and can be used to help interpret site-specific data and make site-specific predictions.

Evidence for some geologic processes that may affect the site may be apparent only outside of the immediate site area. For example, no known evidence exists for volcanic activity at Yucca Mountain since the Miocene, but the presence of cinder cones nearby to the south and west (Section 1.3.2.1.2) indicates a need to investigate the potential for volcanic activity at the site. In general, knowledge of the geologic setting constrains and provides confidence in local interpretations.

Understanding of the site is based on four sources of information: site-specific data, knowledge of the geologic setting, related global observations and associated knowledge, and generally accepted principles and concepts of science. Uncertainty and deficiencies in any of these sources can lead to uncertainty in the system description. Examples of current site-specific data deficiencies exist in regard to the potential for surface fault rupture at and near the proposed locations of surface facilities in Midway Valley, hydrologic parameters within the Yucca Mountain block, past changes in local water-table elevations, and past climatic conditions. Current knowledge about ground-water flow conditions in adjacent regions is inadequate and represents a deficiency in knowledge of the hydrogeologic setting. Uncertainty in global climate models creates uncertainty in predicting future precipitation and ground-water flux. Limited scientific ability to date geologic materials and structures contributes significantly to uncertainty about the geologic history of the site area. A conceptual understanding of the potential for ground-water fluctuations due to coupled igneous and tectonic effects is another area of current uncertainty.

Uncertainties of all types in the present system description were considered in defining the information needs that the site program is designed to satisfy.

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Confidence building

The site program embodies a number of approaches for building confidence that the necessary data will be acquired. These include a flexible, iterative strategy for issue resolution, the use of performance allocation to ensure that site investigations acquire the most important information for resolution of performance and design issues, explicit testing of hypotheses associated with alternative conceptual models, studies that focus on particular phenomena of concern, the use of probabilistic as well as deterministic evaluations of site performance, and extensive internal and external technical review.

Flexible strategy

The flexibility in the strategy for conducting the site program, illustrated in Figure 8.3.1.1-1, was discussed earlier. Any changes in the defined information needs will be documented in semiannual progress reports on site characterization activities. The testing strategy will be reevaluated on the basis of any such changes and modified, as necessary, to acquire the needed information. Modifications to the testing strategy will also be documented in the semiannual reports.

Performance allocation

The first steps in performance allocation (Section 8.1.2.2) lead to the identification of information needs--those categories or types of information that are needed to resolve each performance and design issue. Performance allocation starts with the formulation of a licensing strategy for each issue. This step uses available information to develop a statement of the site features, engineered features, conceptual models, and analyses that are considered important to the resolution of the issue. The principal product of this step is the identification of the elements of the site that will be investigated to resolve the issue, that is, if these elements can be shown to perform as assumed in the licensing strategy, the issue is likely to be resolved. The next step is the establishment of performance measures for each of the elements identified in the preceding step. Tentative goals and indications of desired confidence that each goal is met are established for each performance measure. As discussed in Section 8.1.2.2, these goals are not standards that must be met for the repository to perform properly; their function is to guide the identification of information that must be provided by the site program. The performance measures are then used to develop information needs. The information needs are expressed in terms of the design and performance parameters that are needed to evaluate the performance measures. Tentative goals and indications of confidence that are consistent with the goals for the performance measures are established for the parameters.

The next step in performance allocation is to define the work that will produce the needed information. The information needs are expressed in terms of the design and performance parameters. To establish values for these parameters, more detailed characterization parameters and associated goals and levels of confidence are defined such that, in principle, they can be established by scientific investigation. The scientific investigations that compose the site program are then designed to provide the defined characterization parameters.

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In the manner just described, performance allocation relates the site data being collected to the information needed to resolve the design and performance issues. It thus ensures that the information that is important to issue resolution will be obtained by the site program.

Further confidence in the site program is provided by the use of conservative goals in performance allocation--goals that, if met, would likely contribute to a finding that the site will meet the technical criteria of the regulations by a sufficient margin to address residual uncertainties in site characteristics.

Hypothesis testing

The site program is designed not only to reduce uncertainty associated with characterization parameters, but also to reduce uncertainty in the conceptualization of the site physical system. For example, reduction of uncertainty in conceptual models of moisture flow in partially saturated, fractured rock has been identified as being particularly important to the prediction of site performance, and this uncertainty is being addressed by studies described in Section 8.3.1.2.

Systematic hypothesis testing is being employed to discriminate between alternative conceptual models by eliminating untenable or nonviable hypotheses and to evaluate the likelihoods that alternative, admissible conceptual models are applicable. As with parameter uncertainty, conceptual uncertainty will be reduced to the extent necessary to satisfy the information needs.

To ensure comprehensive consideration of potentially viable alternative conceptual models and to document this consideration, hypothesis-testing tables have been developed for several particularly relevant disciplines. Specifically, hypothesis-testing tables have been developed for investigations related to geohydrology (Section 8.3.1.2), geochemistry (8.3.1.3), rock characteristics (8.3.1.4), climate (8.3.1.5), preclosure and postclosure tectonics (8.3.1.17 and 8.3.1.8), natural resources that could lead to future human disruption of the site (8.3.1.9), and thermal and mechanical rock properties (8.3.1.15).

These tables summarize information in five categories: (1) the current representation of the system, (2) the uncertainty and rationale in current hypothesis, (3) alternative hypotheses, (4) the significance of the alternatives, and (5) the studies or activities needed to reduce the uncertainties.

The first category, the current representation, identifies the elements of the system being evaluated and describes the current or preferred hypotheses regarding these elements. Typically, the elements of the system include its physical domain and geometry, key features and properties of the system, processes and events that may be important, and boundary conditions. The current hypotheses describe the assumptions made regarding these elements from the available information about the site.

The second category specifies the uncertainty in each current hypothesis and gives a rationale for this specification. A qualitative judgment (high, medium, or low) of ambiguity in the current conceptual understanding is presented, based on the available data and information. For example, a high specification is indicated when a particular hypothesis could be very uncertain because data are lacking or because large uncertainties arise in the interpretation of measured parameters. In other cases, when the level of uncertainty is more constrained, a medium or low rating is specified, depending on the degree and reliability of the constraints.

The third category presents possible alternative hypotheses that might also explain the available data. Where the uncertainties are judged to be very low, no alternative hypothesis may be listed. An alternative hypothesis may also be omitted when the alternative is simply that the preferred hypothesis is false.

The fourth category provides judgments of the significance of the uncertainties based on the identified information needs and the sensitivity of the information needs to the uncertainties. Specifically, the performance measures and design or performance parameters that were defined through performance allocation are listed in each table, along with the needed confidence in the measure or parameter, a judgment of the sensitivity of this information to the uncertainty in the hypothesis, and, based on the preceding elements, a judgment about the ultimate need to reduce the uncertainty. The role of the fourth category is to link the alternative conceptual models to resolution of performance and design issues. Alternative conceptual models will be considered primarily as they affect information needs associated with performance and design issues. Thus, the significance of each conceptual model is dependent on how sensitive the information needs are to the model assumptions.

The fifth category identifies the activities that are planned to discriminate between competing hypotheses or to otherwise reduce the estimated uncertainty. These activities cut across disciplines and program lines, where necessary. For example, the hypothesis-testing table for unsaturated-zone hydrology (Table 8.3.1.2-2a) lists activities being conducted under the postclosure tectonics program to assess the effects of tectonic processes and events on local fracture permeability and effective porosity, activities in the geochemistry program to provide information on water chemistry, and activities in the thermal and mechanical rock properties program to determine ambient thermal conditions.

The hypothesis-testing tables are necessarily preliminary and, therefore, list not only uncertainties known to be important, but also uncertainties that are probably inconsequential. Even so, there are undoubtedly more hypotheses that could be listed. The tables list modeling uncertainties that appear, now, to be possibly relevant.

Focus on phenomena

Another approach to building confidence that the needed information will be gathered is the phenomenological focus of many of the site characterization investigations and studies, that is, many investigations and studies have as an explicit objective an improved understanding of a physical process

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that may affect or occur at the site. These investigations and studies typically involve different types of activities to gain the necessary information about the process. Examples are the geohydrology investigation (8.3.1.2.2) of water movement in the unsaturated zone, the geochemistry study (8.3.1.3.2.2) of the history of mineralogic and geochemical alteration of Yucca Mountain, and the postclosure tectonics study (8.3.1.8.3.2) of the potential effects of tectonic processes and events on the water-table elevation. With an understanding of phenomena as the basis for the system description, potentially important uncertainties are less likely to be overlooked.

Studies that focus on phenomena are often interdisciplinary and, therefore, require programmatic integration. As discussed previously, the linkage between information that is being provided by one program and that is being used by another program is documented in the hypothesis-testing tables. This linkage is also documented in performance-allocation tables for each site program (e.g., Table 8.3.1.2-1) which illustrate the connection between the design and performance issues and the information being provided by each activity. Logic diagrams for each site program (e.g., Figure 8.3.1.2-2) also indicate linkages between the various site programs. Integration across disciplines and programs during the course of site characterization will be facilitated by meetings and workshops in which the responsible investigators in different disciplines will participate.

Deterministic and probabilistic evaluations

Both deterministic and probabilistic evaluations of site performance will be performed. The deterministic evaluations include bounding analyses as well as representative estimates using point values for performance and design parameters. Probabilistic analyses will be used where appropriate to quantify and determine the importance of uncertainty in the parameters. In some cases probabilistic analysis is used as an adjunct to deterministic design-basis analysis; an example is the development of a seismic design basis for preclosure facilities that are important to safety (Section 8.3.1.17.3).

The support of probabilistic analyses provides added confidence that the data needed to adequately characterize the site will be collected. Probabilistic evaluations typically treat scenarios over a wide range of occurrence likelihoods and quantitatively consider the impact of both conceptual and parametric uncertainty. Probabilistic analyses, therefore, often require more information than deterministic analyses. Probabilistic analysis also provides an excellent framework for testing the sensitivity of modeling results to various modeling assumptions. The identification of critical assumptions will be used to help keep the site program focused on obtaining the most important information.

Technical review

The site characterization plan has been developed under a DOE quality assurance program and has been subject to an extensive review and a documented comment-resolution process before its completion and issuance, lending further confidence that the site program will acquire all information needed

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to resolve the design and performance issues. In addition, all technical reports produced by Yucca Mountain Project participants are reviewed according to the DOE quality assurance program.

Organization of the investigations

The subsections of Section 8.3.1 are organized according to the major topics of investigation within the site program. Following this overview, Sections 8.3.1.2 through 8.3.1.9 address topics generally associated with the postclosure performance and design issues; Sections 8.3.1.10 through 8.3.1.17 treat topics generally associated with preclosure design and safety issues. As shown in Table 8.3-1, Section 8.3.1.2 describes the investigations making up the geohydrology program. Section 8.3.1.3 covers the geochemistry program. Section 8.3.1.4 describes the plans to develop an integrated site-characterization-drilling program and the investigations to determine the three-dimensional distribution of rock properties at Yucca Mountain. Investigations planned to predict the range of possible future climatic conditions and their effects are described in Section 8.3.1.5. Section 8.3.1.6 covers the investigations related to present and future erosion rates. Section 8.3.1.7 addresses rates of rock dissolution. Section 8.3.1.8 describes the plans for investigation of tectonic processes and events that could occur during the postclosure period. Section 8.3.1.9 considers the investigations to establish the potential for human interference at the site. Preliminary site-related data needs for preclosure radiological safety assessments are covered by Sections 8.3.1.10 through 8.3.1.13 (population density and distribution, land ownership and mineral rights, meteorological conditions, and offsite installations, respectively). Section 8.3.1.14 describes the investigations to establish the surface characteristics at the site for purposes of siting repository surface facilities. Investigations addressing data needs for thermal and mechanical rock properties and for ambient stress and temperature conditions are described in Section 8.3.1.15. Section 8.3.1.16 describes the investigations planned to provide information on hydrologic conditions and processes important during the preclosure period. Finally, Section 8.3.1.17 describes the investigations to provide information on the potential for preclosure igneous activity, ground motion, and surface faulting at the Yucca Mountain site.

The site investigations described in each section are divided into studies and activities. The studies will be described in further detail in study plans; a list of study plan topics is provided in Section 8.5.1.

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8.3.1.2 Overview of the geohydrology program: Description of the present and expected geohydrologic characteristics required by the performance and design issues

The performance issues that require data from this site characterization program are discussed, together with the current strategy that the Yucca Mountain Project (formerly the Nevada Nuclear Waste Storage Investigations (NNWSI) Project) intends to use in the conduct of this site characterization program. The investigations and studies to be conducted are identified and discussed with explanations for how these investigations and studies will adequately address requirements of the test program.

The major part of Section 8.3.1.2 summarizes the studies and activities that have been chosen to provide the information required by the characterization investigations, and relates these studies and activities to the performance and design issues. The test program directly relates to various performance requirements identified in 40 CFR Part 191 and 10 CFR Part 60, specifically the following:

40 CFR 191.13(a)

> Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, based upon performance assessment, that the cumulative releases of radionuclides to the accessible environment for 10,000 yr after disposal from all significant processes and events, that may affect the disposal system shall:
>
> (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A); and
>
> (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).

40 CFR 191.16(b)

> Disposal systems for spent nuclear fuel or high-level or transuranic radioactive wastes shall be designed to provide a reasonable expectation, that for 1,000 yr after disposal, undisturbed performance of the disposal system shall not cause the radionuclide concentrations averaged over any year in water withdrawn from any portion of a special source of ground water to exceed:
>
> (1) Five picocuries per liter of radium-226 and radium-228;
>
> (2) Fifteen picocuries per liter of alpha-emitting radionuclides (including radium-226 and radium-228 but excluding radon); or

(3) The combined concentrations of radionuclides, that emit either beta or gamma radiation that would produce an annual dose equivalent to the total body or any internal organ >4 rems/yr if an individual consumed 2 L/day of drinking water from such a source of ground water.

10 CFR 60.113 (a)(1)(ii)(A)

Containment of high-level waste (HLW) within the waste package will be substantially complete for a period to be determined by the Commission taking into account the factors specified in Part 60.113(b) provided that such period shall be not less than 300 yr nor more than 1,000 yr after permanent closure of the geologic repository.

10 CFR 60.113 (a)(1)(ii)(B)

The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000/yr of the inventory of that radionuclide calculated to be present at 1,000 yr following permanent closure, or such fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate <0.1 percent of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000/yr of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 yr of radioactive decay.

10 CFR 60.113 (a)(2)

The geologic repository shall be located so that pre-waste-emplacement ground water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission.

Regulations 40 CFR 191.13(a) and 10 CFR 60.113(a)(2) are associated with the movement of ground water in the immediate vicinity of the proposed repository. Regulations 40 CFR 191.16(b), 10 CFR 60.113(a)(1)(ii)(A), and 10 CFR 60.113(a)(1)(ii)(B) are associated with the existence of ground water around the repository; in particular, 10 CFR 60.113(a)(1)(ii)(A) and 10 CFR 60.113(a)(1)(ii)(B) directly depend on the emplacement environment, because ground-water moisture is presumed to be the primary mechanism for waste package degradation and for releases from the engineered barrier system.

Each of these regulations is addressed by a specific issue within the Yucca Mountain Project Issues Hierarchy. The respective issues for these regulations are 1.1, 1.3, 1.4, 1.5, and 1.6 (Sections 8.3.5.13, 8.3.5.15, 8.3.5.9, 8.3.5.10, and 8.3.5.12 respectively). The hydrologic information required to satisfy these issues is discussed in Section 8.3.5, and is

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summarized in the following discussion, where a correlation is made to the data to be collected under the geohydrology program.

In addition to the performance requirements just identified, hydrologic information provided by the geohydrologic test programs is also required to address the favorable conditions identified in 10 CFR 60.122(b) and the potentially adverse conditions of 10 CFR 60.122(c). These conditions are examined under Issue 1.8 (Section 8.3.5.17).

An understanding and a quantitative assessment of the hydrologic conditions at Yucca Mountain are also required to address the higher level findings required by 10 CFR Part 960 for the qualifying conditions on the postclosure system guideline and the disqualifying and qualifying conditions on the technical guidelines for geohydrology, geochemistry, climatic changes, and human interference. An assessment of these findings is addressed under Issue 1.9 (Section 8.3.5.18).

Issue 1.9 also addresses the comparative evaluations required by 10 CFR 960.3-1-5, which is associated with cumulative releases to the accessible environment during 100,000 yr. Once again, the hydrologic system is the primary mechanism by which these releases can occur, and so an understanding of the ground-water and surface-water systems is required to perform these evaluations.

Approach to satisfy performance and design requirements

An understanding of the geohydrologic environment is essential to assessing the suitability of the site because ground water is expected to be the major transport medium of radionuclides to the accessible environment. A potential additional radionuclide transport process is by gaseous-phase flow in the unsaturated zone, which is also addressed by the Geohydrology Program.

The general strategy for carrying out the geohydrology program is to conduct investigations that will result in a complete and accurate description of the pertinent components of the hydrologic system that will reflect an understanding of the hydrologic properties, initial and boundary conditions and processes, and their interrelationships. The results of the geohydrology program will then be combined with the results of other site programs to produce a site model, or complete description of the site.

The geohydrology program consists of the data-collection and evaluation activities that will result in hydrologic models that describe two distinct regimes of the hydrologic system: the unsaturated zone and the saturated zone. Each of these regimes is impacted by the surface-water flow regime, and so a surface-water hydrologic model will also be developed to provide input to the other two hydrologic models. The unsaturated-zone hydrologic model will be developed only at the site scale, whereas the surface-water and saturated-zone hydrologic models will be developed at both site and regional scales. The hydrologic regimes described by these models are those that significantly affect the resolution of hydrologic-related design and performance issues; these regimes, therefore, are the principal subjects of investigation in the geohydrology program.

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The geohydrology program is a broad program that includes activities in the disciplines of unsaturated-zone hydrology, saturated-zone hydrology (on both a regional and site scale), and surface-water hydrology. Much of the effort of the geohydrology program will focus on the thick (500 to 750 m) unsaturated zone at the site. This is the environment in which the repository would be constructed; thus, many of the design requirements relate to the unsaturated zone, and this environment is expected to serve as the primary barrier to transport of radionuclides. Despite the extensive investigations planned for the hydrologic characterization of the unsaturated zone, a certain level of uncertainty may still remain as to its effectiveness as a barrier even after the investigations are completed. This is because detailed understanding of hydrologic processes in thick, arid-region, fractured-rock unsaturated zones is generally poor, and, therefore, various untried and nonstandard approaches must be taken. Consequently, in keeping with the multiple barrier concept, substantial emphasis will also be placed on characterizing the saturated zone.

The saturated zone beneath the site serves as the final portion of the flow path for ground-water flow and transport to the accessible environment. Evaluation of the regional saturated-zone flow system provides knowledge of the boundary conditions at the site; this knowledge is needed to assess accurately the impacts of changes (such as climate) on the flow system beneath the site.

Surface water is expected to be a major source of infiltration to the unsaturated zone and, ultimately, recharge to the saturated zone. Changes in the surface-water flow regime could significantly impact ground-water flow paths and gradients and, thus, radionuclide transport from the site to the accessible environment. In addition, surface-water flooding and debris transport may pose a hazard to repository facilities.

Figure 8.3.1.2-1 is a logic diagram that shows the interface between the geohydrology program and the design and performance issues and other site characterization programs for which the geohydrology program provides information. The diagram shows that the parameters obtained by the geohydrology program will be used in a wide variety of issues and programs in the Yucca Mountain Project.

The logic diagrams of Figures 8.3.1.2-2 through 8.3.1.2-4 show the relationships between the three hydrologic models (surface-water, unsaturated zone, and saturated-zone) and the geohydrology program. The diagrams expand the hydrologic models to show the models, model components, and common parameter categories used to build that model. The diagrams also show that each hydrologic model consists of numerical models and conceptual/descriptive models, which combine to provide a complete description.

The hydrologic models contain four major components: (1) system geometry, (2)material properties, (3) initial and boundary conditions, and (4) hydrologic hypotheses. In Figures 8.3.1.2-2 through 8.3.1.2-4 these components are given designations more specific to the particular hydrologic model that they constitute. For each of these hydrologic models, the system geometry is provided by the geologic framework. The material properties

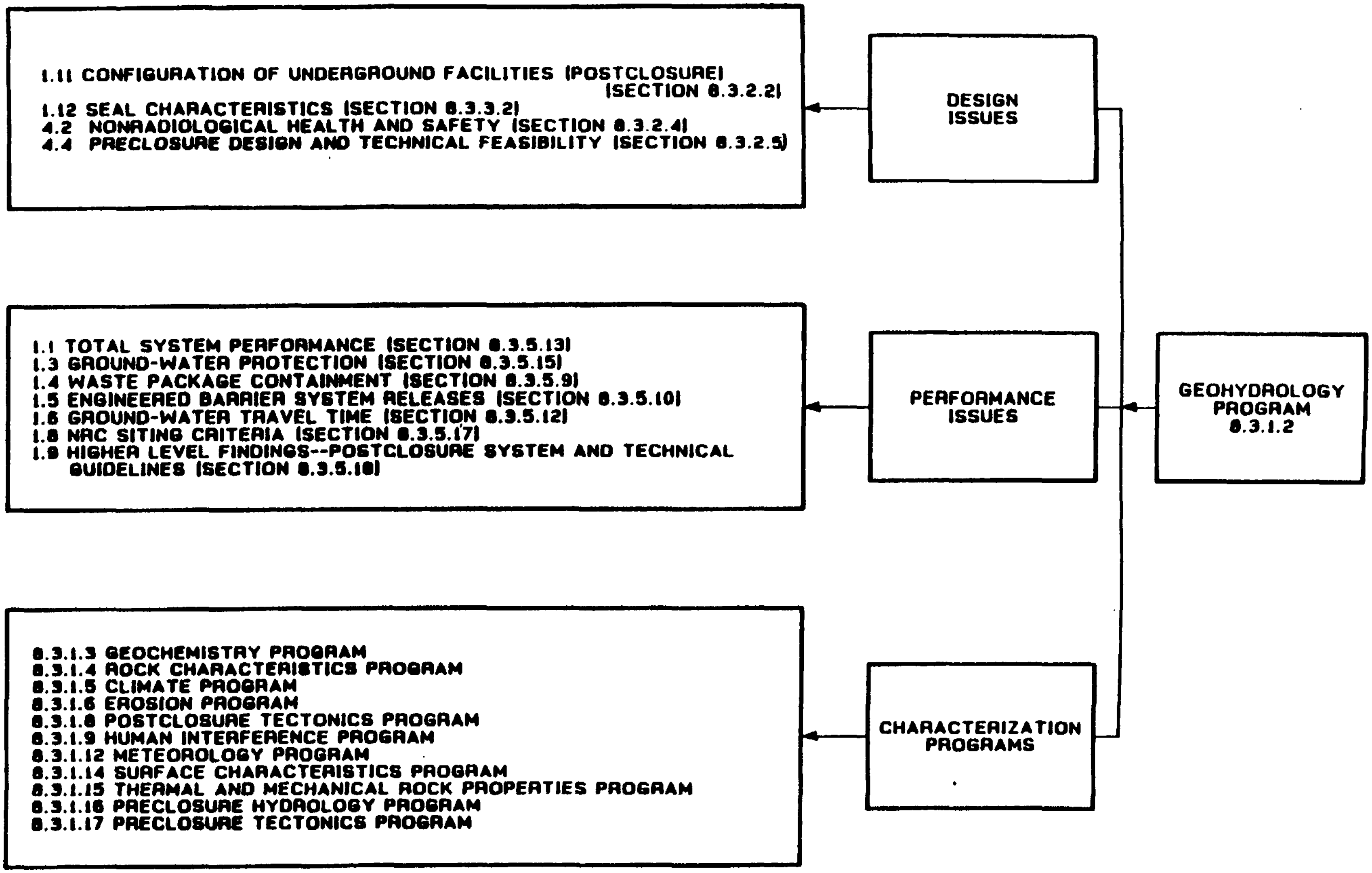

Figure 8.3.1.2-1. *Interface of the geohydrology program with design and performance issue and other characterization programs.*

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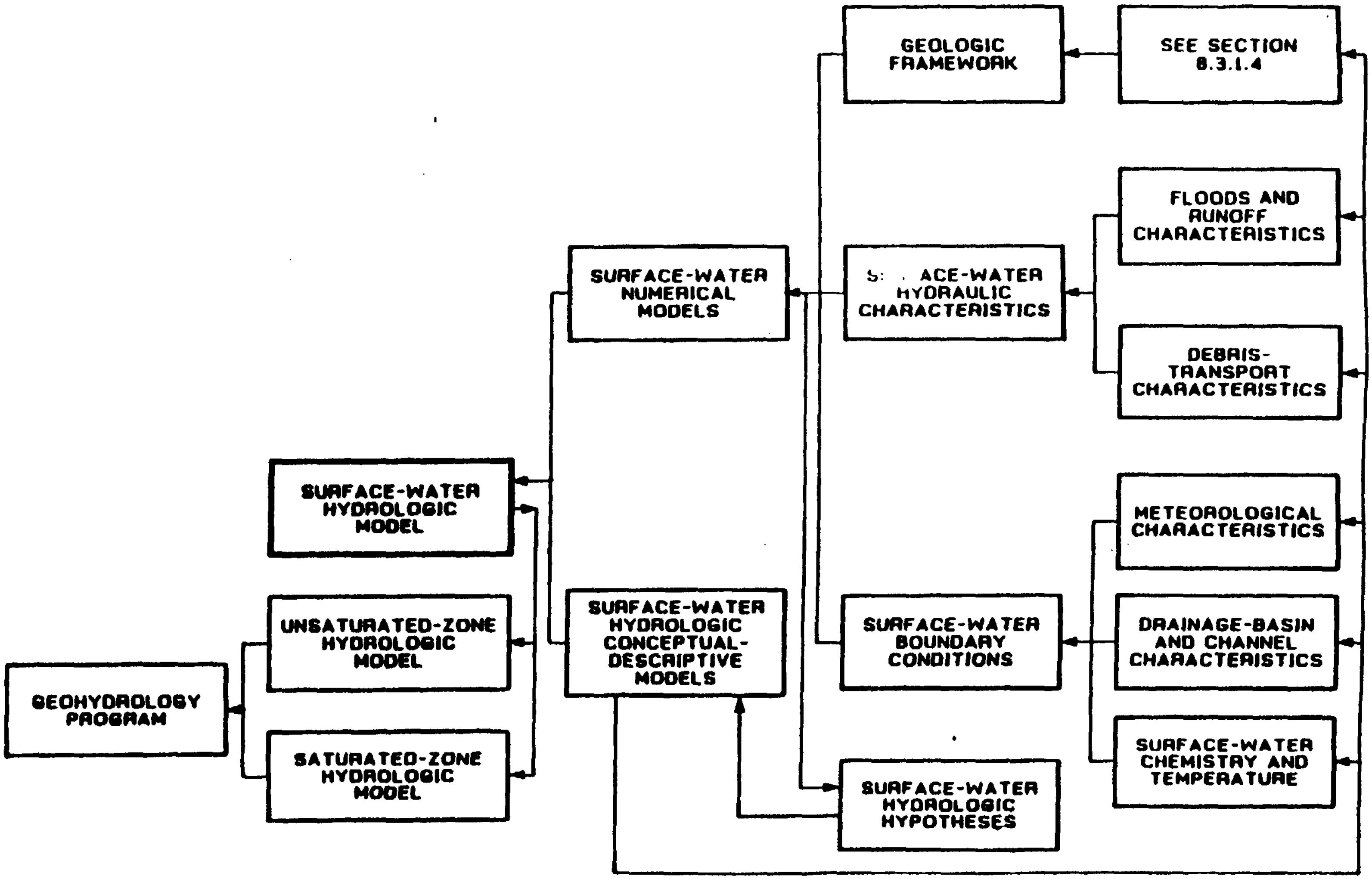

8.3.1.2-2

Figure 8.3.1.2-2. Logic diagram of the surface-water hydrology component of the geohydrology program.

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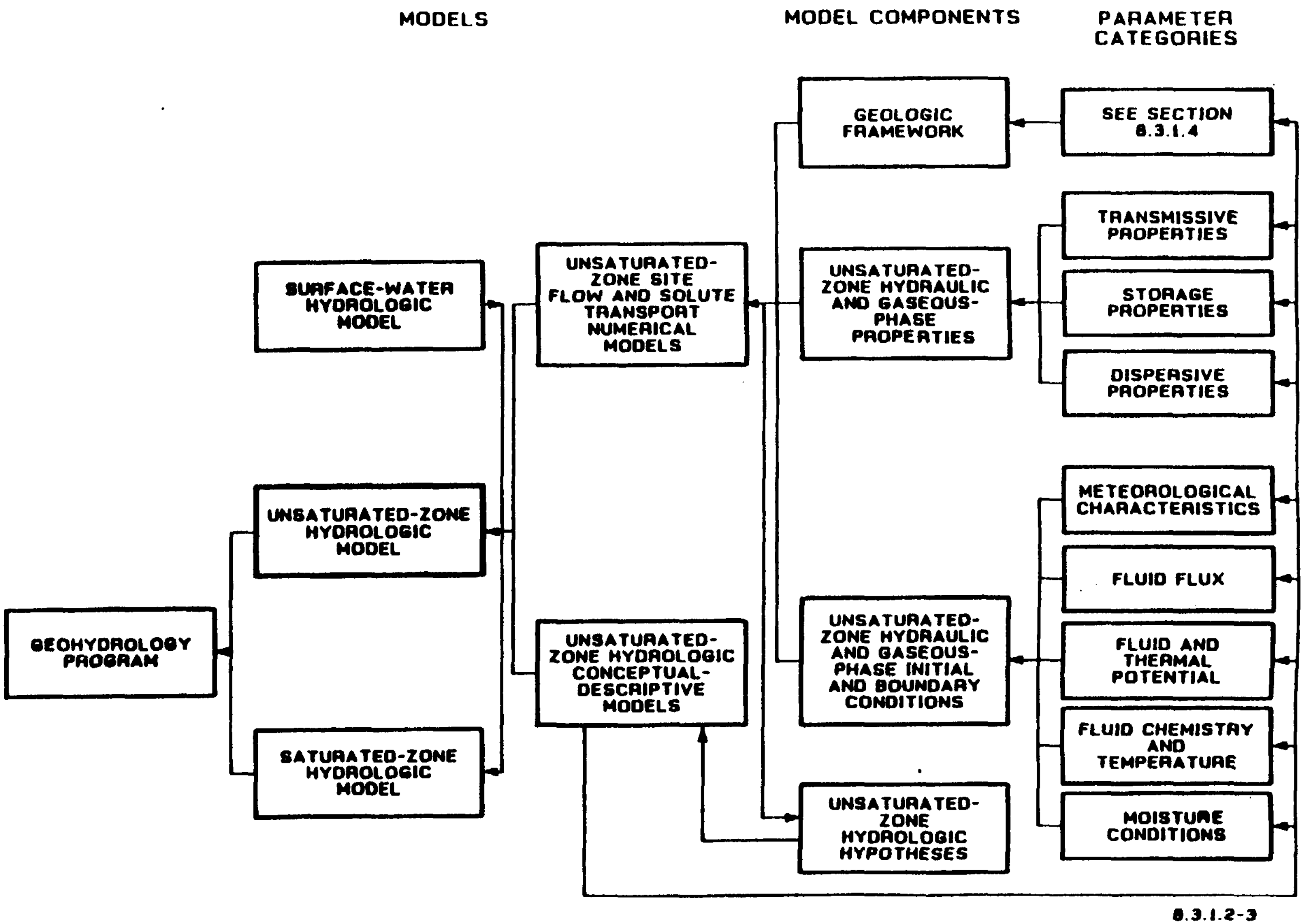

Figure 8.3.1.2-3. Logic diagram of the unsaturated-zone hydrology component of the geohydrology program.

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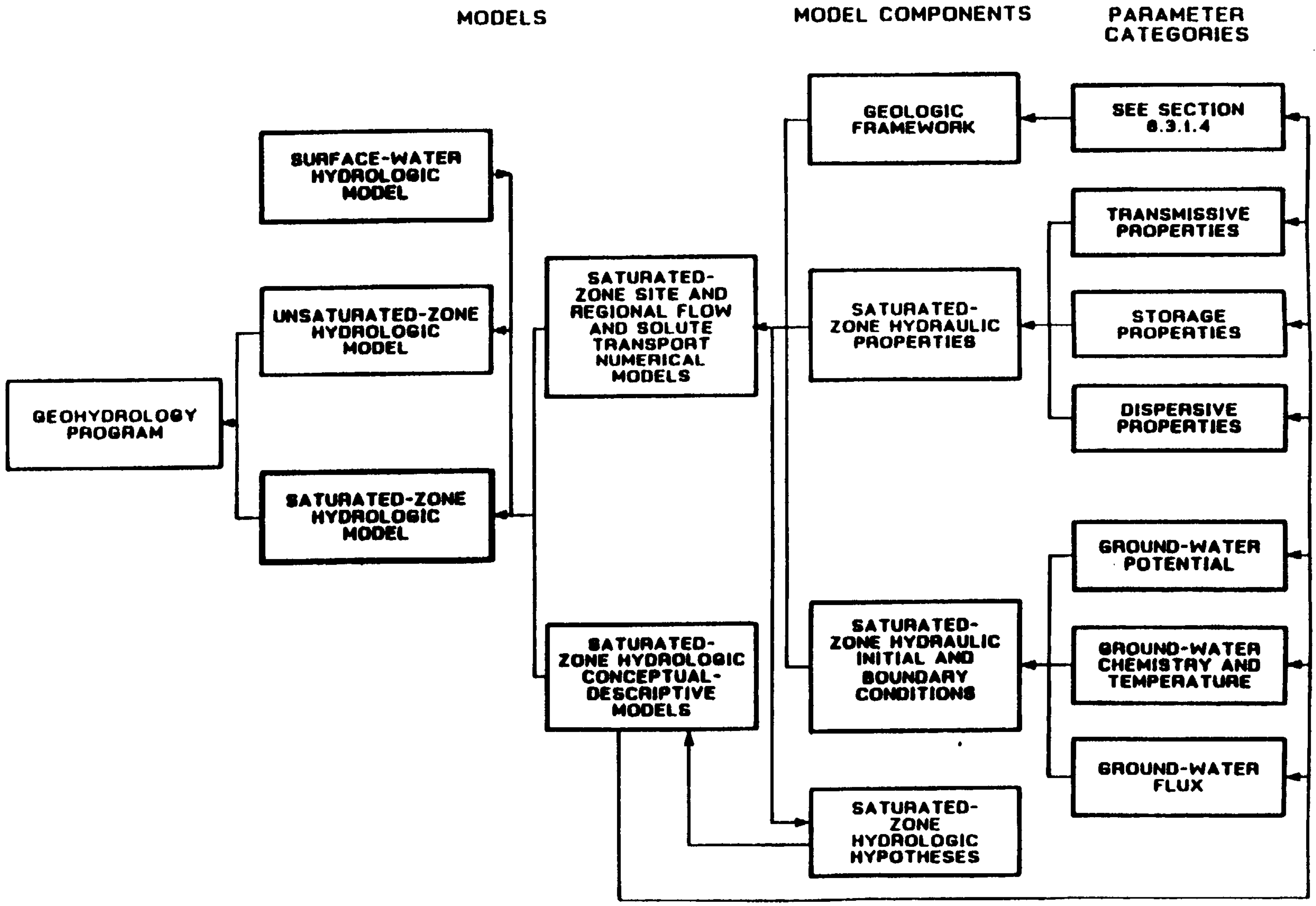

8.3.1.2-4

Figure 8.3.1.2-4. Logic diagram of the saturated-zone hydrology component of the geohydrology program

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include the surface-water hydraulic characteristics (Figure 8.3.1.2-2) the unsaturated hydraulic and gaseous-phase properties (Figure 8.3.1.2-3) and saturated-zone hydraulic properties (Figure 8.3.1.2-4). Each of the three hydrologic regimes has its own set of initial and boundary conditions. The first three components together form the basis for developing the numerical models that quantitatively describe various aspects of the hydrologic system. These components also support the fourth component, the hypotheses concerning the conditions, properties, and processes of the particular hydrologic regime being modeled. A consistent set of hypotheses leads to a conceptual model for that hydrologic regime.

Parameters define the geologic framework, hydrologic properties and characteristics, and initial and boundary conditions. Categories of these parameters and their relationships to these model components are shown for each of the hydrologic regimes in Figures 8.3.1.2-2 through 8.3.1.2-4.

The parameter categories in Figures 8.3.1.2-2 through 8.3.1.2-4 are tied to Table 8.3.1.2-1, which provides the initial framework for relating (1) the parameter requirements of the design and performance issues, and (2) the parameters that will be provided by the geohydrology program to satisfy those requirements. Table 8.3.1.2-1 lists in the two left-hand columns the issues and section numbers that call for information from the geohydrology program. In the two right-hand columns, the table lists the activity parameters that will be obtained in the program in response to those requirements, along with the section numbers where the activities are described that will obtain the parameters. The middle column (parameter category) provides the linkage between the performance and design and the characterization parts of the table; this column also provides the organizational structure upon which the listings of issues and activity parameters are based.

Activity parameters generally are those parameters that will be generated by the field and laboratory testing activities. They represent the most basic measurements that will be used in analyses to characterize the geohydrology of the site. Many of the activity parameters are building blocks to support various aspects of the project. Some, such as hydraulic conductivity, support design and performance issues directly; others, such as drainage-basin areas, primarily provide bases for analyses and evaluations to be conducted within the geohydrology program or within other characterization programs.

In Table 8.3.1.2-1, the activity parameters are grouped according to parameter categories. These categories, including major categories (such as "unsaturated-zone hydraulic and gaseous phase properties") and subcategories (such as unsaturated-zone transmissive properties) are topical categories that serve to group similar types of performance and design parameters and match them with groups of similar types of parameters to be obtained during site characterization. Generally, a one-to-one correspondence is not to be expected between a performance parameter and an activity parameter because of the great diversity, number, and highly specific nature of both types of parameters.

The parameter category serves as a convenient and logical classification scheme that can aid the reader in assessing the appropriateness and completeness of the data collection program. The technical logic for the parameter

Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 1 of 38)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program	
Issue	SCP section		Activity parameter	SCP activity
		METEOROLOGICAL CHARACTERISTICS		
1.12 2.1 2.2 2.3 2.7 4.4	8.3.3.2 8.3.5.3 8.3.5.4 8.3.5.5 8.3.2.3 8.3.2.5	Meteorological characteristics	Storm movement and intensity; meteorological input to unsaturated-zone infiltration and gas-phase circulation studies; (with integrated meteorological network)	8.3.1.2.1.1
			Atmospheric pressure and pressure variability	8.3.1.2.1.1.1
			Atmospheric stability; relations to storms	8.3.1.2.1.1.1
			Atmospheric temperature	8.3.1.2.1.1.1
			Humidity, relative; diurnal and seasonal variability	8.3.1.2.1.1.1
			Precipitation chemistry	8.3.1.2.1.1.1
			Precipitation, intensity and duration (monthly and seasonal variability)	8.3.1.2.1.1.1
			Radiation and irradiation, infrared (diurnal and seasonal variability)	8.3.1.2.1.1.1
			Wind, speed, and direction (diurnal, seasonal, and storm-specific variability)	8.3.1.2.1.1.1
			Air temperature	8.3.1.2.1.2.1
			Precipitation, quantity and timing	8.3.1.2.1.2.1
			Air temperature	8.3.1.2.1.3.3
			Precipitation, quantities and frequency	8.3.1.2.1.3.3
			Precipitation	8.3.1.2.2.1.2

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 2 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		METEOROLOGICAL CHARACTERISTICS (continued)		
		Meteorological characteristics (continued)	Rainfall, experimentally induced	8.3.1.2.2.1.3
			Air temperature	8.3.1.2.2.6.1
			Barometric pressure	8.3.1.2.2.6.1
			Relative humidity	8.3.1.2.2.6.1
		SURFACE-WATER HYDRAULIC CHARACTERISTICS		
1.1	8.3.5.13	Surface-water flood and runoff characteristics	Runoff and streamflow, hydrologic characteristics	8.3.1.2.1.2
1.12	8.3.3.2		Durations of individual runoff events	8.3.1.2.1.2.1
2.1	8.3.5.3		Occurrences and geographics extent of runoff	8.3.1.2.1.2.1
2.3	8.3.5.5		Runoff quantities, at specific site for specific events	8.3.1.2.1.2.1
2.7	8.3.2.3		Runoff rates at specific sites	8.3.1.2.1.2.1
4.4	8.3.2.5		Runoff durations	8.3.1.2.1.3.3
			Runoff frequencies	8.3.1.2.1.3.3
			Runoff quantities	8.3.1.2.1.3.3
			Runoff rates	8.3.1.2.2.1.1
			Runoff	8.3.1.2.2.1.2
			Runoff; experimentally induced	8.3.1.2.2.1.3

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 3 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		SURFACE-WATER HYDRAULIC CHARACTERISTICS (continued)		
1.1 1.12 2.7	8.3.5.13 8.3.3.2 8.3.2.3	Surface-water debris-transport characteristics	Sediment component of runoff	8.3.1.2.1.2.1
			Flood debris, physical characteristics	8.3.1.2.1.2.2
			Hillslope and channel erosion, location and areal extent	8.3.1.2.1.2.2
			Sediment deposits, location and areal extent	8.3.1.2.1.2.2
		SURFACE-WATER BOUNDARY CONDITIONS		
1.2 1.12	8.3.5.13 8.3.3.2	Surface-water drainage-basin and channel characteristics	Hillslope and channel erosion, timing	8.3.1.2.1.2.2
			Drainage-basin and channel geometry (aspect, area, configuration, slope, Manning coefficient)	8.3.1.2.1.3.3
			Surficial deposits, distribution, and characteristics	8.3.1.2.1.3.3
1.1 1.12	8.3.5.13 8.3.3.2	Surface-water chemistry and temperature	Hydrochemistry, surface water	8.3.1.2.1.3.3

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 4 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		SURFACE-WATER HYDROLOGIC CONCEPTUAL/DESCRIPTIVE MODELS		
1.1 1.12 2.7	8.3.5.13 8.3.3.2 8.3.2.3	Surface-water hydrologic conceptual/ descriptive models	Precipitation and its relation to surface runoff with particular emphasis on the Fortymile Wash drainage basin; rainfall-runoff model	8.3.1.2.1.1
			Flood and fluvial-debris hazards (8.3.1.16.1.1)	8.3.1.2.1.2
			Runoff and streamflow, relation to amounts and processes of ground-water recharge	8.3.1.2.1.2
			Runoff and streamflow, relation to precipitation	8.3.1.2.1.2
			Relations of runoff to weather conditions	8.3.1.2.1.2.1
			Runoff frequencies in specific and general areas	8.3.1.2.1.2.1
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES		
1.1 1.6 1.10 1.12 4.4	8.3.5.13 8.3.5.12 8.3.4.2 8.3.3.2 8.3.2.5	Unsaturated-zone transmissive properties	Recharge locations, rates, and history	8.3.1.2.1.3.3
			Hydraulic conductivity	8.3.1.2.2.1.3
			Flux-related, matrix hydrologic properties (transmissive) of geologic samples	8.3.1.2.2.3
			Permeability, effective, hydraulic, matrix; subsurface geologic samples	8.3.1.2.2.3.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 5 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES (continued)		
		Unsaturated-zone transmissive properties	Permeability, relative, hydraulic, matrix, subsurface geologic samples	8.3.1.2.2.3.1
			Effective matrix porosity	8.3.1.2.2.3.2
			Hydraulic conductivity	8.3.1.2.2.3.2
			Permeability, in situ, hydraulic, bulk	8.3.1.2.2.3.2
			Permeability, in situ, pneumatic, bulk	8.3.1.2.2.3.2
			Permeability, matrix, as a function of saturation and matric potential, laboratory	8.3.1.2.2.3.2
			Effective porosity	8.3.1.2.2.3.3
			Fracture connectiveness	8.3.1.2.2.3.3
			Permeability, in situ, hydraulic, bulk	8.3.1.2.2.3.3
			Permeability, in situ, pneumatic, bulk	8.3.1.2.2.3.3
			Effective permeability to air as a function of saturation, water potential, and applied stress	8.3.1.2.2.4.1
			Effective permeability to water as a function of saturation, water potential, and applied stress	8.3.1.2.2.4.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 6 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
			UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES	
1.1	8.3.5.13	Unsaturated-zone transmissive properties	Effective porosity for single fracture	8.3.1.2.2.4.1
1.6	8.3.5.12		Permeability, effective, single fractures	8.3.1.2.2.4.1
1.10	8.3.4.2		Effective porosities of the matrix and fractures	8.3.1.2.2.4.2
1.12	8.3.3.2		Effective porosity, matrix and fractures	8.3.1.2.2.4.2
4.4	8.3.2.5		Fracture connectiveness	8.3.1.2.2.4.2
			Hydraulic conductivity	8.3.1.2.2.4.2
			Hydraulic conductivity; unsaturated to air and water as functions of water saturation and matric potential	8.3.1.2.2.4.2
			Pneumatic conductivity, fracture networks	8.3.1.2.2.4.2
			Unsaturated hydraulic conductivity to air as a function of bulk water saturation and matric potential (including determination of critical saturation)	8.3.1.2.2.4.2
			Unsaturated hydraulic conductivity to water as a function of bulk water saturation and matric potential (including determination of critical saturation)	8.3.1.2.2.4.2
			Effective porosity of matrix and fractures (including pore-size distribution of matrix)	8.3.1.2.2.4.3

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 7 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES (continued)		
		Unsaturated-zone transmissive properties (continued)	Effective porosity, bulk; fracture-matrix networks	8.3.1.2.2.4.3
			Fracture and fracture-set spacing and density	8.3.1.2.2.4.3
			Hydraulic conductivity, unsaturated, relative to air and water as a function of saturation and matric potential	8.3.1.2.2.4.3
			Permeability; (air) before and after excavation; hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Permeability; (pneumatic) bulk, fracture/matrix networks; hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Pneumatic conductivity; directional and saturation dependence; hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Unsaturated hydraulic conductivities relative to air as a function of saturation and matric potential	8.3.1.2.2.4.3
			Bulk permeability	8.3.1.2.2.4.4
			Bulk permeability, pneumatic	8.3.1.2.2.4.4
			Bulk porosity	8.3.1.2.2.4.4
			Fracture permeability	8.3.1.2.2.4.4
			Gas permeability, excavation effects	8.3.1.2.2.4.4
			Permeability (pneumatic) bulk, fractured rock	8.3.1.2.2.4.4

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 8 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES (continued)		
		Unsaturated-zone transmissive properties (continued)	Permeability (relative), gas; rock matrix	8.3.1.2.2.4.4
			Permeability (relative), water; rock matrix	8.3.1.2.2.4.4
			Permeability (saturated), gas; rock matrix	8.3.1.2.2.4.4
			Air-permeability profiles	8.3.1.2.2.4.5
			Permeability profiles	8.3.1.2.2.4.5
			Hydraulic conductivity, perched-water zones	8.3.1.2.2.4.7
			Transmissivity, perched-water zones	8.3.1.2.2.4.7
			Bulk permeability (pneumatic)	8.3.1.2.2.4.9
			Effective porosity	8.3.1.2.2.4.9
			Hydraulic conductivity (perched-water zones)	8.3.1.2.2.4.9
			Transmissivity (perched-water zones)	8.3.1.2.2.4.9
			Air permeability, matrix	8.3.1.2.2.4.10
			Water permeability, matrix	8.3.1.2.2.4.10
			Conductive properties, gas flow	8.3.1.2.2.6
			Effective porosity	8.3.1.2.2.6.1
			Fracture connectivity	8.3.1.2.2.6.1
			Fracture permeability, anisotropic	8.3.1.2.2.6.1
			Permeability, pneumatic, bulk	8.3.1.2.2.6.1
			Porosity, fracture, effective	8.3.1.2.2.6.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 9 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES (continued)		
1.1	8.3.5.13	Unsaturated-zone	Matrix porosity	8.3.1.2.2.1.1
1.6	8.3.5.12	storage properties	Moisture retention curves	8.3.1.2.2.1.1
			Flux-related, matrix hydrologic properties (storage) of geologic samples	8.3.1.2.2.3
			Matrix pore-size distribution, subsurface geologic samples	8.3.1.2.2.3.1
			Moisture retention curves, subsurface geologic samples	8.3.1.2.2.3.1
			Porosity; subsurface geologic samples	8.3.1.2.2.3.1
			Matrix pore-size distribution	8.3.1.2.2.3.2
			Porosity, total, laboratory	8.3.1.2.2.3.3
			Moisture retention, rock matrix	8.3.1.2.2.4.4
			Porosity pore-size distribution, matrix	8.3.1.2.2.4.4
			Porosity, bulk, fractured rock	8.3.1.2.2.4.4
			Porosity, matrix	8.3.1.2.2.4.4
			Storage coefficient, perched-water zones	8.3.1.2.2.4.7
			Storage coefficient (perched-water zones)	8.3.1.2.2.4.9
			Storage properties, gas phase	8.3.1.2.2.6
			Storativity, gas	8.3.1.2.2.6.1
1.1	8.3.5.13	Unsaturated-zone	Dispersivity, fractures	8.3.1.2.2.4.1
1.10	8.3.4.2	dispersive properties	Effective dispersivity for single fracture flow	8.3.1.2.2.4.1
			Flow-path tortuosity in single fractures	8.3.1.2.2.4.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 10 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE PROPERTIES (continued)		
		Unsaturated-zone dispersive properties (continued)	Tortuosity, fracture-flow paths	8.3.1.2.2.4.1
			Convective dispersivity, fracture networks	8.3.1.2.2.4.2
			Diffusive tortuosity, fractured rock and rock mass	8.3.1.2.2.4.4
			Dispersive properties, gas flow	8.3.1.2.2.6
			Convective dispersivity	8.3.1.2.2.6.1
			Fracture constrictivity	8.3.1.2.2.6.1
1.1	8.3.5.13	Unsaturated-zone diffusive properties	Matrix diffusion coefficient, fracture networks	8.3.1.2.2.4.2
			Gaseous diffusion coefficient, fractured rock units	8.3.1.2.2.4.4
			Diffusivity coefficient	8.3.1.2.2.5.1
1.1	8.3.5.13	Unsaturated-zone fault hydrologic characteristics	Air permeability, rock mass	8.3.1.2.2.4.10
1.6	8.3.5.12		Hydraulic potential, rock mass	8.3.1.2.2.4.10
1.11	8.3.2.2		Pneumatic potential, rock mass	8.3.1.2.2.4.10
1.12	8.3.3.2		Water content, rock mass	8.3.1.2.2.4.10
4.4	8.3.2.5		Water permeability, rock mass	8.3.1.2.2.4.10

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Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS		
1.1	8.3.5.13	Unsaturated-zone fluid potential	Water potential	8.3.1.2.2.1.1
1.6	8.3.5.13		Flow paths, beneath experimental infiltration plots	8.3.1.2.2.1.3
			Matric potential, beneath experimental infiltration plots	8.3.1.2.2.1.3
			Flux-related, matrix hydrologic properties (fluid potential) of geologic samples	8.3.1.2.2.3
			Matric potential, subsurface geologic samples	8.3.1.2.2.3.1
			Water potential (total), subsurface geologic samples	8.3.1.2.2.3.1
			Matric potential	8.3.1.2.2.3.2
			Pneumatic potential	8.3.1.2.2.3.2
			Pressure head, profiles	8.3.1.2.2.3.2
			Water potential, total	8.3.1.2.2.3.2
			Matric potential	8.3.1.2.2.3.3
			Pneumatic potential	8.3.1.2.2.3.3
			Potential fields (ambient), lateral variation near Solitario Canyon fault zone	8.3.1.2.2.3.3
			Water potential, total	8.3.1.2.2.3.3
			Water potential (fracture), matrix networks	8.3.1.2.2.4.2
			Hydraulic potential of matrix and rock mass	8.3.1.2.2.4.3
			Water potential, matric and rock mass	8.3.1.2.2.4.3

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 12 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)		
		Unsaturated-zone fluid potential (continued)	Water potential (total), hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Matric potential, fractured rock and rock mass	8.3.1.2.2.4.4
			Pneumatic potential, distribution	8.3.1.2.2.4.4
			Water potential (rock matrix), total fractured rock	8.3.1.2.2.4.4
			Water potential (total), perched-water zones	8.3.1.2.2.4.7
			Hydraulic head (perched-water zones)	8.3.1.2.2.4.9
			Matric potential	8.3.1.2.2.4.9
			Water potential	8.3.1.2.2.4.9
			Pneumatic potential	8.3.1.2.2.6.1
			Vapor-pressure deficit (potential), relative, soil gas	8.3.1.2.2.6.1
1.1	8.3.5.13	Unsaturated-zone fluid chemistry, temperature, and age	Hydrochemistry, ground-water	8.3.1.2.1.3.3
1.6	8.3.5.12		Flow paths from tritium analysis	8.3.1.2.2.1.2
1.10	8.3.4.2		Tritium isotopic composition	8.3.1.2.2.1.2
1.12	8.3.3.2		Chloride; soil and tuff samples	8.3.1.2.2.2.1
4.4	8.3.2.5		Chlorine-35 to chlorine-37 ratios, soil and tuff samples	8.3.1.2.2.2.1
			Chlorine-36 to chlorine ratios, soil and tuff samples	8.3.1.2.2.2.1
			Pore gas, composition	8.3.1.2.2.4.4
			Radioactive isotopes	8.3.1.2.2.4.4
			Stable isotopes	8.3.1.2.2.4.4

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 13 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)				
		Unsaturated-zone fluid chemistry, temperature, and age (continued)	Temperature, fractured rock	8.3.1.2.2.4.4
			Hydrochemical properties, perched-water zones	8.3.1.2.2.4.7
			Radioactive isotopes	8.3.1.2.2.4.7
			Stable isotopes	8.3.1.2.2.4.7
			Water quality	8.3.1.2.2.4.7
			Hydrochemistry	8.3.1.2.2.4.8
			Moisture loss (water content 0-18/0-16 and D/H ratios)	8.3.1.2.2.4.8
			Pore-gas composition	8.3.1.2.2.4.8
			Radioactive-isotope activity (C-14)	8.3.1.2.2.4.8
			Radioactive-isotope activity (Ar-39)	8.3.1.2.2.4.8
			Radioactive-isotope activity (Cl-36)	8.3.1.2.2.4.8
			Radioactive-isotope activity (tritium)	8.3.1.2.2.4.8
			Stable-isotope activity	8.3.1.2.2.4.8
			Stable-isotope ratio analyses	8.3.1.2.2.4.8
			Water quality, cations and anions	8.3.1.2.2.4.8
			Composition of formation gases	8.3.1.2.2.4.9
			Composition of formation water	8.3.1.2.2.4.9
			Radioactive and stable isotope composition	8.3.1.2.2.4.9
			Thermal potential	8.3.1.2.2.4.9
			Water chemistry (perched-water zones)	8.3.1.2.2.4.9
			Carbon-14 activity	8.3.1.2.2.4.10
			Composition of formation gases	8.3.1.2.2.4.10
			Composition of formation water	8.3.1.2.2.4.10
			Stable-isotope composition (oxygen-18, deuterium)	8.3.1.2.2.4.10

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 14 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)		
		Unsaturated-zone fluid chemistry, temperature, and age (continued)	Thermal potential, rock mass	8.3.1.2.2.4.10
			Tritium activity	8.3.1.2.2.4.10
			Gas composition	8.3.1.2.2.6.1
			Soil temperature	8.3.1.2.2.6.1
			Temperature profiles	8.3.1.2.2.6.1
			Gas chemistry and age	8.3.1.2.2.7
			Water chemistry and age	8.3.1.2.2.7
			Water-rock chemical interaction and geochemical evolution of water	8.3.1.2.2.7
			Pore-gas composition	8.3.1.2.2.7.1
			Radioactive-isotope activities in gas phase (tritium and C-14)	8.3.1.2.2.7.1
			Stable-isotope activities in gas phase (tritium and C-14)	8.3.1.2.2.7.1
			Pore water hydrochemical properties	8.3.1.2.2.7.2
			Radioactive-isotope activities in liquid phase	8.3.1.2.2.7.2
			Stable-isotope activities in liquid phase	8.3.1.2.2.7.2
			Water quality, cation and anions	8.3.1.2.2.7.2
1.1	8.3.5.13	Unsaturated-zone moisture conditions	Soil moisture content	8.3.1.2.1.3.3
1.6	8.3.5.12		Moisture content	8.3.1.2.2.1.1
1.10	8.3.4.2		Water content, gravimetric	8.3.1.2.2.1.1
1.11	8.3.2.2		Water content, saturation	8.3.1.2.2.1.2
1.12	8.3.3.2		Water content, volumetric	8.3.1.2.2.1.2

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 15 of 38)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program	
Issue	SCP section		Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)		
2.7 4.4	8.3.2.3 8.3.2.5	Unsaturated-zone moisture conditions (continued)	Flux-related, matrix hydrologic properties (moisture conditions) of geologic samples	8.3.1.2.2.3
			Moisture content (volumetric), subsurface geologic samples	8.3.1.2.2.3.1
			Water content (gravimetric), subsurface geologic samples	8.3.1.2.2.3.1
			Moisture content, time dependence	8.3.1.2.2.3.2
			Water content	8.3.1.2.2.3.2
			Water content, gravimetric	8.3.1.2.2.3.2
			Water content, saturation profiles	8.3.1.2.2.3.2
			Moisture content, lateral variation	8.3.1.2.2.3.3
			Water content, gravimetric	8.3.1.2.2.3.3
			Water content, volumetric	8.3.1.2.2.3.3
			Water content	8.3.1.2.2.4.3
			Water content of matrix and rock mass	8.3.1.2.2.4.3
			Water content, matrix	8.3.1.2.2.4.3
			Water content (gravimetric), rock mass	8.3.1.2.2.4.4
			Water content (volumetric), rock mass	8.3.1.2.2.4.4
			Moisture content, in situ degree of saturation	8.3.1.2.2.4.5
			Gravimetric moisture content	8.3.1.2.2.4.9
			Volumetric moisture content	8.3.1.2.2.4.9
			Water-content profiles	8.3.1.2.2.4.9
			Water content, matrix	8.3.1.2.2.4.10
			Water-vapor content	8.3.1.2.2.6.1

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Calls by performance and design issues		Parameter category	Response by geohydrology characterization program	
Issue	SCP section		Activity parameter	SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)		
1.1	8.3.5.13	Unsaturated-zone fluid flux	Infiltration locations	8.3.1.2.1.3.3
1.6	8.3.5.12		Infiltration rates	8.3.1.2.1.3.3
1.10	8.3.4.2		Recharge locations, rates, and history	8.3.1.2.1.3.3
1.12	8.3.3.2		Infiltration rates	8.3.1.2.2.1.1
4.4	8.3.2.5		Vegetative cover, type and density	8.3.1.2.2.1.1
			Evapotranspiration rates	8.3.1.2.2.1.2
			Flow velocities	8.3.1.2.2.1.2
			Natural infiltration	8.3.1.2.2.1.2
			Net infiltration, beneath surficial evapotranspiration zone	8.3.1.2.2.1.2
			Water flux	8.3.1.2.2.1.2
			Evapotranspiration rates, experimental conditions	8.3.1.2.2.1.3
			Flow velocities beneath experimental infiltration plots	8.3.1.2.2.1.3
			Infiltration rates (saturated and unsaturated), experimentally induced	8.3.1.2.2.1.3
			Water flux beneath experimental infiltration plots	8.3.1.2.2.1.3
			Vapor flux	8.3.1.2.2.3.1
			Water flux	8.3.1.2.2.3.1
			Hydrogeologic unit definition	8.3.1.2.2.3.2
			Flux (volumetric) through fracture-matrix networks	8.3.1.2.2.4.2
			Volumetric flux and travel time through the rock mass	8.3.1.2.2.4.2
			Water velocity (directional distributions) fracture-matrix networks	8.3.1.2.2.4.2

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 17 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)				
		Unsaturated-zone fluid flux (continued)	Directional water velocity distributions	8.3.1.2.2.4.3
			Flux, volumetric	8.3.1.2.2.4.3
			Fracture and fracture-set densities and spacings	8.3.1.2.2.4.3
			Volumetric flux and travel time through the rock mass	8.3.1.2.2.4.3
			Water velocity (directional distributions), hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Discharge, perched-water zones	8.3.1.2.2.4.7
			Flow rates, perched-water zones	8.3.1.2.2.4.7
			Flow paths, hydrochemical determination	8.3.1.2.2.4.8
			Travel times, hydrochemical determination	8.3.1.2.2.4.8
			Fluid flow, structural controls	8.3.1.2.2.6
			Gas-flow field, pre-waste emplacement	8.3.1.2.2.6
			Moisture flux, in gas phase	8.3.1.2.2.6
			Flow direction	8.3.1.2.2.6.1
			Flow velocities (air), in surface-based boreholes	8.3.1.2.2.6.1
			Flow velocity profiles	8.3.1.2.2.6.1
			Water-vapor flux	8.3.1.2.2.6.1
			Gas flow direction, flux, and travel time	8.3.1.2.2.7
			Gas transport mechanisms	8.3.1.2.2.7
			Water flow direction, flux, and travel time	8.3.1.2.2.7

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 18 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		UNSATURATED-ZONE HYDRAULIC AND GASEOUS-PHASE INITIAL AND BOUNDARY CONDITIONS (continued)		
		Unsaturated-zone fluid flux (continued)	Gas flow paths, hydrochemical determination	8.3.1.2.2.7.1
			Gas flux, hydrochemical determination	8.3.1.2.2.7.1
			Gas travel times, chemical determination	8.3.1.2.2.7.1
			Water flow paths of (O^{18} to O^{16}, deuterium to hydrogen) pore waters	8.3.1.2.2.7.2
			Water travel times (C-14 and tritium)	8.3.1.2.2.7.2
		UNSATURATED-ZONE HYDROLOGIC CONCEPTUAL/DESCRIPTIVE MODELS		
1.1 1.6	8.3.5.13 8.3.5.12	**Unsaturated-zone hydrologic conceptual/descriptive models**	Description of the scale dependence of pneumatic, hydrologic, and transport parameters	8.3.1.2.2.8.1
			Fluid and solute fluxes through variably saturated, fractured rock	8.3.1.2.2.8.1
			Liquid water matric potential; time-dependent spatial distribution (coupled heat and moisture-flow model)	8.3.1.2.2.8.2
			Validity of conceptual models describing flow and transport in variably saturated, fractured rock	8.3.1.2.2.8.2
			Boundary and initial conditions of the system	8.3.1.2.2.9.1
			Geologic framework of the system	8.3.1.2.2.9.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 19 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		UNSATURATED-ZONE HYDROLOGIC CONCEPTUAL/DESCRIPTIVE MODELS (continued)		
		Unsaturated-zone hydrologic conceptual/descriptive models (continued)	Hydrologic and other related physical processes that operate within the system under the constraints imposed by the geologic framework and the boundary and initial conditions	8.3.1.2.2.9.1
		UNSATURATED-ZONE FLOW AND SOLUTE-TRANSPORT NUMERICAL MODELS		
1.1 1.6	8.3.5.13 8.3.5.12	Unsaturated-zone flow and solute-transport numerical models	Ground-water travel time, fracture-matrix networks	8.3.1.2.2.4.2
			Ground-water travel time, hydraulic and pneumatic tests	8.3.1.2.2.4.3
			Description of the scale dependence of pneumatic, hydrologic, and transport parameters	8.3.1.2.2.9.1
			Fluid and solute fluxes through variably saturated, fractured rock	8.3.1.2.2.9.1
			Validity of numerical models describing flow and transport in variably saturated, fractured rock	8.3.1.2.2.9.2
			Boundary conditions, hydrologic (Dirichlet, Neumann, mixed, evaporative, seepage-face, evapotranspiration, etc.)	8.3.1.2.2.9.2
			Code geometry (modeled parameters)	8.3.1.2.2.9.2

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 20 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE FLOW AND SOLUTE-TRANSPORT NUMERICAL MODELS (continued)		
		Unsaturated-zone flow and solute-transport numerical models (continued)	Discretization method (finite-difference, finite-element, or integrated finite-difference)	8.3.1.2.2.9.2
			Hydrologic and coupled processes (liquid-water flow, gas-phase flow, water-vapor, heat-flow, solute transport, chemical kinetics, stress-field dynamics, two-phase flow)	8.3.1.2.2.9.2
			Matrix solver (direct or iterative)	8.3.1.2.2.9.2
			Solution methodology (Picard iteration or Newton-Raphson linearization)	8.3.1.2.2.9.2
			Boundary fluxes, pressures, and potentials	8.3.1.2.2.9.3
			Hydrologic and thermomechanical properties for the component hydrogeologic units	8.3.1.2.2.9.3
			Time-dependent spatial distribution of matric potential, liquid water, saturation, pore-gas pressure, water-vapor concentration, moisture flux, and temperature	8.3.1.2.2.9.3
			Measurement errors	8.3.1.2.2.9.4
			Probable limits of uncertainty	8.3.1.2.2.9.4
			Statistical distribution functions	8.3.1.2.2.9.4
			Land-surface net infiltration to the unsaturated zone and its distribution in space and time	8.3.1.2.2.9.5

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Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		UNSATURATED-ZONE FLOW AND SOLUTE-TRANSPORT NUMERICAL MODELS (continued)		
		Unsaturated-zone flow and solute-transport numerical models (continued)	Site geologic framework and its change with time	8.3.1.2.2.9.5
			Site water-table configuration and its change with time	8.3.1.2.2.9.5
			Spatial distribution of moisture flux within the unsaturated zone and its change with time	8.3.1.2.2.9.5
			Spatial distribution of temperature and stress within the unsaturated zone and their change with time	8.3.1.2.2.9.5
		SATURATED-ZONE HYDRAULIC PROPERTIES		
1.1	8.3.5.13	Saturated-zone transmissive properties	Hydraulic conductivity, assessment of data needs	8.3.1.2.1.3.1
1.6	8.3.5.12		Transmissivity, assessment of data needs	8.3.1.2.1.3.1
			Hydraulic conductivity	8.3.1.2.1.3.2
			Permeability	8.3.1.2.1.3.2
			Storativity	8.3.1.2.1.3.2
			Transmissivity	8.3.1.2.1.3.2
			Hydraulic conductivity, spatial distribution, concepts in regional flow model	8.3.1.2.1.4.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 22 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC PROPERTIES		
		Saturated-zone transmissive properties (continued)	Hydraulic conductivity, spatial distribution, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Hydraulic conductivity, spatial distribution, subregional cross-sectional model	8.3.1.2.1.4.3
			Hydraulic conductivity, spatial distribution, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Hydraulic conductivity, spatial distribution, regional three-dimensional model	8.3.1.2.1.4.4
			Hydraulic conductivity, saturated zone	8.3.1.2.3.1.2
			Effective porosity (bulk), estimate from earth-tide analysis of water levels	8.3.1.2.3.1.3
			Transmissivity (bulk) estimates at multiple-well test locations	8.3.1.2.3.1.3
			Hydraulic conductivity; tensor of equivalent porous media; multiple-well test locations	8.3.1.2.3.1.4
			Average linear velocity, pore water and tracers	8.3.1.2.3.1.5
			Effective porosities	8.3.1.2.3.1.5

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 23 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		SATURATED-ZONE HYDRAULIC PROPERTIES (continued)		
		Saturated-zone transmissive properties (continued)	Effective porosity, single-well and multiple-well tracer test locations	8.3.1.2.3.1.5
			Fracture permeability	8.3.1.2.3.1.5
			Average linear velocity, pore water and tracers	8.3.1.2.3.1.6
			Effective porosities	8.3.1.2.3.1.6
			Effective porosity (well-test locations throughout the site) conservative tracers	8.3.1.2.3.1.6
			Hydraulic conductivity (well-test locations throughout the site) conservative tracers	8.3.1.2.3.1.6
			Sensitivity, transmissive properties	8.3.1.2.3.3.1
			Hydraulic conductivity, effective, variation with fracture geometry	8.3.1.2.3.3.2
			Hydraulic conductivity, spatial distribution	8.3.1.2.3.3.3
1.1 1.6	8.3.5.13 8.3.5.12	Saturated-zone storage properties	Storage coefficient, assessment of data needs	8.3.1.2.1.3.1
			Porosity	8[illegible]1.2.1.3.2
			Storage coefficient	[illegible].2.1.3.2
			Effective porosity, spatial distribution, concepts in regional flow model	8.3.1.2.1.4.1
			Storage coefficient, spatial distribution, concepts in regional flow model	8.3.1.2.1.4.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 24 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC PROPERTIES (continued)		
		Saturated-zone storage properties (continued)	Effective porosity, spatial distribution, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Storage coefficient, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Effective porosity, assumptions for subregional cross-sectional model	8.3.1.2.1.4.3
			Storage coefficient, assumptions for subregional cross-sectional model	8.3.1.2.1.4.3
			Effective porosity, spatial distribution, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Storage coefficient, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Aquifer compressibility	8.3.1.2.3.1.2
			Storage coefficient, estimate from water-level fluctuations, well tests	8.3.1.2.3.1.2
			Barometric efficiency	8.3.1.2.3.1.3
			Dilatational efficiency	8.3.1.2.3.1.3
			Specific storage	8.3.1.2.3.1.3
			Storage coefficient, bulk estimates from well testing data	8.3.1.2.3.1.3
			Storage coefficient, stratigraphic variations at multiple-well locations	8.3.1.2.3.1.4
			Specific storage	8.3.1.2.3.1.6

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 25 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC PROPERTIES (continued)		
		Saturated-zone storage properties (continued)	Effective porosity, spatial distribution, assumptions for site conceptual model	8.3.1.2.3.3.1
			Sensitivity, storage properties	8.3.1.2.3.3.1
			Storage coefficient, spatial distribution, assumptions for site conceptual model	8.3.1.2.3.3.1
			Effective porosity, spatial distribution	8.3.1.2.3.3.3
			Storage coefficient, spatial distribution	8.3.1.2.3.3.3
1.1	8.3.5.13	Saturated-zone dispersive properties	Dispersion coefficients	8.3.1.2.3.1.5
1.6	8.3.5.12		Dispersivity, conservative tracers	8.3.1.2.3.1.6
			Dispersion coefficients, single-well and multiple-well tracer test locations, reactive tracers	8.3.1.2.3.1.7
			Dispersion coefficients, well-test locations throughout the site	8.3.1.2.3.1.8
1.1	8.3.5.13	Saturated-zone diffusive properties	Hydraulic diffusivity	8.3.1.2.3.1.2
			Pneumatic diffusivity	8.3.1.2.3.1.3
			Vertical hydraulic diffusivity	8.3.1.2.3.1.3

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 26 of 38)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program	
Issue	SCP section		Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC PROPERTIES (continued)		
1.1	8.3.5.13	Saturated-zone fault hydrologic characteristics	Fault zone, transmissive character	8.3.1.2.3.1.1
1.6	8.3.5.12		Hydraulic gradient	8.3.1.2.3.1.1
			Saturated hydraulic conductivity, fault zone	8.3.1.2.3.1.1
			Storage coefficient, fault zone	8.3.1.2.3.1.1
			Storage coefficients, wall rocks	8.3.1.2.3.1.1
		SATURATED-ZONE HYDRAULIC INITIAL AND BOUNDARY CONDITIONS		
1.1	8.3.5.13	Saturated-zone water potential	Ground-water flow-path directions and gradients; assessment of data needs	8.3.1.2.1.3.1
1.6	8.3.5.12		Hydrologic initial and boundary conditions; regional and subregional ground-water models; assessment of data needs	8.3.1.2.1.3.1
			Effective saturated thickness	8.3.1.2.1.3.2
			Ground-water flow directions, rates, and velocities	8.3.1.2.1.3.2
			Hydraulic gradient	8.3.1.2.1.3.2
			Hydraulic head	8.3.1.2.1.3.2
			Depth to saturation	8.3.1.2.1.3.4
			Hydraulic head, spatial distribution	8.3.1.2.1.3.4
			Hydraulic gradient, concepts in regional flow model	8.3.1.2.1.4.1
			Potentiometric surface, concepts in regional flow model	8.3.1.2.1.4.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 27 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		SATURATED-ZONE HYDRAULIC INITIAL AND BOUNDARY CONDITIONS (continued)		
		Saturated-zone water potential (continued)	Hydraulic gradient, used in subregional two-dimensional areal model	8.3.1.2.1.4.2
			Potentiometric surface, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Saturated thickness distribution, effect on flux direction and magnitudes	8.3.1.2.1.4.2
			Hydraulic gradient, used in subregional cross-section model	8.3.1.2.1.4.3
			Hydraulic gradient, used in regional three-dimensional model	8.3.1.2.1.4.4
			Potentiometric surface, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Hydraulic gradients	8.3.1.2.3.1.2
			Relative hydraulic gradients	8.3.1.2.3.1.3
			Potentiometric surface, assumptions for site conceptual model	8.3.1.2.3.3.1
			Sensitivity, potentiometric surface	8.3.1.2.3.3.1
1.1 1.6	8.3.5.13 8.3.5.12	Saturated-zone ground-water chemistry, temperature, and age	Hydrologic initial and boundary conditions (regional and subregional ground-water models), assessment of data needs	8.3.1.2.1.3.1
			Thermal conductivity, ambient heat flow	8.3.1.2.1.3.2

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 28 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC INITIAL AND BOUNDARY CONDITIONS (continued)		
		Saturated-zone ground-water chemistry, temperature, and age (continued)	Water temperature	8.3.1.2.1.3.2
			Radioisotope activities, ground water	8.3.1.2.1.3.3
			Radiometric ages, ground water	8.3.1.2.1.3.3
			Hydrochemistry, ground-water assumptions for subregional two-dimensional area model	8.3.1.2.1.4.2
			Ground-water chemical concentration	8.3.1.2.3.2.1
			Radioisotope activity	8.3.1.2.3.2.1
			Stable-isotope ratios	8.3.1.2.3.2.1
			Ground-water chemical concentrations	8.3.1.2.3.2.2
			Radioisotope activity	8.3.1.2.3.2.2
			Stable-isotope ratios	8.3.1.2.3.2.2
			Chemical concentration	8.3.1.2.3.2.3
			Radioisotope activity	8.3.1.2.3.2.3
			Stable-isotope ratios	8.3.1.2.3.2.3
			Conservative-solute transport, scale of Yucca Mountain	8.3.1.2.3.3.3
1.1 1.6	8.3.5.13 8.3.5.12	Saturated-zone ground-water flux	Discharge locations and rates, assessment of data needs	8.3.1.2.1.3.1
			Hydrologic initial and boundary conditions (regional and subregional ground-water models), assessment of data needs	8.3.1.2.1.3.1
			Recharge locations and rates, assessment of data needs	8.3.1.2.1.3.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 29 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		SATURATED-ZONE HYDRAULIC INITIAL AND BOUNDARY CONDITIONS (continued)		
		Saturated-zone ground-water flux (continued)	Evapotranspiration component of ground-water discharge	8.3.1.2.1.3.4
			Evapotranspiration rates and areal distribution	8.3.1.2.1.3.4
			Discharge, locations and rates, concepts in regional flow model	8.3.1.2.1.4.1
			Ground-water flux, concepts in regional flow models	8.3.1.2.1.4.1
			Recharge, locations and rates, concepts in regional flow model	8.3.1.2.1.4.1
			Discharge, locations and rates, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Evapotranspiration, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Ground-water flux, assumptions for subregional cross-sectional model	8.3.1.2.1.4.2
			Ground-water flux, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Hydrologic boundary conditions	8.3.1.2.1.4.2
			Recharge, locations and rates, assumptions for subregional two-dimensional areal model	8.3.1.2.1.4.2
			Discharge, locations and rates, assumptions for subregional cross-sectional model	8.3.1.2.1.4.3

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 30 of 38)

Calls by performance and design issues		Parameter category	Response by geohydrology characterization program	
Issue	SCP section		Activity parameter	SCP activity
		SATURATED-ZONE HYDRAULIC INITIAL AND BOUNDARY CONDITIONS (continued)		
		Saturated-zone ground-water flux (continued)	Recharge, locations and rates, assumptions for subregional cross-sectional model	8.3.1.2.1.4.3
			Discharge, locations and rates, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Ground-water flux, regional three-dimensional model	8.3.1.2.1.4.4
			Recharge, locations and rates, assumptions for regional three-dimensional areal model	8.3.1.2.1.4.4
			Flow rates, interborehole and intra-borehole	8.3.1.2.3.1.3
			Nature of hydraulic boundaries and conduits type of flow	8.3.1.2.3.1.3
			Average linear velocity, pore water and tracers	8.3.1.2.3.1.5
		SATURATED-ZONE HYDROLOGIC CONCEPTUAL/DESCRIPTIVE MODELS		
1.1 1.6	8.3.5.13 8.3.5.12	Saturated-zone hydrologic conceptual/descriptive models	Ground-water flow direction and magnitude based on regional hydrologic, hydrochemical, and heat-flow data	8.3.1.2.1.3

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 31 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE HYDROLOGIC CONCEPTUAL/DESCRIPTIVE MODELS (continued)		
		Saturated-zone hydrologic conceptual/descriptive models (continued)	Porosity type; matrix and fracture, regional geohydrologic units; assessment of data needs	8.3.1.2.1.3.1
			Hydraulic boundaries and conduits; scale of well tests and type of flow	8.3.1.2.3.1.3
			Aquifer heterogeneity and spatial distribution	8.3.1.2.3.1.4
			Effective porosity, spatial distribution, assumptions for site conceptual model	8.3.1.2.3.3.1
			Ground-water flux, assumptions for site conceptual model	8.3.1.2.3.3.1
			Hydraulic conductivity, spatial distribution, assumptions for site flow model	8.3.1.2.3.3.1
			Hydraulic gradient, concepts in site flow model	8.3.1.2.3.3.1
			Relations between fracture geometry characteristics and hydrologic response	8.3.1.2.3.3.2
			Relations between geophysical and hydrologic models	8.3.1.2.3.3.2

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 32 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		SATURATED-ZONE SITE AND REGIONAL-FLOW AND SOLUTE-TRANSPORT NUMERICAL MODELS		
1.1	8.3.5.13	Saturated-zone site and regional flow and solute-transport numerical models	Effective porosity	8.3.1.2.1.4
1.3	8.3.5.15		Ground-water flux	8.3.1.2.1.4
1.6	8.3.5.12		Hydraulic conductivity	8.3.1.2.1.4
			Hydraulic gradient	8.3.1.2.1.4
			Storage coefficient	8.3.1.2.1.4
			Geochemical reaction (modeling)	8.3.1.2.3.2
			Conservative-solute transport	8.3.1.2.3.3
			Effective porosity	8.3.1.2.3.3
			Ground-water flux	8.3.1.2.3.3
			Hydraulic conductivity	8.3.1.2.3.3
			Hydraulic gradient	8.3.1.2.3.3
			Storage coefficient	8.3.1.2.3.3
			Conservative-solute transport, fracture networks, steady state and transient	8.3.1.2.3.3.2
			Effective porosity, fracture networks	8.3.1.2.3.3.2
			Ground-water flux, fracture networks, steady state and transient	8.3.1.2.3.3.2
			Hydraulic conductivity, fracture networks	8.3.1.2.3.3.2
			Hydrodynamic dispersion, fracture networks	8.3.1.2.3.3.2
			Storage coefficient, fracture networks	8.3.1.2.3.3.2
			Ground-water flow paths, scale of Yucca Mountain	8.3.1.2.3.3.3

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 33 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
SATURATED-ZONE SITE AND REGIONAL-FLOW AND SLUITE-TRANSPORT NUMERICAL MODELS (continued)				
		Saturated-zone and regional flow and solute-transport numerical models (continued)	Ground-water flow velocities, scale of Yucca Mountain	8.3.1.2.3.3.3
			Ground-water flux, scale of Yucca Mountain	8.3.1.2.3.3.3
SATURATED-ZONE GEOCHEMICAL PROPERTIES				
1.1	8.3.5.13	Saturated-zone sorptive properties	Adsorption rate constants	8.3.1.2.3.1.7
			Sorption equilibrium constant	8.3.1.2.3.1.7
			Adsorption rate constants	8.3.1.2.3.1.8
			Sorption equilibrium constants	8.3.1.2.3.1.8
ROCK-UNIT GEOMETRY AND PROPERTIES				
1.1	8.3.5.13	Rock-unit contact location and configuration	Hydrostratigraphic units	8.3.1.2.1.3.2
1.6	8.3.5.12		Stratigraphic contacts, hydrogeological units	8.3.1.2.1.3.2
1.11	8.3.2.2		Contact altitude, geohydrologic units	8.3.1.2.2.3.2
1.12	8.3.3.2		Lithology from geophysical logging	8.3.1.2.2.3.2
4.4	8.3.2.5		Depth to hydrogeologic contacts	8.3.1.2.2.4.9
			Geohydrologic units, physical properties	8.3.1.2.3.1.1
1.1	8.3.5.13	Rock-unit lateral and vertical variability	Alluvium thickness	8.3.1.2.2.1.1
1.6	8.3.5.12		Rock-unit surficial slope and aspect	8.3.1.2.2.1.1
1.11	8.3.2.2		Soil texture	8.3.1.2.2.1.1

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 34 of 38)

Calls by performance and design issues: Issue	Calls by performance and design issues: SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	Response by geohydrology characterization program: SCP activity
		ROCK-UNIT GEOMETRY AND PROPERTIES (continued)		
1.12	8.3.3.2	Rock-unit lateral and vertical variability	Thickness of soil and alluvium	8.3.1.2.2.1.1
4.4	8.3.2.5		Stratigraphic variation of hydraulic properties inferred from hydraulic tests	8.3.1.2.3.1.1
			Geohydrologic unit physical properties	8.3.1.2.3.1.2
			Geophysical properties, geohydrologic units, structural features	8.3.1.2.3.1.2
1.1	8.3.5.13	Rock-unit mineralogy/petrology and physical properties	Bulk density	8.3.1.2.1.3.2
1.6	8.3.5.12		Depositional environment	8.3.1.2.1.3.2
1.11	8.3.2.2		Grain size distribution	8.3.1.2.1.3.2
4.4	8.3.2.5		Lithologies, hydrogeologic units; drill cuttings, water-table holes	8.3.1.2.1.3.2
			Porosity	8.3.1.2.1.3.2
			Bulk density	8.3.1.2.2.1.1
			Clay mineralogy	8.3.1.2.2.1.1
			Grain density	8.3.1.2.2.1.1
			Porosity, subsurface geologic samples	8.3.1.2.2.3.1
			Bulk density, rock matrix	8.3.1.2.2.4.4
			Grain density, rock matrix	8.3.1.2.2.4.4
			In situ rock physical properties	8.3.1.2.2.4.5
			Porosity	8.3.1.2.2.4.5
			Porosity, perched-water zones	8.3.1.2.2.4.7
			Bulk density	8.3.1.2.2.4.9
			Fracture weathering	8.3.1.2.2.4.9
			Grain density	8.3.1.2.2.4.9
			Matrix pore-size distribution	8.3.1.2.2.4.9

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 35 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		ROCK-UNIT GEOMETRY AND PROPERTIES (continued)		
		Rock-unit mineralogy/petrology and physical properties (continued)	Total density	8.3.1.2.2.4.9
			Pore-size distribution, matrix	8.3.1.2.2.4.10
			Porosity, matrix	8.3.1.2.2.4.10
			Matrix compressibility, inferred from barometric and earth-tide analysis	8.3.1.2.3.1.3
		FRACTURE GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Fracture distribution	Fractures	8.3.1.2.1.3.2
1.6	8.3.5.12		Lineaments	8.3.1.2.1.3.2
1.11	8.3.2.2		Fracture density	8.3.1.2.2.1.1
1.12	8.3.3.2		Fracture distribution	8.3.1.2.2.3.2
4.4	8.3.2.5		Fracture spacing	8.3.1.2.2.3.2
			Fracture distribution	8.3.1.2.2.3.3
			Fracture spacing	8.3.1.2.2.3.3
			Fracture distribution	8.3.1.2.2.4.4
			Fracture frequency, spacing, and distribution	8.3.1.2.2.4.9
			Fracture distribution and geometry from core and geophysical logs	8.3.1.2.3.1.1
			Fracture distribution, spacing and geometry from core and geophysical logs	8.3.1.2.3.1.2
			Fracture-system characteristics inferred from tracer tests, geophysical logs	8.3.1.2.3.1.5

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Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		FRACTURE GEOMETRY AND PROPERTIES (continued)		
		Fracture distribution (continued)	Fracture-system characteristics inferred from hydraulic packer and tracer tests; conservative tracers	8.3.1.2.3.1.6
			Fracture location, orientation, and density in vertical planes between wells	
1.1	8.3.5.13	Fracture orientation	Fracture orientation	8.3.1.2.2.1.1
1.6	8.3.5.12		Fracture and fracture-set orientations	8.3.1.2.2.4.3
1.11	8.3.2.2		Fracture orientation	8.3.1.2.2.4.5
4.4	8.3.2.5		Fracture orientation from core and geophysical logs	8.3.1.2.3.1.1
			Fracture orientation inferred from core and geophysical logs	8.3.1.2.3.1.2
1.1	8.3.5.13	Fracture aperture	Fracture aperture geometry	8.3.1.2.2.4.1
1.6	8.3.5.12		Fracture aperture, roughness and contact area	8.3.1.2.2.4.1
			Fracture aperture	8.3.1.2.2.4.2
			Fracture and fracture-set apertures	8.3.1.2.2.4.3
			Fracture aperture	8.3.1.2.2.4.4
			Fracture aperture distributions inferred from hydraulic tests	8.3.1.2.3.1.1
			Fracture aperture inferred from hydraulic tests, matrix properties, geophysical logs	8.3.1.2.3.1.4

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 37 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		FRACTURE GEOMETRY AND PROPERTIES (continued)		
		Fracture aperture (continued)	Fracture aperture distribution inferred from hydraulic packer and tracer tests, conservative tracers	8.3.1.2.3.1.6
1.1	8.3.5.13	Fracture length	Fracture connectivity	8.3.1.2.2.4.2
1.6	8.3.5.12		Fracture and fracture-set connectivities	8.3.1.2.2.4.3
1.11	8.3.2.2		Fracture and fracture-set length and connectiveness	8.3.1.2.2.4.3
4.4	8.3.2.5		Fracture and fracture-set lengths	
1.1	8.3.5.13	Fracture-filling mineralogy and physical properties	Fracture weathering	8.3.1.2.2.4.4
1.6	8.3.5.12		Fracture roughness	8.3.1.2.2.4.5
4.4	8.3.2.5			
		FAULT GEOMETRY AND PROPERTIES		
1.1	8.3.5.13	Fault location	Fault-zone location	8.3.1.2.2.3.3
1.6	8.3.5.12		Fault-zone location	8.3.1.2.3.1.1
1.11	8.3.2.2		Structural locations	8.3.1.2.3.1.2
1.12	8.3.3.2			
4.4	8.3.2.5			

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Table 8.3.1.2-1. Activity parameters provided by the geohydrology program that support performance and design issues (page 38 of 38)

Calls by performance and design issues: Issue	SCP section	Parameter category	Response by geohydrology characterization program: Activity parameter	SCP activity
		FRACTURE GEOMETRY AND PROPERTIES (continued)		
1.1	8.3.5.13	Fault geometry	Fault-zone effective width	8.3.1.2.2.3.3
1.6	8.3.5.12		Fault-zone orientation, width	8.3.1.2.3.1.1
1.11	8.3.2.2		Structural orientations and widths	8.3.1.2.3.1.2
1.12	8.3.3.2			
4.4	8.3.2.5			
1.1	8.3.5.13	Fault-zone mineralogy and physical properties, site area	Fault-zone mineralogy	8.3.1.2.2.3.3
1.6	8.3.5.12		Fault-zone physical properties	8.3.1.2.2.3.3
1.11	8.3.2.2			
1.12	8.3.3.2			
4.4	8.3.2.5			
		ROCK MECHANICAL PROPERTIES		
1.11	8.3.2.2	Rock-deformation	Fracture deformation	8.3.1.2.2.4.5
4.4	8.3.2.5			
1.10	8.3.4.2	Rock in situ stress, repository area	In situ stress, magnitude and orientation	8.3.1.2.2.4.5
1.11	8.3.2.2			
1.12	8.3.3.2			
4.4	8.3.2.5			

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categories that are applicable to the geohydrology program is reflected in the logic diagrams (Figures 8.3.1.2-2 through 8.3.1.2-4). In these diagrams, the categories are shown supporting specific model components that make up the various hydrologic models, from which the principal products of the geohydrology program will be derived.

The various geohydrology-related performance and design parameters listed in the performance allocation tables in Sections 8.3.2 through 8.3.5 can readily be matched to the various categories shown in Table 8.3.1.2-1. In particular, the supporting performance parameters used in resolving Issue 1.6 (ground-water travel time), as listed in Table 8.3.5.12-2, provide a close match to the activity parameters and their categories in Table 8.3.1.2-1.

As the process of integration of the geohydrology program with the design and performance issues matures, Table 8.3.1.2-1 will be modified in subsequent progress reports to include characterization parameters and associated testing bases. A characterization parameter is a parameter obtained by a characterization program that has a logical, direct tie to a performance or design parameter and for which a testing basis can be defined. Most characterization parameters will be developed from some combination of activity parameters; i.e., they will be the products of data reduction, test analyses, and modeling. An example would be unsaturated-zone flux, which will be derived from the analysis of many activity parameters obtained from a wide variety of tests.

Characterization parameters commonly will be expressed as functions of space and/or time and will be shown on maps, graphs, tables, or other formats that provide a means of synthesizing the information into a form that is usable to help resolve design and performance issues. Thus, even an activity parameter that seemingly directly supports performance and design analyses (such as saturated hydraulic conductivity) will require some analyses, to provide the appropriate spatial distribution to meet performance and design needs.

In the modifications of Table 8.3.1.2-1, which will be included in SCP progress reports, a testing basis will be included for each characterization parameter. A testing basis consists of some means of expressing the goals, confidence levels, and accuracy that is (or is expected to be) associated with each characterization parameter, in order to provide satisfactory input to the appropriate performance or design parameter requirements. For discussions of the terms "goal" and "confidence," as used in this context, see the description of performance allocation in Section 8.1.2.

The specific means of expressing the testing basis of a characterization parameter are currently being developed. For example, consider that the distribution of saturated hydraulic conductivity of the rock mass in the unsaturated zone below the repository horizon is designated as a characterization parameter. The distribution of this characterization parameter could be shown on a map. The testing basis could be that some statistical measure, such as the mean, of the values of each map unit be known to a specified degree of accuracy. If knowledge of this parameter were highly important in resolving a performance issue, such as ground-water travel time, the needed level of confidence for the accuracy of the map units would be high. Based

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on the current state of knowledge of the distribution of this parameter, the current level of confidence probably would be low.

In addition to supporting design and performance analyses, the activity parameters included in Table 8.3.1.2-1 are needed (1) to test hypotheses that support conceptual models and (2) as input to hydrologic numerical models. A common requirement for all the parameters is that sufficient confidence can be placed in their values and in the understanding of their interrelationships that they can be used with confidence for the purpose intended. Therefore, a principal strategy of the geohydrology program is to use approaches that minimize uncertainty in the values of the parameters and in the understanding of their interrelationships, within the constraints of available resources. Some degree of uncertainty is inevitable because parameters vary in space and time, measurements contain errors, and hydrologic processes are slow and difficult to measure. But, as described in the following paragraphs, the strategy of the geohydrology program is to increase confidence by using multiple approaches to parameter determination, by testing hypotheses, and by developing valid models.

Confidence in the information is increased by applying multiple approaches for determining parameters not readily amenable to measurement or analysis. Table 8.3.1.2-1 shows that many parameters listed are being generated by more than one activity. For example, infiltration, needed as a boundary condition for evaluating deeper percolation, is being assessed through monitoring of natural infiltration, characterizing hydrologic properties or surficial materials, and conducting various controlled infiltration tests. The combined effect of these investigations will be to produce reasonable confidence in the spatial distribution of infiltration rate.

Another way in which the use of multiple approaches increases confidence in the results is to measure a parameter at different scales. For example, various tests are designed to measure unsaturated fracture hydraulic conductivity at various scales, from the conductivity of a single fracture to that of an increasingly more-extensive fracture network. The results will increase confidence that an understanding has been gained of the relationship between hydraulic conductivity and fracture characteristics, and that the appropriate scale has been selected for modeling.

A major advantage to using multiple approaches for determining parameters is that, in general, reliance is not placed only on one test to determine a value for a given parameter. Because some of the tests planned for site characterization are nonstandard, the possibility that one or more tests may fail in completely achieving the desired objectives is recognized. The use of multiple approaches for determining parameter values increases confidence that the failure or the partial failure of one or more tests will not severely inhibit the ability of the characterization activities in providing the information required by the performance and design issues. In addition, prototype testing of many aspects of tests planned for site characterization, especially those related to characterization of the unsaturated zone, will be performed to increase confidence that test objectives will be achieved.

The testing and refinement of hydrologic hypotheses provide a logical and systematic approach to improving our understanding of how the geohydrologic system functions. The result is an improved conceptual model which, in

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turn, leads to increased confidence in the hydrologic models and ultimately in the geohydrologic model. As shown in Figures 8.3.1.2-2 through 8.3.1.2-4, the refinement of conceptual models also helps guide and modify the investigative program, including parameter determination. In turn, results of the program provide a basis for updating and revising the hypotheses. The net effect is a program that is efficiently directed toward the goals of the overall project and improved confidence in the outcomes.

In conducting preliminary performance and design analyses, certain assumptions must be made regarding parameter values and hydrologic processes and conditions. These preliminary analyses may include assumptions involving parameters such as flow paths, velocities, fluxes, gradients, conductivities, anisotropies, boundary conditions, and structural and stratigraphic controls on saturated and unsaturated flow. Concepts that may affect these aspects of the hydrologic system include the potential for lateral flow and capillary barriers in the unsaturated zone, the conditions under which matrix and fracture flow occur, and the development of perched water systems. The ongoing process of hypothesis testing helps to increase confidence that the assumptions made in preliminary analyses are reasonable and based on current investigative results.

The successful development of calibrated numerical models of the hydrologic flow systems increases confidence that the hydrogeologic framework, the distribution of input parameters, and the nature of initial and boundary conditions are appropriate for use in performance and design analyses. Such models can be used as tools to improve understanding of the functioning of the flow system, to test hypotheses, and to further guide data collection. Many of the specific parameters listed in Table 8.3.1.2-1, while not required directly for resolving performance and design issues, are required to accomplish satisfactory hydrologic modeling. Since model input data cannot be known explicitly everywhere throughout the modeled area, the input parameters must be expressed as statistical distribution functions. Calibration of the model to observed conditions (generally, heads measured at specific points) increases confidence that the modeled distribution of parameters is an accurate representation of actual conditions. Numerical models will be used as a principal approach to assess whether the data collected to describe the present and expected geohydrologic characteristics provide the information required by the performance and design issues. Complete validation of the flow models is not possible because of the long times for which numerical predictions must be calculated.

The models will be evaluated through a combination of peer review and comparison of model predictions with laboratory experiments, field experiments, and natural analogs, and by comparison with conceptual models that are based on hydrochemical data. Successful application of any of these methods will increase confidence that the encoded mathematical model adequately describes the physical processes of the flow system.

Alternative conceptual models

As discussed in the overview of the site characterization program (Section 8.3.1.1), hypothesis-testing tables have been constructed that summarize (1) the current hypotheses regarding how the site can be modeled and how modeling parameters can be estimated, (2) the uncertainty associated

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with this current understanding including alternative hypotheses that are also consistent with available data and that may compose an alternative conceptual model, (3) the significance of alternative hypotheses, and (4) activities or studies designed to discriminate between alternative hypotheses or to reduce uncertainty. Tables 8.3.1.2-2a and 8.3.1.2-2b summarize current understanding in modeling the regional- and site-unsaturated zone and the site saturated zone, respectively. Integration of information from different disciplines is often necessary to comprehensively evaluate alternative hypotheses. Accordingly, the hypothesis-testing tables for each site program call for information from studies and activities in other programs, as appropriate.

To help ensure comprehensiveness of the hypotheses considered in Tables 8.3.1.2-2a and 8.3.1.2-2b, hypotheses for modeling site hydrogeology have been divided into elements or components that describe the physical domain defined by the model, the driving forces/processes that operate within the hydrogeologic systems, the boundary conditions for the systems, the system internal geometry, and the system response/dynamics in response to the driving forces, boundary conditions, and system geometry. These elements are listed in column one.

The second column of the table lists the current representations for each model element in the form of hypotheses that are based on currently available data.

The third column in Tables 8.3.1.2-2a and 8.3.1.2-2b provides a judged level of uncertainty designated "high," "medium," or "low" associated with the current representation for each element. A brief rationale for the judgment is also given.

The fourth column describes alternative hypotheses to the current representation that are consistent with currently available data. As site characterization proceeds and more information becomes available, alternative hypotheses may be deleted or added or the current hypothesis may be revised and refined.

The fifth column indicates the performance measure or performance parameter that could be affected by the selection of hypotheses related to that element.

The sixth column gives the needed confidence in the indicated performance measure or performance parameter, as defined in the performance allocation tables.

The seventh column presents a judgment of the sensitivity of the performance parameters in column five to the selection of hypotheses in columns two and three for that element. The sensitivity is rated high if significant changes in the values of the performance parameter might occur if an alternate hypothesis were found to be the valid hypothesis for the system.

The eighth column presents a judgment on the need to reduce uncertainty in the selection of hypotheses. This judgment is based on the uncertainty in the current representation, the sensitivity of the performance parameters to alternative hypotheses, the significance and needed confidence of affected

Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 1 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DOMAIN				
Unsaturated zone (UZ) underlying Yucca Mountain	The UZ is defined as a distinct hydrgeologic regime	Low--dominant processes defining UZ occur over geologic time scales	UZ is undefinable because of strong short-term coupling with saturated-zone, tectonic, and thermal regimes	GWTT[a]; water inflow to the underground facility[b]	High	High--UZ is presumed to be principal natural barrier to water-borne radionuclide migration	High--integrity of UZ needs to be preserved for 10,000 yr	8.3.1.2.2.10.1, 8.3.1.2.2.10.5
				INTERNAL GEOMETRY				
Stratigraphy	The unsaturated zone comprises a finite number of discrete, statistically homogeneous hydrogeologic units	Low--layered tuffs and zones of alteration lend themselves to characterization as hydrogeologic units	Hydrologic properties are graded over space; discrete hydrogeologic units cannot be distinguished Lateral and ververcal heterogeneities preclude defining hydrogeologic unit	GWTT; radionuclide releases to the accessible environment	High	High--hypothesis defines approach to calculate GWTT and radionuclide releases to the accessible environment	Low--statistical methods could be used to calculate GWTT for completely random systems	8.3.1.2.2.3.1, 8.3.1.4.3, 8.3.1.3
Structural features Fractures Faults	Fractures and fracture systems are barriers to or conduits for liquid-water flow, depending on ambient matrix saturation	Medium--current evidence indicates that spontaneous longitudinal water flow in fractures is not initiated until matrix is at or near complete saturation	Water may move longitudinally within fractures even at low values of matrix saturation	GWTT; water inflow to the underground facility	High	High--hydrologic interaction between matrix and fractures will affect possible magnitudes of both parameters	High--hydrologic interaction between partially saturated fractures and matrix may have profound effect on conditions within UZ	8.3.1.2.2.4.1, 8.3.1.2.2.4.2, 8.3.1.2.2.9.1 8.3.1.2.2.9.2

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 2 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				INTERNAL GEOMETRY (continued)				
Structural features (continued)	Fractures and fracture systems are conduits for air and water-vapor flow in fractured tuffs	Low--experimental data indicate high efficacy of gas-phase transport in fractured tuffs	Fractures contain sufficient moisture that air and water-vapor flow is ineffective	GWTT; gas-phase radionuclude transport	High	High--gas-phase transport and local moisture balance could depend on presence of bulk gas flow in fractures	High--ambient moisture conditions in Topopah Spring may depend on hypothesis	8.3.1.2.2.7.1
	Faults are conduits or barriers to liquid water flow in welded tuff units, depending on ambient matrix saturation	Medium--fault hydraulics probably are similar to fracture hydraulics in welded tuffs	Faults are everywhere conduits for liquid-water flow in welded tuffs	GWTT; water inflow to the underground facility	High	High--rationale similar to that for fractures	High--faults transect entire UZ; their hydrologic significance needs to be assessed	8.3.1.2.2.3.3
	Faults are barriers to fluid flow in nonwelded tuff units for all matrix saturations	Low--faults and fault zones in ductile, nonwelded units, probably are sealed with fault gouge, clays, or mineralization	Faults are everywhere conduits for liquid-water flow in nonwelded tuff units	GWTT; water inflow to the underground facility	High	Medium--sealed faults would redirect water flow, but overall mass balance would be preserved	Medium--sealed faults could produce temporary perched water bodies under transient conditions	8.3.1.2.2.3.3
	Transient, nonequilibrium flow of water occurs in open fractures and faults	Low--direct and indirect evidence indicate viability of this effect in the Tiva Canyon unit	Water is rapidly imbibed into the rock matrix at the fracture boundaries	Water inflow to the underground facility	Medium	Low--such flow would likely occur in upper UZ with redistribution toward uniformity in deep UZ	Medium--may be principal mechanism by which water enters UZ as net infiltration	8.3.1.2.2.1.3

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 3 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
			INTERNAL GEOMETRY (continued)					
Structural features (continued)	Orientation of fractures and faults influences degree of transmissiveness, thereby introducing a fundamental system anisotropy	Low--open fractures and faults tend to be aligned with principal axis of greatest horizontal stress	Fractures, regardless of orientation, tend to be closed or otherwise seald by mineralization, or tend to be open	GWTT; water inflow into the underground facility	High	Medium--anisotropy produces directionally dependent flowpaths for water and air	Medium--repository design and GWTT calculations can accommodate anisotropy if known	8.3.1.2.2.4.2, 8.3.1.2.2.4.3, 8.3.1.2.2.4.4, 8.3.1.3.2.1.3, 8.3.1.3.3.3, 8.3.1.2.2.7.1
	Hydrologically interconnected fracture systems and rock matrix define a macroscopic composite or equivalent porous medium	High--hydrologic interaction between matrix and fractures remain poorly known and unquantified	Fractures and fracture systems must be regarded as distinct hydrologic entities	GWTT	High	Medium--if hypothesis is invalid, GWTT calculations will be more difficult	Medium--site-scale modeling will depend on validity of this hypothesis	8.3.1.2.2.4.2, 8.3.1.2.2.4.3
Eastward dipping fault blocks	Downdip lateral flow of liquid water occurs under spatially (and temporally) varying conditions	Low--eastward-dipping fault blocks introduce eastward gravitational component for fluid flow	All liquid-water flow within the UZ is dominated by the vertically downward gravitation force	GWTT; water inflow into the underground facility	High	Medium--phenomenon would induce redistribution of time and spatially varying water flow in UZ	Medium--a complete description of this process probably is beyond scope of the site characterization program	8.3.1.2.2.3.2, 8.3.1.2.2.1.2

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 4 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				BOUNDARY CONDITIONS				
Lower boundary condition	The water table, defined to be that spatially and temporally variable surface on which $P_w = P_{atmos}$	Low--the surface is well defined but its spatial and temporal dependence needs to be specified	The water table changes too erratically in space and time to be specifiable as a continuously connected surface	GWTT	High	High--water-table configuration beneath the repository is critical for calculating GWTT and radionuclide transport from disturbed zone to accessible environment	Medium--water-table configuration is unlikely to change significantly over next 10,000 yr	8.3.1.2.3.1.2, 8.3.1.8.3.2
Upper boundary condition	The land surface is the flux boundary for liquid water, air, and water vapor; flux across this boundary is spatially and temporally variable	Low--there exists a distinct surface of discontinuity between the land surface and the atmosphere	Note: land surface may be a zero- or uniform-flux boundary for any or all fluid phases	GWTT; water inflow to the underground facility	High	High--rates and distribution of net infiltration are needed to predict water flux and velocity fields in UZ	High--is net infiltration occurring? Damped and redistributed with depth? Capable of transient penetration into deep UZ?	8.3.1.2.2.1.1, 8.3.1.2.2.1.2, 8.3.1.2.2.1.3, 8.3.1.5.2.2.2, 8.3.1.2.2.7.1
Lateral boundary conditions	Site UZ is surrounded by a set of vertically oriented, lateral, zero-flux hydrologic boundaries	High--may be definable by fault complexes delimiting the Yucca Mountain site	Lateral inflow/outflow boundaries enclose part or all of of the site UZ hydrogeologic system	GWTT; water inflow to the underground facility	High	Low--place boundaries sufficiently distant to have no effect on repository environment	Low--but need to identify hydrologically viable boundaries	8.3.1.2.1.4.2, 8.3.1.2.1.3.3, 8.3.1.2.1.3.1

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 5 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			DRIVING FORCES/PROCESSES					
Equation of motion	Darcy's Law is applicable to the nonwelded tuff units	Low--nonwelded units generally are characterized by high porosities and large values of K_{sat}	None identified	GWTT; water inflow to the underground facility	High	High--Darcy's Law forms basis for calculating liquid-water fluxes and velocities in the rock matrix	Low--nonwelded tuffs probably satisfy conditions for validity of Darcy's Law	8.3.1.2.2.3.1
	Darcy's Law is applicable to the welded tuff units	Medium--effective porosity is unknown; K_{sat} values are near lower limit pf meaningful measurement	Storage and flow of liquid water in welded tuff units is controlled by surface adsorption within sparse, interconnected pores	GWTT; water inflow to the underground facility	High	Same as above	High--pore distribution in welded tuffs may not permit Darcian flow approximation	8.3.1.2.2.3.1
	Barometrically induced forced convection across surface drives airflow in hydrologically integrated fracture systems	High--effect is only observed in boreholes that penetrate and disturb present system	Water-vapor pressure and liquid-water capillary presure are in equilibrium within fractures that don't intersect land surface	Water inflow to the underground facility	Medium	Medium--appreciable forced convection of air will affect moisture distribution in repository environment	Low--repository design does not require precise data for this possible process	8.3.1.2.2.7.1
	Existing geothermal temperature gradient induces free convection within integrated fracture systems	High--fracture tortuosity impedes free thermal convection	Moisture balance in highly fractured zones is determined by both water-vapor and liquid-water movement	Water inflow to the underground facility	Medium	Same as above	Same as above	8.3.1.2.2.7.1

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 6 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				DRIVING FORCES/PROCESSES (continued)				
Equation of motion (continued)	Molecular diffusion of water vapor in fractures occurs under existing geothermal temperature gradient	Medium--geothermal gradient induces upwardly decreasing water-vapor concentrations, but diffusion flux is small	None identified	Water inflow to the underground facility	Medium	Low--phenomenon probably would induce little effect on rock-matrix moisture distribution	Low--probably of negligble consequence	8.3.1.2.2.7.1, 8.3.1.2.2.5.1
	Changes in the tectonic environment cause changes in fracture hydrologic properties	Low--e.g., fracture apertures and orientation of open fractures depend on directions of principal horizontal stress	None identified	GWTT; water inflow to the underground facility	High	Medium--changing fracture properties could affect spatial distribution of possible transient effects in deep UZ	Medium--local stress fields within UZ probably change slowly with geologic time	8.3.1.8.3.3.1, 8.3.1.8.3.3.2, 8.3.1.8.3.3.3
	Nonequilibrium saturation profiles indicate net downward vertical liquid water flow	Medium--complete saturation profiles for UZ are not yet available	Upward water-vapor migration and downward liquid-water percolation define a steady-state circulation system; $S_w(Z) < S_R(Z)$; S_w value may pertain to "capillary fringe" above the water table	GWTT; water inflow to the underground facility	High	Low--assumption of vertical liquid-water flux consistent with local saturation values and unit hydraulic gradient assumption yields upper flux boundary	Low--present S_w values will yield upper-bound values for present vertical downward liquid-water fluxes	8.3.1.2.2.3.2

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 7 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
			DRIVING FORCES/PROCESSES (continued)					
Conservation of mass	Moisture storage within the rock matrix and the interstitial pore space is partitioned among (1) capillary water, (2) adsorbed water, (3) water of hydration, and (4) water vapor	Low--uncertainty arises in quantifying the spatial and temporal distributions of the partitioning	Moisture storage within the UZ consists of uncoupled processes involving capillarity, adsorption, water vapor, and water of hydration	GWTT; water inflow to the underground facility	High	High--ambient liquid-water saturations depend on moisture storage and release mechanisms	Low--there are no other known mechanisms operating within the UZ	8.3.1.2.2.3.1, 8.3.1.3.2.2.2, 8.3.1.3.3.3
	Liquid water and water-vapor tend to be in thermodynamic phase equilibrium within the rock-matrix pore space	Medium--liquid-water and water-vapor migration in pores is slow compared with time required to establish equilibrium	None identified	Water inflow to the underground facility	Medium	Low--only local, transient, temporary departures from local thermodynamic equilibrium (LTE) are likely to occur	Low--local departures would produce small, temporary effects	8.3.1.2.2.3.2, 8.3.1.2.2.7.1, 8.3.1.15.2.2.1
	Nonthermal equilibrium distributions of water vapor may occur in fracture and fault openings	Medium--bulk air flow would tend to disrupt distribution of water vapor-pressure equilibrium	None identified	Water inflow to the underground facility	Medium	Low--effects probably would be restricted to matrix near fractures	Low--phenomenon would have little effect on possible water inflows to resposi-tory	8.3.1.2.2.3.2, 8.3.1.2.2.3.3

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 8 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				DRIVING FORCES/PROCESS (continued)				
Conservation of mass (continued)	Volumes containing many pores are definable such that changes in boundary fluxes are equal to changes in internal moisture content	Medium--probably true in nonwelded tuffs; depends on density and hydrologic properties of fractures in welded tuffs	Dynamic state of system precludes defining simultaneous values of flux and moisture content	GWTT; water inflow to the underground facility	High	High--hypothesis is basis for the application of Richard's equation for water flow in UZ	High--need to ensure applicability of Darcian flow in welded tuffs	8.3.1.2.2.3.1
	Volumes containing many pores and fractures are definable such that changes in boundary fluxes equal changes in internal moisture storage	High--this is the representative elementary volume (REV) concept applied to macroscopically highly fractured (welded) tuffs	Fractures and fracture networks must be treated as distinct hydrologic entities	GWTT; water inflow to the underground facility	High	Medium--REV concept for combined fractures and matrix simplifies numerical hydrologic modeling	Medium--site-scale modeling will be difficult if hypothesis is invalid	8.3.1.2.2.4.8
	Release or absorption of crystalline water of hydration will not significantly affect UZ saturation or moisture flux distributions	Low--the phenomenon can occur but probably would involve only small volumes of water	Sufficient water release could occur locally to affect moisture-flow pathways and fluxes	GWTT; water inflow to the underground facility	High	Medium--resulting increase or decrease of saturation would affect moisture fluxes and pathways	Medium--appreciable changes in present thermal or stress fields would be required to produce significant effects	8.3.1.3.2.2.2

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 9 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
			DRIVING FORCES/PROCESSES (continued)					
Conservation of mass (continued)	Tectonic events are unlikely to affect rock-matrix fluid-storage properties within the UZ hydrogeologic system	Low--pore-size distributions within the UZ are largely independent of prevailing tectonic environment	Episodic or cyclic tectonic processes or events will alter rock-matrix pore-size distributions	Water inflow to the underground facility	Medium	Low--only small total quantities of water probably would be involved	Low--effects on repository environment in UZ would be small	8.3.1.8.3.3, 8.3.1.3.2.2.2, 8.3.1.3.3.3
	Perched-water bodies and capillary-barriers may be temporarily present with the UZ system	High--perched water bodies and capillary barriers are intrinsically unstable hence, can occur only under transient conditions	Localized water inflows to the UZ are sufficient to sustain a perched-water body or capillary barrier in a quasi-stable state	GWTT; water inflow to the underground facility	High	Medium--conditions to produce naturally occuring perched-water bodies in repository environment probably are lacking	Medium--perched-water bodies probably are transient phenomena and would disperse if they are formed	8.3.1.2.2.4.7
Conservation of energy	Although presence of the geothermal temperature gradient viti-global isothermal approximation, local thermodynamic equilibrium (LTE) can be assumed for localized regions within the system	Low--Darcy's Law, for example, remains valid locally if one refers it to the ambient temperature	System is in such a highly dynamic state that LTE is nowhere established or maintained within the system	GWTT; water inflow to the underground facility	High	High--Darcy's Law becomes invalid for highly nonisothermal fluid flow	Low--system is unlikely to be in such a thermally dynamic state	8.3.1.2.2.3.1, 8.3.1.2.2.3.2, 8.3.1.2.2.3.3

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 10 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
SYSTEM DYNAMICS/RESPONSE								
System dynamics/ response	Nonwelded Calico Hills unit (CHnw) is the principal hydrochemical barrier to water-borne radionuclide transport between disturbed zone and accessible environment	Medium--CHnw is a thick (100 to 400 m) sparsely fractured, partially zeolitized tuff of low to medium saturated hydraulic conductivity	Flowpaths and fluxes in CHnw are such that they do not significantly impede radionuclide transport from disturbed zone to accessible environment	Radionuclide releases to the accessible environment	High	High--if CHnw is not an effective barrier, then possible rapid transport from disturbed zone to accessible environment could occur	High--hydrologic and geochemical properties of CHnw need to be well understood and quantified	8.3.1.2.2.3.1, 8.3.1.2.2.3.2, 8.3.1.2.2.4.6, 8.3.1.3.2, 8.3.1.3.3, 8.3.1.4.3, 8.3.1.8.4
	Climatic changes are unlikely to produce significant large-scale effects within the UZ hydrogeologic system during the next 10,000 yr	High--paleoclimatic data indicate past occurrences of major climatic changes within 10,000-yr intervals	Climatic changes and episodic variations are likely to occur and affect UZ hydrogeologic system	GWTT; water inflow to the underground facility	High	High--climatic changes may result in increased net infiltration and subsaturation and moisture-flux distributions within the UZ hydrogeologic system	High--assessment of future repository performance depends on moisture fluxes and flowpaths within the UZ	8.3.1.5.2.2.2
	Renewed faulting at Yucca Mountain is unlikely to significant local or large-scale effect on the UZ hydrogeologic system	Low--local fault movement would produce transient, temporary, localized effects within the UZ hydrogeologic system	Episodic or cyclic faulting may cause corresponding large-scale changes in the moisture flux distribution in the UZ	GWTT; water inflow to the underground facility	High	Low--because effects would tend to be localized and temporary	Low--frequency of occurrence and magnitude of effects probably are low	8.3.1.8.3.1.3, 8.3.1.8.3.1.4, 8.3.1.8.3.1.5, 8.3.1.8.3.2.5, 8.3.1.8.3.2.6, 8.3.1.8.4.1.3

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 11 of 16)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				SYSTEM DYNAMICS/RESPONSE (continued)				
System dynamics/ response (continued)	Volcanism is unlikely to affect the UZ hydrogeologic system during the next 10,000 yr	Medium--frequency of occurrence and magnitude of effects are incompletely known	Episodic or cyclic volcanism may cause corresponding large-scale changes in the moisture flux distribution in the UZ	GWTT; water inflow to the underground facility	High	High--volcanism could produce significant thermal-mechanical effects on the UZ hydrogeological system	Low--event is unlikely to occur during next 10,000 yr	8.3.1.8.3.1.1, 8.3.1.8.3.1.2
	Igneous intrusions are unlikely to disrupt the UZ hydrogeologic system during the next 10,000 yr	Medium--frequency of occurrence and magnitude of effects are incompletely known	Episodic or cyclic igneous intrusions may cause corresponding large-scale change in the moisture flux distribution in the UZ	GWTT; water inflow to the underground facility	High	High--igneous intrusions could produce significant thermal-mechanical effects on the UZ hydrogeological system	Low--event is unlikely to occur during next 10,000 yr	8.3.1.8.3.2.1, 8.3.1.8.3.2.2
	Uplift or subsidence of Yucca Mountain block is unlikely to affect the UZ hydrogeologic system during the next 10,000 yr	Medium--frequency of occurence and magnitude of effects are incompletely known	Large-scale uplift or subsidence will produce corresponding effects on the UZ hydrogeologic system	GWTT	High	Medium--the degree to which flowpaths and the water-table configuration would change is not known	Low--appreciable uplift or subsidence is unlikely to occur during next 10,000 yr	8.3.1.8.3.1.7, 8.3.1.8.3.1.4

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 12 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				SYSTEM RESPONSE/DYNAMICS (continued)				
System dynamics/ response (continued)	Pore-water chemical and isotopic composition reflects pore-water source regions and mechanisms	Medium--chemical and isotopic concentrations may be altered by pore-water interaction with rock matrix	Chemical and isotopic concentrations may be nondiagnostic mixture of waters from different sources	GWTT	High	Low--isotopic concentration alone is insufficient to determine source of UZ water	Medium--isotopic and anionic concentrations could be used as supporting if not definitive evidence for source of UZ water	8.3.1.2.2.8.2, 8.3.1.3.1.1, 8.3.1.3.2.2, 8.3.1.3.3.3
	Present UZ moisture flow system is derived from present and past net infiltration from above	Medium--rates of possible net infiltration and distributions in time and space are unknown	System below the Paintbrush unit is in quasi-equilibrium due to upward water-vapor migration and downward liquid-water percolation; consequently, there is no effective net percolation of water into the Topopah Spring and lower units Moisture in the UZ is a remnant of past rises of the water table	GWTT; water inflow to the underground facility	High	High--if hypothesis is valid, it will determine spatial and temporal distribution of water flux in repository environment	High--need to establish most probable bounds on rates and areal distribution of possible net infiltration and percolation below the Paintbrush nonwelded unit	8.3.1.2.2.3.2, 8.3.1.2.2.1.2

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 13 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DATA-REDUCTION MODELS (continued)				
Data-reduction models (continued)	Liquid water flux in rock matrix can be calculated from Darcy's Law	Low for nonwelded tuffs Medium for welded tuffs where adsorption effects may dominate	Application of Darcy's law results in inaccurate calculation of flux in welded tuffs	GWTT; water inflow to the underground facility	High	High--need accurate fluxes to estimate GWTT	High--calculations of system state and performance must be consistent with actual system dynamics	8.3.1.2.2.3.1
	Dupuit-Forchheimer assumption (fluid pore velocity = Darcian flux divided by rock-matrix porosity) applies	Medium--uses volume-averaged data to calculate a localized quantity; tends to underestimate true water-particle velocity	A random-walk model is a more appropriate approach	GWTT; water inflow to the underground facility	High	High--standard but not fully validated method for calculating pore-water velocities	High--need to know the fastest modes of pore-water movement	8.3.1.2.2.3.1, 8.3.1.2.2.9.3, 8.3.1.2.2.2.1
	Discrete fractures and fracture networks can be modeled as equivalent porous media	High--intuitively plausible, but mechanisms of fluid flow in partially saturated known and unquantified	Fluid flow in fractures is inherently dynamic and cannot be treated by simple global models	GWTT; water inflow to the underground facility	High	High--hydrologic significance of fractures under partially saturated conditions remains poorly known and unquantified	High--quantified mechanisms of matrix-fracture interactions and bounding uncertainties need to be known	8.3.1.2.2.4.1, 8.3.1.2.4.1.2, 8.3.1.2.4.1.3, 8.3.1.2.2.9

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 14 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			SYSTEM RESPONSE/DYNAMICS (continued)					
System dynamics/ response (continued)	Pore water in the UZ is in local solutional equilibrium with the surrounding rock matrix	Low--water movement in the rock matrix is sufficiently slow to permit establishment of solutional equilibrium	None identified	Waste container corrosion	Medium	High--waste container design must allow for possible contact with water in UZ	Low--It is highly unlikely that pore water in deep UZ is not in equilibrium with the surrounding rock matrix	8.3.1.2.2.8.2, 8.3.1.3.2.2, 8.3.1.5.2.1.2, 8.3.1.5.2.1.5, 8.3.1.3.3.3
			DATA-REDUCTION MODELS					
Data-reduction models	Rock-matrix hydrologic properties are defined by Darcian theory of fluid flow	Low for nonwelded tuffs Medium for welded tuffs	Use random-walk models to calculate synthetic flow-path and fluid-velocity distributions	GWTT; water inflow to the underground facility	High	High--need pore-water velocities to calculate GWTT	High--definition of hydrologic properties must be consistent with actual system state and processes	8.3.1.2.2.3.1, 8.3.1.2.2.2.1, 8.3.1.2.2.8.2, 8.3.1.2.2.4.6
	Matric potential is definable and measurable in terms of capillarity/ adsorption theory (Kelvin equation)	Low--hypothesis, however, presumes local thermodynamic equilibrium	Local thermodynamic equilibrium is nowhere established within UZ; hence, standard capillary theory does not apply	GWTT; water inflow to the underground facility	High	High--fluid flux calculations require measured in situ potential gradients	Low--definition of hydrologic functions must be consistent with actual system state and processes	8.3.1.2.2.3.1, 8.3.1.2.2.3.2

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 15 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			SYSTEM RESPONSE/DYNAMICS (continued)					
System dynamics/ response (continued)	Liquid water flux in Topopah Spring rock matrix is distributed in space but is generally directed vertically downward	Medium--moisture fluxes have yet to be reliably computed or estimated	Rate of downward liquid-water flux may be approximately equal to upward directed water-vapor flux; Calico Hills unit defines vertical extent of the capillary fring above the water table	GWTT; water inflow to the underground facility	High	Low--if flow is otherwise, need to account for it in GWTT calculations and assessment of water flow in repository environment	High--hypothesis establishes boundary condition at base of Topopah Spring unit for GWTT calculations	8.3.1.2.2.3.2, 8.3.1.2.2.4.6
	Hydrologic system below the Paintbrush nonwelded unit is in approximate steady-state dynamic equilibrium	High--hypothesis depends on rapid damping of transient effects, (e.g., infiltration events in the upper UZ)	Transient effects penetrate deep into or through the UZ via faults and fractures	Water inflow to the underground facility	Medium	Low--assessment of moisture content and change in repository environment must allow for dynamic conditions	High--hypothesis, if approximately valid, would facilitate predictive numerical hydrologic modeling of the system	8.3.1.2.2.3.2
	Liquid-water flow in the Topopah Spring is restricted to the rock matrix	Medium--available sparse saturation data indicate that saturations in Topopah Spring unit is too low to induce spontaneous flow in fractures	Longitudinal flow of water in fractures may occur locally or episodically over a wide range of rock-matrix saturations	Water inflow to the underground facility	Medium	Medium--dynamically changing water flow in fractures probably would affect moisture content and flow near repository	High--dynamics of matrix-fracture hydrologic interactions needs to be elucidated	8.3.1.2.2.3.2, 8.3.1.2.2.3.3

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Table 8.3.1.2-2a. Current representation and alternative hypotheses for unsaturated-zone hydrologic system conceptual models for the geohydrology program (page 16 of 16)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DATA-REDUCTION MODELS (continued)				
Data-reduction models (continued)	The rock-matrix hydrologic properties within distinct hydrogeologic units can be characterized by using classical-statistical and geostatistical methods	Low--present stratigraphic data indicate that the layered tuffs within the UZ, can be subdivided into statistically characterizable hydrogeologic units	Macroscopic vertical and lateral lateral heterogeneity within the layered tuffs precludes statistical characterization within the site doma...	GWTT; radionuclide transport from disturbed zone to accessible environment	High	High--GWTT and radionuclide transport calculations depend on presence of statistically characterizable hydrogeologic units and properties	High--statistical characterization of hydrogeologic units is required to (1) estimate statistics of radionuclide release to accessible environment and of GWTT distributions, and (2) estimate errors in UZ flux calculations	8.3.1.2.2.3.1, 8.3.1.2.2.1.1, 8.3.1.2.2.9.4, 8.3.1.3.4.1.5, 8.3.1.4.2
	Laboratory-scale measurements of matrix hydrologic properties can be extrapolated to evaluate field-scale problems	High--laboratory scale "point" measurements are unlikely to be representative of large-scale dynamics	Laboratory-scale measurements of matrix hydrologic properties exceed both REV dimensions and field-scale statistical correlation lengths	GWTT; radionuclide transport from disturbed zone to accessible environment	High	High--liquid-water and gas-phase fluxes depend on properly defined hydrologic properties	High--need to obtain classical statistical and geostatistical data to assess error of extrapolation to field-scale problems	8.3.1.2.2.3.1, 8.3.1.2.2.1.1, 8.3.1.3.4.1.5, 8.3.1.3.7.2

[a]GWTT refers to pre-waste-emplacement ground-water travel time.
[b]Water inflow to the underground facility includes any and all water that may enter the facility from the unsaturated zone during preclosure and postclosure conditions.

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the geohydrology program (page 1 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DOMAIN				
Regional saturated zone (SZ) hydrogeologic system	The regional SZ system is defined approximately by the hydrogeologic study area	Medium--hydrogeologic boundaries for the regional SZ flow system are not well defined	Larger (or smaller) area should be considered in evaluating regional SZ flow system	GWTT*, radionuclide transport in the SZ, radionuclide transport in the UZ	High	High--the SZ is the main path for radionuclide transport from the unsaturated zone (UZ) to the accessible environment; definition of regional system domain affects SZ flux and flow paths beneath Yucca Mountain; water-table elevation is sensitive to boundary conditions	Medium--based on uncertainty	8.3.1.2.1
Subregional SZ hydrogeologic system	The subregional SZ system is defined by the Alkali Flat/Furnace Creek Ranch subbasin	Medium--hydrogeologic boundary conditions for the sub-basin are not well established	The subregional SZ is defined by the Franklin Lake playa (Alkali Flat) subbasin; discharge that occurs at Furnace Creek Ranch is from a separate deep carbonate aquifer system	GWTT*, radionculide transport in the SZ; radionuclide transport in the UZ	HIgh	High--the SZ is the main path for radionuclide transport from UZ to the accessible environment; definition of subregional system domain affects SZ flux and flow paths beneath Yucca Mountain; water-table elevation is sensitive to boundary conditions	Medium--based on uncertainty	8.3.1.2.1, 8.3.1.2.3

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 2 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DOMAIN (continued)				
Site SZ hydrogeologic system	The site SZ system is defined by the boundary of the accessible environment	Medium--specification of site boundaries will have a large effect on distance used for GWTT calculations	None identified	GWTT; radionuclide transport in the SZ	Low	High--the SZ is the main path for radionuclide transport from the UZ to the accessible environment; definition of site-system domain affects length of SZ flow path to accessible environment	Low--based on needed confidence	8.3.1.2.1.3.2
Hydrogeologic units	Ground-water flow occurs in a complex framework of Paleozoic, Tertiary, and Quaternary rocks and sediments within the regional flow system, among which identifiable hydrogeologic units can be defined	Medium--borehole and surface-based observations indicate the presence of multiple hydrogeologic units of various ages and hydraulic properties, but the spatial relation is poorly defined	Variations of hydraulic properties within lithologic units is as great as among them; thus, no meaningful subdivision into hydrogeologic units can be made	GWTT; radionuclide transport in the SZ; radionuclide transport in the UZ	High	High--GWTT and transport characteristics are largely dependent on hydrogeologic units; transient behavior of water-table elevation is dependent on properties of hydrogeologic units	Medium--based on uncertainty	8.3.1.2.3.1

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 3 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				DOMAIN (continued)				
Hydrogeologic units (continued)	Flow of interest at Yucca Mountain occurs primarily through fractured Tertiary volcanic rocks; this system is separated from and lies above a deeper regional carbonate aquifer system with higher hydraulic head	Medium--in one drillhole (UE-25 p#1) the hydraulic head in a carbonate-aquifer unit underlying the Tertiary volcanic units is about 20 m higher than in the overlying units; but data are few and structure complex	Paleozoic carbonate unit plays a significant role in flow system beneath the site; areas exist where the carbonate aquifer is missing, has flow system that is interconnected with overlying volcanics, or has lower hydraulic head	Same as above	High	High--SZ GWTT and transport characteristics are largely dependent on hydrogeologic units; transient behavior of water-table elevation is dependent on properties of hydrogeologic units	Medium--based on uncertainty	8.3.1.2.1.3.2, 8.3.1.2.3.1
Structural Features								
Fractures	Fractures in Tertiary volcanic rocks serve as principal pathways for ground-water flow	Low--borehole and surface-based observations indicate that most Tertiary volcanic tuff units are highly fractured, and that fracture permeability is much greater than matrix permeability	None identified	Same as above	High	High--flow in fractures has a large effect on SZ and GWTT and transport characteristics and on transient response and storage characteristics	Low--based on uncertainty	8.3.1.2.3.1.3, 8.3.1.2.3.1.4

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 4 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DOMAIN (continued)				
Fractures (continued)	Fracture permeability decreases with increasing depth in tuffaceous units at Yucca Mountain	Low--observations from borehole flow surveys show a systematic decrease in fracture permeability with depth	Large fracture permeability occurs even at great depths	Same as above	High	High--GWTT; transport characteristics and transient response of water table are largely dependent on permeability of rock	Low--based on uncertainty	8.3.1.4.2.2.2, 8.3.1.4.2.2.3, 8.3.1.4.2.2.4
Faults	None selected	High--evidence indicates that some faults, such as Solitario Canyon fault, may act as barriers, whereas others, such as faults east of Yucca Mountain, may act as conduits	Faults are either barriers or conduits to ground-water flow and have a large effect on ground-water flow direction and and magnitude, and on transport characteristics	Same as above	High	High--the permeability of a fault or fault zone has a large effect on SZ GWTT and transport characteristics, and transient behavior of SZ flow system	High--response of water-table elevation to increased recharge or tectonic changes may be very sensitive to the permeability of fault zones	8.3.1.2.1.3.2, 8.3.1.2.3.1.1, 8.3.1.2.3.1.2, 8.3.1.2.3.1.4
Lineaments	None selected	Medium--lineaments may have a substantial effect on the ground-water flow system	Lineaments may act as either conduits or barriers to ground-water flow and may be associated with regional-scale fault or fracture systems	Same as above	High	High--the permeability of a lineament zone has a large effect on SZ GWTT time, transport characteristics, and transient response	Medium--based on uncertainty	8.3.1.2.1.3, 8.3.1.2.3.1.2, 8.3.1.2.3.1.3, 8.3.1.2.3.1.4

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 5 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				BOUNDARY CONDITIONS				
Upper boundary	The water table is the upper boundary of the SZ ground-water flow system	Low--evidence from drillhole tests shows the SZ as being unconfined and responding as if it had	None identified	Same as above	High	High--transient models of ground-water flow, used to estimate SZ GWTT, transport characteristics, and transient responses of water-table elevation are dependent on the specification of confined versus unconfined upper boundary conditions	Low--based on uncertainty	8.3.1.2.3.1.2
	Average recharge to the SZ at Yucca Mountain through the UZ is small	High--no direct evidence is available to estimate recharge directly; annual precipitation at Yucca Mountain is small, resulting in probable small amounts of recharge, but areal variations in recharge may be substantial	Localized recharge through fractures and or fault zones is substantial	GWTT; radionuclide transport in the UZ[b], radionuclide transport in the SZ	High	High--GWTT and transport in the UZ and SZ are directly affected by amount of recharge	High	8.3.1.2.1.1, 8.3.1.2.1.2, 8.3.1.2.1.3.3, 8.3.1.2.1.3.4

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 6 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
			BOUNDARY CONDITIONS (continued)					
Upper boundary (continued)	Discharge from the subregional SZ flow system occurs primarily as evapotranspiration at Franklin Lake playa, minor evapotranspiration within the Amargosa Desert, and spring flow that occurs at Furnace Creek Ranch from Paleozoic carbonate unit	Medium--potentiometric data indicate a continuum of the flow system from Yucca Mountain to known discharge areas at Franklin Lake playa; origin of spring flow at Furnace Creek Ranch is uncertain	Discharge from the subbasin is restricted to discharge occurring as evapotranspiration at Franklin Lake playa and minor amounts elsewhere in the Amargosa Desert	Same as above	High	High--SZ GWTT and transport characteristics are directly affected by location and rate of discharge	Medium--based on uncertainty	8.3.1.2.1.3.4, 8.3.1.2.1.4
	Recharge to the regional SZ flow system occurs primarily at Rainier and Pahute mesas	Low--potentiometric and hydrochemical data show a direct source to groundwater at Yucca Mountain	Primary recharge to SZ flow system at Yucca Mountain occurs from upward leakage from underlying Paleozoic carbonate rocks, or is areally distributed, occurring beneath washes throughout the subbasin	Same as above	High	High--SZ GWTT and transport characteristics are directly affected by location and rate of recharge	Low--based on uncertainty	8.3.1.2.1.1, 8.3.1.2.1.2.1, 8.3.1.2.1.3.3

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 7 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
			BOUNDARY CONDITIONS (continued)					
Upper boundary (continued)	A substantial amount of recharge to the SZ occurs along Fortymile Wash	High--little data exist to determine the extent and rate of recharge in Fortymile Wash	Recharge along Fortymile Wash is minor	GWTT; radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	High--SZ and UZ GWTT and transport characteristics are directly affected by location and rate of recharge at and near the site	High--recharge at Fortymile Wash may be one of the most critical boundary conditions affecting SZ and UZ at Yucca Mountain	8.3.1.2.1.3.3
	Water-table mounds and perched-water bodies originate primarily from water infiltrating from above	Medium--testing of perched or mounded water has not been sufficient to develop a complete understanding of the origin of this water	Water-table mounds and perched water are the result of geothermal and/or seismic pumping of deep-seated ground water	Same as above	High	Medium--upward migration of deep-seated ground water would have a large effect on GWTT and water-table altitude	Medium--based on uncertainty and sensitivity	8.3.1.2.2.4.7, 8.3.1.2.3.1.2

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 8 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				BOUNDARY CONDITIONS (continued)				
Lower boundary	Lower boundary is the base of the Tertiary units (volcanics and basin-fill sediments), across which little or no flow occurs	High--few data exist at depth to establish lower flow or no-flow boundary conditions, or lithologies therein; evidence indicates that the number of open fractures decreases with increasing depth, and potentiometric data from several drillholes indicate increasing head with increasing depth	Lower boundary is the base of the Tertiary units (volcanics and basin-fill sediments), across which substantial upward or downward leakage occurs Lower boundary is undefined; substantial circulation of flow occurs via deep-seated, thermally driven convection cells or seismic pumping through open vertically interconnected fracture networks	Same as above	High	Medium--position of boundary and amount and direction of flux across it significantly affects GWTT, transport through the SZ to the accessible environment, and the response of the water-table elevation to temporal changes	Medium--based on sensitivity	8.3.1.2.2.9.3

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 9 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				BOUNDARY CONDITIONS (continued)				
Lateral boundary								
Subregional	Subbasin lateral boundaries are no-flow boundaries, consisting of either streamlines or ground-water divides, except for flux boundaries, specified as follows: (1) throughflow from the Timber Mountain region; (2) throughflow from the western Amargosa Desert; and (3) throughflow from the Ash Meadows springline	Medium--observations of hydraulic-head distribution indicate that these probably are appropriate descriptions of the boundary conditions of the subregional ground-water flow system of Yucca Mountain and vicinity; but data are sparse and unevenly distributed	Lateral boundaries should be defined to exclude ground-water discharge at Furnace Creek Ranch in Death Valley; other lateral boundaries could be defined	Same as above	Low	Medium--exclusion of spring discharge at Furnace Creek Ranch would have a significant effect on estimates of ground-water flow direction and magnitude at Yucca Mountain; the position of other lateral boundaries probably would have minimal effect	Low--based on needed confidence	8.3.1.2.1

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 10 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				BOUNDARY CONDITIONS (continued)				
Lateral boundary (continued)								
Site	No natural lateral flow boundaries occur that would logically define the boundaries of the site, therefore, lateral site boundary conditions will be specified at the accessible environment, based on results obtained from regional ground-water flow models	Medium--boundary flux specifications will be only as reliable as the results from the regional models of ground-water flow	None identified	Same as above	Low	High--estimates of GWTT and water-table altitude will depend in large part on model results	Low--based on needed confidence	8.3.1.2.1.4
Temporal	Under present-day conditions, boundary locations and fluxes are considered invariant with time	Low--water-table altitude variations are small relative to the total effective saturated thickness	Active and expected future tectonic and thermal processes may cause substantial changes in water-table altitude	GWTT; radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	High--a knowledge of the temporal changes in water-table altitude is important for estimating long-term water-table altitude	Low--based on uncertainty	8.3.1.2.1, 8.3.1.2.3.1, 8.3.1.2.3.2

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 11 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance: Needed confidence in parameter or performance measure	Significance: Sensitivity of parameter or performance measure to hypothesis	Significance: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				BOUNDARY CONDITIONS (continued)				
Temporal (continued)	Over the 10,000-yr isolation period, boundary positions and fluxes may change significantly; for modeling purposes, the SZ ground-water flow system will be treated as a transient system in evaluating effects of tectonics and climate	High--water-table altitudes may change substantially, but potential magnitudes of change are unknown	None identified	Radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	High--substantial water-table rises could saturate respository and affect transport in UZ and SZ	High	8.3.1.2.1.4, 8.3.1.2.2.9
	Material properties are assumed to be invariant with time	Medium--within the 10,000-yr isolation period, the effect of climatic and tectonic changes on material properties (transmissivity and storage) are expected to be small, but existing modeling and analyses to demonstrate this are inadequate	Material properties are likely to change significantly during the 10,000-yr isolation period	Same as above	High	High--transport in the UZ and SZ and water-table altitudes are largely dependent on material properties	Medium--based on uncertainty	8.3.1.2.1.4, 8.3.1.5.2

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 12 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DRIVING FORCES/PROCESSES				
Equation of motion	Darcy's Law is applicable in describing ground-water flow throughout the regional and site flow systems	Low--acceptable representation of the regional and site potentiometric surface has been made using models based on Darcy's Law	Flow through fractures may be turbulent and violate Darcy's Law	GWTT; radionuclide transport in the SZ	Low	High--estimates of SZ GWTT and transport characteristics are largely dependent on applicability of Darcy's Law	Low--based on needed confidence	8.3.1.2.3.1.3, 8.3.1.2.3.1.4
Conservation of fluid mass	Changes in fluid-mass storage are negligible within the flow system because recharge is essentially equal to discharge	Medium--recharge estimates are very approximate and assume mass balance with discharge	Recharge was greater during the late Pleistocene and a recharge pulse is still propagating through the flow system	Same as above	Low	High--estimates of SZ GWTT and transport characteristics are largely dependent on recharge and discharge within the flow system	Low--based on uncertainty	8.3.1.2.1.4, 8.3.1.5.1.2
Heat energy	The coupled effects of heat energy on fluid flow in the SZ flow system do not significantly affect ground-water flow	Medium--deviations from linearity in the geothermal gradient, as measured in the SZ, generally are statistically insignificant, but data are sparse	Deep-seated geothermal waters are thermally driven vertically upward within the flow system	GWTT; radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	High--estimates of GWTT, water-table altitude, and transport characteristics are largely dependent on ground-water flow direction and magnitude	Medium--based on uncertainty	8.3.1.15.2.2

Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 13 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
			DRIVING FORCES/PROCESSES (continued)					
Strain energy	The coupled effects of strain energy on fluid flow in the SZ flow system do not significantly affect ground-water flow	Medium--insufficient data exist to correlate changes in tectonically or underground nuclear explosion related strain-energy releases with substantial changes in water-table altitude	Strain energy has a large effect on water-table altitude and flow-system response	Same as above	High	High--estimates of GWTT, water-table altitude, and transport characteristics are largely dependent on understanding the coupled effect of strain energy and fluid flow	Medium--based on uncertainty	8.3.1.8.3.2.3
			SYSTEM DYNAMICS/RESPONSE					
Future climatic effects	Future climatic changes are unlikely to produce substantial large-scale effects within the SZ during the next 10,000 yr	High--paleoclimatic data indicate that major climatic changes can occur within 10,000-yr intervals	Climatic changes and episodic variations are likely to occur and significantly affect ground-water flow within the SZ during the 10,000-yr isolation time	Radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	High--estimates of SZ and UZ transport characteristics are largely dependent on recharge to the SZ, which is directly linked to climate	High--climatic changes to significantly wetter conditions could drastically affect radionuclide transport	8.3.1.5.2

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 14 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance: Needed confidence in parameter or performance measure	Significance: Sensitivity of parameter or performance measure to hypothesis	Significance: Need to reduce uncertainty	Studies or activities to reduce uncertainty
DRIVING FORCES/PROCESSES (continued)								
Stress/strain effects	Renewed faulting or regional aseismic processes at Yucca Mountain are unlikely to have any local or large-scale effect on the SZ hydrologic system, during the 10,000-yr isolation period	High--few data exist related to the effects of renewed faulting or regional aseismic processes on the SZ hydrogeologic system	Changes in tectonically induced stress could substantially alter hydraulic properties, causing increased permeability, a decrease in open interconnected fractures, or a water-table rise	Same as above	High	High--radionuclide transport characteristics are largely dependent on permeability distribution within the flow system, which could be altered during an earthquake	High--neotectonics could have a large effect on radionuclide transport particularly in areas of large hydraulic gradients	8.3.1.8.3
Thermal effects	The coupled effect of heat convection and ground-water flow is likely to be minimal during the 10,000-yr isolation period	Medium--some evidence of significant thermally driven convection exists from data collected from boreholes in the vicinity of Yucca Mountain, but magnitude of potential future changes is unknown	Thermally driven convection is significant and is likely to have major effect on ground-water flow during the 10,000-yr isolation period	Same as above	High	High--transport characteristics are largely dependent on whether significant thermally driven convection is likely to occur within the flow system	Medium--thermally driven convection could significantly affect transport of radionuclides	8.3.1.8.3

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 15 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
SYSTEM DYNAMICS/RESPONSE (continued)								
Volcanism effects	The effect of renewed volcanism on the regional flow system would be very localized. However, changes in local ground-water flow direction and magnitude, and water-table altitude could be very large	Low--renewed volcanism during the 10,000-yr isolation period is highly unlikely	None identified	Same as above	High	High--transport characteristics are largely dependent on permeability distribution within the flow system, which could be altered during a volcanic eruption or igneous intrusion	Low--based on uncertainty	8.3.1.8.3
DATA REDUCTION MODELS								
Porous-media versus fracture-flow models	Region: ground-water flow at the regional scale may be acceptably approximated using porous-media-equivalent models, even though flow occurs through fractured rock in much of the flow system	Low--existing models at the regional scale have acceptably approximated the flow system	None identified	GWTT; radionuclide transport in the SZ	Low	Medium--estimates of SZ GWTT and radionuclide transport are largely dependent on the choice of model used	Low--based on uncertainty	8.3.1.2.1.4

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 16 of 20)

Current representation: Model element	Current representation: Current representation	Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis: Performance measure, design or performance parameter	Significance of alternative hypothesis: Needed confidence in parameter or performance measure	Significance of alternative hypothesis: Sensitivity of parameter or performance measure to hypothesis	Significance of alternative hypothesis: Need to reduce uncertainty	Studies or activities to reduce uncertainty
				DATA-REDUCTION MODELS (continued)				
Porous media versus fracture-flow models (continued)	Site: None selected	High--large uncertainty remains whether ground-water flow at the site may be acceptably described using porous-media-equivalent models	The site SZ flow system may be acceptably represented by a fracture network model The site SZ flow system may be acceptably represented by a dual-porosity model The site SZ flow system may be acceptably represented by an equivalent-porous-media model with superimposed discrete fault zones	Same as above	Low	Medium--estimates of SZ GWTT and radionuclide transport are largely dependent on the choice of model used	Low--based on confidence	8.3.1.2.1.4

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 17 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DATA-REDUCTION MODELS (continued)				
Geostatistical model	Local variations in material properties and hydraulic head are less significant at the regional scale than at the site scale. Estimates of ground-water flow direction and magnitude will be statistically based, which means that unknown local heterogeneities in material properties will probably not be predicted with geostatistical models	Low--geostatistical models have been successfully applied for characterizing material property distributions in hydrogeologic systems	None identified	Same as above	Low	High--estimates of SZ GWTT and transport characteristics are largely dependent in material properties	Low--based on uncertainty	8.3.1.2.1.4

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 18 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DATA-REDUCTION MODELS (continued)				
Inverse model	Because few material property data are available to estimate transmissivity, inverse models of ground-water flow (which provide estimates of transmissivity based on model-specified flux, potentiometric distribution, and other known geohydrologic properties) are acceptable for use in characterizing the ground-water flow system at the regional and site scale	Low--inverse models have been used successfully in the past to characterize ground-water flow beneath Yucca Mountain and vicinity	Forward modeling is an acceptable alternative to inverse modeling	Same as above	Low	Medium--estimates of SZ GWTT and radionuclide transport are dependent on the type of model selected	Low--based on needed confidence	8.3.1.2.1.4

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 19 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DATA-REDUCTION MODELS (continued)				
Transient model	The present-day regional and site ground-water flow systems may be acceptably represented as steady-state systems, based on minimal changes in storage (see model elements listed under boundary conditions); for simulations involving potential future of climatic changes, increased pumping of groundwater, or renewed faulting transient conditions may need to be assumed	Low--steady-state models have been developed previously that successfully simulated the regional ground-water flow system	None identified	GWTT; radionuclide transport in the UZ[b]; radionuclide transport in the SZ	High	Medium--estimates of GWTT and radionuclide transport are dependent on the type of model selected	Low--based on uncertainty	8.3.1.2.1.4

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Table 8.3.1.2-2b. Current representation and alternative hypotheses for the saturated-zone hydrologic system conceptual models for the site geohydrology program (page 20 of 20)

Current representation		Uncertainty and rationale	Alternative hypothesis	Significance of alternative hypothesis				Studies or activities to reduce uncertainty
Model element	Current representation			Performance measure, design or performance parameter	Needed confidence in parameter or performance measure	Sensitivity of parameter or performance measure to hypothesis	Need to reduce uncertainty	
				DATA-REDUCTION MODELS (continued)				
Coupled-effects modeling	Effects of heat- and strain-related changes on ground-water flow are expected to be small; therefore, extensive models of coupled effects of heat and strain on ground-water flow will not be needed for simulating flow system response during 10,000-yr isolation period	Medium--insufficient data exist to determine if effects will be signficant	Effects are expected to be large; therefore, coupled-effects modeling is the only way to accurately simulate combined effects of heat, strain, and fluid flow	Same as above	High	High--estimates of GWTT and radionuclide transport are largely dependent on the magnitude of the effects of heat and strain on the flow system	Medium--based uncertainty	8.3.1.2.1.4, 8.3.1.8.3

[a]GWTT = pre-waste-emplacement ground-water travel time in the saturated zone.
[b]The principal manner in which the selection of the correct saturated-zone hypothesis affects estimates of radionuclide transport in the UZ is the influence that the correct hypothesis would have on water-table altitude at the site; any rise in the water table would result in a foreshortening of the UZ and, thereby, a shortening of transport time through the UZ to the water table.

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performance parameters, and the likelihood that feasible data-gathering activities could significantly reduce uncertainty.

The ninth column identifies that characterization studies or activities that will discriminate among alternative hypotheses or that will reduce uncertainties associated with the current representation for each model element.

Interrelationships of geohydrology investigations

Three investigations are identified for the geohydrology program, namely

Investigation	Subject
8.3.1.2.1	Description of the regional hydrologic system
8.3.1.2.2	Description of the unsaturated-zone hydrologic system at the site
8.3.1.2.3	Description of the saturated-zone hydrologic system at the site

This program will develop an understanding of the present and expected geohydrologic characteristics of each of the saturated and unsaturated flow regimes, and of the gaseous and water-vapor flow process.

The regional hydrologic flow system surrounding Yucca Mountain (Investigation 8.3.1.2.1) must be understood to define the following: (1) the boundary conditions (present and expected) for the site unsaturated and saturated zone ground-water models (Information Needs 1.1.4 (Section 8.3.5.13.4), 1.6.2 (Section 8.3.5.12.2), and Investigations 8.3.1.2.2 and 8.3.1.2.3) and (2) the hydrogeologic setting in which the site occurs.

The hydrogeologic conditions and processes of the unsaturated and saturated zone must be understood to develop models of the current and potential future flow paths and fluxes (Investigations 8.3.1.2.2 and 8.3.1.2.3), and to calculate ground-water travel time (Information Needs 1.1.4 and 1.6.2). The hydrologic characteristics to be obtained in the studies of Investigations 8.3.1.2.2 and 8.3.1.2.3 will be complemented by the data from studies of water chemistry (Investigation 8.3.1.3.1), geologic stratigraphy and structure (Investigation 8.3.1.4.1), and paleohydrology (Investigation 8.3.1.5.2).

Changes to the ground-water flow system due to potential climate changes, erosion, tectonic activity, and human interference will be evaluated in Investigations 8.3.1.5.2, 8.3.1.6.4, 8.3.1.8.2, and 8.3.1.9.3, respectively, using models developed in Investigations 8.3.1.2.1, 8.3.1.2.2, 8.3.1.2.3, and 8.3.1.5.2. Temperature and other data collected under this work will be assessed for its resource potential in Section 8.3.1.9.2.1.3 and for its tectonic implications on volcanism in Section 8.3.1.8.5.2.3.

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As a means of estimating the future conditions, baseline studies of the regional hydrologic conditions will be performed (Investigation 8.3.1.2.1). Paleohydrologic investigations in Investigation 8.3.1.5.2 will provide information about the Quaternary hydrology at Yucca Mountain.

Summary of studies

Saturated zone. Site characterization of the ground-water system within the saturated zone focuses on determining the boundary conditions imposed by geologic structure, recharge, and discharge; hydraulic gradients in three dimensions; and bulk aquifer properties of hydrostratigraphic units. Studies have been developed to characterize the regional meteorology, surface-water runoff, and ground-water flow system. The resulting description of the boundary conditions, hydraulic gradients, and aquifer properties will form the basis for synthesis and modeling activities that will conclude with calculations of flow paths, fluxes, and velocities within the saturated zone.

Precipitation is the ultimate source of surface water and ground water. Therefore, sufficient data must be collected throughout the region to characterize present-day precipitation as a function of topographic setting and storm track. Data on rainfall intensity and duration will be collected to provide input to rainfall-runoff models and for infiltration studies. Modern meteorological conditions, together with long-term indirect climatic records, will also form a basis for deducing paleoconditions and predicting future conditions.

Knowledge of flood hazards and the relationships of streamflow to ground-water recharge is essential to properly understand the regional hydrologic system. The specific data needs of flood-hazard prediction and an acceptable understanding of the quantities and processes of ground-water recharge require the collection of adequate streamflow data. The needed data cannot be acquired through simulation technology or by transfer from other nearby or distant areas; therefore, a program to measure land-surface runoff (streamflow) and to assess the relationships between precipitation and runoff has been implemented to describe adequately the regional hydrologic system. The study of floods and associated debris movement will also provide the data required to relate modern flood processes and occurrences to those of the past and, thus, provide some of the needed perspective to compare and relate the effects of paleoclimates to those of the present climate.

Adequate statistical characterization of the geometry of hydrostratigraphic units and their hydraulic conductivity, storativity, dispersivity, and porosity requires that a sufficient number and distribution of boreholes be drilled to determine these properties. Results of production surveys, combined with hydraulic-test results, have failed to identify definitive hydrostratigraphic units. Instead, the results indicate that discrete production zones associated with fractures in one well may be connected to fractures occurring in overlying or underlying stratigraphic units in other wells. The hydrologic significance of intervening bedded units is not known. If pervasive fracturing crosses stratigraphic boundaries and accounts for orders of magnitude greater hydraulic conductivity than does the matrix, the effect of dipping beds on ground-water flow paths may be insignificant. Additional well tests are needed to determine three-dimensional relationships among stratigraphy, fracture connectivity, and bulk aquifer properties.

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Recharge and discharge quantities and locations will be investigated to provide the boundary conditions required for modeling. The location of present and paleodischarge points will be sought by defining the regional head distribution from observations of wells, mines, and springs, and by using field reconnaissance and remote sensing tools. Whereas regional discharges have been quantified in the past, additional studies will improve the quantifications. Activities in the discharge areas will characterize controls and locations of present and former discharge sites, as well as estimate fluxes. Evidence of recharge to the regional ground-water flow system by infiltration of Fortymile Wash streamflow will also be sought through field experiments and infiltration modeling.

Regional ground-water flow models will then be used to provide (1) a synthesis of the available hydrogeologic data; (2) direction for additional data collection; (3) predictions of spatial and temporal changes in the regional and site potentiometric-surface configuration; and (4) estimates of ground-water flow paths, fluxes, and velocities. In addition, the regional models will provide tools for analyzing the possible effects of changes in future stresses to the hydrologic system such as increased recharge resulting from future climatic changes, potential increased withdrawal of ground water, and changes in hydrogeologic properties resulting from tectonic events.

Unsaturated zone. For the purpose of site characterization investigations, the unsaturated-zone system at Yucca Mountain has been divided into the infiltration boundary and the percolation region. Each component of the system will be studied using multidisciplinary approaches (i.e., hydraulic, pneumatic, and gaseous and aqueous-phase hydrochemical studies) to describe the spatial and temporal distributions of the flux and travel times within this system. On this basis, four data collection studies have developed the characterization of (1) infiltration, (2) percolation, (3) gaseous-phase movement, and (4) hydrochemistry. A fifth study is concerned with developing conceptual models for the flow of water in partially saturated fractures and the subsequent interaction between the hydrologic dynamics of fractures and the enclosing rock. This study also intends to quantify these processes and to construct and validate numerical models to simulate water flow in discrete fractures and fracture systems. A sixth study is designed to integrate data and concepts in order to develop conceptual models for the undisturbed unsaturated-zone hydrogeologic system and to construct numerical models to simulate mathematically the response of the system or its subsystems to changing boundary or internal conditions. An important product of the modeling effort will be to predict the spatial and temporal distributions of moisture flux within the system in order to provide the predictions of the moisture velocity field that are needed by performance-assessment activities for calculating ground-water travel times and total system releases to the accessible environment.

The infiltration boundary, or the surficial units, at Yucca Mountain is one of the most important boundaries that needs to be characterized. Through this boundary, water and air can enter, and gases and water vapor can escape the unsaturated zone directly above the repository. The infiltration study will be targeted at characterizing this upper boundary of the unsaturated zone system. Its goal will be to determine the present day net infiltration rates. These data are needed as input into the system flow model.

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The goal of the percolation study will be to provide an understanding of the spatial distribution of the present-day fluxes within the unsaturated zone system. These values are not only required for the site system model but are essential for the performance assessment modeling. The salient conditions to be characterized in the percolation zone are the hydraulic and pneumatic potential gradients that extend from the land surface to the water table (which is 500 to 750 m below the surface at Yucca Mountain). Saturation and matric potential may vary discontinuously from stratum to stratum. The characterization of flow in Yucca Mountain must include, for all hydrostratigraphic units, the determination of flux distribution under a variety of conditions. Since flux is difficult to measure adequately at either the infiltration boundary or the water table, it must be inferred from the potential distribution and the conductive properties of the system, or by other indirect means. From the viewpoint of nuclear waste isolation, the most significant findings will be to predict the transport of radionuclides from the repository to the water table, 200 to 400 m below the repository. The hydraulic-properties data that will be used for flux calculation will be collected in the surface-based and exploratory shaft drilling and testing program.

Because it can transport moisture as water vapor, gas flow in the unsaturated zone may have an important hydrologic application and, in addition, may provide a mechanism for transporting gas-phase radionuclides to the accessible environment. Whereas the coexisting matrix and fracture pore systems greatly complicate computations of total-system behavior under present or future fluxes, the existence of the large-aperture fractures provides not only drainability in the unsaturated zone but also large relative gas permeability. Consequently, natural gas-phase fluxes are driven through the mountain by seasonal atmospheric density differences between the slopes and the summit, and by geothermal heat within. Vapor discharges from the air filled fracture system may offset the infiltration of rain and snowmelt because of convective and diffusive vapor transport out of the mountain. By desaturating the matrix, perhaps below free-drained residual saturation, increased moisture tension aids in damping infiltration pulses that may be channeled in the fractures or faults. It is important to be able to quantify the vapor flux because it is likely to be in a direction opposite of the liquid flux.

Activities addressing this phenomenon include all those yielding air conductivities from packer tests with gas injection in boreholes, cross-hole air flow, and gas tracer tests. A study has been specifically designed to define the gaseous flux distribution.

Essential corroboration of ground-water velocities and the transport of dissolved chemicals and gases will be sought through isotopic-dating of the fluids and gases found in the pores at various depths. A thorough understanding and evaluation of all factors influencing the hydrochemistry of the natural flow system will be needed because such knowledge provides the only potential means for assessing rates of water movement independent of the hydrologic deduction process, as well as a means of discriminating between hydrologic processes that would otherwise remain hypothetical. In addition to its contributions to the assessment of ground-water travel time, hydrochemistry provides information relevant to the characterization of gas

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transport, to the assessment of paleohydrologic conditions, to geochemical relationships, and to contamination by exploration activities.

Flow behavior in the unsaturated zone of Yucca Mountain involves complex interactions that are amenable to solution with the aid of numerical modeling. A great depth of understanding is required to predict the transport of solutes and gases in a sequence of dipping pyroclastic units that have variable granularity, degree of welding and alteration, porosity, and fracturing. How these variables interact is essential knowledge for attaining a correct solution; however, the interactions are very complex. For example, variable saturation relates to variable relative conductivity and anisotropy in hydrostratigraphic units whose fluxes relate to complex distributions of hydraulic and pneumatic potential between ill-defined boundaries with internal discontinuities. The general approach that is being used to solve this problem is to (1) refine the existing concepts of the phenomena of unsaturated, sometimes transient, flow of fluids and constituents in double-porosity layered media; (2) construct detailed digital models that spatially and temporally integrate the processes, incorporating boundary conditions, physical properties, and parameters; (3) compute fluxes, potentials, concentrations and missing data that can be verified by field tests and observations; and (4) establish consistency with all relevant verifiable knowledge. Since the environment of field tests seldom isolates one phenomenon from all others, models will be used as working tools on many levels. Ultimately, two- and three-dimensional models of Yucca Mountain will be constructed that integrate the whole system as a means of assessing combined effects of heat, water, and gas flow for modern, ancient, and future conditions. The conceptual model and verification steps will be cycled until the results are scientifically defensible.

8.3.1.2.1 Investigation: Studies to provide a description of the regional hydrologic system

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
3.1	Description of surface hydrology
3.2.1.1	Ongoing and future studies of flood and debris hazards potential
3.4	Chemical composition of adjacent watercourses

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SCP section	Subject
3.5	Points of ground-water discharge
3.6.1	Hydrogeologic units
3.6.2	Relationship among hydrogeologic units
3.6.3	Potentiometric levels
3.6.4	Hydraulic characteristics of principal hydrogeologic units
3.7.1	Identification of recharge and discharge areas
3.7.2	Principal ground-water flow paths
3.10.1	Summary of significant results (regional hydrology)
3.10.3	Identification of investigations (regional hydrology)

Parameters

The following parameters will be measured or calculated as a result of the site studies planned to satisfy this investigation:

1. Meteorologic characteristics. Spatial and temporal variability of atmospheric temperature, pressure, wind, and precipitation.

2. Surface water characteristics. Spatial and temporal variability of runoff and debris movement.

3. Ground-water characteristics. Spatial distribution of the physical and hydraulic properties of the rock units in the saturated zone and the areal distribution of flux.

Other site activities that provide information that support the determination of the previous parameters include the following:

Activity	Subject
8.3.1.5.2.1.1	Regional paleoflood evaluation
8.3.1.5.2.1.3	Evaluation of past discharge areas
8.3.1.16.1.1.1	Site flood and debris hazards studies

Purpose and objectives of the investigation

The objective of this investigation is to develop a conceptual model of the regional hydrologic system to assist in assessing the site's suitability

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to contain and isolate waste. A consistent regional model of ground-water flow will be constructed, so that reliable boundary conditions can be assigned to the more critical site area embedded within the regional model. To do so, fluxes and hydraulic heads at boundaries of the regional system are required, as well as regional transmissivities. Sensitivity analyses pertaining to these variables are needed to prioritize additional data collection.

Technical rationale for the investigation

Numerous hydrogeologic investigations that have been conducted during the last few decades in and around the Nevada Test Site (NTS) have provided a broad understanding of the regional hydrogeologic framework (for example, Winograd and Thordarson, 1975). Existing data have been used in developing preliminary two-dimensional flow models of this system. As a result of evaluations of the data base and of these models, certain additional data have been identified as needed to satisfy the investigation on the regional hydrologic system, as described in Section 8.3.1.2.1.1. Potential additional data needs will be identified and prioritized based on sensitivity analyses using a flow model. As a result, some additional activities may later be proposed to fill significant gaps in the data base.

Within the hydrogeologic study area Figure 8.3.1.2-5) regional hydrogeologic data delineate an elongate ground-water subbasin crossing several topographic divides from Pahute Mesa 145 km (90 mi) south to the Amargosa Desert and Death Valley. The Yucca Mountain area, midway between the high- and low-potential ends, lies near the western boundary of the subbasin. Because of the great depths to the water table in the northern half of the subbasin, potentiometric data are limited. However, in the southern half of the subbasin, depths to ground water are less, and more potentiometric data are available.

Aquifer properties have been measured in many deep drillholes over the course of 30 yr of hydrogeologic work on the NTS. Many uncertainties remain, however, that limit the accuracy available for site-specific applications. The hydraulic properties of the hydrogeologic units vary greatly within the hydrogeologic study area. These units include tuffaceous, carbonate, and alluvial aquifers, as well as clastic and crystalline aquitards. These aquitards act as major barriers to ground-water flow and have a major impact on regional ground-water flow direction and magnitude. In addition, faults within the area may act either as barriers or conduits to ground-water flow.

Regional ground-water modeling to date has included regional heterogeneities of various hydrogeologic units. Major assumptions inherent in regional models pertain to the location and magnitude of recharge and discharge boundary conditions and regional transmissivities. Recharge estimates across model boundaries are often crude resulting from lack of sufficient hydraulic gradient and transmissivity data; however, prioritization of data collection may be facilitated through sensitivity analyses using regional flow models. The task is to prioritize data collection and reduce the potential range of key model variable values. Regional ground-water flow models provide valuable synthesis of available hydrogeologic data as well as estimates of ground-water potentiometric levels, flow paths, fluxes, and velocities; these models are also useful for directing additional data

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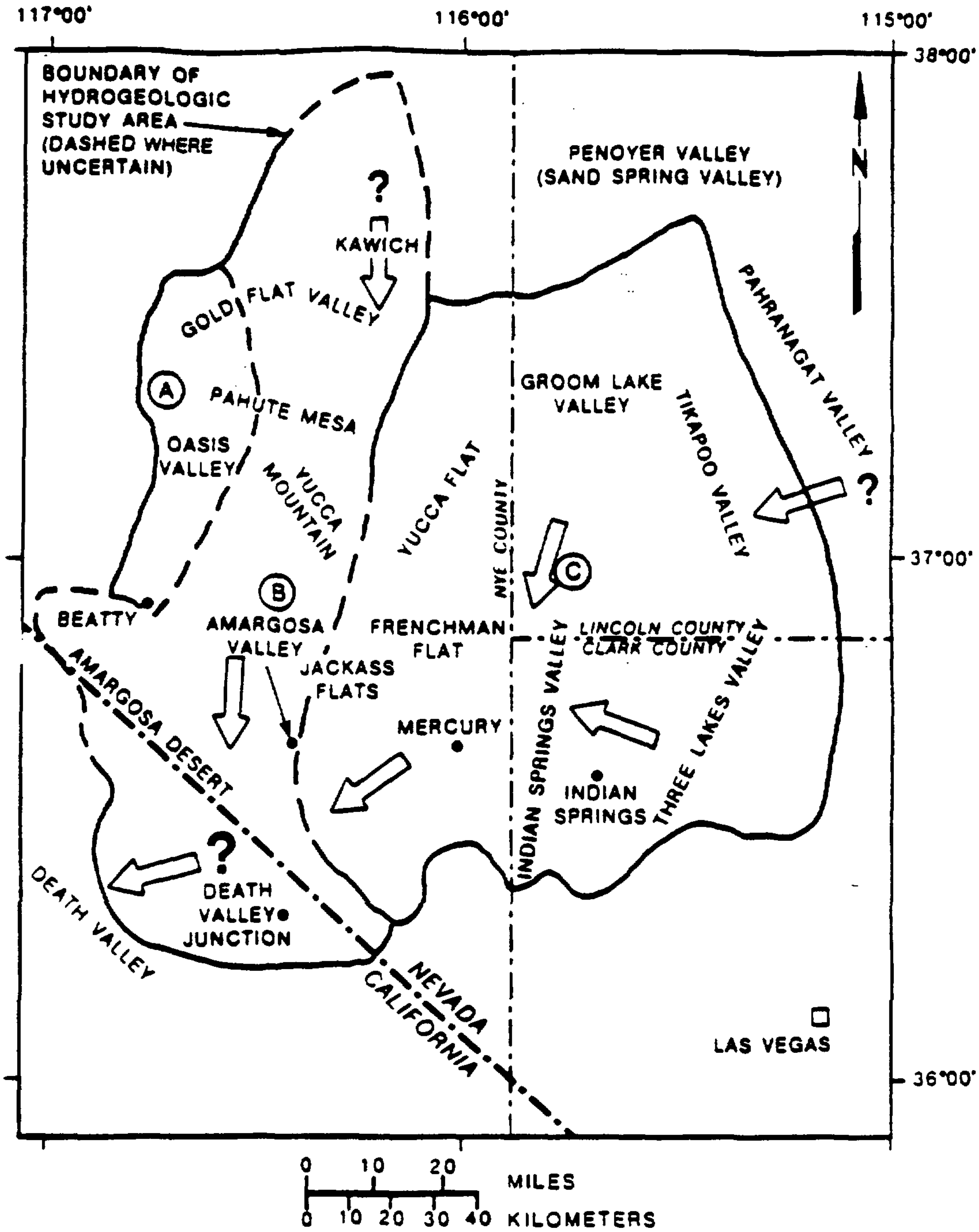

GENERAL DIRECTION OF REGIONAL GROUND-WATER FLOW (QUESTION MARK INDICATES UNCERTAINTY)

A. OASIS VALLEY SUBBASIN
B. ALKALI FLAT-FURNACE CREEK RANCH SUBBASIN
C. ASH MEADOWS SUBBASIN

Figure 8.3.1.2-5. Hydrogeologic study area showing three ground-water subbasins. Modified from Rush (1970), Blankennagel and Weir (1973), Winograd and Thordarson (1975), Dudley and Larsen (1976), Waddell (1982), and Waddell et al. (1984)

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collection. Regional models also provide tools for analyzing the possible effects of changes in future stresses to the hydrologic system such as increased recharge resulting from future climatic changes, potential increased withdrawal of ground water, and changes in hydrogeologic system properties and geometry resulting from tectonic events.

Records of existing precipitation gages at the NTS and surrounding region will be used to characterize regional precipitation patterns. Additional precipitation gages will be established to support infiltration studies (Section 8.3.1.2.2.2) and rainfall-runoff modeling (Section 8.3.1.2.1.3.3). These activities require detailed knowledge of rainfall events, to relate precipitation to observations of infiltration and runoff. The additional gages will be systematically incorporated into the existing monitoring system to form an integrated regional gaging network (Section 8.3.1.12.1). Although the records that will be obtained from these new gages will be too short to serve in themselves as a basis for characterizing regional precipitation, the records are expected to contribute to an improved understanding of regional precipitation patterns.

There are no perennially flowing streams on or near Yucca Mountain or at the adjacent NTS. As a result, very few streamflow data have been collected within a radius of tens of miles from Yucca Mountain. Knowledge of flood hazards and the relationships of streamflow to ground-water recharge is essential to properly understanding the regional hydrologic system. The specific data needs of flood-hazard prediction and an acceptable understanding of the quantities and processes of ground-water recharge require the collection of adequate streamflow data. The needed data cannot be attained through simulation technology or by transfer from other nearby or distant areas. Therefore, a program to measure land-surface runoff (streamflow) and to assess the relationships between precipitation and runoff is essential to adequately describe the regional hydrologic system.

The study of floods and associated debris movement will relate modern flood processes and occurrences to those of the past, and thus provide some of the needed perspective to compare and relate the effects of paleoclimates to those of the present climate. The two investigative strategies are as follows:

1. Present-day floods will be documented by measurements of the peak magnitudes of flood flows in selected channels. These peak flows will then be correlated with precipitation and weather conditions, and evaluated with respect to qualitative and quantitative assessments of any severe debris movements caused by and associated with the intense flows.

2. Prehistoric floods will also be investigated through the identification and interpretation of their land-surface scars and deposits.

It is recognized that short-term records of floods in arid regions, such as will be obtained in these studies, cannot be used in detailed quantitative evaluations of the potential for major floods. The documentation of modern floods and associated debris transport will be used principally in a qualitative manner to improve understanding of the relationship between climate and

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flooding. An assessment of extreme flooding and debris transport will be conducted principally on the basis of paleoflood evaluations.

Fortymile Wash, the major surface drainage following the axis of the ground-water subbasin, is a principal subject for surface-water investigations. It is a focus of attention because it may prove to be a major source of recharge, and may thus affect the movement and accumulation of ground water at the repository site near Yucca Mountain. Neutron-probe measurements will be made and soil water samples will be collected in the bed of the wash to characterize relationships between infiltration and runoff, and to investigate if preferential recharge takes place along possible faults. Ground-water flow rates may be deduced through the use of conservative tracers and interpretations of water chemistry. Evidence of recharge to the regional ground-water flow system by infiltration of Fortymile Wash streamflow will be sought. Infiltration modeling is planned. Infiltration, percolation, and recharge studies described in Investigation 8.3.1.2.3 will also contribute quantitative measures of the regional input fluxes.

8.3.1.2.1.1 Study: Characterization of the meteorology for regional hydrology

The objectives of this study are (1) to characterize the area surrounding Yucca mountain in terms of precipitation and its relationship to surface runoff, with particular emphasis on the Fortymile Wash drainage basin, and (2) to provide input into the rainfall-runoff model development effort. One activity is planned to collect the data required to satisfy these objectives.

8.3.1.2.1.1.1 Activity: Precipitation and meteorological monitoring

Objectives

The objective of this study is to provide site-specific information on storm precipitation at, and near, the network streamflow-measurement sites.

Parameters

The parameters for this study are as follows:

1. Precipitation amounts.
    a. Rainfall intensity and duration.
    b. Monthly and seasonal precipitation variability.
2. Surface temperature.
3. Atmospheric pressure and pressure variability.
4. Relative humidity and diurnal humidity cycles and seasonal variability.

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5. Incoming and outgoing short-wave radiation and its diurnal and seasonal variability.

6. Wind speed and direction and diurnal, seasonal, and storm-specific variability.

7. Atmospheric stability and its relationship to storm events.

Description

Runoff and streamflow at and around Yucca Mountain and the NTS are almost always direct responses to precipitation, mainly rainfall. Although the National Weather Service (NWS) has operated a precipitation gage network at the NTS since late 1957, the precipitation-gage network was not designed for, and is not ideally suited to, the development of rainfall-runoff relations. Systematic streamflow measurements were started in 1983, and since that time a network of precipitation gages was installed, which is growing and evolving (Figure 8.3.1.2-6 and Table 8.3.1.2-3). This network is providing an understanding of the relations between localized rainfall and the runoff. In addition, precipitation data from the NWS network complements and supplements the precipitation measurements collected in tandem with the streamflow records.

The precipitation measurement network being operated as part of the streamflow measurement program consists of 2 continuously recording, tipping-bucket rain gages and 14 nonrecording plastic rain gages. One of the recording gages is located in upper Fortymile Wash at the site of a recording streamflow gage near Pahute, Rainier, and Buckboard mesas (Station 2 in Figure 8.3.1.2-6); the other is located atop a small ridge (Exile Hill) at the base of the east-facing slope of Yucca Mountain, in the general area of proposed nuclear waste storage facilities (Station 5 in Figure 8.3.1.2-6). These two gages provide general calibration data on rainfall intensities and durations for comparisons with the cumulative-precipitation data for specific and select storms that are obtained from the plastic rain gages. Most of the plastic gages are located at sites of streamflow-measurement network sites; thus, the cumulative precipitation trapped by the plastic gages gives some sense of rainfall quantities in specific drainages that promote streamflows of varying magnitudes. They were located at the stream-measurement sites for logistic efficiency in operation and maintenance. Five of the plastic gages are located at sites without streamflow gages. These precipitation gages were located in places where supplementary rainfall information is needed to fill data gaps between other networks and collection sites. The precipitation data collected by plastic rain gages are not as accurate as those obtained by more sophisticated gages. Also, the data collected by the plastic gages must be recorded quickly, following a storm, before evaporation depletes the precipitation collected by the gages. Because of these limitations, such precipitation data will only be supplementary to those collected by the more formal precipitation-measurement network. These supplementary data will provide added detail to improve interpretations of the areal distribution of precipitation that causes runoff.

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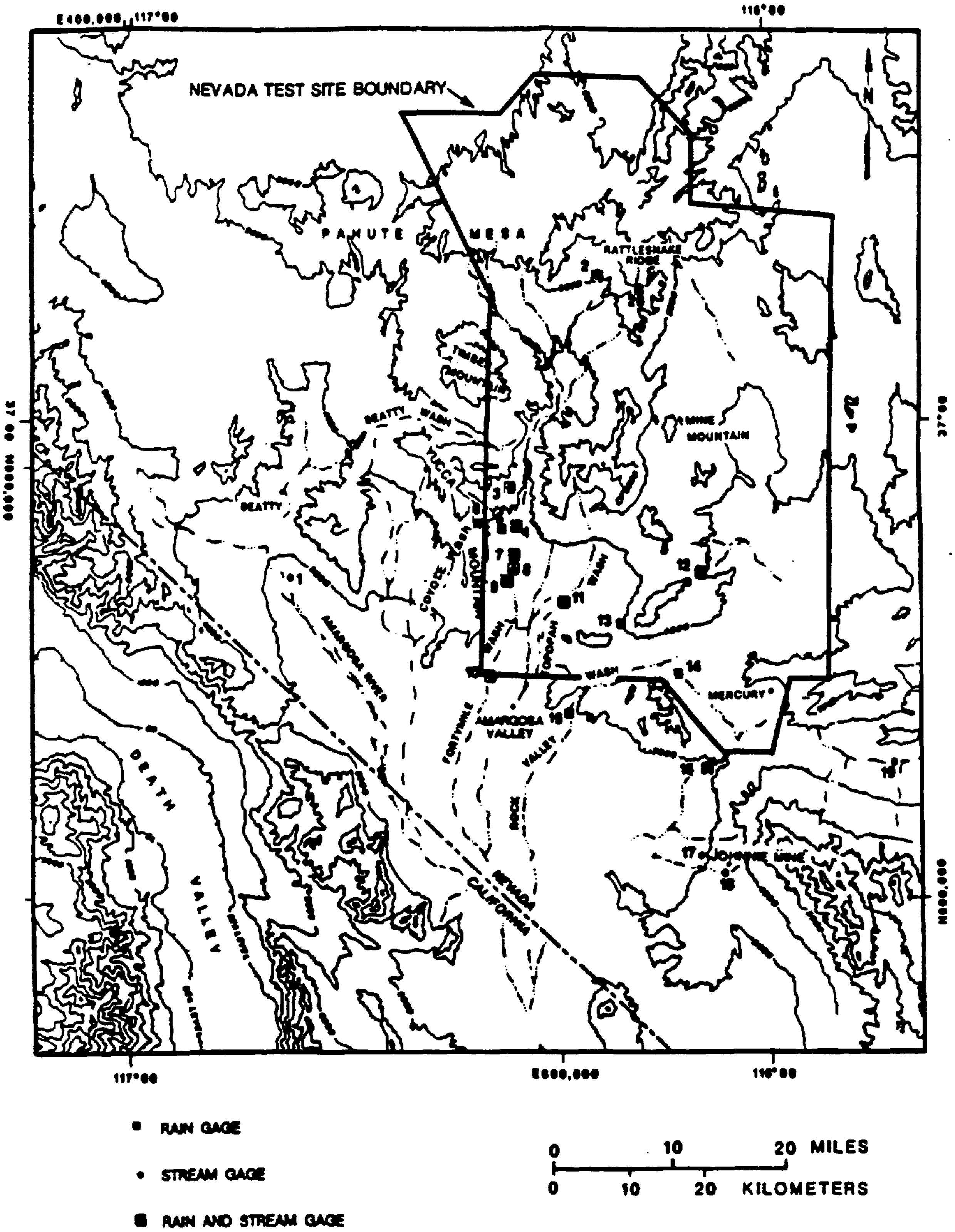

Figure 8.3.1.2-6. Regional precipitation and streamflow stations (numbers correspond to those shown in Table 8.3.1.2-3).

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Table 8.3.1.2-3. Regional precipitation and streamflow stations (see Figure 8.3.1.2-6 for locations)

Map location	Location	Gage type	Nevada State coordinates North	Nevada State coordinates East
1	Amargosa River near Beatty	CSG[a]	780,900	472,880
2	Unnamed Tributary to Fortymile Wash North Rattlesnake Ridge	RRG[b] RSG[c]	865,620	616,670
3	Fortymile Wash at Narrows	PRG[d] RSG	778,010	583,580
4	Yucca Wash	PRG CSG	770,320	579,750
5	Exile Hill	RRG	764,990	569,340
6	North Fork Coyote Wash	PRG	766,120	563,030
7	Drillhole (Sever) Wash	PRG CSG	753,630	578,750
8	Fortymile Wash at well J-13	PRG RSG	749,400	577,890
9	Dune Wash	PRG CSG	743,770	575,700
10	Fortymile Wash near Highway 95	PRG RSG	699,320	568,200
11	Topopah Wash	PRG CSG	736,070	602,410
12	Cane Springs Wash Tributary	PRG CSG	749,390	667,300
13	Skull Mountain Pass on Jackass Flats Highway	PRG	723,750	627,060
14	Rock Valley on Jackass Flats Highway	PRG	704,400	651,830
15	Rock Valley at Highway 95	PRG	683,380	604,810
16	Amargosa River Tributary near Mercury	PRG CSG	659,900	666,890

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Table 8.3.1.2-3. Regional precipitation and streamflow stations (see Figure 8.3.1.2-6 for locations) (continued)

Map location	Location	Gage type	Nevada State coordinates North	Nevada State coordinates East
17	Amargosa River Tributary #1 near Johnnie	CSG	622,800	664,360
18	Amargosa River Tributary #2 near Johnnie	CSG	614,160	674,320
19	Indian Springs Valley Tributary near Indian Springs	CSG	661,500	432,950
20	Stockade Pass	PRG	878,700	635,610

[a]CSG = crest-stage stream gage.
[b]RRG = recording rain gage (tipping bucket).
[c]RSG = recording stream gage.
[d]PRG = plastic rain gage.

An upgrading and expansion of the currently operating network is planned to provide a better accounting of precipitation occurring in the area surrounding Yucca Mountain. A plan to develop an integrated precipitation network is discussed in Section 8.3.1.12.1. The network will be of sufficient density to characterize and track storm movement and intensity within the regional study area. The network will be of greater density within the site boundaries to provide input to the infiltration studies for use in water budget calculations (Activity 8.3.1.2.2.1.2). Meteorologic data will also be collected at network stations that are located within the boundaries of the site to provide input to the gas-phase circulation study (Activity 8.3.1.2.2.6.1) as well as the infiltration studies (Activity 8.3.1.2.2.1.2). The plan for the integrated precipitation network will also include a description of precipitation sampling for chemical and isotopic analyses. This program will be coordinated with other precipitation sampling efforts (Activities 8.3.1.2.1.3.3 and 8.3.1.2.2.2.1). The amount and timing of rainfall will be related to the amount and timing of runoff. The information collected under this study will be correlated with that discussed in Section 8.3.1.12 (meteorology). Findings from this study will be used in conjunction with those of paleoflood studies (Activity 8.3.1.5.2.1.1) to help provide a basis for future flood predictions (Activity 8.3.1.5.2.2.1).

The precipitation data collected as a part of this study will span only a short-term duration compared with the length of time nuclear waste will be stored. These relatively short-term data can probably be statistically correlated with regional precipitation data spanning a longer (but also relatively short) time (Section 8.3.1.12.1). Both regional and site-specific data will be correlated with paleoclimatic data (Investigation 8.3.1.5.1).

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Overall worth of the short-term, site-specific data will depend on the quality and quantity of data obtained and on the range of variability of the data compared with the long-term range of natural variability of the climatic system. Techniques of data analysis and interpretation will depend on the analytical technology available at the time of analysis and on the quality, quantity, and characteristics of the available data of that time; techniques will also depend on the quality and quantity of regional data and paleoclimatic data available for comparisons and correlations.

8.3.1.2.1.2 Study: Characterization of runoff and streamflow

The objectives of this study are to (1) collect basic data on surface-water runoff at, and peripherally to, Yucca Mountain and its hydrologic flow system; (2) use the streamflow data to describe the runoff characteristics of the area and assess the response of runoff to precipitation; (3) assess the potential for flood hazards and related fluvial-debris hazards to the Yucca Mountain Project; and (4) provide basic data and interpretations of surface-water runoff to investigations that evaluate the amounts and processes of ground-water recharge at Yucca Mountain and surrounding areas.

Two activities are planned to provide the knowledge required to satisfy the objectives stated previously: (1) collect and interpret streamflow data within the regional hydrologic study area, and (2) document movement of debris initiated or perpetuated by the direct or indirect processes of surface-water runoff when and where the debris movement constitutes a hazard or significantly alters the geomorphic landscape.

8.3.1.2.1.2.1 Activity: Surface-water runoff monitoring

Objectives

The objectives of this activity are as follows:

1. To develop needed basic data on the characteristics, magnitudes, frequencies, and timing of surface-water runoff to develop an understanding of the relationships between specific runoff events and the characteristics of the storms and associated precipitation.

2. To develop a streamflow data base adequate to provide the necessary calibration data for precipitation-runoff modeling efforts for the regional study area.

Parameters

The parameters of the activity are

1. Occurrences of runoff.
2. Areal extent of runoff.
3. Frequencies and runoff recurrence in specific and general areas.
4. Magnitudes of streamflow at specific sites.

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5. Durations of individual runoff events.
6. Quantities of runoff at specific sites.
7. Relations of runoff to weather conditions.

Description

Streamflow data will be collected to document surface-water runoff, both quantitatively and qualitatively, in selected streams of the Yucca Mountain area and the NTS. Two stream gage networks currently exist: one for the regional study area and one for the site. These two networks satisfy a variety of Yucca Mountain Project needs. A dense network is required on site to provide detailed data for the unsaturated-zone infiltration studies (Section 8.3.1.2.2.1.2). A broader network is required in the regional study area to develop an understanding of the relationships between specific runoff events and the characteristics of the storms and associated precipitation. These two networks will complement each other in providing a comprehensive understanding of the surface-water regime for input into the conceptual model.

Application of the streamflow data generally will be restricted to the specific purposes described. The short duration of the records that will be obtained probably will preclude development of meaningful long-term runoff characteristics. Long-term records were checked from gaging stations in a broad region around the Yucca Mountain area to evaluate their usefulness in correlating with the Yucca Mountain data. No records that were useful and appropriate for this purpose were found.

Surface-water runoff studies, in general, document the occurrences of runoff by measuring streamflow, when it occurs, at selected sites. A network of streamflow-measurement sites has been established for the regional study area and locations of the sites are shown in Figure 8.3.1.2-6 and Table 8.3.1.2-3. At many of the regional network sites, measurements consist of only a determination of the peak magnitude of streamflow and accompanying stream stage (height) at that specific site; however, at several sites along the Fortymile Wash, the stage of streamflow in the channel is continuously monitored. This continuous record of stream stage will be mathematically converted into a continuous record of the rate of streamflow past the site.

Currently, four continuous stream stage gages are operating:

1. One in an unnamed 4-mi^2 tributary to the headwaters of Fortymile Wash near Rattlesnake Ridge.

2. One at a relatively narrow channel constriction of Fortymile Wash (hereafter referred to as the narrows), a short distance upstream from the mouth of Yucca Wash. At this site, flow from the integrated upstream drainage of about 250 mi^2 of Fortymile Wash is monitored; a video cassette recorder is also installed at this site to furnish a visual record of streamflow to compare experimentally with the continuous record of stream stage.

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3. One in Fortymile Wash, downstream from the Yucca Mountain road crossing, near well J-13. In addition to the runoff passing the narrows site upstream, that passing this site also includes inflow from Yucca Wash (about 17 mi^2) and much of the runoff from Yucca Mountain that enters Fortymile Wash from the Drillhole-Sever Wash drainage (about 16 mi^2).

4. One downstream on Fortymile Wash near Highway 95 and Lathrop Wells. This streamflow record shows losses or gains in flow downstream from the gage upstream near well J-13, and thus, may indicate the potential for streamflow in the wash to recharge the ground-water system along its alluvial pathway.

These continuously recording stream gages are visited approximately each month for maintenance, and, also, as soon as possible, following each runoff event.

In support of Activity 8.3.1.2.1.3.3 (Fortymile Wash) recharge study, the regional streamflow-measurement network in the Fortymile Wash basin will be expanded. Approximately six additional streamflow-measurement stations, three snow courses, six precipitation-measurement sites, and two air-temperature measurement sites will be installed and operated in the upper drainage basin of Fortymile Wash to collect data that will supplement the currently operating streamflow and precipitation networks, and thus allow precipitation-runoff model assessment for Fortymile Wash. Establishment of the meteorological stations will be coordinated with Study 8.3.1.12.1.2 (plan for synthesis of Yucca Mountain Project meteorological monitoring. The monitoring equipment for these temperature and precipitation measurement sites will include standard, continuous-recording precipitation and air-temperature gages, and the streamflow-measurement equipment will consist of continuous-recording stage recorders.

In addition, a continuously recording stream gage will be installed near Beatty, Nevada, in either the Amargosa River or Beatty Wash and will record runoff and flood flows from the northwestern part of Pahute Mesa. This drainage, which is similar in size to the Fortymile Wash drainage, is currently not being monitored, and monitoring will provide valuable input to the evaluation of the rainfall-runoff relationship of the Yucca Mountain area.

Scour chains have been installed at the narrows, well J-13, and Highway 95 (Lathrop Wells) gaging sites. Scour chains are vertically suspended lengths of chains buried in an individual vertical pit excavated in the alluvial streambed along a line perpendicular to the direction of streamflow. About a half dozen of these chains, spaced about 5 to 10 ft apart along the cross-channel lineament, are buried at each gaging site. They were vertically suspended in the pits dug in the streambed and were buried in the vertically extended position. Because of their flexibility, any scour of the streambed during periods of streamflow will deform the upper segment of the chains to a nonvertical position to the depth of streambed scour. Documentation of the levels of deformation of the individual chains along the channel cross section will generally define the cross-sectional depth and shape of scour for a specific runoff event. The depth and degree of scour will provide a sense of the degree of reliability of the recorded stream

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stage to depict the varying cross-sectional area of streamflow during the runoff event.

In addition to the established network of continuous streamflow-measurement sites, peak magnitudes of streamflows will be selectively measured in drainages that do not contain network sites, and at nonnetwork sites in drainages that contain network sites. These miscellaneous measurements will be made, as deemed necessary, to characterize specific runoff events in, or peripheral to, the regional study area. They also will permit a more efficient expansion of the markedly deficient streamflow data base for the general area. These miscellaneous measurements are expected to add important data regarding intensive runoff events that are needed to assess the potential for severe runoff that might occur throughout the area or region under prevailing climatic conditions. This regional peak stream gage network currently includes ten crest-stage gages. Locations are shown in Figure 3-3. These gages record only the peak stage of any specific runoff event and do not record any data on rising or receding stages below the peak, the timing of runoff, or the duration of runoff.

Half of these crest-stage gages are part of a statewide network of crest-stage gages that have been operated since the 1960s. Thus, they make up the only historical streamflow data base for the area immediately surrounding and including the Yucca Mountain area and the NTS. These five incorporated sites outside of the proposed Yucca Mountain regional study area but are relatively nearby. This historical core network has, thus far, been supplemented by five additional crest-stage gage sites located closer to Yucca Mountain. The crest-stage gage network is visited periodically, generally monthly, in concert with operational visits to the continuously recording gages. They are also visited as soon as possible during or following runoff events. Thus, the occurrences of flow events and runoff peaks recorded by the crest-stage gage component of the stream gage network can be correlated with data from the continuously recording gages.

This regional streamflow network is not of an adequate areal density, or of a needed level of detail, to satisfy the specific requirements of accounting for all streamflow in the many small drainages in the site area that is proposed for waste storage. The more detailed and continuous site data are needed to understand the full range of responses of the varying terrain of Yucca Mountain to varying ranges and characteristics of precipitation. The streamflow component of the hydrologic cycle needs to be quantitatively defined for the specific geographical area that will encompass proposed waste storage facilities. This definition is necessary to allow a meaningful quantitative assessment of infiltration of precipitation to the unsaturated ground-water zone (Activity 8.3.1.2.2.1.2, natural infiltration monitoring). To satisfy this need, streamflow will be measured and surface runoff will be documented at about two dozen selected sites on Yucca Mountain drainages (Figure 8.3.1.2-7 and Table 8.3.1.2-4). These streamflow measurement sites will be instrumented with continuously recording stream stage gages at flumes calibrated to mathematically relate stream stages to streamflow rates. In this manner, streamflow will be continuously documented at the measurement sites. The sites were selected to provide streamflow data for a variety of different size drainages of variable aspects and widely scattered locations on Yucca Mountain.

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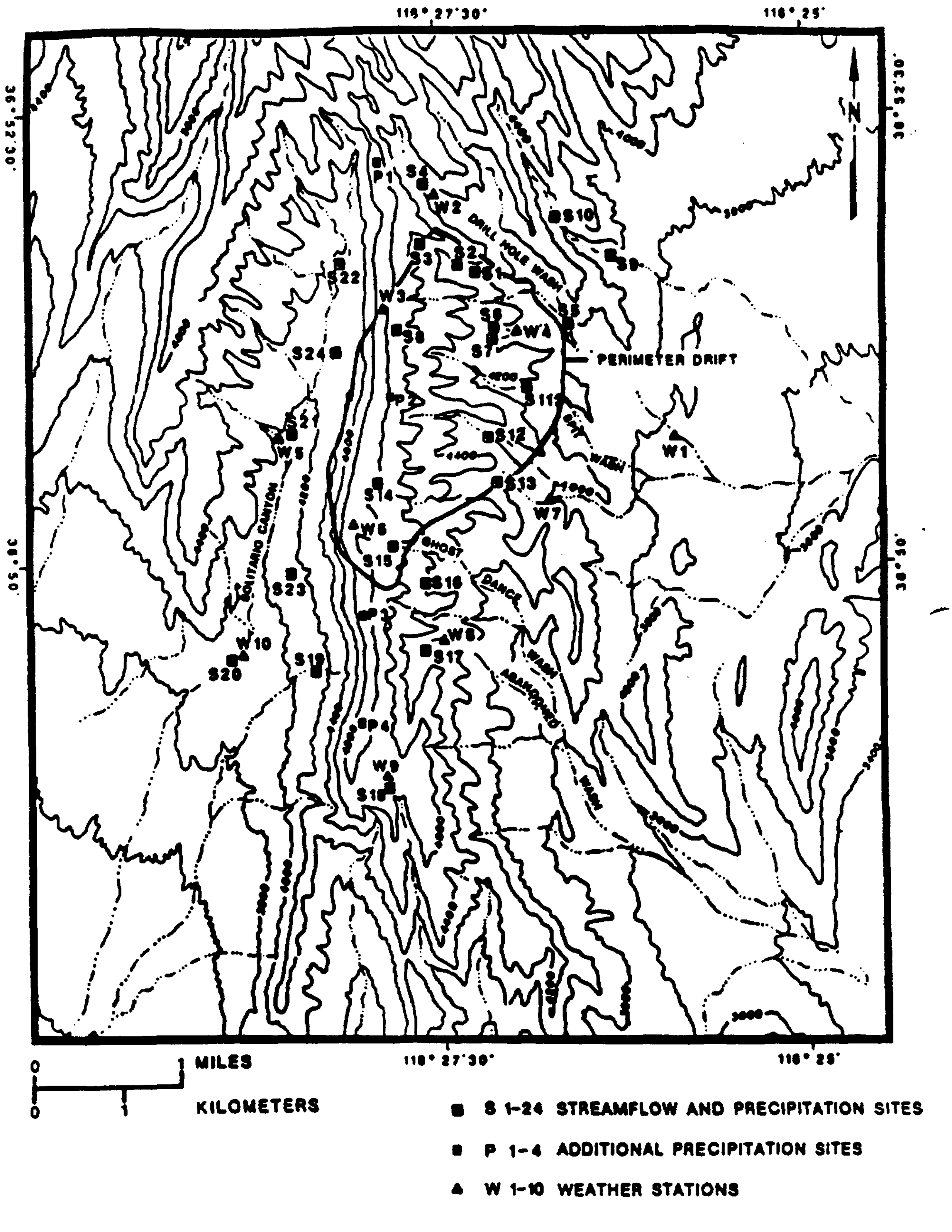

Figure 8.3.1.2-7. Site precipitation, streamflow, and proposed weather stations (refer to Table 8.3.1.2-4 for precipitation and streamflow location descriptions)

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Table 8.3.1.2-4. Site precipitation and streamflow stations (see Figure 8.3.1.2-7 for locations)

Map location	Location	Gage type	Nevada State coordinates North	East
S1	Wren Wash--below USW UZN-98, just below lower confluence	TBD[a]	767,900	562,250
S2	Wren Wash--above USW UZN-26, just below upper confluence	TBD	768,890	560,450
S3	Wren Wash--above USW UZ-N70, near top of drainage	TBD	769,450	559,830
S4	Drill Hole Wash--just above USW UZ-N46	TBD	772,250	559,700
S5	Drill Hole Wash--just below UE-25 UZN-18	TBD	766,350	565,240
S6	Coyote Wash--north fork, 100 ft downstream from trench	TBD	766,300	562,500
S7	Coyote Wash--south fork, just upstream from USW UZ-N42	TBD	765,650	562,700
S8	Coyote Wash--south fork, just below crest of Yucca Mountain	TBD	766,150	559,675
S9	Pagany Wash--just below UE-25 UZN#12	TBD	768,550	566,800
S10	Pagany Wash--just above UE-25 UZN-10	TBD	770,050	564,650
S11	Split Wash--500 ft above UE-25 UZN-19	TBD	763,910	564,125
S12	H-4 Canyon--1,000 ft above USW H-4	TBD	762,275	563,150
S13	WT-2 Canyon--just below USW UZ-7	TBD	760,850	563,000
S14	WT-2 Canyon--north fork, just below USW UZ-N73	TBD	760,950	559,010
S15	Ghost Dance Wash--north fork, west of QTec deposit	TBD	758,700	559,600
S16	Ghost Dance Wash--south central Fork, lower part	TBD	757,480	560,375

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Table 8.3.1.2-4. Site precipitation and streamflow stations (See Figure 8.3.1.2-7 for locations) (continued)

Map location	Location	Gage type	Nevada State coordinates North	East
S17	Abandoned Wash--just below Ghost Dance fault trench	TBD	755,050	560,500
S18	Drainage south of USW UZ-13--just below USW UZ-N33	TBD	750,300	559,350
S19	Solitario Canyon--near USW UZ-N35	TBD	754,525	556,875
S20	Solitario Canyon--Canyon Mouth near USW WT-7	TBD	755,300	554,225
S21	Solitario Canyon--mid-part of Canyon just above USW H-6 road	TBD	762,750	556,190
S22	Solitario Canyon--upper part of canyon-due west of Wren Wash	TBD	768,780	557,725
S23	Solitario Canyon--unnamed tributary between USW UZ-N81 and USW UZ-N79	TBD	757,675	566,000
S24	Solitario Canyon--unnamed tributary just above USW UZ-N36	TBD	765,800	557,775
P1	Yucca Crest--north end	TBD	772,100	558,670
P2	Yucca Crest--near top of Split Wash	TBD	763,920	559,300
P3	Yucca Crest--near USW H-3	TBD	756,540	558,450
P4	Yucca Crest--near USW G-3	TBD	765,780	558,480

[a]TBD = to be determined.

Continuously recording precipitation gages are also planned for each of the streamflow sites to provide geographically specific data on rainfall for the drainages of interest (Activity 8.3.1.2.1.1.1, regional precipitation monitoring). Site-specific precipitation data will be used in conjunction with the regional precipitation data to define quantitative relations between rainfall and runoff for the selected drainages. Fluvial suspended-sediment monitoring is also planned for about six of the measurement sites. These measurements will provide data regarding the magnitudes and temporal distributions of the relative proportions of water and sediment in the streamflow

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mixtures. The sediment data are needed to improve accuracy when assessing the true water-volume component of the streamflow mixtures. This detailed site streamflow data will be useful in the study of regional runoff and streamflow and to related activities investigating flood hazards and associated fluvial-debris hazards (Activity 8.3.1.16.1.1.1, site flood and debris hazards studies).

Because runoff is ephemeral, erratic, unpredictable, and generally of short duration in and around the Yucca Mountain area, direct measurements of streamflow using standard USGS current meter-measuring techniques are precluded. Almost all measurements at both network and miscellaneous sites must be made using indirect measurement techniques after the runoff has occurred. These data will also be useful to planned future rainfall-runoff modeling studies of Fortymile Wash (Activity 8.3.1.2.1.3.3, Fortymile Wash recharge study).

Although these indirect techniques are made according to accepted standard USGS practices, they are generally acknowledged to be less accurate than normal current meter measurements made during stable streamflow conditions. They, nonetheless, provide extremely valuable data, at a reasonable cost, for an area where quantitative and qualitative streamflow data are practically nonexistent.

Indirect measurements of peak flows also are made following runoff events in drainages, or at sites, where no continuous stream stage recorders or crest-stage gages are located. Sites for these miscellaneous measurements are selected as targets of opportunity when a field reconnaissance of recent runoff suggests that these normally unmonitored drainages have experienced runoff of a character that requires measurements to adequately characterize storm-runoff relations. The data thus collected supplement and complement data collected systematically and periodically throughout the formal streamflow-measurement network. Often, the spotty nature of desert flooding results in significant or severe runoff in the area that only marginally affects streams that are instrumented with continuously recording gages or crest-stage gages. At these times, the supplementary data are critical in characterizing the magnitude and extent of local runoff and flooding that might otherwise be overlooked or undeveloped. Because the locations and numbers of miscellaneous measurement sites vary greatly from storm to storm and from year to year, none of the sites are shown in Figure 8.3.1.2-6. The locations of miscellaneous-measurement sites will be shown in periodic progress and summary reports of this investigation to properly document the data collected during specific time intervals during the study.

8.3.1.2.1.2.2 Activity: Transport of debris by severe runoff

Objectives

The objective of this activity is to document, both quantitatively and qualitatively, the characteristics of debris transported by intense surface runoff.

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Parameters

The parameters of this activity are

1. Quantities of erosion and deposition.
2. Characteristics of erosion and deposition.
3. Physical characteristics of debris transport by streamflow.

Description

This activity is closely tied to Activity 8.3.1.2.1.2.1 (surface-water runoff monitoring). If field investigations of surface runoff reveal intense and rapid movement of debris by surface runoff, data will be collected to document this movement. The documentation will include qualitative and quantitative (when feasible and practical) assessments of the characteristics of erosion, transport, and deposition of debris by surface runoff. These data will be collected in the Yucca Mountain area and peripheral areas important to understanding hazardous (severe and intensive) debris transport at the proposed nuclear waste storage area. The information will be used to evaluate debris hazards near the surface-facilities locations, as described in Activity 8.3.1.16.1.1.1 (site flood and debris hazards studies). The information will also increase knowledge of severe erosion and depositional processes currently active on the landscape, and the part these processes play in present-day fluvial-debris hazards.

Times, locations, areal extent, and depths of severe erosion and deposition caused by intense runoff will be noted, measured, or estimated, if possible, where erosion scars or deposits are prominent. Direct and indirect measurements will be used to quantify or describe (1) the amount of channel or hillslope erosion that was caused by a given flood at a specific site or sites, (2) the sediment deposit(s) that were created by the erosion and transport of debris, and (3) the physical characteristics of the debris that was eroded, transported, and deposited by flooding. Direct measurements of the transport of sediment during periods of hazardous movement will probably not be possible. Land-surface photography, aerial photography, and remote sensing will be used in the post-fact analyses of the debris movement during major runoff events whenever possible and feasible. Scars and deposits resulting from known recent flash floods will be used to develop measurement and estimation techniques. When severe sediment transport takes place, the causes and knowledge of the processes of movement will be sought. These causes and processes will be related to specific storm and runoff characteristics if, and when, possible.

8.3.1.2.1.3 Study: Characterization of the regional ground-water flow system

The objectives of this study are (1) to further define the distribution of hydraulic properties of the regional ground-water flow system, and (2) to use hydrologic, hydrochemical, and heat-flow data to determine the magnitude and direction of ground-water flow.

Four activities are planned to collect the data required to satisfy this objective: (1) an assessment of regional hydrogeologic data needs in the saturated zone, (2) regional potentiometric-level distribution and hydrogeologic framework studies, (3) a Fortymile Wash recharge study, and (4) evapotranspiration studies.

8.3.1.2.1.3.1 Activity: Assessment of the regional hydrogeologic data needs in the saturated zone

Objectives

The objective of this activity is to prioritize data needs for use in the regional ground-water flow description.

Parameters

The parameters of this activity are

1. Distribution of hydraulic conductivity, transmissivity, storage coefficient, and porosity type (matrix, fracture).

2. Location and rate of recharge and discharge.

3. Potentiometric levels.

Description

A hierarchy of priorities will be assigned to data requirements for the description of regional ground-water flow description of the saturated zone. As only one of various methods that will be used, a two-dimensional ground-water flow model (Czarnecki and Waddell, 1984) will be updated to evaluate the adequacy of regional hydrogeologic data and to guide future data collection. While enough data currently exist to construct models of regional ground-water flow, sufficient uncertainty in initial and boundary conditions exists to reduce the certainty of model results. The effects of the positions and conditions of lateral-flow boundaries will be tested by specifying alternative configurations of model grids or meshes. By prioritizing model variables as to their effects on key model-calculated results (such as ground-water flow-path directions and gradients), data collection may be focused to minimize uncertainties in these key variables.

Sensitivity analyses will be performed using the updated two-dimensional digital, finite-element model of ground-water flow to prioritize the effects of key model variables, such as hydraulic conductivity, transmissivity, storage coefficient, porosity, and locations and rates of recharge and discharge. For example, little is known about the potentially steep hydraulic gradient between the Amargosa Desert and the Furnace Creek Ranch discharge area in Death Valley, or the hydrologic properties of the fault zone that causes the spring line at Ash Meadows. The sensitivity of hydrologic properties of these and other areas will be evaluated using the modeling approach.

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Hydrologic data have been collected from boreholes drilled in the Amargosa Desert by a mining company (Activity 8.3.1.2.1.3.2). Preliminary assessment of these data indicated that their interpretation may result in revision of the conceptual model or regional flow.

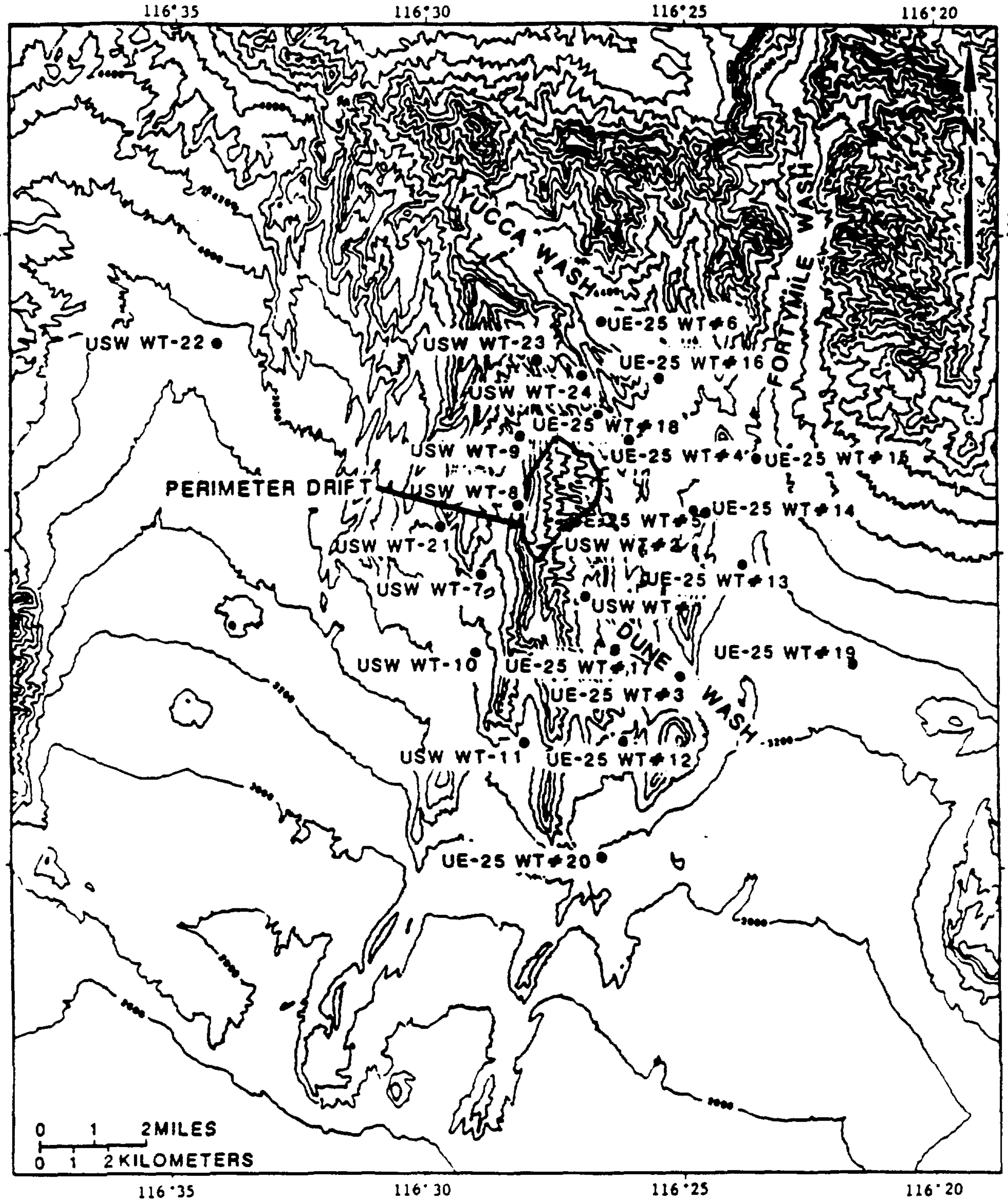
Potentiometric and temperature data from these holes indicate a potential upward component of ground-water flow (hydraulic gradients of 0.02) from depths as great as 500 m. Upward flow of ground water was confirmed from concave-downward profiles of temperature as a function of depth. In addition, potentiometric data indicate that a ground-water divide may exist in the Greenwater Range, between the Amargosa Desert and Death Valley. Hydraulic head under the Greenwater Range is as great as 875 m, whereas in the Amargosa Desert, head is about 615 m, and in Death Valley, head is about sea level (Czarnecki, 1987).

Potentiometric and temperature data from these holes are potentially significant for characterizing the regional ground-water flow system, because they suggest that (1) upward flow from great depths may occur within the subbasin, possibly from underlying carbonate rocks, which constrains the saturated-zone flow paths from the site to occur only in the upper part of the ground-water system; (2) ground-water recharge may have occurred even in relatively low-lying arid areas, such as the Greenwater Range and the Funeral Mountains, a hypothesis that was previously not favored; (3) ground-water discharge near Furnace Creek Ranch may occur via a deeper, confined flow system, possibly through carbonate rocks; (4) the conceptual model of the ground-water flow system can be simplified by removing the ground-water discharge boundary condition at Furnace Creek Ranch; and (5) a smaller amount of ground water flows beneath Yucca Mountain than previously estimated, when discharge from this flow system was assumed to occur at Furnace Creek Ranch (Czarnecki, 1987).

Although these data support the need to revise previous conceptual models, they are not conclusive. As a result, these data will be further evaluated in the context of the regional flow system, and an assessment will be made to determine what additional data are needed to test alternative conceptual models. As described below, consideration will be given to the following efforts: (1) drill additional piezometer nests; (2) drill a deep borehole into the Paleozoic rocks beneath the Amargosa Desert; and (3) deepen proposed drillholes USW WT-21 and USW WT-22 into Paleozoic rocks (Figure 8.3.1.2-8). These tasks would be conducted as part of Activity 8.3.1.2.1.3.2. Any proposed new drilling would be integrated with drilling plans developed in Studies 8.3.1.4.1.2 and 8.3.1.4.1.3.

Piezometer nests would be constructed to determine the altitude of the potentiometric surface and changes in hydraulic head with depth along the eastern edge of the Funeral Mountains, where Paleozoic carbonate rocks outcrop. Potentiometric data from these shallow piezometer nests (150 m deep) would allow for the determination of whether the Paleozoic carbonate rocks drain ground water from the Amargosa Desert to Furnace Creek Ranch.

Although these boreholes would greatly augment existing hydrogeologic data for the regional flow system, no drillholes have been constructed to penetrate and test Paleozoic hydrogeologic units (probably carbonate rocks) underlying Tertiary basin fill at estimated depths as great as 6,000 ft



• DRILL HOLE

• PROPOSED DRILL HOLE

Figure 8.3.1.2-8. Location of existing and proposed water-table holes.

(1,800 m) in the Amargosa Desert. The need to do this will be evaluated in the context of existing hydrogeologic data and conceptual models of the regional flow system. A drillhole constructed into the Paleozoic units would be used to determine the amount and direction of ground-water flow between these and overlying units, by installing multiple piezometers. Groundwater samples obtained form these Paleozoic and overlying units would be analyzed to determine the stable isotopes of oxygen and hydrogen for use in determining the source (magmatic, meteoric, etc.), based on methods presented in Barnes (1979), as part of Activity 8.3.1.2.3.2.2. Similar types of information would be obtained by deepening drillholes USW WT-21 and USW WT-22 into the underlying carbonate rocks.

8.3.1.2.1.3.2 Activity: Regional potentiometric-level distribution and hydrogeologic framework studies

Objectives

The objectives of this activity are (1) to determine the potentiometric distribution within the regional ground-water flow system, and (2) to characterize the hydrogeologic framework of the regional ground-water flow system to support reliable estimates of ground-water flow direction and magnitude within the saturated zone.

Parameters

The parameters of this activity are

1. Potentiometric-surface configuration.
2. Hydraulic gradient.
3. Heat flow.
4. Transmissivity.
5. Storativity.
6. Lineaments.
7. Fractures.
8. Hydrostratigraphic units.

Description

A general field reconnaissance will be conducted to locate previously unknown or unobserved wells, springs, and mine shafts that may yield information about regional ground-water levels. In addition, searches will be made for agencies, local residents, and well drillers that are likely to have well records or water-level information. Where possible, depth-to-water measurements will be obtained in these previously unknown or unobserved wells. Depth to water and total well depth will be determined by means of a measuring tape, or a sensor, that is lowered into the hole on a logging cable that goes over a sheave with a counter. In addition, where possible, geophysical logs similar to those for new water-table holes (described below) will be run.

Results from regionally oriented geophysical surveys (Activities 8.3.1.4.2.1.2 and 8.3.1.17.4.3.1) will be used to (1) provide data on

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structural and stratigraphic controls affecting ground-water flow and (2) determine or infer the position of the water table, based on correlating known water-table altitudes with results from these surveys. These surveys will be very important for inferring the cause of the large hydraulic gradient north of the perimeter drift area and for directing the location of additional confirmatory drilling.

Because Crater Flat lacks water-level data and hydrogeologic information needed for modeling of that area, two new water-table holes, USW WT-21 and USW WT-22, will be drilled (Figure 8.3.1.2-8). Other proposed water-table holes shown in Figure 8.3.1.2-8 are considered under Activity 8.3.1.2.3.1.2 (site potentiometric-level evaluation). Additional wells will be drilled if determined to be needed as a result of Activity 8.3.1.2.1.3.1. USW WT-21 will be located 1.5 km southwest of USW H-6 and drilled to a probable depth of about 549 m. USW WT-22 will be located in northern Crater Flat and drilled to a probable depth of about 396 m. Both holes will be drilled using the air-foam method and completed similarly to previously drilled water-table holes. They will have diameters of about 22 cm. The drilling of these holes will be integrated and coordinated with the overall drilling program, as outlined in Section 8.3.1.4.1.

Lithologic logs based on cuttings collected at regular intervals during the construction of USW WT-21 and USW WT-22 will be used to describe the stratigraphy as part of Activity 8.3.1.4.2.1.1. Core will be obtained near the unsaturated/saturated zone interface to extract gas and water samples for chemical analyses to determine ground-water age, origin and recharge rates in conjunction with Activities 8.3.1.3.2.2, 8.3.1.2.2.7.1, and 8.3.1.2.2.7.2.

The newly drilled water-table holes will be geophysically surveyed to attain all the logs that are typically run in the unsaturated-zone holes drilled in support of the Yucca Mountain Project. Such logging programs include a gyroscopic survey (for vertical deviation) and logs used in support of structural and stratigraphic analyses, such as vibroseis and optical television surveys, and dielectric, gamma-ray spectrum, caliper, fluid density, electric, density, and epithermal neutron logs. In addition, magnetometer or other logs may be made.

After downhole geophysical logs are completed in each hole, a small-capacity pump will be hung in the hole on tubing, and the pump will be operated for about a week to obtain water samples for chemical and isotopic analyses (Activity 8.3.1.2.3.2.2). The pump will be removed and the tubing reinstalled to enable measurements of the water levels.

Depth-to-water measurements will be obtained by means of a measuring tape, or a sensor, that is lowered into the hole on a logging cable that goes over a sheave with a counter. The water-level depth will be converted to altitude when combined with the surveyed altitude of land surface. For newly drilled water-table holes, water levels may also be monitored continuously by means of a semipermanently installed downhole pressure transducer that is connected to recording equipment at the surface. These holes will be added to the existing water-level monitoring network of about 25 holes located in the vicinity of Yucca Mountain. If determined applicable, corrections will be made to account for factors that could affect hydraulic head, such as relative density differences.

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Although it is recognized that these boreholes will not be ideally constructed for heat-flow calculations, some useful heat-flow information can be obtained from them. Therefore, where feasible, temperature logs and thermal-conductivity measurements or estimates will be made in newly drilled holes and newly located existing holes, and heat flow will be calculated. Various methodologies, such as the silica geothermometer method of Morgan and Swanberg (1978), will be considered. The results will be integrated with ongoing heat-flow analyses to supplement potentiometric data in interpreting regional ground-water flow directions and hydraulic gradients (Activity 8.3.1.8.5.2.3).

A mining company is drilling boreholes to depths of 2,000 ft in valley-fill deposits of Tertiary age in the Amargosa Desert as a part of its exploration program. This commercial company has agreed to allow (1)installation of piezometers in their holes for Yucca Mountain Project data collection, and (2) borehole geophysical logging of these holes. Some piezometers and piezometer nests have been installed to measure water levels in areas adjacent to the Yucca Mountain site to provide data for regional hydrologic studies. Additional piezometers will be installed if additional holes are made available to the Project. General areas where these boreholes will be located are shown in Figure 3-1. Standard geophysical logs--resistivity, caliper, gamma-gamma, and neutron-density--will be run in these boreholes to provide data on stratigraphy, lithology, porosity, and permeability of the host rock. Borehole cuttings, collected at 10-ft intervals from these holes by the mining company, will be provided for analysis of (1) lithology, (2) grain size, (3) bulk density, (4) porosity, (5) permeability and hydraulic conductivity, (6) environment of deposition, and (7) effective saturated thickness. Instrumentation of each of these holes with two piezometers will provide deep and near-surface potentiometric data for determining vertical hydraulic head distribution. Water samples will be obtained from these piezometers for hydrochemical analyses.

Water-level recovery will be monitored after sampling to determine estimates of transmissivity. Downhole temperature will be measured at selected intervals to estimate the vertical component of ground-water flow. Regional ground-water flow rates and velocities may then be estimated from transmissivity, hydraulic conductivity, porosity, effective saturated thickness, and hydraulic gradient.

A large gradient has been mapped in the potentiometric surface north of the site (Figure 3-28). The horizontal hydraulic gradient between wells UE-25 WT#6 and USW H-1 is about 300 m in 3,000 m, or about 0.1. This is about four orders of magnitude greater than the hydraulic gradient south of well USW H-1. Although the specific cause and nature of this large hydraulic gradient are not yet known, several hypotheses have been proposed (Czarnecki and Waddell, 1984): (1) existence or faults in the area that contain nontransmissive fault gouge or that juxtapose transmissive tuff units against nontransmissive tuff units; (2) the presence of a different type of lithology that is less subject to fracturing, such as rhyolite or argillite, or the presence of an intrusive body, such as a volcanic dike; or (3) a change in the direction of the regional stress field and a resultant change in the density, interconnectedness, and orientation of fractures on either side of the large hydraulic gradient.

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Because the potential repository would be located about 200 to 400 m above the modern-day water table, and because it would be located immediately downgradient from the large hydraulic-gradient area (Figure 3-28), the stability of the low-transmissive property of this barrier to ground-water flow (fault zone, different rock type, etc.) needs to be evaluated. Neotectonics (renewed movement along faults) or alteration of stress fields could have a large effect on this stability, resulting in changed altitudes of the water table beneath the site itself. Furthermore, an understanding of this feature is needed in order to simulate accurately ground-water flow under present and changed conditions, using subregional models (Study 8.3.1.2.1.4).

This activity will analyze the cause of the large hydraulic gradient by integrating the results from several interrelated activities, including (1) analysis of existing and planned borehole fracture data (Activity 8.3.1.4.2.2.3) and data from surface fracture-network studies (Activity 8.3.1.4.2.2.2); (2) determination of in situ stress on either side of the gradient (Study 8.3.1.17.4.8); (3) refinement of the description of the potentiometric surface, using geophysical surveys (Study 8.3.1.4.2.1) and water levels from wells UE-25 WT#23 and UE-25 WT#24 (Activity 8.3.1.2.3.1.2); (4) construction of UE-25 G#5 (Activity 8.3.1.4.2.1.1) north of the gradient to provide stratigraphic, lithologic, borehole-geophysical and potentiometric data; and (5) pumping tests conducted in association with the Solitario Canyon fault study (Activity 8.3.1.2.3.1.1). In addition, existing data from large gradients elsewhere in the Nevada Test Site region will be reviewed for their applicability to understanding the feature at Yucca Mountain.

Definition of the hydrogeologic framework is an essential component of conceptual and numerical models of the regional flow system and evaluations of the impacts of potential tectonic and climatic changes on isolation (Figure 8.3.1.2-4). This activity will utilize extensively the hydrologic, geologic, geochemical, and geophysical information obtained during site characterization in order to define this framework. Data collected specifically as part of this activity will also be incorporated, including data from boreholes USW WT-21 and USW WT-22 and other drillholes that might be drilled as a result of the analyses of data needs (Activity 8.3.1.2.1.3.1).

Also, as part of this activity, major lineaments and fracture zones will be identified and characterized. Because these regional-scale features generally are distinctive high-permeability zones, they may significantly affect ground-water flow, by providing preferred regional vertical and horizontal flow paths. Preliminary lineament and linear-feature maps will be prepared from statistical analysis of digitized linear features derived from remote sensing data (Landsat Thematic Mapper and MSS imagery, passive and active radar imagery, Skylab, and aerial photographs). These maps will be compared to geologic, hydrologic, geochemical, and geophysical data (by digital, statistical, or manual correlation) to produce final lineament maps. The mapped lineaments will then be incorporated into conceptual and numerical models of regional flow (Study 8.3.1.2.1.4).

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8.3.1.2.1.3.3 Activity: Fortymile Wash recharge study

Objectives

The objective of this activity is to determine to what extent (quantitatively, if feasible) that Fortymile Wash has been a source of recharge to the saturated zone under present and past conditions.

Parameters

The parameters of this activity are

1. Times, magnitudes, recurrence frequencies, and volumes of streamflow.

2. Times, rates, and volumes of precipitation.

3. Maximum and minimum daily temperatures.

4. Depth and water content of snowpack.

5. Location and rates of recharge, past and present, in Fortymile Wash.

6. Type and density of vegetative cover.

Description

Ground-water modeling of the saturated ground-water flow system has supported the inference that the Fortymile Wash drainage channel may be an important zone of regional ground-water recharge (Czarnecki and Waddell, 1984). Modeling studies have also indicated that the position of the water table beneath Yucca Mountain may be sensitive to the rate of recharge flux through Fortymile Wash (Czarnecki, 1985). If so, ground-water levels beneath the proposed Yucca Mountain nuclear waste storage areas may be significantly influenced by the percolation of streamflow into and through the bed of the wash. Other smaller washes at and near Yucca Mountain are also being evaluated for their recharge potential (Activity 8.3.1.2.2.1.2). Infiltration studies along the channel of Fortymile Wash will address this potential for streamflow to act as a recharge mechanism. Rainfall-runoff modeling of the wash, upstream from Yucca Mountain, will characterize the relationships between precipitation and runoff in various segments of the Fortymile Wash drainage basin. Actual streamflow and precipitation data will be needed to calibrate the rainfall-runoff modeling exercises. If the data thus obtained allow a reasonably good calibration of the model, or models, the models' capabilities to accurately predict changes in runoff related to future changes in climate will be enhanced. The use of measured data are essential to a realistic calibration of rainfall-runoff models if these models are to provide acceptable predictions of streamflow for precipitation that varies in today's climate and with changing climatic conditions.

Hydrologic characteristics of Fortymile Wash drainage basin will be determined and subbasins will be selected for precipitation and streamflow measurements. After the number and locations of data-collection sites have been determined, streamflow gages will be installed to continuously record

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stream stages, and precipitation gages will be installed to continuously record precipitation. Maximum and minimum daily temperatures will be recorded at select sites. These stations will be established as part of Activity 8.3.1.2.1.2.1 (surface-water runoff monitoring). Stream stages, precipitation, and temperatures will probably be continuously transmitted to a data-assembling and storage site. Snowpack accumulation and dissipation will be monitored automatically by snowpillows and manually at designated snowcourses. Snowpillow data will probably be relayed on a real-time basis. (A snowpillow consists of an inflated elastomeric bladder connected to a pressure transducer in such a way that the weight of snow falling on the bladder may be determined by changes in pressure within the bladder.)

The infiltration rate along the channel of Fortymile Wash will be estimated by measuring the streamflow losses and monitoring the moisture pulses. Devices, such as neutron moisture tubes, will be installed at key locations in and across the channel of Fortymile Wash. The completed depths will be below 10 m, the maximum depth where significant evapotranspiration occurs. The devices will be monitored during infiltration events with a frequency that will ensure adequate observation of the movement of moisture pulses through the shallow unsaturated zone. The results of these measurements will be used to estimate the infiltration locations and rates.

In addition to aqueous samples collected, gas samples will be obtained from a series of piezometer nests that will be installed across Fortymile Wash, in order to help establish the extent and timing of recharge to the regional ground-water system. Gas samples will be analyzed for chemical composition and stable isotopes. Analytical results will be synthesized with other analyses of samples collected from the unsaturated zone, as described in Activities 8.3.1.2.2.7.1 and 8.3.1.2.3.2.2

Three drillholes (UE-25 FM#1, UE-25 FM#2, and UE-25 FM#3) will be drilled into the saturated zone to obtain unsaturated-zone moisture samples and saturated-zone water samples to determine the recharge history. Drillhole UE-25 FM#1 will be located in a wash that is 1.2 km east of UE-25 WT#15 (Figure 8.3.1.2-9). This drillhole will have a total depth of approximately 427 m. Drillhole UE-25 FM#2 will be located in a wash that is at the crossing of the main road to Yucca Mountain and will have a total depth of approximately 381 m (1,250 ft). Drillhole UE-25 FM#3 will be located south of well J-12 and will have a total depth of approximately 290 m.

Moisture measurements will be obtained in each of these holes by coring selected intervals within the unsaturated zone. Water samples will be obtained near the top of the saturated zone in each hole and about 91 m deeper, which is near the bottom of each hole. Samples will also be collected if perched water is encountered. Each of the three drillholes will be used for infiltration experiments. These experiments will be similar to those planned for the unsaturated zone, where an infiltration pond will be constructed around the drillhole casing. Periodic or continuous moisture content measurements will be made in the drillhole casing at selected locations, as water infiltrates downward from land surface. Ponding tests conducted in Activity 8.3.1.2.2.1.3 are expected to show the relationship of thickness, texture, and porosity of unconsolidated deposits to net-infiltration rates. Results from the ponding tests may be extrapolated to Fortymile Wash, which has deposits with a similar range of properties. Results from

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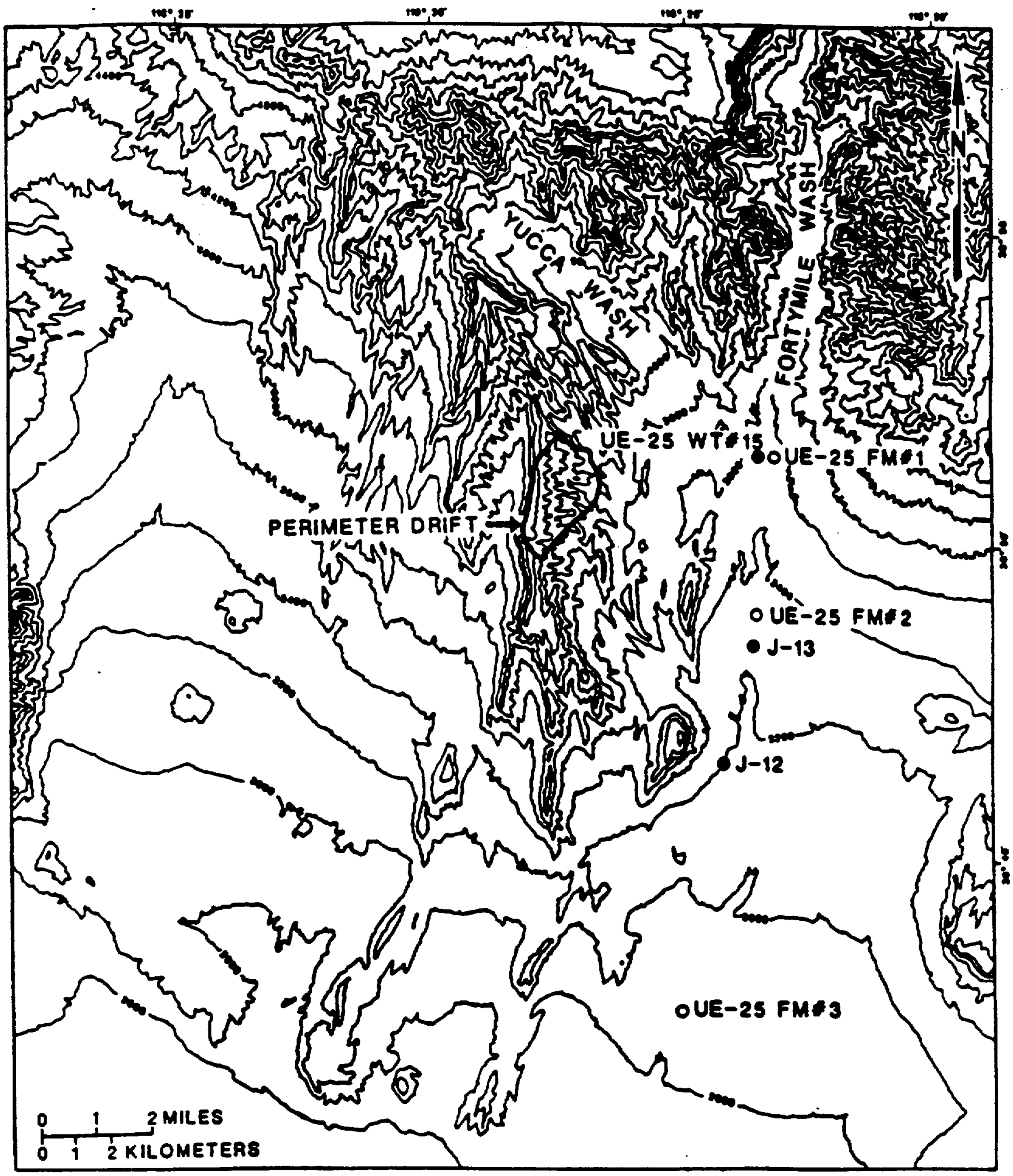

● EXISTING DRILL HOLE
○ PROPOSED DRILL HOLE

Figure 8.3.1.2-9. Location of existing and proposed drillholes for the Fortymile Wash recharge study.

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these infiltration experiments will be used with results from Studies 8.3.1.2.1.1 and 8.3.1.2.1.2 to estimate annual average estimates of recharge occurring along Fortymile Wash for use in the regional and site models of ground-water flow.

All samples will be sent to the laboratory for chemical and isotope analyses. The isotope analyses will include determination of the oxygen-18, deuterium, carbon-13, carbon-14, and tritium content. The precipitation, surface water, and ground-water sample analyses will be compared and interpreted in terms of probable sources and flow paths in the Fortymile Wash drainage. The results of other investigations from which ground-water movement or the paleoenvironment may be inferred, such as studies of zeolite facies (Section 8.3.1.3.2.2), will be used in conjunction with hydrologic interpretations based on these surface and subsurface chemical analyses to determine the recharge history.

8.3.1.2.1.3.4 Activity: Evapotranspiration studies

Objectives

The objective of this activity is to improve estimates of ground-water discharge by evapotranspiration in the Amargosa Desert, in order to provide boundary-condition data for regional ground-water flow models.

Parameters

The parameters of this activity are

1. Evapotranspiration rates and areal distribution.
2. Spatial distribution of hydraulic head.
3. Depth to saturation.

Description

A data requirement of the two-dimensional regional ground-water flow model is to specify the distribution and rate of ground-water discharge. Discharge occurs primarily as evapotranspiration and spring discharge from the regional ground-water flow system and by pumping of irrigation wells. The two principal natural discharge areas in the flow system are Franklin Lake playa and the Furnace Creek Ranch area (Figure 8.3.1.2-10). Estimates of spring discharge and evapotranspiration (Section 3.5) have been made for these areas (Walker and Eakin, 1963; Hunt et al., 1966; Winograd and Thordarson, 1975; Miller, 1977). The spring discharge measurements are considered reliable, but estimates of evapotranspiration at Franklin Lake playa do not conclusively yield annual-average discharge fluxes because the area over which evapotranspiration occurs is not adequately defined. The need for improved estimates stems from the sensitivity analyses performed by Czarnecki and Waddell (1984).

The amount of ground-water discharge depends on numerous variables, including depth to the saturated zone. Evapotranspiration probably is maximum and relatively uniform at Franklin Lake playa, where depths generally

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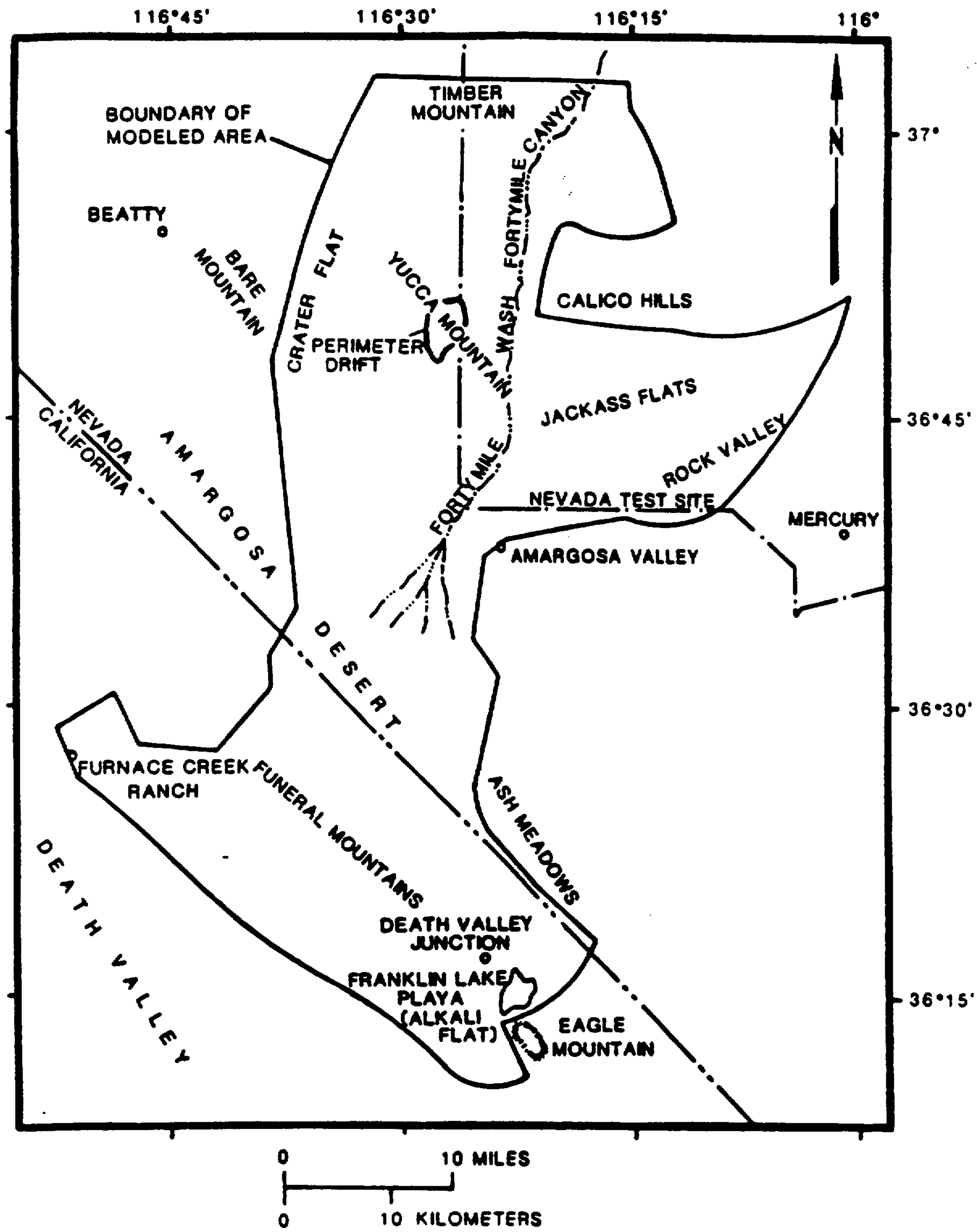

Figure 8.3.1.2-10. Subregional ground-water flow study area showing principal discharge areas at Furnace Creek Ranch and Franklin Lake Playa (Czarnecki and Waddell, 1984).

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are less than 5 m; probably no evapotranspiration from the saturated zone occurs where depths exceed 15 m, upgradient from Franklin Lake playa. Thus, a critical depth range (5 to 15 m) occurs beneath a large but poorly defined fringe area, within which evapotranspiration is variable and generally known.

Definition of the fringe area and its associated evapotranspiration will come from the following activities: (1) mapping of phreatophytes; (2) construction of piezometer and tensiometer nests, to determine depths to saturation and the presence or absence of upward hydraulic potentials for water flow from the shallow saturated zone to land surface; and (3) measurement of evapotranspiration using micrometeorological techniques.

Phreatophyte mapping will be used to identify the type, density, size, and areal extent of phreatophytes growing in the subregional ground-water flow system. Phreatophytes derive their water supply from the phreatic surface, or water table, and generally tap ground water at depths that exceed the threshold of bare-soil evaporation. Phreatophyte growth and evapotranspiration are limited by depth to water, soil and water salinity, and soil type (texture). Water salinity is high beneath Franklin Lake playa but decreases away from its margins (Czarnecki and Oatfield, 1986). Thus, phreatophytes tend to grow only in the fringe area where salinity is low and depth to saturation is less than about 15 m. It is expected, therefore, that the mapped areal extent of phreatophytes will approximately delimit the area of ground-water discharge by evapotranspiration.

In the area of evapotranspiration, an upward hydraulic gradient is expected in the saturated and unsaturated zones; elsewhere, beyond discharge areas, the gradient is expected to be downward or lateral. To determine whether an upward gradient exists, 10 to 30 nests of piezometers and tensiometers will be installed at sites in the area defined by phreatophyte mapping. Because of the large uncertainty in estimating in situ vertical hydraulic conductivity at these sites, no attempt will be made to estimate ground-water discharge using Darcy's law. However, gradient data will be used qualitatively to corroborate the location of the evapotranspiration area boundary and its associated depth to water. It is recognized that this depth varies in space and time, depending on various factors, such as soil texture, plant type and density, precipitation, temperature and runoff. These factors will be considered in locating evapotranspiration measurement sites and in evaluating evapotranspiration data.

At about 10 sites within the evapotranspiration area, total evapotranspiration will be measured using micrometeorological techniques, such as the Bowen ratio method (Stannard, 1985) or the Eddy-correlation technique (Weeks et al., 1985). These measurements will help to determine the spatial and temporal variation in net saturated-zone evapotranspiration, and provide a basis for determining the annual average saturated-zone discharge rate from the subregional flow system. Continuous measurements throughout the year will be made at two to five of these sites.

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8.3.1.2.1.4 Study: Regional hydrologic system synthesis and modeling

The objectives of this study are (1) to synthesize the available data into a model and make a qualitative analysis of how the system is functioning and, (2) to represent quantitative observations of hydrogeologic data pertaining to the ground-water flow system in a comprehensive numerical model of ground-water flow. Four activities are planned to analyze and integrate the data in order to satisfy these objectives: (1) conceptualization of regional hydrologic flow models, (2) subregional two-dimensional areal hydrologic modeling, (3) subregional two-dimensional cross-sectional hydrologic modeling, and (4) regional three-dimensional hydrologic modeling.

Results from these modeling activities are not intended to directly estimate ground-water travel time from the repository to the accessible environment. Rather, the modeling results will be used as a basis for specifying boundary conditions for more detailed models of ground-water flow at the site.

8.3.1.2.1.4.1 Activity: Conceptualization of regional hydrologic flow models

Objectives

The objectives of this activity are

1. To synthesize the available data into a model and make a qualitative analysis of how the regional hydrologic system functions.

2. To outline ground-water flow system boundaries, hydrogeologic units, structural controls, and other hydrogeologic features pertaining to the regional ground-water flow system.

Parameters

The parameters of this activity are

1. Spatial distribution of hydraulic conductivity.
2. Hydraulic gradient.
3. Ground-water flux.
4. Recharge.
5. Discharge.
6. Hydrogeologic properties of the saturated-zone rock units.
7. Potentiometric-surface configuration.

Description

All reliable data (hydrologic, geologic, and geophysical) and reasonable interpretations of it will be assimilated into a description of the regional ground-water flow system. This description will include the physical and hydraulic characteristics of the rock units and structural features, as well as the likely ways that the flow system operates within this framework. The data will contain information obtained from the published literature and site

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characterization activities. This conceptual description of the flow system will be used to update a regional ground-water flow model originally developed by Waddell (1982). This updated model will be used as the baseline condition for regional ground-water flow at the site.

8.3.1.2.1.4.2 Activity: Subregional two-dimensional areal hydrologic modeling

Objectives

The objective of this activity is to improve estimates of regional ground-water flow, by updating an existing two-dimensional, subregional, parameter-estimation model through the incorporation of additional hydrogeologic data.

Parameters

The parameters of this activity are

1. Spatial distribution of hydraulic conductivity.
2. Hydraulic gradient.
3. Water flux.
4. Recharge.
5. Discharge.
6. Hydrogeologic properties of the saturated zone rock units.
7. Potentiometric-surface configuration.

Description

A subregional model of two-dimensional ground-water flow has been developed by Czarnecki and Waddell (1984) for estimating ground-water flow. Since the development of the model, numerous additional studies and data-collection activities have occurred and are planned in and around the modeled area (Figure 8.3.1.2-10). Additional drillholes have been and will be constructed in the study area yielding potentiometric data and hydraulic properties. Potentiometric data will be used, in part, as a basis for model calibration and as an indicator of variations in hydraulic properties, based on variations in hydraulic gradients.

The refined two-dimensional model will be a highly simplified representation of a complex three-dimensional system, but it is expected to be useful for various applications. These include preliminary evaluations of the effects of potential future pumping on the hydrologic system (Activities 8.3.1.9.3.2.1 and 8.3.1.16.2.1.4). The model will also be used to help guide development of more rigorous three-dimensional models (Activity 8.3.1.2.1.4.4), which will be used to test the impacts of future ground-water development, tectonic events, and climatic changes on the saturated-zone hydrologic system.

The use of a two-dimensional model for these purposes is warranted because, on a regional scale, vertical flux probably is small relative to horizontal flux. This concept will be tested as new data are obtained and by

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means of a two-dimensional cross-sectional model (Activity 8.3.1.2.1.4.3). If it is ascertained that significant upward or downward leakage occurs between, for example, the Paleozoic carbonate aquifer and the overlying valley-fill sediments or volcanic rocks, these fluxes will be accommodated in the two-dimensional model as source/sink terms. The model would be calibrated on the basis of estimated hydraulic properties and vertical CC-38 fluxes.

Geophysical studies have produced and will provide additional information regarding stratigraphic and structural features in and around the site. Of particular utility is seismic refraction work that will be used to define the location, type, and distribution of structural and stratigraphic units that may affect ground-water flow. Although hydraulic properties in the vertical dimension are lumped, when used in the areal two-dimensional ground-water flow model, information such as effective saturated thickness can be combined with model ground-water flux estimates to yield estimates of ground-water travel times. Additional data in the third dimension also aid in the development of three-dimensional models of ground-water flow (Activity 8.3.1.2.1.4.4). Other geophysical studies that will produce results for consideration of incorporation into the model include the following: (1) resistivity surveys, (2) gravity surveys, (3) magnetic surveys, (4) seismic reflection surveys, and (5) borehole geophysical surveys (Activity 8.3.1.4.2.1.2). All these various activities have the potential for providing additional data on the distribution, type, and properties of stratigraphic and structural units, for use in the subregional ground-water flow model. Results from these various activities will be reviewed as they become available, and incorporated into the model as appropriate.

Additional hydrogeologic data will be provided from the analyses of drillhole cuttings from exploration boreholes constructed in the Amargosa Desert in Tertiary valley-fill sediments, to depths of 2,000 ft by a commercial mining company (Study 8.3.1.2.1.3). These analyses will provide further knowledge of the areal and vertical distributions of hydraulic conductivity, porosity, bulk density, lithology, and stratigraphy. Additional estimates of hydraulic conductivity will be provided by monitoring the recovery of water levels in wells and piezometers after they have been pumped for hydrochemical samples (Activity 8.3.1.2.3.2.3). The need for additional information on the distribution of hydrogeologic properties will be determined as part of a regional data-needs assessment (Activity 8.3.1.2.1.3.1).

Annual average estimates of evapotranspiration were made for Franklin Lake playa, based on measurements made at various times throughout the year. These estimates (Activity 8.3.1.2.1.3.4) will be used in the two-dimensional subregional model as one of the discharge boundary conditions. Sensitivity analyses (Czarnecki and Waddell, 1984) have indicated that the flow system is sensitive to evapotranspiration, and that the flow model would be improved by refining these values. This sensitivity results partly because of the large magnitude of the specified discharge used in the model and because the discharge area is located directly downgradient from Yucca Mountain along the axis of the Amargosa Desert. In addition, recharge estimates made at Fortymile Wash will be used in the model; other refinements in recharge estimates throughout the study area will also be used.

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Hydrochemical studies at site and regional scales will provide additional data to be considered as part of the ground-water flow modeling activities (Activities 8.3.1.2.3.2.2 and 8.3.1.2.3.2.4). Hydrochemical analyses will be used to help define the flow paths of ground water through various lithologies, to account for the evolution of various water chemistries and ages. This hydrochemical perspective will be used as a partial basis for conceptual models of ground-water flow.

The finite-element computer program to be used in the simulations of this study is FEMOD. FEMOD has been verified against numerous analytical test cases and has been successfully used in field applications (Czarnecki, 1985), and comparisons against other models.

8.3.1.2.1.4.3 Activity: Subregional two-dimensional cross-sectional hydrologic modeling

Objectives

The objective of this activity is to estimate the ground-water flow direction and magnitude along a potential flow path through the repository block to the accessible environment, and extending into the region, to help test the assumption of horizontal flow.

Parameters

The parameters of this activity are

1. Spatial distribution of hydraulic conductivity.
2. Hydraulic gradient.
3. Water flux.
4. Recharge.
5. Discharge.
6. Hydrogeologic properties of the saturated zone rock units.
7. Potentiometric-surface configuration.

Description

A two-dimensional, steady-state, cross-sectional model of ground-water flow in the saturated zone will be constructed along an inferred ground-water flow line through Yucca Mountain (Figure 8.3.1.2-11). The model will be constructed to evaluate the lateral and vertical components of ground-water flux in the saturated zone and to examine the importance of potential structural features (such as fault-zone barriers) on the ground-water flow path. Sensitivity analyses will be performed to (1) evaluate the effect of saturated thickness distribution on ground-water flux direction and magnitude, and (2) evaluate the effect of recharge from the unsaturated zone. Results from this model may be used, in conjunction with other models and studies that are designed to estimate effective porosity at the site, as part of the basis for estimating ground-water travel time, in the saturated zone, from the site to the accessible environment. A highly simplified representation of the section will be used, with each layer being modeled as isotropic with respect to the hydraulic properties.

The cross-sectional line shown in Figure 8.3.1.2-11 is based on a potential flow path estimated by Czarnecki and Waddell (1984) using a two-dimensional areal ground-water flow model. The flow line depicted in the figure enters the region at the northern boundary, passes beneath the repository perimeter drift, continues south, and is diverted to the southeast around the Funeral Mountains barrier to discharge at an altitude 606 m at the Franklin Lake playa. One of the basic assumptions made in using the areal model was that ground-water flow was strictly horizontal. By modeling along a cross section, this assumption can be tested, particularly from the repository block to the accessible environment. If the vertical component is minor, then the two-dimensional areal modeling approach may be valid instead of using a fully three-dimensional model. A vertical component of ground-water flow would also lengthen the flow path in the zone of saturation, although it would not necessarily increase travel time.

8.3.1.2.1.4.4 Activity: Regional three-dimensional hydrologic modeling

Objectives

The objectives of this activity are to

1. Develop a quasi-three-dimensional ground-water flow model of the saturated zone of the Yucca Mountain region.
2. Use the regional model to improve concepts of ground-water flow and to estimate the distribution of hydrologic properties where they are not well known.
3. Improve the regional model simulation through incorporation of new hydrologic data and information as it becomes available from other studies.
4. Use the regional model to test the impacts of possible future tectonic activity and climatic changes on the saturated hydrologic system.

Parameters

The parameters of this activity are

1. Spatial distribution of transmissivity.
2. Hydraulic gradient.
3. Water flux.
4. Recharge.
5. Discharge.
6. Hydrogeologic properties of the saturated zone rock units.
7. Potentiometric levels.

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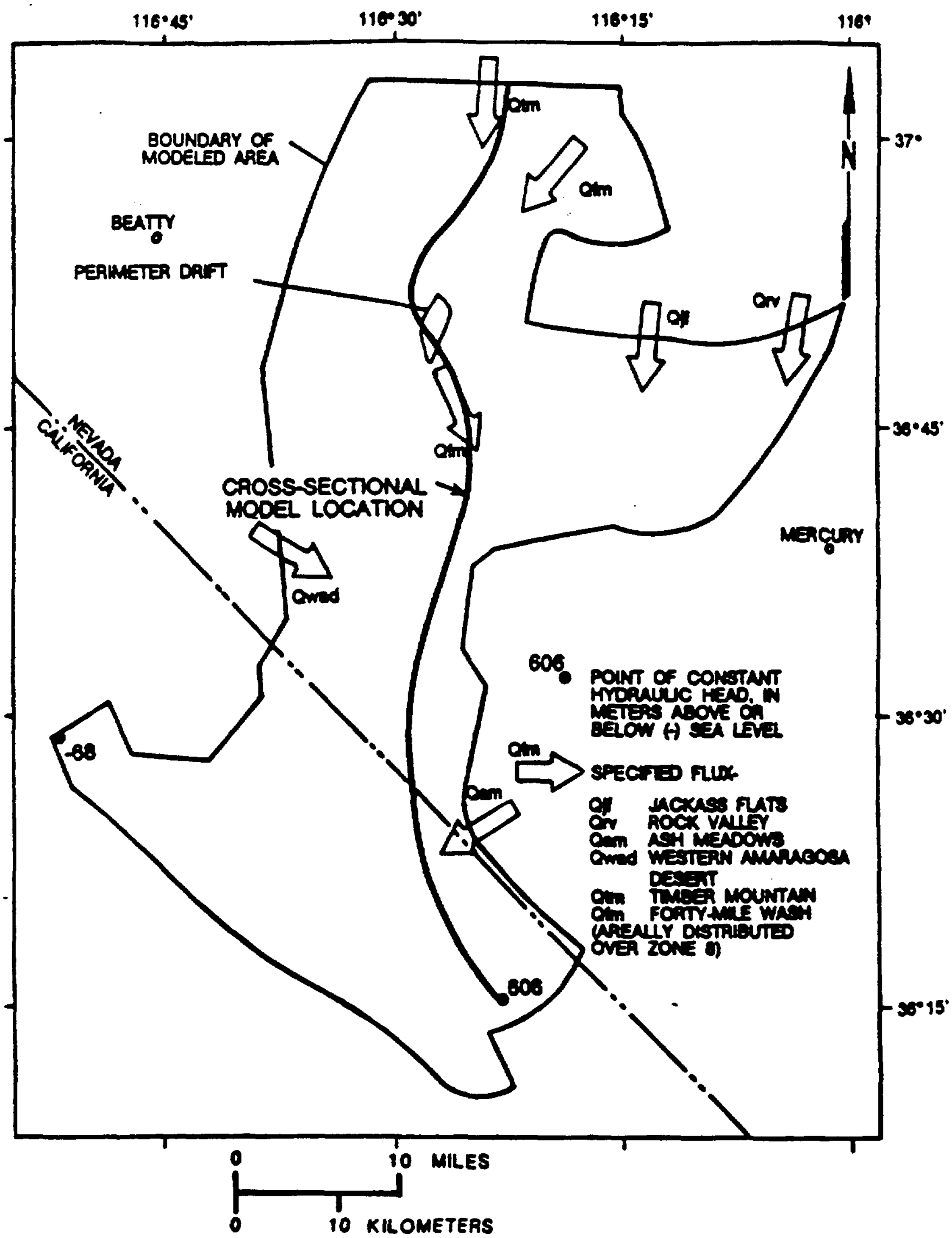

Figure 8.3.1.2-11. Location of the flow line for the subregional two-dimensional cross section of hydrologic model (modified from Czarnecki and Waddell, 1984).

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Description

A numerical, quasi-three-dimensional ground-water flow model of the saturated zone of the Yucca Mountain region will be constructed and calibrated. Because of the highly complex geologic structure and stratigraphy in the region, it is presently feasible to define only broad hydrogeologic units. Because of the sparseness of hydraulic-property data, particularly vertical hydraulic conductivity values for individual units, only a quasi-three-dimensional model is warranted at this time for simulation of the regional saturated-zone flow system. In this model, a leakance layer is used to simulate vertical flow between layers (see following description), and detailed knowledge of the distribution of vertical flow properties is not required. If feasible, a fully three-dimensional model will be developed for the site saturated-zone flow system (Study 8.3.1.2.3.3).

Initially, the model will contain two layers that simulate horizontal flow in each of two major hydrogeologic units in the study area: (1) a combination of the Plio-Pleistocene deposits and the Miocene volcanic rocks and (2) the Paleozoic carbonate rocks. In areas where one of these units is missing, only a single layer will be used in the model. Vertical flow between the two hydrogeologic units will be simulated by a leakance layer in the model. The leakance layer will represent the composite effects of upper and lower layer thicknesses, vertical hydraulic conductivities, and any low-permeability zones present. The technical basis for using the leakance layer in the quasi-three-dimensional model is discussed in McDonald and Harbaugh (1984). With the existing data base, use of more than two layers to represent the regional ground-water-flow system is not expected to be justified because of a sparsity of data on the three-dimensional hydrogeologic properties of the system. This quasi-three-dimensional (or layered) simulation of the saturated zone is needed because of the differences in hydraulic properties between the two major hydrogeologic units and the differences in potentiometric head (50 to 60 ft (16 to 20 m)) between the two units. These differences in hydraulic properties and potentiometric head could not be simulated with a single-layered, two-dimensional model.

The USGS modular three-dimensional finite-difference ground-water flow code (McDonald and Harbaugh, 1984) is the numerical technique that will be used to simulate the ground-water flow system in the Yucca Mountain region. The USGS three-dimensional code allows ground-water flow simulations both in two and three dimensions and, therefore, provides considerable flexibility for simulating complex geohydrologic systems.

The model will be constructed using hydrogeologic data from previous studies of the Yucca Mountain and Nevada Test Site areas. Data will be compiled from previous drilling programs, geologic reports, well-scheduling efforts, the regional and site characterization studies (8.3.1.2.1.3 and 8.3.1.5.2.1.3), the USGS Great Basin Regional-Aquifer System Analysis (Sun, 1986), and the USGS WATSTORE data base. Remote sensing studies (Activity 8.3.1.5.2.1.3) will provide information on possible ground-water flow paths from recharge to discharge areas. Initial model simulations will use the transmissivity distributions, recharge, and boundary conditions described by Waddell (1982) and Czarnecki and Waddell (1984) for a previously constructed two-dimensional ground-water flow model of the study region. Leakage from the unsaturated zone will be simulated as areal recharge to the

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saturated zone in upland areas, which have wetter and cooler climatic conditions, and in lowland areas, such as Fortymile Wash, where periodic surface runoff is believed to be a source of recharge. Where arid conditions prevail, leakage from the unsaturated zone is considered negligible on a regional scale and available data do not justify simulation. However, model simulations of the saturated zone at the site scale in the immediate vicinity of Yucca Mountain (Study 8.3.1.2.3.3) will consider leakage from the unsaturated zone.

Virtually no information exists regarding vertical hydraulic conductivity of the hydrogeologic units. An extensive testing program to determine values for this parameter probably is not warranted. The units will be modeled as isotropic with respect to hydraulic properties, and sensitivity analysis will be conducted to evaluate the impacts of this assumption.

The model will be calibrated for steady conditions based on water-level data contained in Winograd and Thordarson (1975), Waddell (1982), and Czarnecki and Waddell (1984), and collected from Activities 8.3.1.2.1.3.2 and 8.3.1.2.3.1.2. Model calibration will consist of successive adjustment of hydraulic properties (transmissivity, recharge, and vertical leakage) within reasonable ranges to minimize the difference between observed and simulated potentiometric head. The most significant adjustments are expected to be for transmissivity in the vicinity of the steep-gradient area northeast of the proposed repository site and for recharge along Fortymile Wash. Sensitivity analyses will be made to address uncertainties, including model boundaries, parameters, and fluxes. As an ongoing activity, the model will be updated and recalibrated using data from the regional and site characterization studies and other geological studies. As the data base improves, an attempt may be made to improve the regional simulation by adding several additional layers (such as the saturated alluvium) to the model in order to simulate flow in the saturated zone in more detail as more hydrogeologic data become available.

As a part of other activities (8.3.1.5.2.2.3 and 8.3.1.8.3.1.2), the regional quasi-three-dimensional ground-water flow model will be used to test the impacts of possible future ground-water developments, tectonic activity, and climatic changes on the saturated hydrologic system. Future movement along faults in the vicinity of Yucca Mountain could change hydraulic properties so as to either impede or enhance ground-water flow. The impact of such changes will be evaluated using the model. Future climate in the study area could be considerably wetter than the present climate and produce corresponding greater amounts of ground-water recharge. Increased recharge will be simulated using the model to predict the impact on ground-water levels under the site of the proposed repository at Yucca Mountain.

8.3.1.2.2 Investigation: Studies to provide a description of the unsaturated zone hydrologic system at the site

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

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The following sections of the data chapters summarize existing data relevant to this investigation:

SCP section	Subject
3.9.2.1	Hydraulic characteristics of the unsaturated zone
3.9.3.1	Accessible environment and credible pathways
3.9.4	Ground-water velocity and travel time
3.9.5	Hydrochemical confirmation of ground-water behavior
3.10.1	Summary of significant results (unsaturated zone hydrology)
3.10.2	Relation to design (unsaturated zone hydrology)
3.10.3	Identification of investigations (unsaturated zone hydrology)

Parameters

The following parameters will be measured or calculated as a result of the site studies planned to satisfy this investigation:

1. Infiltration characteristics, spatial distribution of the physical and hydraulic properties of the surficial hydrogeologic units at Yucca Mountain.

2. Unsaturated zone percolation characteristics, spatial distribution of the physical and hydraulic properties of the repository host rock and surrounding hydrogeologic units.

3. Unsaturated zone gas-phase movement characteristics, gas-phase (pneumatic) properties of the repository host rock and surrounding units.

4. Unsaturated zone hydrochemical characteristics, spatial and temporal variation of the gas and water quality in the repository host rock and surrounding units.

5. Velocities, fluxes, and travel times of water and gases in the unsaturated zone.

Other site studies that supply information that support the determination of the above parameters include the following:

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Study	Subject
8.3.1.2.1.1	Characterization of the regional meteorology (precipitation patterns)
8.3.1.2.1.2	Characterization of the regional surface water (runoff component of the precipitation)
8.3.1.2.1.4	Characterization of the regional ground-water flow system (Fortymile Wash ground-water recharge to the site unsaturated zone)
8.3.1.4.2.1	Characterization of the vertical and lateral distribution of stratigraphic units within the site area (site hydrogeologic units)
8.3.1.4.2.2	Characterization of site structural features (site fractures and hydrogeologic units)
8.3.1.4.2.2	Exploratory shaft facility geological studies (site lithostratigraphy and structure that would lead to hydrogeologic unit definitions)
8.3.1.5.2.1	Characterization of the Quaternary regional hydrology (site unsaturated zone water age and analog recharge chemistry)
8.3.1.5.2.2	Characterization of the future regional hydrology due to climate changes (future site unsaturated zone flow)
8.3.1.6.4.1	Evaluation of impact of future erosion on hydrologic characteristics at Yucca Mountain and vicinity (future site unsaturated zone flow)
8.3.1.8.3.1	Characterization of the future regional hydrology due to igneous and tectonic activity (future site unsaturated zone flow)

Purpose and objectives of the investigation

The objective of this investigation is to develop a model of the unsaturated-zone hydrologic system at Yucca Mountain that will assist in assessing the suitability of the site to contain and isolate waste. Developing this model requires an understanding of the manner in which water and gases move through the unsaturated zone, including the directions, paths, and rates in which flow occurs. This information will be provided through studies of the characterization of infiltration, percolation, gaseous-phase movement, and hydrochemistry. Flow and transport modeling designed to simulate the natural system will provide sensitivity analyses to help prioritize additional data collection.

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Technical rationale for the investigation

In this introduction, the rationale for organization of the studies in this information need is discussed and a logic for integration of the studies and activities is presented. There are nine studies planned to be conducted under this investigation: (1) characterization of unsaturated-zone infiltration, (2) water movement tracer tests, (3) characterization of percolation in the unsaturated-zone surface-based studies, (4) characterization of percolation in the unsaturated-zone exploratory shaft facility studies, (5) diffusion tests in the exploratory shaft facility, (6) characterization of gaseous-phase movement in the unsaturated zone, (7) characterization of the unsaturated-zone hydrochemistry, (8) flow in unsaturated fractured rock, and (9) site unsaturated-zone modeling and synthesis. Of these, there are seven data collection studies that have specific objectives, and although each will have modeling as part of the test design and data analysis, there will be no system modeling associated with these studies. System modeling will be conducted in the last two studies listed previously. Prototype test activities will be conducted in support of the unsaturated-zone site characterization investigation. These activities will not be part of site characterization but will be performed to develop specific procedures/methods or instrumentation/equipment that will be used in characterizing Yucca Mountain. All prototype activities referenced in the subsequent discussion of the unsaturated-zone investigation plans will not be conducted at the Yucca Mountain site nor will they use samples from Yucca Mountain.

The infiltration study is targeted at characterizing the upper boundary of the unsaturated zone system. Present day net infiltration into this boundary and estimates of the bounds on the future net infiltration rates are needed as an input for the system flow model. The goal of the percolation studies are to provide an understanding of the spatial distribution of the present day fluxes within the unsaturated zone system. These values are not only input for the site system model but also are essential for the performance assessment modeling. The percolation studies and gaseous-phase studies also will provide the material property and potential distribution values that will be needed for the system modeling. All four data collection studies are designed to reduce the uncertainties in the characteristics of site properties in the two-phase flow model developed for the unsaturated zone and in the information required to identify disruptive scenarios and to quantify their likelihood.

One of the features of Yucca Mountain that permits consideration of a repository in the unsaturated zone is the very deep water table, generally about 500 to 750 m below land surface (Robison, 1984). As proposed, the repository would be constructed in the lower part of a densely welded fractured tuff, the Topopah Spring Member of the Paintbrush Tuff. These rocks appear to have geomechanical properties that permit the construction of stable openings and geochemical and thermal properties that are suitable for storage of waste (Johnstone et al., 1984). In addition, these rocks have fracture densities and apertures (Scott et al., 1983) that probably facilitate large, episodic increases of flux while maintaining unsaturated conditions. Accordingly, a waste container and underground facility probably can be designed to enhance water drainage through the surrounding rocks. Capillarity is expected to cause percolating water to bypass openings such as

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drifts and canister holes, so that only minimal water contact is made with the waste containers (Roseboom, 1983).

At the Yucca Mountain site, the unsaturated zone could be a natural barrier to radionuclide migration that would add to the barriers that exist in the saturated zone system. The first component of the unsaturated zone barrier is the likelihood that the ambient fluid flux of water is very slow at Yucca Mountain. Next, a sequence of nonwelded porous tuffs that overlies the Topopah Spring Member probably form a natural capillary barrier to retard the entrance of transient pulses of water into the fractured tuffs. A similar sequence of nonwelded tuffs underlies the Topopah Spring Member. These underlying nonwelded tuffs locally contain sorptive zeolites and clays that could be an additional barrier to the downward transport of radionuclides from a repository to the water table.

Although the general conditions just described probably exist, details of the hydrologic processes, conditions, and properties in the unsaturated zone are poorly known. These details need to be known to characterize the site properly. The current lack of knowledge is the result of (1) lack of data, because of the newness of the focus on the unsaturated zone; (2) inadequacy of the general state of understanding of the physics of flow in thick, fractured-rock unsaturated zones in arid environments; and (3) lack of well-established techniques for testing and evaluating the hydrology of such unsaturated zones. To develop the information and understanding needed to assess the suitability of the unsaturated zone at Yucca Mountain within the time frame imposed by the national site-selection effort, an efficient and focused investigative program needs to be conducted, and preliminary results need to be obtained early in the program.

The phenomena of unsaturated flow have been studied extensively for application to agricultural soil conditions (e.g., Van Schilfgaarde, 1974; Hagan et al., 1967; Childs, 1957; and Hillel, 1982); however, this is not true for the lithified fractured porous media of Yucca Mountain. In all hard rock settings, predictions of fluid-flow behavior depends on the correct applications of fracture hydrology, a topic no more than 25 yr in development. The state of the knowledge of unsaturated flow in fractured media is even less advanced. Confidence in the capability of the Yucca Mountain site to isolate nuclear waste depends upon developing valid concepts of fluid flow through such media. Therefore, many of the unsaturated-zone site characterization activities are directed at developing quantitative methodologies to assess fluid flow through unsaturated, fractured porous media.

For this purpose, the unsaturated zone system at Yucca Mountain was divided into the infiltration boundary and the percolation region. Each component of the system will be studied by multidisciplinary approaches (i.e., hydraulic, pneumatic, and gaseous and aqueous-phase hydrochemical studies) to describe the spatial and temporal distributions of the flux and travel times within this system. On this basis, seven studies have been developed: (1) infiltration characterization, (2) water-movment tracer studies, (3) percolation--surface-based, (4) percolation--exploratory shaft facility, (5) diffusion tests, (6) gaseous-phase movement, and (7) hydrochemistry. An eighth study, fluid flow in unsaturated fractured rock is designed to help design and interpret hydrologic and pneumatic tests, and to provide information about model parameters that can be incorporated into

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site-scale models, and also enable evaluation of the sensitivity of the flux and travel time calculations to certain site characteristics that may not readily be determined. Finally, the ninth study is designed to develop a conceptual model for the unsaturated zone on the basis of which the testing programs can be designed and modified. This conceptual model will be modified and eventually will lead to the integration of the information acquired in the first eight studies to provide a sufficient understanding of the unsaturated zone at Yucca Mountain. The last study will select, develop, and apply numerical hydrologic models of the hydrogeologic system at the site scale.

The infiltration boundary, or the surficial units, at Yucca Mountain is one of the most important boundaries that needs to be characterized. Water and air can enter and gases and water vapor can escape through this boundary from the unsaturated zone where the repository is proposed to be constructed.

The net infiltration at Yucca Mountain is now imprecisely estimated from regional water balance studies and other sources (Sections 3.9.3.3 and 3.9.3.4); improved estimates will be obtained by monitoring the natural infiltration process and simulating a variety of infiltration conditions in a controlled manner. Physical properties and distribution of surficial soils, rocks and vegetation influencing infiltration will be determined by field sampling studies and mapping techniques. Drill core and cuttings, plus neutron probe use, will provide lithologic and structural data, and especially the distribution of moisture and effective permeability. Geophysical tools will enhance the coverage of inaccessible units and their properties. About 100 neutron access holes will be drilled and monitored to permit the calculation of liquid flux and to characterize natural infiltration events from the propagation of moisture fronts under a variety of conditions. Analysis of stable isotopes, tritium, chlorine-36, fluorocarbons, and carbon dioxide content from waters extracted from cores will provide independent estimates of infiltration rates. To understand the effects of rainfall intensity and duration outside the present natural range, artificial tests on several soil plots will be run using simulated rainfall and ponding, while monitoring transient and steady water movements in the underlying units. Dye and chemical tracers will be used. Numerical modeling will be intrinsic to these tests, facilitating not only the design and operation but also the interpretation of results and the extrapolation to hypothetical future conditions, which will serve as the boundary flux conditions for models of the entire unsaturated zone.

The unsaturated zone at Yucca Mountain consists of a gently dipping sequence of fine-grained ash-flow tuffs, mostly welded and fractured, with some ash-flow and air-fall, nonwelded, sparsely fractured tuffs that are vitric in some parts and zeolitized in others. The definition of the physical properties and spatial distribution of the different media within the unsaturated zone is the subject of much of the testing (Studies 8.3.1.2.2.2 through 8.3.1.2.2.7) because all modeling and synthesis work require these data. The thickness, lateral extent, inhomogeneities, and geophysical properties of all hydrostratigraphic units, as well as the distribution of fractures and faults and their effective apertures, orientations, and interconnectedness, are being studied as part of the surface-based and exploratory shaft drilling and testing programs.

Salient conditions to be characterized in any thick unsaturated zone are the hydraulic and pneumatic potential gradient that extend from the land surface to the water table (500 to 750 m at Yucca Mountain). Saturation and matric potential may vary discontinuously from stratum to stratum. The characterization of liquid-water flow in Yucca Mountain must include, for all hydrogeologic units, the determination of liquid-water flux distribution under a variety of present and future conditions. Since liquid-water flux is difficult to measure adequately at either the infiltration boundary or the water table, it must be deduced from the potential distribution and the conductive properties of the system, or by other indirect means. From the viewpoint of isolation, the most significant findings will be to predict the transport of radionuclides from the repository, 335 to 585 m beneath the surface of Yucca Mountain, to the water table about 165 m below the repository. The hydraulic properties data that will be used for liquid-water flux calculations will be collected in the surface-based and exploratory shaft drilling and testing program (Studies 8.3.1.2.2.2 through 8.3.1.2.2.7).

Gas flow in the unsaturated zone has an important hydrologic role, as well as providing a potential mechanism for transport of radionuclides to the accessible environment. Whereas the coexisting matrix and fracture pore systems greatly complicate computations of total-system behavior under present or future fluxes, the existence of the large-aperture fractures not only provides drainability in the unsaturated zone but also provides large relative gas permeability. Consequently, there may be natural gas-phase fluxes through Yucca Mountain driven by seasonal atmospheric density differences between the slopes and the summit and by geothermal heat within. Vapor discharges from the air-filled fracture system may offset the infiltration of rain and snowmelt because of convective and diffusive vapor transport out of the mountain. By desaturating the matrix, perhaps below free-drained residual saturation, increased moisture tension aids in damping infiltration pulses that may be channeled in the fractures or faults. It is important to be able to quantify the vapor flux because it may be in a direction opposite to the liquid flux. Activities addressing this phenomenon include all those yielding air conductivities from packer tests with gas injection in boreholes, cross-hole air flow and gas tracer tests. Activities specifically designed to define the gaseous flux distribution include the gas-phase circulation study (Activity 8.3.1.2.2.6.1), the Solitario Canyon horizontal borehole study (Activity 8.3.1.2.2.3.3), and the simulation of the natural hydrogeologic system (Activity 8.3.1.2.2.9.3).

The hydraulic and pneumatic testing described under this investigation will provide a basis for estimating the distribution of fluid flux through the unsaturated zone. To compute travel times from the fluid flux estimates, a good understanding of the effective porosity is required. Presently, there are very few methods that can provide the effective porosity, and these are discussed under appropriate activities. Integration of the percolation information with the hydrochemical data will provide a basis for travel time calculations and future hydrologic condition predictions. The process for providing parameters required by ground-water travel time (Issue 1.6) is depicted in Figure 8.3.1.2-12.

Knowledge of liquid-water flow paths (fracture or matrix) in the unsaturated zone and an understanding of factors affecting the occurrence of liquid-water flow in fractures are needed to assess current and future travel

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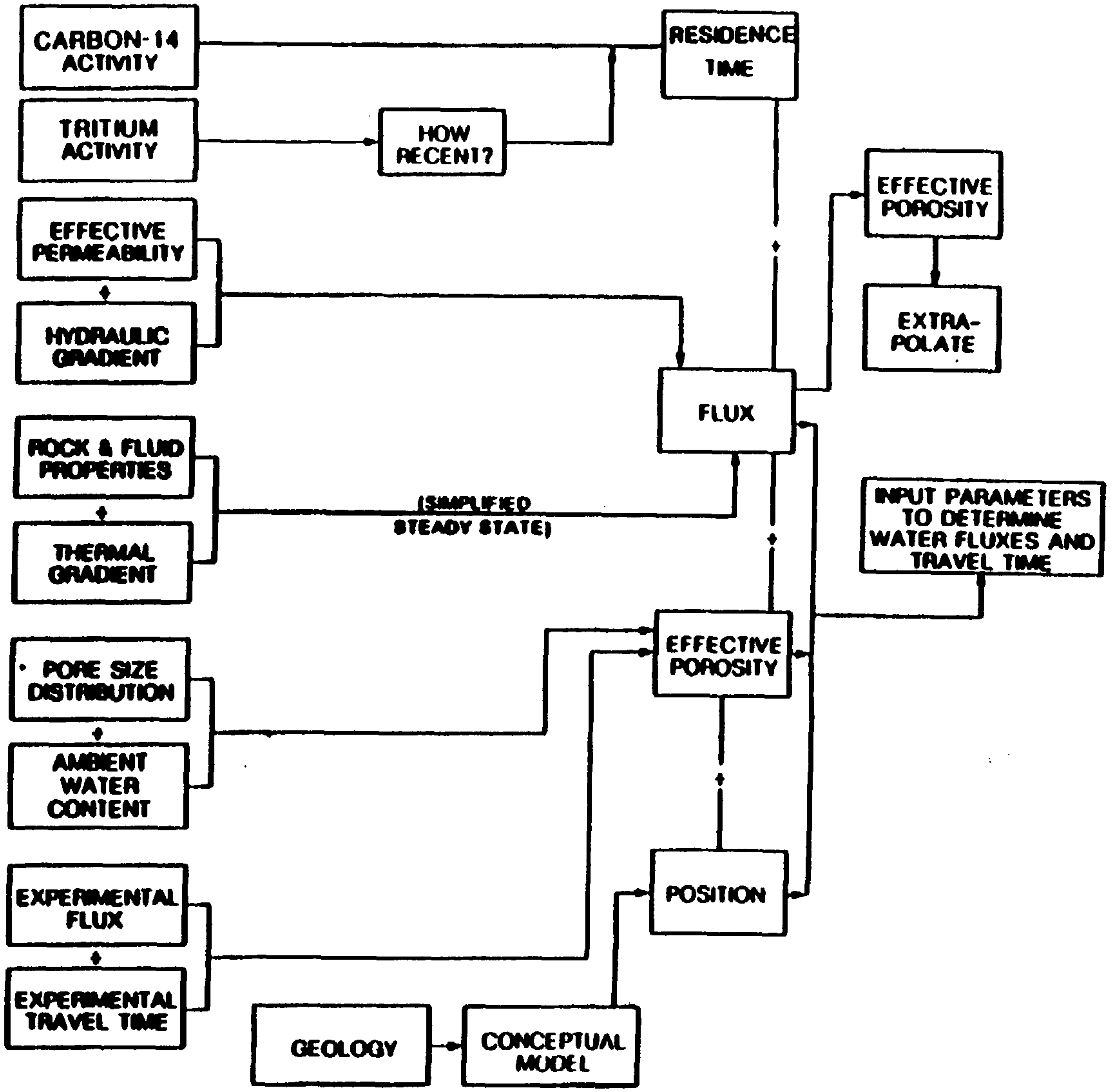

Figure 8.3.1.2-12. Process for providing parameters required by Issue 1.6 (pre-waste-emplacement ground-water travel time).

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times. Many surface-based and in situ activities include an evaluation of fluid flow paths under current conditions. The intact-fracture test (Activity 8.3.1.2.2.4.1, percolation test (Activity 8.3.1.2.2.4.2), and bulk-permeability test (Activity 8.3.1.2.2.4.3) are specifically designed to evaluate liquid-water flow in fractured rocks at various scales, saturations, and fluxes.

Essential corroboration of ground-water velocities and the transport of dissolved chemicals and gases will be sought through age dating of the fluids and gases found in the pores at various depths. A thorough understanding and evaluation of all factors influencing the hydrochemistry of the natural flow system will be needed, because the knowledge provides the only potential means for assessing rates of water movement independent of the hydrologic deduction process, as well as a means of discriminating between hydrologic processes that would otherwise remain hypothetical. In addition to its contributions to ground-water travel time, hydrochemistry provides information relevant to the characterization of gas transport, to the assessment of paleohydrologic conditions, to geochemical relationships, and to contamination by exploration activities. In the gaseous-phase and aqueous-phase investigations (Activities 8.3.1.2.2.7.1 and 8.3.1.2.2.7.2), analyses to support the various test programs include not only a suite of inorganic components but also certain organics, including freon-11 and freon-12 (which serve as tracers); lithium and bromine used to tag drillwater; SF_6 used to tag drilling air; and carbon-14 dioxide, chlorine-36, methane, HTO, HDO and the oxygen-18 to oxygen-16 ratio, all natural or man-made tracers. Large numbers of gas and water samples will be analyzed. These data will be used to characterize (1) waste container environment at the repository and (2) the environment under which sorption and solubility of waste elements will occur along flow paths in the unsaturated zone.

Flow behavior in the unsaturated zone of Yucca Mountain involves complex interactions that are amenable to solution only with the aid of numerical modeling. A great depth of understanding is required to predict the transport of solutes and gases in a sequence of dipping pyroclastic units that have variable granularity, degree of welding and alteration, porosity, and fracturing. How these variables interact is essential knowledge for attaining a correct solution; however, the interactions are very complex. For example, variable saturation relates to variable relative conductivity and anisotropy in hydrogeologic units whose fluxes relate to complex distributions of hydraulic and pneumatic potential between ill-defined boundaries with internal discontinuities. The general approach that is being used to solve this problem is to (1) refine the existing concepts of the phenomena of unsaturated, sometimes transient, flow of fluids and constituents in double-porosity layered media; (2) construct detailed digital models that spatially and temporally integrate the processes, incorporating boundary conditions, physical properties, and parameters; (3) compute fluxes, potentials, concentrations; and (4) maintain consistency with all validated data. Since the environment of field tests seldom isolates one phenomenon from all others, models are working tools on many levels. Ultimately, two- and three-dimensional models of Yucca Mountain will be constructed that integrate the hydrogeologic system as a means of assessing coupled effects of heat, water, and gas flow for present, past, and possible future conditions. The flow and transport modeling described in this issue, for both the saturated and un-

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saturated zones, will be coordinated with modeling efforts in Performance Issues 1.1 through 1.6 (Section 8.3.5).

Flow model calibration will likely require redundant data to be gathered. For example, imprecise measurements of matric potential may produce distributions of hydraulic properties and boundary conditions that are not internally consistent. The reason is that relative bulk conductivity is very sensitive to matric potential. In general, fracture and fault systems have very low porosity but very high conductivity relative to the matrix (up to 4 orders of magnitude difference) (Davis and DeWiest, 1966; Snow, 1969); thus, fluid flux can be greatly enhanced by small increases of saturation. Fluxes characteristic of different climates may be modeled, perhaps within the range of present observational precision. It will be necessary to refine measurement methods to give meaning to such behavior as the penetration of episodic, secular, or pluvial infiltrations in a double-porosity model. Young fracture water may bypass older matrix water, depending on fracture coatings present.

Hydrochemical data will be vital to the validation of the concepts of flow in this unsaturated medium. The mechanisms will be examined and modeled in connection with underground tests in which infiltration will be induced artificially at various rates. Whereas fracture-system flow channeling may occur readily in the uppermost unit, the Tiva Canyon welded tuff, models and tests may suggest that fractures are less significant in the Paintbrush and Calico Hills nonwelded tuffs, so that matrix imbibition damps out infiltration pulses, within these nonwelded units.

Gas-phase flux and potential distributions will be calculated from two-dimensional and three-dimensional modeling that incorporates fracture system anisotropic conductivity and saturation relationships, plus gas storativity of fracture and matrix pore systems, for all units above the water table. Flow will be driven by atmospheric pressures and temperatures, varying daily and seasonally, and also by the ambient geothermal gradient. A data-gathering program is designed to provide input to such models as well as to validate derived quantities.

When the phenomenologic components of the system have matured sufficiently to permit reasonable synthesis, a three-dimensional coupled heat and two-phase moisture flow model will be constructed for the existing natural, pre-waste-emplacement system. The model must incorporate appropriate external and internal boundary conditions and material properties. This model will serve as a baseline description of the natural hydrologic and transport processes, and, additionally, will be used to model past and future natural conditions. Such a model requires interactive complexity to accomplish such objectives as (1) assess the importance and effects of topographic and structural boundaries; (2) assess the relative roles of water vapor and liquid-water transport; (3) describe the gas-phase and liquid-phase transport of such tracers as tritium, deuterium, carbon-14 and others introduced by man; (4) establish limiting conditions for lateral flow, perched water and structural drainage; and (5) establish consistency of fluxes with temporal and spatial variations of boundary conditions.

Although the heat released by the waste is recognized to have a significant effect on repository behavior and will have to be evaluated, the thrust

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of the work described here is to understand hydraulic and transport behavior of the natural system, unaffected by the repository or the emplaced waste; analysis of thermal effects is discussed in Sections 8.3.5.12.4.1 and 8.3.5.13.3.1.

8.3.1.2.2.1 Study: Characterization of unsaturated-zone infiltration

The objectives of the unsaturated-zone infiltration study are (1) to determine the effective hydraulic conductivity, storage properties, and transport properties as functions of moisture content or potential, and (2) to determine the present and estimate the future spatial distribution of infiltration rate over the repository block. Four activities are planned to collect the data that are required to satisfy these objectives: analysis of matrix hydrologic properties in the laboratory, evaluation of natural infiltration, characterization of hydrologic properties of surficial materials, and studies of artificial infiltration.

8.3.1.2.2.1.1 Activity: Characterization of hydrologic properties of surficial materials

Objectives

The objective of this activity is to characterize the infiltration-related hydrologic properties and conditions of the surficial soils and rocks covering Yucca Mountain.

Parameters

The parameters of this activity are

1. Infiltration rates.
2. Runoff rates.
3. Porosity.
4. Density.
5. Water content.
6. Water potential.
7. Clay mineralogy.
8. Soil texture.
9. Soil and alluvium thickness.
10. Fracture density and fracture orientation.

Description

Methods designed to characterize the hydrologic properties of surficial materials include sampling, testing, and mapping; remote sensing; nuclear borehole geophysical logging; shallow surface seismic exploration; and geotomography studies. The main purpose of these tests is to help characterize the infiltration-related hydrologic properties of the surficial materials of Yucca Mountain. Hydrologic property data from these and other tests described in this report will be analyzed using statistical and geostatistical

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methods to help delineate surficial hydrogeologic units. Representative hydrologic-property data from surficial hydrogeologic units will then be used by others to model infiltration processes on Yucca Mountain.

Units that are defined on the basis of shallow infiltration processes in the upper 1 ft of surficial material are called infiltration-runoff units. Units that are defined to characterize net infiltration processes at depths below 1 ft are termed surficial hydrogeologic units. The relationship between surface infiltration and net infiltration is described in artificial infiltration studies (Activity 8.3.1.2.2.1.3).

Some of the methods described in this section are divided into a prototype component and a site characterization component. The prototype component is designed to determine how equipment and methods must be adapted to be used successfully on Yucca Mountain during site characterization.

Sampling, testing, and mapping methods will be used to help develop an unconsolidated surficial-materials map of Yucca Mountain delineating units with common shallow infiltration and runoff properties. These units will aid in modeling runoff and shallow infiltration as a function of precipitation. A 1:12,000-scale geologic map of the surficial materials covering Yucca Mountain will be produced (Activity 8.3.1.5.1.4.2). These surficial geologic units are expected to be a satisfactory base and starting point for developing units with common infiltration and runoff properties. The new units will be called infiltration-runoff surficial units.

Preliminary studies will be conducted on an adjoining canyon and ridge test area on Yucca Mountain to select the most appropriate infiltration-related hydrologic property measurements to make on desert-mountain surficial materials, to test state-of-the-art measurement techniques on these materials, and to determine a sampling program necessary to characterize infiltration-runoff units. These studies also will determine if surficial geologic units can serve as a basis, or starting point, for defining infiltration-runoff units.

A preliminary surficial geologic unit map will be developed for the surficial materials covering the canyon-ridge test area. Surficial materials will be classified mainly on the basis of geomorphic processes and characteristics. Geomorphic processes and characteristics include both pedologic and hydrologic factors. Samples of surficial materials will be collected from each map unit; and hydrologic properties, conditions, and related characteristics will be measured. Hydrologic properties measured in the laboratory will include texture, density, water content, and water potential. Clay mineralogy will be determined on selected samples. Density and water-content measurements will also be made in the field. Related characteristics include soil thickness, slope, and aspect.

Geostatistics will be used to determine the spatial relationship between measurements and to determine if additional measurements are required beyond the boundaries of surficial geologic units. Areas with similar hydrologic properties will be defined, and the boundaries of these areas will be compared with the boundaries of surficial geologic map units. This analysis will permit the determination of the geologic map units, or portions thereof, that will be useful in defining infiltration-runoff units.

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The preliminary definitions of infiltration-runoff units developed in these preliminary studies will be evaluated and refined by conducting double-ring infiltrometer tests in this same canyon-ridge test area (artificial infiltration Activity 8.3.1.2.2.1.3). Furthermore, the feasibility of using remote sensing techniques to aid in the mapping of infiltration-runoff units will be evaluated, as described below. When optimum methods are identified for mapping infiltration-runoff units, these methods will be used to produce a map of infiltration-runoff units for the surface of Yucca Mountain.

Remote sensing methods will be used to help define infiltration-runoff units and the changes in water content that may occur within these units as a result of variations in precipitation and other meteorological parameters. Preliminary tests will be conducted on the canyon-ridge test area of Yucca Mountain to determine the feasibility of correlating remote sensing imagery data with hydrologic properties (infiltration-runoff units) and conditions of surficial soils and rocks. Potentially useful infrared, visible, thermal, and radar remote sensing data from this ridge system will be analyzed and map units with statistically different spectral characteristics will be identified. infiltration-runoff units in the canyon-ridge system defined by the sampling, testing, and mapping methods will be compared with map units defined by common spectral characteristics. Spectral characteristics that correlate well with infiltration-runoff units in this canyon-ridge system will be identified for possible use in the site characterization mapping of rainfall runoff units. The determination of acceptable levels of correlation will be determined. In addition, thermal and radar remote sensing data will be collected before and after precipitation events over a 1-yr period in this canyon-ridge system. These data will be analyzed to determine if they can be used to describe changes that occur in the water contents of the surficial materials as a function of precipitation, and other meteorological parameters that may affect these water contents.

If the spectral characteristics of any of the various remote sensing imagery correlate well with previously mapped infiltration-runoff units and/or hydrologic conditions in the canyon-ridge test area, these remote sensing imagery and associated spectral characteristics will be used throughout the site. Remote sensing methods will be incorporated with the sampling, testing, and mapping methods and the double-ring infiltrometry methods described under the artificial infiltration studies (Activity 8.3.1.2.2.1.3). Finally, if thermal or radar remote sensing methods prove successful in monitoring moisture changes in the surficial materials covering the canyon-ridge test area, the methods will also be used to monitor moisture changes on the entire surface of Yucca Mountain.

Borehole nuclear geophysical logging methods will be used (1) to develop reliable laboratory field and calibration procedures that can be used for selected borehole geophysical logging tools (including hand-held neutron moisture meters used in neutron access hole logging); (2) to determine density and porosity profiles in near-surface boreholes using gamma-gamma density, neutron-moisture and neutron-porosity logging methods; and (3) to complement the neutron-moisture logging program by independently obtaining water-content profiles in neutron access holes and other near-surface boreholes using neutron porosity methods. The scope of this logging program is limited to measuring the hydrologic or hydrologically related parameters of moisture content, porosity, and density. This logging program complements density and porosity data obtained from core samples and will provide the only source of these data in regions of boreholes where cores are not collected. The program is not intended to generate a complete suite of borehole geophysical logs that would yield electrical, magnetic, or spectroscopic data.

Prototype borehole nuclear logging has been conducted to develop optimum methods for calibrating the logging tools in the laboratory, and preliminary tests have been conducted in the field. Neither standard field calibration pits nor laboratory calibration facilities of any type for tuffaceous rock existed before the beginning of these tests.

Three permanent laboratory calibration simulation tanks that simulate borehole conditions around a 5-in.-inner-diameter casing have been successfully constructed during prototype tests. Each tank has a significantly different water content, a slightly different dry bulk density, and a similar chemical composition. All geophysical logging tools have been successfully calibrated in these tanks. Based on these prototype tests, quality assurance Level I procedures have been written for the construction of additional simulators. These additional simulators will permit a more complete calibration of nuclear logging tools over a wider range of densities and water contents. Furthermore, these tanks will help resolve the effects of large differences in dry bulk density on neutron moisture tool response.

Preliminary field calibration tests have been successfully conducted in cased and uncased sections of alluvium and nonwelded tuffs. However, testing is required in cased and uncased sections of welded tuff to determine under what conditions (if any) field calibrations can be successfully conducted. Tests are also planned to determine if multidetector compensated neutron porosity and gamma-gamma tools improve calibration curves, especially in welded sections of tuff penetrated by the hole. Field calibrations in cased nonwelded sections of boreholes compare favorably with laboratory calibrations previously described. These field calibrations have also resulted in progress in determining optimum tool and decentralizer design, logging rates, and time constants for various rock types.

When these laboratory prototype tests and preliminary field tests are successfully completed, all near-surface boreholes including neutron access holes, shallow core instrument holes, and artificial infiltration monitoring holes will be logged at least once with the gamma-gamma density, neutron porosity, and neutron moisture analog recording borehole logging tools. These logs will be in addition to neutron moisture meter logging described under natural infiltration studies (Activity 8.3.1.2.2.1.2). Volumetric water content and wet bulk density profiles will be generated directly from calibration curves. Dry bulk density and porosity profiles will be calculated from these measured profiles. These continuous profile data will be used together with core data to determine the vertical spatial variation of the physical and hydrologic properties measured. These vertical profile data measured in a number of boreholes will also be useful in determining the horizontal spatial variability between boreholes using geostatistical techniques. The spatial variability data will be used to help define surficial hydrogeologic units.

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Shallow surface seismic methods will be used to (1) help define the fracture densities and orientations in surficial bedrock units covering Yucca Mountain, and (2) determine depth to bedrock beneath alluvium-filled canyons dissecting Yucca Mountain.

Shallow seismic techniques utilizing small energy sources will be used to characterize the seismic velocities of surficial rock units. Information about rock matrix density, fracture density, and fracture orientation in some instances can be inferred from seismic velocities (e.g., Crampin et al., 1980). These properties, together with the thickness of various surficial layers, are important factors that affect the flow of water in these surficial materials. In this study, they will be treated as hydrologic properties.

Prototype shallow surface seismic studies will be conducted off Yucca Mountain to determine optimum methods that apply to determining the thickness of alluvium in canyons on Yucca Mountain during site characterization. All prototype work concerned with determining the alluvium-bedrock contact will be carried out in areas where depth-to-bedrock is clearly defined by boreholes. Seismic lines will be run parallel, perpendicular, and at an approximate 45 degree angle to the major axis of shallow canyons where bedrock depths are accurately known from borehole data. Interpretative as well as field methods will be developed in this study.

Seismic fracture studies will be conducted on surficial bedrock units covering Yucca Mountain to determine the fracture properties of these units. Fracture data from the bedrock units will be analyzed together with the hydrologic characteristics of the overlying soils to help define surficial hydrogeologic units. Seismic studies will also be conducted to determine the thickness of alluvium in canyons and/or portions of canyons not containing boreholes. Maps of bedrock depth in canyons will be generated.

Surface seismic methods previously described are relatively inexpensive and easy to conduct but are inherently low-resolution techniques and are not expected to yield detailed fracture geometry data. Recent advances in high-resolution geophysics (Ramirez and Daily, 1985), however, suggest that the geotomography method, when coupled with infiltration experiments, has the potential to characterize both detailed fracture geometry and possibly the hydraulic properties of fracture systems.

In theory, geotomography has the potential to produce an image or a cross-sectional picture of the subsurface distribution of the electrical conductivity and the dielectric constant between boreholes. Electrical conductivity is related to fluid salinity and mineralogy, and the dielectric constant is proportional to water content. Therefore, if a saline tracer is added to water infiltrating into rock under steady-state conditions, it may be possible to monitor both the changes in water content and the movement of the saline tracer.

Prototype geotomography studies will be conducted off Yucca Mountain in conjunction with several prototype artificial infiltration studies (Activity 8.3.1.2.2.1.3) to evaluate the potential of using geotomography during site characterization to evaluate the properties of the near-surface fracture regime and to monitor infiltrating waters in the surficial rocks covering

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Yucca Mountain. Artificial infiltration tests will include as many as three ponding prototype tests and two large-plot rainfall simulation (LPRS) prototype tests. Ponding tests will involve ponding water at the ground surface and monitoring the saturated (or near-saturated) wetting front that advances downward and the drainage that occurs after ponding is stopped. LPRS tests will mainly involve monitoring unsaturated wetting front advancement resulting from the application of artificial rainfall. Both ponding and LPRS prototype test plots will be located in areas that contain the range of fracture properties expected at Yucca Mountain.

Prototype tests will be conducted first in relatively homogeneous alluvium containing no fractures to test equipment and to produce baseline images of wetting and drying of the profile during infiltration experiments. Similar tests will then be conducted on fractured rock with simple fracture patterns at the ground surface. Finally, tests will be conducted on fractured rock with a high degree of heterogeneity. Dye tracers will be used during the last infiltration test at each site to stain the mineral surfaces of flow pathways. All sites will be excavated and flow pathways mapped to verify the geotomography images.

If prototype test results indicate that geotomography methods can be successfully used to characterize the fracture geometry and hydrologic properties of fracture systems beneath artificial infiltration plots, these methods will be used in site characterization studies. It is planned to use geotomography methods on the majority of ponding and LPRS plots proposed for artificial infiltration studies (Activity 8.3.1.2.2.1.3).

8.3.1.2.2.1.2 Activity: Evaluation of natural infiltration

Objectives

The objective of this activity is to characterize present-day infiltration processes and net-infiltration rates in the surficial soils and rocks covering Yucca Mountain.

Parameters

The parameters of this activity are

1. Infiltration rates.
2. Net infiltration rates.
3. Flow velocities.
4. Precipitation.
5. Runoff.
6. Evapotranspiration.

Description

The main purpose of the natural infiltration studies is to characterize the upper flux boundary condition for Yucca Mountain under present-day climatic conditions. This upper boundary condition is required to model flow through the thick unsaturated zone beneath Yucca Mountain. The determination

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of this boundary condition will be accomplished by four major studies. Neutron access hole studies will monitor natural infiltration in approximately 100 neutron access holes located with the intent of sampling the range in expected surficial hydrologic properties and conditions on Yucca Mountain. Artificial infiltration control plot studies will be monitoring natural infiltration beneath as many as 25 small and 12 large rainfall-simulation control plots located in major hydrogeologic-surficial units. Tritium profiling studies will determine flow velocities averaged over approximately the last 30 yr by analyzing bomb-produced tritium concentrations in core obtained from representative neutron access holes. Consideration will be given to profiling of gaseous as well as liquid tritium, because movement of tritium in the vapor phase could affect infiltration analyses. Water budget studies will calculate net infiltration by mass balance methods.

Some of the studies in the following description have been divided into prototype and site-characterization components. The prototype component is designed to determine how methods and equipment must be adapted to be applied successfully at Yucca Mountain during site characterization. These prototype studies will be conducted at locations off Yucca Mountain. All prototype work has been completed for neutron access hole studies. Prototype work has not begun on water budget or artificial infiltration control plot studies.

Neutron moisture logging techniques are currently being used in 74 neutron access holes to monitor natural infiltration. The locations of these 74 holes and 24 additional proposed holes are shown in Figures 8.3.1.2-13a, 8.3.1.2-13b, and 8.3.1.2-13c. Water-content profiles in these holes can be obtained from neutron moisture logging data and appropriate calibration data. Differences between water-content profiles from consecutive logging dates is an indication that water movement is occurring, at least in the vicinity of the borehole. Changes in water profiles are indicative of nonsteady state flow processes that typically result from high-intensity and short-duration precipitation events (thunderstorms) that yield surface runoff.

Steady state flow processes by definition do not result in water content changes and therefore cannot be monitored by neutron moisture logging methods. Steady-state or approximately steady-state flow processes may exist during and for a short period after long-duration and low-intensity winter rainfall where constant-head (or constant-flux) boundary conditions have the potential to develop. These conditions may also be approximated during the slow melting of a winter snowfall. Steady state flow conditions will be purposely generated during some artificial infiltration studies (Activity 8.3.1.2.2.1.3). The potential importance of steady state flow during natural infiltration processes will be further evaluated after the completion of these artificial infiltration tests.

Water flow velocities can be estimated from tritium concentration versus depth profiles obtained by conducting tritium analyses on core samples collected from unsaturated zone boreholes. The maximum depth reached by elevated bomb-produced tritium concentrations is estimated from the profiles. Tritium concentrations greater than approximately ten tritium units are considered to be elevated above natural background levels. This depth is then divided by the time elapsed from the midpoint in the period of above-ground atmospheric testing (approximately 30 yr). This quotient is an estimate of

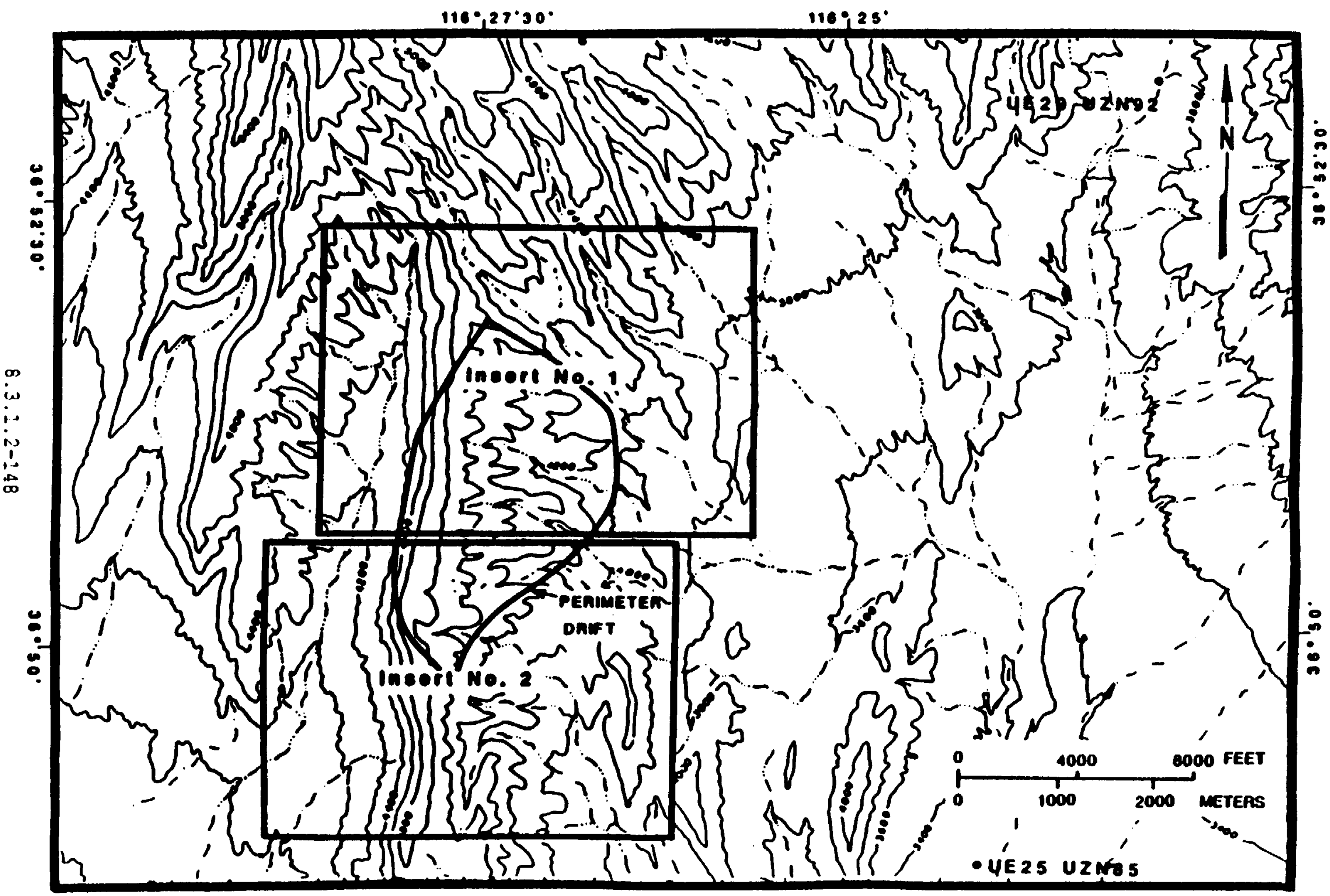

Figure 8.3.1.2-13a. Neutron access hole locations Se 8 3 1 2-13b and -13c for inserts No 1 and 2, respectively

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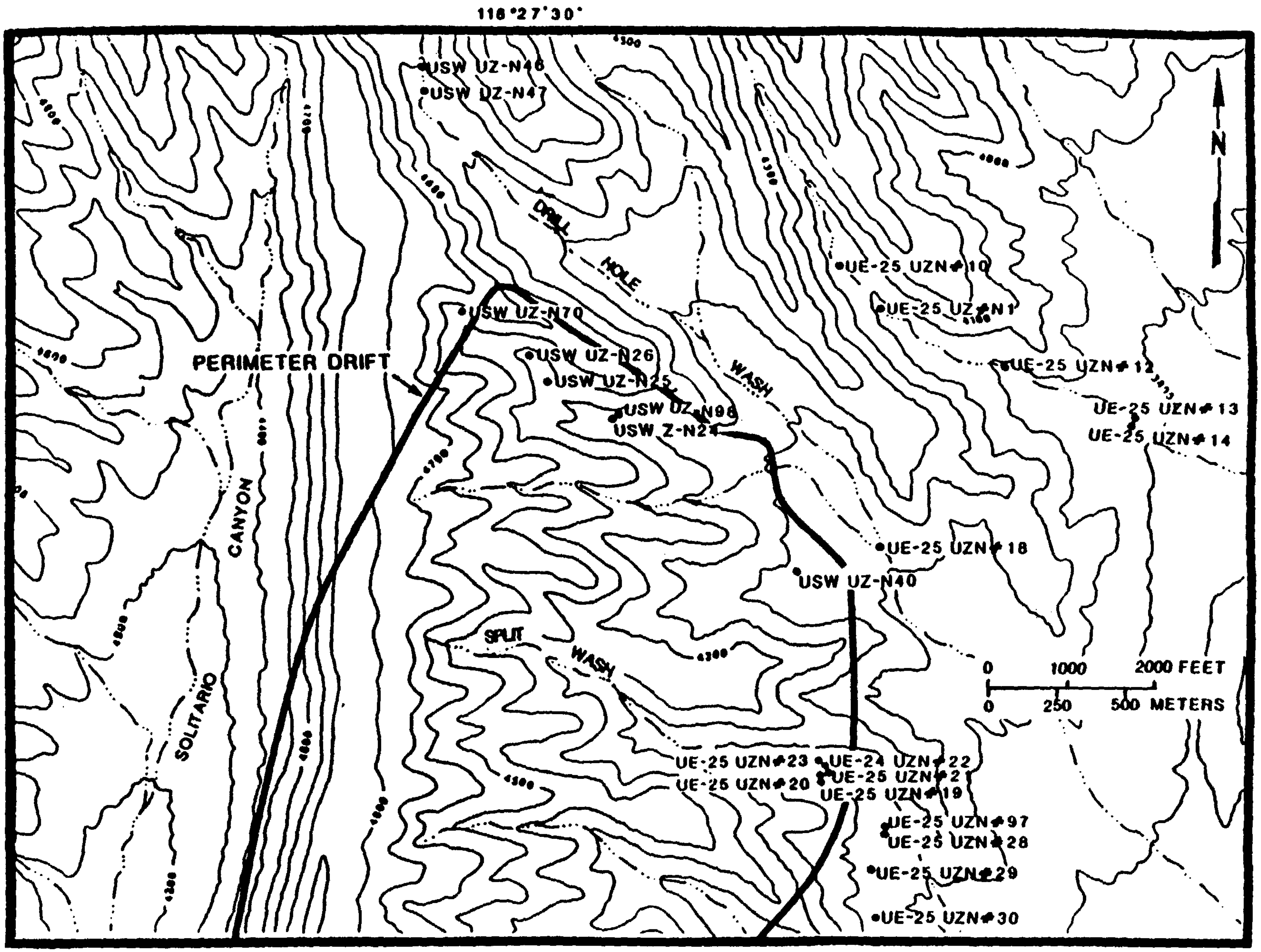

Figure 8.3.1.2-13b. Insert 1 to Figure 8.3.1.2-13a, neutron access hole locations.

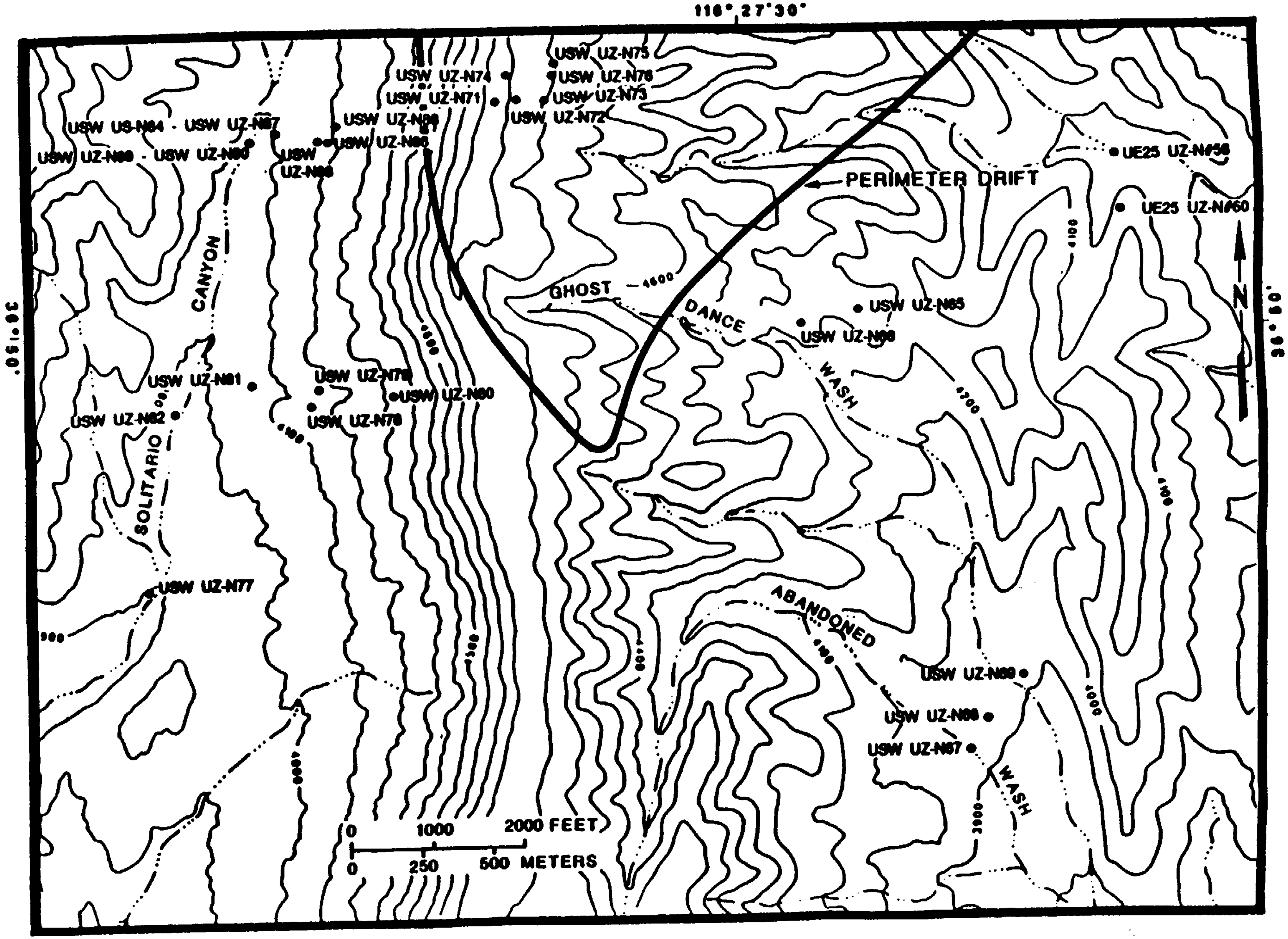

Figure 8.3.1.2-13c. Insert 2 to Fi .1.2-13a, neutron access hole locations.

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flow velocity over the last 30 yr. The analyses could be affected by perturbations caused by movement of tritium in the vapor phase, and so profiling of gaseous tritium will be considered as well.

Boreholes selected for initial tritium concentration profiling studies are located in rock units thought to cover the range in surficial hydrologic properties found on Yucca Mountain. When the initial program of tritium analyses is completed, the data will be analyzed to determine additional boreholes that should be tested for tritium content. The flow-velocity data will be subjected to geostatistical analyses where possible. These spatial variability results, when combined with other hydrologic property data, should be useful in determining additional holes that should be tested. These results should also be helpful in defining surficial hydrogeologic units.

Natural infiltration will also be monitored in the control plots associated with both small- and large-plot rainfall simulation sites. Prototype and site-characterization studies planned for these control plots along with associated test plots are described in more detail under artificial infiltration studies (Activity 8.3.1.2.2.1.3). Natural infiltration will be monitored with several nuclear logging techniques from monitoring holes located on the edges of the control plots (and test plots), and with a variety of water content and water potential probes and sensors installed in different horizontal planes beneath the plots. Control plots will be located at different sites to cover the range in expected infiltration capacities within each surficial hydrogeologic unit. Natural infiltration will then be monitored beneath as many as 25 small- and 12 large-plot rainfall simulator control plots for the duration of site characterization studies on Yucca Mountain.

Water budget studies will be conducted to (1) evaluate the potential of using water budget techniques as a tool to estimate infiltration in different surficial materials covering Yucca Mountain under different climatic conditions and (2) if these methods show potential, to apply these techniques to monitor infiltration from both natural and artificial precipitation events. The water budget studies will be used to supplement direct measurements of infiltration.

The simplest form of the mass-balance water-budget equation used to estimate infiltration is as follows:

Infiltration = (precipitation) - (runoff) - (evapotranspiration)

Unfortunately, the combined error from precipitation, runoff, and evapotranspiration measurements may be equal to or larger than infiltration values in desert climates. Evapotranspiration can be calculated from meteorological and soils data as well as from evapotranspiration simulators to varying degrees of accuracy depending on climatic, soil, and vegetation conditions. However, the error in the calculations and measurements of evapotranspiration alone may be as large or larger than the low natural infiltration rates expected for Yucca Mountain.

A similar problem exists in the evaluation of infiltration rates, which are typically a small component of the overall mass-balance equation. For

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this reason, infiltration values will be measured directly. Evaluation of infiltration values from the mass-balance equation will be done only for confirmatory purposes.

Because of the problems expected with applying mass-balance methods to infiltration problems on Yucca Mountain, a preliminary prototype study will first be conducted to evaluate the suitability of using this approach for different surficial materials under both natural and artificial rainfall conditions. An analysis of the source and magnitude of errors of measurement will be made in these preliminary studies. Attempts will be made to determine the conditions under which the errors of measurement are significantly less than infiltration values. These conditions may occur only during and after artificial rainfall simulations of precipitation events having higher intensity, frequency, and duration than is encountered in a typical year under present-day climatic conditions. The problem of defining the relationship between natural and artificial rainfall will also be addressed. This problem is discussed in further detail under the artificial infiltration studies (Activity 8.3.1.2.2.1.3).

8.3.1.2.2.1.3 Activity: Evaluation of artificial infiltration

Objectives

The objectives of this activity are

1. To characterize the range and spatial variability of infiltration rates in approximately the upper foot of unconsolidated surficial material using double-ring infiltrometer studies.

2. To characterize the range and spatial variability of infiltration rates, flow velocities, and flow pathways in approximately the upper 15 ft of both consolidated and unconsolidated surficial materials using ponding studies.

3. To characterize the complex relationship between rainfall, thickness of soil, and development of perched water tables in approximately the upper 3 ft of unconsolidated surficial material using small-plot rainfall simulation tests.

4. To characterize the relationship between precipitation, runoff, infiltration, and evaporation, in approximately the upper 15 ft, on at least one site, in each hydrogeologic surficial unit using large-plot rainfall simulation tests.

Parameters

The parameters of this activity are

1. Rainfall.
2. Evapotranspiration.
3. Runoff.
4. Saturated and unsaturated infiltration rates.

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5. Water fluxes.
6. Flow velocities.
7. Flow pathways.

Description

Artificial infiltration tests will be conducted on the surficial materials covering Yucca Mountain to characterize near-surface water movement. Water fluxes, flow velocities, and flow pathways will be characterized in the major hydrogeologic surficial units under present-day and simulated wetter climatic conditions. The main purpose of these tests is to determine the upper flux boundary conditions for Yucca Mountain under simulated wetter climatic conditions. A series of four different types of artificial infiltration studies is proposed in this plan: double-ring infiltrometer studies, ponding studies, small-plot rainfall simulation studies (SPRS), and large plot rainfall simulation studies (LPRS). Beginning with the double-ring infiltrometer studies, each type of study increases in complexity and builds on the results of previous studies.

Some of these studies will consist of prototype and site characterization components. Prototype studies, to be conducted off Yucca Mountain, will be limited in scale and will be designed to determine how methods and equipment must be adapted to be applied to the surficial materials on Yucca Mountain during site characterization.

Double-ring infiltrometry measurements will be used in this study to characterize infiltration rates in approximately the upper foot of unconsolidated surficial materials covering Yucca Mountain. The characterization of surficial infiltration rates over Yucca Mountain is important for several reasons. The infiltration rate, relative to the rate of rainfall or snowmelt, determines how much water will enter surficial materials and how much will run off. The relationship between snowmelt or precipitation rate and surface runoff is of critical importance in modeling the effect of wetter climatic conditions on the unsaturated-zone hydrology of Yucca Mountain. In addition, surficial infiltration rates may, in some instances, be low enough to be the limiting factor that controls infiltration to deeper zones. In these instances, measurements of surficial infiltration rates can be used to estimate net infiltration rates. The term infiltration rate is defined here as the infiltration flux resulting when water, at atmospheric pressure, is made freely available to the unconsolidated material surface.

If infiltration-runoff units defined from double-ring infiltrometry measurements correlate well with units previously determined from (1) mapping activities involving field and laboratory hydrologic property measurements (Activity 8.3.1.2.2.1.1, characterization of hydrologic properties of surficial materials), and (2) remote-sensing data-collection activities, then site-characterization mapping procedures will rely mainly on these previously used methods and only a limited number of double-ring infiltrometry measurements will be used. If the correlation is poor, double-ring infiltrometer measurements will be used extensively to define infiltration-runoff units over Yucca Mountain. The infiltration-runoff units will be used to help model shallow infiltration and runoff from possible future precipitation events.

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Ponding tests will use existing neutron access holes; however, additional boreholes will be drilled at ponding sites if prototype geotomography tests (Activity 8.3.1.2.2.1.1) are successful. Impoundments will be built around selected neutron access holes to permit the ponding or flooding of surficial units. Monitoring the water-level changes in the impoundment gives an estimate of the maximum intake or infiltration rate into the surficial unit. Tracking the wetting-front advancement via neutron moisture logging, geotomography, or other geophysical logging methods will give an estimate of flow velocities and an indication of the relative importance of fracture and matrix flow. Following changes in the water content profile during drainage can provide an estimate of hydraulic conductivity as a function of formation water content (Libardi et al., 1980).

An organic dye tracer that will adsorb on mineral surfaces to a limited extent will also be added to the ponded water to define pathways. After ponding experiments are completed, several sites covering the range of infiltration rates for each hydrogeologic unit will be excavated and flow pathways mapped by following the colored dye tracer. This procedure will help evaluate the potential for downslope flow. The tracer dye will be selected to be as conservative as possible, and yet to absorb enough on mineral surfaces to be readily visible or detectable. The area beneath some highly fractured ponding sites may be excavated to depths as great as 25 ft. This will require a mining operation to reach these depths. After mapping of the flow pathways is completed, the large holes will be backfilled with mixtures of muck and bentonite. No more than six 25-ft deep excavations are estimated to be required. All other excavations will be shallow enough so that they can be completed with surface excavation equipment.

In this study, ponding tests that measure infiltration rates over approximately the upper 15 ft of unconsolidated surficial materials will be conducted at the same location as double-ring infiltrometry measurements. If shallow infiltration rates measured by double-ring infiltrometry methods correlate well with net infiltration rates determined by ponding methods in a particular area, double-ring infiltrometry data will be used to describe the spatial variation of net infiltration over that particular area.

Over 80 percent of the bedrock above the valley floor on Yucca Mountain is estimated to be covered by a layer of unconsolidated rock or soil ranging in thickness from less than 1 in. to 5 ft or more. Depending on the thickness of this layer, its porosity, and the size of a precipitation event, the unconsolidated material can theoretically act as a storage zone and prevent infiltration into the underlying fractured bedrock. In this situation, unconsolidated layers act as capillary barriers. However, if rainfall occurs for a long (as yet undetermined) period of time, perched water conditions are likely to develop at the bedrock-unconsolidated material contact. The positive pressure heads in this perched water zone can cause flow into any large open fractures in the bedrock. Field data are required from each hydrogeologic unit to determine the complex relations between rainfall, thickness and properties of unconsolidated rock or soil, and the development of perched water tables. Small-plot rainfall simulation (SPRS) studies will be conducted to collect this needed data. The main purpose of SPRS tests is to determine these relationships in the upper 3 ft of surficial material covering Yucca Mountain. The SPRS studies are ideally suited for studying infiltration through shallow, layered systems. In the relatively unlayered alluvium

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deposits found in valleys, SPRS tests will be used to define unsaturated hydraulic conductivity functions and flow parameters in the upper 3 ft.

A control plot will also be located adjacent to each SPRS test plot in an equivalent hydrogeologic setting. Note that it may be very difficult to find an equivalent setting in fractured rock, even in adjacent areas. SPRS control plots will be instrumented similarly to SPRS test plots, but they will not receive artificial rainfall. The control plot will be used to monitor infiltration and runoff from natural rainfall. These control plots are described more fully under natural infiltration activities (Activity 8.3.1.2.2.1.2).

The instruments to be used in the program include various moisture and water potential sensors, vacuum samplers for unsaturated-zone water, and surface runoff flumes. Control plots will be instrumented identically to test plots, except that vacuum ground-water samplers will be omitted. Artificial rainfall of different intensities and durations will be applied to the SPRS test plots. This artificial rainfall will contain conservative ground-water dye tracers to help monitor the movement of infiltrating waters. Wetting-front advancement will be monitored by moisture and water-potential sensors, by ground-water tracers, and by geophysical logging techniques. These monitoring techniques will also yield data on fluxes and flow velocities.

Results from double-ring infiltrometry, ponding, and other data collection programs should facilitate the combination of similar hydrogeologic surficial map units and help locate the SPRS plots. Ponding tests are expected to show that the thickness, texture, and porosity of unconsolidated soil are important factors in governing net-infiltration rates. In some instances, soil hydrologic properties may be more important than the properties of the underlying bedrock. SPRS plots will be located adjacent to ponding sites in order to characterize in more detail the infiltration process occurring in the upper 3 ft of unconsolidated surficial material and bedrock in the vicinity of the ponding site. Care will be taken to locate all SPRS plots in positions that are equivalent in every way to the nearby ponding plots. In addition, SPRS plots will be located in such a way as to ensure that the water content of the rock beneath the SPRS plots has not been disturbed by the ponding tests.

After completion of SPRS tests, more complex large-plot rainfall simulations (LPRS) will be carried out on at least one site from each hydrogeologic unit to measure rainfall, infiltration, runoff, and evapotranspiration under simulated wetter climatic conditions. LPRS tests are better suited for studying these processes than SPRS tests because larger areas and deeper depths can be studied. Factors affecting the development of perched water tables will also be examined. After the artificial rainfall application is stopped, and the profile is sufficiently wet, the drainage of that profile will be monitored. A comparison of drainage data with profile wetting data will yield an estimate of hydraulic conductivity as a function of water content.

LPRS control plots will be located adjacent to each LPRS test plot in an equivalent hydrologic environment. Artificial rainfall will not be applied to the control plots. infiltration-runoff data from control plots during

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natural rainfall, compared with infiltration-runoff data from LPRS plots during simulated rainfall, will help establish the relationship between natural and simulated rainfall. The LPRS control plots are also important components of the natural infiltration monitoring program.

Both control and test LPRS plots will be instrumented similarly to the SPRS plots discussed previously. These instruments plus various geophysical logging techniques will be used to monitor moisture movement beneath these plots in response to both natural and artificial rainfall.

Parameters will also be measured at each site for water budget calculations of infiltration. Meteorological data will be collected at each site for evapotranspiration calculations. Runoff and sediment yield as a function of rainfall will be determined by monitoring flumes. The meteorologic and runoff data will be collected as part of Studies 8.3.1.2.1.1 and 8.3.1.2.1.2.

8.3.1.2.2.2 Study: Water movement tracer tests using chloride and chlorine-36 measurements of percolation at Yucca Mountain

The objective of this study is to obtain information from isotopic measurements of soil, tuff, and water samples collected from Yucca Mountain that is pertinent for assessing the performance of a nuclear waste repository. Measurements of chlorine isotopic distributions will help characterize the percolation of precipitation into the unsaturated zone. The chlorine-36 in the unsaturated zone occurs from atmospheric fallout of chlorine-36 produced by cosmic-ray secondaries reacting with argon-40 and, to a lesser extent, with argon-36 and as global fallout from high-yield nuclear weapons tests conducted at the Pacific Proving Grounds between 1952 and 1963. When chloride ions at the surface are washed underground by precipitation, the radioactive decay of the chlorine-36 in the chloride can be used to time the rate of water movement. The chlorine-36 half-life of 301,000 yr permits the detection of water movement in the range of approximately 50,000 yr to 2 million years. These data are part of the input for developing numerical models of ground-water flow at this site.

Chlorine-36 is just one of many natural isotopes that could be used to evaluate infiltration, mixing, ground-water sources, and alternative models of possible upwelling of deep water. In fact, various stable isotopes will be analyzed as part of Activity 8.3.1.2.2.7.2 (aqueous-phase chemical investigations). In addition, however, the natural isotope technetium-99 could be used as an alternative or as a supplement to work already planned. Laboratory methodologies regarding the analysis of technetium-99 are available. Analyses of the noble gases helium, argon, and neon could also be used as a powerful tool to evaluate the mixing of waters (i.e., source determination, upwelling). These isotopes could provide a distinct reservoir signature. If a need is established to utilize natural isotopes other than those previously identified, technical plans will be developed and included in an SCP progress report, and the study plan will be revised to include a new activity.

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8.3.1.2.2.2.1 Activity: Chloride and chlorine-36 measurements of percolation at Yucca Mountain

Objectives

The purpose of this activity is to help quantify the amount of percolation from precipitation into the unsaturated zone at Yucca Mountain. The data will be used as part of the input to characterize the movement of water through the unsaturated zone at Yucca Mountain.

Parameters

Data are needed for the following parameters:

1. Precipitation measurements.
2. Dry chloride fallout.
3. Fracture morphology in Paintbrush Tuff.
4. Site hydrology and hydrochemistry.

Data have been gathered for the following parameters:

1. Depth of each sample from the surface.
2. Chloride in soil and tuff samples.
3. Chlorine-36 to chlorine ratios in soil and tuff samples.
4. Chlorine-35 to chlorine-37 ratios in soil and tuff samples.

Description

Previous work in this activity has resulted in the measurement of chlorine-36 as a function of depth in soils from two locations at Yucca Mountain. The data permitted the calculation of infiltration during the past quarter century at one location, trench YW-6. The small quantity of chlorine-36 observed at a second location in Coyote Wash indicated that recent hydrologic activity carried the chlorine-36 either laterally or downward. Chloride analyses of samples from greater depths will be performed to characterize the extent to which recent water movements can be traced by chlorine-36.

Additional chloride measurements will be performed on samples to be collected after a survey of Yucca Mountain to determine areas of active percolation (Activity 8.3.1.2.2.1.2). These measurements will define the areal and part of the vertical distribution of chloride and its isotopes. Measurements of tuff samples will elucidate meteoric chloride movement into the tuff. These data will aid in estimating the effect of the tuff matrix in retarding the migration of water and solutes in the more permeable fracture zones.

All the data collected in this activity will be used to develop numerical models to estimate the effective infiltration rate at Yucca Mountain.

8.3.1.2.2.3 Study: Characterization of percolation in the unsaturated zone--surface-based study

The objectives of the surface-based unsaturated zone percolation study are to (1) determine the present in situ hydrologic properties of the unsaturated zone hydrogeologic units and structural features, (2) determine the present vertical and lateral variation of percolation flux through the hydrogeologic units and structural features, (3) investigate the relationships between present flux and past climatic conditions, and (4) determine the effective hydraulic conductivity, storage properties, and transport properties as functions of moisture content or potential. Three activities are planned to collect the data that are required to satisfy these objectives. The planned activities are (1) matrix hydrologic properties testing, (2) site vertical borehole studies, and (3) Solitario Canyon horizontal borehole study.

In the matrix hydrologic properties laboratory analysis, a variety of standard laboratory tests will be conducted in support of hydrologic studies: matric suction and moisture content, moisture retention, porosity, density, and the effective conductivity moisture characteristics for air and water. Tests will be run on core, cuttings, and excavated blocks collected during drilling and mining. Prototype tests to determine optimum methods of sample handling and to develop and evaluate various testing methods for matrix hydraulic property acquisition will be performed. The objective is to characterize ambient matrix properties for all penetrated hydrogeologic units, and to provide the data necessary for modeling past and future hydrologic conditions as well as to serve the many ongoing activities. A data base will be built to provide statistics of measurement errors and populations important to the definition of cumulative distribution functions of travel time and contaminant breakthrough. Samples to be tested will be obtained from the exploratory shaft facility, from surface-based boreholes described in this investigation, and from other surface-based boreholes.

In the site vertical borehole studies, 17 vertical holes are planned to provide information on hydrologic characteristics of the unsaturated tuffs across the site. Immediately following drilling, packer nitrogen-injection tests will be run in each vertical borehole (except two) to determine gas-phase permeabilities of the rock mass. Cross-hole pneumatic tests will be run in two cluster sets of boreholes. The hydraulic properties such as permeabilities to air and water will be determined using packer-injection tests in single and cross-hole configurations. Gas tracer diffusion studies will be undertaken at one borehole cluster set. Samples will be collected from the boreholes to be tested to determine hydrologic properties and their variation across the site. In addition, core and gas samples will be used under Study 8.3.1.2.2.7 for chemical/isotopic analyses. The determination of the in situ potential field across the site will be attempted by installing instrumentation within each borehole and monitoring them for 3 to 5 yr. It is recognized that drilling the borehole may initially disturb the in situ conditions and that time will be required for conditions to reequilibrate. Prototype tests are being performed to evaluate the capabilities and limitations of the instrumentation to be used in the extended monitoring time period and to evaluate whether in situ conditions will return within the monitoring period. Numerical analyses will also be used to predict how long the disturbed region around the boreholes will take to return to its in situ

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condition. The objectives and design of the boreholes will be evaluated after completion of these prototype tests and analyses. If these tests prove feasible, a definition of the in situ potential field will provide the initial condition of in situ pressure head distribution across the site that is called for by Issue 1.1 and 1.6 (Section 8.3.5).

Lateral variations in permeability will be determined in part by drilling a horizontal borehole into the west side of the repository block, where the Solitario Canyon slope and fault zone provide different infiltration and gas-flow conditions than the rest of the block. By penetrating about 100 m of the steep fault zone within the fractured Topopah Springs welded tuff, the borehole will facilitate measurement of fault zone permeability to air (packer tests within the zone) and transverse permeability (packer-to-packer across the fault). The distribution of moisture as a function of depth under the slope, together with core properties and air permeabilities will be used to define the boundary conditions for modeling.

No natural perched water has been observed in holes drilled in Yucca Mountain. However, circulating drilling fluid that was lost in hole USW G-1 was observed in USW UZ-1, 335 m distant. This occurrence suggests that there is the potential for perched water to form and move laterally under certain conditions. Therefore, in the event that other seeps are discovered in any excavation, the perched-water test has been developed to measure flows and to sample the water for chemical composition and age determination. Hydraulic properties of any perched zones located will be determined, and instruments will be installed to monitor pressure or potential. A possible horizon for perched water conditions may exist above a capillary barrier in the Paintbrush nonwelded or bedded tuff. Though it is not presently evident, perched water might contribute to the diversion of higher fluxes, if pluvial climatic conditions were to return. Prototype testing will be performed in G-tunnel to develop instrumentation and test procedures.

8.3.1.2.2.3.1 Activity: Matrix hydrologic properties testing

Objectives

The objectives of this activity are

1. To characterize the flux-related, matrix hydrologic properties of major unsaturated-zone hydrogeologic units through laboratory testing of geologic samples obtained from surface based boreholes and excavations and from coreholes in the primary science ramp (north ramp) and emplacement drifts.

2. To use statistical and geostatistical methods to calculate, with known certainties, the values of flux-related matrix hydrologic properties within large volumes of rock beneath Yucca Mountain.

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Parameters

The parameters of this activity are

1. Porosity.
2. Density.
3. Permeability.
4. Relative permeability.
5. Moisture retention.
6. Matric potential.
7. Water potential.
8. Water content.
9. Water storage capacity.
10. Fluid flux.

Description

This investigation is designed to develop a comprehensive matrix-property data base to be used in calculation of matrix flux within the unsaturated zone of Yucca Mountain under both present and possible future climatic conditions. To accomplish this, matrix hydrologic properties will be measured on geologic samples collected from the coring of surface-based boreholes (Activity 8.3.1.2.2.3.2 and Site Program 8.3.1.4), and from coreholes in the primary science ramp (north ramp) and emplacement drifts. Matrix hydrologic property measurements will be conducted on consolidated geologic rock samples only. The sampling program from this activity will be coordinated with the sampling program activity described in Investigation 8.3.1.4.1. Measurements will not be made on unconsolidated geologic samples (drive-core samples) of alluvium-colluvium whose matrix properties can be easily disturbed during sampling. The collection and handling of samples and measures taken to minimize the alteration of sample matrix hydrologic properties from in situ conditions is discussed in detail by Hammermeister et al. (1986).

Prototype tests will be conducted to determine optimum methods of collecting, dividing, coring, preserving, transporting, and storing large rock samples from exploratory shaft facility excavations. These tests will also determine (1) the minimum sample dimensions that will be required for the large rock samples to be obtained from exploratory shaft facility excavations and (2) the minimum sample dimensions of large rock samples required to obtain 2.56-in.-outer- diameter core. These cores are required for matrix hydrologic property tests and the extraction of water for geochemical analyses. Air rotary coring procedures will be developed to obtain core from large rock samples with minimally disturbed water content.

A summary of all existing and planned surface-based unsaturated zone boreholes that have or will yield geologic core samples suitable for matrix hydrologic property testing is given in Table 8.3.1.2-5. This table does not yet include the boreholes planned under the rock characteristics program (8.3.1.4) because specific information on those holes has not been developed. The information will be included when available. Total numbers of samples available for matrix hydrologic property testing is given in Table 8.3.1.2-6 for all existing and currently planned boreholes. For planned unsaturated zone boreholes, this same information is estimated. Unsaturated boreholes

Table 8.3.1.2-5. Borehole information and estimates of numbers of core samples available for permeability related tests (page 1 of 2)

Borehole	Non- to partially welded and bedded tuff units: Completion date	Total depth (ft)	Continuously cored intervals (ft)	Number of samples available	Moderately to densely welded tuff units: Depth interval between "spot cores" (ft)	Number of samples available
SHALLOW CORED AND INSTRUMENTED HOLES						
UE-25 UZ#4	9/84	366.5	275.8	83	10	8
UE-25 UZ#5	10/84	363.0	264.0	94	10	2
USW UZ-7	1/85	207.0	81.0	31	10 to continuous	10
USW UZ-13	3/85	430.1	57.0	21	10	18
USW UZ-6s	5/85	519.0	85.0	18	20	21
USW UZ-8	-[a]	350.0	80.0	30	10	25
USW UZ-11	-	500.0	20.0	10	10	40
DEEP CORED AND INSTRUMENTED HOLES						
UE-25 UZ#9	-	2,000.0	85.0	30	10	75
UE-25 UZ#9a	-	1,500.0	85.0	30	10	50
UE-25 UZ#9b	-	1,500.0	85.0	30	10	50
USW UZ-10	-	1,500.0	60.0	25	10	50
USW UZ-2	-	1,500.0	90.0	35	10	50
USW UZ-3	-	1,400.0	90.0	35	10	50
NEUTRON ACCESS HOLES						
UE-25 UZN#10	12/85	99.0	99.0	16	-	-
USW UZ-N24	2/86	75.0	51.0	21	10	2
USW UZ-N46	1/86	99.0	99.0	30	-	-
USW UZ-N47	1/86	86.4	17.4	7	intermittent	2
USW UZ-N98	2/86	75.0	49.0	15	-	-
USW UZ-N11	-	50.0	-	-	5	10
USW UZ-N15	-	50.0	-	-	5	10
UE-25 UZN#16	-	50.0	-	-	5	10
USW UZ-N17	-	50.0	50.0	20	-	-
USW UZ-N27	-	50.0	-	-	5	10
USW UZ-N31	-	50.0	-	-	5	10
USW UZ-N32	-	50.0	-	-	5	10
USW UZ-N33	-	50.0	-	-	5	10
USW UZ-N34	-	50.0	-	-	5	10

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Table 8.3.1.2-5. Borehole information and estimates of numbers of core samples available for permeability related tests (page 2 of 2)

Borehole	Non- to partially welded and bedded tuff units: Completion date	Non- to partially welded and bedded tuff units: Total depth (ft)	Non- to partially welded and bedded tuff units: Continuously cored intervals (ft)	Non- to partially welded and bedded tuff units: Number of samples available	Moderately to densely welded tuff units: Depth interval between "spot cores" (ft)	Moderately to densely welded tuff units: Number of samples available
NEUTRON ACCESS HOLES (continued)						
USW UZ-N35	-	50.0	-	-	5	10
USW UZ-N36	-	50.0	-	-	5	10
USW UZ-N37	-	50.0	-	-	5	10
USW UZ-N38	-	50.0	-	-	5	10
USW UZ-N39	-	50.0	-	-	5	10
USW UZ-N53	-	50.0	-	-	5	10
USW UZ-N54	-	50.0	-	-	5	10
USW UZ-N55	-	50.0	-	-	5	10
USW UZ-N57	-	50.0	-	-	5	10
USW UZ-N58	-	50.0	50.0	20	-	-
USW UZ-N61	-	50.0	-	-	5	10
USW UZ-N63	-	50.0	-	-	5	10
SMALL-PLOT ARTIFICIAL INFILTRATION MONITORING HOLE						
SPRS-1 -- SPRS-24	-	5.0	0 to 5	48	-	-
SPRS-25 -- SPRS-100	-	5.0	-	-	2.5	198
LPRS-1 -- LPRS-50	-	35.0	0-35	700	-	-
LPRS-50 -- LPRS-120	-	35.0	-	-	2.5	980
TOTAL				748		1,178

a- denotes not available.

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Table 8.3.1.2-6. Estimated number of unsaturated zone core samples available for matrix-hydrologic property testing

Borehole symbol	Purpose of hole	Number of hole	Estimated number of core samples originally available[a]	Estimated number of core samples available for matrix hydrologic property tests[b]
UZ	Unsaturated zone hydrology studies	334	3,270	3,270
A	Initial geologic stratigraphy and structure study	5	849	636
B	Initial saturated zone hydrology study	1	420	316
C	Saturated zone tracer studies	3	150	112
G	Geologic stratigraphy and structure studies	5	3,259	2,444
H	Saturated zone hydrology study	6	323	242
	TOTAL		8,271	7,020

[a]One core sample was assumed to be obtained for every 2.5 ft of continuous core. If a core interval was less than 2.5 ft long, 1 sample was assumed to be originally available.

[b]100 percent of original samples of unsaturated zone holes was assumed to be available for matrix property testing; 75 percent of original samples from all other holes was estimated to be currently available for testing.

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include shallow core and instrument holes (200 to 500 ft deep), deep core and instrument holes (1,000 to 2,000 ft deep), neutron access holes (20 to 100 ft deep), and artificial recharge monitoring holes (5 to 35 ft in depth). In all unsaturated boreholes, the depth interval between core samples designated for matrix hydrologic property tests in continuously cored portions of tuff is approximately 2.5 ft.

Classical statistics and property testing methods will be used to determine the number and locations of the geologic samples to be tested for matrix hydrologic properties for each surface-based borehole. Sufficient samples will be collected to permit assessment of the combined effects of inherent random and spatial variation among samples and the experimental error of measurement. The random and spatial variation in matrix properties will be estimated both in the vertical directions and in lateral direction parallel to the dip of the units.

Initially, the vertical spatial variation in matrix properties will be estimated by intensive sampling of a few surface-based reference boreholes. Preliminary tests on samples from these reference holes will be conducted to characterize the vertical structure of the spatial variability using values of matrix hydrologic properties in the vertical direction as accurately as possible. The analysis of data from these tests will then be used to determine testing frequency in all other surface-based boreholes. The testing frequency of the holes described here will be coordinated with the holes planned under Issue 8.3.1.4.

Regions where reference boreholes show statistically similar matrix hydrogeologic properties will be defined as preliminary hydrogeologic units. These preliminary hydrogeologic units are expected to encompass lithostratigraphic units or subunits. This expected relationship between hydrologic properties and lithostratigraphic units will greatly facilitate the identification of boundaries of preliminary hydrogeologic units. However, if the analysis of matrix hydrologic property data indicates that no such relationship exists, preliminary hydrogeologic units will be defined independently of lithostratigraphic units.

During excavation of the exploratory shaft facility, samples will be collected from each subsurface hydrogeologic unit for use in estimating matrix hydrogeologic properties. The horizontal spatial variation in subsurface matrix properties will be examined on a small scale during the excavation of the primary science ramp, on a larger scale (several hundred feet) during the excavation of alcoves and drilling of radial boreholes, and up to 2,000 ft (610 m) in drifts to major structural features. Lateral spatial variability on any scale larger than 2,000 ft (610 m) will be estimated from the surfaced-based boreholes over Yucca Mountain. The opportunity to collect a virtually unlimited number of geologic samples during excavation will mean that sample availability will not be a constraint on the number of samples tested, permitting improved estimates of the experimental error for the various testing methods. The large number of samples will also permit improvement in the accuracy of geostatistical models.

The vertical and lateral spatial variability of matrix hydrologic properties in approximately the upper 30 ft (9 m) of surficial rocks covering Yucca Mountain will be estimated from core samples obtained from 220 shallow artificial infiltration boreholes and selected neutron access holes. To make these estimates in both surface and subsurface regions some assumptions must be made about the structure of the variability in the measured properties. This uncertainty may be accounted for in geostatistical models that estimate spatial functions. Methods for geostatistics, such as kriging, will be used to interpolate between measured data points using fitted spatial distributions. Stochastic models will then be used to simulate possible structure of matrix hydrologic properties for large volumes of rock.

These statistical methods will permit the definition of both surface and subsurface hydrogeologic units for site characterization purposes. These hydrogeologic units will replace the preliminary hydrogeologic units described previously. The surface and subsurface hydrogeologic units are expected to encompass at least some adjacent lithostratigraphic units as defined by Scott and Bonk (1984). The new hydrogeologic unit boundaries, however, may not conform to lithostratigraphic unit boundaries or the boundaries of the hydrogeologic units proposed earlier by Montazer and Wilson (1984) from limited matrix and fracture property data.

Before matrix hydrologic property testing on geologic samples for site characterization begins, preliminary prototype work is required to develop and evaluate various testing methods to ensure that the resulting matrix hydrologic property data is of the highest possible quality. Matrix property tests will be conducted to (1) determine the most suitable established methods for measuring permeability, relative permeability, and moisture retention relationships; (2) develop new or adapt existing methods for measuring hydrologic properties when existing methods are not appropriate or do not exist; and (3) compare appropriate established methods with new methods to determine optimum procedures for various tuffaceous rocks at Yucca Mountain.

The development and evaluation of new methodology is desirable for several reasons. Proven methods to measure parameters such as water and matric potential on consolidated rock core samples do not exist. In addition, many of the established methods for measuring moisture retention and relative permeability have limitations and disadvantages that make it difficult to apply these methods to the wide range of tuffaceous rocks found at Yucca Mountain. Finally, the potentially large number of tests to be conducted, and their high cost, require that new multipurpose methods that would yield more than one type of data be evaluated. If a new method proves successful, it will be compared with other methods that measure the same property to select the most appropriate method of measurement. The preliminary testing will be used to determine which of the various methods under consideration is the most practical and will yield the most satisfactory results.

Drilling and coring methods used in most unsaturated-zone boreholes produce core samples with water contents, and in some instances water potentials, that are similar to those in the formation rock surrounding the borehole (Hammermeister et al., 1985). In these instances, the determination of water potentials and/or matric potentials of core samples would permit the characterization of these potentials in the formation rock. Knowledge of the

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distribution of these potentials in unsaturated zone formations is necessary to characterize liquid flow processes in these regions. Unfortunately, methods and equipment to measure both water and matric potentials have been developed for field agricultural soils or plant materials and not for consolidated rock core samples. Preliminary testing is required to determine if existing methods and equipment can be adapted for this purpose. Work will be conducted to attempt adaptation of tensiometer-transducer (Watson, 1965) and heat-dissipation probe (Phene et al., 1971) techniques, permitting the measurement of matric potentials on rock cores. Tests have been successfully conducted to adapt a Richards thermocouple psychrometer technique (Richards and Ogata, 1958) and commercially available equipment (Decagon Devices, Pullman, Washington) to reproducibly measure water potentials on samples of rock core and, in some instances, samples of drill cuttings.

Fluid permeability tests to be compared will include air permeability, Klinkenberg air permeability at different overburden pressures, specific water permeability, and oil permeability. The relationship between these different fluid permeabilities is discussed by Amyx et al. (1960). Although water is the primary fluid of interest, air permeability is being evaluated because it is the quickest and least expensive method. Because oil does not interact with the matrix, Klinkenberg air permeability and oil permeability have been included to characterize the deviation of air and water from ideal fluid behavior.

Established methods that will be evaluated to determine moisture retention curves include pressure plate (Rose and Bruce, 1949), centrifuge (Hassler and Brunner, 1945), and mercury porosimetry (American Petroleum Institute RP-40) techniques. A variation of the established pressure plate method, called the submersible pressure plate method (Constantz and Herkelrath, 1984), will be evaluated to determine if this method and equipment can be modified for use on various types of tuffaceous rock core from Yucca Mountain. A psychrometer method (Peters et al., 1984), which uses a Richards thermocouple psychrometer in conjunction with microwave drying techniques, is also being evaluated. Additional tests will be conducted to determine if the gas-drive relative-permeability method can be modified to also collect moisture retention data without significant evaporation. Significant amounts of time and money will be saved if this dual purpose gas-drive technique proves to be a reliable method. Finally, methods suitable for characterizing moisture retention hysteresis effects will also be identified.

Both steady-state and nonsteady-state relative-permeability methods will also be evaluated. Steady state methods include a centrifuge method (Nimmo et al., 1987) and an evaporation method (Constantz, 1982) for water relative permeability measurements and the Hassler method (Hassler, 1944) for both water and gas relative permeability measurements. Nonsteady-state methods for water relative permeability measurements include a centrifuge method (Van Spronsen, 1982), a gas-drive method (Owens et al., 1956), and a pressure plate outflow method (Passioura, 1976). Accurate measurements of relative permeability will be made using steady-state methods in the region of 100 percent water saturation (e.g., approximately 80 to 100 percent) on various core with a range of permeabilities. These accurate measurements will then be used to evaluate the same portion (extrapolated or measured) of relative permeability curves obtained from less accurate nonsteady-state methods.

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In addition to these direct measurements of relative permeability, various indirect methods of calculating relative permeability from moisture retention data (Mualem, 1976) will be evaluated. Finally, tests will be conducted to determine if the nonsteady-state centrifuge method can be modified to produce both moisture retention and relative permeability data at the same time.

After the matrix property measurements have been completed and the hydrogeologic units determined, three-dimensional models will be developed using geostatistical techniques. The boundaries of the hydrogeologic units will be defined so that each unit contains a set of matrix hydrologic properties judged sufficiently different from adjacent hydrogeologic units. Stochastic models will be used to simulate possible heterogeneities for each hydrogeologic unit. Enough simulations will be run so that confidence levels can be set for the occurrence of heterogeneities. The simulations will provide the initial and boundary conditions and the necessary matrix properties that will be used in large scale hydrologic modeling of Yucca Mountain.

8.3.1.2.2.3.2 Activity: Site vertical borehole studies

Objectives

The objectives of this activity are

1. To define the potential field.

2. To determine the in situ bulk permeability characteristics of the unsaturated media within the proposed repository host rock and surrounding units at Yucca Mountain, Nevada.

Parameters

The parameters of this activity are

1. Gravimetric moisture content (ambient/matrix/laboratory).

2. Volumetric moisture content (ambient/matrix/laboratory).

3. Matric potential (ambient/matrix and bulk/laboratory and in situ).

4. Water potential (ambient/bulk/in situ).

5. Thermal potential (ambient/in situ).

6. Pneumatic potential (ambient/in situ).

7. Matrix permeability as a function of saturation and matric potential (laboratory).

8. Matrix pore size distribution (laboratory).

9. Grain density (laboratory).

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10. Bulk density (laboratory).

11. Total porosity (matrix/laboratory).

12. Effective porosity (matrix/laboratory).

13. Bulk permeability (pneumatic/in situ).

14. Bulk permeability (hydraulic/in situ).

15. Fracture frequency, orientation, spacing, and distribution.

16. Depths to hydrogeologic contacts.

17. Definition of hydrogeologic units.

18. Saturation profiles.

19. Pressure head profiles.

Thermal and mechanical properties will be measured as described in the activities under Studies 8.3.1.15.1.1 through 8.3.1.15.1.6.

Description

This investigation is confined to that area of Yucca Mountain immediately overlying and adjacent to the primary repository boundary (Figure 8.3.1.2-14). Vertically, the study area extends from the near surface of Yucca Mountain to the underlying water table. This activity involves dry drilling and coring of 17 vertical boreholes ranging in depth from 60 to 610 m. Nine of the proposed boreholes will range in depth from 60 to 150 m and will terminate above the proposed repository horizon. The remaining eight boreholes will be drilled to depths ranging from 365 to 610 m and will penetrate the unsaturated zone below the proposed repository horizon. Construction details applicable to each of the proposed boreholes are shown in Table 8.3.1.2-7.

An additional (eighteenth) borehole, may be required to support the vertical seismic profiling (VSP) investigation. Present plans are to install the downhole geophones in USW UZ-6 as part of the instrumentation program for that borehole. If this is not feasible, an additional borehole will be required.

The locations of the unsaturated-zone vertical boreholes were selected in conjunction with the development of the integrated drilling plan (Section 8.3.1.4.1) and in consideration of the concern for representativeness of data (Section 8.4.2.1.5). The rationale used in siting the individual boreholes was based on the need to provide areal coverage of Yucca Mountain with sufficient detail locally to examine the effects of faulting, topographic relief, and the presence of surface drainage on the hydrologic conditions at depth; and, in the case of the multiple borehole sites, to provide adequate facilities for gas tracer studies, crosshole pneumatic testing, and VSP investigations.

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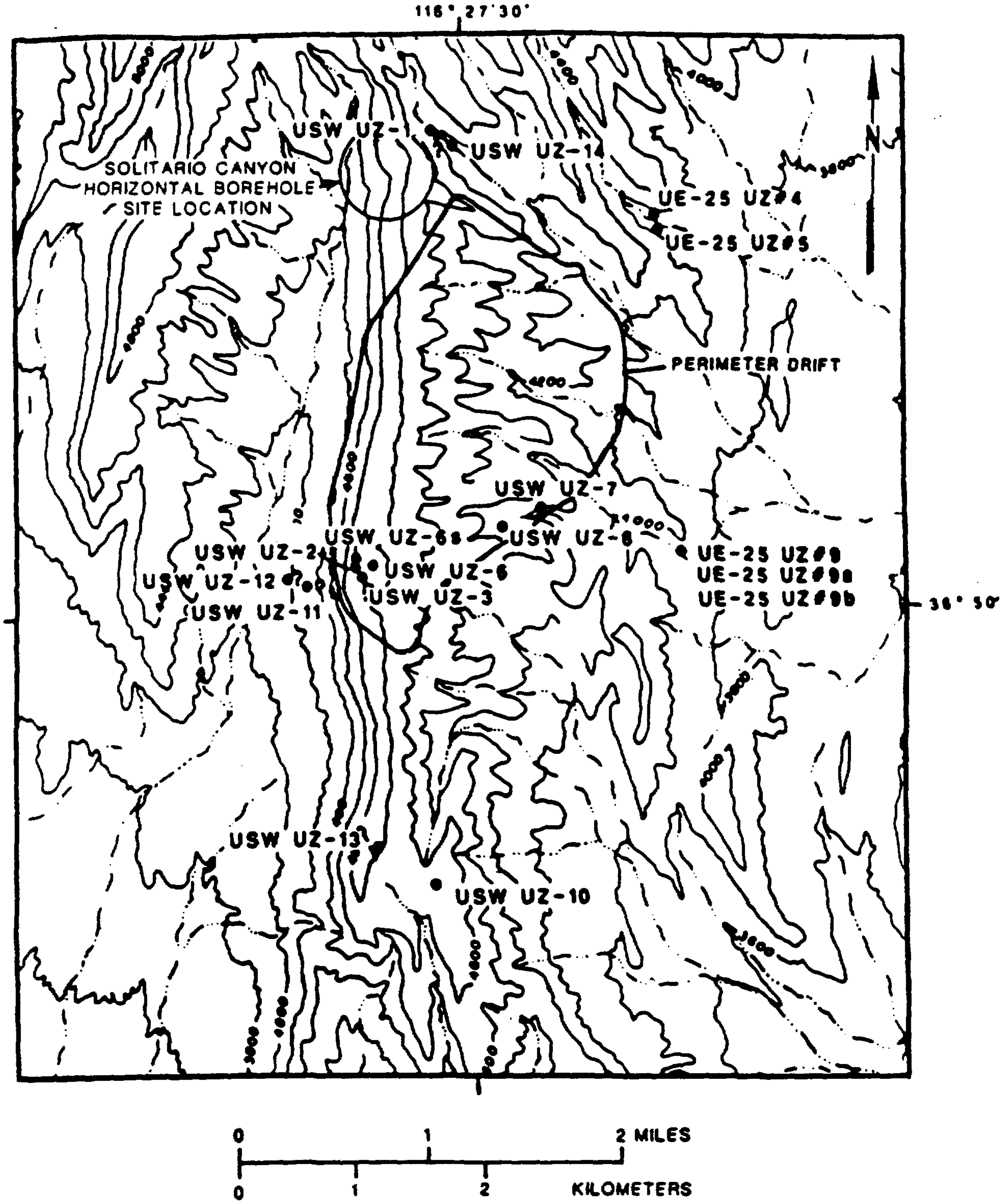

Figure 8.3.1.2-14. Map of existing and proposed unsaturated-zone borehole locations.

Table 8.3.1.2-7. Summary of construction details of vertical boreholes (page 1 of 3)

Borehole designation	Status	Drilling method	Total depth (m)	Bit Diameter (mm)	Depth interval (m)	Casing inside diameter (mm)	Casing depth interval (m)	Stratigraphic unit at total depth	Comments
USW UZ-1	Completed (07/31/83)	Reverse vacuum	387.1	1219 914 610 444 381 235	0-12.6 12.6-29.6 29.6-30.8 30.8-385.6 385.6-386.8 386.8-387.1	1041	0-12.0	Topopah Spring Member of Paintbrush Tuff	Drilling terminated because of large volume of water.
USW UZ-2	Planned	ODEX/ reverse vacuum	±460	≤445	--[a]	--	--	Tuffaceous beds of Calico Hills	Approximately 60 m west of USW UZ-6, paired with USW UZ-3 for cross-hole testing.
USW UZ-3	Planned	ODEX/ reverse vacuum	±430	≤445	--	--	--	Tuffaceous beds of Calico Hills	Approximately 60 m west of USW UZ-6, paired with USW UZ-2 for cross-hole testing.
UE-25 UZ#4	Completed (10/10/84)	ODEX/ cored	111.9	153 108	0-68.9 68.9-111.9	127	0-17.7	Topopah Spring Member of Paintbrush Tuff	Paired with UE-25 UZ#5 to investigate flux in and near a drainage.
UE-25 UZ#5	Completed (11/19/84)	Reverse vacuum	111.3	153	0-111.3	127	0- 5.2	Topopah Spring Member of Paintbrush Tuff	Paired with UE-25 UZ#4 to investigate flux in and near a drainage.
USW UZ-6	Completed (09/26/84)	Reverse vacuum	575.2	762 610 445	0-12.2 12.2-103.9 103.9-575.2	660 483	0-12.2 0-98.6	Prow Pass Member of Crater Flat Tuff	Drilling terminated because of overrun of drilling time and excessive breakage of drillstring.

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Table 8.3.1.2-7. Summary of construction details of vertical boreholes (page 2 of 3)

Borehole designation	Status	Drilling method	Total depth (m)	Bit Diameter (mm)	Depth interval (m)	Casing inside diameter (mm)	Casing depth interval (m)	Stratigraphic unit at total depth	Comments
USW UZ-6s	Completed (09/09/85)	ODEX	158.2	216 102	0-150.9 150.9-158.2	178	0- 0.9	Topopah Spring Member of Paintbrush Tuff	Drilled to complete sampling that drilling problems precluded in USW UZ-6.
USW UZ-7	Completed (01/22/85)	ODEX	63.1	152	0-63.1	127	0-6.1	Topopah Spring Member of Paintbrush Tuff	Designed along with USW UZ-8 to straddle Ghost Dance fault.
USW UZ-8	Incomplete (10/86)	ODEX	±107	216	--	--	--	Topopah Spring Member of Paintbrush Tuff	Designed along with USW UZ-7 to straddle Ghost Dance fault.
UE-25 UZ#9	Planned	ODEX/ reverse vacuum	±610	≤445	--	--	--	Tuffaceous beds of Calico Hills	Part of three-hole cluster for cross-hole testing.
UE-25 UZ#9a	Planned	ODEX/ reverse vacuum	±460	≤445	--	--	--	Tuffaceous beds of Calico Hills	Part of three-hole cluster for cross-hole testing.
UE-25 UZ#9b	Planned	ODEX/ reverse vacuum	±460	≤445	--	--	--	Tuffaceous beds of Calico Hills	Part of three-hole cluster for cross-hole testing.
USW UZ-10	Planned	ODEX/ reverse vacuum	±460	≤445	--	--	--	Tuffaceous beds of Calico Hills	
USW UZ-11	Planned	ODEX	±122	216	--	--	--	Topopah Spring Member of Paintbrush Tuff	In Solitario Canyon; straddles Solitario Canyon fault.

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Table 8.3.1.2-7. Summary of construction details of vertical boreholes (page 3 of 3)

Borehole designation	Status	Drilling method	Total depth (m)	Bit Diameter (mm)	Depth interval (m)	Casing inside diameter (mm)	Casing depth interval (m)	Stratigraphic unit at total depth	Comments
USW UZ-12	Planned	ODEX	±122	216	--	--	--	Topopah Spring Member of Paintbrush Tuff	In Solitario Canyon; straddles Solitario Canyon fault.
USW UZ-13	Completed (04/18/85)	ODEX/ cored	131.1	152 102	0-125.0 125.0-131.1	127	0-100.6	Topopah Spring Member of Paintbrush Tuff	
USW UZ-14	Planned	ODEX	±122	216	--	--	--	Topopah Spring Member of Paintbrush Tuff	Near USW UZ-1; needed to complete sampling. May need to drill deeper.

[a]-- denotes not applicable.

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Locations of the deep boreholes are primarily controlled by the requirements (1) to cover Yucca Mountain areally, (2) to minimize disturbance to the main body of the proposed repository block, and (3) for a site suitable for construction of a relatively large drilling pad. The four deep drillhole sites, USW UZ-1, USW UZ-6, UE-25 UZ#9, and USW UZ-10, are located on the north, west, east, and south sides, respectively, of the proposed repository block.

Selection of the sites for the shallow unsaturated-zone (UZ) boreholes was more site specific with regard to structural and surface features than for the deep boreholes. All the shallow boreholes have been designed to penetrate the Paintbrush nonwelded unit into the Topopah Spring welded unit. In addition, each site was chosen for a specific investigative purpose. UE-25 UZ#4 and UE-25 UZ#5 were sited in and adjacent to a large drainage (Pagany Wash) to investigate infiltration related to runoff. USW UZ-7 and USW UZ-8 are located on opposite sides of the Ghost Dance fault to investigate hydrologic characteristics related to the fault. USW UZ-8 is located to penetrate the fault. USW UZ-11 and USW UZ-12 will be located on opposite sides of the Solitario Canyon fault in a similar manner. USW UZ-13 was drilled at the southern end of Yucca Mountain to provide better areal coverage as well as to investigate the Tiva Canyon welded unit, where the unit has maximum thickness. USW UZ-14 will be located near USW UZ-1 for the purpose of providing data from depths that drilling problems in USW UZ-1 precluded.

Other surface-based boreholes are planned to obtain information on rock characteristics at the site. These boreholes are described in Section 8.3.1.4. The samples obtained from those boreholes will be used to determine, among other things, stratigraphy, thermal properties, mechanical properties, and hydrologic properties at the site.

For the boreholes described here, the ODEX drilling method will be used to the maximum extent possible. Reverse air-vacuum drilling may be required for attainment of the deeper depths. Depending on the drilling method used to achieve the targeted depths, borehole diameters will range from 15 to 25 cm for ODEX and up to 45 cm for reverse air vacuum. Drive core, rotary core, and cuttings will be taken throughout the drilling operation. In alluvium, 2-ft (0.6-m) core will be taken at 5-ft (1.5-m) intervals. In the densely welded tuff, rotary core will be taken for 1 ft (0.3 m) at 10-ft (3.0-m) intervals. In the non-to-partially welded tuff, rotary core will be taken continuously wherever possible.

An onsite lithologic log will be developed to guide the drilling operations and to determine when core samples should be taken outside of the normal sampling schedule. An onsite laboratory analysis of cutting samples will also be conducted to determine gravimetric moisture content. All other samples, core and cuttings, with the exception of those used for later lithologic analysis, will be capped, taped, and waxed to inhibit evaporation. These samples will be sent to a laboratory for determination of ambient volumetric moisture content and matric potential and for determination of other physical and hydrologic rock properties as identified on the parameter listing for this section. These samples will be tested under the matrix hydrology properties laboratory analyses investigation described under Activity 8.3.1.2.2.3.1.

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Borehole geophysical logs will be run in each borehole, either during a pause in drilling or following completion of drilling. A listing of these logs is given in Table 8.3.1.2-8. Radial (side scan viewing) and axial (forward viewing) oriented television video camera logs of each borehole will also be run. These will be used for mapping fracture orientations, distributions, and densities.

Two deep boreholes, one at or near the USW UZ-6 complex, and the other at the UE-25 UZ#9 complex (Figure 8.3.1.2-15), will be instrumented with a string of permanently emplaced, oriented, three-component geophones located at 7.3-m intervals. These geophones will be used in a vertical seismic profiling (VSP) investigation across the central portion of Yucca Mountain. The VSP technique is being used in this investigation to provide three-dimensional information on the lateral and vertical extent of fracturing within each hydrogeologic unit over a contiguous volume of rock mass much larger than that available to single isolated boreholes. The test volume includes the Ghost Dance fault structure. The VSP technique will also be used for discrimination of geologic units and stratigraphic correlation purposes.

Immediately following drilling (or during a pause in drilling), packer nitrogen-injection tests will be run in each of the vertical boreholes except USW UZ-1 and USW UZ-6 to determine gas permeabilities of the combined fracture and rock matrix system. Multiple test zones will be selected for each hydrogeologic unit. These zones will be tested with a straddle packer system consisting of a variable length injection interval, and two sensing sections equipped with thermocouple psychrometers (or another humidity sensor), thermocouples, and pressure transducers. The flow rate and injection pressure of the gas (nitrogen) will be monitored until steady state conditions (i.e., pressure measured in the sensing sections remains essentially constant) are achieved. The same procedure will be carried out at higher flow rates and pressures for each tested interval. Widths of tested intervals will be varied to test effects of heterogeneity and fracturing within a given section of rock mass.

Cross-hole pneumatic testing will be undertaken in the two cluster sets of boreholes (USW UZ-6 and UE-25 UZ#9 complexes). Monitoring will be conducted in both the injection borehole and the satellite observation boreholes using straddle packer systems. Tests will be run until steady state conditions are achieved. Multiple intervals will be tested to assess the influence of fracturing on bulk rock mass permeabilities. Cross-hole pneumatic testing will be prototyped in G-tunnel and test procedures will be developed.

Gas tracer diffusion studies will be undertaken at the UE-25 UZ#9 borehole complex. These tests are designed to (1) measure in situ gaseous phase travel times through an unsaturated fractured rock system, (2) measure contaminant transport and pneumatic properties of the medium, and (3) establish whether diffusion or convection is the dominant gaseous transport mechanism. Testing will take place after the boreholes have been stemmed and instrumented. Gas samples will be taken periodically from tested intervals in the observation boreholes equipped with sampling tubes. Tracer breakthrough

Table 8.3.1.2-8. Status of drillhole logging activities in the unsaturated zone[a,b]

Drillhole designation	Status	Depth (m)	Diameter (cm)	Lith. and geol.	Television	Caliper	Density gam. gam.	Epit. neut. poro.	Seismic vel.	Dielectric	Gamma ray	Spectral gam.	TV fracture	Direct. surv.	Temperature	Induction	Neut. moist meter	Neut. scat.	Neut. or gam. att.	Fld.
USW UZ-1	c	386.8	44.4	c	c	c	c	c	-	c	c	c	-	c	-	c	-	-	-	-
USW UZ-2	p	457.2	44.4	p	p	p	p	p	p	p	p*	p*	p	p	p	p	-	p	-	-
USW UZ-3	p	426.7	44.4	p	p	p	p	p	p	p	p*	p*	p	p	p	p	-	p	-	-
UE25 UZ#4	c	111.9	15.2	c	c	p	p	p	p	p	p	p	p	p	p	p	c	p	-	-
UE25 UZ#5	c	111.3	15.2	c	c	p	p	p	p	p	p	p	p	p	p	p	c	p	-	-
USW UZ-6	c	575.2	44.4	c	c	c	c	c	c	c	c	c	-	c	c	c	-	p	-	c
USW UZ-6s	c	158.2	21.6	c	c	p	p	p	p	p	p	p	p	p	p	p	c	p	-	-
USW UZ-7	c	63.1	15.2	c	p	p	p	p	p	p	p	p	p	p	p	p	c	p	-	-
USW UZ-8	i	106.7	15.2	i	p	p	p	p	p	p	p	p	p	p	p	p	p	p	-	-
UE-25 UZ#9	p	609.6	44.4	p	p	p	p	p	p	p	p*	p*	p	p	p	p	p*	p	p	-
UE-25 UZ#9a	p	457.2	44.5	p	p	p	p	p	p	p	p*	p*	p	p	p	p	p*	p	p	-
UE-25 UZ#9b	p	457.2	44.4	p	p	p	p	p	p	p	p*	p*	p	p	p	p	p*	p	p	-
USW UZ-10	p	457.2	44.4	p	p	p	p	p	p	p	p*	p*	p	p	p	p	p*	p	-	-
USW UZ-11	p	121.9	21.6	p	p	p	p	p	p	p	p	p	p	p	p	p	p*	p	-	-
USW UZ-12	p	121.9	21.6	p	p	p	p	p	p	p	p	p	p	p	p	p	p*	p	-	-
USW UZ-13	c	131.1	15.2	c	c	p	p	p	p	p	p	p	p	p	p	p	p	p	-	-
USW UZ-14	p	121.9	21.6	p	p	p	p	p	p	p	p	p	p	p	p	p	p*	p	-	-

[a]c = completed; i = incomplete; p = planned; p* = not done because final borehole diameter is too large to effectively run the designated geophysical log; - = not available; the planned log needs to be run early in the drilling of the drillhole while there is a smaller diameter pilot drillhole.

[b]Lith. and geol. = lithologic and geologic; gam. gam. = gamma gamma; Epit. neut. poro. = epithermal neutron porosity; vel. = velocity; surv. = survey; Neut. moist meter = neutron moisture meter; scat. = scatter; att. = attenuation; and Fld. = formation density log.

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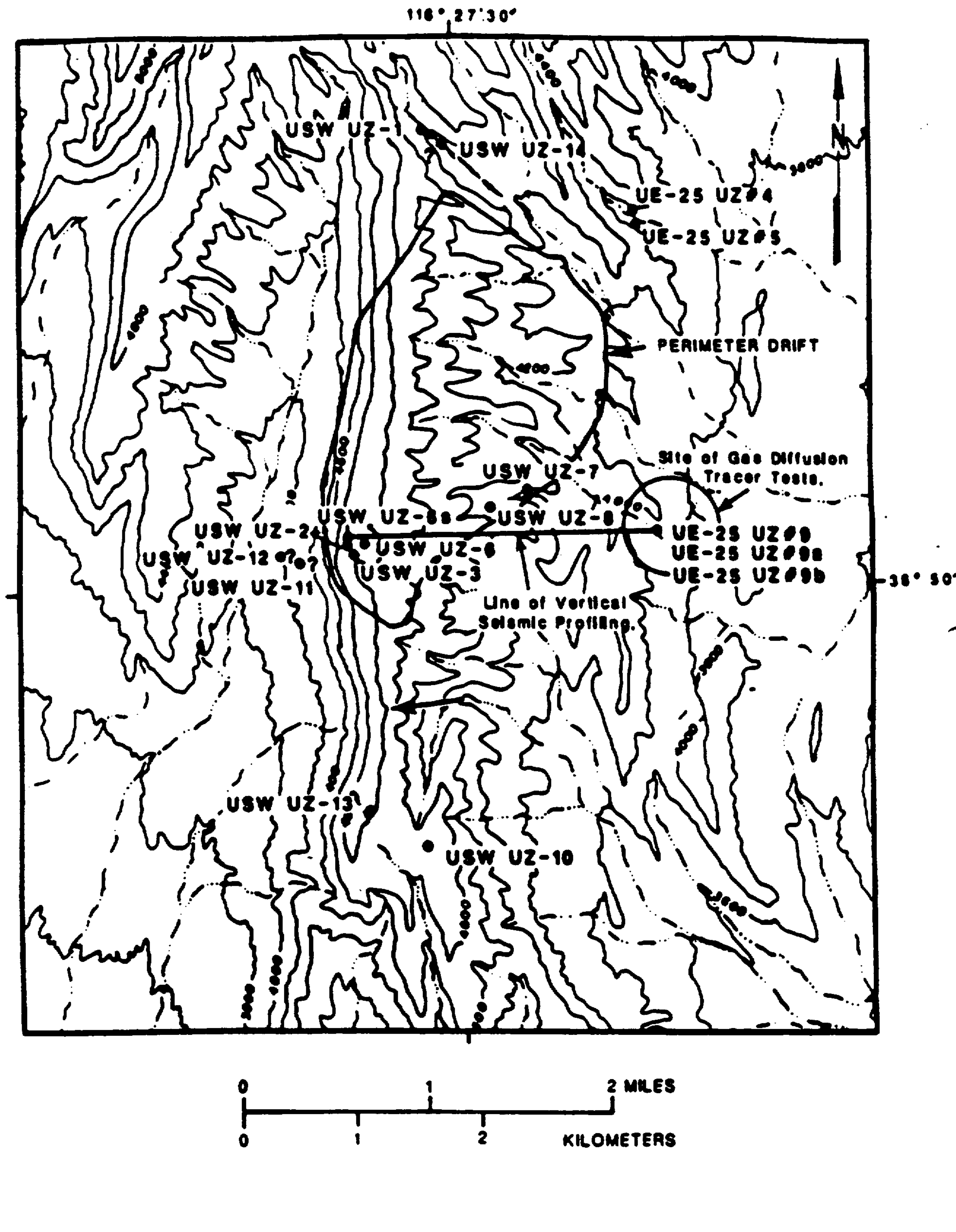

Figure 8.3.1.2-15. Map depicting location of gas tracer diffusion and vertical seismic profiling testing programs

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curves will be constructed from the gas analyses data. Interpretation of test results will be based on analyses of borehole logs, matrix hydrologic and physical properties data, pneumatic testing, and information obtained from the gaseous phase movement study.

Downhole sensors, consisting of pressure transducers, thermocouple psychrometers, heat dissipation probes, and thermal sensors will be installed in each of the 17 vertical boreholes. These will be monitored for an extended period of time (estimated at from 3 to 5 yr). Monitoring will be accomplished using a fully automated, computer activated and controlled, integrated data acquisition system (IDAS). The downhole sensors will be used to measure (in situ) pneumatic potential, water potential, matric potential, and thermal potential. In contrast to laboratory measurements, downhole sensors will measure these parameters for the combined rock matrix and fracture system. In addition to these instruments, each borehole will be provided with tubing to permit recovery of in situ pore gases and water vapor for hydrochemical analyses as part of the hydrochemical characterization study.

It is recognized that drilling of the borehole will disturb in situ conditions in the rock mass adjacent to the borehole. Numerical analyses are being done to estimate the time required for the rock mass to return to a condition close to its original in situ hydrologic condition. The drilling method to be used to drill the boreholes was chosen to minimize the in situ disturbance of the hydrologic system. It is not known at this time if in situ conditions will return within the time period allotted for monitoring (3 to 5 yr). The objectives and extent of this part of the surface-based borehole investigations study will be evaluated at the completion of the cross-hole prototype testing and the numerical analyses. Prototype testing will also investigate the capabilities and limitations of the instrumentation to be used in the long-term monitoring of the hydrologic characteristics.

It is also recognized that nitrogen pressure injection testing in the borehole before in situ instrumentation and monitoring could impact on the objectives of long-term monitoring by driving moisture away from the near field environment of the downhole instrumentation cavities. The probable magnitude of this effect on pre-injection equilibrium conditions will need to be evaluated for proper interpretation of the long-term monitoring data. Pre-injection baseline information, relevant to this concern, will be collected before nitrogen injection testing. This information consists of laboratory measurements of moisture content and matric potential from core and cuttings and geophysical logging records correlated with these data. Estimates of the time needed to reestablish pre-injection equilibrium conditions will be developed from numerical modeling and from tests in existing, open boreholes. The latter testing program will use packers to monitor selected borehole intervals before injection testing and following injection testing. Different lithologic rock types with varying fracture densities will be tested in this manner. The nature of the impact on long-term monitoring objectives will depend on whether or not vapor-phase equilibrium or liquid-phase equilibrium will need to be reestablished to represent the pre-injection hydrologic state of the affected rock mass.

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Following the monitoring phase, the gas sampling access tubes will be used to inject water into each of the isolated, downhole instrument stations. These tests will be conducted to measure in situ saturated hydraulic conductivities. Constant-head injection tests will run until steady state flow conditions can be achieved.

8.3.1.2.2.3.3 Activity: Solitario Canyon horizontal borehole study

Objectives

The objectives of this activity are

1. To examine, on a local and limited scale, the extent of fracturing, brecciation, and gouge development associated with the Solitario Canyon fault.

2. To evaluate, locally, the hydrogeologic significance of fault-related features on water movement within the Solitario Canyon fault zone.

3. To evaluate, based on the findings developed under the first two objectives, whether additional information is needed to characterize adequately hydrologic boundary conditions along the Solitario Canyon fault zone, should the results indicate potentially adverse effects on repository performance.

Parameters

The parameters of this activity are

1. Gravimetric moisture content (ambient/matrix/laboratory).

2. Volumetric moisture content (ambient/matrix/laboratory).

3. Matric potential (ambient/matrix and bulk/laboratory and in situ).

4. Water potential (ambient/bulk/in situ).

5. Thermal potential (ambient/in situ).

6. Pneumatic potential (ambient/in situ).

7. Matrix permeability as a function of saturation and matric potential (laboratory).

8. Matrix pore size distribution.

9. Grain density (laboratory).

10. Bulk density (laboratory).

11. Total porosity (laboratory).

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12. Effective porosity (laboratory).

13. Bulk permeability (pneumatic/in situ).

14. Bulk permeability (hydraulic/in situ).

15. Fracture frequency, orientation, spacing, distribution, interconnectedness.

16. Effective width of fault zone.

17. Lateral variation in moisture content.

18. Lateral variations in ambient potential field.

Description

One horizontal borehole is planned for this activity. Its exact location has not yet been determined. A detailed site reconnaissance survey will be required to select an appropriate site. From preliminary analysis of existing geologic maps, it is likely that the selected site will be near the northwestern part of Yucca Mountain (Figure 8.3.1.2-15). The horizontal borehole will be sited to penetrate the Solitario Canyon fault structure at a point where the fault plane (zone) is bounded by blocks of the Topopah Spring welded tuff on both sides. Additional siting consideration will be given to minimizing the length of the borehole but only to the extent that minimization will not compromise the overall objectives of this investigation. It is recognized that the hydraulic properties of the fault zone may vary from unit to unit, but the principal investigative effort will be focused on the Topopah Spring unit because it is the proposed repository host rock.

It is anticipated that the total length of the borehole could be as much as 300 m, depending on final site selection. The borehole will be dry cored and drilled with air to preserve the ambient moisture content of recovered core and cuttings and of the in situ rock mass. The borehole will be drilled at a 2 to 3 degrees inclination downward to a depth at least sufficient to penetrate undisturbed (unfaulted) Topopah Spring tuff. A slight downward deviation of the borehole is preferred to aid in the containment and sampling of perched water should it be encountered during drilling. Core will be scribed during drilling to permit orientation of fracture surfaces. The site geologist will log the structural features onsite shipment of core and cuttings to the laboratory for further testing of matrix hydrologic and physical (parameter listing) properties. Oriented television video camera surveys will be run in the borehole following construction and removal of casing. Geophysical logs of the borehole will be obtained during a pause in drilling or upon completion of drilling.

Gas permeability will be measured by injection of nitrogen gas beyond a single packer set every 3 m as drilling proceeds to obtain a continuous permeability profile. Following drilling and casing removal, testing using a single-hole straddle packer configuration will be conducted to the extent that borehole conditions will permit.

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Following pneumatic testing, the borehole will be stemmed and instrumented to measure temperature, pressure, matric potential, and water potential. Gas-sampling tubes will be provided to permit recovery of pore gas and water vapor for periodic analyses of isotopic, tracer, and gaseous phase chemical composition.

After recovery from the pneumatic testing, water will be injected into the borehole using the gas sampling tubes. These tests will be conducted to measure in situ saturated hydraulic conductivities.

8.3.1.2.2.4 Study: Characterization of Yucca Mountain percolation in the unsaturated zone--exploratory shaft facility study

This study consists of nine individual sets of hydrologic tests that will be conducted in the exploratory shaft facility (ESF). The ultimate purposes of the ESF hydrologic tests are to (1) supplement and complement the surface-based hydrologic information needed to characterize the Yucca Mountain site and (2) provide information for analyzing fluid flow and the potential for radionuclide transport through unsaturated tuff. The integrated results from the ESF hydrologic tests will be combined with data from the surface-based studies to provide an overall understanding of the unsaturated-zone hydrologic system.

The design of the ESF hydrologic tests is principally based on the initial conceptual unsaturated-zone hydrologic model for the site (Montazer and Wilson, 1984). These tests are different from those being conducted as part of the surface-based investigations, in that the ESF tests are designed to provide phenomenological information about water flow through unsaturated fractured tuffs, in addition to providing basic hydrogeologic data.

The ESF test data will include hydrologic information that is not readily obtainable from the surface-based boreholes, by providing a testing environment that is suitable for three-dimensional characterization of the rock mass. Large volumes of rock will be studied in situ, and experiments will be designed to provide information in various directions. Lateral variations will be studied through horizontal drifts and boreholes and by careful mapping of large areas of underground rock exposure. Excavation of the primary science ramp will produce large volumes of rock that can be used for determination of water chemistry and for laboratory analyses of rock/hydraulic properties. In addition, a relatively good representation of fracture orientation, distribution, and continuity will be available in the walls of the excavations. Therefore, correlation between hydrologic and geologic information will be made with a higher level of confidence. Samples of rock containing intact fractures will be obtained from various locations within the underground openings. Results of hydraulic tests on such samples are expected to be representative of in situ conditions. Percolation tests will be conducted in a rock mass that is not disturbed by weathering and is thus representative of the repository host rock. Large-scale bulk permeability tests are possible only in an underground environment.

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In addition to providing data that could not be readily or adequately obtained from surface-based boreholes, the ESF will be the source of a large amount of supplementary hydrologic data. In order to obtain from a surface-based program the types and amounts of data comparable to those that will be produced from the exploratory shaft facility, many deep, instrumented, unsaturated-zone boreholes in close proximity to each other would be required.

The planned ESF tests described in this study are the (1) intact fracture test, (2) percolation test, (3) bulk permeability test, (4) radial boreholes test, (5) excavation effects test, (6) Calico Hills test, (7) perched water test, (8) hydrochemistry tests, (9) multipurpose-borehole testing and (10) hydrologic properties testing of major faults. These ESF tests are described in detail in the following activities.

The intact fracture test will evaluate the fluid-flow and chemical-transport properties of individual fractures to assess the in situ behavior of fracture systems. Meteoric potentials, moisture content, and the characteristic conductivity relationships will be measured in the laboratory. Properties of single fractures selected for testing require undisturbed sampling, to be accomplished by overcoring a tensioned rock sample containing a candidate fracture. Fracture specimens, instrumented with low-voltage displacement transducers to register aperture changes, will be tested in the laboratory with flow of air and water at different stress levels and with differing fracture saturations. By injecting a conservative tracer and observing breakthrough concentrations, measures of single-fracture dispersivity and retardation by matrix diffusion will be obtained. Details of flow channelization on a single fracture surface will be observed by dye tracing and film registration. Discrete fracture computer modeling will assist the work of establishing porous media equivalent properties. Because many aspects of this test are not standard, prototype testing will be performed to develop testing techniques and evaluate the limitations and usefulness of the resulting data.

Conceptual and numerical model development for fractured, porous media will be included in several activities, especially in the percolation test (Activity 8.3.1.2.2.4.2). The properties of individual fractures in this environment are fundamental to developing valid concepts of flow. The test of water flow and chemical transport is a basic investigation of properties of the Topopah Spring welded tuff at the repository horizon, aimed at resolving the contributions of fracture and matrix flow under varying artificial percolation rates. Tracer-tagged water will be supplied uniformly on a sand bed overlying a block of fractured rock instrumented with a number of boreholes. Logging, fracture mapping, and nitrogen-injection packer tests will characterize the conduit system, along with laboratory tests of the matrix permeability. This test will provide well-controlled boundary conditions (flux and gradient) on a scale that may be judged representative of the formation fracture system. The lowest measurable rate will include some fracture flow, thus applied fluxes representing various climatic conditions and the measured potentials will define the characteristic variation of fracture system hydraulic conductivity versus potential, a property required for travel time and transport calculations. This test is

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an opportunity to define conditions for the initiation of significant fracture flow and the propagation of percolation pulses via fractures. The test requires knowledge of the rate of matrix uptake through fracture walls under a range of antecedent moisture conditions in the matrix.

The relationship between effective permeability for air and for water will be investigated, so the numerous packer air tests in boreholes can be interpreted for hydraulic conductivities. Hysteresis will be investigated, if possible, by reversing the sequence of steady state fluxes applied. Anisotropy and the dip of the beds may result in lateral flow components. Consideration of steady state potential distributions across the various units for different fluxes suggests that above the contacts of units of different characteristics, gradients other than unity prevail, and since the beds dip 5 to 10 degrees east, the gradient can have small lateral components, aligned with or against the dip direction. A fundamental understanding of tracer velocity and effective porosity, the convective dispersion tensor and matrix diffusion can also be obtained from the test, since the fracture system geometry will be well described. Numerical modeling will be required at several stages. Tracer tests will be conducted in a cluster of vertical holes, with the objective of determining the dispersion properties of the medium by gas injection and sampling. Single-well and multiple-well configurations will be used. After several years of gas-phase monitoring at these test holes, the gas-sampling tubes will be used to inject water in a series of tests to determine saturated hydraulic conductivity and aqueous dispersive properties.

Dispersivity may be predicted by digital modeling of the medium. Because of the fractured and low-matrix permeability environment in which this test is to be conducted, this test will be prototyped on a large scale and various pretest numerical analyses will be performed to evaluate test feasibility. Because water movement in unsaturated welded tuff matrix is expected to be very slow, only small changes in hydrologic characteristics may be detectable on the time-scale available in which to perform this experiment. Prototype instrumentation to be used to monitor hydrologic characteristics will also be developed. After prototype testing and numerical analyses have been performed, the most effective approach to performing the test as a site characterization activity will be evaluated.

The bulk permeability test is designed to measure air flow to obtain the average conductivity of a much larger mass that contains a large number of different fracture conduits. If the distribution of fracture apertures, spacings, and orientations were known from independent single-fracture or packer tests, it would be possible to compute the volume required to include a sufficiently large number of conduits so that the bulk permeability provides a representative average within a specified tolerance. Lack of confidence in the application of this approach arises because the fluid flux within individual fractures depends on the cube of the apertures, whereas the bulk permeability depends on ill-defined continuity, homogeneity, and interconnectivity relations within the fracture system. Models must regard as discrete features all conduit sizes, such as large aperture fractures or faults, outside the range appropriate to the bulk system. The application of continuum theory to microscopically discontinuous properties entails the definition of a representative elementary volume (REV), below which discrete

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models of individual conduits must be used, and above which continuum average properties are justifiable within large-scale boundaries, such as large aperture faults.

The bulk permeability test will be conducted at the main test level core area on the Topopah Spring level and in exploratory drifts on both the Topopah Spring and Calico Hills levels. Single-hole packer air-injection tests, cross-hole tests, frustum tests, and tracer tests will be conducted at each test site to assess flood transport properties. Borehole arrangements will be used to test a variety of scales.

As with the previous test, the innovative nature of this experiment is recognized and prototype testing will be performed. The results of this test are expected to provide valuable information on scale effects on hydrologic characteristics. As well as prototyping instrumentation and experimental techniques, technical procedures will be developed and analysis techniques to interpret the resulting data will be evaluated. The results of these activities will support evaluation of the experiment for use in site characterization activities.

The radial boreholes in the radial boreholes test will be the principal means of eliminating the bias of vertical holes that are incapable of characterizing rocks dominated by near-vertical fractures. Short radial boreholes will be drilled during construction of the north ramps. Orientation of the boreholes will be determined by analyzing fracture orientation data, and an attempt will be made to drill parallel to the minimum and maximum directional permeability axes. Core will be logged to describe the physical characteristics of the rock. In situ hydraulic testing and long-term monitoring will be conducted to (1) detect vertical movement of water, in both vapor and liquid forms; (2) evaluate the potential for lateral movement of water along the hydrogeologic contacts; (3) estimate tortuosity and effective porosity of the drained pore spaces of the hydrogeologic units; and (4) determine the effective vertical permeability to air of the various hydrogeologic units. Prototype testing will be performed in support of this test to evaluate pneumatic testing and to develop instrumentation and techniques required to measure hydrologic characteristics in welded tuff.

The excavation effects on permeability will be related to stress changes in the excavation effects test. The excavation effects test is to be deferred until after construction and other prioritized ESF testing activities have been completed. The status and scope of the test is currently being addressed for ESF ramp accesses to be consistent with the reference ESF design concept described in Section 8.4. In the event that an optional shaft is constructed, excavation effects tests may be completed in the nonwelded Paintbrush Tuff and in the Topopah Spring welded tuff. The conceptual design of the test is based on the assumption that excavation of the shaft will cause opening or closure of fractures at various locations in the vicinity of the shaft. These deformations will modify the hydrologic properties and conditions of the rock mass, which will be detectable by measurements made at various times during shaft construction. Orientation of the fractures with respect to the shaft is important in determining the type of modification that might occur. As planned, these tests will be conducted in 18 vertical and angled boreholes drilled in radial arrangements in the floors of each of the two breakout rooms. Permeabilities will be measured by packer-injection testing of 6 of the 18 boreholes. Neutron logging will be used to measure moisture content. Directional deformation will be measured in the other 12 boreholes by installation of deformation and load measuring devices. Quantitative evaluation of stress-dependent conductivity will be made, so that future loading effects can be modeled.

Hydrologic processes, conditions, and properties under both present and expected future conditions for the Calico Hills nonwelded unit will be determined from a suite of tests proposed for the unit. The Calico Hills nonwelded unit is expected to be a principal barrier to the flow of ground water and transport of radionuclides. Therefore, it is important to understand, in particular, the effects that fractures and faults have on flow paths and travel times and the conditions under which fracture flow may occur.

The perched-water test is designed to detect and estimate properties of any perched-water zones in the part of the unsaturated zone penetrated during ESF ramp construction, drifting, and testing. This evaluation is needed to understand the hydrogeologic conditions causing accumulation of perched water; the implication of such a zone on flux, flow paths, and travel time; and whether perched water is a transient or permanent feature.

No perched water is expected in the host rock, except, perhaps, immediately above the Calico Hills nonwelded unit. The presence or potential for future perching of water in the host rock, however, might interfere with construction, operation, and ultimate performance of a repository at Yucca Mountain. In addition, perched water could cause substantial modification of geochemical interactions, transport processes, flow paths, and travel times. For example, inflow of perched water during construction of the ESF or repository might substantially affect construction techniques, schedules, and safety concerns because of the potential for flooding. Perched water in the Paintbrush nonwelded unit, above the host rock, could affect the spatial and temporal distribution of flow in the host rock by modulating pulses of infiltration and by diverting flow laterally to faults. Perching of water beneath the host rock in the Calico Hills nonwelded unit could affect travel times and flow paths to the accessible environment. Perched-water zones could result from barriers to flow, which would thereby increase travel time, or from shortcircuits, which would decrease travel time.

The perched-water test will be conducted only if perched water is encountered during ESF construction. Seeps or saturated zones will be looked for in conjunction with geologic mapping activities. If inflow of appreciable quantities of water is reported, hydraulic tests will be initiated immediately. If perched water or fracture flow is observed, boreholes will be drilled laterally into the ESF wall to test and sample the zone. A pumping test will precede the borehole drilling if the flow rate into the facility is sufficiently large.

The hydrochemistry tests in the ESF are designed to collect gas and uncontaminated pore and fracture water and perched water during the construction of ESF ramps and drifts. Near-fracture matrix samples will be centrifuged to collect uncontaminated water. These gas and water samples will be analyzed for their major compositions and stable and radioactive isotopes.

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The current plans for multipurpose borehole (MPBH) testing are tied to the original ESF design configuration with two shafts in close proximity. Test plans are currently being revised to be consistent with the reference ESF design concept described in Section 8.4. The principal purposes of the testing would be (1) to determine the ambient in situ conditions (hydrologic, chemical, thermal, and mechanical) before ramp construction; and (2) to evaluate the changes in these conditions as a result of the excavations and subsurface structures. If the multipurpose boreholes are not drilled as currently planned and if the information is still considered necessary, then equivalent information will be acquired by alternative testing strategies or thorough analyses of available information. A full suite of matrix and rock mass properties would be determined from core samples. Geophysical logs and hydrologic tests would be conducted before, during, and after ramp construction to evaluate in situ changes. Perched water, if encountered, would be sampled for chemical and isotopic testing and hydrologic tests performed. The multipurpose boreholes will not be permanently instrumented.

The hydrologic properties of major faults encountered in the ramps and in drifts at both the Calico Hills and Topopah Spring levels of the ESF will be evaluated. Principal faults to be studied include the Ghost Dance fault, a suspected fault in Drill Hole Wash, and the imbricate fault zone. Evaluations will determine the matrix and rock mass characteristics of these areas. Tests will be conducted in boreholes drilled from the underground drifts through the fault zones. Matrix properties of fault zone samples and core will be determined and geophysical logs obtained. Pneumatic and hydraulic testing (packer-injection and cross-hole) will be conducted in the boreholes to estimate the storage and transmissive characteristic of zones that may be significant pathways for ground-water movement.

8.3.1.2.2.4.1 Activity: Intact-fracture test in the exploratory shaft facility

Objectives

The objective of this activity is to evaluate fluid-flow and chemical-transport properties of single, relatively undisturbed fractures.

Parameters

The parameters of this activity are

1. Effective fracture permeabilities to air and water as functions of fracture saturation, water potential, and applied stress.

2. Effective porosity and dispersivity for fluid flow in single fractures.

3. Flow-path tortuosity in single fractures.

4. Fracture aperture geometry.

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Description

The intact fracture test is comprised of a detailed laboratory analysis of the hydraulic and transport properties of single, variably saturated natural fractures collected from the exploratory shaft facility. Minimally disturbed core samples of fractures will be collected from different rock types, locations, and orientations in the facility to provide samples that represent natural, rough-walled fractures in the unsaturated zone. Laboratory analyses under controlled conditions will provide hydraulic and transport parameters and an opportunity to directly observe fluid-flow processes over a range of hydraulic and mechanical conditions.

Neither the samples nor the parameter values are considered to be directly representative of the site in a statistical sense, due to the inherent biases in sampling locations, sampling method limitations, and the insufficient number of samples. However, it is anticipated that the opportunity to observe flow processes in a controlled laboratory environment will provide the necessary understanding required to test conceptual models of fracture flow and, based on the measured parameters, the corresponding numerical models.

The sample collection methods will be evaluated initially during a prototype testing phase. A variety of methods will be used to determine the suitability of the sampling techniques for the anticipated conditions of the exploratory shaft facility. In particular, methods must be developed both to ensure that the fracture samples are obtained with as little disturbance as possible and to describe the extent of the fracture disturbance caused by the sampling process. The required methods and procedures will be developed during the prototype testing program.

Photographs of exposed surfaces in the exploratory shaft facility ramps and drifts and the associated mapping activities (Activity 8.3.1.4.2.2.4) will provide the information necessary to select sample locations for the intact fracture test. Suitable fracture sampling locations will be determined from the three-dimensional projections obtained from localized detailed fracture maps. Fracture fillings and pieces of intact fractures will be collected and analyzed. The results are expected to allow determination of fracture origin, whether artificial (induced due to excavation) or natural.

Two coring methods will be used for fracture sampling: (1) a bolting and overcore technique, and (2) a clamp-core technique. The bolting and overcore method will be used to collect fractures that are approximately perpendicular to the core axis for subsequent radial flow studies. These samples are collected by first drilling a pilot hole perpendicular to the fracture; the fracture is then secured by a mechanical rock bolt, which holds the fracture together during core extraction, minimizing damage to the fracture plane. The sample is overcored, and then broken off with a coring shovel and removed. Approximately twelve fracture samples will be collected from each of four general areas where drift-wall mapping has indicated there are suitable locations for coring. The three hydrogeologic units to be sampled are the Tiva Canyon, Pah Canyon, and Topopah Spring members of the Paintbrush Tuff stratigraphic unit. Sampling is also proposed for the Calico Hills unit. Both welded and nonwelded samples will be collected. The pilot hole will be 1.9 cm (0.75 in.) in diameter and will be drilled approximately 15 cm (5.9 in.) beyond the fracture. Before seating the rock bolt anchors, a groove will be cut down the wall of the pilot hole to determine if the core has rotated during overcoring.

Intact fractures that are parallel to the axis of the extracted cores will also be collected in approximately the same numbers from the same areas, using the clamp-core method for subsequent axial flow studies. These samples will be obtained by first drilling two HQ-sized boreholes that are relatively parallel to the fracture and are diametrically opposed to each other on the periphery of where the sample will be cored. The fracture will then be cored (with the HQ boreholes on the periphery of the borehole cut). Circumferential clamps will be placed around the core (placing the union of the clamp in one of the HQ boreholes so that it can be tightened), starting at the farthest end of the core with each subsequent clamp closer to the mined surface. Before the core is broken off with a coring shovel, plaster will be placed across the fracture aperture. Any change in the plaster (i.e., cracking or spalling when the core is removed) will indicate if the fracture has been disturbed.

Onsite and offsite laboratory determinations will be made of the hydraulic properties of the rock matrix in each core sample. Gravimetric water content analyses will be performed locally to ensure water content does not change as a result of handling, shipment, or exposure to air. The matrix parameters to be determined offsite include matrix potential (via psychrometry and tensiometry), water content (volumetric), bulk density (liquid displacement), water potential (Richard's psychrometer), liquid and gas permeability (steady state), relative permeability (diffusivity), unconfined compressive strength, Young's modulus, and porosity (Boyle's Law using helium and/or mercury intrusion). The samples for matrix testing will be collected from portions of the core that break off when a coreshovel is used to separate the fracture sample from the remaining overcore and from material remaining after the core is trimmed to fit a laboratory confining vessel.

Two principal tests will be conducted in the laboratory. First, stress-permeability tests will be performed, which will provide hydraulic transport parameter measurements under a range of mechanical conditions. Also, flow-channelization tests will be conducted, which will provide information on the geometrical properties of fluid-phase distributions and fracture apertures.

The stress-permeability tests will be conducted in the laboratory by injecting liquids and gases into the core sample under varying applied stress conditions using a hydrostatic test machine (axial fractures) or a loading frame apparatus (radial fractures). The single- and two-phase permeability tests will also be conducted in the laboratory.

The single-phase liquid permeability test is similar to methods cited in both the soil physics and petroleum literature. A specimen will be dewatered through porous water-wet plates. The plates are used to establish a constant unit hydraulic gradient that can be incrementally increased or decreased over a desired suction range. The flow regime will be controlled by using a Mariotte reservoir system to obtain differential head values in the wetter range and positive gas pressures for the drier portion of the permeability curves. In situ water-potential measurements will be made to determine when steady-state conditions are achieved or approached. Electrical resistivity measurements will also be used to evaluate in situ moisture redistribution in the sample. Unit-gradient conditions and steady one-dimensional flow conditions will allow the permeability to be set equal to the volumetric flux, simplifying the determination of the permeability at various water potentials. A series of unsaturated permeability determinations will be made over the full range of imposed suctions during both the wetting and drying cycles to evaluate the magnitude of hysteresis effects in the fracture sample. A conservative tracer (bromide or chloride) will be injected into the flow system at various steady state intervals and breakthrough curves will be constructed from the tracer concentration measured from the outflow collected. Once a value for the liquid permeability is obtained (i.e., steady state), gas flow will be initiated to determine a gas permeability for the particular saturation. Tests will be conducted on approximately four fracture samples from each of the four hydrogeologic units to be sampled and both radial and axial orientations.

Flow rates of injected liquids and gases will be held constant to indicate how permeability is affected by stress-induced aperture variations for both the single- and two-phase permeability tests. Flow rates and fracture displacement will be measured at each loading step up to the maximum and then every unloading step back to zero. Testing will be performed on three or four fracture samples of each fracture orientation and each rock type. Loading-unloading cycles will be repeated so that permeability hysteresis attributed to asperity deformation can be evaluated.

Laboratory injection tests will also evaluate simultaneous two-phase flow properties, particularly the permeability to both water and air at varying stages of saturation. The tests will be conducted under constant loading conditions by monitoring transient outflow of both air and water phases during injection of either fluid. Saturations will be changed during simultaneous flow by changing the ratio of the gas and liquid flow rates. Tests will be conducted on approximately four fracture samples from each of the hydrogeologic units to be sampled and both fracture orientations.

Tracers will be injected into the fracture samples and their concentrations will be monitored during the steady-state flow tests. The data collected will be used to construct breakthrough curves and to obtain values for effective porosities and dispersivities. Small sample sizes and anticipated uncertainties in measurement accuracy may limit the direct application of the tracer test results. However, a significant gain in the understanding of the fluid flow and transport processes is expected. Some added degree of confidence probably will also be achieved for the subsequent model validation and calibration exercises.

Flow-channelization in the fracture plane of three or four intact-fracture samples from each hydrogeologic unit and orientation will be quantitatively and qualitatively described using several laboratory methods during the final phase of laboratory testing. Initially, visible dyes will be introduced in known quantities over time and the movement of dye-tagged water across the plane of the fracture will be observed. The core will be taken apart at the conclusion of the test and photographs taken of the fracture plane to record the fluid movement pattern. Fracture-plane roughness, which is an important factor in characterizing flow channelization, will be evaluated using a projection moire technique. The moire projection equipment will be used to perform three-dimensional adjustable resolution contouring of variable-size rock-fracture surfaces using back- projection methods. The equipment will allow the optical generation of contour fringes on the specimen surface, which can be optically (still and video photography) recorded and easily interpreted.

In addition, two other methods will be used to obtain casts of the fracture plane. A low-melting-point metal will be injected into the fracture plane to obtain a cast of the flow channel. A resin impregnation method is also being considered to obtain flow channel casts. These casts will be used to determine the topography of the flow channels between the contact points.

A computer model of fluid flow in discrete fractures will be used to design and predict the results of the intact fracture tests for planning purposes. The model is a semi-analytical flow model for a single rough fracture that combines the equations for capillary rise and the cubic law to predict the relative permeability of a fracture at various saturations. The model accounts for the capillary-controlled distribution of the liquid phase at low saturations and high tensions and for the gravity-induced flow at higher saturations, when a continuous liquid phase has been achieved. The model assumes that the water is supplied to the fracture at the contact points between the fracture walls.

The aperture generated by computer simulation uses a digitized, real or artificial fracture wall, which is then replicated to simulate the aperture. The walls can be manipulated in a compressional or shear sense so as to create a simulated in situ fracture. The aperture is then discretized in three dimensions and coupled with the flow portion of the computer code.

The measured fracture aperture geometrical properties obtained from the flow-channelization experiments will be compared with those predicted by the aperture generator contained within the single-fracture flow model. An assessment will then be made as to the adequacy of the aperture generator that has been conditioned by the measured data (e.g., roughness profiles and mean physical apertures). The specific geometrical parameters will be compared for both measured and predicted values and uncertainties in the aperture generator estimations will be established.

The measured unsaturated permeability values will be compared and regressed against predicted values obtained from the following: (1) the model that has been conditioned by measured fracture geometry data, (2) two-dimensional analytical Navier-Stokes solutions for planar and cross sections of the fracture flow domain, and (3) semi-empirically derived estimates of the unsaturated permeability values obtained from the pore-size distribution data and/or the moisture retention data.

The experimentally determined tracer breakthrough curves will provide an opportunity to at least qualitatively evaluate the effects of tortuosity on fluid flow due to flow-channelization in the fracture plane at various saturations. It may not be possible to determine meaningful estimates of transport parameters, such as mechanical dispersion (in the more mobile fracture domain) or diffusion (in the lesser mobile matrix domain), caused by the

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small size of the samples and the core sampling being nonrepresentative of the rock mass as a whole. However, the curves constructed using laboratory-collected data will be compared with the predicted curves from standard numerical models with transport capabilities (based on the advection- dispersion equation) and from codes that rely on a particle-tracking approach to determining a distribution of travel times. These comparisons will be made to better understand the nature of the transport mechanisms at the microscale and to evaluate the applicability of standard transport modeling approaches in a fracture-dominated flow system.

The comparisons between measured and predicted values will determine how appropriate the various approaches are. Favorable comparisons will imply that the predictive method adequately accounts for the essential processes and controls on the variably saturated flow domain. The uncertainties of making predictions with each of the methods will be established and interpreted by comparing the results obtained from replicating the experiments under varying initial and boundary conditions or testing with samples with widely varying geometrical properties. These comparisons will also establish confidence limits with which fracture parameters (used as input to the flow model or empirical estimation methods) can be varied when attempting to predict unsaturated permeabilities with a fracture network in the larger-scale or macroscale tests.

When sufficient data have been obtained from the previously described tests (i.e., single- and two-phase permeability, and flow-channelization), the results of the laboratory tests will then be used to help develop numerical models to be used in subsequent larger-scale tests (percolation and bulk permeability tests, as described in Activity 8.3.1.2.2.4.2 and 8.3.1.2.2.4.3) where fracture flow properties will also be studied. Activity 8.3.1.2.2.8.2 (validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock) describes the relationship between the scale-based tests (i.e., the intact fracture, percolation, and bulk permeability tests) and associated conceptual and numerical models.

8.3.1.2.2.4.2 Activity: Percolation tests in the exploratory shaft facility

Objectives

The objectives of this activity are to determine the hydrologic conditions that control the occurrence of fluid flow within fractures and matrix and to provide experimental data against which the validity of numerical and conceptual models can be tested.

Parameters

The parameters of this activity are

1. Unsaturated hydraulic conductivities to air and water as functions of bulk water saturation and matric potential (including the determination of critical saturation).

2. Effective porosities of the matrix and fractures.

3. Volumetric flux and travel time through the rock mass.

4. Fracture spacings, orientations, connectivity, and apertures.

Description

Because the permeability of the fracture system at Yucca Mountain is expected to be both scale dependent and spatially variable, a percolation test conducted at a single scale at a single location has limited value for characterizing the overall fracture-network permeability of the hydrogeologic unit in which it is performed. The primary value of such a test is the opportunity it provides to test hypotheses concerning the nature of fluid flow in unsaturated, fractured rock systems (Activity 8.3.1.2.2.8.1). Experimental validation of numerical models that describe unsaturated flow and transport in systems containing a limited number of discrete fractures provides a tool to allow extrapolation to larger scales at which physical experiments are not feasible. In other words, numerical "experiments" can then be performed at scales at which the physical experiments are impractical because of time or financial restraints. If the model has been physically validated at some smaller scale, the numerically generated "data" for an assumed fracture network can be used to test other simpler modeling approaches such as the composite porosity approach described below.

Detailed models that consider the effects of individual fractures or other spatial heterogeneities within a rock mass can also be used to estimate bulk parameters for the rock mass, as well as evaluate the limitations of using a bulk parameter approach. The ability of these models to estimate the bulk flow and transport parameters of an unsaturated, fractured rock mass will be examined by conducting a sequence of experiments at successively increasing scales. These experiments include the intact-fracture test (Activity 8.3.1.2.2.4.1), the percolation test (this activity), and the bulk permeability test (Activity 8.3.1.2.2.4.3). The results from each experiment can then be compared with simulated results produced by models appropriate to that scale (Activity 8.3.1.2.2.9.2).

The composite conductivity-matric potential relationship for a fractured rock mass is one example of a bulk parameter approach. It ignores the spatial heterogeneity caused by the fracture system and considers the fracture and matrix domains as a composite, homogeneous continuum. The composite conductivity-matric potential relationship can be physically determined by applying a known flux to the surface of the rock and measuring the average matric potential and total hydraulic gradient across it. From Darcy's law, the equivalent conductivity of the rock mass can be calculated by dividing the flux by the total head gradient. The calculated conductivity and average matric potential at the applied flux provide one point on the characteristic curve. By successively altering the percolation rates and average matric potential, the entire composite curve can be determined. If, at each successive percolation rate, a conservative tracer is added to the inflowing water, two additional effective parameters (effective porosity and effective dispersivity) can also be determined for that rock mass. The percolation test, to be conducted on a single block of rock excavated from the Topopah

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Spring welded unit at the repository horizon, is intended to test the composite continuum hypothesis. The results of this experiment, in conjunction with the results of the intact-fracture test and the bulk permeability test, will be used to assess the validity of conceptual and numerical models describing fluid and solute movement in fractured, porous rock.

Percolation tests are currently planned for the main test core area on the Topopah Spring level. A pillar of rock composed of fractured, welded tuff will first be isolated. From this pillar, a diamond-impregnated wire saw will cut a block of rock approximately 2 m on a side into which tracer-tagged water will later be introduced. This volume of rock does not necessarily reflect the dimensions of the so-called "representative elementary volume" (REV), but has been chosen because it becomes increasingly difficult to induce steady-state flow in larger volumes of low-permeability rock within the time constraints of the site characterization activities.

The test block will be hydrologically and pneumatically isolated from the surrounding rock mass on all sides. This will facilitate the collection of effluent from the base of the block so that both the volume of outflow as well as areally averaged tracer concentrations may be obtained. In addition, isolation of the block and sealing of its sides with a clear, impermeable substance will enable better characterization of the fracture network geometry and will ensure that there are no lateral flow components.

The test block will be excavated from the surrounding rock by removing tapered slabs of rock immediately adjacent to it. Holes will be first drilled through the pillar at the intersections of the horizontal and vertical faces of each slab. The wire will be threaded from driving pulleys in the first drift through a borehole and into the second drift, and then returned to the first drift through a separate hole. As the wire is circulated through the drillholes in a continuous loop, it will cut the rock in the plane defined by the holes. After each slab face is cut, the slab will be pushed into the drift adjacent to the wider end where it will be broken up and removed. The drillhole orientation will produce the tapered cuts. The bottom slab will be removed first and a vertical support system installed. The top slab will be removed next, followed by the side slabs and finally the end slabs.

Before excavation of the test block, small-diameter (1.3-cm) boreholes will be drilled through the pillar and the test block and used to perform both single-hole and cross-hole packer injection tests (using nitrogen gas). Packer spacing will be designed to isolate discrete fractures or fracture zones, as determined from mapping of the sides of the block and from borehole logging. Values of pneumatic conductivity calculated for tests conducted before the excavation of the block from the pillar will be compared with the values calculated from similar tests conducted after the excavation has been completed. In this way, the effects of excavation on changes in effective fracture aperture can be quantified. The information on fracture geometry and conductivity provided by air-injection packer tests will also be used to refine and calibrate a preliminary computer model of the test block. The boreholes in which the pneumatic tests are initially conducted can also be used as conduits for rock bolt supports during excavation.

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All boreholes will be drilled and cored using air. The boreholes will be surveyed for fracture locations using downhole TV cameras and by conducting single-hole packer air-injection tests.

The core from all boreholes will be logged in detail for fracture locations and geometric parameters (e.g., fracture spacing, fracture orientation, apparent aperture, trace roughness). When fractures are identified, their location, strike and dip will be measured and recorded. When available, other features will be determined, such as length of trace, surface roughness of fracture walls, fill materials, degree of weathering, mineralized coatings, and hydraulic aperture.

Onsite laboratory determinations will be made of the hydraulic properties of the rock matrix in the core sample (Activity 8.3.1.2.2.3.1, matrix hydrologic properties testing). The parameters to be measured include saturated hydraulic conductivity, moisture content (gravimetric and volumetric), moisture content-matric potential relationships, water and matric potential (via psychrometers, heat-dissipation probes, tensiometers), grain density, porosity, and bulk density. From these measurements, relative permeabilities of air and liquid water as a function of matric potential or water saturation will be calculated. The spatial variability of the above-mentioned quantities within the block will be described with semivariograms.

Samples of core from the boreholes will be tested to determine the effective diffusion coefficients of the matrix (and fracture coatings, should they exist) with respect to nonreactive tracers, such as potassium bromide. An attempt will also be made to measure the permeability of any fracture coatings observed in the cores.

A ventilation door will be installed near the entrance to each of the two side drifts. These doors will be completely sealed on all sides and around inlet and outlet ventilation ducts. Instrumentation will be installed to monitor air pressure, temperature, and relative humidity of both incoming and outgoing ventilation.

Individual fractures, joint sets, and fracture networks will be mapped along the exposed surfaces of the drifts as part of the geologic mapping project (Activity 8.3.1.4.2.2.4). Similar fracture maps will be prepared for each face of the percolation test block. Photographs of the drift and test-block surfaces will also be taken to provide a record of the fracture trace patterns. Fracture orientations and three-dimensional projections into the test block will be determined from the fracture maps, core samples and borehole data.

The first step in the percolation test will be to saturate the block to the maximum extent possible by ponding water directly on the surface of the block. Outflow collected from the bottom of the block will then be de-aired and recirculated. Water will move through the fracture network and be imbibed from the fractures into the matrix. Small amounts of air will be trapped and compressed within each of the fracture-bounded matrix blocks as the wetting front advances from the saturated fractures toward the centers of the blocks. Based on preliminary modeling, this small amount of compressed air probably will not significantly affect the results of the test.

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Steady-state conditions will be assumed to occur when the rate of inflow into the block equals the rate of outflow from the block (to within a specified tolerance). The saturated bulk-rock conductivity and the associated percolation rate will be determined in this first phase of the test.

A sand bed and flow tank apparatus will then be installed on the upper surface of the test block and a ceramic (or metal) porous plate attached to the base of the block. A suction less than the air-entry suction of the plate will be applied to the lower plate surface with a vacuum pump. The applied suction will draw percolating fluid out of the plate to where it can be collected, measured, and analyzed. A thin (1-cm-thick) sand layer placed between the block and the porous plate will ensure that good hydraulic connection is maintained between the rock and the plate, and will reduce pressure buildup near the fractures caused by plate impedance.

Water will be applied to the sand bed surface using hypodermic syringes or perforated tubing. Capillary forces within the sand will cause water to spread laterally from the application points, so that for a homogeneous sand, the matric potential within the sand at a given height above the sand-block interface will become relatively uniform. The sand bed apparatus will consist of a framed-in box filled with well-sorted sand and instrumented with heat dissipation probes, tensiometers, and thermocouple psychrometers.

At high percolation rates, water movement at the base of the sand bed will have a strong horizontal component because the water will tend to pond above the intact matrix blocks and drain into the intervening fractures. A sand with a high saturated conductivity will maintain small lateral pressure gradients and relatively uniform matric potential at the base of the sand and within the upper part of the block. The saturated hydraulic conductivity of the sand should be larger than the measured bulk-rock conductivity.

When the sand bed and porous plate are in place, water will be infiltrated into the sand bed at rates less than the saturated hydraulic conductivity of the rock mass. The block, and particularly the fractures, will have drained somewhat as the sand bed and porous plate were being installed. However, steady-state conditions will be reestablished fairly rapidly at the new percolation rate, because drainage of water from the matrix is expected to be small. Because the matrix will remain nearly completely saturated over the range of matric potentials in which liquid-water flow within the fracture is thought to be important, very little water will need to be drained from or added to the matrix to maintain pressure-potential equilibrium between the fractures and the matrix. Therefore, the system should equilibrate quite rapidly with respect to altered boundary conditions once the initial saturation phase has been established. By measuring the average matric potential and average hydraulic gradients at steady state for successively lower applied percolation rates, the composite conductivity-matric potential relationship of the block can be determined. Because it becomes increasingly difficult to reestablish steady-state flow (or for that matter to measure fluxes) when water flow is primarily through the matrix, the percolation test will focus on that portion of the composite curve above and just below the point at which the fracture and matrix contributions to total flux are equal. This is the matric potential at which the fracture and matrix contributions to the total flux are equal, and below which the fracture contribution to the total flux becomes increasingly insignificant.

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After steady-state flow conditions have been established at a given percolation rate, a conservative tracer, such as potassium bromide, will be added to the inflowing water. The effective porosity (or more precisely, effective water content) of the block at that flow rate will be determined by dividing the Darcy flux by the length of the block and multiplying the result by the time required to observe an effluent concentration that is one-half of the input concentration. Effective moisture content, that is, the water-filled pore-volume available to solute moving through the rock, probably is a function of the flow rate and decreases with increasing fluid fluxes. A knowledge of the relationship between fluid flux and effective porosity is essential to the calculation of ground-water travel time.

The instruments employed in the percolation test must be capable of the following: (1) measuring water content and potential in the matrix, (2) distinguishing conducting (wet) fractures from nonflowing fractures, (3) monitoring the arrival of the wetting front or tracer pulse in the fractures, and (4) quantifying imbibition into the matrix through fracture walls.

Tracer movement will be monitored using electrical conductivity probes. Time domain reflectometry (TDR) will be used to measure bulk-rock water content in all phases of the experiment. During wetting, TDR will be used to monitor the wetting front in the matrix (and possibly fractures). Thereafter, TDR will be used to measure moisture redistribution during drying. Thermocouple psychrometers or heat dissipation probes will be used to measure the baseline (ambient) water potential in the rock before and during the initial wetting phase. If the initial matric potentials before wetting are less than -1,000.0 kPa, psychrometers will be used. If the potentials are between -80 and -1,000.0 kPa, heat dissipation probes will be used. Tensiometer-transducer systems will be used to measure matric potentials during wetting and subsequent steady-state conditions. The tensiometers will be arranged such that measurements in the vicinity of the fracture and in the center of the matrix block can be recorded simultaneously. In this way, imbibition rates into the matrix from adjacent fractures can be monitored during the transient wetting and drying phases. The tensiometer-transducer system can also verify that steady-state conditions predicted by inflow and outflow measurements have been attained.

All instruments will be emplaced horizontally within the test block with the exception of the TDR probes. Horizontal instrumentation will minimize disturbance of the percolation front and will eliminate the problem of preferential flow channeling that may occur along vertical boreholes.

8.3.1.2.2.4.3 Activity: Bulk-permeability test in the exploratory shaft facility

<u>Objectives</u>

The objectives of this activity are

1. To determine the scale at which the host rock behaves as an equivalent anisotropic porous medium.

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2. To compare hydraulic test results against a distribution of simulated results calculated from a large number of realizations of the possible fracture networks conditioned on average fracture orientation and/or fracture density data.

3. To use a numerical fracture-flow model to establish the minimum dimensions at which other rock masses with the same fracture characteristics behave as equivalent porous media and to examine the dependence of rock-mass dimensions on changing saturation.

Parameters

The parameters of this activity are

1. Unsaturated hydraulic conductivities relative to air as a function of liquid-water saturation and matric potential.

2. Water content of matrix and rock mass.

3. Effective porosity of matrix and fractures (including pore-size distribution of matrix).

4. Hydraulic potential of matrix and rock mass.

5. Volumetric liquid-water flux and travel time through the rock mass.

6. Directional water velocity distributions.

7. Fracture and fracture-set lengths, densities, spacings, orientations, connectivities, and apertures.

Description

The bulk permeability test is closely linked with the intact-fracture test (Activity 8.3.1.2.2.4.1) and percolation test (Activity 8.3.1.2.2.4.2) in validating conceptual and numerical models of fluid flow through unsaturated fractured rock (refer to Activity 8.3.1.2.2.8.2). The bulk permeability test will be conducted at sites in the Calico Hills nonwelded unit and in the lower breakout zone in the Topopah Spring welded unit. Single-hole packer air-injection tests, cross-hole tests, frustum tests, and tracer tests will be conducted at each site to assess the fluid transport properties of the units. Fracture mapping at the individual sites as well as in other drifts at these levels will be conducted to characterize the fracture network (Activity 8.3.1.4.2.2.4). Rock-matrix lithologic and hydrologic properties will also be characterized at each site as well as within other drifts at these levels. These fracture and rock-matrix data will be collected in order to evaluate fully the independent contributions of the rock matrix and the fractures to the overall composite rock mass hydrologic properties of the Topopah Spring welded unit at the repository target horizon. Resulting data from this test will be incorporated in a fracture fluid-flow model that will establish the minimum dimensions at which the rock mass behaves as an equivalent porous medium. The following paragraphs describe the data-collection process in detail.

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Individual fractures, joint sets, and fracture networks will be mapped along the exposed surfaces of the exploratory shaft facility. The fracture mapping will include (1) the measurement of individual fracture orientations, lengths, and apertures; (2) the identification of prevalent fracture sets; (3) the determination of fracture densities and spacing with sampling bias removed; and (4) the assessment of fracture and fracture-set interconnectivities. Sufficient fracture data will be collected on rock surfaces of varying orientations and locations to determine the three--dimensional geometry and properties of the extant fracture systems at the repository target horizon. Prototype testing is planned to identify the most appropriate methods for accomplishing this task. Fracture mapping will be done as part of Activity 8.3.1.4.2.2.4 (geologic mapping of the exploratory shaft facility).

In addition to the detailed fracture mapping, rock-matrix lithology and hydrologic properties will be determined for sample sets collected within the drifts excavated at the Calico Hills and Topopah Spring levels. Samples will be collected for mineralogic, petrographic, and hydrologic properties studies. The physical properties that will be determined include pore geometry, welding, grain density, bulk density, and porosity. The hydrologic properties that will be determined include the moisture content (gravimetric and volumetric), water potential, matric potential, and moisture retention. This work will be done as part of Activity 8.3.1.2.2.3.1 (matrix hydrologic properties testing).

Following the acquisition, analysis, and evaluation of the fracture characteristics and the rock-matrix hydrologic property data, sites within the Calico Hills and Topopah Spring levels will be chosen for air permeability testing. The air permeability test sites will be located (1) in a rock mass of effectively homogeneous composition and properties so as to be unaffected by transecting faults or the presence of abrupt lithologic discontinuities and (2) so that the experiments performed within it will remain unaffected by the other activities occurring at these levels. Modeling and prototype testing will be used to approximate the minimum distance required to avoid interference with adjacent activities.

The drilling and air permeability testing at each test site will be conducted in three stages. The first stage will consist of drilling three holes into the end or sidewall of an existing drift. These holes will be arranged in a frustum configuration, thus maximizing the variety of scales at which permeability testing can occur; this will provide the most data possible for determining at what scale the host rock behaves as an equivalent anisotropic porous medium. The holes will be 40 m long and diverging at an angle of 20 to 25 degrees from each other.

Following drilling, fractures that are conductive and thus suitable for testing will be located in each of the boreholes by using the single-hole packer air-injection method. This method consists of injecting nitrogen gas into a 2-ft test interval while observing the injection pressure and flow rates. If open fractures are not present, then the flow rates would be expected to decline significantly while the injection pressure remains relatively high. Thus, the location of open fractures will be inferred from

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high flow-rate test intervals and confirmed by examining the core and video logs. The entire lengths of both injection observation boreholes will be tested in this manner.

Next, cross-hole tests will be used to evaluate the reservoir properties, such as permeability and porosity, and to evaluate the homogeneous, anisotropic conditions in the fracture rock. The cross-hole testing method consists of injecting gas into an isolated test interval within a drill hole and monitoring the formation's response to the change in fluid pressure in nearby observation drillholes. To achieve this, a straddle packer system, consisting of four inflatable packers placed in series and separated from one another by spacer rods or well screens, will be placed in the injection borehole. Nitrogen gas will be injected into the test interval isolated between the second and third packers and the pressure response will be monitored in the adjacent observation boreholes. The observation boreholes also contain a straddle-packer system, thus providing up to three observation zones per hole where the response from fluid injection can also be monitored. In addition to the test interval, the injection borehole will contain two guard zones that straddle the test interval. These zones will be used to monitor fluid leakage from the test interval past the packers straddling the test zone.

Three types of sensors will be utilized in the cross-hole testing method for monitoring in situ air pressure, air temperature, and relative humidity in the guard and test intervals. These sensors include strain gauge pressure transducers for measuring absolute pressures, resistance temperature devices (RTDs) for measuring temperature, and thermocouple psychrometers for measuring relative humidity. Electrical leads for the sensors will be routed through the packers using gas and water-tight connectors to the collar of the drillhole. The test results, namely active and observation well fluid pressures, temperatures, and injection or production flow rates, will be used to calculate permeability.

Following the cross-hole testing, a gaseous tracer will be injected into several test intervals, and its arrival time will be measured at the outflow point to determine the effective porosity of the system. Prototype testing is planned to identify the most appropriate tracer for accomplishing this task.

The second stage of drilling and air permeability testing at each site will consist of drilling a central borehole to the same depth of 40 m. This borehole will also be injection tested along its length in 2-ft increments, using nitrogen gas to locate permeable zones suitable for cross-hole testing. Then, it will be used as the injection test borehole with the other three boreholes being used as observation boreholes during the subsequent cross-hole tests. The purpose of drilling the fourth borehole is to cut the distance between boreholes in half and thus provide a smaller scale at which cross-hole testing can be repeated.

For the third stage of drilling and permeability testing, the frustum test will be conducted. This test will consist of packing off the first 5 m of each of the four boreholes and simultaneously injecting nitrogen gas into the remaining 35 m of each borehole by connecting them to the same manifold.

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In this way, the test will be simulating a large-diameter, single-hole injection test, whereby a zone of constant pressure is formed from the center out to the diameter of the circle created by the ring of outer holes. The first 5 m of each hole will be packed off to minimize the permeable boundary effects of the relaxed zone. By performing this frustum test, a third scale, which is larger than the first two scales, will be investigated.

Following the air permeability testing, the data will be analyzed using discrete fracture and stochastic modeling approaches, as described in Study 8.3.1.2.2.9. In the discrete fracture modeling approach, the hydraulic test results will be compared against a distribution of simulated results calculated from numerous realizations of the possible fracture networks conditioned on average fracture orientation and/or fracture density data. In the stochastic modeling approach, the hydrologic and pneumatic test data will be treated as the realization of a stochastic process defined over a continuum, thus, allowing scales smaller or larger than the scale of measurement to be studied by means of deconvolution or spatial averaging (or both) techniques. The results of the two modeling approaches will then be compared for consistency and a final evaluation made.

8.3.1.2.2.4.4 Activity: Radial borehole tests in the exploratory shaft facility

Objectives

The objectives of this activity are to

1. Detect vertical movement of water in both the vapor and liquid forms and to evaluate the potential for lateral movement of water along the hydrogeologic contacts.

2. Evaluate the radial extent of excavation effects on the hydrologic properties of unsaturated hydrogeologic units.

Parameters

The parameters of this activity are

1. Rock matrix hydrologic properties, which include gravimetric water content, volumetric water content, grain density, porosity, bulk density, water potential, matric potential, moisture retention, saturated gas permeability, saturated liquid permeability, relative gas permeability, relative water permeability, moisture content, and porosity pore-size distribution.

2. Rock mass hydrologic properties, which include matric potential, water potential, temperature potential, pneumatic potential, bulk air permeability, bulk water permeability, bulk porosity, tortuosity, dispersivity, gaseous diffusion coefficient, gas permeability before and after shaft excavation, and fracture permeability.

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3. Hydrochemistry test, which includes composition of formation water, composition of formation gases, composition of radioactive and stable isotopes and time of residence.

4. Fracture characteristics, which include orientation (dip amount and direction), spacing, density, relative length of trace, surface regularity, fracture fill material, degree of weathering, and fracture aperture.

Description

Short radial boreholes are planned to be drilled in the north ramps leading to both the Topopah Spring and Calico Hills levels. The long radial boreholes test has been deferred until after construction and other prioritized ESF testing activities have been completed. The status and scope of the long radial boreholes test are currently being addressed for ramp accesses, to be consistent with the reference ESF design concept described in Section 8.4.

Radial boreholes will be used to obtain fracture sample statistics for each hydrogeologic unit, to measure conductive properties under ambient conditions beyond the relaxed zone, and to register effects of excavation. Interference testing (a procedure whereby the response to hydraulic stresses imposed on an interval in one hole is monitored in an interval of a second hole) will help evaluate the potential for lateral movement of water along hydrogeologic contacts. Core and cutting samples for laboratory hydrologic analysis will be obtained.

At each depth location, two 4- to 8-in (10.2- to 20.3-cm) diameter, 30-ft (9.1-m) long coreholes will be drilled using air as the drilling fluid. Air will be used instead of water in order to preserve, to the extent possible, the ambient moisture conditions of the core and surrounding rock mass. A tracer (namely, sulfur hexafluoride) will be added to the drilling fluid (air) so that contamination of the formation by the drilling fluid can be determined later during gas sampling.

Orientation of the radial boreholes at each depth location will be determined by analyzing fracture data collected during geologic mapping of the ramp and drift walls (see Activity 8.3.1.4.2.2.4 for mapping details). The fracture data, which include fracture orientation (i.e., strike, dip, and dip direction), length of trace, surface regularity, fracture-fill material, degree of weathering, and aperture, will be used to estimate the ansiotropic permeability tensor of the fractured-rock system. The projection of the estimated minimum and maximum principal permeability axes onto the horizontal plane will form the basis for locating the boreholes. The boreholes will be drilled parallel to these horizontal projections. Fracture data, obtained from the drill core, will be used to further refine the permeability tensor calculations and to determine the location of instruments. Therefore, maximum core recovery will be sought during the drilling process. A television camera will also be used to view, log and record the fractures intersecting each borehole. This information will be used to (1) verify fracture orientation, if oriented core is taken during the drilling process;

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Parameters

The following parameters will be collected during the activity:

1. Air permeability profiles.
2. In situ stresses.
3. In situ rock physical properties.
4. Fracture geometry (mappings).
5. In situ degree of saturation (water).
6. Porosity.

Description

This activity will be conducted at two breakout zones in the shaft approximately 400 ft. apart. The present design is preliminary and includes 18 boreholes at each breakout horizon. After completing the breakouts, two rows of three vertical holes will be air drilled for permeability measurements. Another set of six vertical air-drilled holes will be used for installation of deformation gages and loading cells at each breakout. In addition, six placement-measuring holes, angled at approximately 45 degrees from the vertical, will be percussion drilled with air.

The stress disturbance caused by the drill holes is expected to be very small compared to disturbance that will be caused by shaft excavation. This is based on the theory of elasticity where most of the stress redistribution takes place within two radii (one diameter) of a circular opening. The surrounding rock is expected to remain in the elastic range during the stress redistribution process. This behavior will be verified during prototype testing.

In situ stress changes will be estimated using deformation gages, flat-jacks, and/or loading cells. Instruments will be emplaced in the stress-relief holes to measure the deformation in at least two perpendicular directions prior to further shaft excavation. The change in instrument response during and after shaft excavation will be recorded. The multiposition borehole extensometers will be installed in the displacement measuring boreholes. In situ stress magnitudes and directions then will be estimated using data from these instruments, along with rock physical properties data that will be determined in the laboratory.

Television camera logs will be made in the permeability and stress measuring holes. Individual fractures and joint sets will be mapped from the television log record so that air and water injection testing zones can be appropriately located. Borehole geophysical surveys also will be conducted in the vicinity of the shaft. Neutron moisture, porosity (epithermal neutron), and gamma-gamma logs will be recorded.

Permeability boreholes will be instrumented with air-injection packer strings to detect permeability changes along these boreholes due to stress changes caused by the shaft excavation. These permeability tests will be performed before excavation of the shaft below the breakout levels and after further excavation until permeability changes are no longer detected.

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Air-injection packer strings then will be installed at certain zones to detect any long-term variations in permeability, temperature, and moisture content.

A coupled hydraulic-mechanical finite-element models will be used to analyze the basic data. Model validation and calibration will be accomplished by comparing measured and predicted in situ stress and permeability changes, given an initial state-of-stress condition. The calibrated model will be used to predict disturbances around openings within the repository.

8.3.1.2.2.4.6 Activity: Calico Hills testing in the exploratory shaft facility

The Calico Hills nonwelded unit is expected to be a principal barrier to the flow of ground water and transport of radionuclides. Therefore, it is critical to have high confidence in the understanding of the unit's hydrologic processes, conditions, and properties, under both present and expected future conditions. In particular, it is important to understand the effects that fractures and faults have on flow paths and travel times, and the conditions under which fracture flow may occur.

An analysis of the risks and benefits of alternative methods for obtaining this needed information from the Calico Hills was completed, and drifting and testing in the Calico Hills was recommended, although the testing program has not yet been defined. Tests currently proposed or planned for the Calico Hills geologic unit include the following:

1. Geologic mapping (Section 8.3.1.4.2.2.4)
2. Hydrologic properties of major faults (Section 8.3.1.2.2.4.10)
3. Bulk permeability test (Section 8.3.1.2.2.4.3)
4. Fracture mineralogy (sampling) (Section 8.3.1.3.2.1.3)
5. Matrix hydrologic properties (sampling) (Section 8.3.1.2.2.3.1)
6. Chlorine-36 (sampling) (Section 8.3.1.2.2.2.1)
7. Perched water test (if encountered) (Section 8.3.1.2.2.4.7)
8. Hydrochemistry tests (Section 8.3.1.2.2.4.8)
9. Vertical seismic profiling (Section 8.3.1.4.2.2.5)
10. Diffusion tests (Section 8.3.1.2.2.5)
11. Intact fracture test (Section 8.3.1.2.2.4.1)
12. Overcore stress experiments (Section 8.3.1.15.2.1.2)

Other testing activities being evaluated for inclusion in the Calico Hills test suite include geomechanical and geochemical tests such as plate loading tests (Section 8.3.1.15.1.7.1).

8.3.1.2.2.4.7 Activity: Perched-water test in the exploratory shaft facility

Objectives

The objectives of this activity are to (1) detect the occurrence of any perched-water zones, (2) estimate the hydraulic properties of the zones, and (3) determine the implication of the existence of such zones on flux, flow paths, and travel times.

Parameters

The parameters of this activity are

1. Transmissivity.
2. Hydraulic conductivity.
3. Hydraulic head and storage coefficient.

Description

Exploratory shaft facility walls will be visually inspected during ramp construction, drifting, and testing for any natural seepage or flow of water. If a seep or wet zone of low discharge is encountered, a small-diameter lateral hole will be drilled into the wall. This will increase the flow rate by concentrating and confining the flow to a perforated well casing to make accurate flow measurements and collect representative water samples for chemical analysis and age dating.

Yields from seeps or flow zones will be determined by collecting the water in a graduated cylinder and using a stopwatch or by a calibrated flow meter to measure the flow rate. If sufficient water production occurs and water level (or pressure) measurements can be made using a water-level measuring device or transducer, then an appropriate pump will be used to run a pumping test. Aquifer tests will be conducted from the exploratory shaft to determine the extent, yield, and hydraulic coefficients of the perched-water zone. The aquifer tests probably will be constant discharge tests so that standard methods may be used to analyze the results. However, detailed plans for conducting and analyzing perched-water tests will be developed before starting the exploratory shaft facility, to ensure that procedures are in place for testing in this unusual environment, if encountered. The implications on flow paths, fluxes, and travel times due to perched water zones will then be determined.

Lateral boreholes in selected low productivity zones will be instrumented with pressure transducers and psychrometers. The pressure transducers will provide hydraulic head data and the psychrometers will provide water potential data in the capped boreholes at selected time intervals.

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8.3.1.2.2.4.8 Activity: Hydrochemistry tests in the exploratory shaft facility

Objectives

The objectives of this activity are to

1. Understand the gas transport processes within the unsaturated zone and to provide independent evidence of flow direction, flux, and travel time of gas.

2. Design and implement methods for extracting uncontaminated pore fluid from rock excavated during ramp construction.

3. Determine the flow direction, flux, and travel time of water in the unsaturated zone by isotope geochemistry techniques.

4. Determine the extent of the water-rock interaction so that geochemical modeling can be performed to deduce the flow path and to understand the geochemical evolution of the unsaturated zone water.

Parameters

The parameters of this activity are

1. Gas composition.
2. Carbon-isotope concentration (in carbon dioxide gas).
3. Hydrogen and oxygen isotopes (in water vapor).
4. Water quality (cations, anions).
5. Flow paths (oxygen-18, deuterium).
6. Travel time (hydrogen-3, carbon-14, chlorine-36).

Description

Carbon dioxide and water-vapor samples will be collected from radial boreholes in the exploratory shaft facility after the holes have been instrumented. Gas samples will be checked for contamination (SF_6 or a similar conservative gas tracer) caused by air coring or blasting before coring. Samples to be used for composition analysis will be drawn by peristaltic pumping, collected in glass or stainless steel collection cylinders, and analyzed by gas chromatography. The carbon dioxide gas will be collected in molecular sieve in stainless steel cylinders and analyzed for carbon-14 and carbon-13 to carbon-12 ratio. Water vapor will be collected in the cold trap by pumping the gas through the cold trap and analyzed for tritium, oxygen-18 to oxygen-16, and deuterium to hydrogen.

The age of the unsaturated zone gases will be determined from the carbon-14 and carbon-13 to carbon-12 isotope data. Stable isotope ratios oxygen-18 to oxygen-16 and deuterium to hydrogen which, can indicate the climatic and evaporative history of moisture, will be used to determine the time of recharge and flow path of the moisture. This information, combined with other moisture data, will be used to interpret the patterns of gas transport.

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Rubble core from construction of the primary science ramp will be used to extract pore fluids from the matrix and near fractures for chemical and isotope analyses. Samples will also be checked for the presence of artificial tracers that would indicate contamination. The fluids will be extracted from the rubble cores by applying pressure, centrifuging, or vacuum distilling depending on the moisture content and core condition. These techniques for fluid extraction will be evaluated during prototype testing.

Fracture fluids are expected to permeate the surrounding matrix. Where fractures occur in core samples, the rock matrix around the fracture will be segregated. Fluids from this matrix with moisture contents greater than 11 percent will be extracted using the centrifuge method.

Fluids from samples with moisture contents less than 11 percent (including samples that have been squeezed and centrifuged) will be extracted using the vacuum distillation method.

Cation concentrations will be determined by using inductively coupled plasma (ICP), and anion concentrations will be determined by ion chromatography. Stable isotope ratios will be analyzed by mass spectrometry. Low-level gas counters or liquid scintillation counters will be used to determine tritium activity. Large carbon-14 samples will be analyzed using conventional gas counting methods, with small carbon-14 and chlorine samples analyzed by tandem accelerator mass spectrometry. All water samples will be analyzed for the presence of gas and water tracers using gas chromatography-mass spectrometry (GCMS). The usefulness and applicability of uranium-series disequilibrium analyses will be evaluated; if determined to be appropriate, these analyses will be done.

Apparent ages of water in the unsaturated zone will be determined from isotope data (carbon-14, tritium, and chlorine-36). Chemical analyses (cations and anions) will be used to verify flow paths indicated by isotope data and to indicate the extent of water-rock interaction. Chemical and isotope data for pore water and fracture-related water will indicate travel times since lower chemical concentrations and the pressure of tritium will indicate younger water.

Additional discussions of these studies are included in Activity 8.3.1.2.2.7.2.

The bulk chemistry data determined in this activity will be used by Study 8.3.1.3.1.1 in its development of ground-water chemistry model. Furthermore, this information and task will be integrated with Activity 8.3.4.2.4.1.3 (composition of vadose water from the waste package environment).

8.3.1.2.2.4.9 Activity: Multipurpose-borehole testing

The current plans for multipurpose borehole (MPBH) testing, as described in the following paragraphs, are tied to the original ESF design configuration (described in the SCP) with two shafts in close proximity. MPBH test plans are being evaluated to determine if it is feasible to conduct

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such tests within the reference ESF design concept described in Section 8.4. Planning for these tests will be tied to the drilling plan for collection of geologic information needed for design and construction of ramp accesses and will require modification to current MPBH and radial borehole tests (Section 8.3.1.2.2.4.4) as previously defined.

Objectives

The planned objectives of this activity are

1. To monitor and evaluate potential hydrologic and engineering interference effects from ramp construction on ESF tests and interference effects between ESF tests.

2. To identify possible occurrence of perched water and, if present, sample and test.

3. To confirm engineering and hydrogeologic properties on which the ESF design is based and identify anomalous conditions in the vicinity of the ESF.

The drilling method for this application has not been selected; the selection will be based on feasibility testing of air drilling and coring methods and equipment in a prototype borehole.

The prototype borehole is planned to be drilled before drilling the first multipurpose borehole (USWMP-1) in a similar stratigraphic profile to the exploratory shaft to ensure that the dry drilling method is feasible to the planned depth. The dry coring technique will be tested to evaluate the feasibility for core sampling in the multipurpose boreholes. The technical procedures for the drilling, sampling, and testing will be developed during prototype testing. If the feasibility testing regarding dry coring techniques is successful, the Project will proceed with multipurpose borehole drilling near the exploratory shafts.

Parameters

The parameters of this activity are

1. In situ gravimetric moisture content.

2. In situ volumetric moisture content.

3. In situ water potential.

4. Water-content profiles.

5. In situ matric potential

6. Temperature profiles.

7. Matrix pore size distribution.

8. Grain density.

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9. Bulk density.

10. Total porosity.

11. Matrix effective porosity.

12. Bulk permeability (pneumatic).

13. Composition of formation water.

14. Composition and stable isotope composition.

15. Radioactive and stable isotope composition.

16. Fracture frequency, orientation, spacing, distribution, and weathering.

17. Depths to hydrogeologic contacts.

18. Transmissivity (perched-water zone).

19. Hydraulic conductivity (perched-water zone).

20. Hydraulic head (perched-water zone).

21. Storage coefficient (perched-water zone).

22. Water chemistry (perched water).

Thermal and mechanical properties will be measured as described in the activities under Studies 8.3.1.15.1.1 through 8.3.1.15.1.6.

Description

If the prototype borehole feasibility testing is successful, two multipurpose boreholes (USW MP-1 and USW MP-2) would be constructed using dry-drilling and spot-coring techniques,to the extent practicable, to achieve the objectives listed above. Both boreholes would be located such that they do not penetrate within a distance of either two shaft or drift diameters, as appropriate, of any underground openings. USW MP-1 would be located near exploratory shaft 1 (ES-1), and USW MP-2 near exploratory shaft 2 (ES-2). Each would be approximately 15 to 18 m from the corre- sponding shaft, USW MP-1 to the south of ES-1, and USW MP-2 to the southeast of ES-2. Both boreholes would be approximately 15 cm in diameter and would be drilled to depths approximately equal to the corresponding shafts, with walls as smooth as practical to maximize the quality of geophysical logging and provide adequate packer seats. The planned coring program in USW MP-1 is more extensive than that planned for USW MP-2. USW MP-1 would be drilled first and spot cored throughout. The amount of coring in USW MP-1 is estimated to be 128 m of the total 335 m. USW MP-2 would be spot cored or continuously cored as deemed necessary or practical based on experience from drilling of USW MP-1, or upon finding any indication of perched water. The MBPH drilling activities are planned to be completed and monitoring begun before exploratory shaft sinking.

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Depth penetration of ES-1 will precede ES-2 until about 30 m is reached. At this level tests will be conducted in the radial boreholes in ES-1 (Activity 8.3.1.2.2.4.4) at the contact of the Tiva Canyon welded unit and the Paintbrush nonwelded unit. Because ES-2 is designed to provide quick access to the main test level, the construction of ES-2 will proceed ahead of ES-1 after the first few tens of meters.

USW MP-1 is planned (1) to be located to provide reference information in the vicinity of ES-1 and (2) to provide a monitoring hole once shaft construction activities begin. The pre-shaft-sinking results of the moisture-sensitive geophysical testing (e.g., neutron activation) are planned to serve as a baseline against which construction-induced variations can be assessed. If significant net amounts of water are introduced by construction, and if that water migrates outward from the shaft, the periodic logs would record the movement of the moisture front. USW MP-1 would also provide for testing and sampling of any perched water zones encountered before possible drainage and contamination from fluids introduced during the construction of ES-1. This borehole would be located outside the anticipated modified permeability zone (MPZ) caused by construction of ES-1, but within the radial distance from ES-1 covered by the radial borehole test. In conjunction with monitoring performed during the radial borehole test in ES-1, periodic geophysical logging and pneumatic testing would be conducted in USW MP-1 to monitor conditions during construction of ES-1. Analysis of the core samples obtained from USW MP-1 and USW MP-2 would provide the data base for establishing pre-shaft in situ ambient conditions and would become part of the site data base compiled in Activity 8.3.1.2.2.3.1 (matrix hydrologic properties testing). Within each hydrostratigraphic unit, a sample would be analyzed for the parameters for this activity. In particular, matrix hydrologic properties and moisture conditions would be characterized to establish in situ conditions that could be correlated with the initial results of geophysical testing.

USW MP-2 is planned to be located near ES-2 in order to provide confirmation of conditions expected to be encountered during shaft construction activities. This borehole is designed to detect any anomalous conditions, including perched water, that may be present at this location. If large amounts of perched water are present in the ESF vicinity, it would probably be detected in USW MP-1. However, even if perched water has not been detected in USW MP-1, continual observations for indications of perched water would be conducted in USW MP-2.

If unexpected conditions do exist, information obtained in the two boreholes could prevent potentially costly delays in shaft construction. The responses observed in USW MP-2 caused by the construction of ES-2 would be expected to be similar to those that might be later observed in USW MP-1 caused by the construction of ES-1. Therefore, observations in USW MP-2 could provide some lead time, so that construction effects can be considered before ES-1 testing.

The models of shaft construction effects developed from observations around ES-1 (radial boreholes test and excavation effects test (Activities 8.3.1.2.2.4.4 and 8.3.1.2.2.4.5 and USW MP-1) and ES-2 (USW MP-2) can be applied to predict what these effects will be at the ESF main test level. This approach will aid in confirming whether the selected test locations at

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the main test level are appropriate. In addition, distinctive tracers will be included in all ESF construction fluids to help identify the sources of any fluids sampled during ESF excavation. If tracers are detected at proposed test locations, this information will also be used to help determine whether proposed test locations are suitable.

A third multipurpose borehole may be drilled midway between ES-1 and ES-2, if further study indicates a need for such a borehole. The primary purpose of this borehole would be to attempt to assess the impact of construction activities in ES-2 on investigations in ES-1. Preliminary modeling (Section 8.4) results indicate that any expected fluid loss from construction activities in ES-2 probably would not migrate in the matrix or small-aperture fractures the 30 to 45 m from the shaft to the additional borehole, and that changes in matrix saturation would be small. However, the potential exists for more extensive fluid movement along large-aperture fractures. In addition, bulk pneumatic permeability would be affected by even small changes in moisture contents of fractures. These effects could be detectable by a multipurpose borehole sited between ES-1 and ES-2. A decision on the need for a third multipurpose borehole will be made before the construction of ES-2 on the basis of additional analyses of the magnitudes and significance of expected effects.

If perched water is detected during the process of drilling either of the two multipurpose boreholes, an attempt to obtain a water sample would be made, possibly by means of a bailer or other type of downhole sampler. A water sample must be obtained with minimal delay before the possible drainage of a small perched water zone. If sufficient water is present to conduct aquifer testing, testing will be initiated, and additional water samples will be obtained.

Because drilling fluid used during construction of nearby test hole USW G-4 contained water, the occurrence of perched water in either of the two multipurpose boreholes could be the result of drilling fluids lost from USW G-4. Drilling fluids used in USW G-4 contained 20 ppm LiBr tracer; thus, analyses for this tracer will establish whether any perched water samples contain drilling fluid that has migrated laterally from USW G-4 to areas of ESF excavation.

A standard suite of borehole geophysical logs would be run in each multipurpose borehole, either during a pause in drilling or following completion of drilling. Radial-(side scan viewing) and axial-(forward viewing) oriented television video camera logs of each borehole would also be run. These would be used for mapping fracture orientations, distributions, and densities. Neutron moisture logs would be made periodically during and after the drilling period to monitor any changes in water-content profiles.

To establish a preconstruction data set for bulk pneumatic permeabilities immediately following drilling, packer nitrogen-injection tests would be performed in each of the boreholes to determine gas permeabilities of the combined fracture and rock matrix system. Multiple test zones would be selected for each hydrogeologic unit. These zones would be tested with a straddle packer system consisting of a variable length injection interval, and two observation intervals. All three intervals would be equipped with thermocouple psychrometers (or other humidity sensors), thermocouples and

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pressure transducers. The observation intervals would be monitored for evidence of bypass of the packers from the injection interval. The flow rate and injection pressure of the nitrogen gas would be monitored until steady-state conditions are achieved. The same procedure would be carried out at higher flow rates and pressures for each tested interval to determine the relationship of permeability versus flow rates and pressure. During construction of the exploratory shafts, additional periodic packer tests would be conducted to determine any changes in gas permeabilities due to shaft construction.

Neither of the two multipurpose boreholes would be permanently instrumented. The open boreholes would allow flexibility in terms of follow-up packer testing and continual neutron-moisture logging that a permanently instrumented borehole could not accommodate.

Drilling of the multipurpose boreholes would disturb in situ conditions in the near-field rock mass adjacent to the boreholes. In addition, nitrogen pressure injection testing could drive moisture away from the near-field environment of the borehole. However, the planned dry drilling and coring methods are expected to minimize the disturbance to the hydrologic system, and pre-injection reference information would be collected before nitrogen injection testing. This information would consist of laboratory measurements of moisture content and matric potential from core and cuttings and geophysical logging records correlated with these data. Although these data would not directly address changes in moisture in fractures, results of neutron moisture logging would provide some indication of moisture contents in fracture zones.

8.3.1.2.2.4.10 Activity: Hydrologic properties of major faults encountered in main test level of the exploratory shaft facility (ESF)

Objective

The objective of this activity is to investigate the permeability and flow conditions of the major faults encountered in the ramps and in drifts at both the Calico Hills and Topopah Spring levels of the ESF.

Parameters

The parameters of this activity are

1. Matrix parameters including water content, porosity, pore-size distribution, air permeability, and water permeability.

2. Rock-mass parameters including water content, hydraulic potential, pneumatic potential, thermal potential, and permeability to air and water.

3. Chemical parameters including composition of formation water, composition of formation gases, carbon-14 and tritium activity, and stable isotope composition (oxygen-18), deuterium) for the purpose of age dating and environmental interpretations.

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Description

This activity is designed to provide hydrologic information in parallel with a portion of Activity 8.3.1.4.2.2.4 (geologic mapping of the exploratory shaft facility). All faults encountered in the ramps and drifts of the exploratory shaft facility (ESF) will be characterized geologically under the geologic mapping activity. Hydraulic properties of major faults encountered in the ESF will be determined in this activity. The major faults or fault zones expected to be tested are the Ghost Dance fault, a suspected fault in Drill Hole Wash, and the imbricate fault zone. Other faults will be tested if flow is observed.

This test is designed to supplement information relative to hydrologic characteristics of faults determined under Activity 8.3.1.2.2.3.3 (Solitario Canyon horizontal borehole study) and in part, under Activity 8.3.1.2.2.3.2 (site vertical borehole studies). In addition, the data collected during this activity will be used to test conceptual models of the hydrologic system and will be used in the development of a model of the unsaturated-zone hydrologic system at Yucca Mountain (Studies 8.3.1.2.2.8 and 8.3.1.2.2.9).

On the basis of the identification of major faults by the geologic mapping activity, a hydrologic testing program will be implemented. This program will consist primarily of tests conducted in boreholes drilled from drifts through fault zones and tests on core collected from the coreholes. Air permeability tests will be conducted between boreholes to determine the permeability to air of the fault zones. Some boreholes will be instrumented to determine in situ conditions of the rock mass and monitored for any changes in these conditions over time. Other sets of boreholes will be used for cross-hole water-injection tests. All water used for injection will be tagged with a tracer. Potential impacts of water-injection testing are described in Section 8.4.3. Core recovered from the holes will be tested to provide a water-content profile across the fault zone. This profile may provide information relative to any recent moisture occurrence in the fault zone.

All boreholes will be drilled using air as the drilling fluid to minimize changes in ambient moisture condition. Core will be examined on the site to obtain a preliminary determination of fracture frequency, orientation, location, and characteristics, as well as indications of fault gouge. This information will be used in conjunction with geophysical and television camera logs for selecting test intervals for air permeability and water-injection testing and for selecting monitoring intervals. The core and cutting samples will be sealed in wax or placed in air-tight canisters and transported to the surface-based field laboratories, where the moisture content of each sample will be determined. Samples will also be sent to laboratories off the site for determinating gravimetric water content, volumetric water content, grain density, porosity, bulk density, water potential, matric potential, moisture retention, saturated water and gas permeability, and relative permeability (Activity 8.3.1.2.2.3.1).

The planned natural gamma, gamma-gamma, neutron-moisture, and caliper geophysical logs will be used to assist in establishing fault zone location in the boreholes, moisture content distribution, and the condition of the borehole. Periodic temperature logs will be made in some boreholes to help determine the thermal gradient across the fault zone and to override indications of variations in flux within the fault zone.

Two types of television cameras will be used for borehole surveys. The first type views downhole just ahead of the camera and will be used to qualitatively judge the condition of the borehole for such information as wall cake (dust, cuttings) and visible moisture. The second type will be a side-view camera that will be used for establishing fracture characteristics.

Packer air-injection tests will be conducted to determine the distribution of permeability to air across the fault zones. A straddle packer system, consisting primarily of four packers, flow meters, pressure transducers, thermocouple psychrometers, and temperature sensors, will be installed at the desired test zone. The packers will then be inflated and nitrogen gas injected into or withdrawn from the central interval, while the two outer intervals are monitored for bypass of the packers. The response will be monitored for changes in pressure, temperature, relative humidity, and flow rate. Analysis of the test data will depend on flow domain boundary conditions, the type of fluid injected or withdrawn and the type of test conducted (steady state, transient, or instantaneous injection).

Cross-hole testing will be conducted using air- and water-injection. During air-injection testing straddle packers will be installed in both an injection and an observation borehole. Nitrogen gas will be injected in the one borehole and pressure changes will be monitored in the observation borehole. From the known flow rate and pressure drop between the two boreholes, the permeability to air of the fault zone will be determined. Water-injection tests will be conducted in a similar manner with tagged water being injected into one borehole and monitored for in the other borehole.

8.3.1.2.2.5 Study: Diffusion tests in the exploratory shaft facility

There is one activity in this study.

8.3.1.2.2.5.1 Activity: Diffusion tests in the exploratory shaft facility

Objectives

The objective of this activity is to determine in situ the extent to which nonsorbing tracers diffuse into the water-filled pores of the tuffs of the Topopah Spring welded unit at the main test level of the ESF. A diffusion test is also proposed in the Calico Hills unit.

Parameters

The parameter of this activity is the diffusivity coefficient.

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Description

Diffusion tests in the exploratory shaft facility are to be conducted in small- diameter boreholes drilled beyond the disturbed zone in the Topopah Spring tuff and in the drifts of the Calico Hills unit. Test results will be used to model the transport of technetium-99 and iodine-129, nonreactive radionuclides, from the repository to the water table.

This test requires the drilling of four boreholes at each test site, each of which will be drilled in an underground drift using air-drilling techniques and the smallest diameter bit available consistent with the methods to be used in the testing activities. The drilling will be done with air to avoid adding drilling water to the pores where the diffusion will occur. The depth of the hole will be approximately 10 m to penetrate beyond the zone of stress relief induced by mining the drift.

Each borehole will be surveyed using television to identify any fractures intersecting the borehole walls in the region where the tracer solution will be placed. Tracer emplacement locations will be chosen in borehole segments that are free from fractures that might result in water flow through the diffusion volume. A small amount of nonsorbing tracers will be introduced into the bottom of the borehole; appropriate methods of emplacement have yet to be identified, but will be evaluated prior to the test. Next, the borehole will be sealed with a packer of appropriate size to isolate the diffusion volume from the remainder of the underground environment. After approximately three months, the borehole will be overcored. The overcoring method has been chosen to ensure that the core recovery is adequate. The exact period of time before the overcoring will begin is contingent in part upon the results of the laboratory diffusion experiments. A year-long test will be run after all of the techniques being developed in the three-month test have been proven.

The core will be transported to an offsite laboratory for determination of tracer concentrations as a function of distance from emplacement. The data will be analyzed to derive diffusivity values. The measured tracer concentrations as a function of distance from emplacement will be analyzed in terms of the diffusion equation for solute transport through a porous geologic medium in the absence of fluid flow. The use of this equation is predicated on the absence of tracers in the tuff at the start of the experiment and on a constant tracer concentration in the source solution.

8.3.1.2.2.6 Study: Characterization of gaseous-phase movement in the unsaturated zone

The objectives of this study are (1) to describe the pre-waste emplacement gas-flow field, (2) to identify structural controls on fluid flow, (3) to determine conductive and dispersive properties of the unsaturated zone for gas flow, and (4) to model the transport of water and tracers in the gas phase. One activity is planned to collect the data required to satisfy these objectives: the gaseous-phase circulation study. The results of this activity will be important to the assessment of transport of gaseous radionuclides (e.g., carbon-14).

In the gaseous-phase circulation study, the approach is parallel to that used for hydraulic fluxes: Data will be collected near the steep western slope of Yucca Mountain to define the boundary conditions and conductive properties; a coupled model will predict the fluxes; and observations will verify and calibrate the model. Existing exsurgent and insurgent boreholes will be instrumented to relate flow to atmospheric conditions. New holes will be stemmed to isolate chambers for gas sampling and pressure measurement where the Solitario Canyon slope provides an unknown boundary condition for the repository block. In-hole, cross-hole, and transverse-site tracer tests, as well as analysis of natural and bomb-produced tracers, will be used to disclose fracture system transport properties (Table 8.3.1.2-9).

The Solitario Canyon horizontal borehole activity has been designed to augment the gaseous phase circulation study in determining the gaseous flux distribution on the western side of the repository. In this activity, two or more boreholes on the Solitario Canyon slope will be drilled to measure the discharge and gas samples will be taken to determine the boundary fluxes and potentials. Many tests of the effective air conductivity of the fractured rocks at many levels will provide model parameters for two- and three-dimensional simulations. Analysis of gas compositions will disclose effective fracture porosities by determining mean travel times, while the breakthrough curves for conservative gas tracers will indicate effective porosities and convective dispersivities for the gas phase.

The magnitude of vapor fluxes and gas transport can only be evaluated by modeling, which requires the collection of sufficient data on properties of the fractured media and appropriate boundary conditions. Numerical models will be constructed to incorporate the presence of boreholes and underground openings, as well as topographic and structural controls. The flow field will depend upon the definition of the transient atmospheric boundary conditions, together with geothermal-drive mechanisms, and upon a spatial definition of conductive, sorative, and dispersive properties of the unsaturated zone.

8.3.1.2.2.6.1 Activity: Gaseous-phase circulation study

Objectives

The objectives of this activity are

1. To describe and model the pre-waste-emplacement gas-flow field and its effect on net water-vapor transport from the unsaturated zone by modeling the western portions of Yucca Mountain as a two-dimensional and/or three-dimensional boundary problem in compressible nonisothermal flow.

2. To provide the parameters necessary for modeling gas flow from and to the repository and the potential transport of radionuclides as well as the gaseous flux of moisture affecting deep percolation after the repository is in place.

Table 8.3.1.2-9. Summary of gas-phase tests (page 1 of 3)

Hole or site	Test	Objectives	Methods
USW UZ-6, -6s (open holes)	Flow distribution in each open hole	Relate flux to atmospheric boundary conditions	Regression analysis
	Flow tests to each sampling chamber	Evaluate effective gas conductivity and storativity	Analytical solutions and 3-D modeling
	Relative humidity of discharging air	Determine moisture flux with time	Gas sampling and analysis
	Natural tracer tests	Determine ages of gases discharged, age of water evaporated Determine dispersivities	Composition of gases discharging at various depths: SF_6, $CBrCl_2F$ for drilling-air contamination, CCl_2F_2, CCl_3F, and ratios of 14 CO_2 to CO_2, tritiated water to H_2O, and ^{18}O to ^{16}O, (sample bimonthly for age determinations).
	Flux distribution	Determine preferential flow paths; site subsequent test	Measure flux distribution (quality assurance) over boundary surface.

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Table 8.3.1.2-9. Summary of gas-phase tests (page 2 of 3)

Hole or site	Test	Objectives	Methods
Solitario Canyon hole (vertical in Topopah Spring) and Solitario Canyon hole (horizontal in Tiva Canyon)	Shallow formation moisture contents	Determine seasonal effects of convective air flow on moisture contents	Measure saturation of sample gases from various depths
	Boundary conductivity	Determine fracture conductivity near (disturbed) surface	Pressure-transducers set in isolated chamgers in holes; rates to open/chambered holes; validate models
	Structural controls	Determine if faults and non-welded strata are air-conductive or barriers	
	Geothermal test	Provide thermal parameters for compressible flow modeling	Measure temperature distribution, test conducted by J.Sass (GPP-02, 05)
UZ-6 borehole complex and UZ-9 borehole complex	Packer injection/interference/nonsteady flow tests	Determine anisotropic air conductivities, storativity for all unsaturated-zone units, parameters needed for all unsaturated-zone units, parameters needed for all large-scale modeling; validate models	Use 3-m injection intervals in each hole, simultaneously measuring gas pressure in array of chambers of adjacent holes, apply the analysis for anisotropic fracture permeability from Hsieh, et al. (1985)

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Table 8.3.1.2-9. Summary of gas-phase tests (page 3 of 3)

Hole or site	Test	Objectives	Methods
UZ-6 borehole complex and UZ-9 borehole complex (continued)	Dispersivity tests	Determine fracture system air dispersivities as function of gradient direction and anisotropy. Parameters needed for large-scale modeling. Validate dispersivity model.	Injection nonsorbed gas tracers in interval, observe breakthrough at array of chambers in adjacent holes. Analyze according to method of Kreamer (1982).

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3. To reconstruct the air circulation history at instrumented boreholes from the time of drilling until stemmed and instrumented in order to estimate the time required for poststemming recovery of ambient gas and moisture conditions as an aid in interpreting gas composition and thermocouple psychrometer data.

4. To determine, by flow and pressure measurements in single holes, and by cross-hole interference tests, the near-field air conductivities, storativity, and anisotropy of the unit above the repository horizon.

5. To determine effective porosities and dispersivities of the fracture system by the interpretation of natural and artificial gas tracer data as an aid in the modeling described in items 1 and 2.

Parameters

The parameters of this activity are

1. Moisture content.
2. Gas composition.
3. Air temperature.
4. Gas potential distribution.
5. Flux.
6. Fracture conductivity and anisotropy.
7. Fault conductivity.
8. Structural controls.
9. Effective porosity.
10. Convective dispersity.

Description

Atmospheric conditions will be characterized during the entire period of gas-flow measurement by using the site meteorological network (Activity 8.3.1.2.1.1.1) to determine and interpolate to drillhole sites of concern, the air temperature, barometric pressure, and relative humidity as a function of time and seasons. Atmospheric samples will also be collected. Their compositions will be analyzed using the same method used for borehole gas samples, described in the following paragraph.

Two existing open wells (USW UZ-6, USW UZ-6s) will be instrumented with recording hot-wire anemometer flow meters (Figure 8.3.1.2-16). The flow will be measured for extended periods of time under open-hole conditions and for partial shut-in conditions. These flow rates will be related to barometric pressure changes and air temperature by regression analysis. All the topographically affected wells along the crest of Yucca Mountain will also be periodically shut in and the pressure difference between the wells and atmosphere will be measured. In turn, each well will be opened, and the pressures will be measured in all surrounding wells to conduct interference tests. The results will be analyzed to determine the horizontal and vertical permeability to air; the air-filled fracture porosity conventional temperature logging tool will be used, whereas the device for flow logging remains undetermined. Gas samples will be obtained in open holes by lowering tubing downhole to various depths. The samples will be collected in syringes and

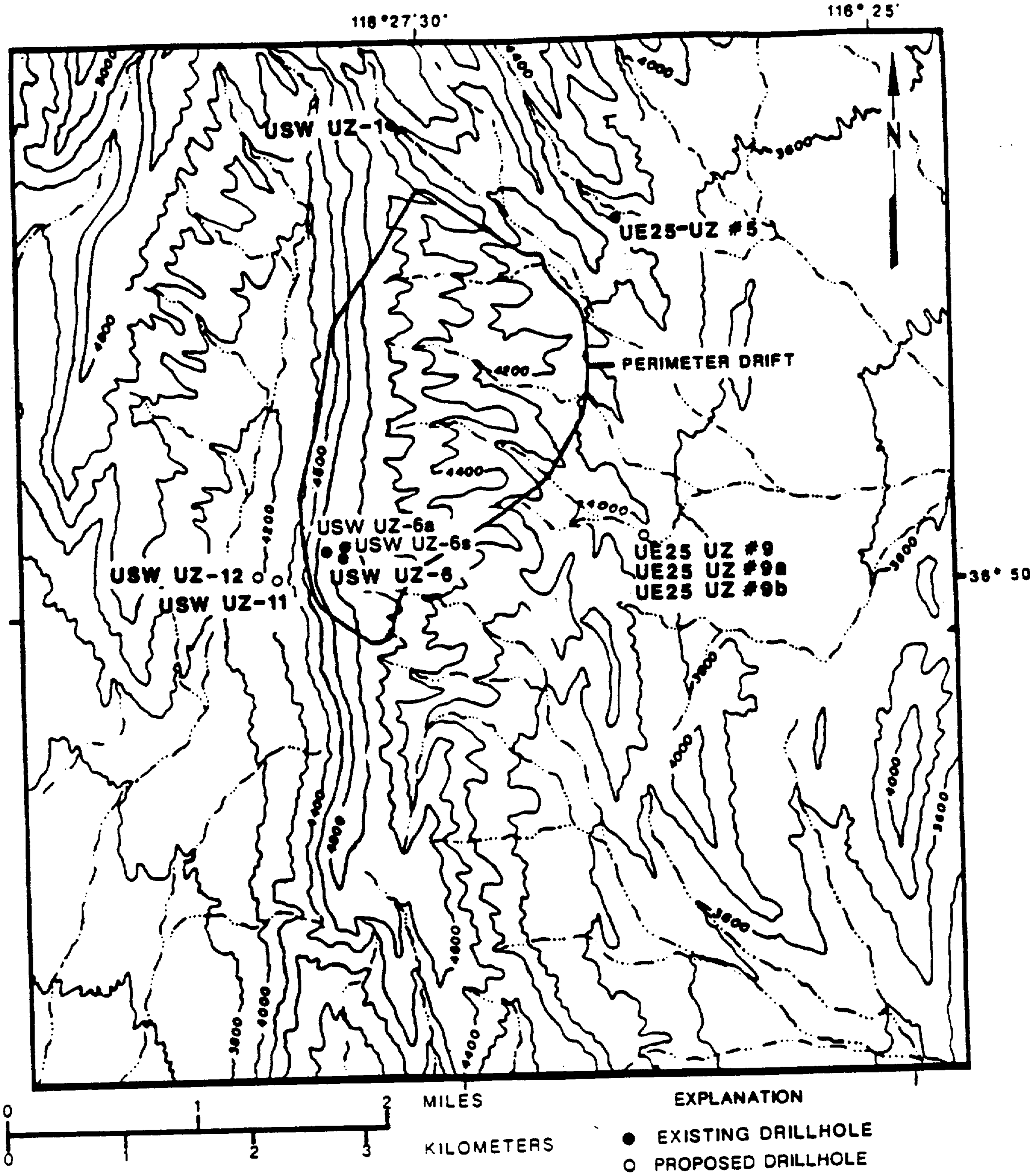

Figure 8.3.1.2-16. Gaseous-phase sampling locations.

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analyzed on site for relative humidity and by gas chromatography to determine the percentage composition of carbon dioxide (CO_2), methane (CH_4), SF_6, $CBrCl_2F$(BCF), CCl_2F_2(F-12), and CCl_3F(F-11). Both CO_2 and methane may serve as natural tracers that indicate fracture zones of strong circulation, information that can be used to estimate the total volume of gas flow in individual zones within the total section tapped by the borehole. Such information is needed to estimate the time for ambient conditions to be recovered at different depths. SF_6 and BCF were added to the air during the drilling of USW UZ-6 and USW UZ-6s, respectively, and their presence and concentration will indicate the extent to which drilling air has been purged from the hole and surrounding rock by convective air flow. F-11 and F-12 behave as long-term man-made tracers that can give additional information on gas transport at the site. If the flux is slow, the long-term tracer tritium may be included in subsequent work. The logging will be conducted every two months until the holes are stemmed.

Fluorocarbon concentrations arising from diffusion transport alone through the unsaturated zone have been attenuated several-fold at a depth of about 50 m based on measurements made in the High Plains of Texas. Hence, near-atmospheric concentrations of F-11 and F-12 at depth would be indicative of convective gaseous-phase transport.

Gas composition data for USW UZ-1 suggest that natural conditions within the borehole require at least 2.5 yr after the hole was stemmed to approach equilibrium with the surrounding rocks. Modeling of open borehole flow will allow evaluation of the length of time required for the moisture content and gas composition for various zones to reequilibrate to ambient conditions once stemming is complete.

At some time subsequent to the stemming of holes USW UZ-6 and USW UZ-6s, two holes (USW UZ-11 and USW UZ-12) will be drilled on either side of the Solitario Canyon fault. Also, a near-horizontal hole will be drilled into the Tiva Canyon welded unit or Topopah Spring welded unit above or below the nonwelded or bedded Paintbrush Tuff. Moisture content and pore-gas relative humidity, as inferred from the Kelvin equation, will be determined on cores and cuttings, and the holes will be instrumented to measure temperature, moisture tension, and pore-gas relative humidity and will be equipped for periodic gas sampling. Gas compositions in all three holes will be determined from periodically collected samples. Although gas-flow conditions will be altered by stemming holes USW UZ-6 and USW UZ-6, the data collected during this study will be invaluable in interpreting and modeling the temperature, relative humidity, and gas composition data collected during those studies, particularly in regard to seasonal variations in near-surface moisture content and trace gas composition. These moisture and trace-gas seasonal changes may provide insight on the magnitude of gas circulation under natural conditions.

In winter, gas tracer tests may be performed by shallow burial of permeation tubes at various horizons along the western scarp of Yucca Mountain. The trace gases will be sampled in the air stream blowing from the summit wells. The interpretation of tracer tests in the light of structural controls, fracture geometry, and breakthrough concentrations will require numerical modeling. These measurements will provide a large-scale test of dispersivity to gas flow and will provide much useful information for the gas-

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tracer tests planned in the UE-25 UZ#9 hole cluster, as described in the following paragraph.

Effective fracture porosity and dispersivity will be obtained by tracer tests conducted between adjacent boreholes, in the unsaturated portions of UE-25 UZ#9, UE-25 UZ#9a, and UE-25 UZ#9b. Unsaturated-zone tracer testing in the cluster is expected to require about 60 days, based on solely diffusive transport and conservative estimates of tortuosity to that transport. While injecting a conservative tracer in one packed-off interval, adjacent boreholes, segmented by packer strings and tapped by sampling tubes, can be sampled to obtain breakthrough curves. Each hydrostratigraphic unit can be characterized by applying distinctly different tracers at several injection intervals, sampling at fixed packer intervals in the adjacent holes. These data could augment "huff-and-puff" tracer tests conducted routinely in connection with each packer air injection test of the exploratory shaft test plan, which would measure, on a small scale, the fracture-system dispersivities.

Gas-phase modeling will be used to interpret the results of observations made during this study, and to extrapolate those results to interpret gas circulation in Yucca Mountain under natural conditions. A two-dimensional model in vertical section normal to the slope will be developed to interpret the measured gas potentials and fluxes in terms of the temperature distribution, moisture contents and structural and stratigraphic controls. Three-dimensional modeling may be needed to incorporate borehole configurations. Average conductivities, porosities, and dispersivities for distinct units are expected results of this modeling. These results will be useful in evaluating water vapor and gaseous radionuclide transport from Yucca Mountain once the repository is in place. Preliminary modeling will be conducted using the HST code (Kipp, 1986).

Structural controls on the gas flow may be recognized by analysis of the flux distribution. Fault zones may be strong conduits for parallel flow and strong barriers to cross flow. Fine nonwelded beds, as exist in the Pah Canyon Tuff, may impede circulation in the mountain, or completely compartment the terrain. Models, substantiated by borehole tests of the degree of saturation at inlet and outlet regions during each season, provide a point of departure for computing ground-water depletion, believed to be a dominant flux component in the unsaturated zone, especially during interpluvial ages. Likewise, the models will provide a basis for estimating gaseous radionuclide transport and moisture migration due to the gas circulation as enhanced by the repository heat load.

If these gas-phase investigations indicate that movement of moisture, gas, or both in the unsaturated zone is potentially significant, either in reducing the potential for deep percolation through the repository or in discharging gases to the atmosphere, additional open-borehole studies may be needed at other locations on Yucca Mountain.

8.3.1.2.2.7 Study: Hydrochemical characterization of the unsaturated zone

The objectives of this study are to (1) understand the gas transport mechanism, direction, flux and travel time within the unsaturated zone; (2) design and implement methods for extracting pore fluids from the tuff; (3) provide independent evidence of flow direction, flux, and travel time of water in the unsaturated zone; (4) determine the extent of the water-rock interaction, and (5) model geochemical evolution of ground water in the unsaturated zone. Two activities are planned to collect the data required to satisfy these objectives.

8.3.1.2.2.7.1 Activity: Gaseous-phase chemical investigations

Objectives

The objective of this activity is to understand the gas transport mechanism, and provide evidence of gas flow direction, flux, and travel time within the unsaturated zone.

Parameters

The parameters of this activity are

1. Gas composition.
2. Carbon-isotope concentration (in CO_2 gas).
3. Hydrogen and oxygen isotopes (in water vapor).

Description

Carbon dioxide and water-vapor samples will be collected from unsaturated zone holes after the holes have been packed and instrumented (Figure 8.3.1.2-17). Gas samples will be checked for contamination caused by air coring (using SF_6 or a similar conservative gas tracer). Samples to be used for composition analysis will be drawn by peristaltic pumping, collected inglass or stainless-steel collection cylinders, and analyzed by gas chromatography. The carbon dioxide gas will be collected by a molecular sieve in stainless steel collection cylinders and analyzed for carbon-14 and carbon-13 to carbon-12 ratio. Water vapor will be collected in the cold trap by pumping the gas through the cold trap and analyzed for tritium and oxygen-13 to oxygen-16 ratio.

The age of the unsaturated zone gases will be determined from the ratio of carbon-14 and carbon-13 to carbon-12 isotope data. Stable isotope ratios (oxygen-18 to oxygen-16 and deuterium to hydrogen), which can indicate the climatic and evaporative history of moisture, will be used to determine the time of recharge and flow path of the moisture. This information, combined with other moisture data, will be used to interpret the patterns of gas transport.

Data from this activity will be combined with data from the unsaturated zone gaseous-phase circulation study (Activity 8.3.1.2.2.6.1), and data collected from the unsaturated zone just above the water table, as described

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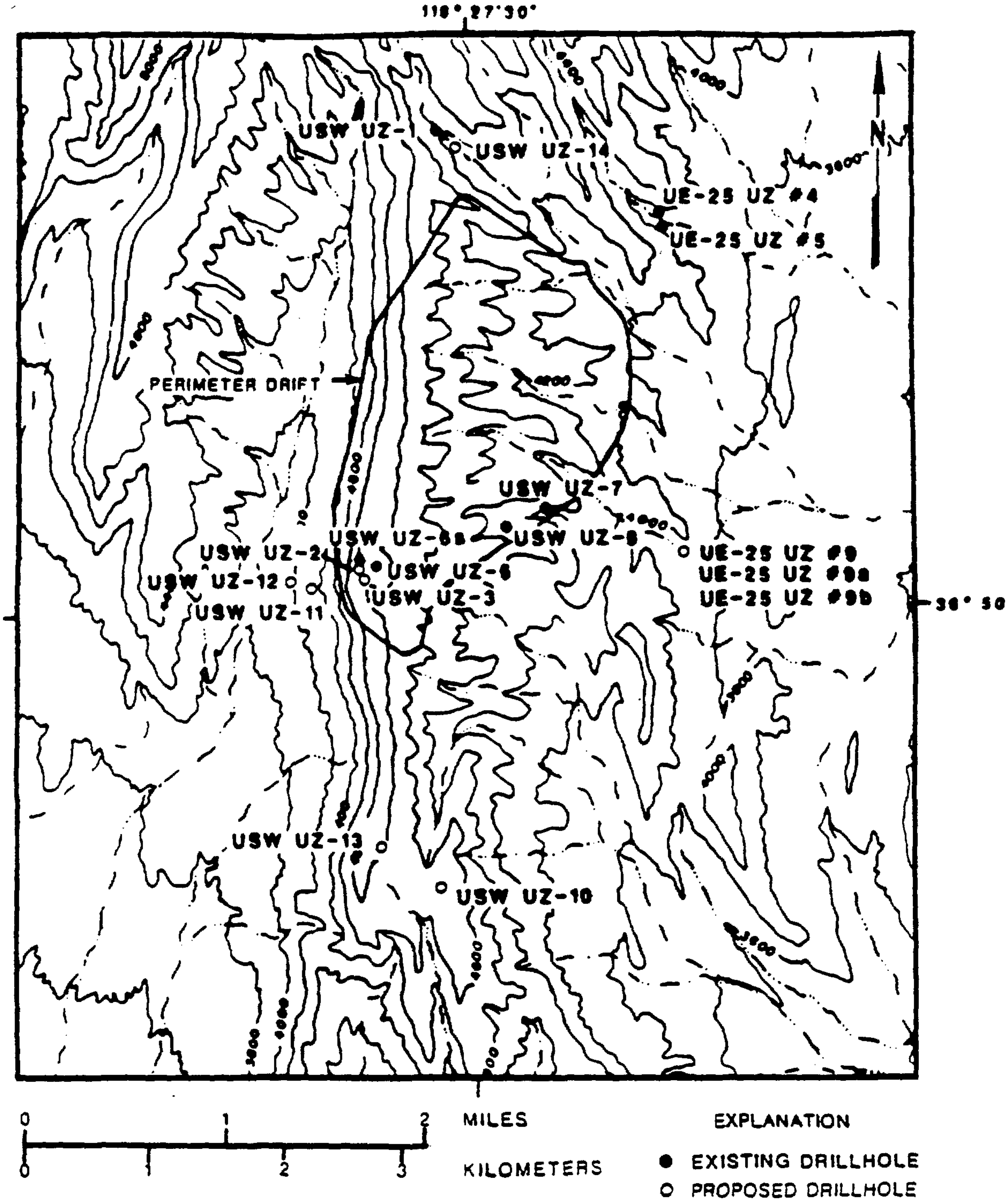

Figure 8.3.1.2-17. Gaseous and liquid-phase chemical sampling locations

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in Activity 8.3.1.2.3.2.2 (hydrochemical characterization of water in the upper part of the saturated zone) in an assessment of the Yucca Mountain gas flow processes.

8.3.1.2.2.7.2 Activity: Aqueous-phase chemical investigations

Objectives

The objectives of this activity are

1. To design and implement methods for extracting pore fluids from unsaturated zone tuff units.

2. To provide evidence of flow direction, flux, and travel time of water in the unsaturated zone.

3. To determine the extent of the water-rock interaction and to model geochemical evolution of ground water in the unsaturated zone.

Parameters

The parameters of this activity are

1. Water quality (cations, anions).
2. Flow paths (oxygen-18-oxygen-16, deuterium-hydrogen).
3. Travel times (hydrogen-3, carbon-14, chlorine-36).

Description

Pore fluids from the rock matrix and near fractures will be extracted from unsaturated zone drill cores for chemical and isotope analyses (Figure 8.3.1.2-20. Samples will also be checked for the presence of various tracers that will be used during the drilling of wells and the construction of the exploratory shaft. The fluids will be extracted by applying pressure, centrifuging, or vacuum distillation depending on the moisture content and core condition. These techniques will be evaluated during prototype testing.

Pore fluids from core samples of matrix with moisture contents greater than 11 percent will be extracted using the triaxial press method (below 11 percent, neither triaxial press nor centrifuge methods will extract any water). This method consists of placing the core in a triaxial confinement chamber and applying axial and confining pressure in step increases. The water chemistry at each pressure step will be determined. The changes in water chemistry as a function of pressure will be analyzed and the maximum pressure at which no significant water chemistry changes occur will be adopted for the future pressure limits.

Fracture fluids are expected to permeate the surrounding matrix. Where fractures occur in core samples, the rock matrix around the fracture will be segregated. Fluids from this matrix with moisture contents greater than 11 percent will be extracted using the centrifuge methods. This method consists of placing core samples in a centrifuge cup and spinning them for

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2 h, with the fluids draining through a perforated plate into a collection cup. Fracture fluids may also be available from perched water zones in the exploratory shaft.

Fluids from samples with moisture contents less than 11 percent (including samples that have been squeezed and centrifuged) will be extracted using the vacuum distillation method. This method consists of placing the core sample inside a glass container that is in an evacuated system, and heating it to 100°C to drive off the moisture. The moisture will then be collected in an alcohol-dry ice trap. This vacuum distillation method will yield distilled water, and therefore can only be used for tritium, oxygen, and hydrogen isotope analyses.

Cation concentrations will be determined by using inductively coupled plasma (ICP) and anion concentrations will be determined by ion chromatography. Stable isotope ratios will be analyzed by mass spectrometry. Low-level gas counters or liquid scintillation counters will be used to determine tritium activity. Large carbon-14 samples will be analyzed using conventional gas-counting methods, with small carbon-14 and chlorine-36 samples analyzed by tandem acceleration mass spectrometry. All water samples will be analyzed for the presence of gas and water tracers using gas chromatography-mass spectrometry (GCMS).

Apparent ages of water in the unsaturated zone will be determined from isotope data (carbon-14, tritium, and chlorine-36). Chemical analyses (cations and anions) will be used to verify flow paths indicated by isotope data and to indicate the extent of water-rock interaction. Chemical and isotope data for pore water and fracture-related water will indicate travel times, since lower chemical concentrations and the presence of tritium will indicate younger water.

Pore water in the unsaturated zone may originate from above as downward percolating water or it may originate from below as water remaining from a previous period of saturation when the water table would have been higher. These alternative concepts will be tested in part by applying, in combination, the following hydrochemical criteria:

1. Age of pore water. If pore water is derived from above, its age would generally be expected to increase with depth. Pore water derived from below would generally be expected to have similar ages throughout the stratigraphic section.

2. Composition of fluid inclusions along fracture planes. During the crystallization of minerals or during recrystallization following fracturing, small amounts of water may become trapped within mineral grains. The isotopic and chemical composition of the fluid can indicate water sources and the temperature at which the minerals precipitated. For example, in general, higher temperature would indicate an origin from below.

3. General water chemistry. Chemical composition, including trace elements and anion-cation distribution, may provide supporting evidence of the water's origin by, for example, providing signatures of distinctive water types.

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4. Stable isotope compositions. The oxygen-18 to oxygen-16 and deuterium to hydrogen ratios of pore waters generally would be expected to vary with depth if pore water is derived from above. Pore water derived from below generally would be expected to have similar ratios throughout the section.

Data from this activity will be integrated with and used by Study 8.3.1.3.1.1 in its development of a ground-water chemistry model. Furthermore, Section 8.3.4.2.4 (Activity 1.10.4.1.3) will also integrate with and use these data as it characterizes the unsaturated zone water to determine the water composition of the waste package environment.

8.3.1.2.2.8 Study: Fluid flow in unsaturated, fractured rock

The purpose of this study is to develop and refine conceptual and numerical models describing both gas flow as well as liquid water and solute movement in unsaturated, fractured rock. The primary function of these models will be to help design and interpret hydrologic and pneumatic tests, and to provide information about model parameters that can be incorporated into site-scale models (Study 8.3.1.2.2.9). As such, the models to be developed in this study are intended for application primarily at both the laboratory and sub-REV (representative elementary volume) scales. The REV for a given parameter is that volume of rock at which the model parameter becomes relatively invariant with further increases in scale. At the scale of the REV, the true medium can be replaced conceptually with an equivalent porous medium whose behavior is described by that parameter. By definition, the real and fictitious media exhibit sufficiently similar behavior at that scale with regard to the process in question.

The validity of conceptual and numerical models describing fluid and solute movement in fractured, porous rock will be assessed through experiments conducted at various scales in both the exploratory shaft facility (ESF) and in the laboratory. In addition, different modeling approaches that consider different scales and different levels of complexity will be compared to determine the adequacy of more simplified modeling approaches. In particular, the limitations of treating the fractured rock mass as a composite, homogeneous continuum will be evaluated.

The activities associated with this study also will directly address regulatory issues that concern flow path characterization and determination of ground-water fluxes and travel times within the unsaturated zone. The activities planned for this study include (1) conceptualization and numerical modeling of the unsaturated-zone hydrogeologic system at the sub-REV scale and (2) comparison of the more detailed modeling approaches with experiments to be conducted within the laboratory and in the ESF.

8.3.1.2.2.8.1 Activity: Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock

Objectives

The objective of this activity is to develop detailed conceptual and numerical models of fluid flow and transport within unsaturated, fractured rock at Yucca Mountain. These models will be applied to volumes of fractured rock at or below the dimensions at which the rock can be replaced conceptually by an equivalent porous medium. Models that consider the system in greater detail or complexity will provide a synthetic data base against which the simulated results of more simplified modeling approaches applied at larger scales can be compared.

Parameters

The parameters for this activity are

1. Fluid and solute fluxes through variably-saturated, fractured rock.

2. Description of the scale dependence of pneumatic, hydrologic and transport parameters.

Description

Conceptual and numerical models that consider fluid flow and transport in fractured rock at various spatial scales and levels of detail will be developed to examine the appropriateness of applying different models at different scales. Sub-REV (representative elementary volume) modeling efforts will support site-scale modeling (Study 8.3.1.2.2.9) by providing information about model parameters appropriate to the larger scale. Sub-REV modeling will examine the implications of spatial heterogeneity within the smallest volume considered as homogeneous within the site-scale model. For instance, sub-REV scale modeling will address the manner in which point measurements of state variables, obtained during monitoring, may be related to volume-averaged values predicted by model simulations performed at the site scale.

The effect of spatial scale on pneumatic, hydrologic, and transport parameters for single fractures and for fracture networks will be evaluated, as will the appropriateness of replacing a fractured rock mass with a stochastic continuum. Detailed modeling approaches that consider fractures as discrete entities, or models that treat the fractured rock mass as a stochastic continuum, will be used to determine the adequacy of simplified modeling approaches that treat the fracture and matrix domains as a composite, homogeneous continuum.

The conceptual model will consider the microscopic processes that influence fluid flow and solute transport both within single fractures with spatially varying aperture, and within networks containing fractures with statistically distributed hydraulic apertures. Those aspects of fluid flow and transport to be evaluated include (1) fluid flow and transport through variably saturated, rough fractures; (2) fluid flow and transport through a network of variably-saturated fractures; (3) fluid and tracer exchange

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between fractures and matrix; (4) small-scale capillary barrier effects between fractures and matrix and among fractures; and (5) gas-phase movement through fractured rock, in volumes of rock at and below the scale of the REV.

8.3.1.2.2.8.2 Activity: Validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock

Objectives

The objective of this activity is to evaluate the reasonableness of the concepts on which the models developed under Activity 8.3.1.2.2.8.1 are based, by using the results of laboratory tests and tests performed in the exploratory shaft facility (ESF) to access the adequacy of model performance.

Parameters

The parameter for this activity is the validity of conceptual and numerical models describing fluid flow and transport in variably saturated, fractured rock.

Description

Hypotheses that describe fluid flow and transport processes in fractured rock are preliminary in nature and will require validation through field and laboratory testing, as described in Study 8.3.1.2.2.4. The process of model validation is intended to ensure that the model can adequately describe the system to which it is being applied. As discussed in the previous activity (8.3.1.2.2.8.1), the reasonableness of a modeling approach can often be evaluated by comparing simulated results from the model with those of a more detailed, and presumably more accurate and realistic model. The limitations of a simpler model can often be exposed in this manner. However, those models determined to be compatible and internally consistent must still be tested by devising experiments that isolate and test individual components in each model. This ensures that these components adequately describe the physical processes at the temporal and spatial scales at which the model application is to be made. By comparing measured and simulated results, a determination is then made as to whether or not the model appears to be adequate for its intended application. In the context of waste repository licensing, "adequacy" may mean simply that the model is accurate enough that a clear-cut decision may be made concerning whether the proposed facility would satisfy the regulatory requirements.

The need to isolate and test the individual components of the overall model provides the rationale for conducting a series of hydrologic tests in both the laboratory and exploratory shaft facility that consider progressively increasing spatial scales. The intact-fracture test (Activity 8.3.1.2.2.4.1) will test models that predict the unsaturated hydraulic characteristics of single fractures based on measurable geometric parameters, such as aperture distribution. This test will also attempt to establish statistical relationships between fracture parameters and to estimate confidence intervals for model predictions by regressing data measured on model-predicted results.

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The numerical and conceptual models examined with the intact-fracture test will be used to provide independent estimates of the hydraulic properties associated with each fracture identified in the percolation test block (Activity 8.3.1.2.2.4.2). The confidence intervals associated with these model predictions provide the limits within which estimates of the hydrologic characteristics for individual fractures may be changed when attempting to match measured fluid and solute fluxes from the percolation test block with simulated results. Statistical relationships established between fracture parameters in the intact-fracture test may also provide additional constraints when assigning fracture hydrologic characteristics to individual fractures in model simulations of the percolation test in the ESF (Activity 8.3.1.2.2.4.2).

The percolation test in the ESF itself will provide an opportunity to compare simulated results with physical measurements of fluid and solute fluxes in variably saturated, fractured rock under conditions in which the boundary conditions and flow-system geometry are reasonably well known. In particular, the percolation test in the ESF will be used to determine the ability of various fracture network or stochastic modeling approaches to estimate the bulk effective parameters of an unsaturated, fractured rock mass. The parameters to be estimated include effective bulk-rock conductivity, effective porosity and dispersivity, each as a function of the overall saturation or average matric potential of the rock mass.

The bulk-permeability test (Activity 8.3.1.2.2.4.3) will employ cross-hole, air-permeability testing methods to determine the scale at which the host rock behaves as an equivalent anisotropic, porous medium, and to determine the directional permeabilities at that scale. The measured dimensions at which porous media behavior is observed and the associated directional permeabilities will be compared against a distribution of simulated results. These results are calculated by assuming various system geometries compatible with available observations. This approach is necessary because the actual distribution of high-permeability conduits in such a large rock volume is not expected to be known except in a statistical sense, for example, in terms of average fracture orientations and/or fracture density.

8.3.1.2.2.9 Study: Site unsaturated-zone modeling and synthesis

The purpose and activities of this study are to (1) develop appropriate conceptual models for the site unsaturated-zone hydrogeologic system; (2) select, modify, or develop numerical hydrologic models capable of simulating the hydrogeologic system and its component subsystems; (3) apply the models to predict the system response to changing external and internal conditions; (4) evaluate the accuracy of the models using stochastic modeling, conventional statistical analyses, and sensitivity analyses; and (5) integrate data and analyses to synthesize a comprehensive qualitative and quantitative description of the site unsaturated-zone hydrogeologic system under present as well as probable, or possible, future conditions. The ultimate goal of this synthesis is to address those information needs for the overall unsaturated-zone hydrogeologic system that pertain to demonstrating site compliance, or noncompliance, with the regulatory criteria and

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guidelines for the long-term storage of high-level nuclear waste in a mined geologic repository in the unsaturated zone at Yucca Mountain.

8.3.1.2.2.9.1 Activity: Conceptualization of the unsaturated-zone hydrogeologic system

Objectives

The objectives of this activity are to develop conceptual models for the overall moisture flow system within the unsaturated zone at Yucca Mountain. The conceptual models of the system and component subsystems constitute the basis both for the hydrologic testing program at the site and for numerical hydrologic modeling of the site. Conceptual-model development is an ongoing, iterative process by which hypotheses and alternative hypotheses are tested using laboratory experiments, field experiments, and numerical modeling. Hypotheses may be accepted, rejected, revised, or refined. The goal is to develop an internally consistent set of hypotheses that describe those aspects of the site hydrogeologic system that are needed to assess the capability of the site to isolate nuclear waste for a period of 10,000 yr or longer.

Parameters

The parameters of this activity are

1. Model elements that include the
   a. Geologic frame work of the system.
   b. Boundary and initial conditions for the system.
   c. Hydrologic and other related physical processes that operate within the system under the constraints imposed by the geologic framework and the boundary and initial conditions.
2. Sets of hypotheses that
   a. Describe and quantify the model elements.
   b. Are compatible with the available empirical data for the system.
   c. Are as simple as possible with respect to the system's known complexity and data.
   d. Are mutually consistent.

More than one set of hypotheses may satisfy the above requirements but differ in that one or more hypotheses of one set may conflict with hypotheses in the other sets. Such an occurrence of competing hypotheses gives rise to the notion of alternative conceptual models and the possible need to perform tests or experiments to eliminate nonviable hypotheses.

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Description

Conceptual models for natural hydrogeologic systems are discussed in general terms in Section 3.9 and are particularized to the Yucca Mountain site in Section 3.9.3. The conceptual model of a system consists of a set of elements that describe the geologic framework for the system, delimit the hydrologic boundary conditions acting on the system, and identify the hydrologic and other related physical processes (e.g., moisture flow, heat flow, tectonic stresses, etc.) operating within the system. The internal system processes operating under the constraints imposed by the geologic framework and the boundary conditions determine the instantaneous state of the system. Because the model elements, in general, tend to change with time, the state of the system also tends to change with time. Consequently, the conceptual model must address the issue of system dynamics and response.

The state of an unsaturated-zone hydrogeologic system is defined, for example, by the spatial distributions of matric potential, liquid-water saturation, pore-gas pressure, temperature, and tectonic stress. The processes operating within the system, together with time-varying internal or external constraints, may cause any one or more of these state variables to change and, in turn, to alter the state of the system. The conceptual model for the system seeks to identify and quantify those principal relations between system processes and constraints that control the state of the system and, thus, that govern the performance of the system. In the present context, those elements of system performance that relate to the isolation of high-level nuclear waste are of principal concern, and thus the conceptualization of the system must be directed toward these elements.

In general, the conceptual model of a system consists of a set of empirical data obtained from the system together with sets of hypotheses corresponding to each of the model elements for the system. A viable conceptual model requires that the hypotheses fit the available data, be as simple as is compatible with the data and known system complexity, and be mutually consistent. The sets of possible hypotheses satisfying these conditions need not be unique, and the occurrence of conflicting or competing hypotheses gives rise to the notion of alternative conceptual models.

If competing hypotheses are shown to affect important aspects of system performance, then tests must be devised to select from the competing hypotheses the one hypothesis that best applies to the system. Because complete knowledge of a macroscopic system and its governing processes and constraints is not attainable, formulating a conceptual model includes attempting to develop the simplest set of mutually consistent hypotheses that accounts for the essential aspects of system performance.

Even if no ostensible internal conflicts exist, a conceptual model is by no means a fixed entity. The acquisition of new or improved data from laboratory or field measurements and tests, the results of numerical experiments, and the reconceptualization of model elements (for example, during peer review) may require that the conceptual model be revised with the addition of new hypotheses and the elimination or revision of previously accepted hypotheses. The development of a conceptual model, therefore, must be regarded as an evolving, frequently iterative process. In general, each hypothesis must be regarded as tentative and subject to continual examination

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and testing. Many of the field and laboratory experiments and tests of the site characterization program are directed at examining the validity of hypotheses and at quantifying tenable hypotheses.

Independent peer review will be an important aspect of conceptual-model development. Peer review will be used to examine the completeness and the consistency of the conceptual-model hypotheses, and to ensure that the physics and mathematics of process hypotheses are formulated correctly. Changes in the conceptual model also should be subjected to appropriate peer review to ensure that the changes are both necessary and sufficient with respect to obtaining a correct conceptual representation of the hydrogeologic system.

The hypotheses that constitute the current but provisional conceptual model for the site unsaturated-zone hydrogeologic system are listed in Table 8.3.1.2-2b together with viable alternative hypotheses and an assessment of their uncertainty and significance.

8.3.1.2.2.9.2 Activity: Selection, development, and testing of hydrologic-modeling computer codes

Objectives

The objectives of this activity are twofold: (1) to select, evaluate, and adapt existing numerical hydrologic-modeling codes for application to the site unsaturated-zone hydrogeologic system and (2) to modify existing codes or develop new codes, as needed, to simulate particular problems or aspects that are unique to the Yucca Mountain system. Code modification and development will require the additional activities of testing (e.g., code verification) and documentation.

Parameters

The parameters of this activity consist of the attributes of the numerical hydrologic computer codes that are selected or developed:

1. Code geometry: One-, two-, or three-dimensional.

2. Discretization method: Finite-differences, finite-element, or integrated finite-difference.

3. Boundary conditions: Dirichlet, Neumann, mixed, evaporate, seepage-face, evapotranspiration, etc.

4. Hydrologic and coupled processes: Variably saturated liquid-water flow, gas-phase flow, water-vapor concentration and transport, heat flow, solute transport, chemical kinetics, stress-field dynamics, two-phase flow in fractures, etc.

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5. Solution methodology: Picard iteration or Newton-Raphson linearization.

6. Matrix solver: Direct or iterative.

Description

Various available computer codes are capable of performing mathematical simulations of complex multiphase, variably saturated hydrogeologic systems. These codes differ, however, in terms of (1) the physical processes they include, (2) the types of boundary conditions they allow, (3) the numerical procedures they invoke, (4) the efficiency with which they perform the various numerical and logical operations, (5) the dimensionality and geometry of the systems they can represent, (6) the computer resources they require, and (7) the ease with which they can be implemented and adapted to solve particular modeling problems. The codes under consideration here provide the physical and mathematical foundation for the construction of predictive numerical models for hydrogeologic systems. The selection of any one or more codes depends upon the problem being solved; the degree of accuracy desired; the possible limitations of available computer resources and funding; and, finally, the degree of approximation to which the physical processes and mathematical procedures embodied in the code represent the elements of the conceptual model of the system.

None of the available codes is expected to be capable of solving all the problems expected with respect to the site unsaturated-zone hydrogeologic system. Consequently, existing codes will require some modification, and new codes will need to be developed, especially for those problems unique to the Yucca Mountain site. For example, Study 8.3.1.2.2.8 is devoted both to understanding the physics of fluid flow and solute transport in partially saturated fractures that transect variably saturated tuff and to developing appropriate quantitative models and codes to simulate fluid-flow processes in variably saturated fractures and fracture networks.

Even though the application of existing documented and verified codes to some specific Yucca Mountain problems may be straightforward, code modification and code development will require that both the new and modified codes be thoroughly tested and documented before their application to site problems. Code testing will include code verification, which demonstrates that the code performs all of the mathematical and logical procedures correctly, as well as testing to demonstrate that the code is indeed applicable to the types of problems for which it is intended. Code verification will be performed by comparing the results produced by the code for a particular problem against existing known analytic or numerical solutions for the problem. Empirical testing of the model will be performed by comparing model results against data obtained from laboratory or field experiments that are analogs to the intended application of the code.

Complete documentation of the new or modified codes will include a description of the physical and mathematical basis of the code, instructions and requirements for implementing the code, and the results of at least some selected set of verification and empirical-testing exercises performed on the code (Silling, 1982). Both the documentation and the code will be subject to thorough independent peer review before any application of the code to

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develop a model or models for the Yucca Mountain system or any relevant subsystem.

8.3.1.2.2.9.3 Activity: Simulation of the natural hydrogeologic system

Objectives

The objectives of this activity are to construct appropriate hydrologic models for the natural site hydrogeologic system to (1) simulate and investgate the present existing state of the system, and (2) predict probable future and past states of the system under changes in the environmental conditions.

Parameters

The parameters of this activity are

1. Time-dependent spatial distributions of matric potential, liquid-water, saturation, pore-gas pressure, water-vapor concentration, moisture flux, and temperature.

2. Boundary fluxes, pressures, and potentials.

3. Hydrologic and thermomechanical properties for the component hydrogeologic units.

Description

A numerical hydrologic model or combination of models will be constructed to simulate mathematically the coupled, simultaneous flow of moisture, gas, and heat within the unsaturated zone underlying the primary repository area. The construction of these flow models follows directly as a continuation and an expansion of the conceptual model development for the site hydrogeologic system (Activity 8.3.1.2.2.9.1). The basic purpose of this modeling activity is to continue but enlarge that scope of identifying and testing the hydrologic conditions, concepts, and processes that control the site hydrogeologic system. It is intended, however, that model construction will culminate in a mathematical representation of the hydrogeologic system that is consistent with respect to available hydrogeologic field and laboratory data and is as comprehensive as possible within the practical constraints imposed by finite numerical simulations of complex physical systems. A final flow model or set of models, will be used subsequently to perform baseline analyses to (1) predict possible future or past states of hydrogeologic system and (2) support the final system synthesis and integration (Activity 8.3.1.2.2.9.5).

The input and output data for the models define the parameters for this activity. Requisite input data include (1) the geologic framework for the site, which determines the model geometry and material composition; (2) the hydrologic, thermal, and mechanical properties of the hydrogeologic units that make up the unsaturated zone at the site; and (3) the environmental conditions that determine the flux, potential, and pressure distributions on the spatial boundaries of the model. In general the land surface will define the upper system boundary, and the water table will define the lower boundary for the models; the lateral hydrogeologic boundaries must enclose the primary repository area, but their exact locations remain to be established. The material property data for the hydrogeologic units will be obtained from field and laboratory determinations and will become available as site characterization proceeds. The environmental conditions that define the present hydrogeologic boundary conditions include the present and past site climatic and tectonic settings.

The output data generated by the models for a specified set of input data consist of predicted time-dependent spatial distributions of liquid-water matric potential and saturation, pore-gas pressure, water-vapor concentration, temperature, and moisture- and pore-gas flux. To the extent that the mathematical formulation of the models incorporates all the significant physical processes and conditions that control the hydrogeologic system, flow models yield internally self-consistent mathematical representations of the hydrogeologic system and its evolution with time. The probable accuracy and validity of this representation is considered under Activity 8.3.1.2.2.9.4 (stochastic modeling and uncertainty analysis). The moisture- and pore-gas flux distributions computed from the flow models provide requisite input data for subsequent solute-transport and hydrochemical modeling.

Some of the specific issues to be addressed by the construction of these models are to (1) develop strategies and methodologies for constructing three-dimensional, fluid-flow models for the site hydrogeologic system; (2) investigate the relative contributions of liquid-water and water-vapor fluxes to the net moisture flux within the three-dimensional system; (3) assess the likelihood for the occurrence of the upward diffusion or advection of water vapor in fractures coupled to a corresponding downward return flow of liquid water within the rock matrix; (4) establish limiting conditions under which capillary barriers and perched water bodies zones can be expected to occur; (5) assess the effects produced by variations with space and time in assumed land-surface net-infiltration rates; and (6) investigate the impact of time-dependent stress and thermal fields on the unsaturated-zone hydrogeologic flow system (Study 8.3.1.15.2.1, characterization of the site ambient stress conditions; Study 8.3.1.15.2.2, characterization of the site ambient thermal conditions). An important task of this activity is to identify those hydrogeologic processes and concepts that are essential for a valid mathematical representation for performance assessment analyses and to eliminate those that can be shown to be of sufficiently negligible effect. The final flow model or models, thus, are intended to provide a summary numerical description of the site hydrologic flow system.

The final flow models will be used to perform a set of baseline simulations of the natural hydrogeologic system. A simulation of the presently existing natural system will be used as the initial conditions to perform a sequence of simulations to extrapolate the system both forward and backward in time. The forward extrapolation will be based on the most probable changes expected in the site climatic regime derived from Study 8.3.1.5.1.6 (characterization of the future regional climate and environment) and in the water-table configuration derived from Study 8.3.1.8.3.2 (analysis of the effect of tectonic processes and events on changes in water-table elevation). The backward extrapolations will be based on past climatic conditions and variations inferred from Study 8.3.1.5.1.4, (synthesis of the paleoenvironmental history of the Yucca Mountain region). The sequence of baseline simulations constitutes a standard set against which the effects of extreme or episodic changes in environmental conditions at the site may be assessed. The most probable limits of uncertainty attaching to the baseline simulations will be estimated as part of Activity 8.3.1.2.2.9.4 (stochastic modeling and uncertainty analysis). These flow models will be used to define flow paths and calculate fluxes and velocities within the unsaturated zone, as described under Activity 8.3.1.2.2.9.5 (system synthesis and integration).

The site-characterization hydrogeologic modeling to be performed as part of this activity is both complementary to and essential to the modeling that will be performed as part of performance-assessment activities. The site characterization models are intended to describe site conditions and processes and to evaluate the response of the site as a whole to changes in the local and regional climatic and tectonic settings. The performance-assessment models focus on the operation of the repository with respect to its components and immediate environment. The repository and its environment, however, are embedded in and interact with the overall site hydrogeologic system. The site models will be used to predict overall site behavior and, thereby, to evaluate the interaction between the internal state of the site and the repository system and environment. For example, the site hydrogeologic models will be used to predict the spatial and temporal distributions of both liquid-water and pore-gas fluxes within and near the repository environment. These flux distributions provide boundary-condition input data for the performance-assessment models that will be used to evaluate pre-waste-emplacement ground-water travel time and to simulate solute-transport processes. Solute-transport models will be used to assess the rates and magnitudes of possible future transport of radionuclides from the repository to the accessible environment.

8.3.1.2.2.9.4 Activity: Stochastic modeling and uncertainty analysis

Objectives

The objective of this activity is to assess the probable limits of uncertainty of numerical-model predictions caused by uncertainties in the material-property and boundary-condition data.

Parameters

The parameters of this activity are

1. Measurement errors.
2. Statistical distribution functions.
3. Probable limits of uncertainty.

Description

An important aspect of modeling physical systems is to assess the accuracy with which the model predictions represent the real system and, thereby, to establish the validity of the model with respect to its intended

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application. As discussed in Section 8.3.5.20.4 (model validation), the classical approach to model validation is to compare directly the model predictions with the observed system performance. The models that will be applied to address repository postclosure issues, however, are required to predict the effects of probable or possible changing conditions over the next 10,000 to 100,000 yr. Consequently, direct model validation is infeasible. Indirect methods must be employed to establish model credibility and to provide reasonable assurance that the long-term model predictions coupled with asymptotic bounding calculations are sufficient to assess the long-term performance of the repository and its subsystems. For hydrogeologic models, uncertainty analyses can be performed to assess model accuracy, stability, and asymptotic behavior.

The precision of the numerical results produced by a numerical hydrologic model is determined by that of the input data and the precision handling capability of the computer system used to perform the numerical calculations. The accuracy of the model predictions considers the discrepancy, or error, between the predictions and the actual performance of the physical system that the model is intended to simulate. Inadequate precision rarely is of practical concern, whereas the assessment of the accuracy of a simulation is of fundamental importance in establishing the adequacy and validity of the model.

The sequence of baseline simulations described in Activity 8.3.1.2.2.9.3 will provide the initial conditions for a set of Monte Carlo simulations in which the hydrologic-property and boundary-condition data will be varied in accordance with empirically determined uncertainty-distribution functions. These distribution functions will be estimated by classical statistical and geostatistical analyses to be conducted as part of this activity or of Activity 8.3.1.2.2.3.1 (matrix hydrologic properties testing). The sensitivity of the model predictions to uncertainties in the input data will be evaluated and quantitative estimates of uncertainty will be estimated specifically for calculated values of liquid water potential and saturation. Not only will these analyses permit an assessment of the probable accuracy of the baseline simulations, but they will also provide a means to generate cumulative distribution functions for the net uncertainty associated with predicted values of moisture flux within the unsaturated zone under existing natural conditions.

8.3.1.2.2.9.5 Activity: Site unsaturated-zone integration and synthesis

Objective

The objective of this activity is to integrate all applicable site data and analyses in order to synthesize a continually updated, comprehensive representation for the site unsaturated-zone hydrogeologic system. Attention will focus both on the present state of the system as well as on the implications concerning probable, or possible, future and past states of the system.

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Parameters

The significant parameters of this activity are the elements that define the state of the hydrogeologic system:

1. The site geologic framework and its change with time.
2. The site water-table configuration and its change with time.
3. Land-surface net infiltration to the unsaturated zone and its distribution in space and time.
4. The spatial distributions of temperature and stress within the unsaturated zone and their change with time.
5. The spatial distribution of moisture flux within the unsaturated zone and its change with time.

Description

As site characterization progresses, a diverse set of empirical data, quantitative analyses, and interpretations will become available for the site unsaturated-zone hydrogeologic system. These data, analyses, and interpretations will be continually integrated with the prevailing conceptual model for the system in order to synthesize overall representations of the system. These representations will be examined for internal consistency and completeness. Consequently, system integration and synthesis are envisioned to be an ongoing activity that will review the validity of the prevailing conceptual model as well as the data acquisition and experimental program to ensure that, to the extent possible, all critical hydrogeologic data are being collected, and the appropriate hypotheses are being tested.

The synthesis performed at the end of the site characterization program is intended to yield a best possible representation of the current state of the hydrogeologic system together with inferences concerning past states of the system. This information will be used to extrapolate the system forward in time to predict short-term system behavior that can be compared with observed system behavior during the performance-confirmation period. Predictions of long-term system performance will have been made before and possibly during the licensing process. Performance-confirmation monitoring will provide a partial set of confirmatory data that can be integrated into the system synthesis to provide a partial test of the validity of the synthesis. Further numerical modeling can be performed to check specific aspects of observed performance-confirmation system dynamics and response.

Assessments of the current state of system integration and synthesis are to be presented as progress and status reports to be issued periodically. Peer review will be an important aspect to ensure the integrity of the system integration and synthesis process. By issuing progress reports, not only will the process of system integration and synthesis be formalized, but implementation of the peer review process also will be facilitated.

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8.3.1.2.3 Investigation: Studies to provide a description of the saturated zone hydrologic system at the site

Technical basis for obtaining the information

Link to the technical data chapters and applicable support documents

The following sections of the site characterization plan data chapters provide a technical summary of existing data relevant to this investigation:

SCP section	Subject
3.9.1.1.2	Baseline monitoring (saturated zone)
3.9.1.2.2	Potentiometric levels (saturated zone)
3.9.2.2.1	Permeability and fractures (saturated zone)
3.9.2.2.2	Transmissivity and hydraulic conductivity (saturated zone)
3.9.2.2.3	Porosity and storage coefficients (saturated zone)

Number	Subject
3.9.3.1	Accessible environment and credible pathways (saturated zone)
3.9.3.2.2	Potentiometric levels and head relationships (saturated zone)
3.9.3.3	Recharge-discharge and leakage
3.9.4.1	Definition of flow paths for travel time calculations
3.9.4.4	Calculation of saturated-zone travel time
3.10.1	Summary of significant results (saturated zone)
3.10.3	Identification of investigations (saturated zone)

Parameters

The following parameters will be measured or calculated as a result of the site studies planned to satisfy this investigation:

1. Characteristics of geohydrologic units: spatial distribution of the physical and hydraulic properties of the rock units in the saturated zone at the site.

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2. Characteristics of ground-water flow: spatial distribution and rate of horizontal and vertical water flux and areally distributed fluxes (recharge and discharge).

Other site studies that provide information that support the determination of the previously listed parameters include the following:

Study	Subject
8.3.1.2.1.3	Characterization of the regional ground-water flow system (saturated zone hydrologic boundary conditions)
8.3.1.2.1.4	Regional hydrologic system synthesis and modeling (saturated zone hydrologic boundary conditions)
8.3.1.2.2.3	Characterization of percolation in the unsaturated zone (unsaturated zone recharge boundary condition to saturated zone)
8.3.1.2.2.9	Unsaturated zone system analysis and integration (unsaturated zone recharge boundary condition to saturated zone)
8.3.1.4.2.1	Characterization of the vertical and lateral distribution of stratigraphic units (saturated zone geologic framework)
8.3.1.4.2.2	Characterization of site structural features (saturated zone geologic framework)
8.3.1.4.2.3	Development of a three-dimensional model of the site geology (saturated zone geologic framework)

Purpose and objectives of the investigation

The objective of this investigation is to develop a model of the saturated-zone hydrologic system of Yucca Mountain, which will assist in assessing the suitability of the site to contain and isolate waste. Developing this model requires an understanding of ground-water flow. This understanding will be provided through studies focusing on the determination of boundary conditions imposed by structure, recharge, and discharge; hydraulic gradients in three dimensions; and bulk aquifer properties of units. Modeling activities will use the resulting information to calculate ground-water flow paths, fluxes, and velocities within the saturated zone.

Technical rationale for the investigation

Site characterization of the ground-water system within the saturated zone focuses on the determination of boundary conditions imposed by structure, and conditions of recharge and discharge; hydraulic gradients in three dimensions; and bulk aquifer properties of hydrostratigraphic units. The resulting description of boundary conditions, hydraulic properties of faults,

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hydraulic gradients, and aquifer properties will form the basis for synthesis and modeling activities that will conclude with calculations of flow paths, fluxes, and velocities within the saturated zone.

Boundary conditions

The hydrologic boundary conditions for the site saturated-zone hydrogeologic system will be based on the results of the two-dimensional subregional model (Section 8.3.1.2.1.4.2), the subregional two-dimensional cross-sectional model (Section 8.3.1.2.1.4.3), and the regional three-dimensional model (Section 8.3.1.2.1.4.4).

Hydraulic properties of faults

The repository block is approximately defined by faults. Numerous normal, west-dipping faults occur east of the block, and the block is bounded on the west by the Solitario Canyon fault. Strike-slip faults of northwest strike probably underlie Drill Hole Wash, bounding the block on the northeastern side.

Faults may act as barriers or conduits for ground-water flow, depending on the fault properties. The Solitario Canyon fault coincides in general with a steep gradient in the potentiometric surface, and, therefore, may act as a barrier. As part of the effort to understand the cause of the steep gradient and the potential for its modification, the hydraulic properties of the Solitario Canyon fault will be specifically evaluated (Activity 8.3.1.2.3.1.1). At Solitario Canyon, stratigraphic offset of high permeability zones against zones of low permeability could create a barrier, independent of the permeability characteristics of the fault itself.

Hydraulic and water-chemistry data from proposed drillholes USW WT-8 and USW H-7, both located east of drillhole USW H-6, will be used principally to help determine (1) if the ground-water flow paths in the vicinity are from west to east across the Solitario Canyon fault, as suggested by differences in water levels in holes on either side of the canyon and (2) the nature and degree of any hydraulic connection across the fault zone. If there is no significant eastward movement across the fault, this would have a major impact on both conceptual and numerical models. The models have assumed that ground-water flow in the saturated zone beneath the repository block generally is toward the south and southeast (e.g., from drillhole USW H-4 toward well J-13), even though present resolution of water-level data from south or east of the block is not enough to determine with high assurance the magnitude or direction of apparent gradients.

The normal faults east of the block coincide with a nearly flat gradient in the potentiometric surface and, therefore, are assumed to act as conduits. Because these faults are expected to be hydraulically indistinguishable from the surrounding fractured tuff, no tests are designed specifically to evaluate the hydraulic properties of these faults. Rather, those evaluations are included in the general analysis of aquifer properties (see discussion following hydraulic gradients discussion). The effects on ground-water flow of faults that probably underlie Drill Hole Wash will be evaluated as part of Activities 8.3.1.2.3.1.2 and 8.3.1.2.3.1.4 of this investigation.

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Hydraulic gradients

At drillhole UE-25p#1, the hydraulic head is 20 m higher in the Paleozoic carbonate rocks and the lowest 134 m of the Tertiary rocks than in the overlying volcanic rocks (Craig and Robison, 1984). Higher heads were observed at a depth of 1,800 m in drillhole USW H-1, where the level is about 773 m, whereas the water table is about 730 m above sea level. Data from Robison (1984, 1986) show that within the upper 500 m of the saturated zone, there is no upward gradient (drillholes UE-25b#1, USW H-1, USW H-3, USW H-4, USW H-5, and USW H-6) (Figure 8.3.1.2-18).

In the vicinity of the repository block at Yucca Mountain and eastward into Jackass Flats for 5 km or more, the potentiometric surface is nearly flat (730 m above sea level). Water-level altitudes in nearby drillholes are higher to the west of the block (775 m) and to the north (778 to 1,031 m).

Beneath the repository block and downgradient from it, the water table is so flat that periodic water-level measurements (every several weeks), even when made with very high accuracy and precision, cannot be used to determine average water-level differences and gradients among wells. The reason for this, based on preliminary measurements, is that in many drillholes the short-term water-level fluctuations due to barometric changes, earth tides and possibly other phenomena, although small, are greater than apparent differences among nearby drillholes. Therefore, water-level averages of months or perhaps years are necessary to determine gradients and probable flow paths near the repository. The present and planned expansion of continuous water-level measurements in observation drillholes will provide the data for determining the needed average water levels.

Continuous water-level data, in addition to being used for calculating average levels, may be helpful for evaluating the general hydraulic character of intervals penetrated by observation drillholes, and for estimating hydraulic parameters from responses to short-term stresses, such as earth tides, barometric changes, seismic events, or pumping of nearby wells. For those drillholes with multiple instrumentation, it will be possible to make separate evaluations of each depth interval represented.

Aquifer properties

The fracture network at Yucca Mountain has a major influence on ground-water flow and solute transport. The ground-water system is so extensively fractured that discrete fracture-network modeling at the scale of the mountain may not be a practical method for calculating travel time of ground water. Nevertheless, models used to calculate travel time must be based on an understanding of the fracture network.

Because fractures are individually different, with apertures, orientations, spacing, lengths, and in-filling characteristics subject to statistical description, in situ tests encompassing scores of fractures are needed to describe hydraulic conductivity and other bulk aquifer properties. Hydraulic conductivity of the fracture network is several orders of magnitude greater than matrix permeability in welded units, and may be an order of magnitude

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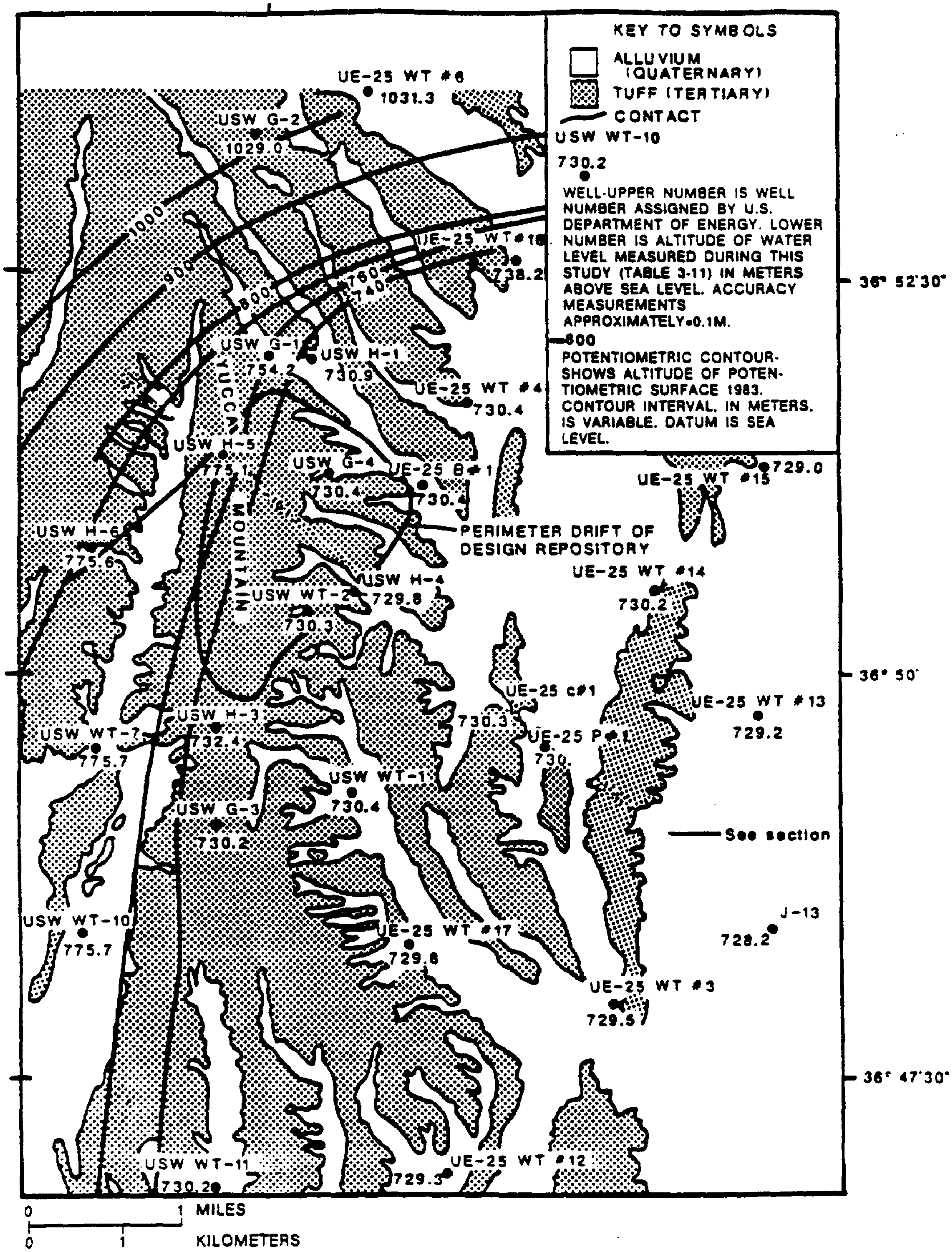

Figure 8.3.1.2-18. Preliminary composite potentiometric-surface map of the saturated zone, Yucca Mountain (modified from Robison, 1984).

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greater in nonwelded units. At the scale of well tests, it may not be possible to describe hydraulic conductivity as a tensor analogous to that of an equivalent porous medium. Criteria for porous-medium equivalence may be more strict for solute transport than for ground-water flow. The character of effective porosity and hydrodynamic dispersion may be completely different from that which would be expected in a porous medium.

Reliable estimation of bulk aquifer properties depends on application of the appropriate conceptual model of flow to results of well tests. Hydraulic tests conducted in wells USW H-4, UE-25p#1, UE-25b#1, UE-25c#1, UE-25c#2, and UE-25c#3 indicate that simple radial flow models may not be adequate to describe the flow of ground water at the scale of the tests. The predominant subvertical orientation and differential connectivity of fractures indicates that a more complex heterogeneous flow model may be needed for interpretation of well-test results. Additional analysis of previously completed hydraulic-stress tests is needed to form a conceptual model of flow during well tests. Additional tests, designed on the basis of this conceptual model, will give more reliable estimates of aquifer properties as well as refine the conceptual model of flow in fractured rock. In general, multiple-well tests will be needed to evaluate complex heterogeneous flow models. While useful for investigating many aspects of saturated-zone hydrology beneath Yucca Mountain, results of single-well tests have limited use in understanding the nature and areal distribution of bulk aquifer properties.

Results of production surveys, combined with hydraulic-test results, have failed to identify definitive hydrostratigraphic units. Instead, the results indicate that discrete production zones associated with fractures in one well may be connected to fractures occurring in overlying or underlying stratigraphic units in other wells. Additional multiple-well testing using packers to isolate production zones is needed to confirm or refute this hypothesis. The hydrologic significance of intervening bedded units is not known. If pervasive fracturing crosses stratigraphic boundaries and accounts for orders of magnitude greater hydraulic conductivity than does the matrix, it may not be appropriate to simulate ground-water flow within a framework of hydrostratigraphic units. Additional well tests are needed to determine three-dimensional relations between stratigraphy, fracture connectivity, and bulk aquifer properties. Single-well tests may have limited use in evaluating many of these relations.

Well tests at Yucca Mountain will be completed in two steps. The first step will consist of a large number of hydraulic and conservative-tracer tests in wells UE-25c#1, UE-25c#2, and UE-25c#3 (i.e., C-hole complex) (Figure 8.3.1.2-29 in Section 8.3.1.2.3.1.4). The tests will include a variety of field procedures and interpretive methods to form a conceptual model of flow in a fractured aquifer system. The site for the C-hole complex was chosen because of its position (down the hydraulic gradient from Yucca Mountain) and because the saturated zone at the site was believed to represent stratigraphic and structural conditions along a flow path to the accessible environment. The second step will consist of either a series of single-well tests at existing wells throughout Yucca Mountain, or drilling and testing at a second multiple-well complex. The purpose of the second step is to validate and refine the conceptual model formed during tests at the C-hole complex.

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Characterization of aquifer properties of the saturated zone has been divided into four activities. These activities are as follows:

1. Completion of the analysis of previously completed hydraulic-stress tests, including pumping and nonpumping intraborehole flow surveys, packer and open-hole injection and withdrawal tests, and transient pressure response of aquifers to barometric and earth-tide stress. Most interpretations will be restricted to data collected at the C-hole complex. Results of interpretations will be used to improve the design of planned well tests and, when possible, to provide preliminary estimates of aquifer properties.

2. Multiple-well interference tests at the C-hole complex, including cross-hole hydraulic tests and long-term pumping tests. Cross-hole tests will use packers to isolate selected intervals in wells for the purpose of monitoring response to a hydraulic stress applied in an isolated interval in a neighboring borehole. Cross-hole tests will be conducted to determine if the fractured rock can be treated as a homogeneous equivalent porous medium or if a more complex conceptual model is needed. Hydraulic conductivity and specific storage will be estimated from results of cross-hole tests. Long-term pumping tests will be conducted to evaluate aquifer properties in a larger rock volume than typically considered in pumping tests.

3. Tests of the C-hole complex with conservative tracers, including drift-pumpback tests, two-well recirculating tests, and two-well convergent tests. Test results will be used to determine properties of conservative-solute transport, evaluate relations between transport properties and fracture characteristics, and determine whether single-well tests can be used to characterize transport properties. By conducting a variety of tests, several relations between principal fracture orientation and hydraulic gradient will be considered. Different volumes of rock also will be tested to evaluate the scale-dependence of transport characteristics.

4. Well tests with conservative tracers throughout the site. If the results of tests at the C-hole complex demonstrate that single-well tests can be used successfully to characterize transport properties, then either a series of single-well tests (drift-pumpback tests) will be conducted at existing wells. If single-well tests cannot be used, then a series of multiple-well tests will be completed at a second site, tentatively planned for construction in the southern part of the study area. The purposes of this activity are to validate the conceptual model (formed during tests at the C-hole complex) of flow and transport in fractures and to evaluate areal variations in aquifer properties.

<u>Synthesis and modeling</u>

The description of ground-water flow paths, fluxes, and velocities within the site area is the ultimate objective of site-hydrogeologic investigations in the saturated zone. This description will be obtained through the development of digital ground-water flow models. Results of field activities and tests described previously will provide an understanding

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of boundary conditions, hydraulic gradients, and aquifer properties. Interpretation of field data will be used to form a conceptual model of the flow system at Yucca Mountain. Fracture-network modeling will aid in forming a conceptual model that treats aquifer properties in a manner that accounts realistically for the influence of the fracture network. Numerical models of the region and/or site will be developed on the basis of the conceptual model and tested by calibration with field data. Once calibrated, the numerical models will be used to estimate flow paths, fluxes, and velocities. These modeling efforts will be coordinated with activities to model flow in the saturated zone called for under Issues 1.1 and 1.6 (Sections 8.3.5.9 and 8.3.5.12).

8.3.1.2.3.1 Study: Characterization of the site saturated-zone ground-water flow system

The objectives of this study are (1) to determine the internal and external boundary conditions that can be applied to the site saturated zone model and (2) to determine the ground-water flow magnitudes and directions at the site.

Eight activities are planned to collect the data that are required to satisfy these objectives: (1) Solitario Canyon fault study, (2) site potentiometric level evaluation, (3) analysis of single- and multiple-well hydraulic stress tests, (4) multiple-well interference testing, (5) testing at the C-hole sites with conservative tracers, (6) well testing with conservative tracers throughout the site, (7) testing at the C-hole sites with reactive tracers, and (8) well testing with reactive tracers throughout the site.

8.3.1.2.3.1.1 Activity: Solitario Canyon fault study in the saturated zone

Objectives

The objective of this activity is to determine the hydrogeologic nature of the Solitario Canyon fault and if it is a barrier to eastward movement of ground water through the repository block.

Parameters

The parameters of this activity are

1. Nature and extent of hydraulic gradients.
2. Orientation and extent of fault zones.
3. Fracture orientations, apertures, and filling characteristics.

Description

To define better the water table west of the Solitario Canyon fault, water-table series drillholes USW WT-8 and USW WT-9 will be drilled using an air-foam method to depths of about 2,100 to 2,200 ft (640 to 670 m). Only surface casing will be installed, and the drillhole diameters will be about

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8.75 in. (22 cm). Drillhole USW WT-8 will penetrate about 150 to 270 ft (50 to 90 m) of the saturated zone; USW WT-9 will penetrate about 240 to 390 ft (80 to 130 m) of the saturated zone. East of the Solitario Canyon fault on the ridge crest of Yucca Mountain, a hydrologic test drillhole, tentatively designated USW H-7, will be drilled in the same manner as previously drilled hydrologic test drillholes at Yucca Mountain. The depth of this drillhole will be about 3,000 ft (914 m); it will penetrate about 450 to 600 ft (150 to 200 m) of the saturated zone and will have a diameter of about 8.75 in. (22 cm). Drillhole locations are shown in Figure 8.3.1.2-19. Drilling of these drillholes will be integrated and coordinated with the drillholes planned under Section 8.3.1.4.1.

Geophysical and television surveys will be run in each of the drillholes. The logging programs will include a gyroscopic survey, vibroseis survey, optical television survey, and dielectric, spectral gamma-caliper, fluid density, electric, density, and epithermal neutron logs. After downhole geophysical logs are completed in each water-table drillhole, a small-capacity pump will be hung in the drillhole on tubing, and the pump will be run for about a week to obtain water samples for chemical and isotopic analyses. The pump will be removed, and the tubing reinstalled to enable measurements of the water levels.

After the initial development and testing of drillhole USW H-7, including a borehole-flow survey, a long-term test (perhaps as much as 30 days) will be conducted. This test will consist of pumping drillhole USW H-7 at an expected rate of 25 L/s or more while observing hydraulic responses in water-level monitoring drillholes located throughout Yucca Mountain, especially those located across (west of) the fault, such as drillholes USW H-6 and the proposed USW WT-8 (Figure 8.3.1.2-22). It will be necessary tc disperse or transport the pumped water a substantial distance away from drillhole USW H-7 to prevent disturbance of local infiltration studies.

After the pumping test at drillhole USW H-7 is complete, it may be determined appropriate to pump drillhole USW H-6 while observing responses in drillhole USW H-7 and other drillholes east of the fault. By observing the responses of wells across the fault, it should be possible to determine if the Solitario Canyon fault acts as a barrier to eastward flow.

8.3.1.2.3.1.2 Activity: Site potentiometric-level evaluation

Objectives

The objectives of this study are to

1. Refine time and configuration of the spatial dependence of the potentiometric surface.

2. Measure water-level variations with time in existing borehole and calculate average levels, as input data for hydraulic gradient calculations.

8.75 in. (22 cm). Drillhole USW WT-8 will penetrate about 150 to 270 ft (50 to 90 m) of the saturated zone; USW WT-9 will penetrate about 240 to 390 ft (80 to 130 m) of the saturated zone. East of the Solitario Canyon fault on the ridge crest of Yucca Mountain, a hydrologic test drillhole, tentatively designated USW H-7, will be drilled in the same manner as previously drilled hydrologic test drillholes at Yucca Mountain. The depth of this drillhole will be about 3,000 ft (914 m); it will penetrate about 450 to 600 ft (150 to 200 m) of the saturated zone and will have a diameter of about 8.75 in. (22 cm). Drillhole locations are shown in Figure 8.3.1.2-19. Drilling of these drillholes will be integrated and coordinated with the drillholes planned under Section 8.3.1.4.1.

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After the pumping test at drillhole USW H-7 is complete, it may be determined appropriate to pump drillhole USW H-6 while observing responses in drillhole USW H-7 and other drillholes east of the fault. By observing the responses of wells across the fault, it should be possible to determine if the Solitario Canyon fault acts as a barrier to eastward flow.

8.3.1.2.3.1.2 Activity: Site potentiometric-level evaluation

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2. Measure water-level variations with time in existing borehole and calculate average levels, as input data for hydraulic gradient calculations.

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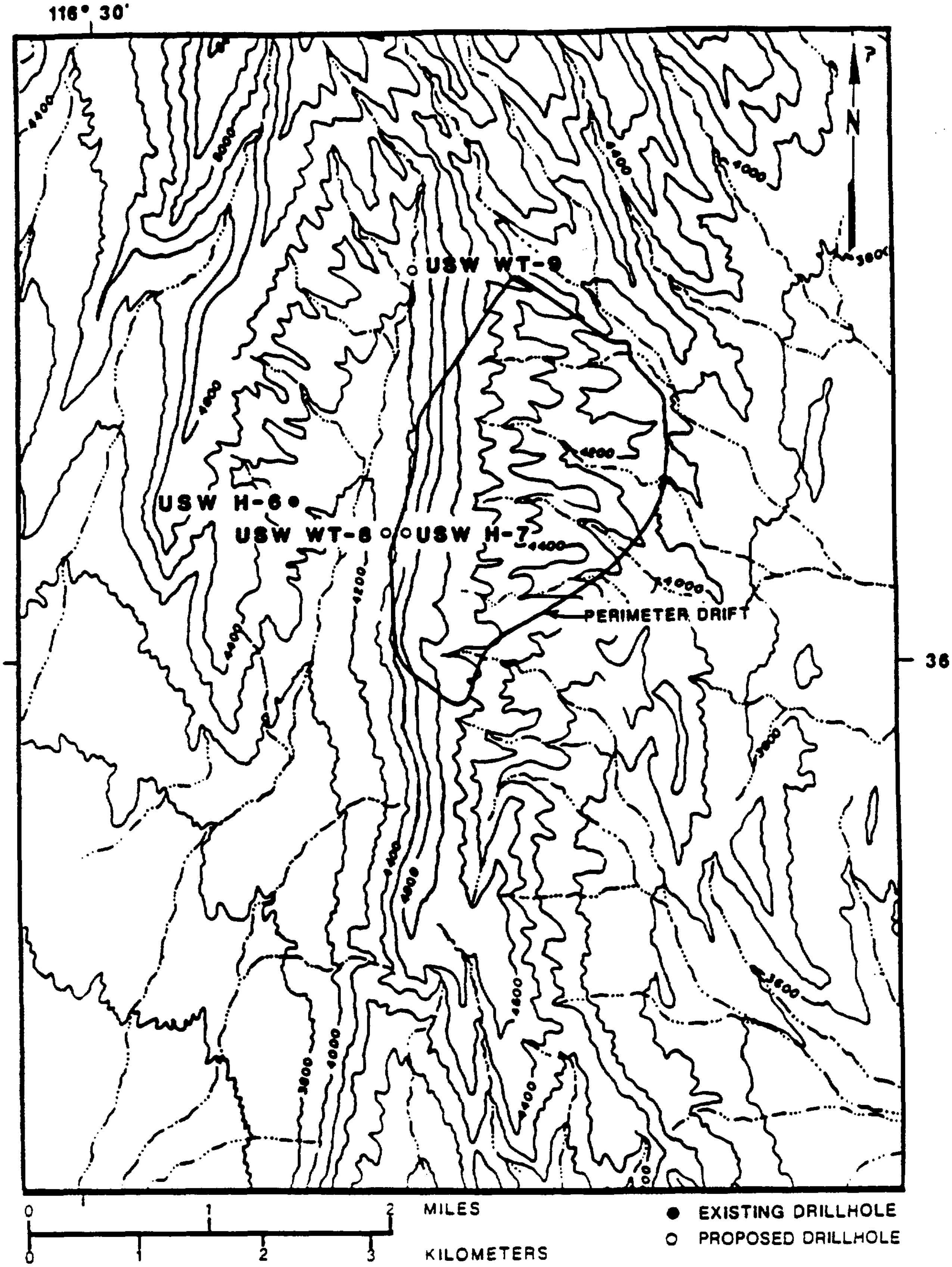

Figure 8.3.1.2-19. Location of the proposed drillholes for the Solitario Canyon fault study in the vicinity of perimeter drift.

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3. Analyze the character and magnitudes of water-level fluctuations to determine their causes, and, if possible, to estimate formation elastic and fluid-flow properties.

Parameters

The parameters for this activity are

1. Physical characteristics of the hydrogeologic units.

2. Hydraulic gradients.

3. Hydraulic diffusivity storage coefficients, hydraulic conductivity, aquifer compressibility.

Description

About 25 geologic, hydrologic, and water-table drillholes are part of an existing monitoring network near the site (Figure 8.3.1.2-8). Water levels in 15 holes have been measured periodically during onsite visits about every two weeks. Ten drillholes have pressure transducers installed below the water surface and connected to digital equipment at the surface; electrical output from the transducers is automatically recorded every hour. The periodically measured drillholes in the network are being converted to this automated monitoring system. Raw data from these field installations are taken to the office, and water-level depths or altitudes are calculated, following a process of conversions, adjustments, and determination and verification of equipment calibrations.

Proposed new test drillholes to be added to the water-table monitoring network include water-table drillholes in the USW holes WT-8, WT-9, WT-21, WT-22, WT-23, and WT-24; and UE-25 holes WT#19 and WT#20 (Figure 8.3.1.2-20). Water-table drillholes USW WT-8 and USW WT-9 will be located near the Solitario Canyon fault to help determine the hydraulic nature of that structural feature, as discussed in Activity 8.3.1.2.3.1.1 (Solitario Canyon fault study in the saturated zone). Water-table holes USW WT-21 and USW WT-22 are considered under Activity 8.3.1.2.1.3.2 (regional potentiometric distribution and hydrogeolgoic framework studies). The drilling of these drillholes will be coordinated with the drilling program described in Section 8.3.1.4.1.

Water table drillholes USW WT-23 and USW WT-24 will be located to the north near Drill Hole Wash to obtain additional data on the steep gradient in this area. Water-table drillhole USW WT-23 will be located in Drill Hole Wash northwest of drillhole USW UZ-1. This drillhole will be drilled to a probable depth of about 670 m. Drillhole USW WT-24 will be located between drillholes USW G-2 (Figure 8.3.1.2-24) and UE-25 WT#18, and will also be about 670 m deep. Both of these drillholes will have diameters of about 22 cm, and will be constructed and completed in the same manner as previously drilled water-table drillholes. The lithologic and geophysical logs will be analyzed and compared with those of other drillholes near Yucca Mountain to determine if the permeability of the rocks in this area is significantly lower than elsewhere, so as to produce a steeper hydraulic gradient than to the south near the Yucca Mountain repository block. Proposed geologic

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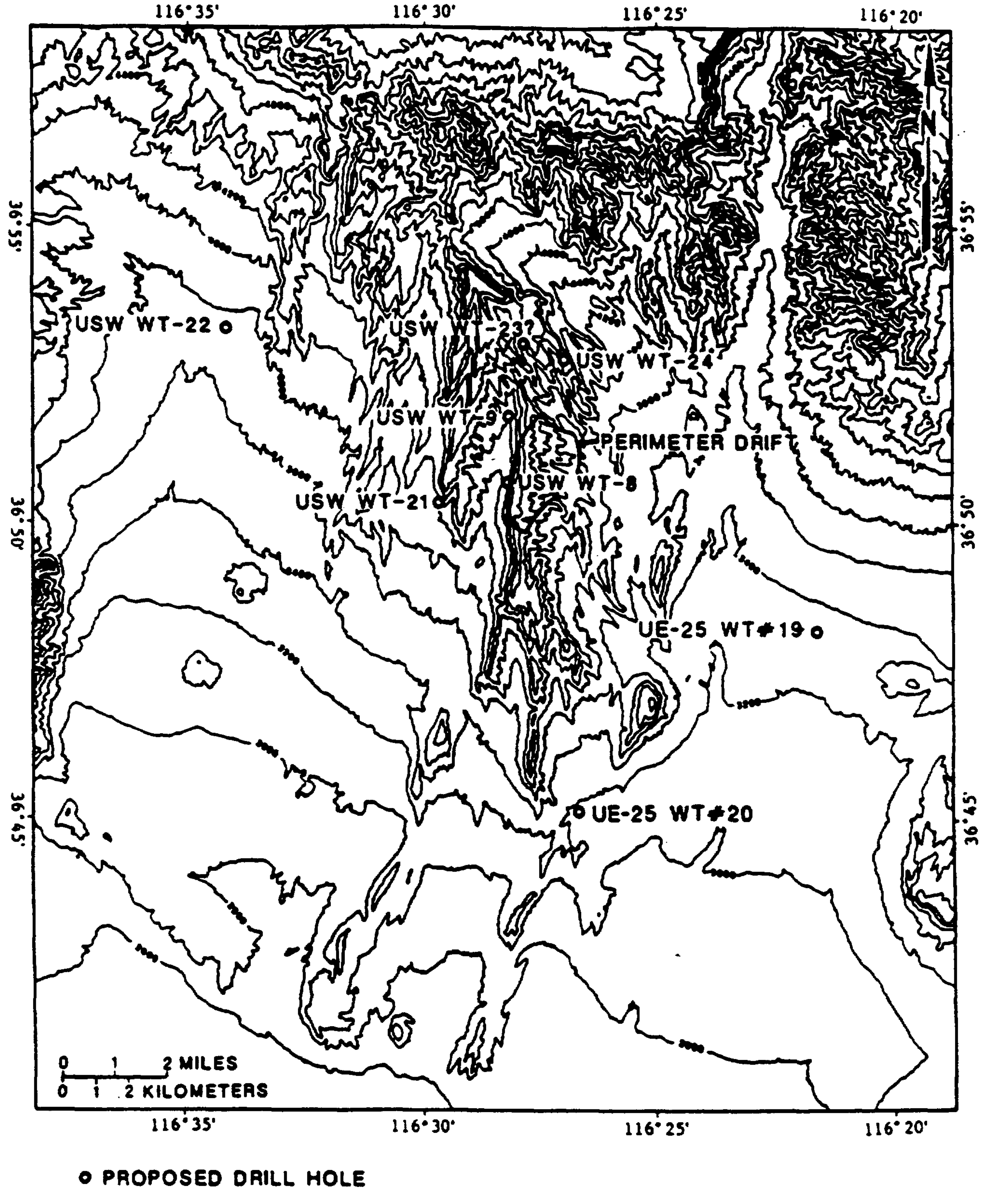

Figure 8.3.1.2-20. Locations of the proposed water-table holes for the site potentiometric-level evaluation.

drillhole USW G-5 (Figure 8.3.1.2-21), located generally north of Yucca Mountain, is expected to provide stratigraphic and other relevant information that will be used to help determine the probable cause and nature of the steep hydraulic gradient. Water-level measurements will also be used to help determine if the gradient is linear though steep, or is stepped.

Water table drillholes UE-25 WT#19 and UE-25 WT#20 will be drilled to determine the potentiometric levels to the south and east of the repository site (Figure 8.3.1.2-23). Drillhole UE-25 WT#19 will be located 3 km east of well J-13 and will be drilled to a depth of about 1,100 ft (335 m). Drillhole UE-25 WT#20 will be located 5 km southwest of well J-13 and will be drilled to a depth of about 1,100 ft (350 m). The drilling, construction, logging, and water sampling of these drillholes will be similar to previously drilled water table drillholes.

Water-level data from the monitoring program will be plotted to show variations and trends with time. Seasonal trends will be evaluated and the data will be averaged over appropriate periods (e.g., annually) so that hydraulic gradients and probable ground-water flow paths can be determined more accurately, especially in areas where the water table is nearly flat.

Water-level responses in observation wells during pumping of other wells will be analyzed in terms of general hydraulic connectivity and, where appropriate, the permeability of the rocks will be evaluated. Responses among the observation wells will be compared, with the purpose of estimating the areal anisotropy of the hydraulic parameters that may be controlled by faults or fractures.

Analysis will be made of water-level fluctuations in wells that occur in response to volume/strain changes in the aquifer(s). Two broad categories of water-level response will be evaluated: dynamic and static responses. The dynamic response, due to passage of a seismic wave from earthquakes or underground nuclear explosions, will be monitored and analyzed to determine the relation between formation fluid pressure and strain, and to provide estimates of formation elastic properties. Water levels in wells may also respond to lower frequency volume/strain changes (the static response), such as those due to earth tides and atmospheric loading. These responses are readily identifiable in most wells in the potentiometric-level network, and are currently being evaluated in the UE-25c-holes and UE-25p#1 (Activity 8.3.1.2.3.1.3). Water levels may also exhibit a coseismic or aseismic low-frequency response to earthquakes. These phenomena are variously referred to as slow earthquakes or fault creep events. Concurrent measurements of strain are necessary to confirm the occurrence of aseismic fault creep. Strain measurements are also needed to improve the analysis of earth tidal effects.

To address this problem, volumetric strain meters or dilatometers will be installed in boreholes in at least three localities near Yucca Mountain. To assess the effects of terrain on the detection of horizontal tectonic displacement or strain, emplacement sites will be located on the crest, flank, and on the flat adjacent to Yucca Mountain. The array location will be coordinated to optimize the detection of explosively induced strain changes, and to complement the hydrologic studies of earth tides and apparent fault creep responses. At each locality, existing boreholes may be used or boreholes will be drilled and cored to facilitate the emplacement of strain

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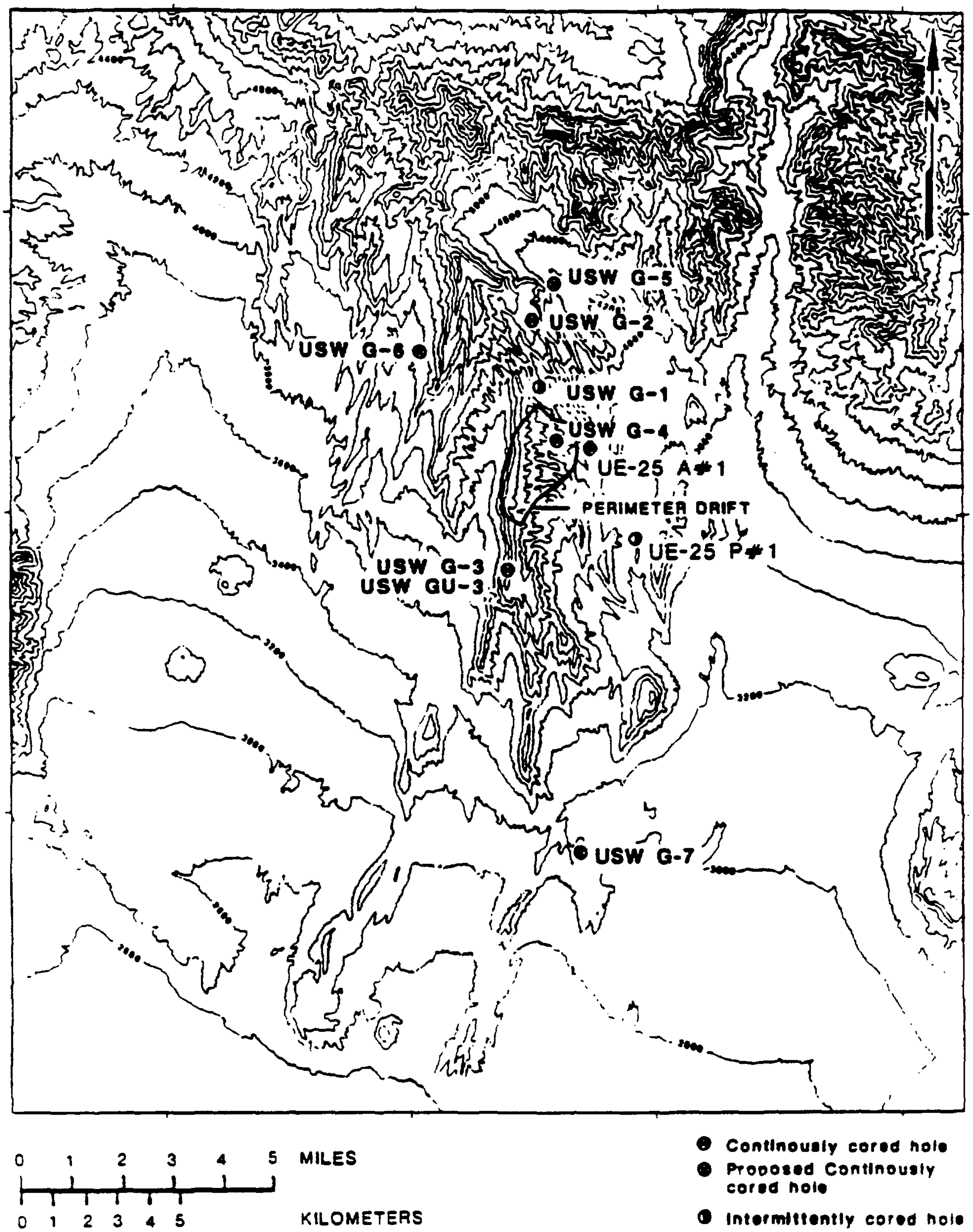

Figure 8.3.1.2-21. Location of existing and proposed geologic drillholes.

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meters. For redundancy, strain meters will be installed in two adjacent holes in at least one site. The selection of borehole sites and the criteria for well construction will be coordinated with the development of Yucca Mountain Project drilling plans (Investigation 8.3.1.4.1).

Because strain meters are temperature-sensitive, the depth of emplacement must be sufficient to minimize the effects of annual changes in surface temperature. Every effort will be made to ascertain the temperature-depth field at each locality before emplacement. Monitoring of climatic factors such as barometric pressure and rainfall will be made on a continuous basis and will be coordinated with other meteorological monitoring at the site (Study 8.3.12.1.2). The output from all strain meters at each locality will be monitored using intelligent data logging systems. Satellite (GOES) telemetry will be used to transmit the data to the office for immediate analysis so that detectable low-frequency strain changes may be observed and an appropriate response for additional field measurements may be initiated.

Currently Sacks-Evertson strainmeters, or Carnegie meters are being considered for use in this activity, because they are relatively simple and robust dilatometers that are readily available. When properly installed, they are capable of sensing strain changes of the order 10^{-10} or greater. The Carnegie meters have been used successfully by the USGS in studies on the San Andreas Fault in California.

8.3.1.2.3.1.3 Activity: Analysis of single- and multiple-well hydraulic-stress tests

Objectives

The objectives of this activity are to

1. Determine intraborehole flow profiles for each of the C-holes during static conditions and while pumping.

2. Correlate lithology, fractures, and intraborehole flow rates.

3. Characterize the type of flow (linear, radial, spherical, fracture, porous) that is occurring between boreholes.

4. Determine the causes of the apparent deviant pressure transients observed in slug tests in UE-25c#1.

5. Identify the nature of significant hydraulic boundaries present at the scale of the tests. This information will be especially important in designing multiple-well interference tests and tracer tests at the C-holes.

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6. Determine bulk estimates of aquifer properties: transmissivity, storage coefficient, specific storage, and effective hydraulic porosity.

7. Determine to what extent the ground-water system responds to hydraulic stress as confined or unconfined.

Parameters

The parameters for this activity are

1. Intraborehole flow rates.

2. Type of flow and nature of significant hydraulic boundaries present at the scale of well tests.

3. Transmissivity, storage coefficient, specific storage, and effective hydraulic porosity.

Description

Well hydraulic tests completed in test wells USW H-4, UE-25p#1, UE-25b#1, and especially UE-25c#1, UE-25c#2, and UE-25c#3 to determine aquifer hydraulic conductivity and specific storage indicate that simple nonsteady radial flow models may not adequately describe the movement of ground water through most of the formations tested (Figure 8.3.1.2-21). Attempts to identify definitive hydrostratigraphic units on the basis of well-test results and production surveys have not been successful. Instead, these data have indicated that discrete production zones associated with fractures in one test well may be well connected to fractures occurring in other stratigraphic units. The role of intervening bedded units is unclear. Because of the predominant subvertical orientation of fractures and their differential connectivity, a complex heterogeneous reservoir flow model probably is needed for interpretation of hydraulic test results. On the basis of these interpretations, additional tests need to be conducted to determine the three-dimensional relations between stratigraphy, fracture connectivity, and hydraulic conductivity.

Three categories of hydraulic-test data have been collected in the past and will be analyzed for site characterization: (1) intraborehole flow data, including pumping and nonpumping temperature logs and tracejector surveys; (2) packer and open-hole fluid injection and withdrawal test data; and (3) aquifer fluid pressure and barometric pressure data to monitor aquifer response to barometric loading and earth-tide stress. The data to be analyzed for site characterization was collected primarily from wells at the C-hole complex since September 1983.

Intraborehole hydraulic test data will be analyzed for site characterization. Temperature logs and tracejector surveys will be used to identify points or zones where fluid enters or leaves boreholes, and may be used to determine the direction and rate of flow. It may be possible to correlate points where fluid enters or leaves a borehole with specific fractures, whereas zones where fluid enters or leaves a borehole may correlate with

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groups of fractures or zones where permeability is due to porous rock. The distinction is important in formulating a conceptual model of flow near the boreholes and will be useful in the design and analysis of fluid injection and withdrawal tests.

Tracejector surveys completed while pumping the wells were done according to the method described by Blankennagel (1967) using iodine-131 as a tracer and will be analyzed by a method similar to the method described by Blankennagel (1967). A wireline tool consisting of an ejector with two gamma detectors on each side of the ejector is used to conduct a tracejector test. Tracer is ejected in the borehole fluid at a selected depth and allowed to travel with the fluid past the stationary gamma detectors. The time of travel between the two detectors is recorded and the velocity is calculated as the ratio of the distance between the detectors and the time of travel. The flow rate is calculated from the fluid velocity and the borehole volume in the interval between the detectors. By repeating the tracejector survey at several depths, a production profile of the pumping well can be described where the relative contributions of the various flow zones to the total flow can be identified.

Analysis of temperature logs made when pumping the boreholes will be divided into qualitative and quantitative interpretations. All analysis will be based on heat transfer theory that accounts for heat flow within the fluid, between the fluid and the formation, and between the fluid and the well plumbing. Qualitative interpretations will include examining the shapes of the temperature profiles to deduce the location and nature of flow points or zones, and the direction of flow. Quantitative analysis will include estimating rate of flow and will be based on the subtangent or delta function (Kunz and Tixier, 1955; Schonblom, 1961; Murphy, 1982). Temperature profiles calculated from known pumping rates and reasonable estimates for formation and fluid thermal properties, and the geothermal gradient will be compared with temperature logs to calibrate thermal properties. The calibrated temperature profiles will be used to calculate intraborehole flow rates.

Temperature logs and tracejector surveys completed under static or nonpumping conditions will be used to identify steady-state flow rates, directions of vertical movement, and permeability contrasts. Methods for conducting static tracejector surveys and the proposed analytical techniques are described by Erickson and Waddell (1985) and Galloway and Erickson (1985). Flow rates will be calculated for static temperature logs using the calibrated thermal model of fluid flow.

Injection and withdrawal hydraulic-test data will be analyzed for site characterization. Twenty-nine injection and withdrawal tests have been conducted in the C-holes to examine the pressure-transient response of the aquifer. Analysis of pressure transients can give information regarding the type of flow, hydraulic boundaries, and aquifer properties, specifically hydraulic conductivity and specific storage. Because estimation of aquifer properties depends on the type of flow and boundaries hypothesized, it is important to develop a conceptual model of the flow before estimating aquifer properties. The primary purpose of analyzing previously completed injection and withdrawal tests is to form a conceptual model of ground-water flow at

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the scale of the C-hole complex. Where appropriate, estimates of aquifer properties will be made. The conceptual model will be used as a basis for designing additional hydraulic and tracer tests that will enable more reliable calculation of aquifer properties.

Several types of stress tests have been completed at the C-hole complex. Twenty-three falling-head injection tests with packers were run in drillhole UE-25c#1 (Figure 8.3.1.2-22). Two additional falling-head injection tests were run in drillhole UE-25c#1 to ascertain pipe-friction head loss. A quasi-constant flux injection test with packers was run in drillhole UE-25c#2 (Figure 8.3.1.2-23) and monitored in drillholes UE-25c#1 and UE-25c#3 (Figure 8.3.1.2-24). A constant-flux withdrawal test without packers was done in each of the C-holes after completion of drilling such that drillhole UE-25c#1 was used as an observation well during the drillhole UE-25c#2 test, and drillholes UE-25c#1 and UE-25c#2 were used as observation wells during the drillhole UE-25c#3 test. Straddle packers were used in observation wells (Figures 8.3.1.2-25, -26, and -27).

The approach to analyzing the stress tests will involve a search for the theoretical reservoir model with a response to an imposed stress that most closely matches that of the actual reservoir and with constraints that are consistent with other information concerning the rock properties of the reservoir. Flow-analysis procedures are well established for porous media that are reasonably homogeneous but are not well established for aquifers with heterogeneities evident at the C-hole complex. New techniques that include aquifer heterogeneity may be needed to develop an adequate conceptual model of flow at the C-hole complex.

The analysis of pressure transients from C-hole pumping and injection tests initially will consider solutions for porous media that are radially infinite, homogeneous, and isotropic. Complexity, in the form of solutions for fractured reservoirs, will be considered as needed. This approach, from simple to more complex flow solutions, will enable the development of a conceptual model for pressure-transient behavior by contrasting the C-hole response to the ideal porous-media response. Porous-media solutions that will be considered include those of Theis (1935) for isotropic confined conditions; Hantush and Jacob (1955), Hantush (1960), and Neuman and Witherspoon (1969a, 1969b) for leaky conditions; and Boulton (1963) for unconfined aquifers with delayed yield from storage. The possible effects of well-bore storage and skin, partial penetration, and outer boundaries such as no flow or constant-head boundaries will be examined.

If porous-media solutions do not adequately match the response of the actual fractured reservoir, more complex solutions will be considered. Homogeneous models that may be considered include the following:

1. Those that consider single and regularly spaced and offset systems of vertically and horizontally fractured systems (Prats, 1972; Asfari and Witherspoon, 1973).

2. Those that implicitly consider fractures by including anisotropy in permeability (Papadopulos, 1965; Saad, 1967).

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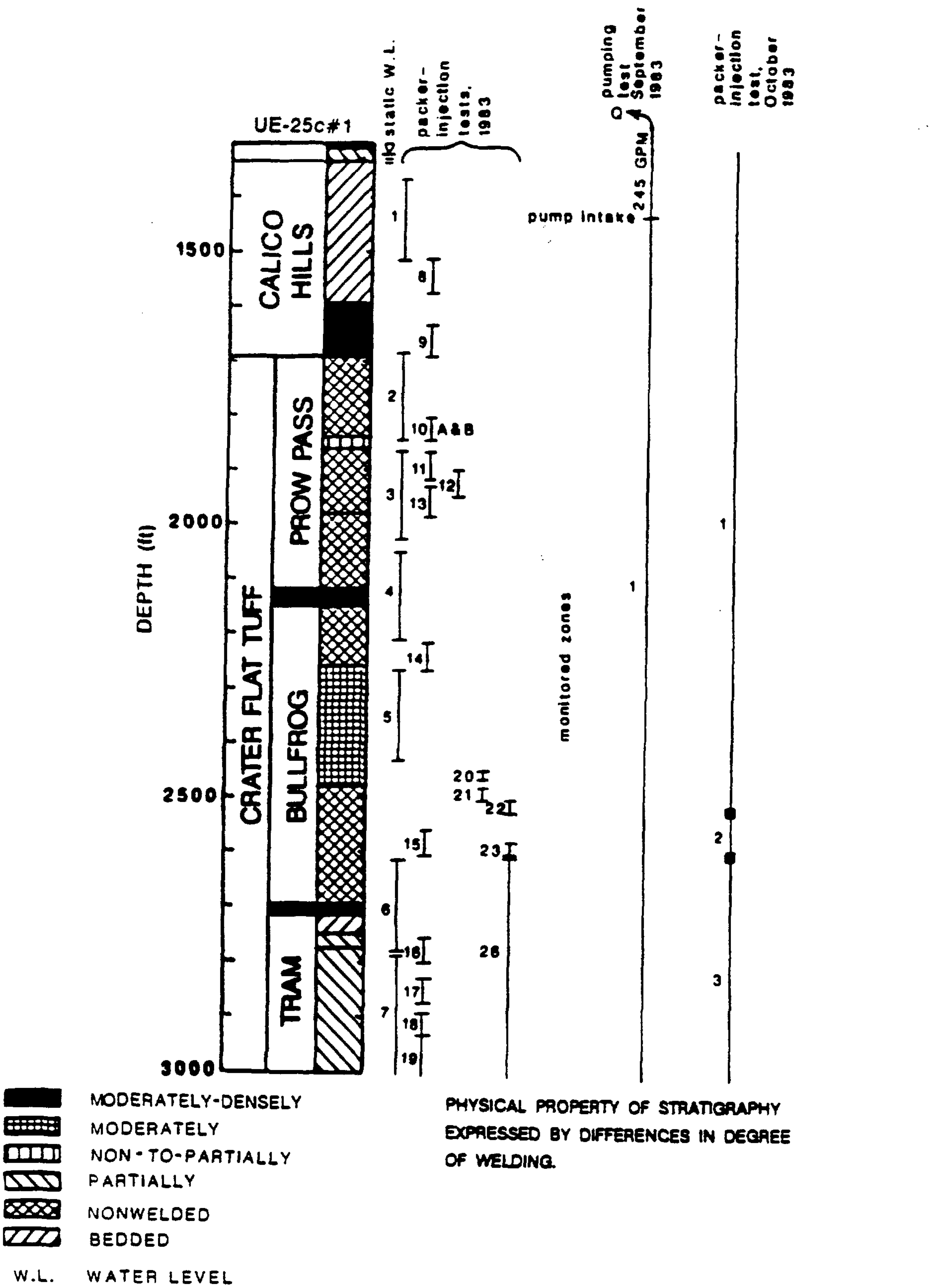

Figure 8.3.1.2-22. Test well configuration for drillhole UE-25c#1 packer-injection and open-hole pumping tests

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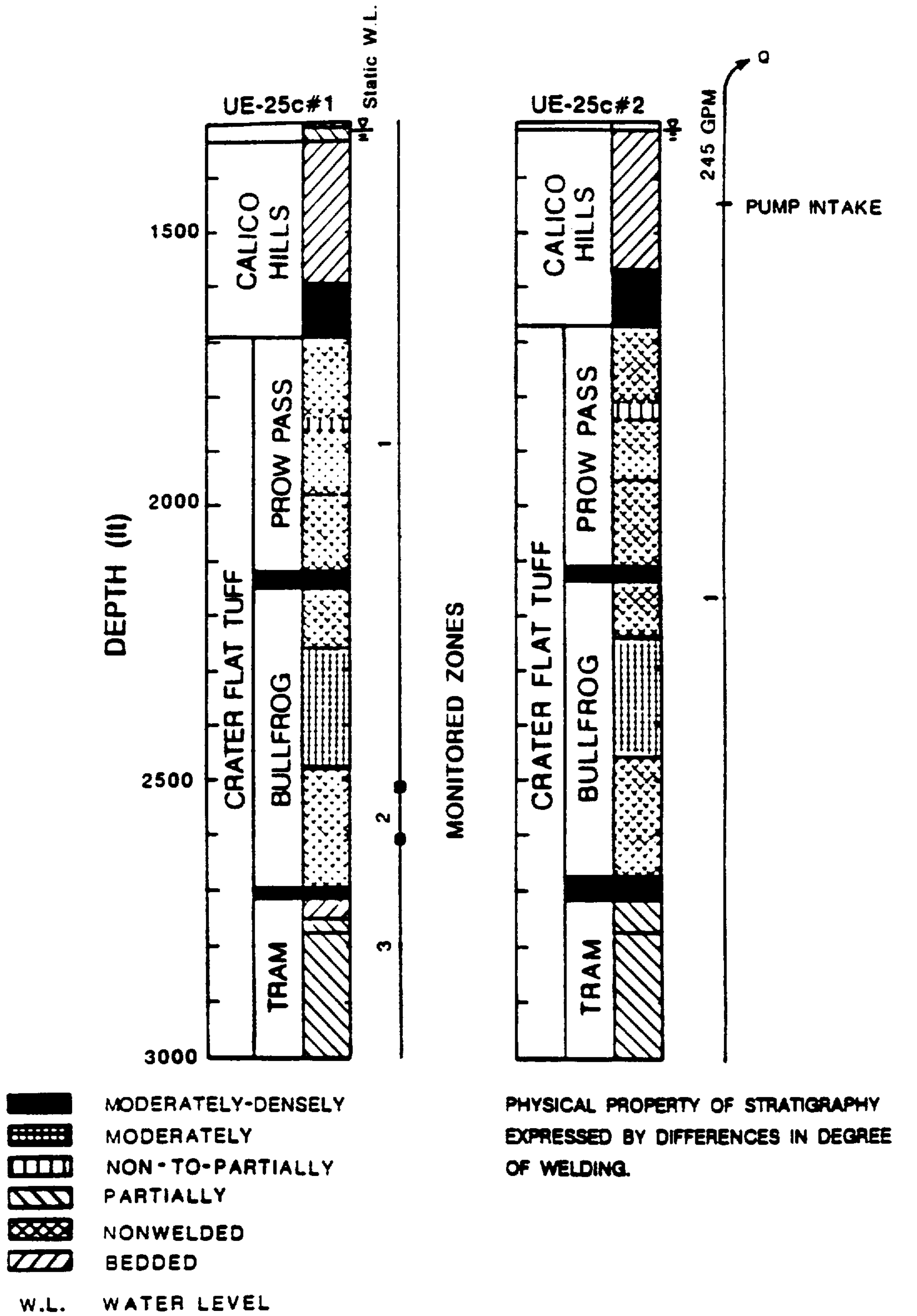

Figure 8.3.1.2-23. Test well configurations for drillhole UE-25c#2 pumping test (March 1984)

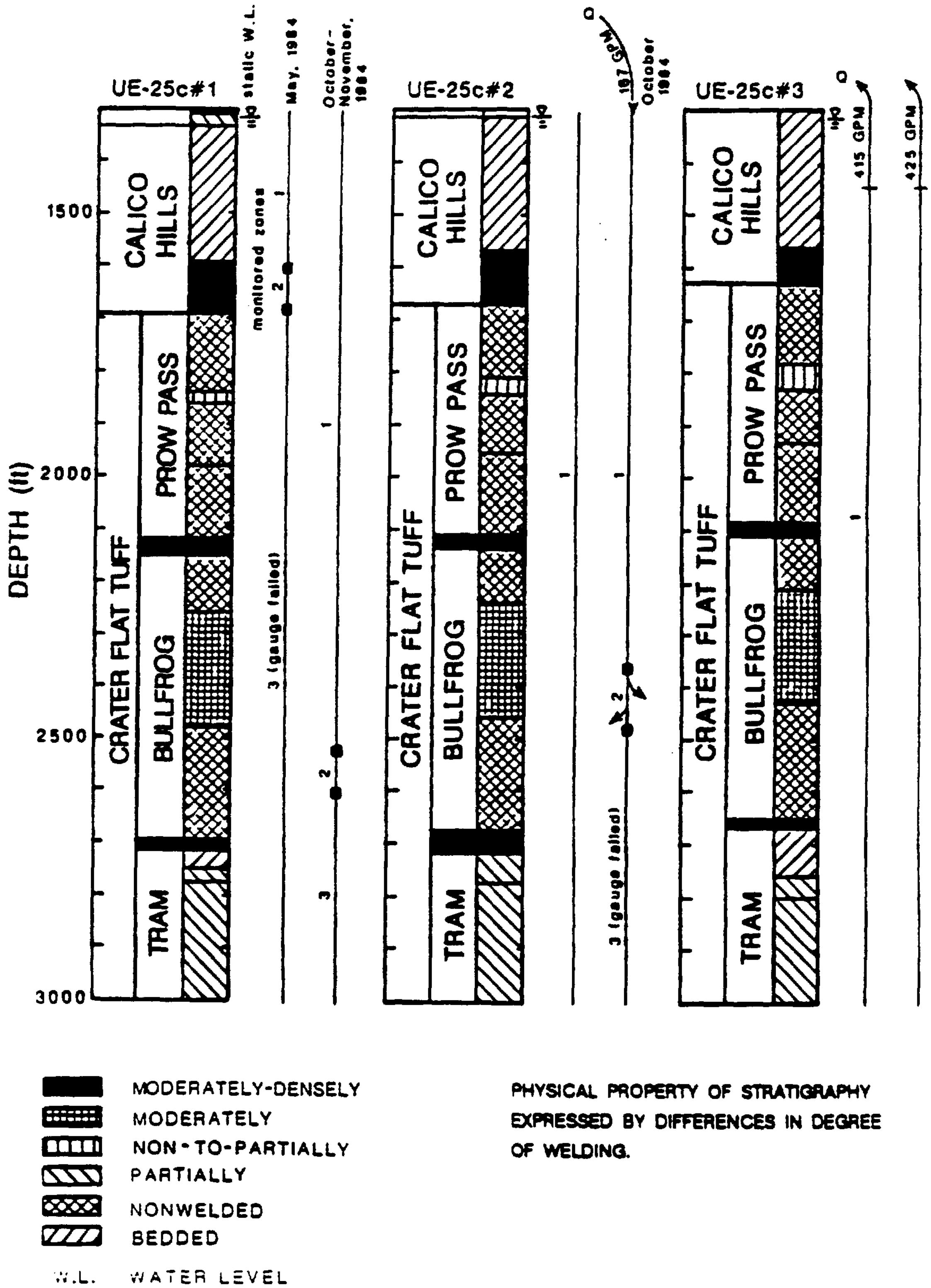

Figure 8.3.1.2-24. Test well configurations for drillhole UE-25c#3 pumping tests (May 1984, November 1984) and drillhole UE-25c#2 packer injection test (October 1984).

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3. Those that consider a stressed well intersecting a single fracture in an otherwise radially infinite porous medium (Gringarten and Witherspoon, 1972; Gringarten et al., 1974; Gringarten and Ramey, 1974; Cinco et al., 1978).

4. Those that consider well-bore storage and skin effects in combination with previously mentioned characteristics (reviewed by Gringarten et al., 1979).

5. Those that consider partial penetration of wells (reviewed by Karasaki, 1987).

If an equivalent homogeneous model is not an adequate representation of the actual system behavior, heterogeneous models will be investigated. Heterogeneous models include double-porosity models (reviewed by Gringarten, 1982; Moench, 1984), multilayered models (reviewed by Gringarten, 1982) and composite models (reviewed by Karasaki, 1987).

Preliminary analysis of falling-head injection tests (slug tests) has been reported by Erickson et al. (1985) and Karasaki (1987). Observed pressure transients from many of the tests could not be represented adequately using available solution techniques. Solutions evaluated included those of Cooper et al. (1967), Moench and Hsieh (1985), and several developed by Karasaki (1987). Possible causes for deviations include: (1) large initial heads may have induced excessive pipe-friction losses, (2) large velocity may have caused non-Darcian flow in the formation near the well bore, and (3) the changing state of in situ stresses may result from high initial injection heads (750 ft above static). Results of slug tests conducted in other wells on Yucca Mountain (USW H-3 for example) indicate that existing fractures were reopened or possibly new fractures were created as a result of excessive injection heads (2,461 ft above static in USW H-3), and that the pressure-transient responses reflect the changes in the fluid flow characteristics resulting from the changing in situ stresses. Therefore, the interaction of the fluid and mechanical processes may need to be considered in the analysis of the UE-25c#1 slug tests.

Additional slug tests will be conducted in selected intervals in UE-25c#1 and possibly UE-25c#2 and UE-25c#3 for purposes of assessing the effect of the magnitude of initial injection heads on the resulting pressure transients. Lower injection heads are expected to mitigate head losses through the injection tubing, at the well/formation interface, and within fractures or faults. Lower injection heads would also decrease the effects of changing in situ stresses, thus providing test results for interpreting the fluid-flow processes relatively uncoupled from mechanical processes.

Additional interpretation of the well-test data may be useful on the basis of results of future well tests. Such tests could be designed to mitigate pipe-flow head losses. Although an analytical model that considers non-Darcian flow in the formation is not available, an equivalent analytical model or a numerical model may be applied to these data.

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Barometric and earth-tide analyses will be performed using water-level data collected from test holes at the site. Water levels were monitored in the C-holes and in drillhole UE-25p#1 to analyze aquifer responses to solid earth tidal strains and surface barometric pressure loads. Techniques have been developed that relate the tidal potential and the resulting aquifer dilatation to aquifer properties such as specific storage, matrix bulk modulus, and hydraulic effective porosity (Bredehoeft, 1962; Rhoads and Robinson, 1979; Kanehiro and Narasimhan, 1980; Hanson, 1984). Each of the techniques is developed for ideal confined aquifers or undrained conditions (although Bredehoeft (1962) presents an analysis for an ideal unconfined aquifer), and thus, the status of the monitored aquifer, confined or unconfined, must be determined before applying these techniques.

The existence of a strong hydraulic-head contrast between two monitored zones in the same borehole is a good indication that the units are not well connected hydraulically and that one unit may be confined to a certain degree. Such a situation exists between the Paleozoic dolomites in drillhole UE-25p#1 and the overlying tuffs where hydraulic heads in the dolomites are 20 m greater than those in the tuffs and indicate a confined aquifer in the Paleozoic section (Craig and Robison, 1984). The lack of a significant contrast of hydraulic heads (<0.5 m) in the vertical section from the water table in the Paintbrush Tuff, through the Calico Hills to the Crater Flat Tuff at depth, indicates that there may be insufficient vertical hydraulic connection to be consistent with an unconfined aquifer in the tuffs. Weeks (1978) presented a study of the response of the deep unconfined aquifer to barometric interaction. Another way to assess the confined status of the aquifers is to examine measured water-level and barometric fluctuations for conformance to Weeks' model.

Some preliminary analyses of aquifer response have been undertaken and reported (Galloway and Sullivan, 1986). Water levels were measured in the C-holes in five intervals (zones) (Figure 8.3.1.2-25) open to the extensively fractured Crater Flat Tuff and in drillhole UE-25p#1 in one interval open to the Paleozoic dolomite. Barometric pressure was monitored at land surface near drillhole UE-25c#2. Measurements were made at 30-min intervals using sensitive pressure transducers, during the period December 5, 1985, to July 17, 1986. A period of uninterrupted measurements from February 23 to April 1, 1986, was selected for analysis. Tidal harmonic analysis of the barograph and the six hydrograph records showed periodic fluctuations in all seven records corresponding to earth tides. An analysis of the periodic and aperiodic fluctuations for drillhole UE-25p#1 based on Rhoads and Robinson (1979) gave estimates of barometric efficiency, 0.57; specific storage, 6.0×10^{-9} cm^{-1}; matrix bulk modulus, 36.4 GPa; and effective hydraulic porosity, 7.7×10^{-2}. Although earth-tide induced water-level fluctuations were observed and calculated for the C-hole hydrographs, the analysis was not extended to these records because of the apparent unconfined-like response in the water-level and barometric fluctuations. Porosities were estimated from Bredehoeft (1962) based on the earth-tide induced water-level fluctuations and were in the range, 2×10^{-4} to 2×10^{-3}.

Although the unconfined-like response observed in the C-holes can be described by the model of Weeks (1978), additional work needs to be done to rule out other phenomena that could explain the response, such as well-bore storage effects. Other monitored zones in other boreholes on Yucca Mountain

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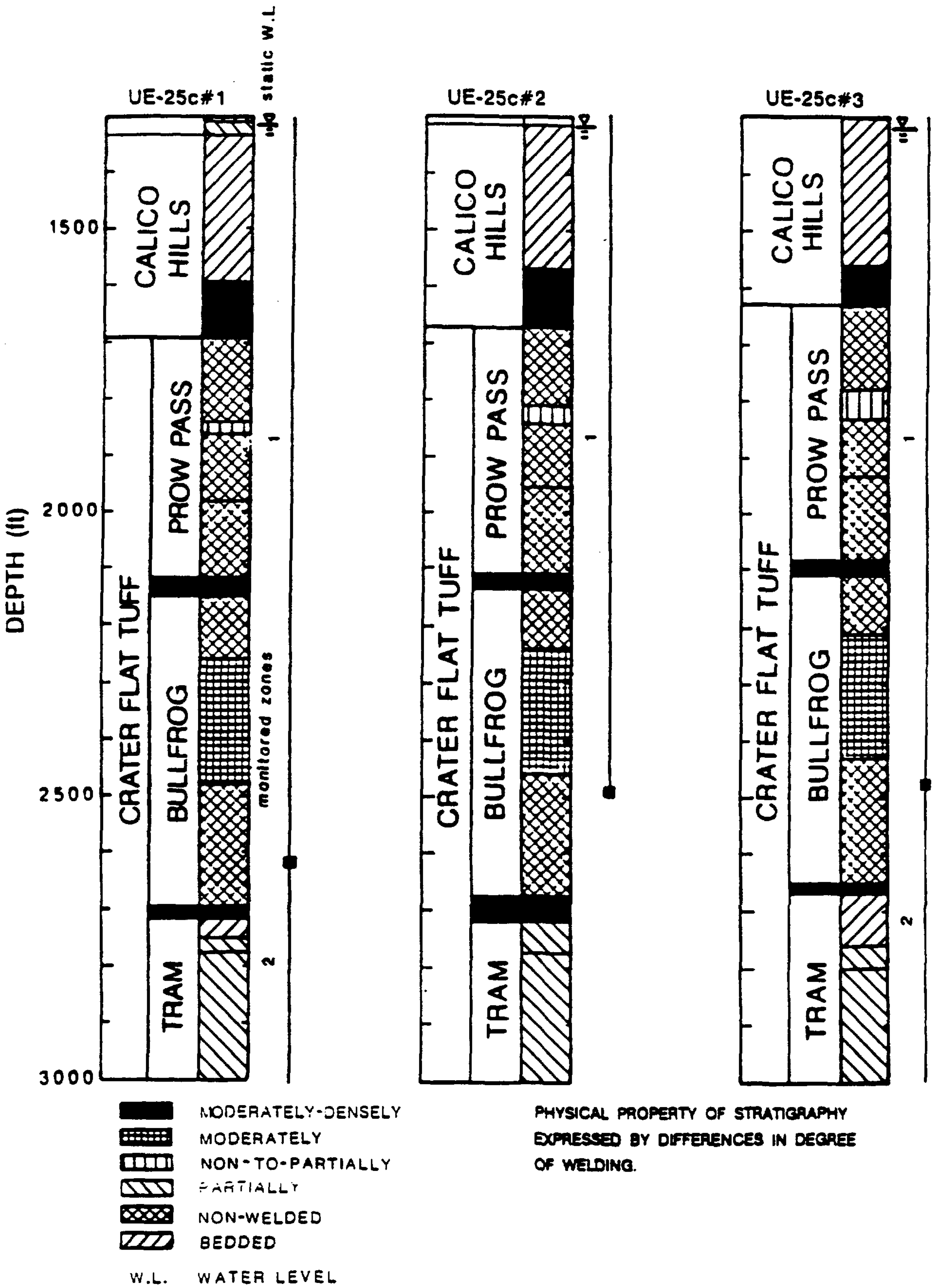

Figure 8.3.1.2-25. Test well configuration for analysis of C-hole earth-tide and barometric induced water-level fluctuations

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need to be examined to determine whether an unconfined-like response is evident and, if so, to relate the response to stratigraphy, well-bore storage, and other conditions. A preliminary analysis of drillhole USW H-1, USW H-4, and USW WT-2, UE-25 WT#3, and UE-25 WT#13 water-level fluctuations indicate that an unconfined-like response to barometric fluctuations is occurring.

A situation exists in drillhole UE-25c#1 that may permit a direct evaluation of the phase shift. A vent in the well cover that is connected to the annular space adjacent and open to the unsaturated thickness of the well bore is exchanging air with the atmosphere similar to that observed by Weeks (1986) for drillholes USW UZ-6 and USW UZ-6s on the crest of Yucca Mountain. It may be possible to correlate fluctuations in barometric pressure, annular space pressure, or air flow, or both, to fluctuations in water level, in order to address the phase shift in water-level and barometric fluctuations characteristic of the unconfined response.

Additional work may be done on the earth-tide analysis by using a technique presented by Hanson (1984). This technique accounts for well-bore storage and well-completion effects, and the presence of discrete fluid-carrying fractures. The method is attractive because it may also provide a first-order approximation of the hydraulic conductivity tensor.

8.3.1.2.3.1.4 Activity: Multiple-well interference testing

Objectives

The objectives of this activity are to

1. Determine hydraulic properties, including hydraulic conductivity and storage coefficient, needed for quantitative evaluation of ground-water flow.

2. Determine if the fractured media of Yucca Mountain can be represented as an anisotropic porous media at the scale of multiple-well tests or if a fracture-network model is more appropriate.

3. Evaluate the relation between hydraulic properties determined by single well tests and those determined by multiple-well tests.

Parameters

The parameters for this activity are

1. Hydraulic conductivity.
2. Storage coefficient.
3. Fracture characteristics.

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Description

A series of tests will be conducted at the C-hole complex (Figure 8.3.1.2-26). In these tests, water will be pumped from small, isolated intervals of one C-hole and the hydraulic response will be monitored in isolated intervals of other C-holes. Approximately 20 tests, using various combinations of pumping well, pumping interval, and observation intervals, will be conducted to identify the nature of the hydraulic connection between the C-holes. Large variations in the fracture characteristics of the rocks penetrated by the C-holes could affect movement of water in the saturated zone. By conducting cross-hole tests at various depths, the hydraulic significance of these variations will be identified.

Each test will be conducted in the following manner. Straddle packer systems will be installed in both pumping and monitoring wells. Packers will be used to isolate intervals identified on tracejector logs as producing zones. Six producing zones have been identified in UE-25c#1; at least two in UE-25c#2 and six in UE-25c#3. After packers have been inflated and tested for effective seals, pressure transducers will be installed in monitoring intervals. A submersible pump will be installed and water will be withdrawn from the selected pumping interval for approximately three days at a rate of between 3.2 and 12.6 L/s. Water temperature will be monitored by a thermocouple in the discharge line. Pressure changes measured in monitoring intervals will be digitally recorded by a data logger. After three days, the pump will be shut off and pressure recovery will be monitored for at least three additional days.

The combinations of pumping and monitoring intervals used in cross-hole testing will be selected in order to describe vertical variations in horizontal hydraulic conductivity, as well as the degree of hydraulic connection between units. For this reason, tests will be conducted by pumping water from the permeable part of the lower Bullfrog Member and monitoring pressure changes in observation wells within the upper Bullfrog, lower Bullfrog, and upper Tram members. Tests will also be conducted by pumping water from the permeable zone of the upper Tram and monitoring pressure response in both the upper Tram and lower Bullfrog members. Permeable zone of the lower Bullfrog Member exists at approximately 716 to 780 m below land surface depending upon the well. The permeable zone in the upper Tram Member is from approximately 838 to 870 m. Tests will be conducted alternately using UE-25c#1, UE-25c#2, and UE-25c#3 as pumping wells. In each test, the wells not used for pumping will be used as monitoring wells. By varying the pumping well, it will be possible to demonstrate the symmetric or unsymmetric nature of the hydraulic conductivity tensor.

A 30-day pumping test will be conducted by pumping UE-25c#1, UE-25c#2, or UE-25c#3 at a rate of between 6.4 and 25.2 L/s, and monitoring the pressure decline in other C-holes, UE-25p#1, USW H-4, and other nearby wells. Pressure recovery will be monitored in all wells for at least 30 days after pumping stops. Water will be pumped from the permeable zone of the lower Bullfrog Member. Pressure response in the C-holes will be monitored in isolated zones of the upper Bullfrog, lower Bullfrog, and upper Tram members. The pressure response in other nearby wells will be monitored without the use of packers to isolate zones.

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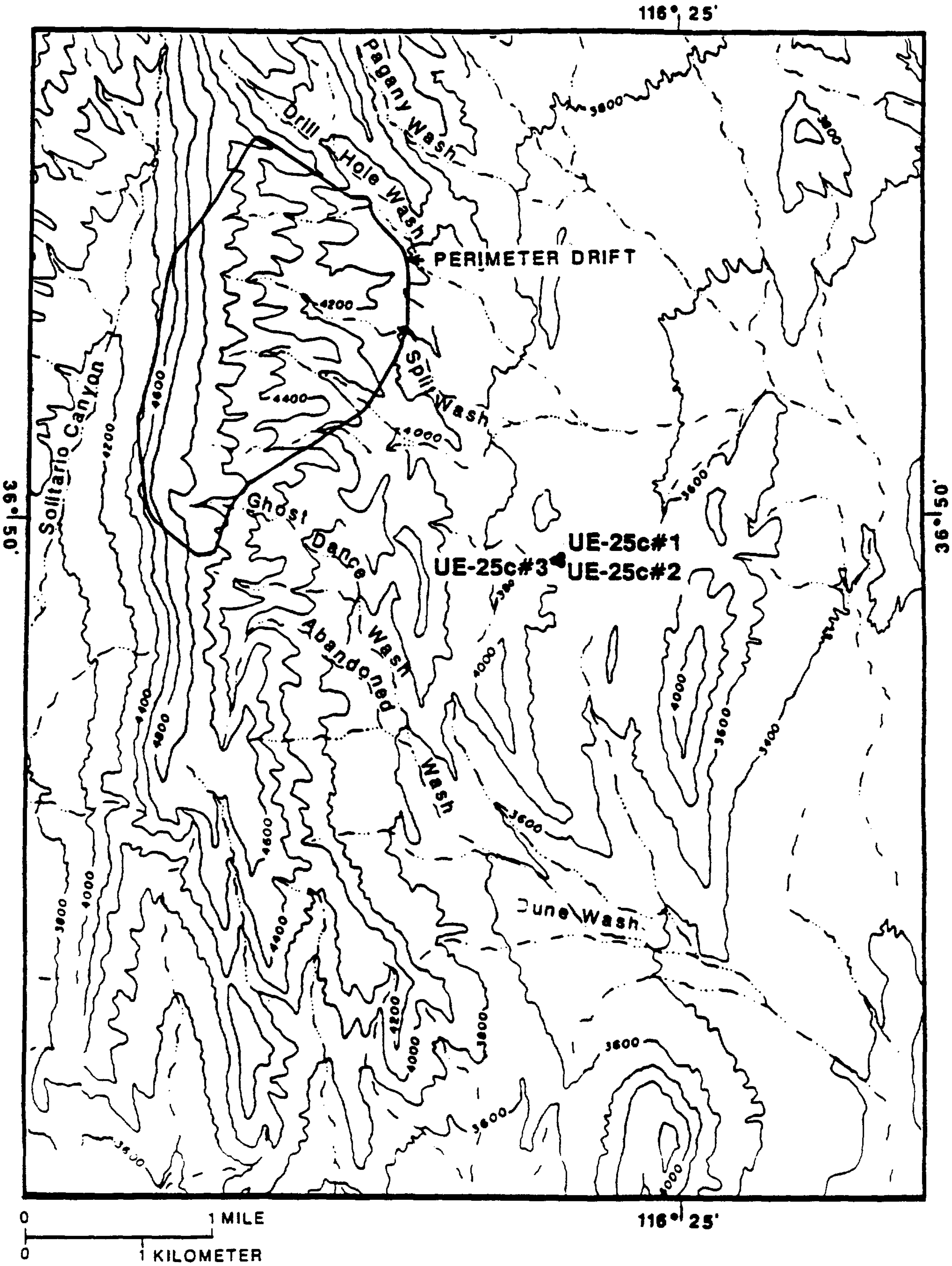

Figure 8.3.1.2-26. Location of C-hole complex.

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Results from this pumping test will be used to estimate aquifer properties at a scale larger than the C-holes scale and to identify the hydrologic significance of the Bow Ridge normal fault. Large-scale estimation of aquifer properties is important to describe accurately ground-water flux within the repository block. Observation wells used during the pumping test will be located on both sides of the Bow Ridge fault. The pressure response in these wells will be used to identify the fault as a barrier or conduit for ground-water flow.

The following porous-media techniques will be useful in evaluating multiple flow hypotheses. Current hypotheses, based on existing knowledge of Yucca Mountain, are equally plausible. The analytical method of Hsieh et al. (1985) is based on an assumption of aquifer homogeneity and may be applied to cross-hole data to determine a three-dimensional hydraulic conductivity tensor and storage coefficient for the C-hole area. Composite analytical methods of Karasaki (1987) may be used to investigate the assumption that flow in the fracture system occurs in an inner region near the pumping well dominated by a small number of fractures and an outer region where the rock is similar to a homogeneous porous medium. If test results indicate the assumption of homogeneity is poor, a numerical model such as Reilly (1984) may be used. Results of the large-scale test may be interpreted using classical Theis theory in addition to the techniques listed previously. If test results indicate the aquifer behaves as a dual-porosity medium, methods such as Moench (1984) may be used.

The fracture-network model developed by Lawrence Berkeley Laboratory (Activity 8.3.1.2.3.3.2) will be applied to interpret the results of both cross-hole and large-scale pumping tests. A set of fracture networks will be generated that brackets the range of uncertainty in fracture statistics. For example, networks with different mean apertures or different distributions of apertures (or both) might be included. Networks also will be developed that correspond to differing hypotheses for describing the distribution of fractures at Yucca Mountain. For example, fractures may be treated either as stratigraphically controlled, or independent of stratigraphy. Fracture networks, initially generated on the basis of geologic evidence, will be used to simulate multiple-well test results. Those networks that best match measured hydraulic response to pumping will be considered for analysis of tracer-test data.

Aquifer properties, estimated by porous-media techniques and fracture networks that successfully simulate hydraulic-test results, will be compared. Differences and similarities in the results of the two methods will be identified. Situations, where each approach is likely to produce meaningful results, will be identified. Limitations of each method will be described.

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8.3.1.2.3.1.5 Activity: Testing of the C-hole sites with conservative tracers

Objectives

The objectives of this activity are to

1. Determine the following properties by single-well and multiple-well tests at the C-holes: (1) effective porosity, (2) longitudinal dispersivity, (3) regional pore-water velocity, and (4) possibly matrix diffusion.

2. Evaluate the relation between aquifer properties estimated by porous-media techniques and fracture characteristics used in fracture-network modeling.

Parameters

The parameters for this activity are

1. Effective porosity.
2. Dispersivity.
3. Velocity and fracture characteristics.

Description

Approximately three drift-pumpback tests will be conducted in the C-hole intervals that have large hydraulic conductivity. These tests will be coordinated with testing with reactive tracers (Activity 8.3.1.2.3.1.7). The depths that will be considered for these tests include approximately 780 m (lower Bullfrog) and 850 m (upper Tram) below land surface in UE-25c#1, 730 m (lower Bullfrog) in UE-25c#2, and 740 m (upper Tram) in UE-25c#3 (Figure 8.3.1.2-27). Straddle packers will be used to isolate the test intervals.

Each drift-pumpback test will consist of placing a tracer in the test interval, letting it drift into the formation and then pumping it back out. The tracer to be placed in the selected intervals, including 3-trifluoromethylbenzoate, will drift into the formation under steady-state hydraulic gradients. Pretest sensitivity analysis and simulation of the flow system at the C-hole location will be used to identify reasonable periods of time for the drift phase of tests. The drift phase will be sufficiently long to permit the tracer to move out of the fractures that intercept the borehole and into the fracture network. In this manner, the influence of individual fractures on seepage velocity will be minimized. A pump will then be installed in the selected interval and water will be withdrawn to begin the pumpback phase of the test. The pumping rate will be 3.2 to 9.5 L/s. The rate of pumping will be measured by an in-line flow meter, and water temperature will be monitored by a thermocouple. Samples of pumped water will be collected and analyzed for tracer concentration. Pumping will continue for at least three days or until virtually all tracer is recovered.

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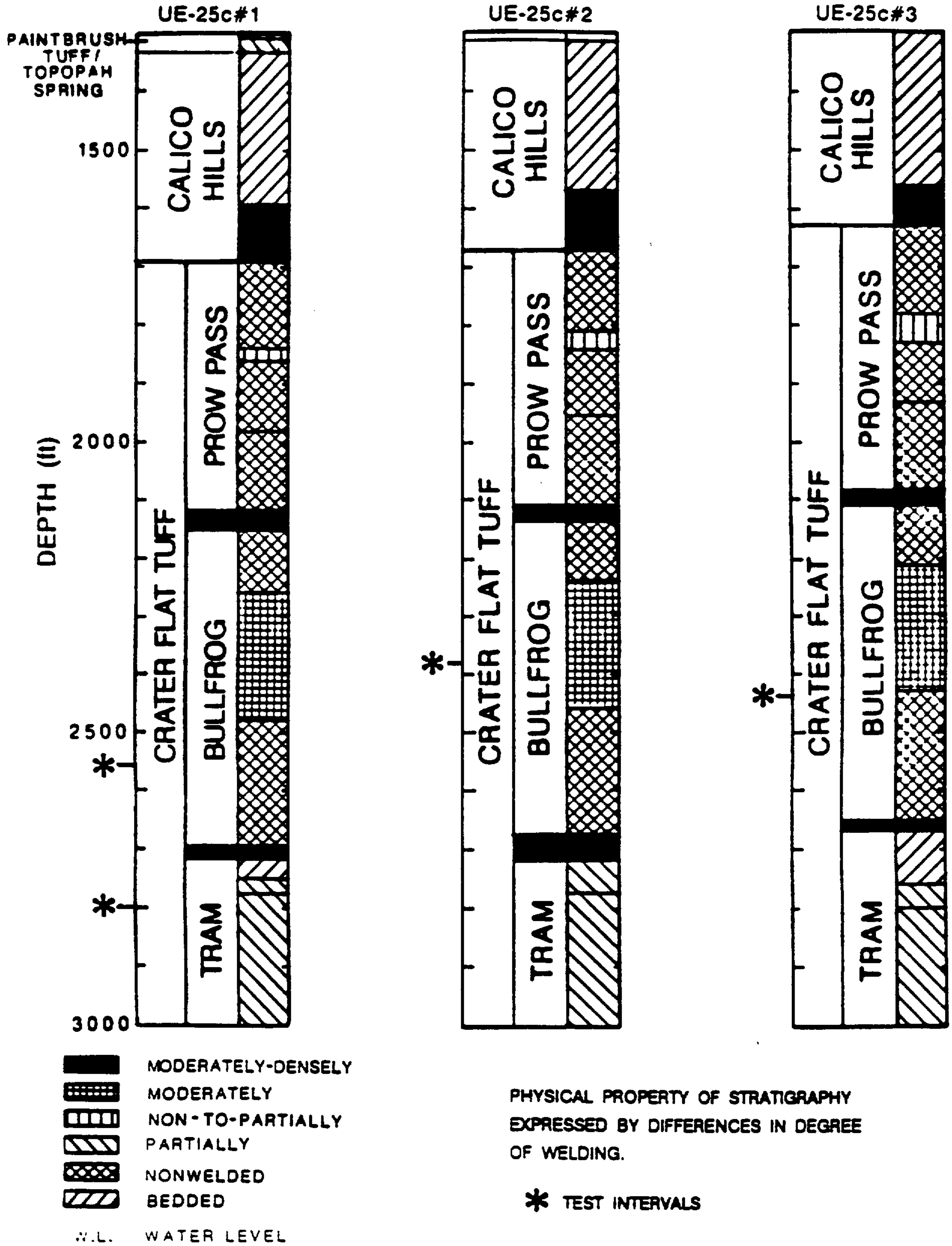

Figure 8.3.1.2-27. Location of test intervals for the drift-pumpback tests.

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Results of drift-pumpback tests may be virtually impossible to interpret. The rate of diffusion in the borehole and deviations of gradient and velocity from regional conditions due to individual fractures that intersect the well bore may confound the analysis of bulk aquifer properties. The influence of these well bore characteristics may be most important during the drift phase of the tests. If experience with drift-pumpback tests shows that interpretation of results will not be possible, injection-pumpback tests may be substituted for remaining drift-pumpback tests.

Two-well recirculating tests will be conducted in the C-hole intervals that have large hydraulic conductivity. Two tests will be conducted in the permeable zone of the lower Bullfrog Member. One test will use wellsUE-25c#2 and UE-25c#3 while the second test will use either UE-25c#1 and UE-25c#3, or UE-25c#1 and UE-25c#2. If the results of these multiple-well hydraulic tests show hydraulic connection between the lower Bullfrog and upper Tram members, a cross-hole recirculating test may be conducted by injecting water into the Bullfrog and pumping from the Tram Member.

Each two-well recirculating test will be conducted in the following manner: Packers will be used to isolate the test intervals in a pumping and injecting well. Water will be pumped from one well at a rate of between 6.3 and 18.9 L/s and injected into the second well. Pumping will continue for approximately three days until a steady-state flow system is established. Pressure transducers will be used to monitor the pressure changes. Conservative tracers will be mixed with water and injected into the aquifer. To determine the effect of matrix diffusion on the migration of tracers, colloids of various sizes will be considered for use in conjunction with conservative tracers, such as 3-trifluoromethylbenzoate. Colloidal and other tracers will be selected such that some tracers will be expected to diffuse into the rock matrix whereas others will not. The tracer will be injected as a short pulse. The steady-state recirculating flow pattern will be maintained following tracer injection. Samples of pumped water will be collected and analyzed for tracer concentration. Sampling will continue for at least one week to ensure that all the tracer has time to move through the formation.

Two-well convergent tracer tests will be conducted in the C-hole intervals that have large hydraulic conductivity. One test will be conducted in the permeable zone of the lower Bullfrog Member and one test will be conducted in the upper Tram Member. Additional tests will be done using various combinations of pumping and injection intervals to evaluate directional characteristics of hydraulic and transport properties. Ideally one or more convergent tests would be conducted during each cross-hole hydraulic test (Activity 8.3.1.2.3.1.4). Each test will be conducted by installing packers in two wells to isolate the permeable interval. Pressure transducers will be installed in all C-holes. Water will be pumped at a rate of between 6.3 to 18.9 L/s from the isolated interval in one well until a steady-state flow system develops. Conservative tracers will be placed in the isolated interval of the second well and will move along converging flow paths toward the pumping well. Water samples obtained from the pumping well will be analyzed for tracer concentration. Pumping and water-quality monitoring will continue for at least four weeks or until measurements indicate that no further recovery of tracer is made by continuing the pumping.

Porous-media techniques will be used to interpret the results of the tracer tests at the C-holes. Analytical methods such as Grove and Beetem (1971) will be used to interpret the results of the two-well recirculating tests. Analytical methods will be useful if the flow system can be represented as a homogeneous media. Numerical models will be useful in both homogeneous and heterogeneous media. Two-dimensional numerical models will be used to interpret drift-pumpback tests and converging tests. If the results of the hydraulic tests indicate that flow is three dimensional, numerical transport models such as Glover (1986) will be adopted for use at the C-holes. Dual-porosity models such as Huyakorn et al. (1983) will be used if test data show evidence of transport in both fractures and intervening unfractured blocks.

Initial porous-media interpretation of tracer-test results will be done using a constant dispersion coefficient or scale dependent dispersion similar to Winter et al. (1984). If test results show transport behavior is not Fickian, analysis of dispersion will be conducted within a stochastic framework similar to one used by Smith and Schwartz (1980) to investigate transport in a parallel-flow field. Stochastic analysis of dispersion in conjunction with field-scale tracer tests has not been attempted previously.

The fracture-network model developed by Lawrence Berkeley Laboratory (Activity 8.3.1.2.3.3.2) will be applied to interpret the results of the tracer tests at the C-holes. Network modeling, described in Activity 8.3.1.2.3.1.4 (multiple-well interference testing), will result in a set of fracture networks that successfully simulate pumping-test results. This set of networks will be used in attempts to simulate tracer-test results. The subset of networks that successfully simulates both hydraulic and tracer tests, will be considered representative of the fracture system at the C-hole location.

Aquifer properties, estimated by porous-media techniques and fracture networks that successfully simulate tracer-test results, will be compared. Differences and similarities in the results of the two methods will be identified. In comparing the two methods, special attention will be given to differences in estimates of the magnitude and distribution of hydrodynamic dispersion and effective porosity. Evidence to support the idea of using a porous-media model to simulate flow and transport in fractured rocks would include dispersion with a normal distribution and constant effective porosity. Evidence to support the idea of using a fracture-network model would include nonnormal dispersion and directional variation in effective porosity, even at large scales.

Results of multiple-well tests will be compared with the results of the single-well tests. Possible reasons for differing results will be identified. The comparisons will be used to decide if the single-well tests can be conducted throughout Yucca Mountain and produce meaningful results, or if additional drilling of multiple-well sites will be needed.

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8.3.1.2.3.1.6 Activity: Well testing with conservative tracers throughout the site

Objectives

The objective of this activity is to determine the following properties at the Yucca Mountain site: (1) effective porosity, (2) longitudinal dispersivity, and (3) regional pore-water velocity.

Parameters

The parameters of this activity are

1. Effective porosity.
2. Dispersivity.
3. Velocity.
4. Hydraulic conductivity.
5. Storage coefficient.
6. Fracture characteristics.

Description

The methods used for testing throughout the site will depend on the results of testing at the C-holes. If drift-pumpback tests give reliable results at the C-holes, then several wells will be selected for single-well testing. If drift-pumpback testing at the C-holes shows that single-well tests cannot be used with confidence, then single-well testing throughout the site will not be conducted. Instead, a second multiple-well location will be proposed and, if developed, tests will be conducted to indicate the range of variations in aquifer properties and transport characteristics that might be expected throughout the site. The methods that might be used at the other wells and proposed multiple-well location are described in the following paragraphs.

Existing geophysical logs for all hydrologic wells in the saturated zone will be reviewed to identify appropriate intervals for conducting tracer tests. Approximately, five to ten wells will be selected for testing (Figure 8.3.1.2-28). The wells will be distributed throughout the site in areas that are likely to be hydraulically downgradient from the repository block. If existing geophysical logs are not sufficiently detailed for the needs of the tracer testing, additional sonic-televiewer, tracejector and heat-pulse logs will be run. Fracture logs will be used to describe the statistical characteristics of fractures intercepted by the boreholes. Results of the log analysis will be used to identify several intervals in each well where tracer tests will be conducted.

Pumping tests will be conducted in each well. Packers will be installed to isolate intervals that will be used in tracer tests. Pressure transducers will be installed in the well to be pumped and any nearby wells that may respond to pumping. In most instances, no observation well will be available. A pump will be installed; water will be withdrawn from the isolated test interval at a rate of between 3.2 to 12.6 L/s; and the pressure response will be monitored. Emphasis will be placed on collecting pressure-response data during the early part of each test because the data may be useful in

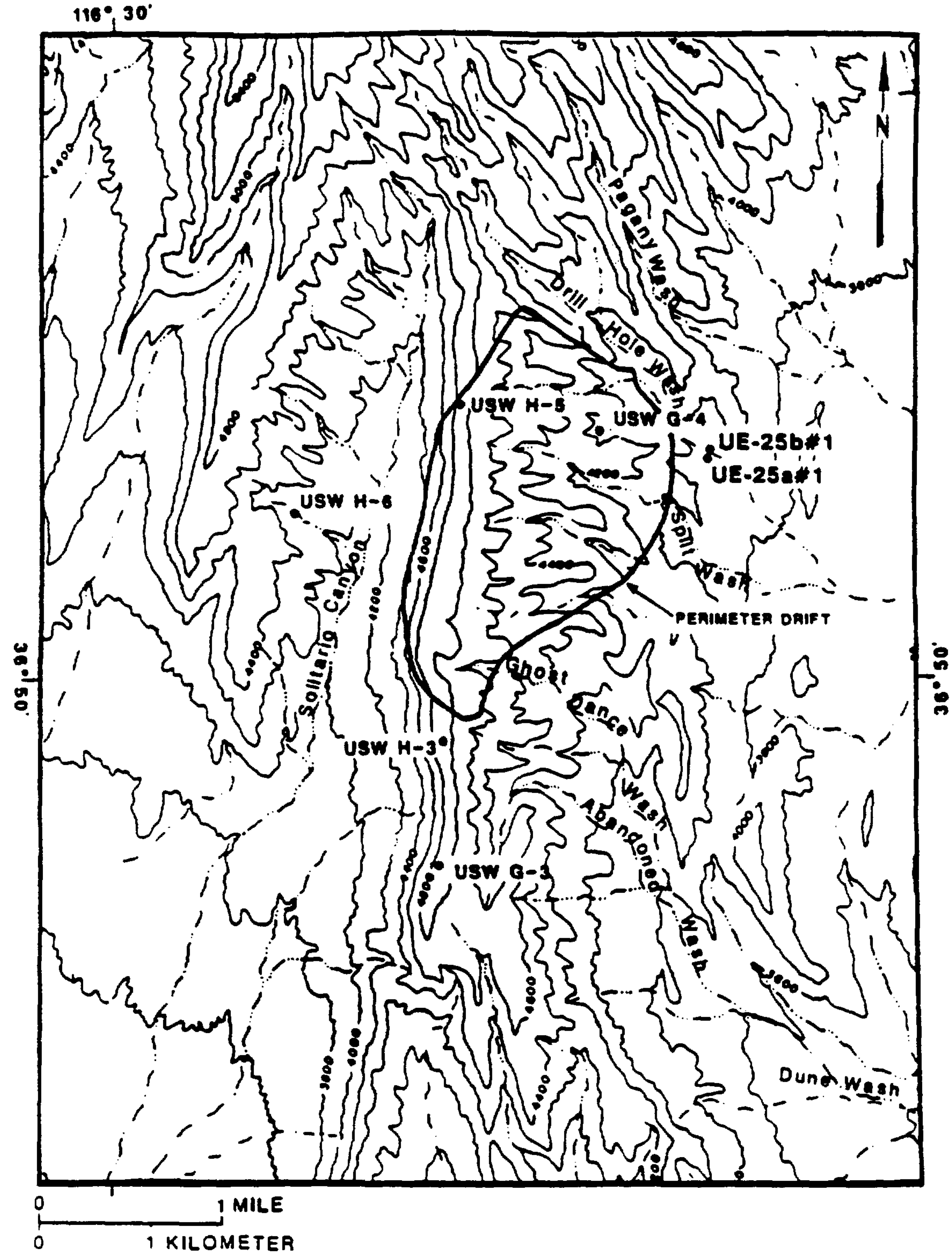

Figure 8.3.1.2-28. Location of the saturated-zone wells that might be used for additional tracer testing.

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understanding the average distance that the tracer will need to move before entering the fracture network near the well. Pumping will continue for approximately 3 to 5 days or until a steady-state flow is established. The pump will be turned off and pressure-recovery data will be collected for a period that is at least equal to the pumping period. Test results will be interpreted using porous-media and/or fracture-network techniques that proved successful when applied to pumping-test results at the C-holes.

Drift-pumpback tests will be conducted in approximately five to ten wells. Within each well, drift-pumpback tests will be conducted in two intervals that have a large hydraulic conductivity. The tracer that is placed in the selected intervals, including 3-trifluoromethylbenzoate, will drift into the formation under steady-state hydraulic gradients. Pretest sensitivity analysis and simulation of the flow system at each well tested will be used to identify reasonable periods of time for the drift phase of these tests. The drift phase will be sufficiently long to permit the tracer to move out of the fractures that intercept the borehole and into the fracture network. In this manner, the influence of individual fractures on seepage velocity will be minimized. Upon completion of the drift phase, a pump will be installed and water withdrawn from the tested interval to begin the pumpback phase of the test. The pumping rate will be 3.2 to 9.6 L/s. The rate of pumping will be measured by an in-line flow meter, and water temperature will be monitored by a thermocouple. Samples of pumping water will be collected and analyzed for tracer concentration. Pumping will continue for at least three days or until virtually all the tracer is recovered. Effective porosity, longitudinal dispersivity and regional pore-water velocity will be determined at each well tested. Porous-media and/or fracture-network techniques will be used to interpret the results of these drift-pumpback tests. Interpretive techniques to be used in the tracer studies at the C-holes will be compared to identify an appropriate technique for application throughout the site.

If the results of the tracer studies at the C-holes show that single-well tests do not give reliable estimates of aquifer properties, then a second multiple-well location will be proposed; if accepted, wells will be drilled and hydraulic and tracer testing will be conducted. A location southwest of the repository block will be selected. The wells will be located as close to the block as practical. A location will be selected where the physical rock properties are significantly different from those of the C-hole location. Three wells will be drilled to depths of approximately 300 m below the water table. Well construction and completion will be similar to the C-holes. Spacing of the wells cannot be stated exactly but some change from the spacing of the C-holes can be expected. Geophysical logs, including sonic televiewer, tracejector, and heat pulse, will be run and interpreted to characterize fractures and identify appropriate intervals for tracer testing.

Pumping tests will be conducted at this second multiple-well location to determine the nature of hydraulic connection among wells. Packers will be installed to isolate intervals that will be used in the tracer tests. Pressure transducers will be installed in all three wells and any nearby wells that may respond to pumping. In each test, a pump will be installed; water will be withdrawn from the isolated test interval at a rate of between 3.2 and 12.6 L/s; and the pressure response will be monitored. Emphasis will be

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placed on collecting pressure-response data during the early part of each test because the data may be useful in understanding the average distance that the tracer will need to move before entering the fracture network near the well. Pumping will continue for approximately 3 to 5 days or until steady-state flow is established. The pump will be turned off and pressure-recovery data will be collected for a period that is at least equal to the pumping period. Test results will be interpreted using porous-media and/or fracture-network techniques that proved successful when applied to pumping-test results at the C-holes.

Two-well recirculating tests will be conducted in well intervals that have large hydraulic conductivity. Two tests, each using different pumping and injecting wells, will be conducted in an approximately horizontal zone of increased hydraulic conductivity. These tests will be used to investigate the symmetric and isotropic nature of transport characteristics. A third test will be conducted in a separate permeable interval. If the results of the multiple-well hydraulic tests show vertical hydraulic connection between permeable zones, a cross-hole recirculating test may be conducted.

Each two-well recirculating test will be conducted in the following manner. Packers will be used to isolate test intervals in a pumping and injecting well. Water will be pumped from one well at a rate of between 6.3 and 18.9 L/s, and injected into the second well. Pumping will continue approximately 8 days until a steady-state flow system is established. Pressure transducers will be used to monitor pressure changes. Conservative tracers, including 3-trifluoromethylbenzoate, will be mixed with water and injected into the aquifer. The tracer will be injected as a short pulse. The steady-state recirculating flow pattern will be maintained following the tracer injection. Samples of pumped water will be collected and analyzed for tracer concentration. Sampling will continue for 1 to 3 weeks to ensure that all the tracer has had time to move through the formation. Test results will be interpreted using porous-media and fracture-network techniques that proved successful when applied to tracer-test results at the C-holes.

8.3.1.2.3.1.7 Activity: Testing of the C-hole sites with reactive tracers

Objectives

The objective of this activity is to characterize the chemical and physical properties of the geologic media in the saturated zone in the vicinity of the C-holes that will affect radionuclides retardation during ground-water flow within the saturated zoned.

Parameters

The parameters for this activity are

1. Adsorption rate constants.
2. Sorption equilibrium constants.

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Description

Tracer identification and characterization

A group of tracers will be selected that will aid in evaluating various controlling mechanisms of radionuclide sorption by the geologic media within the saturated zone in the vicinity of the C-wells. The tracers will be used in field tests that are part of site characterization investigations.

First, a screening of potential tracers to define controlling sorption mechanisms in various minerals will be conducted from literature reviews and consultations with experts. Second, laboratory tests will be conducted to select those procedures and analyses (for geologic material and water) that can facilitate the distinction among prevailing sorption mechanisms. Third, modeling of sorption experiments will be conducted using both kinetics and equilibrium expressions. Geochemical modeling will assist in defining the prevailing sorption mechanisms in laboratory studies.

The approach used to select these tracers is based upon the possible occurrence of various sorption mechanisms between solutes and geologic media. These mechanisms can be generally classified into two categories, physisorption and chemisorption. Physical adsorption exhibits low-energy changes in physical and chemical properties of the solute. On the other hand, chemical bonding results in energy changes that are strong enough to make the adsorbate (solute) exhibit physical and chemical properties different from those in solution. For example, physisorption shows heats of adsorption of 30 to 50 kJ $mole^{-1}$ compared with 200 to 500 kJ $mole^{-1}$ in chemisorption. Physical adsorption is characterized by small changes in vibrational frequency (~0.1%), while chemical adsorption is characterized by large changes (>0.1%). Chemical bonds, in contrast to physical bonds, are not readily broken at low temperatures. There is a third category, less understood, where sorption may have characteristics of both chemical and physical adsorption.

Within the two general categories of adsorption, two major mechanisms, and possibly a third, are of concern in these investigations: electrostatic adsorption, chemisorption, and possibly, molecular sieve. Electrostatic adsorption represents for this study a physical adsorption where ions in solution migrate to a diffuse layer because of electrostatic attraction of ions to a surface of opposite charge and because of the dispersive influence of diffusion forces. Ion exchange behavior is included in this definition. Chemisorption refers to those cases where forces with the order or magnitude of chemical bonds hold the adsorbate (solute) to a site surface. Molecular sieve falls in the category of physical sorption with energies of adsorption representing diffusional activation energies that are present when molecules are caught in cages as in zeolites.

This task will also evaluate manufactured polystyrene spheres as colloid tracers. These colloid tracers will be evaluated as to their interaction with the other tracers. These spheres have been shown to be conservative, and their size (1 micron) is larger than the dissolved chemical species so the spheres travel through the paths with the largest fractures or pores. It is anticipated that in fractured media, the polystyrene spheres will provide some information on fracture aperture.

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The rationale for using sorption mechanisms as a basis for selecting the tracers is the assumption that either of the three general mechanisms can prevail in the sorption of radionuclides at Yucca Mountain. The link between the radionuclides and the sorption mechanisms must be made in the laboratory because of constraints for environmental regulations and the complex chemistry exhibited by many of the actinides. Another advantage of using the sorption mechanism criterion for the reactive tracer study is the acquisition of fundamental information describing the interactions of general tracers with the rock media. This information increases the ability to interpret field experiments because marked differences in relative behavior of the mechanisms can provide a better insight into tracer response. An example is electrostatic sorption, which is a relatively reversible process as compared with chemisorption.

In this study, a combined approach is proposed that is a compromise between a more rigorous analysis based on surface coordination theory, for example, triple-layer concepts, and the more "empirical" approach associated with development of simple isotherms. Rates and isotherms will be derived to describe mathematically the generalized reaction of the tracers with the solid tuff material. At the same time, experiments will be conducted with individual minerals present in the tuff to develop a fundamental data base for mineral-tracer interactions. The number of minerals will be limited to those that are expected to be more reactive, for example, iron oxides. In this manner, some elements of a more rigorous approach are used. This work complements the empirical and mechanistic sorption work in Activity 8.3.1.3.4.1. The data obtained in the C-well reactive tracer work is specific to the C-well site (i.e., mineralogy, stratigraphic unit) and specific only to evaluation of proper tracers for this field test. The mechanistic work of Activity 8.3.1.3.4.1 is applied to the understanding of actinide sorption and will extrapolate or determine a spatial distribution of sorption for all important radionuclides across the site.

Initially, batch experiments will be performed with the primary emphasis on kinetics and equilibrium experiments. Column experiments will follow the batch experiments to evaluate simultaneous migration and interactions among selected tracers, including colloids, under various flow conditions. Geologic material, or their surrogates, and water from the Yucca Mountain vicinity will be used in experiments for isotherm development. Minerals, extracted from Yucca Mountain samples or purchased, and electrolyte solutions will be used in experiments to collect fundamental data on mineral-tracer interactions.

Initial batch experiments will attempt to identify tracers retarded by the primary controlling mechanism using thermodynamic indicators, adsorption-desorption differences, or response to desorption with electrolyte solutions. Supporting experiments will determine changes in electrostatic behavior, for example, zero point of charge. Also, batch experiments will be used to develop kinetics and equilibrium models. Laboratory column experiments will provide breakthroughs to simultaneously evaluate the selected tracers for their interactions with each other and their behavior in a transport environment. These breakthrough curves will also serve to validate the applicability of the models developed from batch data to continuous flow conditions.

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Appropriate sorption expressions, both kinetics and equilibrium, will be used to model experimental sorption data. The parameters from these models will be used in defining sorption processes and in predicting and interpreting field-observed breakthrough curves for the well experiments. Geochemical models will assist in designing laboratory experiments and in defining prevailing sorption mechanisms.

Modeling of tests

Concurrently with the tracer identification and characterization task, an extensive program of numerical modeling of the reactive-tracer field tests will be conducted. The purpose of this modeling is to define concentration ranges of tracers for the field tests and to indicate an expected duration and sampling frequency. Modeling of both single-well and multiple-well experiments will be conducted. Currently, it is unknown if the hydraulic response at the scale of the C-wells can be treated as a porous media equivalent. Therefore, both fracture network and porous media continuum models will be used. The media properties used in the numerical modeling will be obtained on a continuing basis; as the tests yield more information about the flow and media characteristics in the regions of the intended tests, these data will be incorporated into the numerical modeling.

Single-well tests

The type of tests, either injection-backflow or drift-pumpback, procedures, pumping rates, tracers, initial tracer concentrations, and durations of single-well tests will be specified by the results of the modeling studies. The goals of the single-well tests are (1) to demonstrate the use of reactive tracers in field tests and (2) to evaluate retardation characteristics of the saturated zone in the region near each of the wells tested.

Multiple-well tests

Two types of multiple-well tests are proposed: two-well recirculating and convergent tests. As for the single-well tests, modeling will be used in conjunction with information on the tracers to design these experiments.

Analysis of test results

In each field test a conservative (nonreactive) tracer will be added with the reactive tracer to permit calculation of flow velocity and dispersion of the tracer. These values will then be used with laboratory values of the sorption parameters for the reactive tracers to predict the response of the reactive tracer. In this way the laboratory parameter values for sorption are evaluated against field data. By making the laboratory connection with radionuclides, the retardation characteristics of the tested regions can be calculated.

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8.3.1.2.3.1.8 Activity: Well testing with reactive tracers throughout the site

Objectives

The objective of this activity is to characterize the chemical and physical properties of the geologic media in the saturated zone throughout the site that will affect radionuclide retardation during ground-water flow within the saturated zone.

Parameters

The parameters for this activity are

1. Adsorption rate constants.
2. Sorption equilibrium constants.

Description

Tracer identification and characterization

The same reactive tracers as were used in the C-hole experiments (Activity 8.3.1.2.3.1.7) will be used unless there is an unexpected change in geologic characteristics or ground-water chemistry. Some laboratory experiments will be required to estimate sorption parameters for the reactive tracers.

Modeling of tests

The wells used for this activity will be the same as those used for conservative (nonreactive) tracer tests throughout the site (Activity 8.3.1.2.3.1.6). The modeling will follow the same procedure as was used for the C-hole reactive tracer tests (i.e., laboratory values for sorption parameters will be used to design the tests). Modeling of both single-well and multiple-well tests will be conducted. Again, the type of model, fracture network versus porous media equivalent, cannot be determined until hydraulic studies have been completed. The media properties used in modeling will be obtained on a continuing basis, so the modeling will be as accurate as possible. The experience gained from the C-hole tests and modeling is expected to reduce significantly the amount of modeling required for this activity.

Single-well tests

If single-well tests in the C-holes indicate that good information on radionuclide retardation properties can be obtained from single well sorbing-tracer tests further single-well tests will be performed throughout the site. The number of tests will be determined by the availability of test wells, amount of information desired, and quality of information attainable. As noted previously, test procedures and specifications will be determined by the pre-test modeling studies.

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Multiple-well tests

If single-well tests do not provide sufficient information, a multiple-well location will be proposed and, if accepted, additional tests will be conducted. If this occurs and the C-hole tests indicate that multiple-well tests give useful information about radionuclide retardation properties in the saturated zone, then this multiple-well location will be used for further reaction tracer tests.

Analysis of test results

Analyses will proceed in the same fashion as was used in the C-hole study (Activity 8.3.1.2.3.1.7). A conservative tracer will be injected with the reactive tracer, and the conservative tracer will be used to estimate velocity and dispersion parameters. Then using laboratory-derived sorption parameters, the response of the reactive tracer will be predicted and compared with the field test. By making a connection in the laboratory between radionuclides and these tracers, inferences about radionuclide retardation can be made.

8.3.1.2.3.2 Study: Characterization of the saturated zone hydrochemistry

The objectives of this study are to (1) describe the chemical composition of, and spatial compositional variations in, saturated-zone ground waters using new and extant data; (2) identify the chemical and physical processes that influence ground-water chemistry; and (3) aid in the identification and quantification of fluxes to, from, and within the saturated zone.

Four activities are planned to meet these objectives. The activities are (1) assessment of saturated-zone hydrochemical data availability and needs, (2) hydrochemical characterization of water in the upper part of the saturated zone, (3) regional hydrochemical characterization, and (4) synthesis of saturated-zone hydrochemistry.

8.3.1.2.3.2.1 Activity: Assessment of saturated-zone hydrochemical data availability and needs

Objectives

The objectives of this activity are to

1. Compile and evaluate extant hydrochemical data for the saturated zone.

2. Identify data deficiencies and potential sampling sites and assemble requisite material for sample and field data collection.

3. Augment extant information by collecting and analyzing new hydrochemical samples and data.

Parameters

The parameters for this activity are

1. Chemical concentration.
2. Stable-isotope ratio.
3. Radioisotope activity.

Description

Extant hydrochemical data for the saturated zone at Yucca Mountain, the Nevada Test Site, and the surrounding region will be compiled. The ionic balance of each analysis will be calculated as a means of initially assessing the quality of the data. Preliminary maps and cross sections of the spatial distributions of selected dissolved species and/or physical parameters will be prepared to depict the extant level of information. Published water-level maps will provide information about ground-water flow directions and gradients. This information will be reexamined as additional data become available. Published geologic descriptions of the site and the surrounding region will provide the locations of major structural features and information regarding formation geometries and lithologies. All the previously noted information will be integrated to delineate areas where additional data are needed.

Water samples will be collected to satisfy identified data needs when sampling opportunities arise in the course of other investigative activities, or when other satisfactory sampling sites are identified. All samples will be analyzed in the field for unstable constituents and intensive properties. They will be analyzed in USGS and contract laboratories for inorganic chemical concentrations; activities of selected radioisotopes, including tritium (hydrogen-3), carbon-14, and chlorine-36; and ratios of selected stable isotopes, including those of carbon, hydrogen, oxygen, strontium, and sulfur.

8.3.1.2.3.2.2 Activity: Hydrochemical characterization of water in the upper part of the saturated zone

Objectives

The objectives of this activity are

1. To describe the hydrochemistry of the upper part of the saturated zone by collecting representative water samples from intervals within the upper 100 m of the saturated zone, within and adjacent to the site area, and studying their chemical and isotopic compositions.

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2. To estimate flux to or from the saturated zone by collecting interstitial water and gas samples from immediately above the water table and studying their chemical and isotopic compositions.

Parameters

The parameters for this activity are

1. Chemical concentration.
2. Stable-isotope ratio.
3. Radioisotope activity.

Description

Fourteen wells that penetrate from 43 to 99 m into the saturated zone have been constructed within the site area (Table 8.3.1.2-10). These water-table (WT) wells are presently part of the water-level monitoring program. Each has been equipped with 2-in. inner-diameter access tubing for water-level measurement; some are instrumented for continuous water-level data collection. The Desert Research Institute collected water samples from five of these wells in early 1988. The samples were collected from within the access tubing with a small-capacity submersible piston pump. These are the only samples that have been collected from these wells. At least eight additional WT wells will be drilled in the course of other investigations of the saturated-zone geohydrologic system (Table 8.3.1.2-10).

Water samples will be collected from each of the extant and planned WT wells using a submersible electric pump. If determined to be feasible, a packer will be installed at appropriate locations in selected boreholes to enable collection of samples from both the upper and lower parts of the saturated interval penetrated by the wells. After samples have been collected, a removable packer/plug and two access tubes will be set about 10 m below the water surface in each well. An additional sample or samples will be collected from this isolated upper interval at a later date, using a small-capacity submersible piston pump.

All samples will be analyzed in the field for unstable constituents and intensive properties. They will be analyzed in USGS and contract laboratories for inorganic chemical concentrations; activities of selected radioisotopes, including tritium, carbon-14, and chlorine-36; and ratios of selected stable isotopes, including those of carbon, hydrogen, oxygen, strontium, and sulfur. These data will significantly augment the hydrochemical data base for the saturated zone within and adjacent to the site area, as existing information include data from intervals much deeper than those penetrated by the WT wells.

Selected planned WT wells will be cored for about 25 m immediately above and into the saturated zone. Interstitial gases and water will be extracted from several sections of unsaturated core from each well. Several sections of drained saturated core will also be squeezed to extract water from the rock matrix, if feasible. The cored wells and, if feasible, several of the extant WT wells will be sampled for interstitial gases from a discrete

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Table 8.3.1.2-10. Existing (November 1986) and planned water-table wells to be sampled and logged

Well number	Well depth (m/ft)	Approximate depth to water (m/ft)	Thickness of saturated interval penetrated (m/ft)
USW WT-1	515/1,689	471/1,545	44/144
USW WT-2	628/2,060	571/1,873	57/187
UE-25 WT#3	348/1,142	301/986	48/156
UE-25 WT#4	482/1,580	439/1,440	43/140
UE-25 WT#6	383/1,256	284/932	99/324
USW WT-7	491/1,610	421/1,382	69/228
USW WT-8[a]	640/2,100[b]	ND[c]	ND
USW WT-9[a]	670/2,198[b]	ND	ND
USW WT-10	431/1,413	343/1,142	83/271
USW WT-11	441/1,446	364/1,194	77/252
UE-25 WT#12	399/1,310	345/1,132	54/178
UE-25 WT#13	352/1,155	303/994	49/161
UE-25 WT#14	399/1,310	346/1,136	53/174
UE-25 WT#15	415/1,360	354/1,162	60/198
UE-25 WT#16	521/1,710	473/1,552	48/158
UE-25 WT#17	443/1,453	395/1,296	48/157
USW WT-19[a]	335/1,099[b]	ND	ND
USW WT-20[a]	305/1,000[b]	ND	ND
USW WP-21[a]	550/1,805[b]	ND	ND
USW WT-22[a]	395/1,296[b]	ND	ND
USW WT-23[a]	670/2,198[b]	ND	ND
USW WT-24[a]	670/2,198[b]	ND	ND

[a]Planned well.
[b]Estimated depth.
[c]ND = no data.

unsaturated interval adjacent to the water table following water-sample collection. Analytical data from these samples will also be used in Study 8.3.1.2.2.7 (hydrochemical characterization of the unsaturated zone).

Data from the WT wells will enable hydrochemical characterization of the upper part of the saturated zone, and comparison with the hydrochemistries of deeper intervals. The comparisons will aid in the development and refinement of a conceptual model of fluid movement in the saturated zone, with respect to fluid flow paths, velocities, and residence times. The data will also enable hydrochemical characterization of that part of the unsaturated zone adjacent to the water table. These data will augment the conceptualization and refinement of flux at the saturated-unsaturated zone interface.

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Caliper, epithermal-neutron porosity, magnetometer, magnetic, susceptibility, and possibly other experimental and supporting logs will be run from total well depth to land surface in each of the extent WT wells. These data will (1) aid in the evaluation of physical formation properties, (2) aid in stratigraphic correlations, and (3) determine vertical profiles of water content in the unsaturated zone. This data-collection activity will be carried out under Activity 8.3.1.4.2.1.3 (borehole geophysical surveys), and will precede sampling if it is logistically more efficient.

8.3.1.2.3.2.3 Activity: Regional hydrochemical characterization

Objectives

The objective of this activity is to describe regional spatial variations in ground-water chemistry in the saturated zone by collecting representative water samples from wells and springs within the region and by studying their chemical and isotopic compositions.

Parameters

The parameters of this activity are

1. Chemical concentration.
2. Stable-isotope ratio.
3. Radioisotope activity.

Description

Water samples will be collected from selected springs and extant wells within the Nevada Test Site and the surrounding region. As appropriate, newly drilled wells will be sampled, but no drilling is proposed for this activity. Sites selected will include some of those where alternative conceptual models of the regional geohydrologic system will be tested by Study 8.3.1.2.1.3 (characterization of the regional ground-water flow system), particularly with regard to ground-water flow rates and directions, and to support the designation of flow-system boundaries. Hydrochemical data from these sites will also provide insight as to the origin of anomalous features in the regional potentiometric surface.

Water samples will be analyzed in the field for unstable constituents and intensive properties. They will be analyzed in USGS and contract laboratories for inorganic chemical concentrations; activities of elected radioisotopes, including tritium, carbon-14, and chlorine-36; and ratios of selected stable isotopes, including those of carbon, hydrogen, oxygen, strontium and sulfur. Water-level drawdown and recovery data will be collected from wells during and after sampling, and used by Study 8.3.1.2.1.3 (characterization of the regional ground-water flow system) to estimate saturated hydraulic conductivities.

Hydrochemical data will be combined with existing data (Walker and Eakin, 1963; Schoff and Moore, 1964; Robinson and Beetem, 1965; Naff, 1973; Winograd and Thordarson, 1975; Benson et al., 1983; Classen, 1985) to

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describe the spatial compositional variations in regional ground-water chemistry. Radioisotope data will enable estimates of ground-water ages and flow rates. Stable isotope and inorganic concentration data will provide insight as to the origins, evolution, and mixing of ground waters, and will aid in comparison of site-specific data in order to delineate possible flow paths. These data will also be used by Activity 8.3.1.2.3.2.4 (synthesis of saturated-zone hydrochemistry) to identify the chemical and physical processes that influence ground-water chemistry; to aid in the identification and/or quantification of ground-water travel times, flow paths, and fluxes to, from, and within the saturated zone; and to estimate climatic conditions during periods of recharge. The data will also be part of the information base used by Study 8.3.1.3.1.1 (ground-water chemistry model).

8.3.1.2.3.2.4 Activity: Synthesis of saturated-zone hydrochemistry

Objectives

The objectives of this activity are to

1. Describe the saturated-zone hydrochemistry.

2. Identify the chemical and physical processes that influence ground-water chemistry.

3. Aid in the identification and/or quantification of ground-water travel times; climatic conditions during periods or recharge; flow paths; and fluxes to, from, and within the saturated zone.

Parameters

The parameter for this activity is geochemical reaction modeling.

Description

Graphical methods will be used to describe spatial distributions of selected chemical and isotopic data. Variations will be integrated with extant information describing ground-water flow directions, spatial distributions of secondary minerals, spatial petrologic variations, and whole-rock and mineralogic compositions, in order to identify sources and sinks of dissolved materials, to infer sources and areas of recharge, and to estimate ground-water flow paths, flow rates, and residence times.

The geochemical modeling code EQ3NR/EQ6 (Wolery, 1979; 1983) will be used with the bases of hydrochemical and mineralogic data to (1) calculate the specifications of dissolved materials, (2) determine the saturation states of relevant solid phases, and (3) test plausible water-rock reaction models. The results of these efforts will aid in the identification of the geochemical process that have combined with ground-water flow to determine the present ground-water chemistry. Process identification will also contribute to an understanding of the paleohydrology of the region, and to general resolution of ground-water flow paths, residence times, and recharge

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conditions. The analytical and process data will also comprise part of the geochemical base needed by performance and design issues 1.1 through 1.12, as addressed by Section 8.3.1.3.

The information generated by this activity will constitute "nonhydraulic" tests of alternative conceptual models of the ground-water flow system.

8.3.1.2.3.3 Study: Saturated zone hydrologic system synthesis and modeling

The objectives of this study are to (1) synthesize the available data into a model and make a qualitative analysis of how the system is functioning and (2) represent quantitative observations of hydrogeologic data pertaining to the ground-water flow system in a comprehensive flow model. Three activities are planned to analyze and integrate the data in order to satisfy these objectives. The planned activities are the conceptualization of the saturated zone flow models within the boundaries of the accessible environment; the development of a fracture network model; and the calculation of flow paths, fluxes, and velocities within the saturated zone.

8.3.1.2.3.3.1 Activity: Conceptualization of saturated zone flow models within the boundaries of the accessible environment

Objectives

The data objectives of this activity are to synthesize the available hydrogeologic data to develop a conceptual model and make a qualitative analysis of how the site saturated-zone hydrogeologic system is functioning.

Parameters

The parameters for this activity are spatial distribution of the hydrogeologic units and their hydraulic properties, including

1. Hydraulic conductivity.
2. Hydraulic gradient.
3. Effective porosity.
4. Flux.
5. Water chemistry.
6. Storage properties.
7. Potentiometric surface configuration.

Description

All reliable data and reasonable interpretations of these data will be assimilated into a description of the saturated-zone flow system within the boundaries of the accessible environment. This description will include the physical and hydraulic characteristics of the rock units and structural features, as well as the likely flow-system operation within this framework.

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The data will contain information accumulated from the published literature and the Yucca Mountain Project activities. This conceptual description of the flow system will be incorporated into computer models as the baseline condition for ground-water flow at the site.

8.3.1.2.3.3.2 Activity: Development of fracture network model

Objectives

The objectives of this activity are to

1. Develop and evaluate methods for simulating ground-water flow and conservative solute transport in saturated fractured rock beneath Yucca Mountain.

2. Relate results of hydraulic and conservative-tracer tests in wells to fracture-network characteristics at Yucca Mountain.

3. Develop methods for identifying transmissive fracture zones in rocks penetrated by boreholes.

4. Identify geohydrologic conditions at Yucca Mountain where ground-water flow and conservative solute transport can be properly evaluated using the porous-medium assumption.

Parameters

The parameters for this activity are various flow and transport characteristics needed to predict rates and directions of ground-water flow and radionuclide migration, including

1. Hydraulic conductivity.
2. Storage coefficient.
3. Effective porosity.
4. Hydrodymanic dispersion.
5. Hydraulic gradients.

Description

Major technical components of the hydrologic analysis of fracture networks are broadly placed into three tasks. The first task (preliminary model development) emphasizes model development and evaluation using existing data or data that can be readily obtained. The second task (analysis of well tests) emphasizes model refinement and validation at multiple-well locations in the saturated zone beneath Yucca Mountain. The third task (analysis at the scale of Yucca Mountain) emphasizes model development at the scale of Yucca Mountain and characterization of spatial variations in aquifer properties in the vicinity of Yucca Mountain.

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Preliminary model development will include development and documentation of computer programs to describe fracture-network geometry and to simulate flow and transport in fractured rock. A model will be developed that is capable of simulating ground-water flow and conservative-solute transport in a saturated discrete-fracture network. The model will be used to simulate pumping and tracer tests at the C-holes. Existing codes are specialized for column research and do not include well-boundary conditions that occur during pumping and tracer tests. The new model will include two computer codes, a fracture-mesh generator and a flow- and-transport code. The fracture-mesh generator will be capable of reproducing statistical descriptions of fracture characteristics. The flow-and- transport code will be capable of simulating both steady-state and transient conditions within the fracture network.

Although the fracture-network model will be developed primarily for application at the C-holes, it will be written with a broad range of potential applications in mind. Boundary conditions will not be restricted to those that will be encountered during pumping and tracer tests but will include boundaries that would be encountered at other scales. Initially the model will be developed on the basis of parallel-plate theory but will also be written in a modular manner so that new theories, such as channeling within single fractures, can be readily included in the codes as they become available. By writing the model in this manner, it will be relatively simple to evaluate the significance of alternative theories when applied to fracture networks. The model will be designed primarily for application in a perturbed flow system that develops during pumping and tracer tests, but also for possible application in a natural system that may exist after radioactive waste is placed in the repository.

Initially, the fracture-mesh generator will be similar to one described by Long et al. (1982). Fractures will be modeled as linear or disc-shaped discontinuities in an impermeable matrix. Fractures will be arbitrarily located within the rock and will have statistical distributions of aperture, length, orientation, and density that can be specified by the user. The mesh generator will be capable of reproducing discrete fractures observed in boreholes. As data and results developed as part of Activity 8.3.1.4.2.2.2 (surface-fracture) network studies become available, these results may be included in the fracture-mesh generator.

The flow and transport code will use a mixed Eulerian-Lagrangian solution technique. Ground-water flow in fractures will be solved using parallel-plate theory within the usual Eulerian framework. Advective transport will be solved by a Lagrangian formulation using particle-tracking techniques. Several techniques, including random-walk theory, will be evaluated before deciding on a method for treating dispersion within single fractures. Modular-program design will make it relatively simple to evaluate techniques for modeling dispersion. Alternative methods for modeling transport at fracture junctions, including complete mixing of solute from different fractures and no mixing, will also be evaluated before finally selecting a method.

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A series of simulations will be designed to test whether the model successfully reproduces known analytical solutions and to evaluate the significance of approximations used in the solution method. Documentation will include descriptions of model theory, use (including input and output descriptions), verification and validation simulations, and program listings.

Parametric studies, using fracture-characteristic data obtained from drillholes UE-25c#1, UE-25c#2, and UE-25c#3 (Figure 8.3.1.2-29), will be done for the following two purposes:

1. To evaluate the effects of fracture characteristics on results of well tests. Such studies may indicate important needs in field investigations, including needs for specific types of well tests. Test designs that are typically used in a porous medium may not be optimal for understanding the hydrologic nature of the fractured rock at Yucca Mountain.

2. To evaluate the general hydrologic behavior of the saturated zone, to establish whether fracture statistics from boreholes at Yucca Mountain are representative of the saturated zone. Special emphasis will be given to (a) identifying scales where flow and transport in a fracture network can be simulated appropriately by analogy to an equivalent porous medium, and (b) investigating the character of convective dispersion.

Fracture networks, used in parametric studies, will bracket the range of uncertainty in fracture characteristics. Fracture frequency and orientation has been measured in boreholes from television and televiewer logs; however, fracture data to describe the distribution of fracture lengths and fracture apertures are not available. Therefore, initial parametric studies will consider fracture networks with uniform lengths and apertures. After the hydrologic response of fracture networks with uniform lengths and apertures is understood sufficiently, distributed lengths and apertures will be used in parametric studies.

Results of Activity 8.3.1.4.2.2.5 (seismic tomography) will be related to characteristics of fracture networks. Major components of the hydrologic investigation that use these results are (1) identification of relations between seismic-wave properties, fractures, and lithology, by prototype vertical seismic profiling at USW G-4; (2) identification of fracture characteristics between boreholes at the scale of well tests by cross-hole seismic profiling at the UE-25c wells and possibly a second multiple-well location; (3) validation of seismic techniques by profiling the exploratory shaft and comparing results to fractures mapped in the shaft; and (4) determination of spatial variations in fracture characteristics in the vicinity of Yucca Mountain by seismic profiling over distances of 0.5 to 1 km.

Fracture networks generated on the basis of preceding geologic and geophysical investigations will be used in the finite-element program to calculate rates of ground-water flow across the network under linear-flow boundary conditions. Rates of flow will be related to hydraulic conductivity of an equivalent porous medium using an approach similar to that described by Long et al. (1982). An approach similar to Endo and Witherspoon (1985) will be used to relate flow rate to hydraulic effective porosity. Methods de-

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scribed by Long et al. (1982) also will be used to identify the scale of representative elementary volumes (REV) of fracture networks; and hence to determine scales where a fracture network can be described by analogy to an equivalent porous medium. The scale of REV may be different for flow and transport.

Multiple fracture networks generated from the same set of fracture statistics may have significantly different hydrologic character. If a fracture system has a REV and the scale of simulation is larger than the REV, by definition, multiple realizations should have reasonably similar hydrologic character. If the scale of simulation is smaller that the REV, the probability of significantly different hydrologic character depends on various parameters, of which fracture frequency and aperture are most critical. The importance of generating multiple fracture networks when applying the fracture-network model in well tests cannot be evaluated until preliminary parametric studies are completed.

The analysis of well tests will be done in two phases. The first, involves testing at the UE-25c wells and will emphasize model refinement, in particular, understanding relations between geophysical and hydrologic models. The previous task, preliminary model development, emphasized the use of existing data or data that could be readily obtained. Some aspects of the conceptual models developed on the basis of these data probably will prove incorrect or will not be sufficiently detailed when applied in deeply buried rocks of the saturated zone beneath Yucca Mountain. Furthermore, no data exist that can be used to investigate possible relations between seismic and hydrologic models. Therefore, significant model refinement is expected as a result of interpreting well tests at the UE-25c wells. (These well tests are described in Activities 8.3.1.2.3.1.4 and 8.3.1.2.3.1.5). The second phase of this activity will emphasize model validation at a second multiple-well location. The second phase will be curtailed if a second multiple-well location is not drilled. Drilling and subsequent hydrologic testing of a second multiple-well location is described in Activity 8.3.1.2.3.1.6.

The hydrologic model of fracture networks will be used to interpret results of hydraulic and conservative-tracer tests at the UE-25c wells. On the basis of results from parametric studies and seismic modeling, a set of fracture networks will be generated that brackets the range of uncertainty in fracture characteristics. These networks will be conditioned so that fractures observed in the boreholes are realized. Components of the geologic model of fracture networks that are uncertain also will be considered in selecting fracture networks. Fracture networks initially generated on the basis of geologic and geophysical evidence will be used to simulate hydraulic-test results. Those networks that best match measured results of hydraulic-stress and tracer tests will be considered representative of the fractured rock in the vicinity of the tested wells. Because fracture-network characteristics probably cannot be determined uniquely by simulation of well-test results, statistical algorithms for determining likely fracture networks will be used.

Assuming a second multiple-well location is drilled and tested, model validation probably will be a four-step process. Because conceptual models have not been formulated in detail, it is not appropriate to speculate on detailed interpretive approaches until gaining experience in testing and

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analysis at the UE-25c wells. The first step in validation will be to drill the wells and collect adequate seismic-profile data to use in geophysical and hydrologic modeling. The second step is to design appropriate hydraulic and tracer tests and predict test results. Geophysical and intraborehole flow data will be used to select appropriate test designs. Geologic and geophysical models will be used to estimate fracture-network geometry. Hydrologic models, using the estimated fracture-network geometry as a basis, will predict test results. Uncertainty in model analysis will need to be evaluated when predicting test results. Therefore, predictions probably will be expressed statistically, either as a range of probable results, or as a best estimate of results and associated confidence regions. The third step will be to conduct the tests. The fourth step in validation will be to compare predicted test results with actual test results.

Hydrologic models that are developed during this investigation probably will be most accurate when applied at the scale of well tests. However, the ultimate use of the model will be at the scale of Yucca Mountain, where details measurable at the scale of well tests will not be measured. Therefore, numerical methods corresponding to the scale of Yucca Mountain will be evaluated and a numerical model will be developed. Computer programs will be written, verified, and documented.

If available, well-documented cases of solute migration in fractured rock will be used to validate models at scales similar to those of Yucca Mountain (1 to 100 km^2). To form an appropriate model-validation exercise, the history of contamination and subsequent migration would need to be known, and the geologic framework would need to be similar to the geologic framework of Yucca Mountain.

Methods for estimating aquifer properties in areas between boreholes will depend on the availability of cross-hole seismic-profiling data and the success in relating seismic-wave propagation to hydrologic properties. If data are available and relations between seismic and hydrologic properties are demonstrated during investigation of multiple-well locations, the geophysical models described previously will be used to estimate spatial variations in fracture networks. Results of geophysical models would then be used in the hydrologic models described previously to predict the spatial distribution of aquifer properties. Aquifer-property estimates obtained from hydrologic well tests, and fracture data obtained from boreholes would be used to condition the predicted spatial distribution of aquifer properties.

If geophysical data are not collected or cannot be used to estimate aquifer properties with confidence, appropriate geostatistical methods might be used to estimate the spatial distribution of aquifer properties. Geostatistical techniques such as kriging and conditional simulation may be appropriate if distances between point estimates of aquifer properties are less than the ranges of the corresponding semivariograms.

8.3.1.2.3.3.3 Activity: Calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment

Objectives

The objectives of this activity are to

1. Estimate ground-water flow direction and magnitude for input into travel-time calculations.

2. Evaluate the porous-media concept and fracture-network concept for determining flow paths, fluxes, and velocities.

Parameters

The parameters for this procedure are

1. Flow paths.
2. Fluxes.
3. Velocities.

Description

Techniques used to interpret results of hydraulic and chemical-tracer tests will be evaluated by the following two criteria:

1. Data must be available at the scale of hydrologic-well tests to justify using the technique. In other words, the technique must not have overly complex data requirements when compared with test data that typically are available.

2. Estimates of flow paths, fluxes, and velocities obtained by applying the technique at the scale of hydrologic-well tests must be reasonably reliable.

Although it is not known if any technique will meet these criteria completely, it is important to make such an evaluation. Techniques that will be evaluated include those based on the concept of an equivalent porous medium, a dual-porosity medium, and a discrete-fracture network. Techniques are described in greater detail in Study 8.3.1.2.3.1 (characterization of the site saturated-zone ground-water flow system).

The relation between techniques applicable at the scale of hydrologic well tests and techniques applicable at regional scales has not been established for most fractured media. Techniques that successfully simulate results or hydrologic-well tests will be extended on a theoretical basis for use in large-scale models. Scale dependence of many model parameters is expected. Hydrologic well tests are conducted in a perturbed flow system, while large-scale models evaluate a relatively unpreturbed system. This raises questions when using well test results in regional analyses.

Applicability of techniques proved successful at the scale hydrologic-well tests to large-scale problems will be evaluated by conducting sensitivity analyses and simulations of flow and transport in hypothetical flow

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systems. The hypothetical systems will be similar conceptually and will retain many of the important hydrologic characteristics of Yucca Mountain but will be simplified for ease of data input.

If fractured rock at Yucca Mountain can be represented by an equivalent porous medium with aquifer properties that are statistically homogeneous at a local scale, then a technique described by Winter et al. (1984) will be evaluated. Winter et al. (1984) recognize the scale dependence of dispersion and velocity but show that, at large scales in statistically homogeneous porous media, these parameters are approximately constant. Large-scale estimates are calculated from local-scale measurements of hydraulic conductivity and dispersion coefficient.

If results of hydrologic well tests show that fractured rocks at Yucca Mountain are realistically represented by equivalent porous media with aquifer properties that are statistically heterogeneous at a local scale or by a discrete fracture network, then a technique described by Schwartz and Smith (1985) will be evaluated. In this technique, local-scale models of flow paths, fluxes, and velocities are developed as a preliminary to a large-scale model. The local-scale models are based either on discrete fracture networks or equivalent porous media with statistically heterogeneous aquifer properties. Boundaries of the local-scale models are established to reproduce conditions expected at the large scale. In practice only a small number of local-scale models, representative of variations in regional conditions, are constructed. The large-scale model uses either finite difference or finite-element medium. Statistics obtained during simulations with the local-scale models are used to describe the character of ground-water movement within large-scale blocks or elements. In this manner, the large-scale model accounts for the influence of fractures in a realistic way.

Flow paths, fluxes, and velocities will be estimated during development of the regional and site model of ground-water flow and transport. The models will be based on the concept of an equivalent porous medium and the classical advection-dispersion equation. Models for developing these models are described elsewhere (Activities 8.3.1.2.1.4.1 through 8.3.1.2.1.4.4, and 8.3.1.2.3.3.1). The models include site information describing recharge and discharge boundaries, potentiometric surfaces, and aquifer properties such as hydraulic conductivity and effective porosity. Sensitivity analyses, formal parameter-estimation techniques, or both will be used to evaluate the reliability of estimates of flow paths, fluxes, and velocities. These modeling activities will be coordinated with flow modeling activities described in Section 8.3.5.12. Specific plans for verification and validation have not yet been developed.

The technique identified previously to account for the influence of fractures in a realistic way will be used with the existing flow and transport models of Yucca Mountain. Sensitivity analyses will be conducted to provide physically based estimates of confidence in flow paths, fluxes, and velocities. If results of investigations show that the fractured rock at Yucca Mountain can be described realistically by an equivalent porous medium with aquifer properties that are statistically homogeneous at a local scale, then a technique similar to that of Winter et al. (1984) will be used and refined estimates probably will be unchanged from initial estimates of flow paths, fluxes, and velocities. Otherwise, a technique similar to that of

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Schwartz and Smith (1985) will be applied and refined estimates may be significantly different from initial estimates.