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Study Plan for
Study 8.3.1.2.3.1.1-6

Characterization of the Site Saturated-Zone Ground-Water Flow System

Revision 0

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

Prepared by
U.S. Geological Survey

received with letter
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Study Plan for
Study 8.3.1.2.3.1.1-6

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Study Plan Title Characterization of the Site Saturated-Zone Ground-Water Flow System

Revision Number 0

Prepared by: U.S. Geological Survey

Date: May, 1990

Approved:

2/4/91
Director, Regulatory and Site Evaluation Division / Date

2/13/91
Director, Quality Assurance / Date

Effective Date: February 26, 1991

ABSTRACT

This study plan describes six site-characterization activities to be performed in order to characterize the saturated-zone ground-water flow system beneath and near Yucca Mountain, Nevada. These activities include:

- o Solitario Canyon fault study in the saturated zone,
- o Site potentiometric-level evaluation,
- o Analysis of single- and multiple-well hydraulic stress tests,
- o Multiple-well interference testing,
- o Testing of c-well complex with conservative tracers, and
- o Well testing with conservative tracers throughout the site.

Two additional activities that are part of the saturated-zone ground-water characterization are:

- o Testing of the c-well complex with reactive tracers, and
- o Well testing with reactive tracers throughout the site.

These activities are part of a Los Alamos National Laboratory study plan and are not included in this document.

The activities will contribute to an understanding of the hydraulic characteristics required to compute ground-water travel times which will ultimately be needed to evaluate the performance of the proposed repository. Two activities, the Solitario Canyon fault study and the site potentiometric level evaluation, are designed to evaluate and understand the ground-water gradients that occur near the site. One activity, the analysis of single- and multiple-well hydraulic-stress tests, is designed to evaluate hydraulic characteristics. A fourth activity, multiple-well interference testing, also will evaluate hydraulic characteristics, but will emphasize the fractured characteristics of the medium in which flow occurs. The fracture characteristics could drastically alter the travel time by leading to preferential flow paths with shorter than average travel times. The remaining two activities are based on using conservative tracer tests and would directly determine ground-water travel times. One activity will be conducted at a three-well complex while the other will be conducted throughout the site.

The rationale of the overall saturated-zone ground-water flow system study is described in Sections 1 (regulatory rationale) and 2 (technical rationale). Section 3 describes the specific activity plans, including the tests and analyses to be performed, the selected and alternate methods considered, and the technical procedures to be used. Section 4 summarizes the application of the study results and Section 5 presents the schedules and associated milestones.

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1 PURPOSE AND OBJECTIVES OF STUDY

1.1 Purpose of the study plan

The U.S. Geological Survey (USGS) and Los Alamos National Laboratory (LANL) are conducting studies at Yucca Mountain, Nevada, as part of the Yucca Mountain Project (YMP). The purposes of the USGS and LANL studies are to provide hydrologic, geologic, and geochemical information with which to evaluate the suitability of Yucca Mountain for development as a high-level nuclear-waste repository and the ability of the mined geologic-disposal system (MGDS) to isolate the waste in compliance with regulatory requirements. In particular, the project is designed to acquire information necessary for the U.S. Department of Energy (DOE) to present in its environmental-impact statement and license application regarding the potential for the MGDS to meet the requirements of federal regulations 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191.

This study plan describes the USGS plans for hydrologic monitoring and hydrologic testing of the site saturated zone at Yucca Mountain. The study is organized into six activities:

- 8.3.1.2.3.1.1 - Solitario Canyon fault study in the saturated zone,
- 8.3.1.2.3.1.2 - Site potentiometric-level evaluation,
- 8.3.1.2.3.1.3 - Analysis of single- and multiple-well hydraulic stress tests,
- 8.3.1.2.3.1.4 - Multiple-well interference testing,
- 8.3.1.2.3.1.5 - Testing of the c-well complex with conservative tracers, and
- 8.3.1.2.3.1.6 - Well testing with conservative tracers throughout the site.

Two additional activities that are part of the saturated-zone ground-water characterization are:

- 8.3.1.2.3.1.7 - Testing of the c-well complex with reactive tracers, and
- 8.3.1.2.3.1.8 - Well testing with reactive tracers throughout the site.

These activities are part of a LANL study plan and are not included in this document.

Numbers used throughout this plan (e.g., 8.3.1.2.3.1.1) serve as references to specific sections of the YMP Site Characterization Plan (SCP). The SCP (U.S. Department of Energy, 1988) describes the technical rationale of the overall site-characterization program and provides general descriptions of the activities described in detail in Section 3 of this study plan.

Monitoring and testing of the site[1] saturated zone is one of three studies planned to characterize the saturated zone at Yucca Mountain (Figure 1.1-1). The other two studies are characterization of the site saturated-zone hydrochemistry, and the saturated-zone hydrologic system synthesis and modeling. These three studies are closely interrelated and will provide information to one another. In addition, the activities within this study also are closely interrelated and will provide information to one another. Figure 1.1-1 shows the location of the study within the SCP geohydrology program. This study is phase one in providing basic hydrologic information at selected points within the site while the hydrochemistry study will provide basic hydrochemical information. These studies will provide information to the third study which will synthesize the results with one or more models of the saturated zone flow system at the site. The synthesis and modeling study also will require information from many other studies, including investigations of the regional hydrologic system, the geologic framework, and the potential effects of future climates.

Part of the synthesis and modeling study will be sensitivity analyses that will define the important hydrologic parameters of the saturated zone. These analyses may lead to a refined conceptual model (milestone P932 in Study Plan 8.3.1.2.3.3) and indicate a need for additional data not collected as part of this study. At that point, a next phase of the study plan would be implemented to include additional data collection. The feedback between this study (data collection) and the other study (modeling and synthesis) will continue through sufficient phases until the model for the saturated zone is sufficient to adequately provide data to address the performance and assessment issues discussed in Section 1.3. The feedback process and relationship between data collection and modeling is shown in Figure 1.1-2.

The activities in this study were selected on the basis of various factors, including design/performance-parameter needs, available methods and analysis, test scale, time requirements, and schedule constraints. These factors are described in Sections 2 and 3. (*Parameter* is used in this study plan to mean a property, characteristic, and/or the numerical value of a constant that is used to describe the hydrologic system). Activities also were selected by evaluating existing geohydrologic data; formulating various hypotheses that, on the basis of existing data, are possible descriptions of the flow system; and identifying additional monitoring and hydrologic tests that would be critical to choosing among those hypotheses. Chapter 2,

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[1]Within this study, <u>site</u> is a general term, with approximate geographic boundaries, and it is intended to include the <u>controlled area</u> as a minimum. <u>Controlled area</u> has been defined to include no more than 100 square kilometers (38.6 square miles) and extend horizontally no more than five kilometers in any direction from the outer boundary of the repository. Beyond the <u>controlled area</u> lies the <u>accessible environment</u>, which will be investigated mostly during site-characterization studies of the <u>region</u>. See glossary in the SCP for complete or specific definitions.

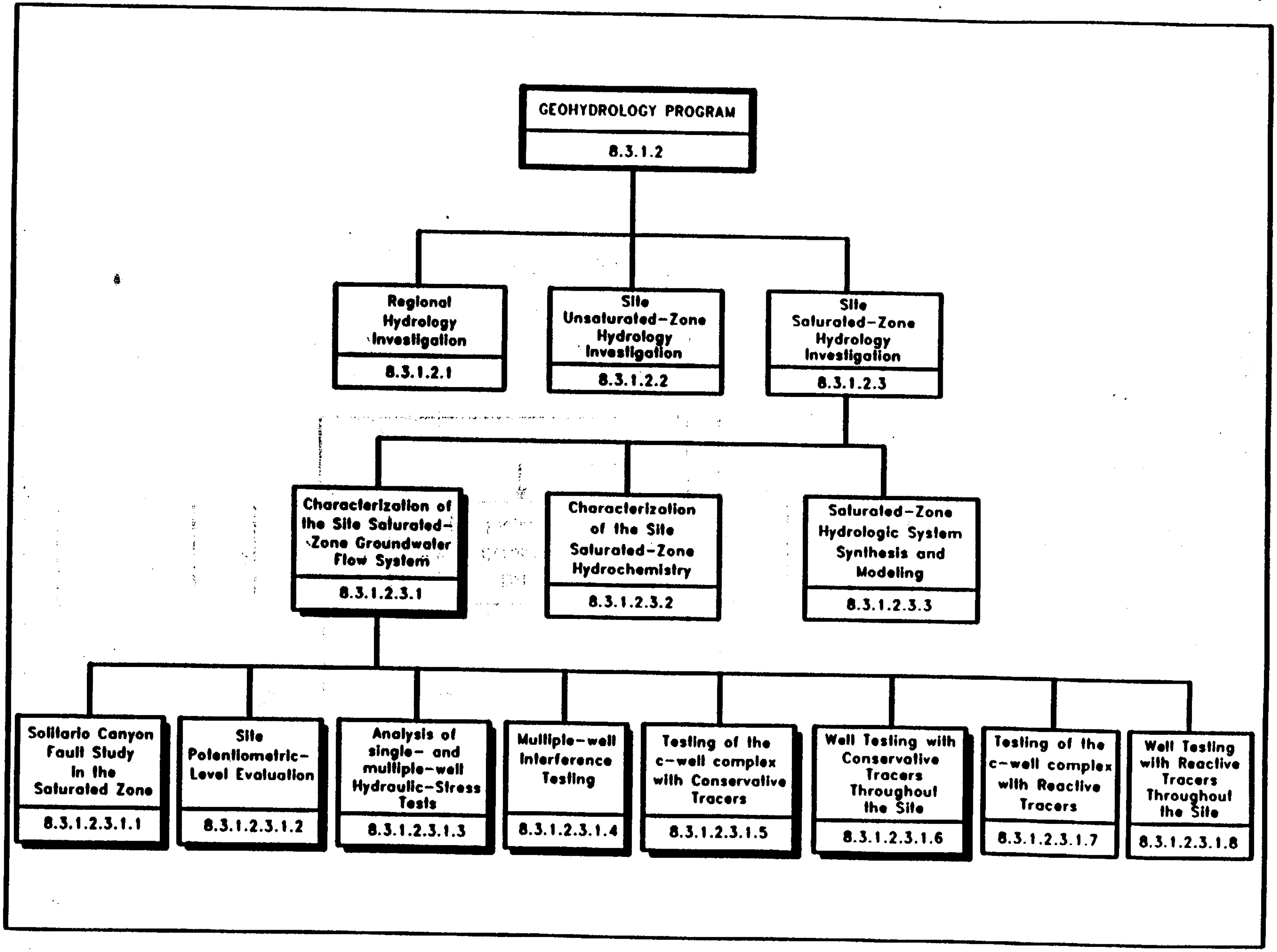


Figure 1.1-1. Diagram showing the location of the study within the site saturated-zone investigation and organization of the geohydrologic-characterization program.

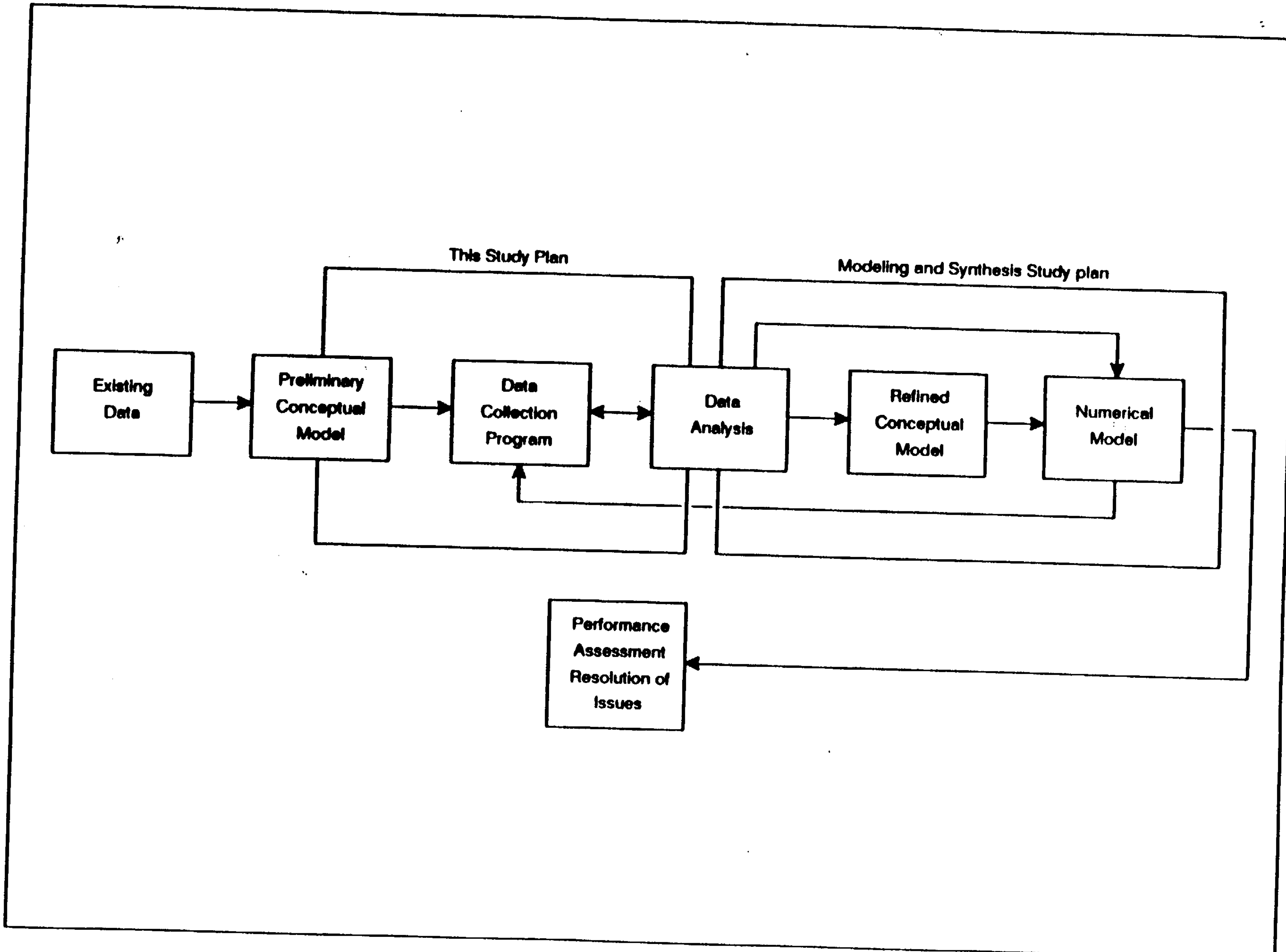


Figure 1.1-2. Diagram showing the relationship between this study and the modeling and synthesis study.

Rationale for Study, provides additional description of the various hypotheses that are addressed by activities in this study plan.

The plans for the six activities in this study are described in Section 3. The descriptions include (a) objectives and parameters, (b) technical rationale, and (c) methods and analyses. Alternates are summarized, and cross references are provided for technical procedures.

Application of the study results to the resolution of design and performance issues is summarized in Sections 1.3 and 4, activity schedules and milestones are presented in Section 5, and a reference list is presented in Section 6.

1.2 Objectives of study

An understanding of the saturated-zone flow system at Yucca Mountain is essential to the site-characterization program because water is the expected medium for transport of radionuclides within the saturated zone. Adequate characterization of the saturated zone is needed to address several Design and Performance Issues. The principal reason for understanding the saturated-zone flow system is to evaluate pre-waste-emplacement ground-water travel time (Performance Issue 1.6) and total system performance (Performance Issue 1.1). These issues will be evaluated, in part, on the basis of an understanding of flow paths, fluxes, and velocities within the saturated zone. A complete discussion of the regulatory rationale for this study is given in Section 1.3.

The objectives of this study are to obtain hydrologic information that can be used in Study 8.3.1.2.3.3 to describe flow paths, fluxes, velocities, and travel times within the saturated zone. Such information includes estimates of hydraulic gradients, boundary conditions imposed by structure, and bulk hydraulic properties. Some of this information has been collected in the past at Yucca Mountain. However, the information base is incomplete. A discussion of the existing information base and the technical rationale for planned hydrologic monitoring and testing is given in Section 2.1 of this study plan.

Results of hydrologic monitoring and testing activities planned in this study will be combined with existing information and results of related studies to form the basis for synthesis and modeling activities (described in Study Plan 8.3.1.2.3.3). This will be an iterative process whereby synthesis and modeling may lead to additional data collection and refinement of the conceptual model. Results of the synthesis and modeling activities will be descriptions of flow paths, fluxes, velocities, and travel times of groundwater within the saturated zone at Yucca Mountain.

Hydrologic monitoring and testing will be conducted generally within the approximate site boundary shown on Figure 1.2-1. Monitoring and testing outside the site boundary is described in study plans of the regional hydrology investigation (8.3.1.2.1). In order to ensure continuity of information collected as part of site and regional studies, some overlap of study areas is expected. Close coordination and integration of information among the studies will assure there is no duplication of effort.

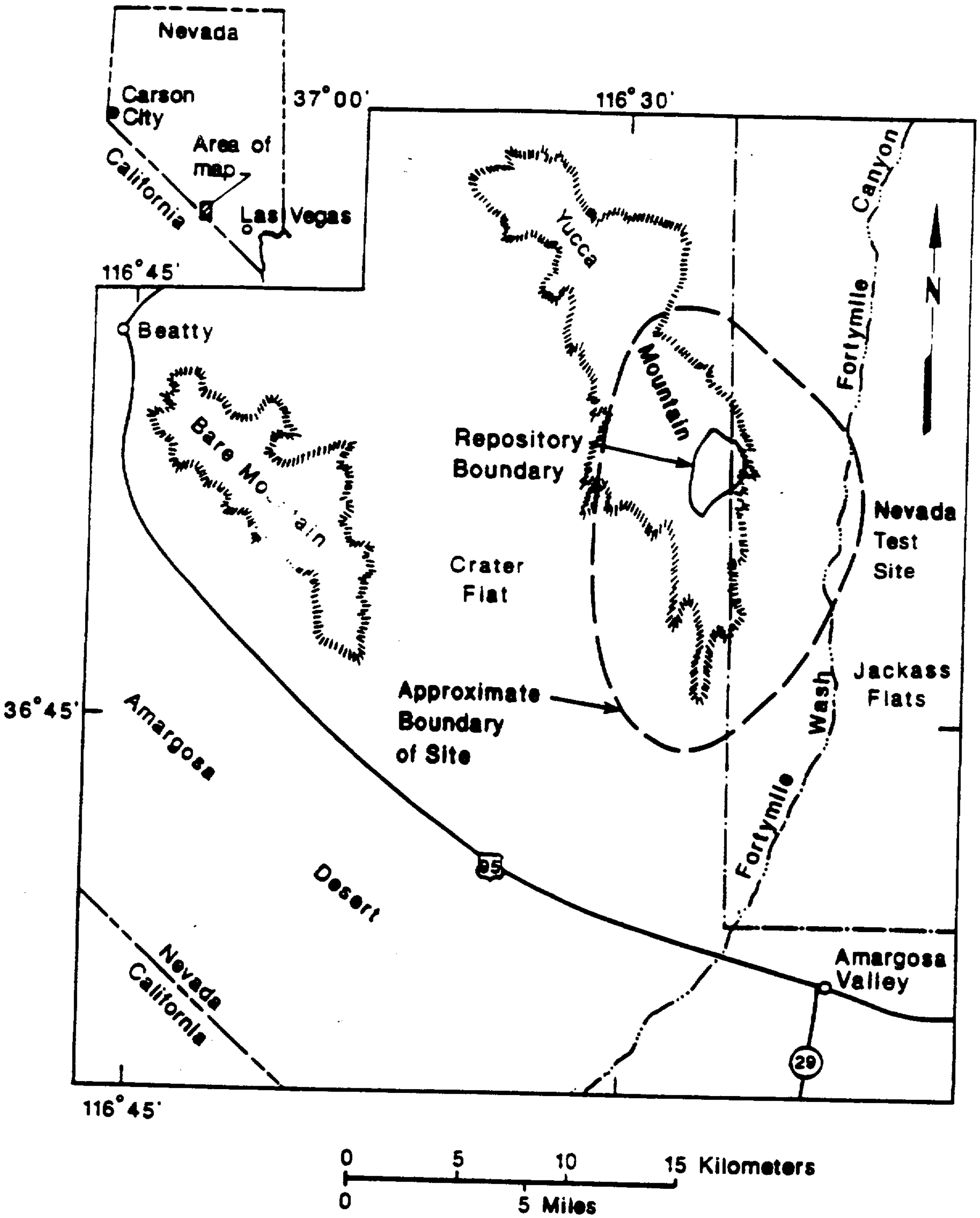


Figure 1.2-1. Map showing location of Yucca Mountain.

1.3 Regulatory rationale and justification

The results of saturated-zone testing conducted in the vicinity of Yucca Mountain will provide some hydrologic data needed for performance-assessment calculations of ground-water travel time and predictions of radionuclide releases to the accessible environment. Hydrologic properties determined in the study will be used in design analyses of the underground facility, repository seals, and waste packages.

The overall regulatory-technical relations between the SCP design and performance informational needs and the data collected in this study are described in the geohydrology testing strategy (SCP Section 8.3.1.2) and the issue-resolution strategies (repository, seals, waste package, and performance assessment) presented in SCP Sections 8.3.2 - 8.3.5. The description presented below provides a more specific identification of these relations as they apply to this study. A detailed tabulation of parameter relations is provided in Appendix 7.2.

Project-organization interfaces between the Characterization of the site saturated-zone ground-water flow system study (8.3.1.2.3.1) and the YMP performance and design issues are illustrated in Figure 1.3-1. The figure also indicates project interfaces with other site studies; these relations are described further in Section 4.2. The relations between the design and performance issues noted below and the regulatory requirements of 10 CFR 60 and 10 CFR 960 are described in Section 8.2.1 of the SCP.

Information derived from the study will be the principal basis for the performance determinations of pre-waste-emplacement, ground-water travel time (Issue 1.6) and the predictions of radionuclide releases to the accessible environment (Issue 1.1). Study results will also provide information for the resolution of the issues concerned with limiting individual doses in the accessible environment protection of special sources of ground water (Issue 1.3), and design requirements for shaft, engineered barriers, and borehole seals (Issues 4.4, 1.11, and 1.12).

In addition, this study provides input into NRC siting criteria (Issue 1.8) and higher level findings (Issue 1.9) through its contributions to Issues 1.1 and 1.6.

Performance Issue 1.1
(Total system performance for limiting radionuclide release to the accessible environment)

This issue requires that the geologic setting, engineered barrier system, shafts, boreholes, and seals be selected and designed so as to limit the cumulative releases of radionuclides for 10,000 years following permanent closure of the repository. Site information resulting from this study will be used to satisfy the requirements of numerous supporting parameters needed to evaluate the nominal case of Scenario Class E of the issue-resolution strategy for total system performance. The study results will also provide baseline data for the disturbed cases. Descriptions of the scenarios are given in SCP Section 8.3.5.13.

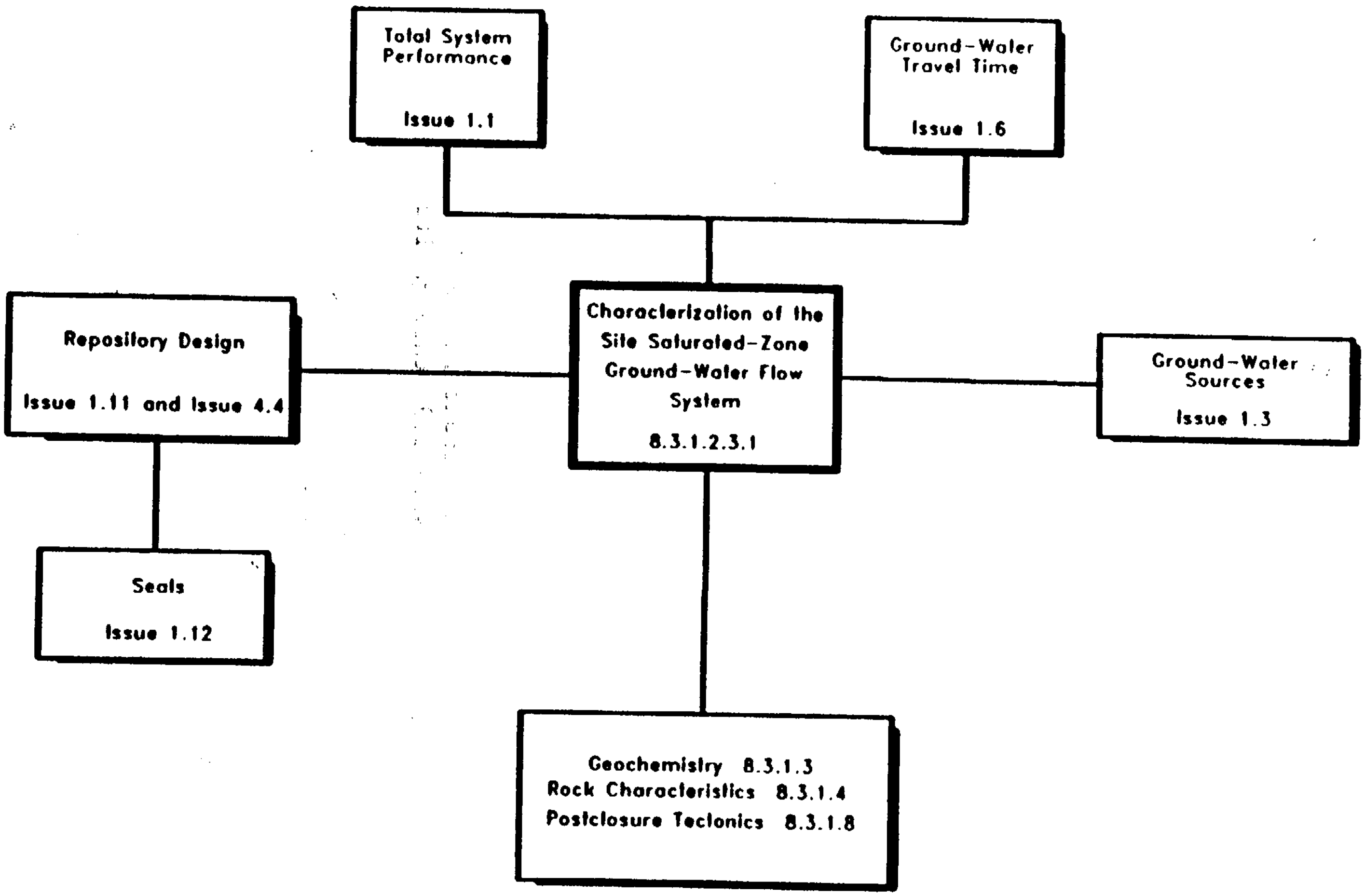


Figure 1.3-1. Diagram showing the organization interfaces of the characterization of the Yucca Mountain site saturated-zone ground-water flow system study with YMP performance and design issues and other site-characterization programs.

The supporting parameters are used in calculations of the performance parameters for the different scenarios. Examples of performance parameters for the nominal case are average discharge [lateral flux] and average effective porosity in the saturated zone. The tentative parameter goals are that average flux be less than 32 mm/yr in the saturated zone under the controlled area and that average effective matrix porosity be greater than 0.1.

The performance parameters for each of the scenario classes apply to expected partial performance measures (EPPM's). For example, Scenario Class E has three EPPM's: one for the unsaturated-zone liquid pathway, one for the saturated-zone liquid pathway, and one for the gas pathway. Determination of each of these EPPM's depends upon data from performance parameters, which in turn depend upon calculations from supporting parameters, which in turn depend upon site information collected in the study. These relations are described in the SCP and are further documented in Appendix 7.2.

Saturated-zone hydrologic properties measured in this study (e.g., matrix and fracture permeability, and effective porosity), as well as altitudes of potentiometric surfaces, contribute to the Issue 1.1 supporting parameters employed in the following calculations.

- Calculations of the specific-discharge fields in the saturated zone and moisture content (effective porosity) of saturated-zone units.

- Calculations of the specific-discharge fields in fault zones in the saturated zone and moisture content (effective porosity) in fault zones.

- Calculation of coupling factors and radionuclide retardation factors in the saturated zone.

Effective porosity of fracture systems and matrix will be used in travel-time calculations which will assist in the prediction of the mass flux for radionuclides. In the controlled area, the altitude of potentiometric surfaces as a function of spatial location; fracture system geometry within fracture networks, including fault zones; and the effective porosity of fracture networks are required. Other required parameters within the controlled area are effective saturated thickness of each stratigraphic unit, effective hydraulic conductivity of rock matrix and fracture networks, and effective porosity of the rock matrix. Spatial variability of these parameters is needed to evaluate fluid flow and radionuclide transport.

This study also provides input into Performance Issues 1.8 (NRC Siting Criteria) and 1.9 (Higher-level findings - postclosure system and technical guidelines) through its contributions to Performance Issues 1.6 and 1.1.

Performance Issue 1.6
(Pre-waste-emplacement, ground-water travel time)

As in Issue 1.1, site information generated by the study are directly applicable to resolution of this issue. An evaluation of pre-waste-emplacement ground-water travel time requires information on the saturated-zone hydraulic conductivity (or transmissivity), flow velocity, Darcian flux, and effective porosity distributions along various flow paths. Computations of water-particle travel times to derive a cumulative density function of arrival times at the accessible environment require models describing the interaction of matrix and fracture pore systems. These will incorporate saturated-zone hydraulic properties measured and monitored in this study.

The overall performance goal for the ground-water travel-time measure for the combination of all units between the disturbed zone and the accessible environment is 1,000 years or more, at a very high confidence level. The strategy for resolving this issue is to define, characterize, and assess multiple barriers to ground-water flow, by dividing flow paths and flow processes into categories. In the unsaturated zone, multiple natural barriers have been identified as seven geohydrologic units for which different types of general flow processes may be distinguished, including dispersive and advective flow in rock pores, similar flow in fractures, and diffusion between and within the matrix and fractures. The saturated zone will be considered a separate barrier or barriers. The frequency distribution of calculated ground-water travel times is the performance measure for each geohydrologic unit.

Information from this study will be used to satisfy various supporting performance parameters needed to assess ground-water travel time in the saturated zone. These supporting parameters (e.g. saturated rock-matrix permeability) are used to define various components of the saturated-zone model, spatial correlation structure model, and fracture hydrologic characteristics model. These components include initial and boundary conditions, material properties, system geometry, and validation of model concepts. The results of the ground-water travel-time model calculations yield performance parameters for the saturated zone. Examples of these performance parameters are flux, saturated hydraulic conductivity, pressure head, effective porosity, distance along flow paths, and flow rates. These performance parameters are further categorized by their fracture, matrix, and fault-zone elements. Darcian flow in fractured porous media will be used to analyze water movement through the saturated zone.

Rock hydrologic and physical properties from the study are required in the ground-water travel-time model needed as supporting parameters for initial and boundary conditions, material properties and system geometry. Porosity and fracture properties are required in the fracture hydrologic-properties model as supporting parameters for material properties, system geometry, and validation. For the initial and boundary conditions of the saturated-zone model, the study contributes data to the supporting parameters of flux and flow rate, and pressure head as a function of depth. For material properties, the study contributes to the supporting parameters of bulk density, saturated permeability, and effective porosity. For system geometry, the study contributes to the supporting parameters of aquifer geometry and contact altitude of stratigraphic units. In the validation of model concepts for the saturated-zone model and the calculation of the spatial correlation structure, the study contributes to the supporting parameters of water-table altitude, porosity, and transmissivity in the rock mass.

Performance Issue 1.3
(Protection of special sources of ground water)

This issue is concerned with the protection of special sources of ground water and possible contamination from radioactive waste. The performance measure is the existence of a special source of ground water, the performance parameter being the existence of aquifers within 5 km of the controlled area. Winograd and Thordarson (1975) described three aquifers that may be of concern for the Yucca Mountain site: the tuff aquifer, the lower carbonate aquifer, and the valley-fill aquifer. The tuff aquifer and the lower carbonate aquifer may both underlie the proposed repository. The valley-fill aquifer is saturated in the region beyond the controlled area, and is the only aquifer in the general vicinity of Yucca Mountain that served a number of people at the time that the site was chosen for characterization. There are withdrawals from the valley-fill aquifer within the Amargosa Desert where valley fill is underlain by the lower carbonate aquifer.

Current evaluations based on available data suggest that none of the three aquifers is vulnerable to contamination within 1,000 yr after emplacing waste at Yucca Mountain. This preliminary assessment is based on the hydraulic and geochemical characteristics of the thick unsaturated zone that would contain the repository.

The tuffs are in excess of one kilometer thick, and are at least locally unconfined and dominated by fracture conductivity. Water-resource potential of the tuffs is demonstrated by the relatively high production of well J-13, located near the boundary of the controlled area in Jackass Flats. Thus, this study contributes data to the determination of flux across that boundary under existing hydraulic gradient and possible drawdown conditions. It will incorporate not only the ground-water flow conditions, but also the geochemical retardation phenomena that are generally appreciable in such rocks, especially where zeolitized.

The lower carbonate aquifer supplies baseflow to the Ash Meadows region in southern Nye County (Dudley and Larson, 1976), which has been designated a critical habitat for several species of endangered fish. The Ash Meadows area, however, is part of a different ground-water subbasin (Ash Meadows) from the Alkali Flat-Furnace Creek Ranch ground-water subbasin, which includes Yucca Mountain. Significant development of the lower carbonate aquifer in the Amargosa Desert might cause interbasin diversion of the baseflow.

In addition to being overlain by a thick unsaturated zone, data from well UE-25p #1 indicate that the lower carbonate aquifer has a higher potentiometric head as compared to the tuff aquifer in the vicinity of the site (Craig and Robison, 1984). Therefore, the potential or tendency for flow is upward from the lower carbonate aquifer rather than downward into it. Both the lower carbonate and tuff aquifers crop out in limited areas of rugged terrain, indicating that the potential for contamination directly into these aquifers due to future human activities is slight.

The valley-fill aquifer may be vulnerable to contamination because the valley fill occurs at the surface over broad areas, and contamination from sources other than the proposed repository may be possible. Hydraulic boundaries and conduits of the valley-fill aquifer need to be determined in order for further evaluation. Information on hydraulic boundaries and conduits, aquifer heterogeneities, and spatial distribution (Table 7.2), as determined during hydrologic monitoring of the site saturated zone may assist in determining the existence of these aquifers as described.

Performance Issue 1.8 and 1.9
(Favorable and potentially adverse conditions) (Qualifying and disqualifying conditions)

The results of this study have indirect applications to the NRC siting criteria - Favorable Condition 7 (pre-waste-emplacement, ground-water travel time) through Issue 1.6, and Favorable Conditions 8(ii) (hydrogeologic conditions - a water table sufficiently below the underground facility such that fully saturated voids contiguous with the water table do not encounter the underground facility) through Issue 1.1. The study also has indirect applications to the higher-level findings for the geohydrology qualifying and disqualifying conditions through Issues 1.1 and 1.6.

Design Issue 1.11
(Characteristics and configurations of the repository and repository-engineered barriers)

Site information of hydraulic gradients and ground-water travel times will be used in conjunction with many other data in resolution of Design Issue 1.11. Proper configurations of the repository engineered barriers will require a detailed understanding of water table elevations in the geohydrologic environment. Data generated by this study will be used in hydrologic modeling of the environment to insure adequate barrier designs.

Saturated-zone physical and hydrologic properties derived from this study indirectly support the assessment of the underground safety of repository workers (Issues 2.2 and 4.2) and repository design criteria (Issue 2.7).

Design Issue 1.12
(Characteristics and configurations of shaft and borehole seals)

Saturated-zone information derived from the study will be used in the design of repository seals. Shaft and borehole seals serve as deterrents to fluid migration into the repository and to control gas transport from the repository. Seal design and construction will be influenced by saturated bulk-rock hydraulic conductivity at the base of ES-1 (exploratory shaft) and boreholes and fracture characteristics in the Tiva Canyon (TCw), Topopah

Spring (TSw) and Calico Hills (CHn) unsaturated-zone geohydrologic units. Data from this study (e.g. effective porosity, average linear velocity, hydraulic conductivity) will help resolve Design Issue 1.12 by providing an understanding of fluid flow in fractures and of the influence of fracture characteristics on saturated flow.

Design Issue 4.4
(Preclosure design and technical feasibility)

For Issue 4.4, only the preclosure elements are considered pertinent. This issue questions whether the repository can be designed, constructed, operated, and closed using reasonably available or proven technology. Hydraulic gradients and ground-water elevations measured in this study will be applied to the design parameter for ground-water elevation at the base of the exploratory shaft. As part of the repository mining (access construction) system element, the tentative goal is that the exploratory shaft (ES-1) termination will be no less than 150 m (492 feet) above the ground-water table. The corresponding performance measure is that shafts and ramps will be compatible with requirements for repository sealing.

2 RATIONALE FOR STUDY

2.1 Technical rationale and justification

Section 3 of this plan provides additional detail for the specific activities, tests and analyses, and methods of the study. This section provides an overview and justification of the overall study.

2.1.1 Statement of problem and test justification

Understanding the saturated-zone flow system at Yucca Mountain is essential to the site-characterization program because water is the expected major medium for any transport of most waste radionuclides. This study plan describes part of the activities of the saturated-zone hydrologic system investigation at the site. Results of these activities will provide information required for site characterization and performance assessment, as well as information for model validation and hypothesis testing. In addition, results of these activities will be used in other studies in this investigation which include the characterization of the site saturated-zone hydrochemistry (8.3.1.2.3.2) and the saturated-zone hydrologic system synthesis and modeling (8.3.1.2.3.3).

Information required for site characterization and performance assessment include bulk-hydraulic conductivity or transmissivity of rocks along flow paths, effective porosity and hydrodynamic dispersion characteristics of rocks along flow paths, boundary conditions imposed by structure, and conditions of recharge, discharge, and hydraulic gradients. Activities within this study have been selected and designed to provide the required information to an adequate level of detail and reliability.

Water flow and storage in the saturated zone are envisioned to be three dimensional, and are controlled by the structural, stratigraphic, topographic, climatological, and perhaps geothermal setting. Therefore, the activities in this study plan are directed toward characterizing the nature and significance of these controls. Principally, flow most likely occurs within interconnected fractures. However, it also is important to evaluate movement between fractures and pores, and movement within interconnected pores. Currently, there are few data available to describe flow and transport characteristics and structural and hydrologic nature of the saturated zone beneath Yucca Mountain.

The saturated zone flow system at Yucca Mountain can be divided, based on stratigraphy, into two systems, the upper tuff system and the lower carbonate system. The two systems may be separated in places by the upper clastic aquitard (Winograd and Thordarson, 1975) which may cause hydraulic decoupling of the two systems as proposed by Dudley and others (written communication, 1990). At one point (well UE-25p #1), the head in the carbonate system is higher than the head in the tuff system, and at a number of other points the potential appears to be for upward flow. Because this potential would limit downward migration of radionuclides and because of its great depth, the lower system will not be investigated extensively in this study.

The upper system consists of a number of stratigraphic units but thus far has not been subdivided into hydrostratigraphic units. Future tests may shed light on the existence of additional hydrologic units. However, based on available data, there appears to be little correlation between stratigraphic units and producing zones in existing wells, possibly because of subvertical faults and fractures. Degree of welding may be a better indication of hydraulic properties than stratigraphic units. Although a more complex model may evolve as a result of this study, for now the tuff aquifer is treated as a single, although highly, variable, unit.

Most major external hydrologic boundaries within the saturated zone are large distances from the repository block, and therefore are considered under Characterization of the Regional Ground-Water Flow System (8.3.1.2.1.3) rather than within this site study. The regional study includes discussion or definition of ground-water divides that are basin boundaries; recharge areas; and discharge areas. The upper boundary to saturated ground water is the water table, and location of the water table (depth and altitude) is part of this study. Flow through the unsaturated zone, which enters the saturated zone at the water-table, is considered in investigations under Characterization of Unsaturated-Zone Infiltration (8.3.1.2.2.1).

Three features near the repository block have been identified as possible internal hydraulic boundaries; one is the Solitario Canyon fault. Activity 3.1 within this study plan describes an investigation of the hydraulic characteristics of the fault. The second, a steep hydraulic gradient immediately north of the site, may reflect the presence of a boundary or barrier; this feature will be considered in activity 3.2 (site potentiometric-level evaluation). The third feature, Fortymile Wash, may provide recharge close enough to directly affect ground water at the site; studies to evaluate the recharge are included under the regional characterization study (8.3.1.2.1.3.3).

Hydraulic conductivity has been determined from exploratory test wells. The values generally were obtained from analysis of single-well hydraulic tests and may only be indicative of conditions within a small radius of the wellbores. Additional determinations or estimates of bulk hydraulic conductivity (matrix plus fracture) are expected to be obtained during this study, as well as information on spatial distribution, spatial variability, and spatial correlation.

Hydraulic and conservative-tracer tests, described in this study plan, will address two general objectives. The first objective is to evaluate aquifer properties using well tests in the saturated zone at Yucca Mountain. Hydraulic-property estimates are needed to calculate ground-water travel time. The second objective is to describe relations between ground-water flow and fracture characteristics. Successful completion of these objectives is a prerequisite to determination of flow paths, fluxes, velocities, and travel times between the proposed repository and the accessible environment.

Hydraulic tests conducted in test wells USW H-4, UE-25p #1, UE-25b #1 (Figure 3.2-1), and especially UE-25c #1, UE-25c #2, and UE-25c #3 (the c-well complex; Figure 2.1-1) indicate that simple nonsteady radial-flow models may not be adequate to describe ground-water flow at the scale of the tests. Results of hydraulic tests and intraborehole flow surveys at the c-well complex also have indicated the absence of definitive hydrostratigraphic units, and indicate that discrete production zones associated with fractures in one well and stratigraphic unit may be connected to production zones associated with fractures in other wells and stratigraphic units. The role of intervening stratigraphic units is unclear. Due to the predominant subvertical orientation of fractures and their differential connectivity, a more complex heterogeneous-reservoir flow model needs to be applied in the interpretation of results from past hydraulic tests of wells. Additional tests need to be conducted to determine the relation between structure, stratigraphy, fracture connectivity, and the degree of anisotropy of hydraulic conductivity in three dimensions.

Well tests at Yucca Mountain will be completed in two steps. The first step consists of a large number of hydraulic stress tests and several conservative-tracer tests at the c-well complex. The c-well complex is located within the site and along the most probable flow path away from the proposed repository. The complex's geographic location makes it most likely to be representative of conditions in the saturated zone between the repository and the accessible environment. The tests include a variety of field and interpretive procedures to assist in methods development. They will also help form a conceptual model of the role of fractures on ground-water movement.

The second step will depend on the results of the c-well complex testing and will consist of single well tests at several locations throughout the Yucca Mountain area or, if necessary, drilling and testing of additional multiple well sites. The second step will provide areal information with which to estimate site-wide hydrologic properties.

Aquifer tests and tracer tests can provide useful information for an evaluation of hydraulic conductivity, effective porosity, and hydrodynamic dispersion; these are necessary components of travel-time and other calculations required by the Nuclear Regulatory Commission for licensing.

Hydrologic parameters to be determined or evaluated in this study include (1) hydraulic conductivity of rocks in the saturated zone at a few selected locations; (2) storage coefficients; (3) hydraulic characteristics of selected fault(s); (4) water-levels at individual locations, and the corresponding hydraulic gradients among the network of locations; (5) characterization of the type of flow (linear, radial, spherical, fractal fissure, porous) that occurs at the single- and multiple-well scale; (6) identification of the degree of vertical

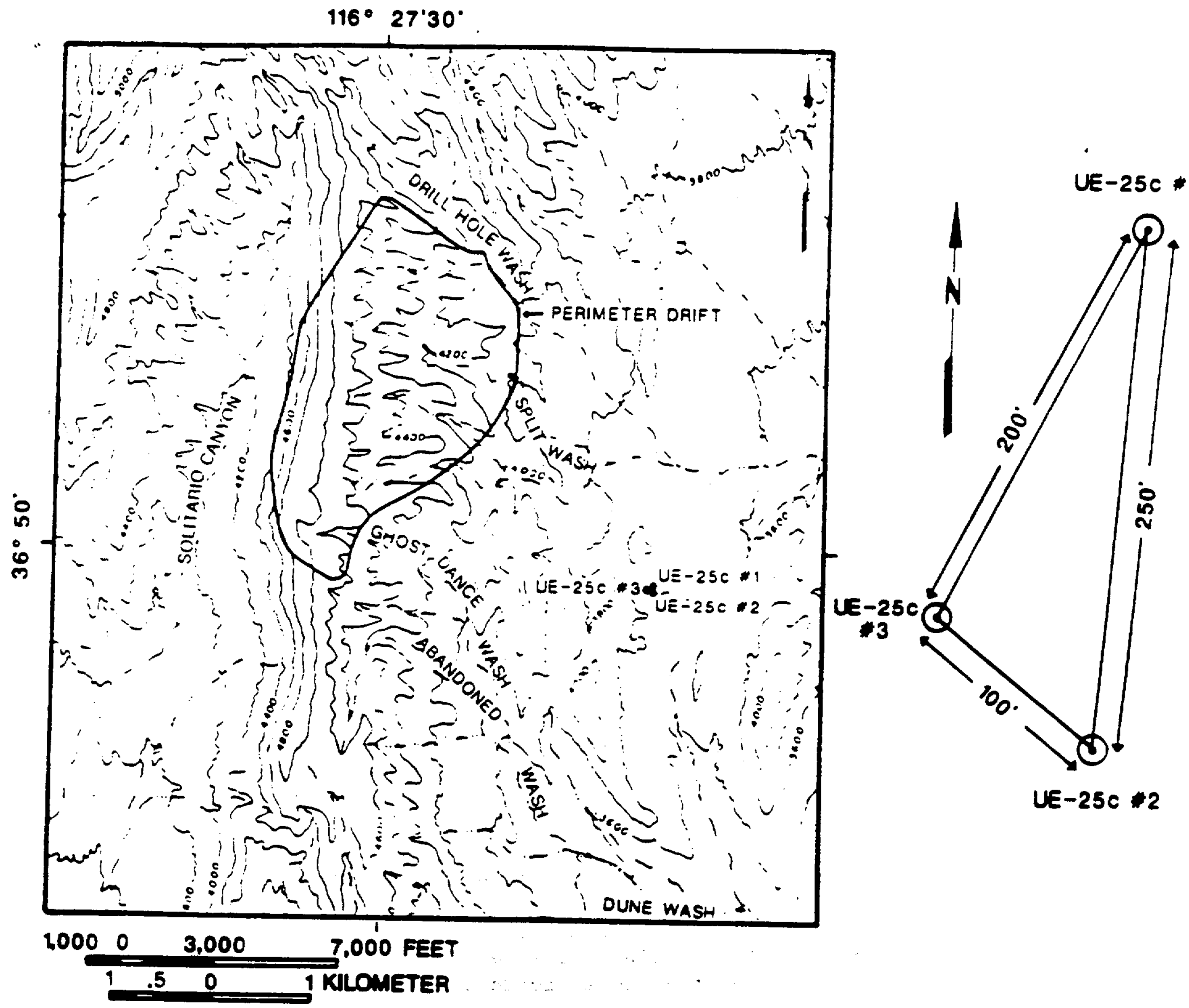


Figure 2.1-1. Map showing location and configuration of the c-well complex.

hydraulic connection between strata; (7) determination of whether ground-water flow can be represented by an equivalent porous medium at the scale of the tests; (8) determination of solute-transport properties of the system; (9) evaluation of the relation between transport properties and fracture characteristics; and (10) determination of whether single-well tests or multiple-well tests are suitable to characterize transport properties.

Hydraulic and tracer tests will be conducted and analyzed to determine the spatial variability transport parameters. A small scale local variability will be addressed during the c-hole tests, and a site scale variability will be obtained by analyzing numerous, site-wide single-well tests. Scale dependency will be addressed by conducting tests at various scales, i.e., under different levels of hydraulic stress and radius of influence. This information and the need for additional information regarding spatial dependence of parameters will be part of an iterative process with feed-back loops between this study plan, and the Site Saturated Zone Hydrologic Synthesis and Modeling Study Plan (SP 8.3.1.2.3.3). These planned tests may not satisfy rigorous analysis of variability on site-wide scale. Additional testing may be required as a result of iterative modeling attempts.

2.1.2 Parameters and testing strategies

Relations of site parameters determined by this study to performance and design parameters are used as a basis for developing the technical rationale of the planned work. Throughout the following sections of this plan, references are made to parameter categories and site-characterization parameters. These terms are used as a means of tracing information from site-characterization activities (SCP 8.3.1) to design- and performance-assessment issues resolutions (SCP 8.3.2 - 8.3.5). Table 2.1-1 lists the site-characterization parameters to be obtained from the site saturated-zone ground-water flow-system study. Table 2.1-2 provides further information for the wells listed in Table 2.1-1. The parameters associated with each activity in Table 2.1-1 are described further in Section 3 in relation to the specific test methods to be used. The parameters are grouped by the parameter categories and model components shown in Figure 2.1-2. The parameters included in Table 2.1-1 serve three principal purposes. They are needed as direct input to design and performance analyses, as input to hydrologic numerical models, and to test hypotheses that support conceptual models.

In order to conduct preliminary performance and design analyses, assumptions must be made regarding parameters and hydrologic processes and conditions, including spatial variation and correlation. These preliminary analyses may include assumptions involving ground-water flow paths, velocities, fluxes, potential gradients, hydraulic conductivities, anisotropies, boundary conditions, and structural and geohydrologic-unit controls on saturated-zone flow. Concepts that may affect these analyses of the hydrologic system include the potential for different flow regimes (e.g., two dimensional or three dimensional) and an uncertainty of the physical processes influencing flow (e.g., fracture flow, matrix flow, or both). A common requirement of the

Table 2.1-1. Site parameters derived from this study

Site parameter	Spatial/geographic location
Solitario Canyon fault study in the saturated zone; 8.3.1.2.3.1.1	
Saturated-zone transmissive properties	
Transmissivity and hydraulic conductivity	USW H-7 USW WT-8 USW WT-9
Saturated-zone storage properties	
Storage coefficient, fault zone and wall rocks	USW H-7 USW WT-8 USW WT-9
Saturated-zone water potential	
Hydraulic gradient	USW H-7 USW WT-8 USW WT-9
Site potentiometric-level evaluation; 8.3.1.2.3.1.2	
Saturated-zone transmissive properties	
Hydraulic conductivity	USW WT-22 USW WT-21 USW WT-23 USW WT-9 USW WT-8 USW WT-24 UE-25 WT #19 UE-25 WT #20
Saturated-zone storage properties	
Aquifer compressibility	USW WT-22 USW WT-21 USW WT-23 USW WT-9 USW WT-8 USW WT-24 UE-25 WT #19 UE-25 WT #20

Page 2 Table 2.1-1. Site parameters derived from this study--Continued

Site parameter	Spatial/geographic location
Site potentiometric-level evaluation; 8.3.1.2.3.1.2	
Saturated-zone storage properties	
Specific storage	USW WT-22 USW WT-21 USW WT-23 USW WT-9 USW WT-8 USW WT-24 UE-25 WT #19 USW UE-25 WT #20
Storage coefficient, estimate from water-level fluctuations, well tests	USW WT-22 USW WT-21 USW WT-23 USW WT-9 USW WT-8 USW WT-24 UE-25 WT #19 UE-25 WT #20
Strain	USW WT-22 USW WT-21 USW WT-23 USW WT-9 USW WT-8 USW WT-24 UE-25 WT #19 USW UE-25 WT #20
Saturated-zone water potential	
Hydraulic gradients	USW WT-22 USW WT-21 USW WT-23 USW WT-9 USW WT-8 USW WT-24 UE-25 WT #19 UE-25 WT #20

Page 3 Table 2.1-1. Site parameters derived from this study--Continued

Site parameter	Spatial/geographic location
Analysis of single- and multiple-well hydraulic-stress tests; 8.3.1.2.3.1.3	
Rock-unit mineralogy/petrology and physical properties	
Matrix compressibility, inferred from barometric and earth-tide analysis	Yucca Mountain site, subregional
Unsaturated-zone diffusive properties	
Vertical pneumatic diffusivity	Yucca Mountain site, subregional
Saturated-zone transmissive properties	
Porosity, estimates from atmospheric loading and earth-tide analysis of water level time series	Yucca Mountain site UE-25c #1, 2, 3
Transmissivity, bulk estimates at multiple-well test locations	"
Saturated-zone storage properties	
Areal strain sensitivity	Yucca Mountain site, subregional
Barometric efficiency	"
Specific storage	Yucca Mountain site UE-25c #1, 2, 3
Storage coefficient, bulk estimates from well testing data	"
Saturated-zone diffusive properties	
Vertical hydraulic diffusivity estimates from atmospheric loading and earth tide analysis of water level time series	Yucca Mountain site, subregional

Table 2.1-1. Site parameters derived from this study--Continued

Site parameter	Spatial/geographic location
Analysis of single- and multiple-well hydraulic-stress tests: 8.3.1.2.3.1.3	
Saturated-zone water potential	
Hydraulic gradients, relative	Yucca Mountain site, UE-25c #1, 2, 3
Saturated-zone ground-water flux	
Flow rates, intraborehole	Yucca Mountain site UE-25c #1, 2, 3
Saturated-zone hydrologic conceptual/descriptive models	
Hydraulic boundaries and and type of flow at scale of well tests	Yucca Mountain site UE-25c #1, 2, 3
Multiple-well interference testing: 8.3.1.2.3.1.4	
Saturated-zone transmissive properties	
Fracture formation transmissivity inferred from hydraulic tests, matrix properties, geophysical logs	Yucca Mountain site UE-25c #1, 2, 3
Three-dimensional hydraulic-conductivity tensor, equivalent porous media, or discontinuous fracture networks?	"
Saturated-zone storage properties	
Storage coefficient, at multiple-well locations	Yucca Mountain site UE-25c #1, 2, 3
Saturated-zone hydrologic conceptual/descriptive models	
Aquifer heterogeneity and hydraulic conductivity structure at the scale of well tests	Yucca Mountain site UE-25c #1, 2, 3

Page 5 Table 2.1-1. Site parameters derived from this study--Continued

Site parameter	Spatial/geographic location
Multiple-well interference testing: 8.3.1.2.3.1.4	
Saturated-zone hydrologic conceptual/descriptive models	
Spatial correlation structure	Yucca Mountain site UE-25c #1,2,3
Testing of the C-hole sites with conservative tracers: 8.3.1.2.3.1.5	
Saturated-zone transmissive properties	
Average linear velocity: pore water and tracers	Yucca Mountain site (UE-25c #1, 2, 3)
Effective porosity from single- and multiple-well tests	Yucca Mountain site UE-25c#1, 2, 3
Saturated-zone storage properties	
Storage coefficient	Yucca Mountain site, UE-25c#1, 2, 3
Saturated-zone dispersive properties	
Hydrodynamic dispersion coefficients, single-and multiple-well tests	Yucca Mountain site UE-25c#1, 2, 3
Well testing with conservative tracers throughout the site: 8.3.1.2.3.1.6	
Saturated-zone transmissive properties	
Average linear velocity, pore water and tracers	Yucca Mountain site, subregional test holes and intervals to be determined
Effective porosity single- and multiple-well tests	"
Hydraulic conductivity well-test locations throughout the site conservative tracers	"

Page 6 Table 2.1-1. Site parameters derived from this study--Continued

Site parameter	Spatial/geographic location
Well testing with conservative tracers throughout the site: 8.3.1.2.3.1.6	
Saturated-zone transmissive properties	
Permeability and transmissivity, characteristics of fracture systems, inferred from hydraulic packer and tracer tests	Yucca Mountain site, subregional test holes and intervals to be determined
Saturated-zone storage properties	
Specific storage	Yucca Mountain site, subregional test holes and intervals to be determined
Saturated-zone dispersive properties	
Dispersion coefficients	Yucca Mountain site, subregional test holes and intervals to be determined
Dispersivity	"

Table 2.1-2. Stratigraphic units and depths below water surface for proposed and existing water table wells

Existing Wells	Stratigraphic unit at the Water Surface	Depth of Penetration Below Water Surface (ft)
USW WT-1	Rhyolite lava and tuff of Calico Hills, ash-flow, 50 m below top.	144
USW WT-2	Crater Flat tuff, Prow Pass Member, ash-flow, 85 m below top.	185
UE-25 WT #3	Crater Flat tuff, Bullfrog Member, ash-flow, 43 m below top.	157
UE -25 WT #4	Rhyolite and tuff of Calico Hills, lava flow, 87 m below top.	140
UE-25 WT #6	Rhyolite and tuff of Calico Hills, lava flow, 167 m below top.	326
USW WT-7	Topopah Spring Member, non-welded ash-flow, 17 m above base.	230
USW WT-10	Topopah Spring Member, non- to partly welded ash-flow, 57 m below top.	273
USW WT-11	Topopah Spring Member, nonwelded ash-flow, 21 m above base.	251
UE-25 WT #12	Topopah Spring Member, densely welded ash-flow, 43 m above base.	173
UE-25 WT #13	Topopah Spring Member, moderate to densely welded ash-flow, 152 m below top.	165
UE-25 WT #14	Topopah Spring Member, nonwelded ash-flow, 23 m above base.	175
UE-25 WT #15	Topopah Spring Member, densely welded ash-flow, 226 m below top.	200
UE-25 WT #16	Rhyolite and lava of Calico Hills, lava, 147 m below top.	160
UE-25 WT #17	Crater Flat tuff, Prow Pass Member, non- to partly welded ash-flow, 16 m below top.	158

Table 2.1-2. Stratigraphic units and depths below water surface for proposed and existing water table wells (continued)

Proposed Wells	Anticipated Stratigraphic unit at the Water Surface	Anticipated Depth of Penetration Below Water Surface (ft)
USW WT-8	Crater Flat tuff	~100
USW WT-9	Lavas and tuffs of Calico Hills	~100
UE-25 WT #19	Lavas and tuffs of Calico Hills	~100
UE-25 WT #20	Base of Topopah Spring Member, ash-flow	~100
USW WT-21	Lavas and tuffs of Calico Hills	~100
USW WT-22	Lavas and tuffs of Calico Hills	~100
USW WT-23	Unknown	~200
USW WT-24	Unknown	~200

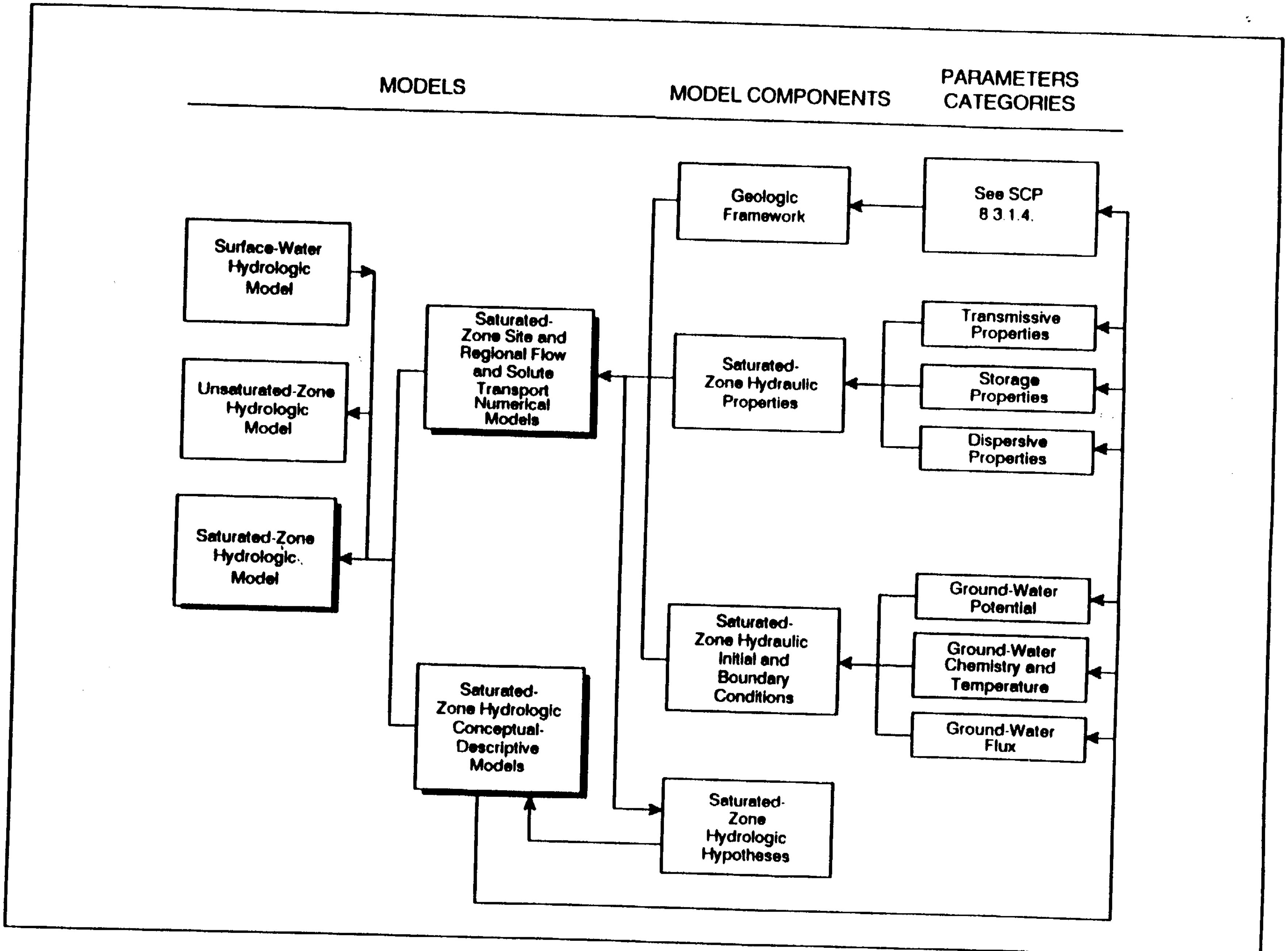


Figure 2.1-2. Logic diagram of the geohydrology program, including model components and parameters categories.

parameters is that sufficient confidence can be placed in their numerical values and their representativeness to permit the construction of hydrologic models and to perform tests of hypotheses. That is, confidence in the calibration and validation of a model to a given level is dependent on the extent to which the input data and observations are characterized and credible.

Some of the specific parameters listed in Table 2.1-1, although not required directly for resolving performance and design issues, are required to accomplish satisfactory hydrologic modeling. A numerical model, based on representative distributions of parameters, will be used as a principal approach to assess whether the data collected to describe dhe present and expected geohydrologic characteristics provide the information required by the performance and design issues. Calibration of the model to observed conditions increases confidence that the modeled distribution of parameters is an acceptable representation of actual conditions.

A principal strategy of the study, therefore, is to use approaches that minimize and quantify the uncertainty in the values of the parameters and in the understanding of their relations 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 difficult to measure. As described below, however, the strategy of the study is to increase confidence by using multiple approaches for determining parameters not readily amenable to measurement or analysis, by testing hypotheses, and by developing acceptable models. Table 2.1-1 shows that some parameters listed are being generated by more than one activity (multiple approaches).

A major advantage to using multiple approaches for determining parameters is that, in general, reliance is not placed on only one test to determine a value for a parameter. Some tests will provide only partial information, whereas others will provide extensive information necessary for determination of a parameter. By combining the test results and studying their relations, a greater understanding and confidence of any particular parameter can be achieved. For example, in the site saturated-zone flow-system study, solute-transport properties in fractured, saturated rock will be evaluated. Several different tests using conservative and reactive tracers will be conducted. Similarly, cross-hole tests and conventional pumping tests will be used to determine permeabilities and connectivities of rock units in the saturated zone. Injection-pumpback tests, convergent tests, and two-well recirculating tests at the c-well complex will (among other things) support the above-mentioned tests and enable evaluation of effective porosities, and dispersivities.

Because of the nonstandard nature of some of the tests, the possibility that one of these tests may fail in achieving the desired objectives is recognized. The use of multiple approaches for determining parameters increases confidence that the failure or the partial failure of one or more tests will not severely inhibit the ability of the characterization activities to provide the information required.

Another way in which multiple approaches can increase confidence in the results is by measurement of parameters at different scales. Using the previous example of pumping tests, the large-scale pumping test will evaluate bulk-aquifer hydrologic properties on a large scale, including boundary effects and structural controls. Smaller-scale well tests will determine more precisely the permeability tensor for different saturated-zone units. The results of single-well tests will be compared to multiple-well tests to evaluate the effects of scale and whether the aquifer can be best represented by an equivalent porous medium or a discontinuous fracture network at the scale of the tests.

The process of variable-scale testing with different approaches to evaluate similar parameters will delineate specific relations between hydrologic parameters and provide an increased multi-scale understanding of the saturated zone beneath Yucca Mountain. The results will increase confidence that an understanding has been gained of flux-related hydrologic properties, and physical and chemical transport phenomena of the saturated-zone flow system at the site.

The information obtained in this study as well as information from other studies will be used to refine models of the ground-water flow system. Sensitivity analyses done with the ground-water flow models indicate which pieces of information are most critical to understand the flow system. As the models are refined and the uncertainty of some of the information is reduced, the most critical remaining information may change. As information needs evolve over time, data collection activities, as well as study plans describing these activities also must evolve. The relationship between data collection and modeling is illustrated in Section 1.1.

2.1.3 Hydrologic hypotheses

The saturated-zone hydrologic hypotheses describe in general terms the manner in which water moves through the saturated zone, including the flow paths. The testing and refinement of hypotheses provide a logical and systematic approach to improving our understanding of how the geohydrologic system functions, the result being an improved geohydrologic program which, in turn, leads to increased confidence in the conceptual model (Figure 2.1-2). The hypotheses component shown in Figure 2.1-2 is tied to Table 2.1-3, which lists current hypotheses for the saturated zone. The table also shows objectives and approaches of the activities that are directly involved in testing these hypotheses.

2.1.4 Hydrologic model

Hydrologic modeling of the saturated zone beneath Yucca Mountain is described in detail in a separate study plan (8.3.1.2.3.3). However, much of the hydraulic information and data used as a basis for that modeling will be obtained by activities described in this study plan and in practice many of the same hydrologists are involved in both studies.

Page 1

Table 2.1-3. Relations between saturated-zone hydrologic hypotheses and the objectives of the activities of this Study
(SCP Study 8.3.1.2.3.1)

Hypothesis	SCP number	Activity objectives
Steep hydraulic gradients north and west of the site are caused by the Solitario Canyon fault to the west and low-permeability rocks or faults to the north.	8.3.1.2.3.1.1	To determine nature of Solitario Canyon fault as a conduit or barrier to eastward movement of ground water, by drilling and testing wells on both sides of the fault.
The nature of ground-water flow in the saturated zone is as follows: Ground-water flow occurs principally in fractures, flow through unfractured rock is of secondary importance. Hydraulic characteristics vary spatially as a result of variations in fracture characteristics. South and east of Yucca Mountain, faults are common, generally interconnected, and serve as principal pathways for flow. In areas where faulting is less frequent, faults generally are not interconnected, and flow is controlled by smaller-scale fracturing. Although ground-water flow is principally through fractures, and storage is mainly in the matrix, the system can be simulated by analogy to a double porosity media. In unfractured rock, hydraulic conductivity is small, but not negligible, whereas its effective porosity is larger. In fracture systems, the oposite prevails. At the site, the ground-water flow system in the tuff behaves as a single, thick unconfined aquifer, with negligible vertical variations in hydraulic aquifer properties and seepage velecity. Flow is controlled by structural features, such as faults and joints, which dip steeply, and effectively limit vertical hydraulic gradients, but facilitate vertical flow.	8.3.1.2.3.1.2	To characterize type of flow during tests (linear, radial, fracture, matrix, or both), to determine the magnitudes and directions of natural flow components at the site, and to evaluate the influence of structural and lithologic controls on these components. The approach will be to evaluate previously completed hydraulic-stress tests at the C-well complex and to expand the database by new tests in the same wells.
"	8.3.1.2.3.1.3	"

Because the two studies are closely linked, a summary of the modeling strategy is presented in the following section. The two studies are not independent but form a feedback process, as shown in Section 1.1.

In assuming that the overall hydrologic system within the saturated zone at Yucca Mountain can be described by conventional theories of fluid storage and movement in porous and fractured rock, the present and probable future spatial distribution and magnitude of hydrologic parameters can be described using appropriately constructed hydrologic models. The successful development of validated numerical models of the hydrologic system will increase confidence that the geohydrologic framework, distribution of input parameters, and nature of initial and boundary conditions are appropriate for design and performance analyses.

Because the spatial and temporal extrapolation of flow within the saturated zone involves complex interactions that can be described best with models, preliminary data from the site saturated-zone flow-system study will be used as a basis for a multiscale, numerical model of the saturated zone. This model will, in turn, contribute to the development of a geohydrologic program for Yucca Mountain. The geohydrologic program will provide a description of the important components of the geohydrologic system and will reflect an understanding of (1) hydrologic parameters, (2) initial and boundary conditions and processes, and (3) their relations.

The hydrologic system at Yucca Mountain will be described by models of the unsaturated and saturated zones. To facilitate site characterization, the hydrologic system is considered to include, beginning at land surface, a zone or region of infiltration, which overlies a thick, unsaturated zone. The unsaturated zone overlies the saturated zone, the contact between the two being the water table. Data from each of these zones or regions will be used in the unsaturated-zone and saturated-zone models. In addition, a surface-water model may be developed (8.3.1.2.1.2.1) which will provide input to the other two models.

Saturated-zone hydrologic-system synthesis and modeling, as described in Study 8.3.1.2.3.3, will be used to interpret the results of observations and measurements made during this study and to extrapolate those results to evaluate flow and transport in the saturated zone under various conditions. The synthesis and modeling will involve: (1) synthesis of available data to make a qualitative analysis of how the system is functioning and the conceptualization of the saturated-zone flow models; (2) development of a fracture-network model for simulating hydraulic and tracer tests; and (3) calculation of flow paths, fluxes, and velocities within the saturated zone.

Hydrologic modeling produces the velocity field essential for defining flow paths and computing radionuclide-migration time. Modeling requires sufficiently detailed knowledge of the geohydrologic framework and distribution of hydrologic parameters. The saturated-zone hydrologic model, which is an integral part of the geohydrologic program, is dependent on hydrologic parameters determined by the site saturated-zone flow-system study. Multiple-approach, variable scale tests of wells and analyses of their variance and spatial distributions will increase the data needed to understand flow and transport. Ultimately, these data will lead to the complete development of a saturated-zone model and to increased understanding of the transport of radionuclides to the accessible environment. The model development/data collection feedback process will be considered complete when, in the judgment of the investigators, prediction errors based on model cross validation are minimized.

2.2 Constraints on the study

2.2.1 Representativeness of repository scale and correlation to repository conditions

The site saturated-zone flow-system study is located within the repository area. The boreholes and wells to be used for the different water-level measurements, sampling, pumping tests, and tracer tests will penetrate some of the same geohydrologic units as does the repository. The saturated-zone to be tested lies beneath the repository block and will constitute a potential path between the repository and the accessible environment. Because of this, the environment in which the site saturated-zone flow-system study will be conducted is an approximate representation of the saturated zone beneath the repository area. How well each test will represent future or present conditions of the repository at the scale of the repository depends on a number of factors relating to the particulars of the test.

Information produced in Activity 1 (Solitario Canyon fault study) will be representative only of that fault and not faults throughout the area. However, data indicates that this fault may be most important to the flow system. Information produced in Activity 2 (Potentiometric-level evaluations) will be representative over the repository area. Information produced in the remaining four activities will be representative of the areas immediately around the wells that are tested. Many of these tests will be done at the c-well complex but additional tests will be conducted elsewhere. While it is anticipated that information for these activities will be representative of conditions throughout the repository, this will not be known until the modeling of the site area, as described in Study Plan 8.3.1.2.3.3, Site saturated-zone synthesis and analysis.

2.2.2 Accuracy and precision of methods

Selected and alternate methods for testing in each activity are summarized in tables at the end of each activity description (Section 3). Methods were selected on a basis of their precision and accuracy, duration, and interference with other tests and analyses. The accuracy and precision of the saturated-zone tests are difficult to quantify prior to implementation of the test method. However, when the results of tests or analyses are reported, the accuracy and/or precision of the results will be described. The degree of accuracy and/or precision of each method within activities is a qualitative, relative judgment based on current knowledge and familiarity with, and understanding of, the method as well as specific aspects of each individual test. The accuracy and precision of the information required for performance assessment has not been specified. Consequently, the accuracy and precision required from the results of this study cannot be specified.

2.2.3 Potential impacts of activities on the site

Water table holes will be drilled to various depths in the saturated zone. Surface facilities for these holes will include drilling equipment, power substations, trailers and access roads. Although some of these holes will penetrate close to the edge of the repository block, *in situ* tests described in this study plan will have little or no impact on natural-state site conditions. The only likely effects would be increased fracturing near the boreholes due to drilling and testing. Any fractures resulting from testing would likely occur well below the repository level. Any fractures produced as a result of drilling would likely occur only very near the boreholes.

Tracer tests and water discharged during pumping tests have the potential to impact other activities such as surface water discharge studies, other tracer studies, and recharge studies. This potential impact will be eliminated by careful disposal of discharged water. This may be accomplished by construction temporary pipelines to carry water away from a potentially impacted area, or if necessary by trucking water away from the potentially impacted area. Tracers used in the tracers tests will be carefully selected to avoid interference with other tests or the tests will be conducted in sequence to avoid interference.

2.2.4 Time required versus time available

A tentative schedule of work activities and reports is given for this study in Section 5. This schedule assumes that the five years available for site-characterization work will be sufficient to complete the activities. The construction and in-borehole testing program is estimated to last approximately two years, with *in situ* monitoring lasting for a period of three to five years and continuing thereafter as part of the performance confirmation process.

3 DESCRIPTION OF ACTIVITIES

The study is organized into six activities:

- o 8.3.1.2.3.1.1 - Solitario Canyon fault study in the saturated zone,
- o 8.3.1.2.3.1.2 - Site potentiometric-level evaluation,
- o 8.3.1.2.3.1.3 - Analysis of single- and multiple-well hydraulic-stress tests,
- o 8.3.1.2.3.1.4 - Multiple-well interference testing,
- o 8.3.1.2.3.1.5 - Testing at c-well complex with conservative tracer, and
- o 8.3.1.2.3.1.6 - Well testing with conservative tracers throughout the site.

The plans for these activities are described in Sections 3.1 through 3.6, respectively.

3.1 Solitario Canyon fault study in the saturated zone

3.1.1 Objectives

The objectives of this activity are:

1. characterize the hydrologic significance, nature, and implications of the Solitario Canyon fault; and

2. determine whether the fault is a barrier to eastward flow of water in the saturated zone beneath the repository block.

3.1.2 Rationale for activity selection

The importance of faults to ground-water movement in the saturated zone has not been determined. A number of normal, west-dipping faults lie east of the repository block, and the block is bounded on the west by the Solitario Canyon fault zone. Northwest-trending, strike-slip faults may bound the block on the northeast. Northeast-trending, strike-slip or oblique-slip faults splay off the Solitario Canyon fault zone. These faults may be hydraulic conductors, barriers, or both. Faults that are either highly conductive or resistive may dominate the flow-field transport properties of the hydrologic system. Water levels appear to change abruptly near the Solitario Canyon fault although some interpretations of the data attribute this change to the Ghost Dance fault. However, because of the design of the test, information will be obtained about the Ghost Dance fault as well as the Solitario Canyon fault. The discussion that follows assumes that the Solitario Canyon fault is the dominate fault, but, as noted above, the test does not depend on which fault dominates the flow system.

Several hypotheses explain the noticeably higher water levels in wells west of Solitario Canyon as compared to east of the canyon. These include:

1. the fault or fault zone within the canyon acts as a barrier to flow across it because of low-permeability gouge along the fault;

2. the fault acts as a barrier to flow because stratigraphic offset juxtaposes a zone of high permeability against a zone of very low permeability, and there is no permeability along the fault plane connecting permeable zones; and

3. bulk permeability of rocks on either side of the fault differs, possibly because of fracturing, or a facies change.

Acceptable hypotheses are lacking to account for some observations. At USW H-5 (Figure 3.1-1), although the well apparently is east of the fault, the potentiometric level (altitude about 775 m) is comparable to that in wells west of Solitario Canyon. Data show that although the potentiometric level (altitude about 730 m) in the upper part (Tram Member of Crater Flat Tuff) of USW H-3 is similar to that in wells to

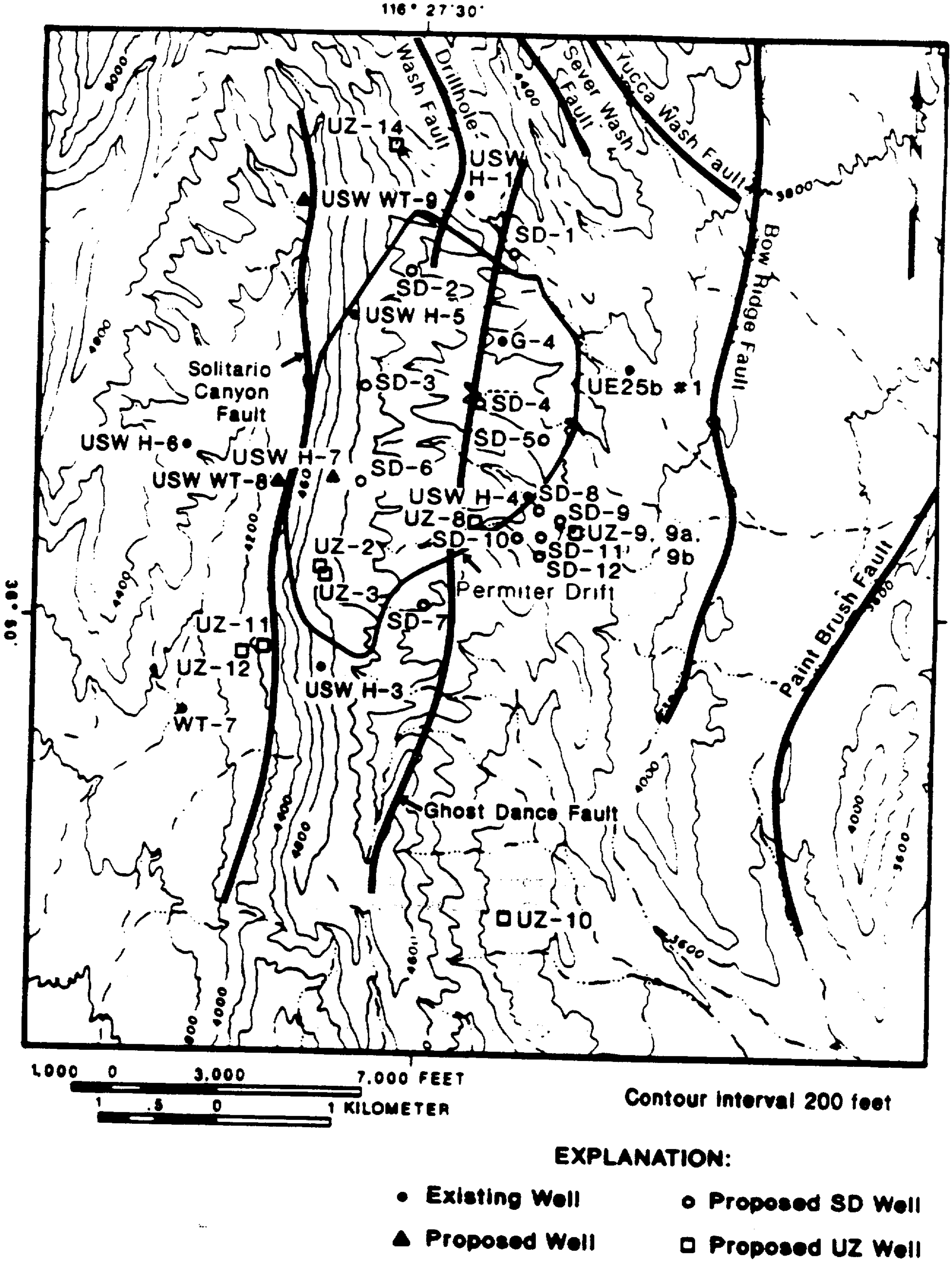


Figure 3.1-1. Map showing location of proposed and selected existing wells for site saturated-zone Solitario Canyon fault characterization.

the east, hydraulic head in the deeper part (Lithic Ridge Tuff) of well USW H-3 is higher, and comparable to head west of the fault (Figure 3.1-2. General stratigraphy in the vicinity, from oldest to youngest - Lithic Ridge Tuff; lava; Tram, Bullfrog, and Prow Pass Members of Crater Flat Tuff; tuffaceous beds of Calico Hills; Topopah Spring and Tiva Canyon Members of Paintbrush Tuff).

Whether the Solitario Canyon fault zone acts as a hydraulic barrier or a conduit will be investigated by pumping one or more wells and observing responses in nearby wells.

3.1.3 General approach, methods, and analyses

West of the Solitario Canyon fault, water-table wells USW WT-8 and USW WT-9 will be drilled to depths of about 640 to 670 m (2,100 to 2,200 ft). The hole diameters are expected be about 22 cm (8.75 in.). The wells will be drilled a short distance into the saturated zone, probably not more than 100 m (328 ft). They will not be cased below the saturated zone unless unusual conditions require it. Well USW WT-8 will be located directly west of well USW H-7 and close to a line between wells USW H-6 and USW H-7. Well USW WT-9 will be located a considerable distance to the north. It, along with well USW WT-7 to the south, will give a better description of possible flow across the fault. Well USW. W-9 will also help define the site potentiometric level (Activity 8.3.1.2.3.2). Wells will be completed with three access tubes; two will be for water-level measurements, and the other for temperature measurements of the unsaturated zone (Activity 8.3.1.15.2.2.1, Surface-based evaluation of ambient thermal conditions). East of the Solitario Canyon fault on the ridge crest of Yucca Mountain, hydrologic test well USW H-7 will be drilled. The expected depth of this well is about 914 m (3,000 ft), with a hole diameter of about 22 cm (8.75 in.) (see Figures 3.1-1 and 3.1-2). The water level in this well will be monitored during drilling. A measurement will be made as soon as possible after the water table is encountered and thereafter as often as appropriate or convenient. Topography limits the location of the proposed wells to the bottom of Solitario Canyon and the crest of Yucca Mountain. Although additional observations wells could potentially provide additional information, those described here are the minimum required.

The wells will be used for geophysical logging, water sampling, and hydraulic tests. Hydraulic and water-chemistry data from proposed wells. USW WT-8 and USW H-7, both located east of USW H-6, will be used principally to help determine (1) if the flow in the vicinity is from west to east across the Solitario Canyon fault, as suggested by the water levels in wells on either side, and (2) the nature and extent of any hydraulic barrier caused by the fault. If no significant eastward flow across the fault is evident, this would bear significantly on both conceptual and numerical models. It is important to test the hypothesis that generalized flow in the saturated zone is towards the south and southeast, even though present resolution of water-level data is not adequate to determine with assurance the magnitude or direction of apparent horizontal gradients beneath the eastern part of the repository block.

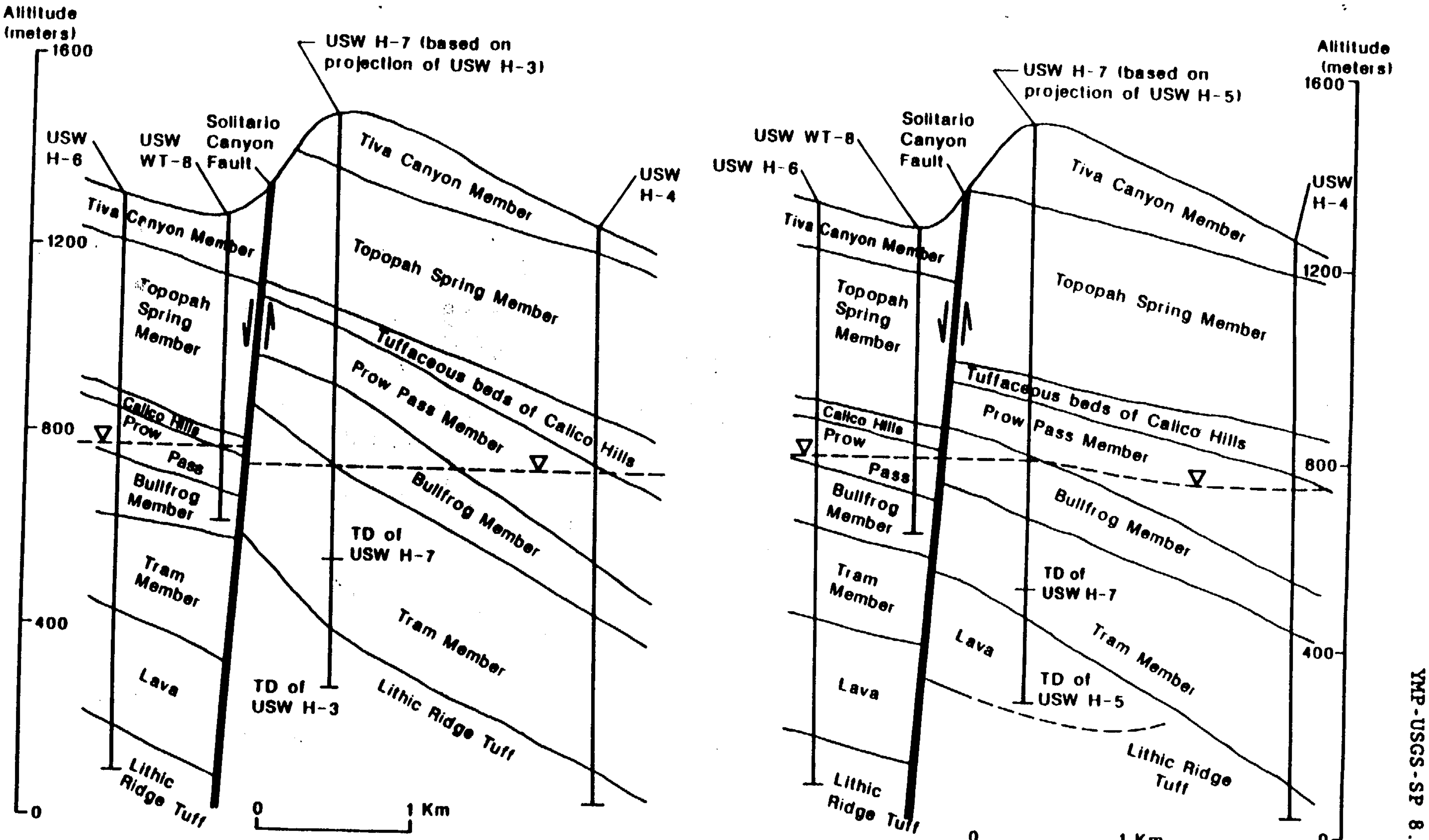


Figure 3.1-2. Postulated west-east sections across Solitario Canyon Fault (based on stratigraphy penetrated at USW H-3 and USW H-5, and projected to the USW H-7 site)

Figure 3.1-3 summarizes the organization of the Solitario Canyon fault characterization activity. A descriptive heading for each method appears in the shadowed boxes of the second row. Figure 3.1-4 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site-characterization parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed boxes, respectively.

The two figures summarize the overall structure of the planned activity in terms of methods to be used and measurements to be made. The descriptions in the following sections are organized on the basis of these charts. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations among (1) the site-characterization parameters to be determined, (2) the informational needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

Data collected during this activity may be used to characterize the saturated zone beneath the repository block. Evaluation of hydraulic properties may be limited to the vicinity of the pumped wells and it may not be possible to extrapolate properties throughout the repository area from this activity alone. An understanding of fault-related features and their significance on water movement within and around the fault zone will be useful for modeling present conditions and potential future repository conditions near discrete structures in the repository block.

3.1.3.1 Borehole geophysical surveys

Various logs will be run in each of the planned wells. The primary purpose of geophysical logging is to obtain continuous records of stratigraphic units and structural features penetrated during drilling so that geologic and hydrologic parameters can be determined or evaluated. These records will be useful for in-hole and cross-hole correlations, and to provide information to assist with selection of downhole instrument stations for hydrologic tests. The logging typically will include a gyroscopic survey, optical television survey; and dielectric, gamma-ray spectrum, caliper, fluid-density, electric, density, and epithermal neutron logs. The primary and secondary applications of these logs as well as their quantitative and qualitative uses are summarized in Table 3.1-1. In addition to geophysical logs, a tracejector survey will be done in well USW H-7. All borehole geophysical data will be collected in accordance with project quality control procedures as they become available. These data will be stored, archived, and distributed in accordance with available project directives.

3.1.3.2 Water sampling

After geophysical logs are completed in each water-table well, representative water samples for chemical and isotopic analyses will be obtained. The sampling process as well as the chemical and

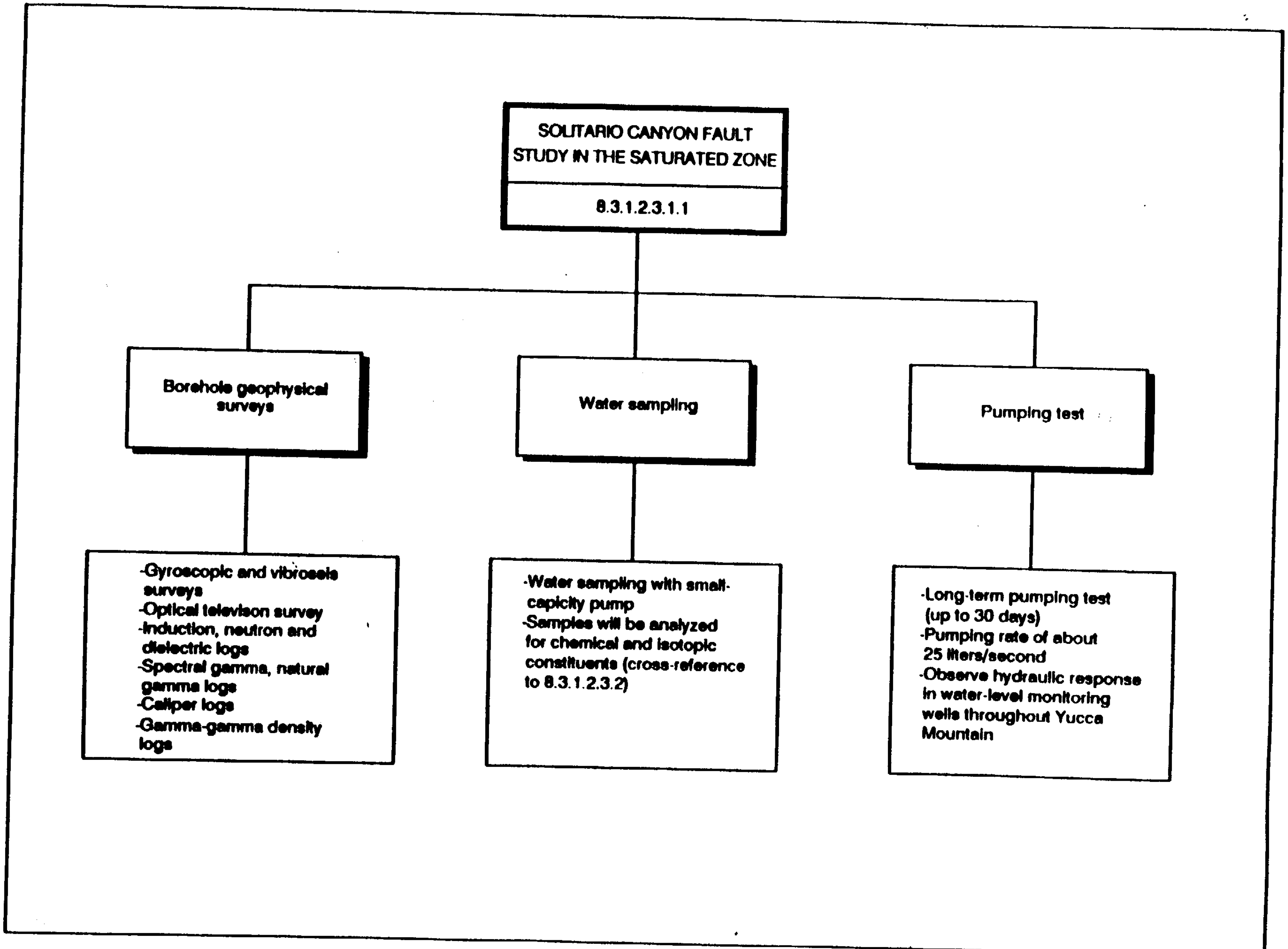


Figure 3.1-3. Logic diagram of the Solitario Canyon fault characterization showing methods and analyses.

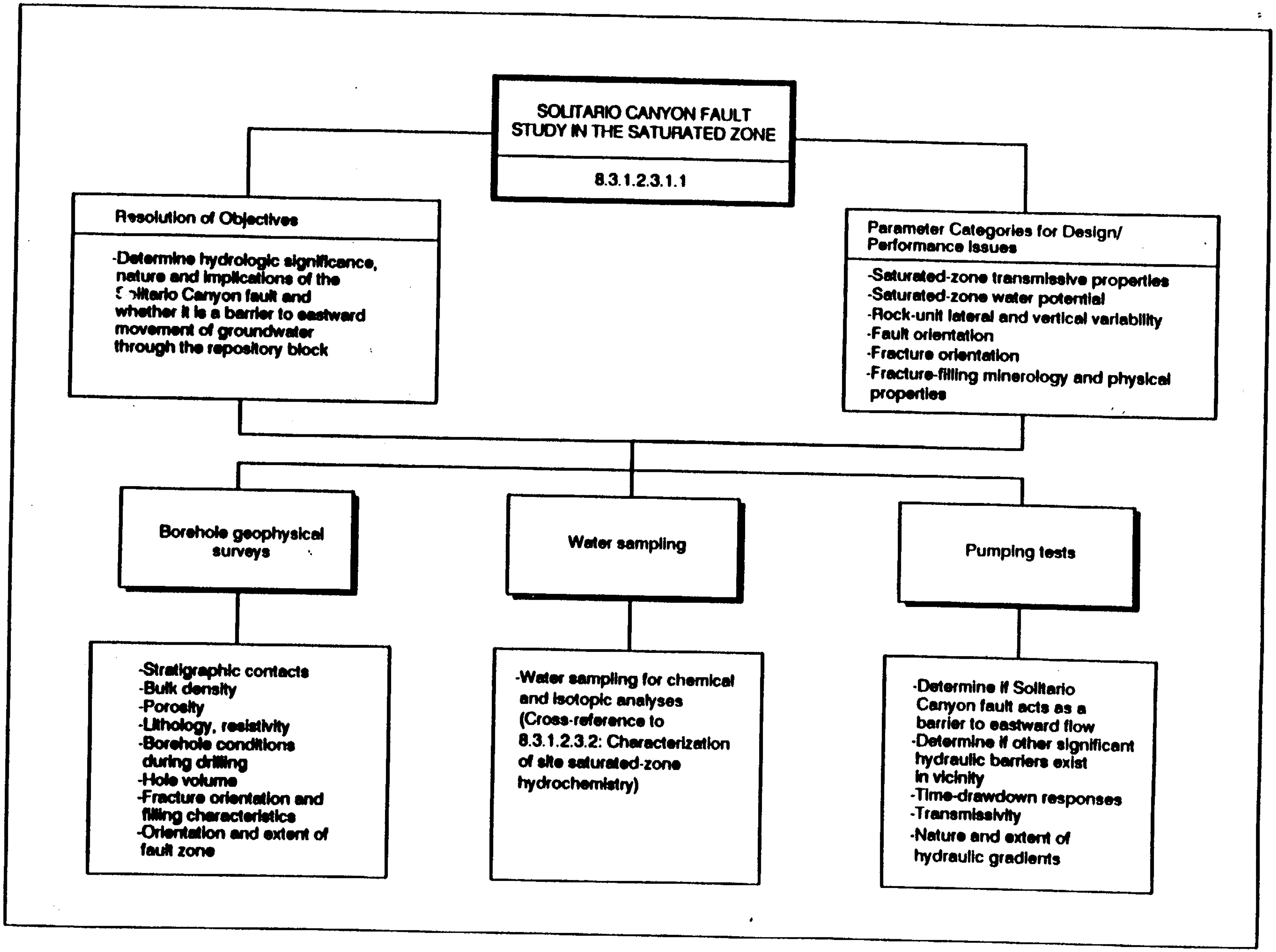


Figure 3.1-4. Logic diagram of the Solitario Canyon fault characterization showing methods, analyses, and site-characterization parameters.

Table 3.1-1. Borehole logging in the saturated zone (SCP Activity 8.3.1.2.3.1.1)
[Dashes (--) indicate information not available or not applicable.]

Type of logging	Primary application	Secondary application	Operational principle	Hole conditions needed	Quantitative uses	Qualitative uses
Caliper	Measure diameters of borehole	Calculate hole volume; identify unstable, caved, or eroded zones	Two, three, four, or six arms. Measures borehole average diameter	Open hole	Control of stemming-material volume during downhole instrument emplacement; selection of packer seats and pump settings; borehole corrections to other logs	Correlation of stratigraphy; identify fracture zones
Television (axial viewing)	Observe lithology, structure, and hydrology	Observe hole conditions, lost tools, and well construction	Videotape camera and compass	Open hole or cased for well-construction data	Fracture geometry and characteristics	Correlation of stratigraphy; observe water seeps and fracture zones
Television (radial viewing)	Observation of fracture character-istics	Observe hole conditions and lithology	Videotape camera and compass with special focusing capability	Open hole	Fracture occurrence and attitude	Fracture-zone identification and description; fracture aperture
Gamma-gamma (density)	Measure bulk density	In conjunction with neutron log and other data, determine porosity and identify lithology	Borehole-compensated gamma-gamma tool. Detects scattered-back gamma rays	Open hole (affected by hole rugosity)	Bulk-density measurements; porosity calculations	

Table 3.1-1. Borehole logging in the saturated zone (SCP Activity 8.3.1.2.2.1.1)--Continued

[Dashes (--) indicate information not available or not applicable.]

Type of logging	Primary application	Secondary application	Operational principle	Hole conditions needed	Quantitative uses	Qualitative uses
Induction	Determine formation resistivity, porosity, and water content	Stratigraphic correlation	Inducing current in the rock from a transmitting coil and to detect electromagnetic field by a receiving coil	Open hole	Determine formation resistivity	Stratigraphic correlation
Gyroscopic	Determine deviation of hole from vertical	Determine true depths from measured depths and spatial location of data points in subsurface	Gyroscope	Open hole or cased	Angular deviation and displacement of hole from vertical	General plumbness and straightness
Epithermal neutron (sidewall)	Counts epithermal neutrons or gamma rays of capture	In conjunction with density log, locate perched water. Use of sidewall and compensated tools improves understanding of sidewall response in UZ	Source of high-energy neutrons and one or two detectors. Counts epithermal neutrons	Must use sidewall tool above water levels; may use sidewall or compensated tool below. Open hole or cased; sensitive to hole rugosity and diameter	Lithology and porosity estimates in conjunction with density log	Detect changes in hydrogen (water content by volume); porosity

Table 3.1-1. Borehole logging in the saturated zone (SCP Activity 8.3.1.2.2.1.1)--Continued

[Dashes (--) indicate information not available or not applicable.]

Type of logging	Primary application	Secondary application	Operational principle	Hole conditions needed	Quantitative uses	Qualitative uses
Epithermal and thermal neutrons (moisture meter)	Make volumetric measurements of water content	--	Short-spaced neutron source to detector that responds to hydrogen nuclei	Open hole or cased (poorer resolution)	Water content by volume	
Dielectric	Used in conjunction with density and neutron logs to estimate water content	--	Measure dielectric permitivity inductively at a frequency of 47 megahertz	Open hole	--	Estimate water content
Fluid density	Locates the water level in hole	--	Density measurement is made by observing the relative absorption of gamma rays passing through the borehole fluid	Open hole	Measure water level during drilling; measure altitude of water table, potentiometric head, or presence of perched water	--

Table 3.1-1. Borehole logging in the saturated zone (SCP Activity 8.3.1.2.2.1.1)--Continued

[Dashes (--) indicate information not available or not applicable.]

Type of logging	Primary application	Secondary application	Operational principle	Hole conditions needed	Quantitative uses	Qualitative uses
Spectral density	Lithology determinator	Precise depth correlation with core and off-set wells	Detects broad spectrum of naturally occuring gamma energy	Open or cored hole; affected by hole diameter	Depth correlation	Rock typing

isotopic analyses to be done are described in detail in Study Plan 8.3.1.2.3.2 (Characterization of the Site Saturated-Zone Hydrochemistry).

3.1.3.3 Pumping tests

After the initial development and testing of USW H-7, including an intraborehole-flow (tracejector) survey to determine water-bearing intervals, a long-term pumping test (perhaps as much as 30 days) will be made. Permeability of the rock permitting, this test will consist of pumping USW H-7 at a rate of about 25 liters per second (400 gal/min) or more while observing hydraulic responses in water-level monitoring wells located throughout Yucca Mountain. Monitoring will focus on, but not be limited to, those wells located on the other side (west) of the fault, such as USW H-6 (two depth intervals to be monitored) and the proposed USW WT-8 and USW WT-9. After the pumping test at USW H-7 is complete, it may be desirable to pump USW H-6 while observing responses in USW WT-8, USW H-7, and other wells east of the fault. This second test would not be performed if no effects were observed on the other side (west) of the fault. It is expected to be necessary to disperse or convey pumped water away from USW H-7 and USW H-6 in order to prevent disturbance of local infiltration studies. Disposal of possibly 25 liters per second of water for up to 30 days may pose a significant problem, especially from USW H-7. Trucking may not be practical and a temporary pipeline may be required to move the water far enough away from any infiltration studies.

By observing pumping responses in wells located on both sides of the fault, it is hoped although not assured that it will be possible to determine qualitatively if the Solitario Canyon fault acts as a barrier to eastward flow; this is important because the fault may be a major factor controlling ground-water flow in the vicinity of the repository block. By observing pumping response in other wells located throughout the site, qualitative information may be obtained on other features, such as the Ghost Dance fault. Test complications include the fact that pumped and observed wells are not likely to be open to similar stratigraphic intervals (Figure 3.1-2), and that fracturing, which appears to control bulk permeability, correlates poorly with stratigraphic units. Based on previous measurements, water-level responses may be small, possibly not much greater than observed periodic fluctuations due to barometric changes and earth tides (Section 3.3); therefore, quantitative evaluations are not likely to be feasible, either of the rocks between pumped and observation wells, or of intervening faults. For example, within a day or two of starting to pump one of the UE-25c wells, routine periodic water-level measurements in the observation wells east of the Solitario fault appeared to have been affected by that pumping. Therefore, it is reasonable to expect that water-level measurements in wells in the general observation network, including new water-table and systematic drilling wells to be drilled, will show which wells are in good hydraulic connection with pumping wells, and which are isolated because of faults or other barriers. By locating the planned wells near Solitario Canyon fault and close to each other, their responses to pumping stress will be maximized.

Depending on the results of the long-term pumping test, a number of shorter-term tests may be indicated. In the initial test, the entire interval of USW H-7 will be pumped; the probable yielding intervals will be indicated by the tracejector survey. If a response is measured in the observation wells and particularly if a different response is noted in the different intervals of USW H-6, further testing will be required. Well USW H-7 will be divided into two or more intervals and each interval will be tested. The duration of each test will be determined by the results of the initial test. The additional testing could determine if the Solitario Canyon fault is an open boundary at one depth and a closed boundary at another depth.

Planned location of the closest well west of Solitario fault from USW H-7 (USW WT-8) would be 750 m (2,500 ft) or more, and therefore, any tracer that might be injected into USW WT-8 is unlikely to be detected in USW H-7 during the planned pumping period, even if the fault is not a barrier. Should early tests indicate this supposition to be incorrect, a tracer could be injected later and monitored by methods similar to those planned in the vicinity of the c-wells (Section 3.5).

3.1.3.4 Methods summary

The parameters to be determined by the tests described above are summarized in Table 3.1-2. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be used if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, there are many approaches to conducting the test. In those cases, only the most common methods are included in the table. The selected methods in Table 3.1-2 were chosen primarily on the basis of accuracy, precision, duration of methods, expected range, and lack of interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site parameter. The expected ranges of the site parameter have been bracketed by previous data collection and computer modeling and are shown in Table 3.1-2.

3.1.4 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires documentation of technical procedures for all technical activities that require quality assurance.

Page 1

Table 3.1-2. Summary of tests and methods for the Solitario Canyon fault characterization in the saturated zone (SCP 8.3.1.2.3.1.1)
[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site-characterization parameter	Expected range
Drilling of water-table observation wells		
Select the drillsites in vicinity of Solitario Canyon fault (selected)	Cross-reference to 8.3.1.4.1 - Development of an integrated drilling program and integration of geophysical activities	--
Use air foam as circulating medium to drill the wells (to minimize effects on the rock) (selected)	"	--
Complete the wells using two access tubes (one for permanently-installed transducers, the other for confirmation of water-level measurements) (selected)	"	--
Use mud as circulating medium to drill the wells (alternate)	"	--
Complete the wells with single-access tubes (alternate)	"	--
Complete or modify the wells to minimize well-bore storage for analysis of storage properties (alternate)	"	--
Retrieve bit cuttings and continuous cores for analysis in order to determine stratigraphy (selected)	Cross-reference to 8.3.1.4.1 and 8.3.1.4.2.1 - Characterization of the vertical and lateral distribution of stratigraphic units within the site area	--
Obtain intermittent cores (alternate)	"	--

Table 3.1-2. Summary of tests and methods for the Solitario Canyon fault characterization in the saturated zone (SCP 8.3.1.2.3.1.1)

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Drilling of water-table observation wells--Continued	
Drill no additional wells. Use existing data plus surface geophysical surveys (alternate)	Cross-reference to 8.3.1.4.1 and 8.3.1.4.2.1 - Characterization of the vertical and lateral distribution of stratigraphic units within the site area	Not applicable
Retrieve bottom cores for analysis in order to determine fracture system geometry (selected)	"	90% recovery
Retrieve bit cuttings and continuous cores for analysis in order to determine stratigraphy and fault zone properties (selected)	"	"
	Borehole geophysical survey	
Television and geophysical surveys (selected)	Cross-reference to 8.3.1.4.2.1.3 - Borehole geophysical surveys	100% of uncased wells
Acoustic surveys below water table (alternate)	"	"
	Water sampling	
Sample with small-capacity pump (selected)	Cross-reference to 8.3.1.2.3.2 - Characterization of the saturated zone hydrochemistry	--

Table 3.1-2. Summary of tests and methods for the Solitario Canyon fault characterization in the saturated zone (SCP 8.3.1.2.3.1.1)

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Pumping tests	
Tracejector survey to determine water bearing intervals (selected)	Hydraulic conductivity, fault zone and wall rocks	10^{-9} to 10^{-5} m/s
Large-scale pumping test monitoring pressure response in nearby wells (selected)	Transmissivity, fault-zone and wall rocks	10^{-2} to 10^{2} m^2/d
Single-well pumping test using packers (alternate)	Fault-zone transmissivity	"
Large-scale pumping test monitoring pressure response in nearby wells (selected)	Hydraulic conductivity, fault zone and wall rocks	10^{-9} to 10^{-5} m/s
Large-scale tracer tests monitoring tracer in pumped well (alternate)	"	"
Single-well pumping test using packers (alternate)	Hydraulic conductivity, fault zone and wall rocks	"
Large-scale pumping test monitoring pressure response in nearby wells (selected)	Storage coefficient, fault zone and wall rocks	10^{-6} to 10^{-3} m/s
Single-well pumping test using packers (alternate)	"	"

Table 3.1-3 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a USGS procedure number and an effective date. Procedures that are not identified with an effect date will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started; these procedures are also identified with a "TBD" (To Be Determined) technical procedure number. Some of the listed technical procedures are primarily outside the objectives of the subject activity (Solitario Canyon fault characterization in the saturated zone) or study (Characterization of the Yucca Mountain site saturated-zone flow system), but are included for general information and ease of cross-referencing. Approved technical procedures not listed may be used during the activity, should that be appropriate, and listed procedures may be revised or replaced with other procedures, as needed.

All procedures listed are currently classified as "standard", as they represent modifications of methods and equipment with established records of use and reliability. Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and stepwise procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Applicable quality-assurance procedures are presented in Appendix 7.1.

Table 3.1-3. Technical procedures for the Solitario Canyon fault characterization in the saturated zone (SCP Activity 8.3.1.2.3.1.1)
[Dashes (--) indicate information is not available and to be determined.

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Borehole geophysical surveys	
GP-10	Borehole-video fracture logging	04/12/85
HP-02	Acoustic televiewer investigations	08/14/84
HP-03	Hydrologic tracejector test	01/11/82
HP-50	Method for neutron scatter and gamma-ray attenuation logging using the USGS Logging Van (I-139055)	11/15/84
TBD	Induction logging (F & S)	--
	Water sampling	
HP-08	Methods for determination of inorganic substances in water	08/06/82
HP-23	Collection and field analysis of saturated-zone ground-water samples	11/04/83
HP-11	Methods for determination of radioactive substances in water	06/18/82
	Pumping tests	
HP-06	Hydrologic pumping test	01/11/82

Table 3.1-3. Technical procedures for the Solitario Canyon fault in the saturated zone (SCP Activity 8.3.1.2.3.1.1)--Continued

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Drilling of water-table observation wells	
TBD	Drilling and coring (REECo)	--
	Water-level measurements	
HP-60	Method for monitoring water-level changes using pressure transducers	05/04/88
HP-71	Method for monitoring water-level changes using a Campbell Scientific 21X Micrologger	09/01/87
HP-93	Method for processing electronic data from a Campbell Scientif 21X Micrologger into water levels	08/11/88

3.2 Site potentiometric-level evaluation

3.2.1 Objectives

The objectives of this activity are to:

1. analyze the character and magnitudes of potentiometric-level fluctuations with time and depth in order to determine their causes, and, if possible, to estimate system parameters such as transmissive and storage properties,

2. measure water-level variations with time in both planned and existing observation wells, and calculate average levels, as input data for hydraulic gradient calculations,

3. correlate water-level variations with earth crustal strain changes,

4. define more precisely the potentiometric surfaces, particularly the upper-most surface,

5. determine well/formation properties: barometric efficiency and dilatational efficiency, and

6. determine the frequency response function of the well/formation to barometric and earth-tide induced strains in order to determine at what frequencies a static-confined response can be inferred; and at what frequencies the effects of vertical fluid flow in the unsaturated and saturated zones are evident.

3.2.2 Rationale for activity selection

The technical rationale for this activity is to define site saturated-zone hydraulic gradients in three dimensions as input to synthesis and modeling activities that will yield calculations of flow paths, fluxes, and velocities within the saturated zone.

At well UE-25p #1 (Figure 3.2-1), the hydraulic head is 20 m (66 ft) higher in the Paleozoic carbonate rocks than in the overlying volcanic rocks (Craig and Robison, 1984). Higher heads were observed at a depth of 1,800 m (5,905 ft) in USW H-1, where the water-level altitude is about 773 m (2,536 ft), whereas the water table is about 730 m (2,395 ft) above sea level. Data from Robison (1984, 1986) show that within the upper 500 m (1,640 ft) of the saturated zone, there is no discernable vertical gradient (UE-25b #1, USW H-1, USW H-3, USW H-4, USW H-5, and USW H-6).

Data from Robison and others (1988), indicates that at wells USW H-1, USW H-3, and USW H-6, there is an upward gradient ranging from a few meters at USW H-6 to over 50 m (164 ft) at USW H-1. Data from well USW H-4 may show a small upward gradient, but if it exists it is only about 0.1 m (0.3 ft) while data from well USW H-5 indicates virtually no gradient. The water level in well UE-25p #1, completed only in the

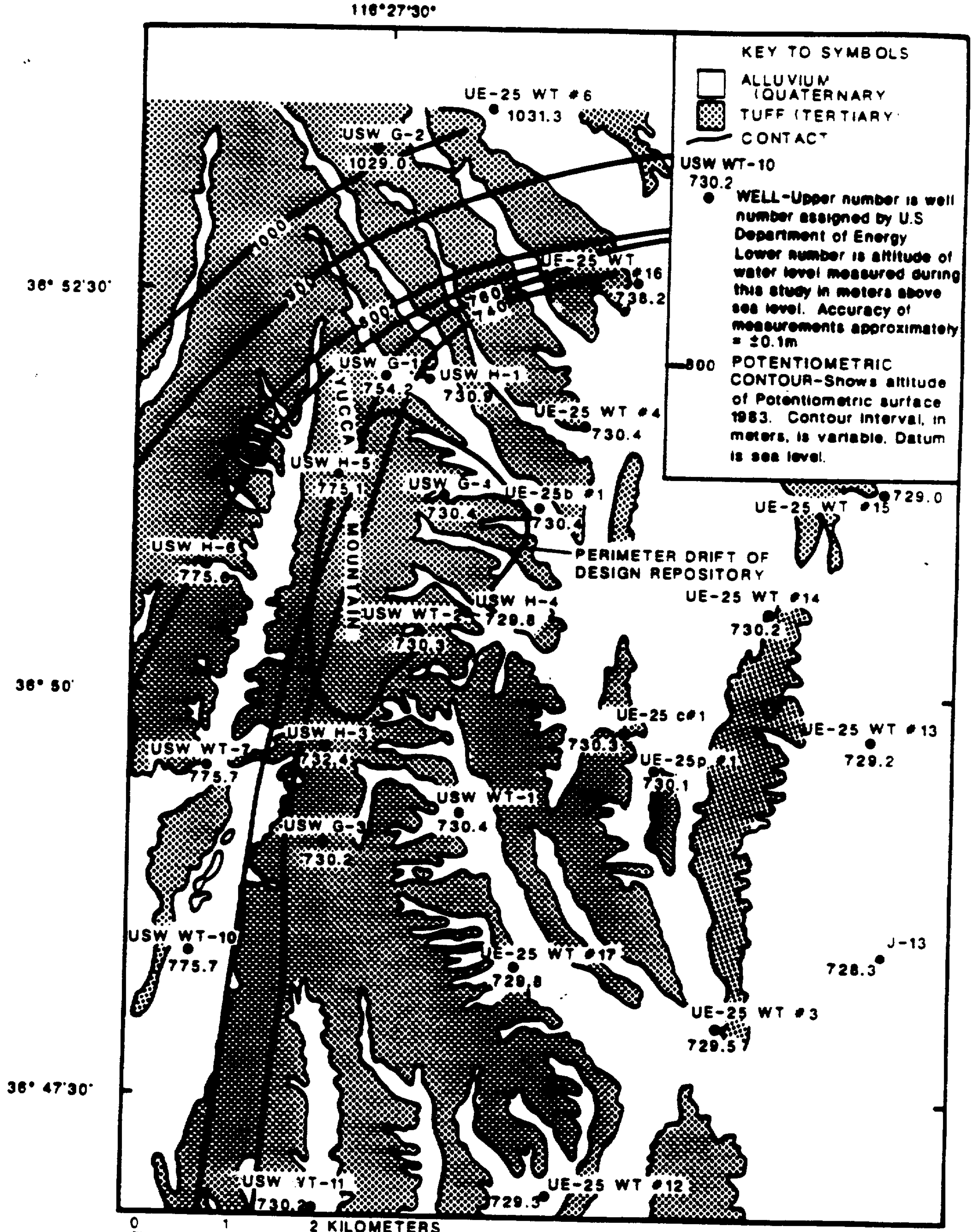


Figure 3.2-1. Map showing preliminary potentiometric-surface of the saturated zone, Yucca Mountain (modified from Robison, 1984).

Paleozoic carbonate, is about 20 m (66 ft) higher than water levels in the upper part of the saturated zone. Because of the upward or non-existent gradients between the upper and deeper units, the water level in the upper part of the saturated zone is of primary importance in describing flow paths and travel times of radionuclides entering the saturated zone from above. Hence the upper-most potentiometric surface is emphasized. Because water levels in the upper 500 m (1,1640 ft) of the saturated zone seem to be constant with depth, defining the upper-most potentiometric surface is not made difficult by vertical gradients.

The data shown in Figure 3.2-1 is from Robison (1984) and was modified by Robison in 1986. However, more recent, and probably more accurate data on water levels can be found in Robison and others (1988) and Gemmell (1990). The potentiometric-surface contour lines in the figure represent an 1984 interpretation and will likely be modified in the future.

In the vicinity of the repository block at Yucca Mountain and eastward into Jackass Flats for 5 km (3.1 mi) or more, the upper-most potentiometric surface is nearly flat (altitude 730 m [2,395 ft]). Water-level altitude in nearby wells is higher to the west (775 m [2,542 ft]) and north (778 to 1,031 m [2,552 ft to 3,382 ft]) of the block. This activity will result in a better definition of the potentiometric surface within and among these three areas.

Beneath the repository block and down gradient from it, the water table is so flat that water-level measurements, even when made with very high accuracy and precision, cannot be used readily to determine average water-level differences and gradients among wells. The primary reason, based on measurements to date, is that in many wells the short-term water-level variations due to barometric changes, earth tides, and possibly other phenomena, although they are small, are comparable to the apparent differences among nearby wells. Therefore, water-level averages of months or perhaps years are necessary to determine gradients and probable flow paths near the repository.

Continuous water-level data may be helpful for evaluating the general hydraulic character of intervals penetrated by observation wells, and for estimating rock elastic and fluid-flow properties from responses to strains induced by earth tides, atmospheric load, and seismic waves. The analysis of the effects of earth-tide and barometric induced water-level fluctuations is discussed in Section 3.3 (3.3.3.3) of this study plan. For those wells with multiple instrumentation intervals, it will be possible to make separate evaluations of each depth interval represented. Within this activity, these analyses will be done for existing WT wells and new wells added to the network that are continuously monitored.

The information obtained in this activity will be used to refine the models of the ground-water flow system. Sensitivity analyses with the refined models may indicate a need to modify data collection and the modeling are interrelated processes that influence each other. This feedback process is described in Section 1.1 and is shown on figure 1.1-2.

3.2.3 General approach, methods, and analyses

The characterization of the site potentiometric surface will involve the drilling of water-table wells, lithologic and geophysical logging of these wells, water sampling and water-level measurements, monitoring of crustal strain, and the interpretation of data resulting from tests.

Figure 3.2-2 summarizes the organization of the site potentiometric-level evaluation activity. A descriptive heading for each method appears in the shadowed boxes of the second row. Below each are the individual methods that will be used. Figure 3.2-3 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site-characterization parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed methods boxes, respectively.

The two figures summarize the overall structure of the planned activity in terms of methods to be used and measurements to be made. The descriptions in the following sections are organized on the basis of these charts. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations between (1) the site-characterization parameters to be determined, (2) the information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

The methods used in this activity will provide information that is essential for understanding the hydrology of the Yucca Mountain area. In particular, the methods will contribute to the statistical data base on conductive properties and head distributions, spatial variabilities of existing conditions for the repository area, and correlations to present and potential future conditions. This test involves the analysis of potentiometric fluctuations with time and depth, and an evaluation of the potentiometric surface for hydraulic gradient calculations by measurements of water-level variations in observation wells. The direct observation of water levels that is afforded by drilling wells is required because indirect methods (e.g. surface geophysical surveys) are inadequately precise. Modeling the vertical variabilities of hydraulic head within boreholes and the lateral variabilities between wells will contribute to the three-dimensional understanding of the site potentiometric surface. Similarly, an analysis of water-level variations with time will be useful for modeling and predicting potential future repository conditions. The water-level data, especially the associated anomalies, will be compared with concurrent crustal strain measurements.

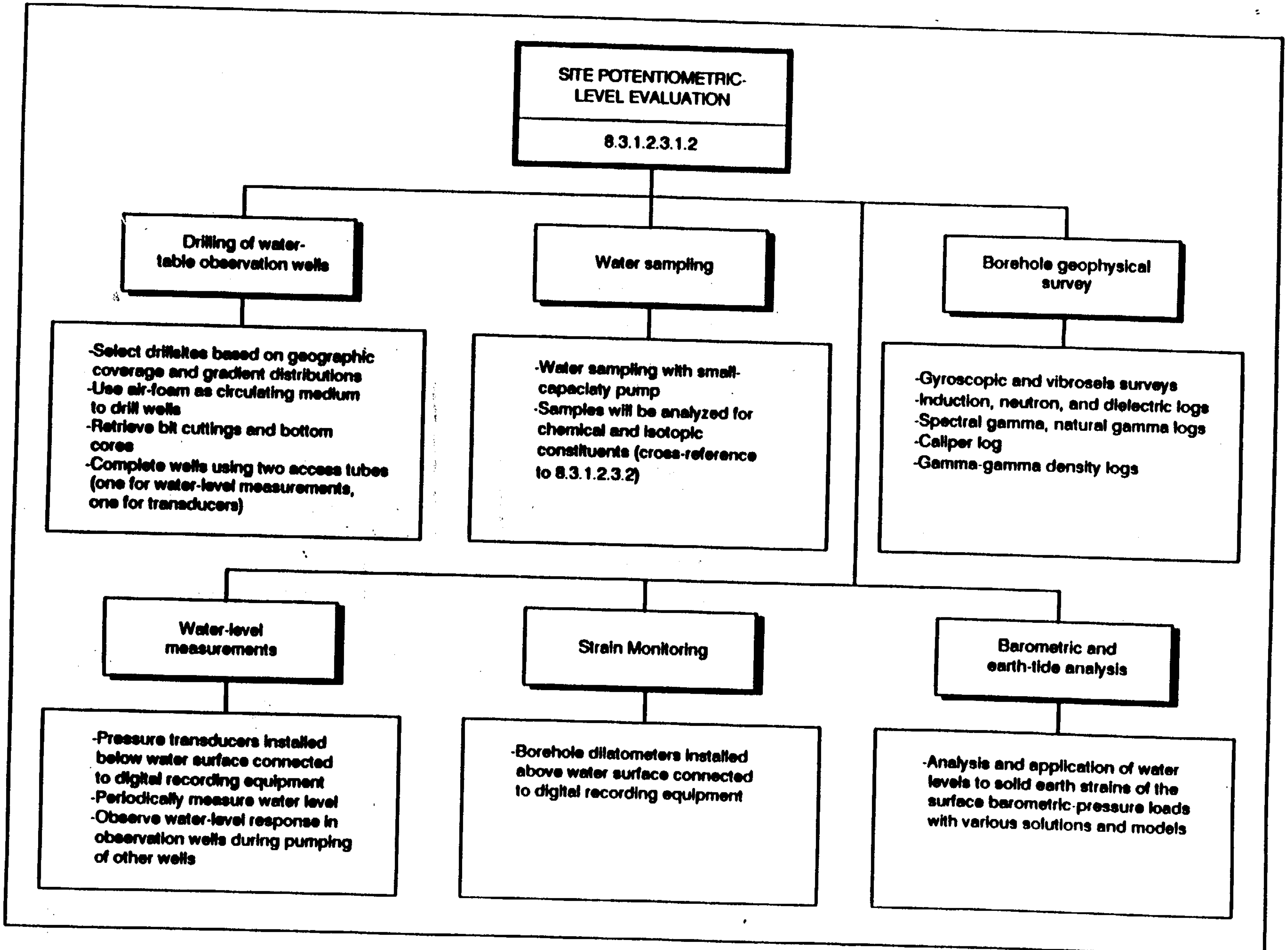


Figure 3.2-2. Logic diagram of the potentiometric-level evaluation activity showing methods and analyses.

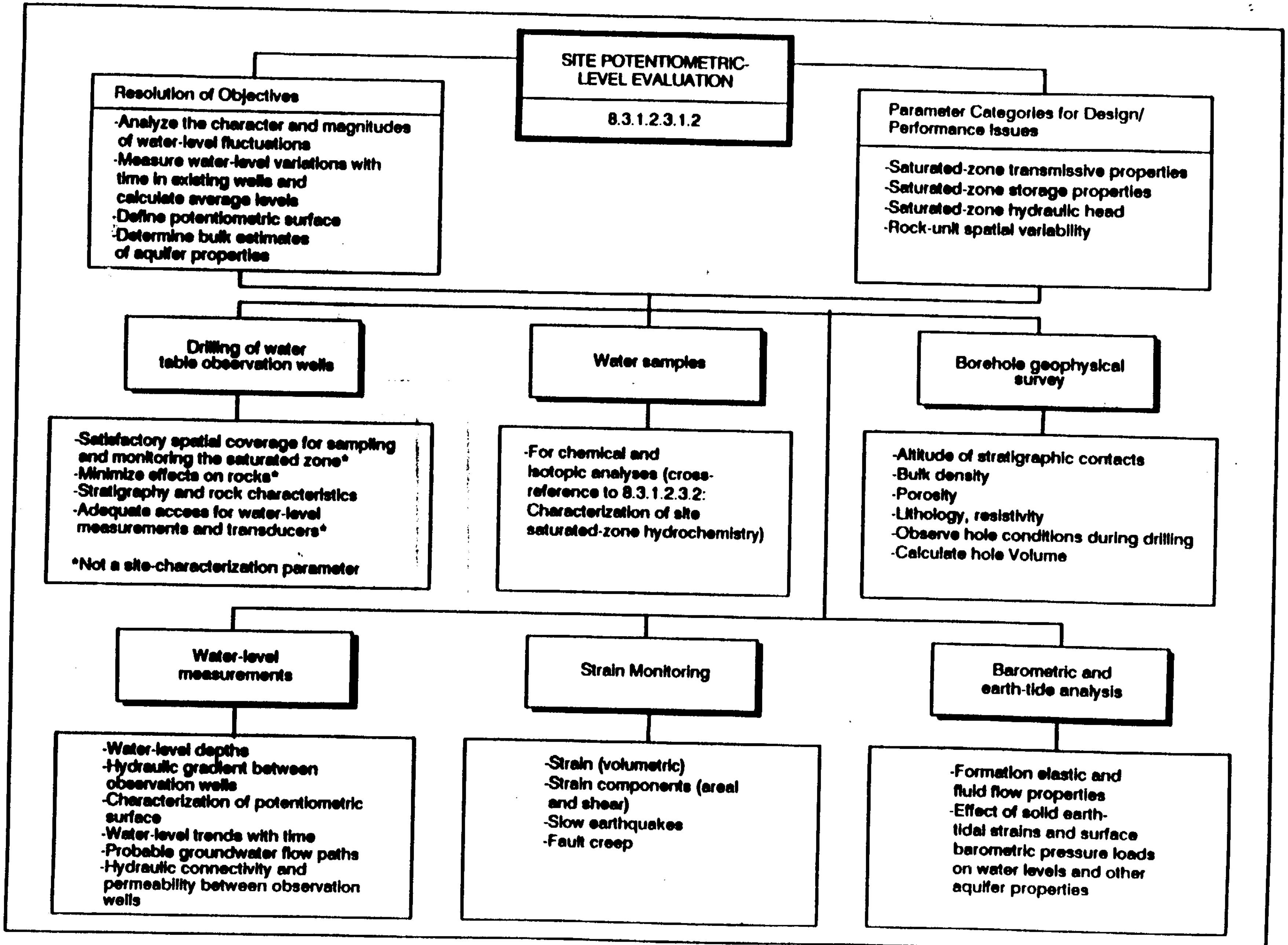


Figure 3.2-3. Logic diagram for the potentiometric-level evaluation activity showing tests, analyses, and site-characterization parameters.

3.2.3.1 Drilling of water-table observation wells

Presently about 25 geologic, hydrologic, and water-table wells are part of a monitoring network in the vicinity of Yucca Mountain (Figure 3.2-1).

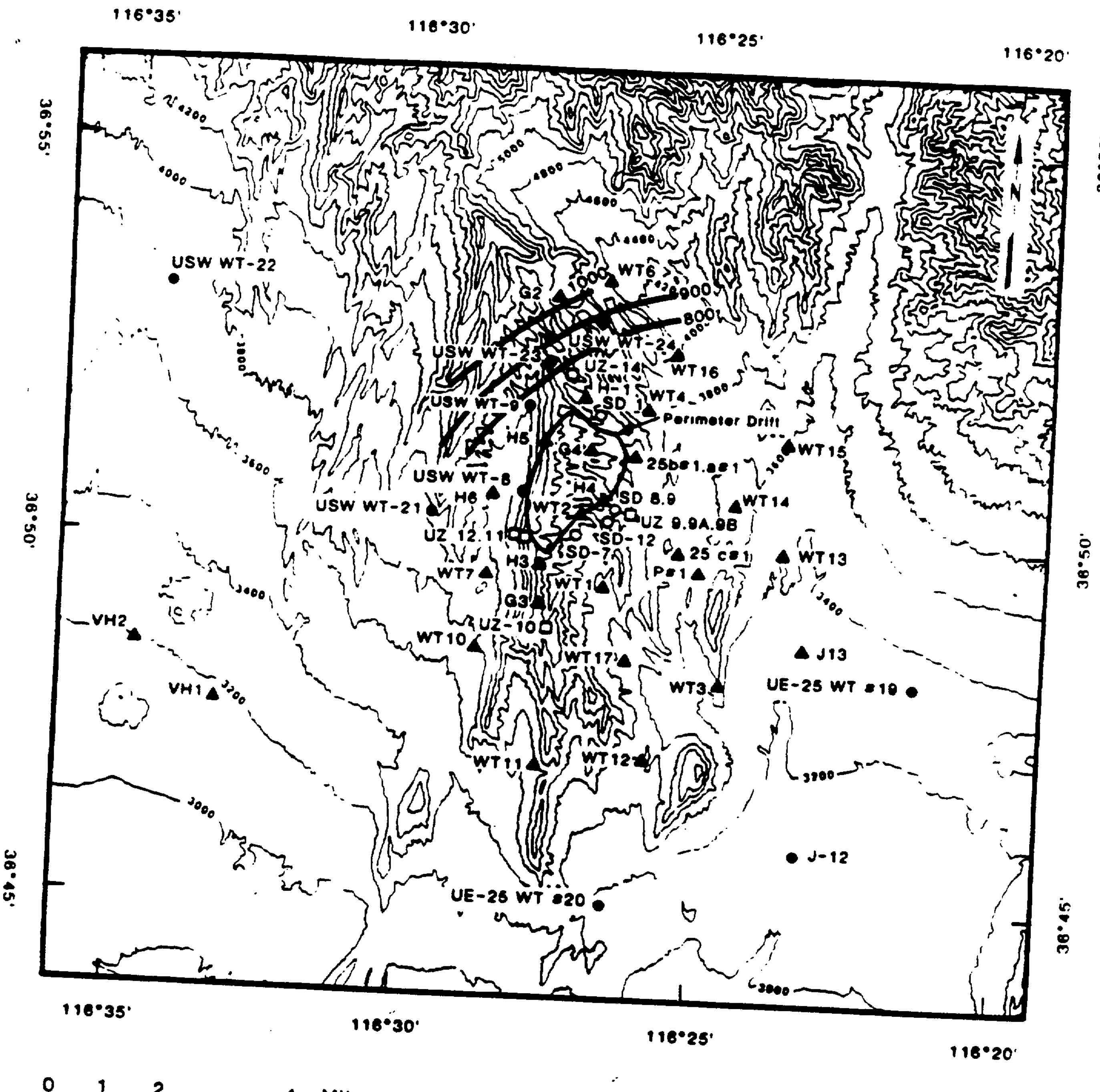
Proposed wells to be drilled and added to the monitoring network include the following: USW WT-8, USW WT-9, UE-25 WT #19, UE-25 WT #20, USW WT-21, USW WT-22, USW WT-23, and USW WT-24 (Figure 3.2-4) and possibly another water-table well whose location is not yet determined. Also, existing supply well J-12 may be added to the network. The number and location of wells was selected by examining existing water-level data and determining where additional data were needed. Location of these wells is based on geographic coverage, and on the need for refinement of the hydraulic gradient in selected areas. Data from these wells may indicate a need for additional wells. The final location and number of wells will be based on professional judgement using all the data. USW WT-8 and USW WT-9, (and hydrologic well USW H-7) will be located near the Solitario Canyon fault in an attempt to determine the hydraulic character of the fault, as discussed in Section 3.1.

The wells will be drilled with air or air-foam in a circulating medium to minimize disturbance to the hydrologic system and to the rock surrounding the boreholes. The wells will be drilled a short distance (probably less than 100 m) into the saturated zone.

This small penetration will allow the wells to reflect the water level near the water table and will minimize potential influence of water levels in deeper zones. The wells will not be cased below the top of the saturated zone unless unusual conditions require it. Wells will be completed with three access tubes; two will be for water-level measurements, and one will be for temperature measurements of the unsaturated zone (Activity 8.3.1.15.2.2.1, Surface-based evaluation of ambient thermal conditions).

USW WT-23 and -24 will be drilled north of the repository block, primarily to determine the cause and nature of the large hydraulic gradient in the area. Water levels in two wells north of the repository block are much higher than in those beneath or southeast of the repository block. It is not known whether this reflects an abrupt change in the potentiometric surface because of discrete barriers such as faults, or whether there is a continuous, but steep gradient due to low-permeability rocks along the flow path. Wells USW WT-23 and -24 will be located approximately one-third and two-thirds of the distance between wells USW H-1 and USW G-2 which presently define the steep gradient. Based on what is found in drilling these two new wells, additional drilling may be required to further define the large gradient.

USW WT-23 will be located in Drill Hole Wash, about 1.3 km (0.8 mi) northwest of USW H-1. This well will be drilled to a probable



EXPLANATION:

▲ Existing WT, H, and VH Wells

● Proposed Well

○ Proposed SD Well

□ Proposed UZ Well

Figure 3.2-4. Map showing location of existing and proposed new wells for the monitoring network and selected water-table elevation contours.

depth of about 670 m (2,200 ft). USW WT-24 will be located between USW G-2 and UE-25 WT #18, and will also be about 670 m (2,200 ft) deep.

UE-25 WT #19 and #20 will be drilled in order to better define the potentiometric surface in the vicinity of the presumed flow path south and southeast from the repository block. UE-25 WT #19 will be located 3 km (1.9 mi) east of well J-13 and will be drilled to a probable depth of about 335 m (1,100 ft). UE-25 WT #20 will be located 5 km (3.1 mi) southwest of well J-12 and will be drilled to a probable depth of about 300 m.

USW WT-21 and WT-22 will be drilled to better define the potentiometric surface west and northwest from the repository block. USW WT-21 will be located about 3 km (1.9 mi) west of USW WT-2 and will be drilled to a probable depth of about 500 m (1,640 ft). USW WT-22 will be located about 9 km (5.6 mi) north of USW VH-2 and will be drilled to a probable depth of about 400 m (1,310 ft). Depending on what is found when drilling USW WT-22, additional wells may be proposed at a later date.

In addition to the WT holes described here, a number of wells will be drilled during the Systematic Drilling Program (SCP Activity 8.3.1.4.3.1.1). These wells will be very similar to the WT holes except for the amount of core obtained. After the Systematic Drilling Program has finished with these wells, they should be configured identical to the WT holes. Additionally, if the UZ holes (or any other holes) encounter the water table, are suitable and desirable for water-level monitoring, and have served their primary purpose, they should be configured like the WT holes.

3.2.3.2 Borehole geophysical surveys

Lithologic and geophysical logs, including those indicative of fractures, will be analyzed and compared with those of other wells of known permeability in order to evaluate the permeability and geohydrologic characteristics of rock units in the Yucca Mountain area. The geophysical-logging program is similar to that discussed for the Solitario Canyon fault characterization (Section 3.1.3.1). All borehole geophysical data will be collected in accordance with project quality control procedures as they become available. These data will be stored, archived, and distributed in accordance with available project directives.

3.2.3.3 Water sampling

After geophysical logs are completed in each water-table well, representative water samples for chemical and isotopic analyses will be obtained. The sampling process as well as the chemical and isotopic analyses to be done are described in detail in Study Plan 8.3.1.2.3.2 (Characterization of the Site Saturated-Zone Hydrochemistry).

3.2.3.4 Water-level measurements

Water levels in about a dozen wells have been measured periodically (once or twice a month) during on-site visits. In 1989, about fifteen wells had pressure transducers installed below the water surface and were connected to digital recorders at land surface; electrical output from the transducers was automatically recorded every hour (floats, water-seeking devices, and manometers have been considered, but pressure transducers are the only practical devices for the continuous monitoring because the water levels that occur at Yucca Mountain are up to 800 m below land surface). Table 3.2-1 lists the wells which have been periodically or continuously monitored.

For continuous monitoring, raw data, in the form of transducer-output voltage from the installations are transferred to magnetic tapes and taken to the office for translation into water-level depths or altitudes, following a process of conversions, adjustments, and determination and verification of equipment calibrations. For some experiments, it may be helpful to supplement digital recording with analog recording; for most purposes digital records are more convenient and more versatile for processing, storing, and analyzing data. Long-term average water levels will be calculated for individual sites in order to derive hydraulic gradients between observation wells. In addition, where earth-tide or barometric effects are apparent in the water-level data, estimation of aquifer properties will be attempted (Section 3.3). For wells showing appropriate responses, water-level variations due to earth tides or barometric fluctuations may be used to estimate hydraulic parameters such as storage coefficients using the method described by Galloway and Rojstaczer (1989).

Water-level data will be plotted to show variations and trends with time. Water levels may take a considerable amount of time to come to equilibrium after drilling; plots will indicate when equilibrium has been approached. The data will be averaged over appropriate periods (e.g. annually) so that hydraulic gradients and probable flow paths can be determined more accurately, especially in areas where the potentiometric surface is nearly flat. Also, altitudes of water levels in planned and existing wells north of the proposed repository will be used to determine if the gradient is linear although steep (probable low-permeability rocks) or is stepped (probable hydraulic barriers).

Data in Robison and others (1988) and Gemmell (1990) indicates that water levels beneath Yucca Mountain are very stable over time. Gemmell (1990) shows that, except for water-supply well J-13, the maximum variation of 0.69 meters for the periodic water level network from 1983 through 1988 occurred at well UE-25 WT #14. However, annual average water levels in well UE-25 WT #14 exhibit a range of only 0.17 m while the average over 1986-88 where the same equipment was used is only 0.03 m. Considering all wells in the periodic network, the annual average water-levels from 1986 through

Table 3.2-1. Summary of wells monitored for water levels
(p, periodic measurements; c, continuous monitoring; d, discontinued)
(from Gemmell, 1990)

Well number	Drilled depth (meters)	Date completed	Water level: Approximate depth[1] (meters)	Water level: Approximate altitude[1] (meters)	Water level: Frequency monitored at end of 1988
USW WT-1	515	5-83	471	730	p
USW WT-2	628	7-83	571	730	c
UE-25 WT #3	348	5-83	300	730	p
UE-25 WT #4	482	6083	438	731	p
UE-25 WT #6	383	6-83	279	1,034	c
USW WT-7	491	7-83	421	776	p
USW WT-10	431	8-83	347	776	p
USW WT-11	441	8-83	363	731	c
UE-25 WT #12	399	8-83	346	729	p
UE-25 WT #13	354	7-83	303	729	c
UE-25 WT #14	399	9-83	346	730	p
UE-25 WT #15	415	11-83	354	729	p
UE-25 WT #16	521	11-83	473	738	c
UE-25 WT #17	443	10-83	394	730	p
UE-25a #1	762	9-78	469	731	d
UE-25b #1	1,220	9-81	471	730	c
UE-25C #1	914	10-83	401	730	p
UE-25P #1	1,805	5-83	362	752	c
USW G-2	1,831	10-81	525	1,029	d
USW G-3	1,533	3-82	750	730	c
USW G-4	915	1-83	529	731	d
USW H-1	1,829	1-81	573	730	c
USW H-3	1,219	3-82	752	731	c
USW H-4	1,219	6-82	518	730	c
USW H-5	1,219	8-82	704	775	c
USW H-6	1,220	10-82	526	776	c
USW VH-1	762	2-81	185	779	p
J-13	1,063	1-63	283	728	p

[1]Composite water level of saturated interval, or level of shallowest zone monitored.

1988 changed from -0.10 to 0.05 m and the average absolute change was 0.04 m. Besides little year-to-year change, the water levels appear to exhibit little seasonal change. Therefore, so long as a sufficient number of measurements are made, average water levels can be used to calculate gradients.

Water-level responses in observation wells during pumping of other wells will be analyzed for general hydraulic connectivity, and, where appropriate, evaluation of the permeability of intervening rocks will be made. Responses among the observation wells will be compared for estimating the areal anisotropy of hydraulic parameters that may be controlled by faults or fractures.

In addition to the water-level monitoring described here, very detailed data on vertical head variations in the WT wells will be obtained during water sampling. The details of this water sampling, including obtaining head data, are described in Study Plan 8.3.1.2.3.2 (Characterization of the site saturated-zone hydrochemistry).

Water-level monitoring will continue throughout site characterization but the frequency of measurements may change. Once sufficient data has been collected from continuously-monitored wells to determine hydraulic properties, these wells may then be measured only periodically. If several years worth of data indicate that water levels are very stable, the frequency of periodic measurements may decrease. On the other hand, if the data indicate a need for more frequent or special monitoring of water levels, this will be done.

3.2.3.5 Strain monitoring

Anomalous water-level fluctuations have been measured in various wells in the monitoring network at Yucca Mountain. The results of their preliminary analyses have been presented in a memorandum to the record (Galloway and Sullivan, 1986). Some of the recorded anomalies have been tentatively attributed to barometric and instrumental causes. Others are attributed to a seismic creep events along some of the faults that bound the repository block; namely, the Solitario Canyon, Abandoned Wash, or Ghost Dance faults.

Many of the wells in the potentiometric-level network respond to deformation of the solid earth; they may be likened to strain meters. For example, several monitored zones within several wells are sensitive to changes in pore pressure due to crustal strain (10^{-8} to 10^{-9}) associated with the earth tide. The analysis of the effects of earth tides and atmospherically induced water-level fluctuations is discussed in Section 3.3 (3.3.3.3) of this study plan.

Some of the wells in the network, particularly the wells along the crest of Yucca Mountain, appear to respond to a seismic fault-creep events or slow earthquakes. The resulting water-level changes usually involve a sharp rise followed by an exponential decay to the baseline with or without offset. These recorded events compare qualitatively with the theoretical water-level (pore-pressure) responses to fault creep developed by Roeloffs and Rudnicki (1984/85). To aid the analysis and interpretation of these anomalous events, continuously recording strainmeters will be installed in selected boreholes. There are several variations of these instruments, such as strain dilatometers or dilational strainmeters (Sacks and others, 1978), three-component strainmeters (Shimada and others, 1987) or tensor strainmeters (Gladwin, 1984), are capable of sensing crustal strain changes of the order of 10^{-10} or greater. The three-component strainmeter was selected because it provides much additional information with little additional cost.

The first instrument will be installed and permanently cemented in a new or existing borehole near the Solitario Canyon fault at a depth no greater than 200 m (660 ft). Prior to installation all final calibrations of the instrument and its parts will be completed. An effort will be made to develop techniques for additional in-place calibration of the permanently installed instrument. The output of the instrument will be digitally recorded, transmitted and stored for subsequent processing and analysis of the strain data. Short- and intermediate-term variations in strain due to earth tides and atmospheric events, and long-term trends due to tectonic processes will be analyzed to provide information on the elastic and viscoelastic properties of the host rock and the mechanics of faulting. These data will be compared with concurrent water-level measurements to better characterize the effects of faulting (tectonic) mechanisms on the aquifer beneath Yucca Mountain.

3.2.3.6 Barometric and earth-tidal analysis

Continuous water-level data may provide bulk estimates of hydraulic properties of the saturated zone by analyzing the aquifer response to earth-tide strain and barometric pressure changes. These analyses are described in detail in Section 3.3.3.3.

Barometric and earth-tidal analysis will be done in Activity 3 for those wells that have previously had hydraulic tests done on them. The analysis will allow a comparison of hydraulic properties determined using different methods. The same analysis will be done in this activity for wells where hydraulic tests were not done in the past.

The earth-tidal analysis may not be feasible for the WT wells because they are not cased below the water table. However, a technique may be developed in the future that allows this analysis.

3.2.3.7 Methods summary

The parameters to be determined by the tests described above are summarized in Table 3.2-2. Also listed are the selected and

Table 3.2-2. Summary of tests and methods for the site potentiometric-level evaluation (SCP 8.3.1.2.3.1.2)
[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site-characterization parameter	Expected range
Drilling of water-table observation wells		
Select the drillsites based on geographic coverage and gradient distribution (selected)	Cross-reference to 8.3.1.4.1 - Development of an integrated drilling program and integration of geophysical activities	--
Use air foam as circulating medium to drill the wells (to minimize effects on the formation) (selected)	"	--
Complete the wells using two access tubes (one for permanently-installed transducers, the other for confirmation of water-level measurements) (selected)	"	--
Use mud as circulating medium to drill the wells (alternate)	"	--
Complete the wells with single-access tubes (alternate)	"	--
Complete or modify the wells to minimize well-bore storage for analysis of storage properties (alternate)	"	--
Retrieve bit cuttings and bottom-hole cores for analysis (selected)	Cross-reference to 8.3.1.4.1 and 8.3.1.4.2.1 - Characterization of the vertical and lateral distribution of stratigraphic units within the site area	--
Obtain intermittent cores for analysis (alternate)	"	--

Table 3.2-2. Summary of tests and methods for the site potentiometric-level evaluation (SCP 8.3.1.2.3.1.2)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Drilling of water-table observation wells--Continued	
Drill no additional wells. Use existing data plus surface geophysical surveys. (alternate)	Cross-reference to 8.3.1.4.1 and 8.3.1.4.2.1 - Characterization of the vertical and lateral distribution of stratigraphic units within the site area	--
	Borehole geophysical survey	
Television surveys to determine physical characteristics of rock (selected)	Cross-reference to 8.3.1.4.2.1.3 - Borehole geophysical surveys	--
Use geophysical and other logs to determine physical characteristics (selected)	"	--
Use acoustic log below water table to examine fractures (alternate)	"	--
Obtain and use continuous core (alternate)	"	--
	Water sampling	
Sample with small-capacity pump (selected)	Cross-reference to 8.3.1.2.3.2 - Characterization of the saturated zone hydrochemistry	--
	Water-level measurements	
Steel tape measurements - periodic (selected)	Hydraulic gradients	--

Table 3.2-2. Summary of tests and methods for the site potentiometric-level evaluation (SCP 8.3.1.2.3.1.2)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Water-level measurements--Continued		
Multiconducter cable measurements - periodic (selected)	Hydraulic gradients	--
Reeled steel tape measurements - periodic (selected)	"	--
Pressure transducer - continuous (selected)	"	--
Digital recording/processing of field data (selected)	"	--
Calculate average water levels at individual sites from periodic and continuous water-level measurements (selected)	"	--
Continue analysis of potentiometric levels as a function of depth in existing, monitored wells (selected)	"	--
Determine and analyze variation of potentiometric head with depth in well USW H-7 (selected)	"	--
Continuous measurements using float system (alternate)	"	--
Continuous measurements using electronic water-seeking devices (alternate)	"	--
Continuous measurements using manometers (alternate)	"	--

Table 3.2-2. Summary of tests and methods for the site potentiometric-level evaluation (SCP 8.3.1.2.3.1.2)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Water-level measurements--Continued		
Analog recording/processing of field data (alternate)	Hydraulic gradients	--
Determine water levels from non-contemporaneous, non-averaged data (alternate)	"	--
Continuous water-level measurements using pressure transducers (selected)	Aquifer compressibility, storage coefficient, specific storage	Storage coefficient 10^{-6} to 10^{-3}, specific storage 10^{-10} to 10^{-8} cm^{-1}
Analysis of water-level fluctuations (selected)	"	"
Hydraulic-stress tests (alternate)	"	"
Core analysis (laboratory) (alternate)	"	"
Continuous water-level measurements using float system (alternate)	"	"
Continuous water-level measurements using electronic water-seeking devices (alternate)	"	"
Continuous water-level measurements using manometers (alternate)	"	"
Analog recording/processing of field data (alternate)	"	"
Water-level responses in observation wells resulting from stress tests conducted in nearby wells (selected)	Hydraulic conductivity	10^{-2} to 10^{2} m/d

Table 3.2-2. Summary of tests and methods for the site potentiometric-level evaluation (SCP 8.3.1.2.3.1.2)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Water-level measurements--Continued	
Hydraulic stress tests (alternate)	Hydraulic conductivity	10^{-2} to 10^{2} m/d
Core analysis (laboratory) (alternate)	"	"
	Strain monitoring	
Borehole strain meter-tensor-three component (selected)	Strain	10^{-10} to 10^{-6}
Borehole dilatometer-volumetric (alternate)	"	"
	Barometric and earth-tide analysis	
Analysis of water-level fluctuations due to barometric changes (selected)	Specific storage	10^{-10} to 10^{-8} cm^{-1}
"	Matrix compressibility	10^{-12} to 10^{-11} cm^{2}/dyne
"	Vertical hydraulic diffusivity	10^{1} to 10^{4} cm^{2}/sec
"	Vertical pneumatic diffusivity	10^{2} to 10^{4} cm^{2}/sec
"	Barometric efficiency	.2 to .95
Earth-tide analysis of water-level fluctuations (selected)	Dilatational efficiency	0.001 to 0.1
"	Porosity, bulk estimates	"

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Table 3.2-2. Summary of tests and methods for the site potentiometric-level evaluation (SCP 8.3.1.2.3.1.2)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Barometric and earth-tide analysis--Continued	
Laboratory analysis of cores (alternate)	Porosity, bulk estimates	0.0001 to 0.1

alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be used if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, only the most common methods are included in the table. The selected methods in Table 3.2-2 were chosen primarily on the basis of accuracy, precision, duration of methods, expected range, and lack of interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site parameter. The expected ranges of the site parameter have been bracketed by previous data collection and computer modeling and are shown in Table 3.2-2.

3.2.4 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires documentation of technical procedures for all technical activities that require quality assurance.

Table 3.2-3 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a USGS procedure number and an effective date. Procedures that are not identified with an effect date will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started; these procedures are also identified with a "TBD" (To Be Determined) technical procedure number. Some of the listed technical procedures are primarily outside the objectives of the subject activity (Site potentiometric-level evaluation) or study (Characterization of the Yucca Mountain site saturated-zone flow system), but are included for general information and ease of cross-referencing. Approved technical procedures not listed may be used during the activity, should that be appropriate, and listed procedures may be revised or replaced with other procedures, as needed.

All procedures listed are currently classified as "standard", as they represent modifications of methods and equipment with established records of use and reliability. Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and stepwise procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Applicable quality-assurance procedures are presented in Appendix 7.1.

Table 3.2-3. Technical procedures for the site potentiometric-level evaluation (SCP Activity 8.3.1.2.3.1.2)
[Dashes (--) indicate information is not available and to be determined.

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Drilling of water-table observation wells	
GP-02	Subsurface investigations	03/01/83
GP-05	Geologic support activities	03/01/83
TBD	Drilling and coring (REECo)	--
MDP-01	Identification, handling, storage, and disposition of drillhole core and samples (Replaced by GP-16,R0, GP-19,R0, and GP-28,R2)	--
	Borehole geophysical surveys	
GP-10	Borehole-video fracture logging	04/12/85
HP-02	Acoustic televiewer investigations	08/14/84
	Water sampling	
HP-23	Collection and field analysis of saturated-zone ground-water samples	11/04/83
--	Cross reference to 8.3.1.2.3.2	--
	Water-level measurements	
HP-25	Method for measuring water levels using a portable multiconduc	08/13/88

Table 3.2-3. Technical procedures for the site potentiometric-level evaluation (SCP Activity 8.3.1.2.3.1.2)--Continued

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Water-level measurements--Continued	
HP-26	Method for calibrating water-level measurement equipment using the reference steel tape	08/14/84
HP-60	Method for monitoring water-level changes using pressure transducers	05/04/88
HP-71	Method for monitoring water-level changes using a Campbell Scientific 21X Micrologger	09/01/87
HP-75	Method for measuring water levels in wells using reeled (2,600-ft and 2,800-ft) steel tape	06/22/87
HP-93	Method for processing electronic data from a Campbell Scientif 21X Micrologger into water levels	05/11/88
	Strain monitoring	
Needed	Method for calibrating borehole strain meters	--
Needed	Method for monitoring strain changes	--
Needed	Method for permanent emplacement of borehole strain meters	--
	Barometric and earth-tide analysis	
HP-25	Method for measuring water levels using a portable multiconduc	08/13/88
HP-26	Method for calibrating water-level measurement equipment using the reference steel tape	08/14/84

Table 3.2-3. Technical procedures for the site potentiometric-level evaluation (SCP Activity 8.3.1.2.3.1.2)--Continued

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Barometric and earth-tide analysis--Continued	
HP-60	Method for monitoring water-level changes using pressure transducers	05/04/88
HP-75	Method for measuring water levels in wells using reeled (2,600-ft and 2,800-ft) steel tape	06/22/87
HP-121	Installing and retrieving information from a Setra pressure transducer	--
--	Cross reference to 8.3.1.2.3.1.3	--

3.3 Analysis of single- and multiple-well hydraulic-stress tests

3.3.1 Objectives

The objectives of this activity are to:

1. determine intraborehole flow profiles for each of the c-wells during static conditions and while pumping,

2. correlate lithology, fractures, and intraborehole flow rates,

3. determine the type of flow (e.g. linear, radial, spherical) that characterizes flow for single- and multiple-well tests at the c-well complex,

4. 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 and tracer tests at the c-wells,

5. determine bulk estimates of aquifer properties: transmissivity, storage coefficient, specific storage, matrix compressibility, effective porosity, and where possible, vertical hydraulic conductivity;

6. determine well/formation properties: barometric efficiency and dilatational efficiency; and

7. determine the frequency response function of the well/formation (c-wells) to barometric and earth-tide induced strains in order to determine at what frequencies a static-confined response can be inferred; and at what frequencies the effects of vertical fluid flow in the unsaturated and saturated zones are evident.

3.3.2 Rationale for activity selection

Well hydraulic tests 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 rock units tested. 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 past hydraulic test results. On the basis of these interpretations, additional tests need to be designed and conducted to determine the three-dimensional relations between stratigraphy, fracture connectivity, and hydraulic conductivity. These additional tests are discussed below under Section 3.4, Multiple-well interference testing.

The analysis of previously completed stress tests (Table 3.3-1) will include pumping and nonpumping intraborehole flow surveys, packer and open-hole injection and pumping tests, and transient pressure response of the aquifer to barometric and earth-tide induced stresses. The analysis of the intraborehole flow surveys would determine flow profiles for each of the c-wells under pumping and nonpumping conditions and permit a correlation between identifiable fractures and flow. The analysis of the c-well multiple-well packer and open-hole hydraulic-stress tests may determine the type of flow (linear, radial, spherical; fissure, porous, or both) that explains the pressure-transient responses at the scale of single- and multiple-well tests in the c-wells. A secondary objective would attempt to determine bulk average values of aquifer transmissivity and storage coefficient, identify the degree of hydraulic connection between strata and between zones with large fracture frequency, and identify the nature of significant hydraulic boundaries occurring at the scale of these tests.

Analysis of single-well stress tests are less optimistic, but the objectives are similar to those for multiple-well tests. The interpretations would be especially important in designing the cross-hole packer tests discussed in Section 3.4.

The analysis of the frequency response function of the well/formation to barometric and earth-tide-induced stresses may provide estimates of bulk aquifer properties (e.g. hydraulic effective porosity, specific storage, matrix compressibility, and barometric and dilatational efficiencies). The analysis may also determine the extent to which the aquifers are connected hydraulically to the water table, and give some insight into the interaction between atmospheric loading and the saturated zone.

The information obtained in this activity will be used to refine the models of the ground-water flow system. Sensitivity analyses with the refined models may indicate a need to modify data collection and analyses within this activity. The data collection and the modeling are interrelated processes that influence each other. This feedback process is described in Section 1.1 and is shown on Figure 1.1-2.

3.3.3 General approach and summary of tests and analyses

The tests and analyses described here in Activity 3.3 and further in Activities 3.4 and 3.5 are primarily concerned with the c-hole complex, wells UE-25c #1 , UE-25c #2 and UE-2c #3. These wells were drilled in 1983 and 1984 to a depth of 914 m each, and completed in the upper part of the Tram Member of the Crater-Flat Tuff. The c-hole complex was configured for eventual multiple-well hydraulic (Activity 3.4) and tracer (Activity 3.5) testing. The location of the c-hole site was chosen on the basis of its proximity to the proposed repository block in order to characterize hydraulic and transport properties of the saturated tuffs -- at the scale of the c-hole complex, approximately 400,000 m³.

Table 3.3-1 -- Hydraulic tests conducted at the c-hole complex during September 1983 - November 1984 -- tests are currently being analyzed

WELL DEPTH	WELL NAME	DATE OF TEST	TYPE OF TEST	OBS. WELL	ZONE TESTED
Approx. 914 m	C #1 Open hole	Sept. 1983	Single well pump test drawdown/recovery	None	416 to 914 m
	C #1	Oct. 1983	Falling-head packer injection	None	16 open hole test 3 shut-in test
Approx. 914 m	C #2 Open hole	Mar. 1984	Multiple-well pump test drawdown/recovery	C #1	769 to 791 m
914 m	C #3	May 1984	Multiple-well pump test -- drawdown/recovery	C #1 C #2	489 to 512 m Open hole
	C #2 720 - 754 m	Oct. 1984	"Quasi" - constant flux injection	C #1 C #3	769 to 791 Open hole
	C #3 Open hole	Nov. 1984	Mutiple-well pump test	C #1 C #2	769 to 791 m 720 to 754 m

The relative location of the c-holes to one another (Figure 2.1-1) was determined on the basis of fracture and hydraulic information obtained following drilling, logging and testing of UE-25c #1. Fracture mapping in UE-25c #1 from geophysical logs, primarily borehole televiewer and television camera logs, indicated two steeply dipping dominant fracture sets, one centered about an azimuth of N30°W and another centered around N25°E. An equivalent permeability tensor was calculated on the basis of fracture orientation (e.g. Snow, 1965; Erickson and Waddell, 1985) to estimate the anisotropy of permeability in order to aid siting of UE-25c #2. UE-25c #2 was sited along the major semi-axis of the calculated permeability tensor -- at a distance from UE-25 #1 that, on the basis of preliminary hydraulic tests in c #2, would be within the zone influence of pressure-transient testing in UE-25c #1. The fractures mapped in UE-25c #2 will be combined with the UE-25c #2 fracture data and the another estimate of the permeability tensor was made. The c#1-c#2 data set yielded a similar tensor as derived from c#1. The location of UE-25c #3 was sited along the least principal semi-axis of the permeability tensor estimated when only the NE-trending fracture sets were conceived. Under the regional stress regime, the NE sets are favorably propped open vis-a-vis the NW sets. Again, the distance, c#2- c#3 was selected on the basis of c#1 hydraulic information, and a stream line analysis of a hydraulic doublet between c#2 and C#3 for expected source-sink fluxes for pumping tests.

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. Additional tests and/or surveys may be conducted to address specific questions raised during the analyses of these data.

This section describes the strategy for analysis of well hydraulic tests conducted at the c-well complex from September 25, 1983, to July 23, 1986. Pumping and nonpumping temperature logs and tracejector surveys were collected to examine intraborehole flow. Packer and open-hole water injection and pumping tests were conducted to examine pressure-transient responses of the aquifers. Aquifer fluid pressure and barometric pressure were monitored over a 7-month period to examine aquifer response to atmospheric and earth-tide induced strains.

Figure 3.3-1 summarizes the organization of the analysis of single- and multiple-well hydraulic stress tests activity. A descriptive heading for each method appears in the shadowed boxes of the second row. Below each are the individual methods that will be used. Figure 3.3-2 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site-characterization parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed methods boxes, respectively.

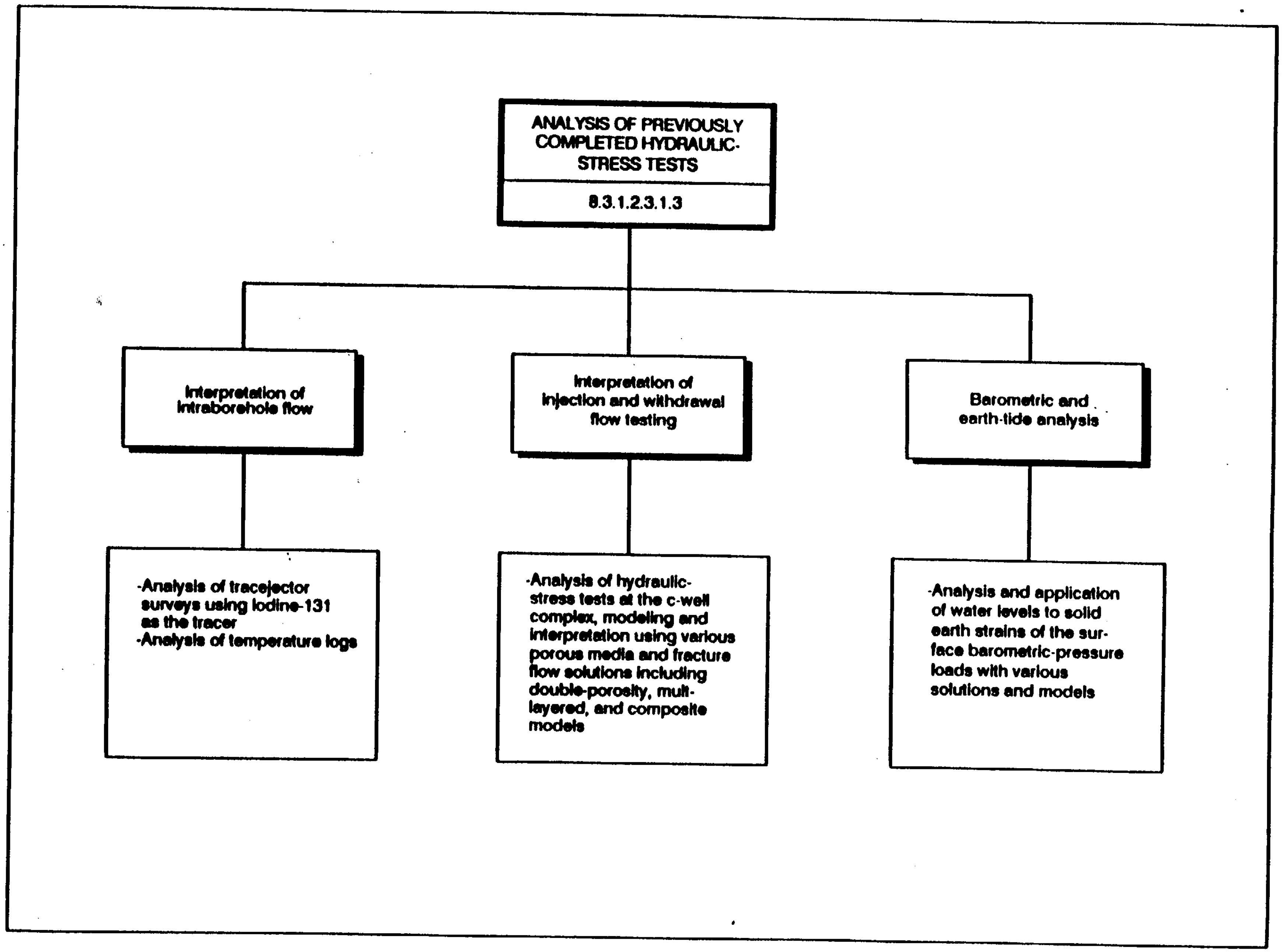

Figure 3.3-1. Logic diagram of the hydraulic-stress tests activity showing tests, analyses, and methods.

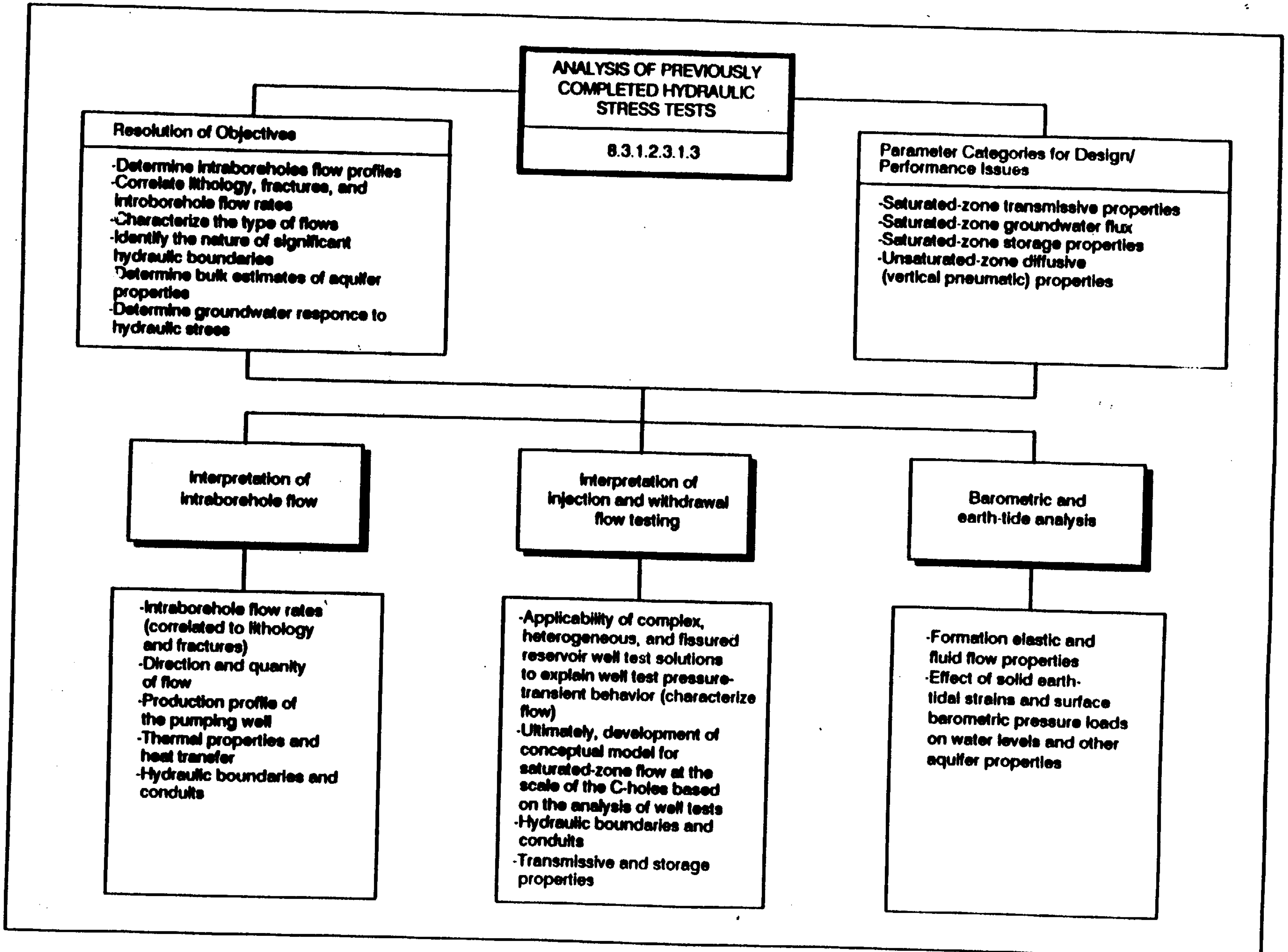

Figure 3.3-2. Logic diagram of the hydraulic-stress tests activity showing tests, analyses, and site-characterization parameters.

The two figures summarize the overall structure of the planned activity in terms of methods to be used and any additional measurements that may be required. The descriptions in the following sections are organized on the basis of these diagrams. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations between (1) the site-characterization parameters to be determined, (2) the information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

The methods used in this activity involve the analysis of data from hydraulic tests in wells at the Yucca Mountain c-well complex. Attempts will be made to estimate flow profiles within and between holes, significant hydraulic boundary conditions, and bulk estimates of transmissivity, storage coefficient, specific storage, and effective porosity. An understanding of the vertical permeability contrast within each well, and lateral contrast between wells, will further a three-dimensional understanding of the aquifer/well ground-water flow system. In addition to providing hydraulic data at the scale of the c-well complex, the methods for well testing and analysis developed in this activity and activities 3.4, 3.5, and 3.6 are expected to be applicable throughout the Yucca Mountain area. These methods will be used at other wells to obtain information about the spatial variability of hydraulic parameters.

3.3.3.1 Interpretation of intraborehole flow

Successful design and future interpretation of hydraulic and tracer tests requires an understanding of the nature of fluid movement between a borehole and the formation. Tracejector surveys and temperature logs can identify points or zones of fluid entry or exit in a borehole and may be used to determine the direction (up or down) and quantity of flow. If discrete flow points can be identified, it may be possible to correlate a point with a specific fracture identified from borehole-televiewer logs or video camera logs; whereas for diffuse-flow zones, groups of fractures may be identified. The distribution of flow points and flow zones is important in the formulation of a conceptual model of flow in the near-borehole environment.

The tracejector surveys and temperature logs were run under both pumping and nonpumping (static) conditions in each of the three c-wells. Tracejector surveys under pumping conditions were run according to the method described by Blankennagel (1967), using Iodine-131 as tracer. Surveys under static conditions were made according to the method described by Erickson and Waddell (1985). The logs collected during pumping were made in conjunction with an open-hole hydraulic test in each well. Surveys made under static conditions are largely indicative of existing vertical head gradients and hydraulic-conductivity contrasts. The subtle contrasts reflected in static temperature logs are overwhelmed during pumping and may otherwise go undetected.

The results of the tracejector survey will provide a qualitative production profile of the pumping well where the relative contributions of the various flow zones to the total flow can be identified.

Static tracejector surveys will be analyzed by techniques of Erickson and Waddell (1985), and Galloway and Erickson (1985). The analysis will identify points where water enters or leaves the wells on the basis of temporal changes in tracer activity. It also may be possible to estimate the vertical-velocity profile in the wellbore. Although qualitative, the analysis will provide the same kind of information obtained from an interpretation of static temperature surveys but with somewhat greater detail.

Temperature logs will be interpreted qualitatively by examining the shapes of temperature profiles to deduce the location and nature of flow points for zones and the direction of flow. Theoretical temperature profiles have been developed from various coupled fluid-flow heat-transfer models in attempts to explain the effects of various contributions of formation water and well-plumbing configurations, including the effects of water flow through borehole-intersected fractures (for example: Loeb and Poupon, 1965; Drury and Jessop, 1982). These profiles will be compared qualitatively to the temperature logs of the c-well complex to identify possible models for subsequent quantitative interpretation.

Quantitative interpretation of temperature logs would be based on the subtangent or delta function (Kunz and Tixier, 1954; Schonbloom, 1961) and an enhancement described by Murphy (1982). Temperature profiles will be calculated from estimates of thermal properties and compared to temperature logs made under pumping conditions. Because the flow rate will be known from the tracejector analysis, the fluid-flow heat-transfer model may be calibrated using the fluid flow rate to determine the range of values for formation and hydrothermal properties, and the geothermal gradient that gives the best match to the measured temperature log. The calibrated model could then be applied to temperature logs made under static conditions to estimate intraborehole-flow rates.

3.3.3.2 Interpretation of injection and withdrawal flow testing

To interpret the results of each analysis, the actual well test results will be compared to theoretical ideal responses for various aquifer characteristics. If the well test results cannot be represented with a theoretical response curve for a specific analysis technique, a different technique will be applied to the data. This procedure will probably lead to several analytical methods that will explain the results of the well test. Determining which methods best describe the real conditions at the c-holes will involve the use of all available geologic and hydrologic information and a continuously refined conceptual model of the system.

The primary purpose in analyzing hydraulic stress tests at the c-wells is to refine the conceptual model of saturated-zone flow at the scale of the c-well complex. Where appropriate, calculations of hydraulic parameters may be made. A conceptual model at this scale based on the analysis of stress tests will aid significantly in designing additional hydraulic interference tests (Section 3.4) and enable a more realistic calculation of aquifer properties.

Several types of stress tests have been conducted at the c-well complex. A constant-rate pumping test without packers was made in each of the c-wells after completion of drilling. During the UE-25c #2 pumping test, UE-25c #1 was used as an observation well; during the UE-25c #3 pumping test, UE-25c #1 and UE-25c #2 were used as observation wells. Twenty-three falling-head injection tests were made in UE-25c #1 using inflatable packers to isolate test zones. Two additional falling-head injection tests were made in UE-25c #1 to measure pipe-friction head losses during injection. Each of these test-well and monitor-well configurations are shown in Figures 3.3-3, 3.3-4, and 3.3-5 with regard to the test well, UE-25c #1, UE-25c #2 or UE-25c #3, respectively. A quasi-constant-rate injection test was run in an isolated interval of UE-25c #2 and monitored in UE-25c #1 and UE-25c #3. A schematic of this test is shown in Figure 3.3-5.

The analysis of pressure-transient data from c-well pumping and injection tests initially will consider porous-media solutions that are radially infinite, homogeneous, and isotropic. Complexity, in the form of solutions for fractured reservoirs, would be considered as needed and in accordance with the analytical approach outlined below. This approach, from simple to complex flow solutions, should enable the development of a conceptual model for the pressure-transient behavior by contrasting the c-well responses to the ideal porous-media response.

Porous-media solutions that will be considered in the analysis of constant-flow tests include the Theis (1935) solution for nonleaky isotropic confined conditions with fully penetrating wells and constant-discharge conditions. Solutions which consider leakage from or to adjacent formations would be applied, such as Hantush and Jacob (1955), Hantush (1960), and Neuman and Witherspoon (1969a, 1969b). Boulton's solution for nonsteady radial flow in unconfined aquifers with delayed-yield from storage (Boulton, 1963) would be considered. Variations of these basic flow models will be considered. In addition, the potential effects of wellbore storage, wellbore skin, outer-boundary (e.g. no-flow or constant-head boundaries), and partial penetration would be examined.

If porous-media solutions prove inadequate for analysis of flow tests at the c-wells, solutions developed for fractured flow systems will be considered. Many of the solutions for well tests in fractured flow systems do not explicitly locate individual fractures within the rock but assume that fractures and porous rock are

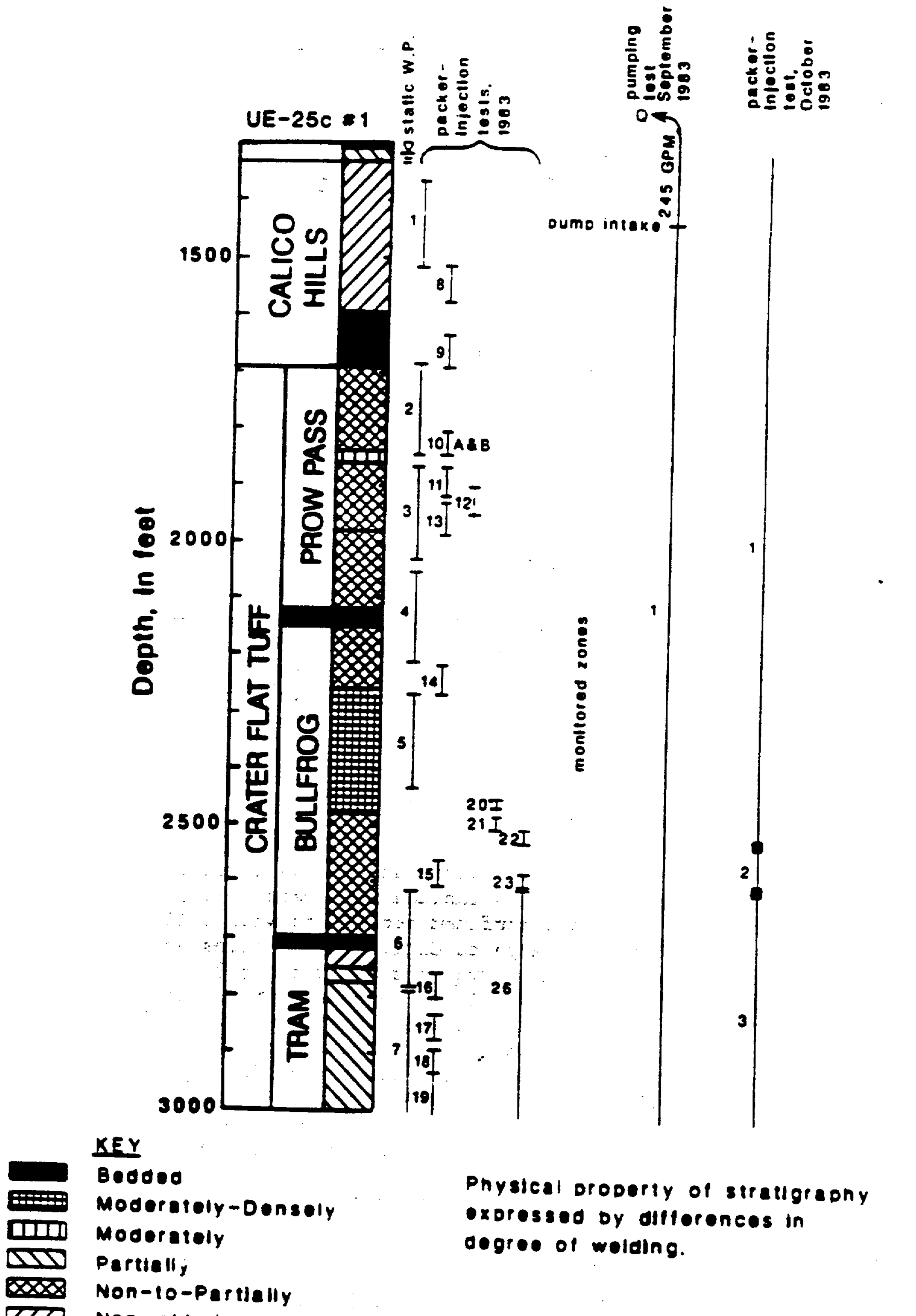

Figure 3.3-3. Test-well configuration for UE-25c #1 packer-injection and open-hole pumping tests.

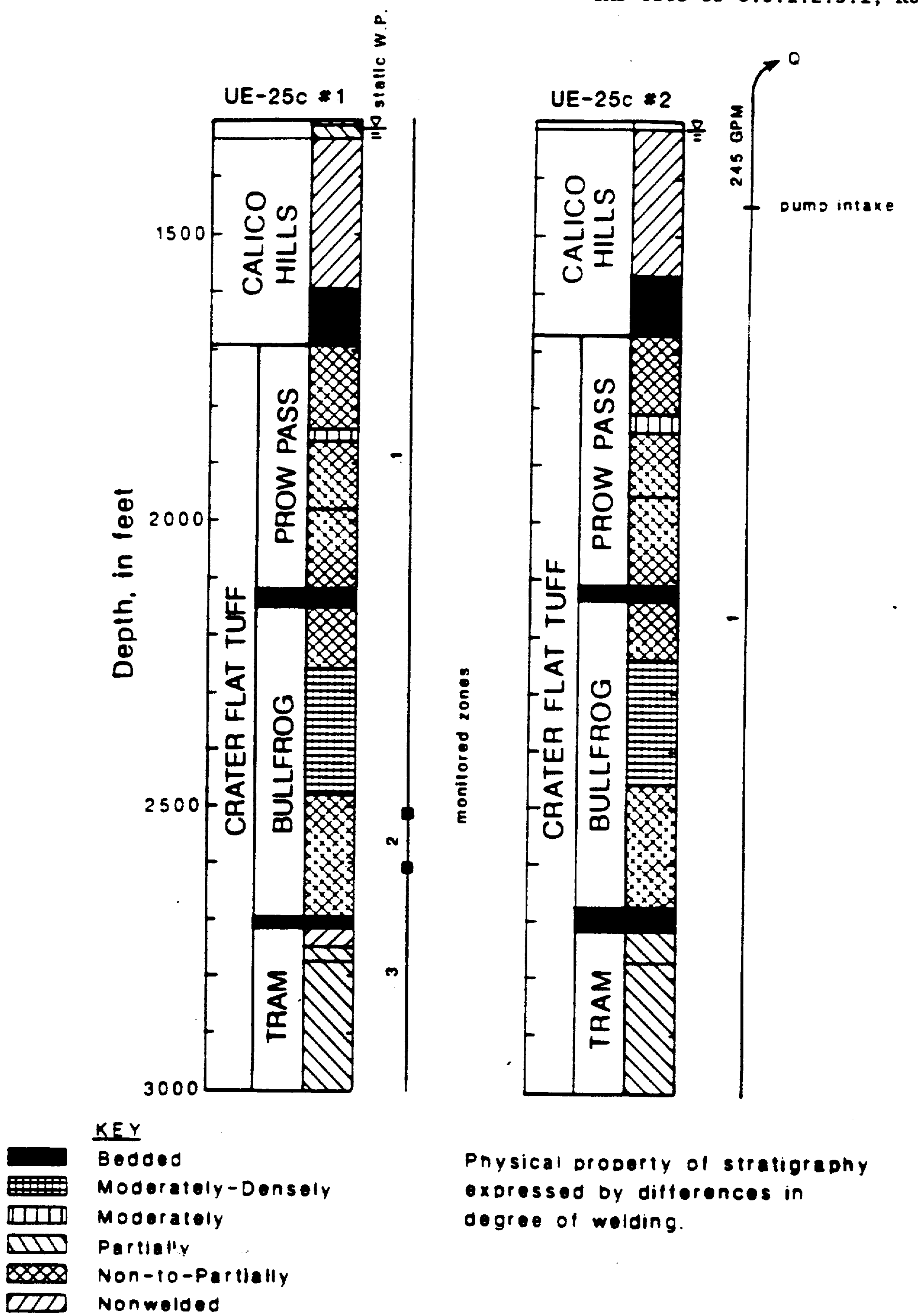

Figure 3.3-4. Test-well configuration for UE-25c #2 pumping test in March 1984.

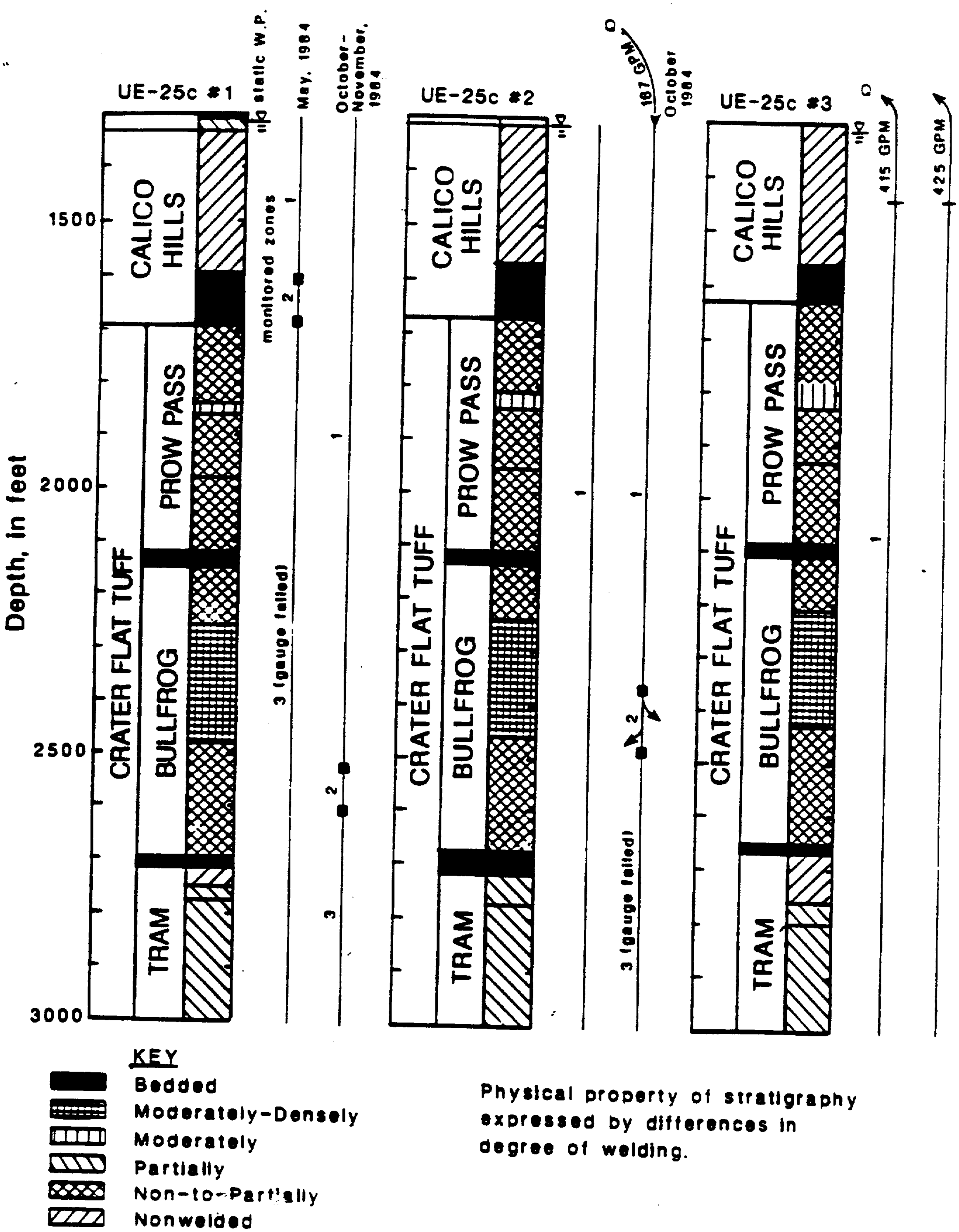

Figure 3.3-5. Test-well configuration for UE-25c #3 pumping tests in May 1984 and November 1984; and UE-25c #2 packer-injection test, October 1984.

distributed uniformly throughout the flow system. The flow system is treated as an equivalent porous medium, either homogeneous or heterogeneous, depending on the measured pressure-transient data from the stress tests. Because of their probable importance in the analysis of stress-test data at the c-wells, solutions for well tests in fractured flow systems will be applied.

A large number of solutions have been developed for nonsteady radial flow in an infinite-acting porous medium with anisotropy introduced by fractures. Identified as homogeneous models by Gringarten (1982), some consider single fractures or relatively simple networks of fractures (Prats, 1972; Asfari and Witherspoon, 1973); others do not consider fractures explicitly but consider anisotropy of hydraulic conductivity and are useful for analyzing pressure-transient data from a monitoring well (Papadopulos, 1965; Saad, 1967). Four types of inner-boundary conditions have been considered; the intersection of the stressed well and a single fracture, wellbore storage, wellbore skin, and partial penetration. Gringarten and others (1979) reviews publications on wellbore storage and skin effects. Karasaki (1986) briefly reviews publications on partial penetration.

Several models have been presented to describe pressure-transient data from a pumping well intersected by a single fracture. Gringarten and others (1974) presented solutions for a well intersecting a single vertical fracture with infinite hydraulic conductivity in a porous medium that is radially infinite and homogeneous. The solution of Gringarten and Witherspoon (1972) accounts for an anisotropic porous medium. Cinco and others (1978) include a vertical fracture with finite hydraulic conductivity. Gringarten and Ramey (1974) present a solution for the transient response when a single horizontal fracture intersects a pumping well in a porous medium that is radially infinite and homogeneous.

An equivalent homogeneous model may not adequately represent behavior of a fractured flow-system; an equivalent heterogeneous model may be more appropriate. Of the heterogeneous models, multi-layered and composite models have received the most attention.

Double-porosity models assume two linked, overlapping continua, one representing rock matrix and a second representing fractures. Two pressures are considered for each point in space; one for the hydraulic pressure in the rock and another for hydraulic pressure in fractures. Assumptions for most double-porosity models include (1) the rock is extensively and uniformly fractured, (2) hydraulic conductivity of fractures is large compared to that of the rock, and (3) storage capacity of the rock is large compared to that of fractures. Two methods have been used to express the fracture-rock interaction: quasi-steady-state flow between blocks and fissures, and transient flow. The concept of a double-porosity system in fractured reservoirs was first introduced by Barenblatt and others (1960), but many variations have been developed. Gringarten (1982) and Karasaki (1986) review double-porosity solutions developed in the fields of petroleum engineering and saturated-zone hydrology.

Effects of wellbore storage and skin have been included in double-porosity solutions. By including effects of wellbore-storage and fracture-skin in double-porosity solutions, Moench (1984) shows the relation between quasi-steady-state and transient-flow methods for simulating fracture-rock interaction. Moench (1984) also analyzes pumping-test data for wells on Yucca Mountain, UE-25b #1 and UE-25a #1 where mineralized fractures were observed in core samples. A good match to the data was obtained for both the pumped well and the observation well using a double-porosity model with wellbore storage and transient flow between the rock and a set of parallel fractures. The type-curve analysis gives values for fracture and matrix hydraulic conductivity, and specific storage.

Several multilayered models have been presented that represent fractured reservoirs as a series of uniformly spaced horizontal matrix and fracture layers. The models are reviewed by Gringarten (1982).

Composite models, where two concentric regions exist about a well with distinctly different properties, have been applied to flow problems in fissured aquifers. For example, where flow in an inner region near a pumping well is dominated by a few fractures which are some distance away from the well in an outer region and may be extensively interconnected, the early-time well response may be more indicative of the inner region flow properties, and less representative of the system's average response. Karasaki (1986) presented three composite models for well tests with a constant-flow inner boundary in fractured media.

Preliminary analyses of the falling-head injection (slug) tests conducted in UE-25c #1 have been undertaken and reported (Erickson and others, 1985; Karasaki, 1986). The pressure-transient data from many of the slug tests could not be adequately represented by the various solutions that were applied. Three probable causes for the unsatisfactory results have been identified. First, high initial heads may have induced excessive friction losses through the delivery pipe and the down-hole packer valve. Second, the resulting large velocity may have led to non-Darcian flow in the rock near the wellbore. Third, excessive injection pressure heads, (approximately 700 ft of water) may have disturbed the *in situ* stress field around affected fractures, causing a change in fracture aperture and subsequently fracture hydraulic conductivity. Additional interpretation of the test data may be useful on the basis of additional injection tests. Such tests could be designed to mitigate the pipe-flow head losses. Although an analytical model that considers non-Darcian flow in the rock is not available, an "equivalent" analytical model or a numerical model may be applied to these data. The relation between injection heads, fracture-aperture hydraulic potential, and effective stresses will be examined.

Excessive pressures sometimes induced during injection well testing can cause hydrofracturing of the rock around the borehole. This results in a distinctive double hump during injection for the particular well test. Hydrofracturing may be investigated as part of this activity by performing several injection tests at successively higher pressures to determine at what pressures the hydrofracturing occurs. These tests will necessarily be performed after all other well tests at the c-holes are completed to avoid interfering with the other tests.

3.3.3.3 Barometric and earth-tidal analysis

Water levels were monitored in the c-wells and in UE-25p #1 in order to analyze aquifer responses to earth-tide strains and surface barometric-pressure loads. Techniques have been developed which relate the strain of the solid earth due to earth tides and the resulting aquifer dilatation to aquifer properties such as specific storage, matrix bulk modulus, and hydraulic effective porosity; for example, see Bredehoeft (1967), Rhoads and Robinson (1979), Bower (1983), and Van Der Kamp and Gale (1983). Each of the techniques is developed for ideal confined aquifers or undrained conditions. Bredehoeft (1967) also presents an analysis for an ideal unconfined aquifer. As such, it is important to determine the frequency response of the monitored aquifer before applying these techniques.

Weeks (1979) presented a study of water-level response to barometric fluctuations in deep unconfined aquifers and proposed a model to explain the interaction based on the air diffusivity of the unsaturated zone. Rojstaczer (1988) extended the analysis of atmospheric loading effects to include the effects of the vertical hydraulic diffusivity and the application of the frequency response function of the well/formation.

Some preliminary analyses of aquifer response have been undertaken and reported (Galloway and Sullivan, 1986). Water levels were measured in the c-wells in five zones (Table 3.3-2) open to the extensively fractured Crater Flat Tuff, and in UE-25p #1 in one zone open to the Paleozoic dolomite. Barometric pressure was monitored at land surface near UE-25c #2. Measurements were made at 30-minute intervals from December 5, 1985, to July 17, 1986, using sensitive pressure transducers. A 57-day period of uninterrupted measurements from February 23 to April 21, 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 UE-25p #1 based on Rhoads and Robinson (1979), gave estimates of barometric efficiency (0.57), specific storage ($6.0 \times 10^{-9}cm^{-1}$), matrix bulk modulus (36.4 GPa), and effective porosity (7.7×10^{-2}).

Table 3.3-2. Test-well configuration for analysis of c-well earth-tide- and barometric-induced water-level fluctuations

Well Number	Monitored Interval (feet below land surface)
UE-25c #1	1,365 to 2,610
	2,620 to 3,000
UE-25c #2	1,365 to 2,482
UE-25c #3	1,323 to 2,465
	2,475 to 3,000

Earth-tide-induced water-level fluctuations recorded for the c-wells could not be analyzed based on the theory of Bredehoeft (1967) or Rhoads and Robinson (1979) due to the strong dependence of earth-tide frequencies on water-level fluctuations to barometric pressure. In accordance with the model of Weeks (1979), phase lag and attenuation were observed in the water-level response to changing barometric pressure.

Although the water-level response observed in the c-wells can be described by Weeks' model (1979) and may indicate that the aquifer is unconfined, other phenomena may explain the response. Additional work needs to be done to rule out phenomena such as well-bore storage effects or the phase shift in fluid pressure caused by the relaxation time of a fractured reservoir with low intergranular permeability. Although, some evidence indicates that air is diffusing to great depth in the unsaturated zone in response to changing barometric pressure. Reversing airflow has been observed at UE-25c #2 in the annular space open to unsaturated rock below 320 feet. Weeks (1986) has observed a similar phenomenon on the crest of Yucca Mountain in boreholes USW UZ-6 and UZ-6s and has postulated two concurrent mechanisms: a topographic effect and a barometric effect.

Additional analysis of earth tides will use the technique of Hanson (1984) to account for well-bore storage and well-completion effects, as well as the presence of discrete fluid-filled fractures. Other useful approaches which would be applied include an analytical technique presented by Kanehiro and Narasimhan (1980) which considers the drained response of an open well; criteria presented by Bower (1983) to evaluate fluid-pressure response of the aquifer based on fracture orientation; a development presented by Van Der Kamp and Gale (1983) which accounts for the effect of compressible solids on the earth-tide response; a technique developed by Hsieh and others (1987) for calculating aquifer hydraulic diffusivity from the earth-tide response, and especially, the techniques presented by

Rojstaczer (1988) for analyzing the response of water levels in wells to atmospheric loading and earth tides.

Other monitored zones in other boreholes at Yucca Mountain need to be examined to determine whether water level transients exhibit a frequency-dependent response to atmospheric pressure, and if so to relate the response to air diffusion effects, water-table connection, well-bore storage, or other conditions.

In addition to earth tides and atmospheric pressure, water levels and fluid pressures respond to earthquakes and nearby underground nuclear explosions. These events will be monitored and used to obtain estimates of bulk aquifer properties using the method of Cooper and others (1965).

3.3.3.4 Methods summary

The parameters to be determined by the methods described above are summarized in Table 3.3-3. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be used if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, only the most common methods are included in the table. The selected methods in Table 3.3-3 were chosen primarily on the basis of accuracy, precision, duration of methods, expected range, and lack of interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site parameter. The expected ranges of the site parameter have been bracketed by previous data collection and computer modeling and are shown in Table 3.3-3.

3.3.4 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires documentation of technical procedures for all technical activities that require quality assurance.

Table 3.3-4 provides a tabulation of technical procedures applicable to this activity. Procedures that are not identified with an effective date will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started; these procedures are also identified with a "TBD" (To Be Determined) technical procedure number. Approved procedures are identified with a USGS procedure number and an effective date. Some of the listed technical procedures are primarily outside the objectives of the subject activity (Analyses of previously completed hydraulic-stress tests) or study (Characterization of the Yucca Mountain site saturated-zone flow system), but are included for general information and ease of

Table 3.3-3. Summary of methods for the hydraulic-stress test analysis activity (SCP 8.3.1.2.3.1.3)

[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site-characterization parameter	Expected range
Interpretation of intraborehole flow		
Analysis of temperature logs (pumping and non-pumping stress) (selected)	Hydraulic gradients, relative	--
Heat flow analysis of temperature logs (non-pumping stress) (selected)	Flow rates, intraborehole	2 l/hr to 400 l/hr
Analysis of tracejector survey (pumping stress) (selected)	"	"
Analysis of tracejector survey (non-pumping stress) (selected)	"	0.5 l/hr to 400 l/hr
Interpretation of injection and withdrawal flow testing		
Conceptual model development by type-curve analysis (selected)	Hydraulic boundries and conduits	--
Connectivity between wells from water-level changes in multiple-well tests (selected)	"	--
Type-curve analysis using fracture-flow models (selected)	Storage coefficient, bulk estimates	10^{-6} to 10^{-3}
Type-curve analysis using porous-media models (selected)	"	"
Type-curve analysis using fracture-flow models (selected)	Transmissivity, bulk estimates	1×10^{-2} to 1×10^{2} m^2/d

Page 2

Table 3.3-3. Summary of methods for the hydraulic-stress test analysis activity (SCP 8.3.1.2.3.1.3)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Interpretation of injection and withdrawal flow testing		
Type-curve analysis using porous-media models (selected)	Transmissivity, bulk estimates	1×10^{-2} to 1×10^{2} m^2/d
Barometric and earth-tide analysis		
Analysis of water-level fluctuations due to barometric changes (selected)	--	--
"	Specific storage	10^{-10} to 10^{-8} cm^{-1}
"	Matrix compressibility	10^{-12} to 10^{-11} $cm^2/dyne$
"	Vertical hydraulic diffusivity	10^1 to 10^4 cm^2/sec
"	Vertical pneumatic diffusivity	10^2 to 10^4 cm^2/sec
"	Barometric efficiency	.2 to .95
Earth-tide analysis of water-level fluctuations (selected)	Dilatational efficiency	0.001 to 0.1
"	Effective porosity, bulk estimates	"
Laboratory analysis of cores (selected)	"	0.0001 to 0.1
Underground nuclear explosion effects on water-level analysis		
Analysis of water-level and shut-in fluid pressure response in wells for UNE-s (selected)	Aquifer strain	10^{-6} - 10^{-9}

Table 3.3-3. Summary of methods for the hydraulic-stress test analysis activity (SCP 8.3.1.2.3.1.3)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Underground nuclear explosion effects on water-level analysis		
Analysis of water-level and shut-in fluid pressure response in wells for UNE-s (selected)	Transmissivity	10^{-2} - 10^{2} m^2/d
"	Storage coefficient	10^{-6} - 10^{3}

Table 3.3-4. Technical procedures for the analysis of previously completed hydraulic-stress tests (SCP Activity 8.3.1.2.3.1.3)
[Dashes (--) indicate information is not available and to be determined.

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Interpretation of intraborehole flow	
--	No technical procedures identified	--
	Interpretation of injection and withdrawal flow testing	
--	No technical procedures identified	--
	Barometric and earth-tide analysis	
HP-25	Method for measuring water levels using a portable multiconduc	08/13/88
HP-26	Method for calibrating water-level measurement equipment using the reference steel tape	08/14/84
HP-60	Method for monitoring water-level changes using pressure transducers	05/04/88
HP-75	Method for measuring water levels in wells using reeled (2,600-ft and 2,800-ft) steel tape	06/22/87
HP-121	Installing and retrieving information from a Setra pressure transducer	--

cross-referencing. Approved technical procedures not listed may be used during the activity, should that be appropriate, and listed procedures may be revised or replaced with other procedures, as needed.

All procedures listed are currently classified as "standard", as they represent modifications of methods and equipment with established records of use and reliability. Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and stepwise procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Applicable quality-assurance procedures are presented in Appendix 7.1.

3.4 Multiple-well interference testing

3.4.1 Objectives

The objectives of this activity are to:

1. determine hydraulic properties, primarily hydraulic conductivity and storage coefficient, needed for quantitative evaluation of water flow,

2. determine if fractured rock beneath Yucca Mountain can be represented as 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,

4. evaluate vertical and horizontal spatial variability of flow parameters at the scale of the c-hole complex,

5. evaluate spatial correlation of flow parameters and cross-correlation between the parameters at the scale of the c-hole complex, and

6. examine scale dependency of flow parameters at the c-hole complex.

3.4.2 Rationale for activity selection

Hydrologic-property data from the saturated zone beneath Yucca Mountain are required to calculate rates and directions of ground-water flow. In this activity, hydrologic properties include properties of the rock-water system. Within a framework of equivalent porous-media flow, the hydrologic properties of interest are hydraulic conductivity and storage coefficient. If the fractured rock at Yucca Mountain cannot be represented by analogy with porous media, hydraulic conductivity and storage coefficient may not be appropriate parameters on which to base models of ground-water flow. If an analogy with porous media is inappropriate, parameters of interest for ground-water modeling include hydrologically-effective fracture-network characteristics.

Most techniques that have been developed for investigating ground-water flow in fractured rock are based on the assumption that the flow system can be simulated as an equivalent porous medium. However, theoretical studies in fractured rock have shown that the porous-medium assumption is valid only in dense fracture systems that are connected. The critical fracture density needed to justify the porous-medium assumption also depends on other fracture characteristics, such as fracture size and orientation. In fractured systems that do not conform to the porous-medium assumption, techniques for investigation of ground-water flow need to include specific information about the fracture network.

Because fracture data are limited, well-test interpretation and regional flow models at Yucca Mountain have been based on assumptions that the fractured rock can be simulated as a porous medium. In many cases, well tests have been difficult to interpret, and data have not supported a particular interpretation to the exclusion of others. Estimates of effective hydraulic conductivity for test intervals typically range over several orders of magnitude. There also has been no clear relation between values of hydraulic properties estimated from well tests and those estimated during calibration of regional and subregional flow models. The sometimes contradictory and confusing results of investigations at Yucca Mountain are evidence that a detailed investigation is needed to describe the hydrologic behavior of fractures.

The results of the c-well testing may not provide data representative of the entire Yucca Mountain area. The representativeness of the c-well complex will be continuously assessed throughout the modeling and testing program. If the properties determined at the c-holes are not representative, additional testing sites may be required.

Results obtained at the scale of the c-wells and single well tests may not accurately represent scale variability throughout the Yucca Mountain area. Various techniques for scaling-up from small scale variability to the larger, site scale (areas) will be evaluated as part of the Site Saturated Zone Synthesis and Modeling Study Plan (SP 8.3.1.2.3.3). Additional testing not included in this study plan may be required as a result of these evaluations of scale dependence.

Tests planned as part of this activity will be used to evaluate the hydrologic behavior of fractured rock. If test results indicate that a porous-media model is appropriate, the tests will be used to estimate hydraulic conductivity and storage coefficient. The nature of the hydraulic-conductivity tensor will be estimated, and the large-scale hydraulic properties, including hydrologic properties of faults in the vicinity of the c-well complex, will be evaluated. If test results indicate that a porous-media model is inappropriate, the tests will be used to estimate effective fracture characteristics at the c-well complex. The term effective fracture characteristics is used to distinguish characteristics estimated as a result of hydraulic-test analysis from characteristics mapped at the surface, in boreholes, or in mine shafts.

The information obtained in this activity will be used to refine the models of the ground-water flow system. Sensitivity analyses with the refined models may indicate a need to modify data collection and analyses within this activity. The data collection and the modeling are interrelated processes that influence each other. This feedback process is described in Section 1.1 and is shown on Figure 1.1-2.

3.4.3 General approach, methods, and analyses

Two types of multiple-well interference tests, cross-hole hydraulic tests and a large-scale pumping test are included in this activity. The series of cross-hole hydraulic tests will be conducted at the c-well complex by pumping water from small isolated intervals of one c-well and monitoring the hydraulic response in isolated intervals of other wells. The analysis of cross-hole tests using various combinations of pumping and monitoring intervals will focus on evaluating several conceptual models for describing ground-water flow and estimating parameters for the models that are most appropriate. Because of the design that will be used in cross-hole tests, the spatial variability of parameters will be estimated at scales of less than 100 meters. The large-scale pumping test will serve a purpose similar to that of cross-hole tests; however, the longer duration of pumping will mean that parameters will be estimated at scales of greater than 100 meters. Because test intervals will be larger, much of the detailed analysis possible with cross-hole tests will not be possible with the large-scale pumping test. The large-scale pumping test will last approximately 30 days, and will involve pumping one of the c-wells while monitoring water-level changes in numerous wells (e.g., UE-25p #1 and USW H-4) beyond the c-well complex.

Tests described as part of this activity emphasize well tests at scales greater than 50 meters. Although estimation of hydraulic properties from mapped fracture geometry is possible, well tests would be needed to validate any estimation technique. Laboratory analysis of core is useful in evaluating matrix properties or single fracture properties but is of limited use in estimating hydraulic properties of interconnected fractures networks.

Figure 3.4-1 summarizes the organization of the multiple-well interference tests activity. A descriptive heading for each method appears in the shadowed boxes of the second row. Below each are the individual methods that will be used. Figure 3.4-2 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site-characterization parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed boxes, respectively.

The two figures summarize the overall structure of the planned work in terms of methods to be used and measurements to be made. The descriptions in the following sections are organized on the basis of these diagrams. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations among (1) site-characterization parameters to be determined, (2) information needs for performance and design issues, (3) technical objectives of the activity, and (4) methods to be used.

The spatial variabilities of existing conditions within the rock and correlations to present and potential future conditions are addressed by

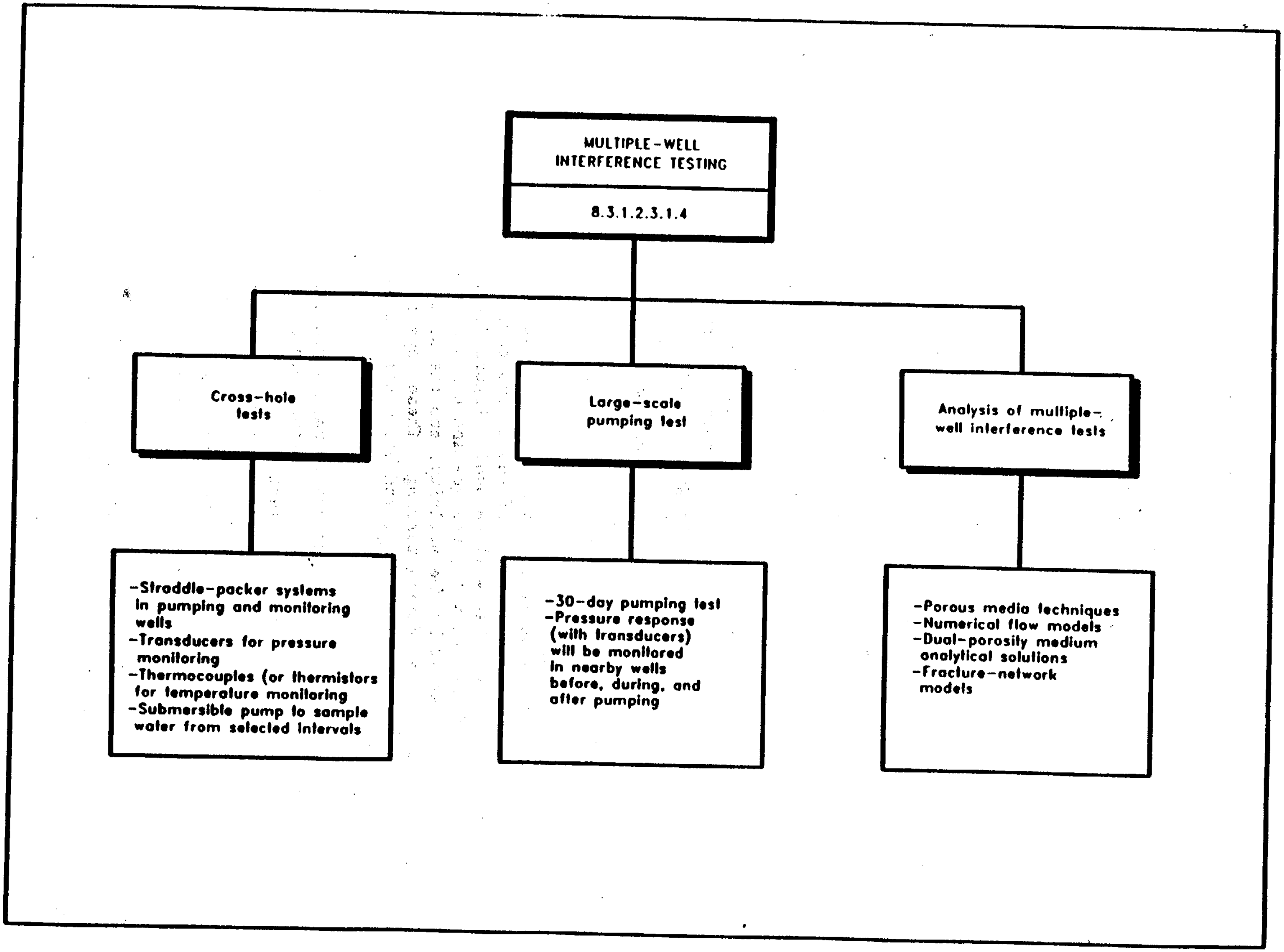

Figure 3.4-1. Logic diagram of the multiple-well interference testing activity showing tests, analyses, and methods.

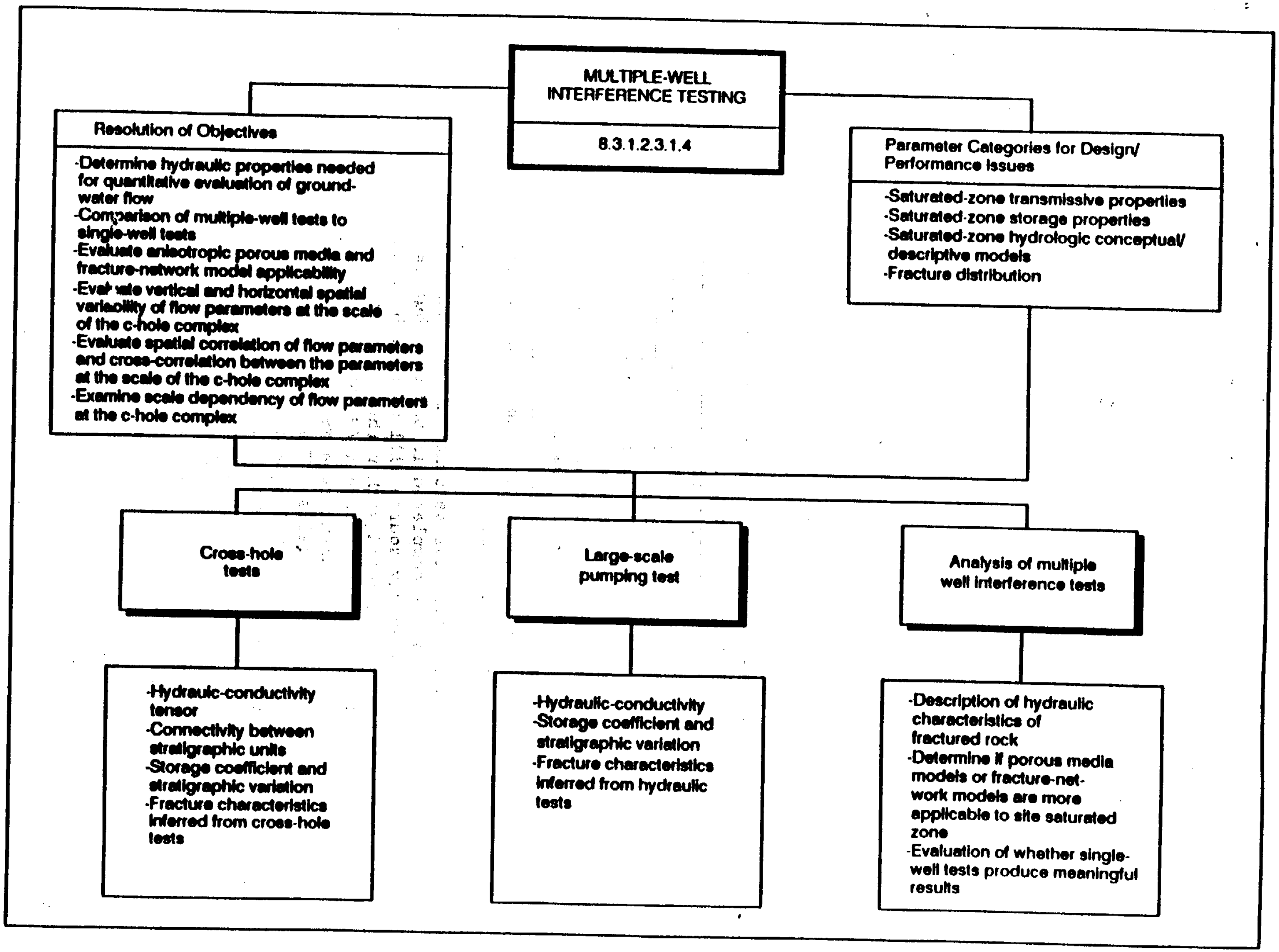

Figure 3.4-2. Logic diagram of the multiple-well interference testing activity showing tests, analyses, and site-characterization parameters.

this activity. These tests will be used to estimate hydraulic-conductivity, storage coefficient, and hydrologically effective fracture characteristics of the aquifer in the vicinity of the c-holes. Results of this work will assist in methods development for testing at other single or multiple hole sites and will be particularly useful in validating various physical models of the flow system beneath Yucca Mountain. Similarly, an understanding of present conditions will be useful for modeling and predicting potential future ground-water conditions beneath Yucca Mountain.

3.4.3.1 Cross-hole tests

A series of cross-hole tests will be made during which water will be pumped from small isolated intervals of one c-well and the hydraulic response is monitored in isolated intervals of other c-wells. Several tests using various combinations of pumping well, pumping interval, and observation intervals will be made in order to identify the nature of hydraulic connection between the c-wells. The exact number of tests and test intervals will be determined based on cross-hole seismic surveys, temperature logs, tracejector surveys, and analyses of completed hydraulic stress tests.

Cross-hole seismic surveys will be conducted that could aid in selecting appropriate combinations of pumping and monitoring intervals. A fence diagram of seismic properties will be constructed to estimate fracture location, density, and orientation in vertical planes between wells. Alternative methods for selecting test-interval combinations, such as random selection, will have to be incorporated if seismic-profiling data cannot be obtained or interpreted. However, alternate methods for selection of test-interval combinations could result in not testing critical interval combinations. Failure to conduct and interpret seismic surveys might greatly reduce the ability to relate hydraulic properties to fracture characteristics.

The exact design for seismic surveys cannot be stated until prototype tests are completed in USW G-4, but general guidelines can be given. The energy source will be a high-frequency point source (up to 5,000 Hz) located within the saturated zone at one of the c-wells. Three-component sources (P, SH, and SV waves) will be used. Strings of three-component receivers will be placed in the saturated zone in the other two wells. The exact spacing of source points and receivers will depend on frequency content of the generated signal and desired detail. For example, much of the water production at the c-wells occurs in the Bullfrog Member of the Crater Flat Tuff. Detailed seismic profiling would be appropriate in this unit. A large fault is suspected in the lower section of each well. Accurate mapping of this fault also would be a priority. Less detail would be required in units overlying the Bullfrog Member. Seismic surveys at the c-well complex may include vertical seismic profiling, with the seismic source placed at the land surface, in order to locate large structural features, such as faults, that may influence results of hydraulic and tracer tests.

Cross-hole pumping will be conducted on zones representing a variety of hydrologic conditions. Each test will be conducted in the following manner. Multiple-packer systems will be installed in both pumping and monitoring wells. Packers will be used to isolate intervals selected for testing from temperature logs, tracejector surveys, analysis of completed hydraulic-stress tests (Section 3.3) and seismic profiling. After packers and pressure transducers are installed in the monitoring interval, the pressures in each zone will be allowed to equilibrate. Vertical head variations will be recorded and each zone will be pumped for a short time to assure the integrity of the packer seals. After all zones equilibrate, a submersible pump will withdraw water from the selected interval for approximately 3 days. The temperature of the pumped water will be monitored and pressure changes will be measured in pumping and monitoring intervals. After the pump is stopped, pressure recovery will be monitored approximately 3 additional days. Proposed pumping rates and durations may be adjusted depending on the interpretations of the previously completed hydraulic stress tests.

The combinations of pumping and monitoring intervals used in cross-hole tests will be selected in order to describe the spatial and directional variation of hydraulic conductivity as well as the degree of hydraulic connection between stratigraphic units. For this reason, tests will be conducted during which water is pumped from permeable intervals in the lower Bullfrog Member and pressure changes will be monitored in observation wells in permeable intervals of the Bullfrog Member and upper part of the Tram Member. Tests also will be conducted by pumping water from the permeable intervals of the upper part of the Tram Member and monitoring pressure response in permeable intervals in the upper part of the Tram Member and lower part of the Bullfrog Member. 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 for monitoring. By conducting tests for various combinations of pumping and monitoring intervals, it may be possible to determine if hydraulic conductivity can be described as a symmetrical tensor and possibly if the tested rock can be represented as an equivalent porous medium.

The overall plan for cross-hole tests includes iteratively designing, conducting, and interpreting hydraulic tests. By iteratively conducting and interpreting individual tests, experience gained during one test can be used to improve the design of future tests. Deferring the analysis of test results until all tests have been conducted may result in short-term efficiency of field operation but also runs the significant risk that test design will be less than optimal or inappropriate.

In order to evaluate the precision of the cross-hole tests, selected tests will be repeated. Adherence to guidelines of the USGS Quality Management Procedures should assure that testing equipment will meet various quality criteria, as well as assuring that testing procedures and data will be adequately documented. However, test replication is needed to evaluate the quality of overall test results. Replication is particularly important as a means of evaluating the importance of experimental errors introduced from unanticipated sources. If results of early test replication show that the magnitude of experimental errors is small in comparison to needed accuracy, the number of replications will be small. If results of early test replication show that errors are large, equipment design and testing procedures will be reevaluated and improved before proceeding with additional tests and additional replication will be required.

3.4.3.2 Large-scale pumping test

One of the c-wells will be pumped for approximately 30 days while changes in pressure are monitored in the c-wells and other nearby wells, such as USW H-4 and UE-25p #1. The exact duration of the test will be determined based on the pressure response measured in the observation wells. After pumping stops, pressure recovery would be monitored in all wells for approximately 30 days or until pressures return to near pre-test conditions or stabilize. Results from the pumping test may be used to estimate hydraulic properties at a scale larger than the c-well complex. Large-scale estimation of hydraulic properties is important to accurately describe saturated-zone flow beneath Yucca Mountain.

In addition, the hydrologic significance of faults in the vicinity of the c-well complex may be evaluated. Observation wells used during the pumping test are located on both sides of the Bow Ridge fault. The pressure response in these wells will be used to determine if the fault acts as a barrier or conduit for ground-water flow.

As an alternative to pumping one of the c-wells, other existing wells could be pumped. This alternative method is not selected because other existing wells at Yucca Mountain are relatively isolated from one another. In order to take full advantage of a large-scale pumping test, observation wells should be located both within the same structural block as the pumping well and in adjacent structural blocks. The c-well complex meets this criterion whereas other wells do not. Because the c-well complex exists and is adequate for tests, drilling other observation wells is not mandatory at this time.

3.4.3.3 Analysis of multiple-well interference test

A description of techniques that would be used to analyze the multiple-well interference test cannot be given until the test has been completed and results have been reviewed; however, it is possible to describe the general strategy for analysis. Interpretation of test results would begin with appropriate, simple assumptions describing the hydraulic characteristics of fractured rock and proceed to more complex descriptions. Complex descriptions would be adopted if interpretive techniques based on simpler descriptions are shown to be inadequate. Information obtained during the analysis of previously completed hydraulic-stress tests (Section 3.3) also would be used to guide the analysis of the planned multiple-well interference tests.

The following is a general description of the planned approach to well test analysis. It is likely that several methods will be used in the final analysis. Also, it is often difficult to distinguish between several possible superimposed effects while analyzing the results of well tests. Several different types of information such as tracejector surveys, temperature logs, borehole fracture mapping, and geologic information must be used to develop a conceptual model of the hydrologic setting. The conceptual model, along with the iterative technique of well test analysis described below, will be used to help distinguish between the possible superimposed effects.

Porous-media techniques, based on the assumption that the rock is homogeneous and anisotropic, will be used for initial interpretation of test results. One technique in this class which may be used to interpret cross-hole tests is the analytical method described by Hsieh and others (1985). If the assumption of a homogeneous porous medium is appropriate, the technique can be used to estimate the three-dimensional hydraulic-conductivity tensor and storage coefficient.

Initial interpretation of cross-hole tests may indicate that the fractured rock at the c-well complex cannot be described by analogy to a homogeneous anisotropic porous medium. Evidence that the assumption of homogeneous anisotropic porous medium is incorrect may be obtained by developing a least-squares fit of hydraulic-conductivity estimates to the equation of an ellipsoid and evaluating the regression model. Statistical tests for lack of fit in the regression model may indicate that the porous-media analogy is not valid at the scale of the cross-hole tests or that the assumption of homogeneity is not valid. Graphs of least-square residual vs. depth may indicate that variations in hydraulic conductivity are related to stratigraphy or lithology. Graphs of least-square residual vs. distance between pumping and monitoring interval may indicate that the concept of a representative elementary volume (REV) is not appropriate at the scale of cross-hole tests.

If initial interpretation indicates that the assumption of homogeneity is not appropriate but the analogy to a porous medium is valid, a numerical model for flow in porous-media would be used. Analytical methods for describing flow in stratified rock have been developed but usually require additional simplifying assumptions regarding flow between strata of different hydraulic properties. Using a numerical model, it also may be possible to evaluate a greater number of assumed patterns of aquifer heterogeneity than would be possible using analytical methods.

Analysis of previously completed hydraulic-stress tests (Section 3.3) may indicate that the fractured rock at the c-well complex can be treated as a dual-porosity medium. Transient pressure response obtained from cross-hole tests also may indicate that the rock at the c-well complex can be treated as a dual-porosity medium. At early and late times during tests, the pressure response would follow separate type curves for porous media. Dual-porosity media are characterized by a rock matrix with hydraulic conductivity that is small compared to that of the fracture system and storage capacity of the rock matrix that is large compared to that of the fracture system.

If initial interpretation indicates the aquifer behaves as a dual-porosity medium, methods such as Moench (1984) may be adapted for use. If analytical procedures for dual-porosity media cannot be adapted to cross-hole tests or assumptions of aquifer homogeneity are judged to be inappropriate, numerical models based on dual-porosity media may be used.

Analysis of previously completed hydraulic-stress tests (Section 3.3) may indicate that the fractured rock at the c-well complex can be treated as a composite porous medium. A composite porous medium is one where flow in an inner region near a pumping well is dominated by a few fractures that are connected to an extensively fractured outer region. As a result, the hydraulic characteristics of the inner region are significantly different from the average characteristics of the flow system. If appropriate, composite analytical methods such as those of Karasaki (1986) would be used to interpret multiple-well interference tests.

The fracture-network model developed by Lawrence Berkeley Laboratory (8.3.1.2.3.3.2) also would be used to interpret results of multiple-well interference tests. A set of fracture networks that brackets the range of uncertainty in fracture characteristics would be generated. For example, networks with estimates of different mean apertures and/or different distributions of apertures might be included. Networks also would be developed that correspond to differing hypotheses for describing the distribution of fractures beneath Yucca Mountain. For example, fractures may be treated as stratigraphically controlled or independent of stratigraphy. Results of cross-hole seismic profiling and geotomographic analysis would be used to guide selection of appropriate fracture networks. Fracture networks generated on the basis of geologic evidence would be used to simulate multiple-well test results. Those networks that best match measured hydraulic response to pumping would be considered for analysis of tracer-test data. A complete description of planned applications of the fracture-network model is given in Study Plan 8.3.1.2.3.3.

3.4.3.4 Comparison with single well tests

Because they sample a larger volume and are less influenced by nearby alteration of the aquifer during drilling, multiple well tests are generally considered to be more reliable than single well tests. However, in many situations single well tests provide meaningful results. The results of the multiple well tests from this activity and from Activity 3.3 will be compared to the results of the single well tests from Activity 3.3. These comparisons are aimed at determining the applicability of single well tests throughout the Yucca Mountain area. If the results of the single well tests at the c-well complex indicate that they are unreliable, additional multiple well complexes will need to be established.

3.4.3.5 Methods summary

The parameters to be determined by the tests described above are summarized in Table 3.4-1. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be used if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, only the most common methods are included in the tables. The selected methods in Table 3.4-1 were chosen primarily on the basis of accuracy, precision, duration of methods, expected range, and lack of interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site parameter. The expected ranges of the site parameter have been bracketed by previous data collection and computer modeling and are shown in Table 3.4-1.

3.4.4 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires documentation of technical procedures for all technical activities that require quality assurance.

Table 3.4-2 provides a tabulation of technical procedures applicable to this activity. Procedures that are not identified with an effective date will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started; these procedures are also identified with a "TBD" (To Be Determined) technical procedure number. Approved procedures are identified with a USGS procedure number and an effective date. Some of the listed technical procedures are primarily outside the objectives of the subject activity (Multiple-well interference testing) or study (Characterization of the Yucca Mountain site saturated-zone flow system), but are included for general information and ease of cross-referencing. Approved technical procedures not listed may be used

Table 3.4-1. Summary of tests and methods for the multiple-well interference testing activity (SCP 8.3.1.2.3.1.4)
[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Cross-hole tests	
Select test intervals based on results of previous hydraulic-stress tests (selected)	--	--
Select test intervals based on borehole geophysical surveys (selected)	--	--
Optimize each test design in series based on results of previous tests (selected)	--	--
Select test intervals based on borehole seismic profiling (selected)	--	--
Design all tests in advance based on available information (alternate)	--	--
Select test intervals at random (alternate)	--	--
Collect data for determining hydraulic-conductivity tensor from tests of appropriate combinations of stressed and monitored intervals (selected)	Aquifer heterogeneity and spatial distribution	Homogeneous to randomly heterogeneous
"	Hydraulic-conductivity tensor	1.0 m/d to 10,000 m/d
	Large-scale pumping test	
Pump entire open interval of one c-well (selected)	--	--

Table 3.4-1. Summary of tests and methods for the multiple-well interference testing activity (SCP 8.3.1.2.3.1.4)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Large-scale pumping test--Continued		
Pump other wells at Yucca Mountain (alternate)	--	--
Increase measurement frequency at all automated observation wells at Yucca Mountain (selected)	--	--
Drill and monitor additional observation wells (alternate)	--	--
Collect data for approximately 30 days of drawdown and approximately 30 days of recovery (selected)	Aquifer heterogeneity and spatial distribution	--
Collect data until effects are observed or expected at observation wells throughout Yucca Mountain (alternate)	"	--
Collect data until double-porosity effects are observed or expected at c-wells (alternate)	"	--
Analysis of multiple-well interference tests		
Test interpretation by porous-media and fracture-flow analytical solutions (selected)	Hydraulic-conductivity tensor of equivalent porous media	0.01 m/d to 10,000 m/d
Numerical flow modeling (selected)	"	"
Dual-porosity medium analytical solutions (selected)	Hydraulic characteristics of fractured rock	--

Table 3.4-1. Summary of tests and methods for the multiple-well interference testing activity (SCP 8.3.1.2.3.1.4)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Analysis of multiple-well interference tests--Continued		
Fracture network modeling (selected)	Hydraulic characteristics of fractured rock	--
Test interpretation by porous-media and fracture-flow analytical solutions (selected)	Storage coefficient, at multiple-well location	10^{-5} to 0.2
Numerical flow modeling (selected)	"	"

Page 1

Table 3.4-2. Technical procedures for the multiple-well interface testing (SCP Activity 8.3.1.2.3.1.4)
[Dashes (--) indicate information is not available and to be determined.

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Cross-hole tests	
HP-34	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	05/15/85
HP-60	Method for monitoring water-level changes using pressure transducers	05/04/88
HP-75	Method for measuring water levels in wells using reeled (2,600-ft and 2,800-ft) steel tape	06/22/87
HP-121	Installing and retrieving information from a Setra pressure transducer	--
TBD	Method for measuring discharge of a pumping well with an in-line flow meter	--
TBD		--
TBD	Calibration and use of a pressure transducer in a well with a multiple-packer system	--
TBD	Calibration and use of a thermister to monitor water temperature	--
TBD	Method for conducting a cross-hole hydraulic test	--
	Large-scale pumping test	
HP-06	Hydrologic pumping test	01/11/82

Table 3.4-2. Technical procedures for the multiple-well interface testing (SCP Activity 8.3.1.2.3.1.4)--Continued

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Large-scale pumping test	
HP-34	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	05/15/85
HP-60	Method for monitoring water-level changes using pressure transducers	05/04/88
HP-71	Method for monitoring water-level changes using a Campbell Scientific 21X Micrologger	09/01/87
HP-75	Method for measuring water levels in wells using reeled (2,600-ft and 2,800-ft) steel tape	06/22/87
HP-121	Installing and retrieving information from a Setra pressure transducer	--
TBD	Method for measuring discharge of a pumping well with an in-line flow meter	--
TBD		--
TBD	Calibration and use of a pressure transducer in a well with a multiple-packer system	--
TBD	Calibration and use of a thermister to monitor water temperature	--
TBD	Method for conducting a large-scale pumping test	--
	Analysis of multiple-well interference tests	
--	No technical procedures identified	--

during the activity, should that be appropriate, and listed procedures may be revised or replaced with other procedures, as needed.

All procedures listed are currently classified as "standard", as they represent modifications of methods and equipment with established records of use and reliability. Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and stepwise procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Applicable quality-assurance procedures are presented in Appendix 7.1.

3.5 Testing of the c-well complex with conservative tracers

3.5.1 Objectives

The objectives of this activity are to:

1. determine the following properties by single- and multiple-well tracer tests in the c-wells: (a) effective porosity, (b) longitudinal dispersivity, (c) average linear velocity, and possibly (d) matrix diffusion,

2. evaluate the relation between hydraulic properties estimated by porous-media techniques and fracture characteristics used in fracture-network modeling,

3. evaluate the relation between transport properties determined by single-well tests and those determined by multiple-well tests, in order to determine whether single-well tests can be used to characterize hydraulic properties,

4. evaluate spatial correlation of transport parameters and cross correlation between parameters at the scale of the c-hole complex, and

5. examine scale dependency of transport parameters at the c-hole complex.

3.5.2 Rationale for activity selection

Predicting rates of radionuclide movement requires knowledge of hydraulic properties that affect advective transport, hydrodynamic dispersion, and rates of reaction between radionuclides, the rock matrix and other dissolved chemicals. Advective transport, movement of nonreactive solutes by the bulk motion of flowing ground water, is usually characterized by the average linear velocity of the water. The four previously described activities are designed to improve knowledge of the distribution of Darcian flux or specific discharge. Average linear velocity is the ratio of specific discharge to effective porosity. In porous media, effective porosity can usually be treated as a constant without directional properties. The nature of effective porosity in fractured rock is not well understood. While the average linear velocity is described by the average rate of movement for nonreactive solutes, deviation from the average rate occurs on a coarser scale commensurate with fracture systems. Such deviation from the average velocity of fracture flow is hydrodynamic dispersion. The amount of dispersion is related to the average linear velocity and small-scale variations in hydraulic conductivity. Hydrodynamic dispersion typically is scale dependent but in many materials can be described at large distances by the product of a dispersivity coefficient and average linear velocity. In flow systems where hydraulic conductivity is isotropic, dispersivity is a second-rank tensor, characterized by components parallel and perpendicular to the direction of flow. Extension to anisotropic fractured systems results in a second-rank dispersivity tensor related not only to the principal axes of the permeability tensor, but also to the hydraulic gradient. The tensor can be modeled with the fracture system geometry as independent variables.

Well tests described as part of this activity are designed to provide field data for evaluating various models of advective transport and hydrodynamic dispersion, and to estimate appropriate hydraulic properties. If porous-media models can be used successfully, the appropriate aquifer characteristics are effective porosity and dispersivity. If dual-porosity models can be used successfully, the appropriate hydraulic properties are effective porosity, dispersivity, and matrix diffusion. If fracture-network models are needed, the appropriate aquifer characteristics are statistical descriptions of fracture density, length, orientation, and aperture. Fracture-network models may generate a statistical measure of effective porosity and dispersivity for evaluation of field tests. It also may be possible to relate fracture characteristics to probability distributions of particle velocity for specified boundary conditions.

The information obtained in this activity will be used to refine the models of the ground-water flow system. Sensitivity analyses with the refined models may indicate a need to modify data collection and analyses within this activity. The data collection and the modeling are interrelated processes that influence each other. This feedback process is described in Section 1.1 and is shown on Figure 1.1-2.

3.5.3 General approach and summary of tests and analyses

Past experience with tracer tests in fractured rock demonstrates the importance of conducting several types of tracer tests at Yucca Mountain (Grove and Beetem, 1971; Claassen and Cordes, 1975; Cullen and others, 1985; Novakowski and others, 1985). Therefore single-well injection-pumpback, two-well recirculating, and multiple-well convergent tests are planned at the c-well complex. Conducting a variety of tests would ensure that solute-transport characteristics will be evaluated for a variety of flow directions relative to the principal axes of fracture permeability, different volumes of rock, and several velocity regimes.

Results of hydraulic-stress tests (Sections 3.3 and 3.4) would be used to identify representative test intervals for tracer tests, and to aid in the final design of each test. In the discussion that follows, candidate test intervals are identified for each type of test that is planned. These test intervals are selected on the basis of present knowledge and are subject to change as the understanding of the fracture network at the c-well complex becomes more complete. Pumping rate, test duration, and other details of a final test design also depend on the understanding of the fracture network and the hydraulic characteristics of the rock. Therefore the test designs given in the discussion that follows also are subject to change on the basis of results from hydraulic-stress tests.

Due to the number of overlapping well tests with conservative tracers which are currently planned, care is needed in selecting tracers. Initial tests will use the conservative, organic, anion trifluoromethyl-benzoate. Depending on the test results, it may be necessary to use different tracers in subsequent tests. Reasons for using alternate tracers include evidence that tracers believed to be conservative in fact react chemically or adsorb to rock, and inability to recover essentially all tracers used in a test. Davis and others (1980) list characteristics that are important in selecting a conservative tracer and review various potential tracers in light of their characteristics. The ideal tracer is not toxic, moves with the water, is easy to detect in small amounts, does not alter the flow system, is not present naturally in large amounts, is chemically stable, and is not filtered or adsorbed by the rock.

Laboratory investigations to develop methods for identification and characterization of conservative tracers are described in Study Plan 8.3.1.2.2.7. After those methods are developed, appropriate inorganic tracers will be selected. The method for identifying conservative tracers will require the use of core from the c-hole complex. Some core is currently available and attempts will be made to have the c-hole core qualified. If these attempts fail it may be necessary to request that an additional hole be drilled at the c-holes from which to obtain level 1 core.

The large number of tracer tests planned at the c-well complex, combined with the number of other tracer tests at Yucca Mountain probably will require that organic chemicals be considered for use. As part of the site saturated-zone hydrology study, various organic chemicals will be evaluated for use as tracers. Responsibility for the identification of suitable organic tracers has been given to researchers at the University of Nevada Las Vegas, working within the USGS Quality Assurance Program. The UNLV study will include: (1) an analytical chemical evaluation of candidate tracers by evaluating detection limits with respect to the Yucca Mountain environment; (2) batch tests on candidate tracers to evaluate their suitability using a mass balance approach with considerations for time dependence; (3) column tests on candidate tracers with both crushed and intact core material with qualitative evaluations relative to bromide; and (4) tests for degradation of tracer compounds due to microbial action and chemical reactions under the environmental conditions anticipated at the c-well complex. Prior to using organic tracers, existing geohydrologic data will be evaluated to determine the potential for interference with studies of carbon-isotope ratios in water and gas. If interference is likely, water and gas sampling will be concluded before organic tracers are introduced. Responsibility for the identification of suitable organic tracers has been given to researchers at the University of Nevada - Las Vegas, working within the USGS Quality Assurance Program.

Each of the test methods (injection-pumpback, two-well recirculating, and convergent) are essentially alternative methods for estimating the same hydraulic properties. Differences among the three tests include different boundary conditions, velocity distributions, and scales. All three will be conducted because it is not possible to know *a priori* which method will provide the most applicable results.

In order to evaluate the precision of the tracer tests at the c-well complex, selected tests will be repeated. Adherence to guidelines of the USGS Quality Management Procedures should assure that testing equipment will meet various quality criteria, as well as assuring that testing procedures and data will be adequately documented. However, test replication is needed to evaluate the quality of overall test results. Replication is particularly important as a means of evaluating the importance of experimental errors introduced from unanticipated sources. Experience has shown that unanticipated sources of error typically are much more important in tracer tests than in hydraulic-stress tests. If results of early test replication shows that the magnitude of experimental errors is large, equipment design and testing procedures will be reevaluated and improved before proceeding with additional tests.

Other methods include single-well drift-pumpback tests, natural-gradient tests, and statistical analysis of hydraulic conductivity. Single-well drift-pumpback tests are not preferred because the scale of the test may not be sufficient to evaluate transport within a network of fractures; estimates of undisturbed pore-water velocity are not possible. Also, single-well drift-pumpback and natural-gradient tests require an understanding of undisturbed gradients in the vicinity of the test. The c-well complex is located within an area of very small gradients. Standard methods for measuring gradients over the very small distances between the c-wells have not proven successful. A large effort within Activity 3.2 (Site potentiometric-level evaluation) is directed towards developing methods that can be used to accurately determine natural hydraulic gradients at Yucca Mountain. Until these methods have been developed and successfully tested, natural-gradient tracer tests are inappropriate.

Geostatistically based models have been proposed to estimate dispersivity from point estimates of hydraulic conductivity. Although initially derived for application to porous media, the method has been used with apparent success in fractured rock at Oracle, Arizona (Winter and others, 1984). The method depends on the existence of a well-defined semivariogram of hydraulic conductivity. If a semivariogram can be defined for the c-well complex, the model will be used to obtain estimates of scale-dependent dispersivity. Validation of the model for Yucca Mountain, however, will require that tracer tests be conducted.

Figure 3.5-1 summarizes the organization of the testing of the c-well complex with conservative tracers activity. A descriptive heading for each method appears in the shadowed boxes of the second and fourth rows. Figure 3.5-2 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site-characterization parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed boxes, respectively.

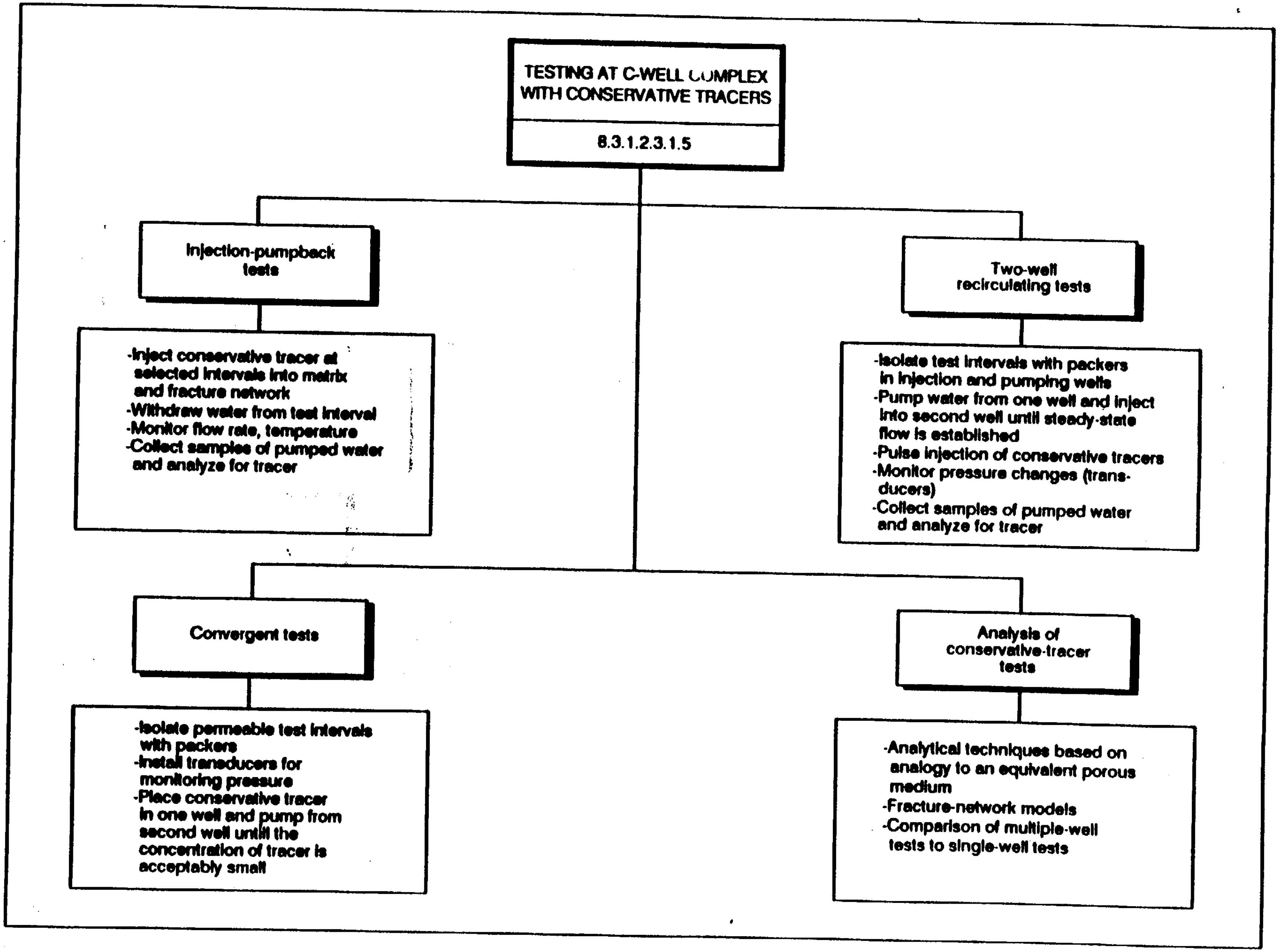

Figure 3.5-1. Logic diagram of the c-well complex conservative-tracer activity showing tests, analyses, and methods.

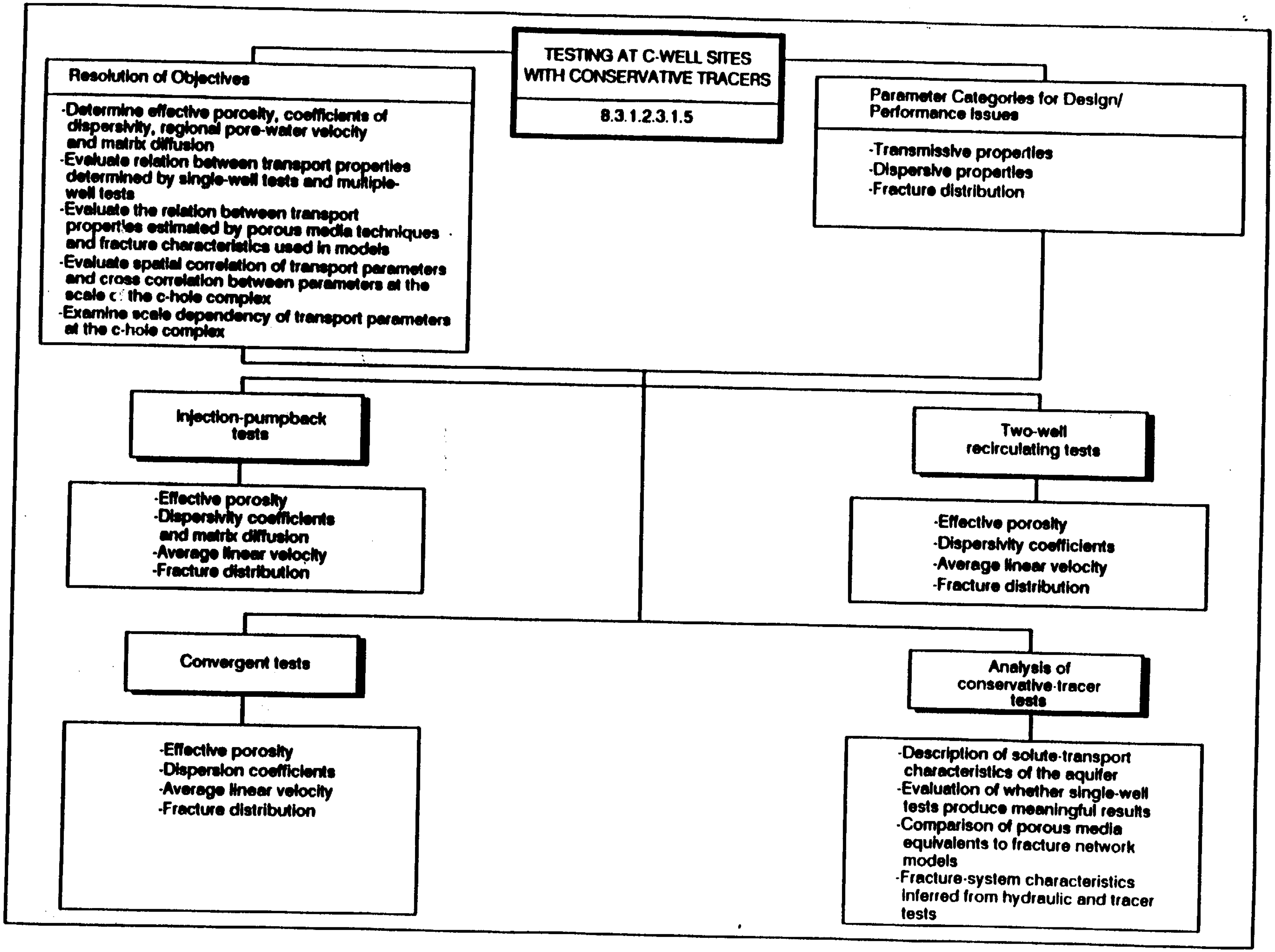

Figure 3.5-2. Logic diagram of the c-well complex conservative-tracer activity showing tests, analyses, and site-characterization parameters.

The two figures summarize the overall structure of the planned activity in terms of methods to be used and measurements to be made. The descriptions in the following sections are organized on the basis of these charts. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations between (1) the site-characterization parameters to be determined, (2) the information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

As part of each tracer test, water samples will be collected from a pumping well and analyzed in the laboratory for tracer concentration. Experience has shown that establishment of a field laboratory at the test location for rapid preliminary analysis of water samples is a valuable means of monitoring a tracer test in progress. Results of the preliminary analyses can be used to adjust sampling frequency as the test progresses. Responsibility for establishing a field laboratory and conducting preliminary water-quality analyses has been given to researchers at the University of Nevada - Las Vegas working within the USGS Quality Assurance Program. Following each test, water samples will be re-analyzed for tracer concentration. These final analyses will be done with greater accuracy and precision than will be possible in the field.

In addition to providing hydraulic data at the scale of the c-well complex, the methods for well testing and analysis developed in this activity and Activities 3.3, 3.4, and 3.6 are expected to be applicable throughout the Yucca Mountain area. These methods will be used at other wells to obtain information about the spatial variability of hydraulic parameters. These tests involve the evaluation of effective porosity, dispersivity, average linear velocity, fracture characteristics, and possibly matrix diffusion. The spatial and temporal variations of these parameters can be modeled to increase the three-dimensional understanding of the hydraulic properties. Similarly, an understanding of present conditions, as determined from the tracer tests, will be useful for modeling and predicting transport properties and potential future ground-water conditions beneath Yucca Mountain.

3.5.3.1 Injection-pumpback tests

Injection-pumpback tests will be conducted in intervals of c-wells that have large hydraulic conductivity. Depths and wells to be considered will be identified from temperature logs and tracejector surveys. Results of hydraulic tests also will be considered in selecting test intervals. Packers will be used to isolate test intervals.

Conservative tracers will be injected into the rock at selected intervals. Results of hydraulic-stress tests (Sections 3.3 and 3.4) and pretest sensitivity analysis will be used to identify reasonable periods of time for the injection phase of tests. This phase will be sufficiently long to permit tracer movement through the fractures that intercept the borehole and into the fracture network. In this manner, the influence of individual fractures on seepage velocity may be minimized.

A pump will be installed and water withdrawn from the test interval to begin the pumpback phase of the test. The rate of pumping will be measured and water temperature will be monitored. Samples of pumped water will be collected and analyzed on site for tracer concentration. Pumping will continue for at least 3 days or until the concentration of tracer is acceptably small.

3.5.3.2 Two-well recirculation tests

Two-well recirculation tests will be conducted between intervals of c-wells that have demonstrated production on borehole-flow surveys. These tests may be conducted in permeable intervals of the lower part of the Bullfrog Member. One test would use wells UE-25c #2 and UE-25c #3; the second test would use UE-25c #1 and UE-25c #3; and the third would use UE-25c #1 and UE-25c #2.

Each test will be conducted in the following manner. Packers would be used to isolate test intervals in a pumping and injecting well. Water will be pumped from one well at a predetermined rate and injected into the second well. Pumping will continue until steady-state flow is established. Pressure transducers will be used to monitor pressure changes. Conservative tracers will be injected as a short pulse into the rock. The steady-state recirculating flow pattern would be maintained following tracer injection and samples of pumped water will be collected and analyzed for tracer concentration. Sampling will continue until virtually all tracer has time to move through the rock.

3.5.3.3 Multiple-well convergent tests

Convergent tracer tests will be conducted in intervals of c-wells that have large hydraulic conductivity. Each test will be conducted by installing packers in wells to isolate permeable intervals. Several tests may be done using various combinations of pumping and injection wells to evaluate directional characteristics of aquifer properties. Ideally, one or more convergent tests would be conducted during each cross-hole hydraulic test (described in Section 3.4).

Pressure transducers will be installed in the c-wells. Water will be pumped at a predetermined rate from the isolated interval in one well until steady-state flow 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 tracer-concentration monitoring will continue for several days or until measurements indicate that the concentration of tracer is acceptably small (i.e., the amount of recoverable tracer will be negligible with further pumping).

3.5.3.4 Analyses of conservative-tracer tests

A detailed description of techniques that may be used to analyze conservative-tracer tests cannot be given until the tests have been completed and test results have been reviewed; however, the general strategy for analysis can be described here. Interpretation of each category of test will follow a similar strategy. Because most of the techniques listed below are numerical, each category of test can be interpreted by modifying boundary conditions within the numerical models.

Because we will be using packed zones during the tracer tests, we assume that borehole storage and transport effects will be minimal. The significance of dispersion within the discharge pipe relative to dispersion occurring in the formation will be addressed using analytical techniques to determine the advective dispersion on the basis of the Hogan-Poiseuille velocity distribution in the discharge pipe.

Interpretation of test results will begin with appropriately simple assumptions describing the solute-transport characteristics of fractured rock and proceed to more complex descriptions. Complex descriptions would be adopted after interpretive techniques based on simple descriptions have been shown to be inadequate. Information obtained during the analysis of hydraulic-stress tests (Sections 3.3 and 3.4) will be used to guide the analysis of planned conservative-tracer tests.

Techniques based on analogy to an equivalent porous medium will be used for initial interpretation of tracer-test results. Analytical methods, such as those of Grove and Beetem (1971), may be used if the flow system can be represented as a homogeneous medium. Numerical models may be useful if the flow system can be represented as a heterogeneous porous medium. If results of hydraulic tests indicate that depth-integrated solution techniques are appropriate, two-dimensional numerical models may be used. Otherwise three-dimensional numerical transport models may be adapted for use at the c-well complex. Dual-porosity models may be used if test data show evidence of transport in both fractures and matrix.

Initial porous-media interpretation of tracer-test results may be done using a constant dispersion coefficient or scale-dependent dispersion similar to that of Winter and others (1984). If initial interpretation indicates non-Fickian transport behavior, analysis of dispersion may be conducted within a stochastic framework similar to one used by Smith and Schwartz (1980) to investigate transport in a linear field.

Analysis of hydraulic-stress tests (Sections 3.3 and 3.4) may indicate that the solute transport in fractured rock at the c-well complex might be treated as a composite porous medium. If appropriate, analysis of tracer-test results will be done within the hydraulic framework of a composite porous medium. Few analytical methods are available for interpreting tracer-test results in a composite porous medium but numerical models for a porous medium could be adapted for use at the c-well complex.

The fracture-network model developed by Lawrence Berkeley Laboratory (8.3.1.2.3.3.2) may be applied to interpret results of tracer tests at the c-well complex. Network modeling described in Section 3.4 (Multiple-well interference tests) may result in a set of fracture networks that simulate hydraulic-test results. This set of networks would be used in attempts to simulate tracer-test results. The subset of networks that successfully simulates both hydraulic and tracer tests would be considered representative of the fracture system at the c-well location. Special attention would be given to comparing effective porosity and the tensorial nature of hydrodynamic dispersion.

Because they sample a larger volume and are less influenced by nearby alteration of the aquifer during drilling, multiple well tests are generally considered to be more reliable than single well tests. However, in many situations single well tests provide meaningful results. Results of multiple-well tests will be compared to results of single-well tests. Possible reasons for differing results will be identified. The comparisons will be used to decide if single-well tests can be made elsewhere beneath Yucca Mountain and produce meaningful results, or if additional drilling of other multiple-well complexes is needed.

Tracer-test results will be used indirectly to estimate average linear velocity at the c-well complex. Direct estimates of linear velocity in the vicinity of well bores reflect wellbore conditions and probably are not representative of average linear velocities at the scale of the c-well complex. Results of tracer tests will be used to estimate effective porosity which, in combination with a knowledge of hydraulic gradients and hydraulic conductivity obtained in other activities, will be used to calculate average linear velocity.

Matrix diffusion will be addressed in the analysis of the tracer tests based on information gained from experiments using polystyrene microspheres. These experiments will be performed at the c-hole complex and are described in detail in Study Plan 8.3.1.2.3.1.7., Study Plan for Reactive Tracer Experiments in the C-Wells.

Most of the techniques listed above are numerical methods requiring the use of inverse techniques for certain parameters. Iterative inversion techniques, such as conjugate gradient, maximum likelihood, or simulated annealing will be used to estimate unknown parameters. We hope to narrow the range of parameter values that will lead to a match of observed data by using all of the available information from the hydraulic testing, our continuously refined conceptual model, and iteratively applying various numerical techniques.

3.5.3.5 Methods summary

The parameters to be determined by the tests described above are summarized in Table 3.5-1. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be used if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, only the most common methods are included in the table. The selected methods in Table 3.5-1 were chosen primarily on the basis of accuracy, precision, duration of methods, expected range, and lack of interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site parameter. The expected ranges of the site parameter have been bracketed by previous data collection and computer modeling and are shown in Table 3.5-1.

3.5.4 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires documentation of technical procedures for all technical activities that require quality assurance.

Table 3.5-2 provides a tabulation of technical procedures applicable to this activity. Procedures that are not identified with an effective date will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started; these procedures are also identified with a "TBD" (To Be Determined) technical procedure number. Approved procedures are identified with a USGS procedure number and an effective date. Some of the listed technical procedures are primarily outside the objectives of the subject activity (Testing at the c-well complex with conservative tracers) or study (Characterization of the Yucca Mountain site saturated-zone flow system), but are included for general information and ease of cross-referencing. Approved technical procedures not listed may be used during the activity, should that be appropriate, and listed procedures may be revised or replaced with other procedures, as needed.

All procedures listed are currently classified as "standard", as they represent modifications of methods and equipment with established records of use and reliability. Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and stepwise procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Applicable quality-assurance procedures are presented in Appendix 7.1.

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Table 3.5-1. Summary of tests and methods for the c-well complex tracer tests activity (SCP 8.3.1.2.3.1.5)

[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Single-well tests	
Single-well injection-pumpback tests (selected)	Estimates of dispersion coefficients	.01 m to 10 m
Single-well drift-pumpback tests (alternate)	"	"
Single-well injection-pumpback tests (selected)	Estimates of effective porosity	.01 to .1
Single-well drift-pumpback tests (alternate)	"	"
Single-well injection-pumpback tests (selected)	Specific storage	10^{-10} to 10^{-8} cm^{-1}
Single-well drift-pumpback tests (alternate)	"	"
Single-well injection-pumpback tests (selected)	Estimates of average linear velocity	--
Single-well drift-pumpback tests (alternate)	"	--
	Two-well recirculating tracer tests	
Two-well recirculating tracer tests (selected)	Dispersive coefficients	0.1 m to 100 m
"	Effective porosity	0.01 to 0.10
"	Specific storage	10^{-10} to 10^{-8} cm^{-1}
"	Average linear velocity	--

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Table 3.5-1. Summary of tests and methods for the c-well complex tracer tests activity (SCP 8.3.1.2.3.1.5)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Two-well convergent tracer tests--Continued	
Multiple convergent tracer tests (selected)	Dispersion coefficients	0.1 m to 10 m
"	Specific storage	10^{-10} to 10^{-8} cm^{-1}
"	Average linear velocity	--
"	Effective porosity	0.01 to 0.1
	Analysis of conservative tracer tests	
Techniques based on analogy to equivalent porous medium (selected)	Permeability, characteristics of fracture systems	--
Fracture network models (selected)	"	--
Comparison of multiple-well tests to single-well tests (selected)	"	--
Analytical techniques based on analog to equivalent porous medium (selected)	Dispersion coefficients	0 m to 100 m
Fracture network models (selected)	"	0.1 m to 100 m
Comparison of multiple-well tests to single-well tests (selected)	"	0 to 100 m
Techniques based on analogy to equivalent porous medium (selected)	Effective porosity	0.01 to 0.1

Page 3

Table 3.5-1. Summary of tests and methods for the c-well complex tracer tests activity (SCP 8.3.1.2.3.1.5)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Analysis of conservative tracer tests--Continued		
Fracture network models (selected)	Effective porosity	0.01 to 0.1
Comparison of multiple-well tests to single-well tests (selected)	"	"
Solution techniques based on analog to equivalent porous media (selected)	Specific storage	10^{-10} to 10^{-8} cm^{-1}
Fracture network models (selected)	"	"
Comparison of multiple-well tests to single well tests (selected)	"	"
Solution techniques based on analog to equivalent porous media (selected)	Average linear velocity	--
Fracture network models Single-well tests (selected)	"	--

Table 3.5-2. Technical procedures for the c-well sites with conservative tracers (SCP Activity 8.3.1.2.3.1.5)
(Dashes (--) indicate information is not available and to be determined.

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Single-well injection-pumpback tests	
HP-06	Hydrologic pumping test	01/11/82
HP-23	Collection and field analysis of saturated-zone ground-water samples	11/04/83
HP-34	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	05/15/85
TBD	Method for measuring discharge of a pumping well with an in-line flow meter	--
TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	--
TBD	Method for injecting a tracer solution in selected intervals of deep wells	--
TBD	Collection of water samples (saturated zone) in wells equipped with a multiple-packer system	--
TBD	Method for conducting injection-pumpback tests	--
	Multiple-well convergent tracer test	
HP-06	Hydrologic pumping test	01/11/82
HP-23	Collection and field analysis of saturated-zone ground-water samples	11/04/83
HP-34	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	05/15/85

Table 3.5-2. Technical procedures for the c-well sites with conservative tracers (SCP Activity 8.3.1.2.3.1.5)--Continued

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Multiple-well convergent tracer test--Continued	
TBD	Method for measuring discharge of a pumping well with an in-line flow meter	--
TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	--
TBD	Method for injecting a tracer solution in selected intervals of deep wells	--
TBD	Collection of water samples (saturated zone) in wells equipped with a multiple-packer system	--
TBD	Long-term storage of water samples	--
TBD	Method for conducting a two-well recirculating tracer test	--
	Two-well recirculating tracer tests	
HP-06	Hydrologic pumping test	01/11/82
HP-23	Collection and field analysis of saturated-zone ground-water samples	11/04/83
TBD	Method for measuring discharge of a pumping well with an in-line flow meter	--
TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	--
TBD	Method fo- injecting a tracer solution in selected intervals of deep wells	--

Table 3.5-2. Technical procedures for the c-well sites with conservative tracers (SCP Activity 8.3.1.2.3.1.5)--Continued

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Two-well recirculating tracer tests--Continued	
TBD	Collection of water samples (saturated zone) in wells equipped with a multiple-packer system	--
TBD	Long-term storage of water samples	--
TBD	Method for conducting a two-well recirculating tracer test	--
TBD	Method for conducting a convergent tracer test	--
	Analysis of conservative tracer tests	
--	No technical procedures identified	--

3.6 Well testing with conservative tracers throughout the site

3.6.1 Objectives

The objectives of this activity are to:

1. determine the following aquifer properties at several locations throughout the Yucca Mountain site: effective porosity, dispersivity, and average linear velocity,

2. evaluate vertical and horizontal spatial variability of flow parameters,

3. evaluate spatial correlation of flow and transport parameters and cross correlation between the parameters, and

4. examine scale dependency of flow and transport parameters.

3.6.2 Rationale for activity selection

While the previous three activities are designed primarily to evaluate and refine various models for ground-water flow and conservative solute transport using the c-well complex, there also is a need to describe spatial variations in hydraulic properties throughout the site. Ideally, well tests designed to estimate hydraulic properties would be conducted in a large number of wells in a variety of stratigraphic and structural settings. At Yucca Mountain, this is practical only if single-well tests give meaningful results. Hydraulic and tracer tests at the c-well complex are designed in part to evaluate single-well tests. If single-well tests are useful, conservative tracer tests will be conducted at a number of locations. Results of the tests, in conjunction with other geophysical and geological data, would be used in site synthesis and modeling (Study Plan 8.3.1.2.3.3).

Results of tests at the c-well complex may show that single-well tests are inappropriate methods for characterizing spatial variations in aquifer properties. In this event, the primary approach to meet our objectives will be changed from conducting several single-well tests to drilling additional multiple-well sites and conducting multiple-well tests. Because it will be impractical to establish as many multiple-well sites as planned single-well sites, there will be additional emphasis placed on modeling efforts (Study Plane 8.3.1.2.3.3). The objective of conducting multiple-well tests will not only include determination of aquifer properties, but will also be to further refine the conceptual model relating aquifer properties to geologic and geophysical characteristics.

The information obtained in this activity will be used to refine the models of the ground-water flow system. Sensitivity analyses with the refined models may indicate a need to modify data collection and analyses within this activity. The data collection and the modeling are interrelated processes that influence each other. This feedback process is described in Section 1.1 and is shown on Figure 1.1-2.

3.6.3 General approach and summary of tests and analyses

The method used for conservative tracer tests at Yucca Mountain will depend on the results of tests at the c-well complex (Section 3.5). If injection-pumpback tests give reliable results at the c-wells, then several wells would be selected for single-well tests. If injection-pumpback tests at the c-wells show that single-well tests cannot be used with confidence, then single-well tests would not be conducted. Instead, additional second multiple-well locations would be selected, and tests would be completed to give an indication of areal variations in hydraulic properties and transport characteristics. While single-well tests would give a better description of areal variations in aquifer properties and transport characteristics, the limited rock volume sampled and the dominance of borehole conditions may render single-well tests unreliable.

Figure 3.6-1 summarizes the organization of the well testing with conservative tracers throughout the site activity. A descriptive heading for each method appears in the shadowed boxes of the second row. Figure 3.6-2 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site-characterization parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed boxes, respectively.

The two figures summarize the overall structure of the planned activity in terms of methods to be used and measurements to be made. The descriptions in the following sections are organized on the basis of these charts. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations between (1) The site-characterization parameters to be determined, (2) the information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

The methods used in this activity will provide hydrologic information at several areas in the vicinity of Yucca Mountain. The spatial variabilities (within the scale of the well tests) of existing conditions within the repository area, and correlations to present and potential future conditions are addressed by these conservative tracer tests. These tests involve the evaluation of effective porosity, dispersivity, and average linear velocity within aquifers in the repository area. In contrast to the c-well complex tracer tests (Section 3.5), these tests will evaluate flow and transport and areal variations in aquifer properties at several locations throughout the site. The spatial and temporal variations of these parameters can be modeled to increase the three-dimensional understanding of the aquifer properties. Similarly, an understanding of present conditions, as determined from the tracer tests, will be useful for modeling and predicting potential future transport properties and ground-water conditions in the repository block.

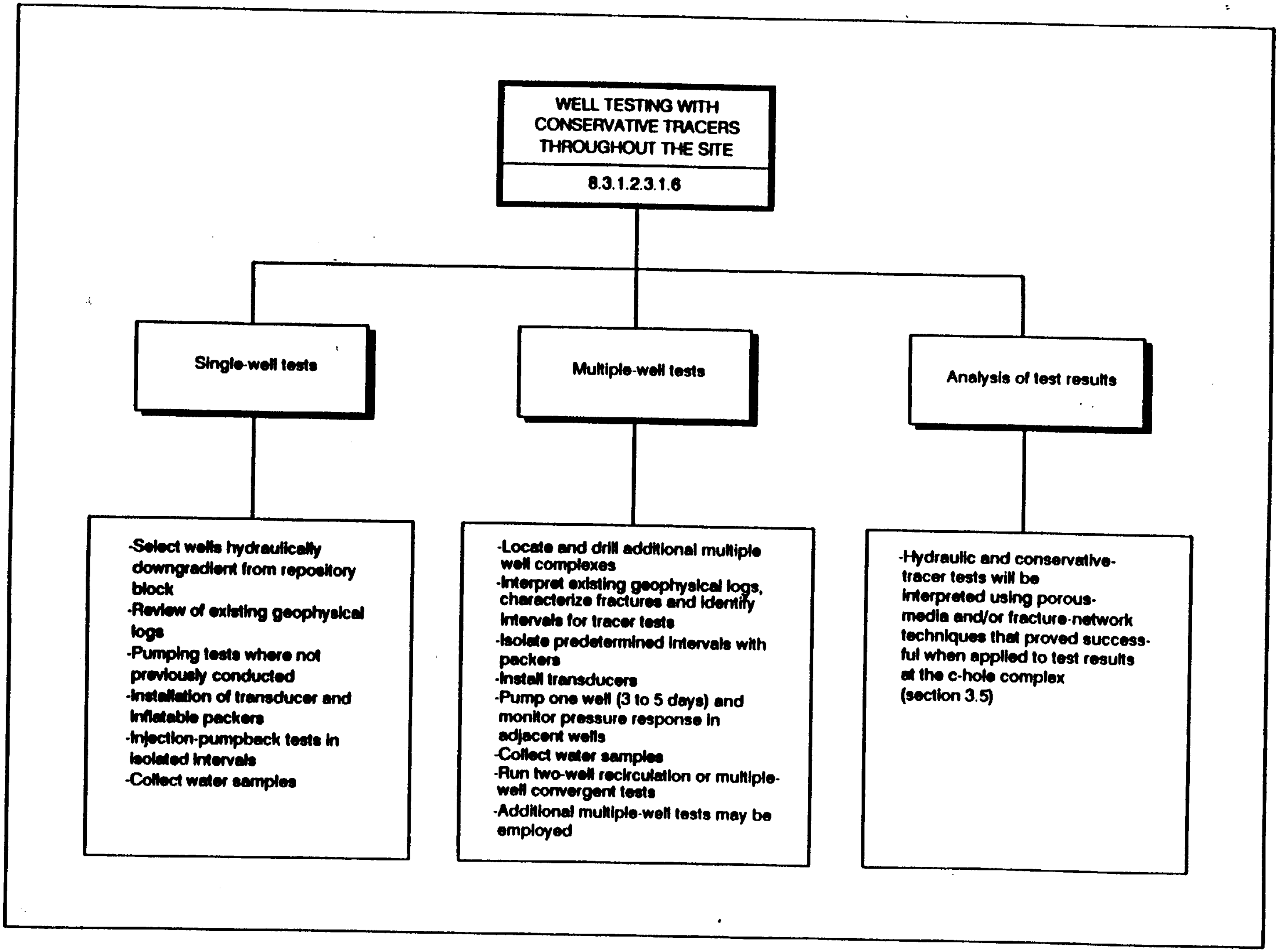

Figure 3.6-1. Logic diagram of the Yucca Mountain site conservative-tracer activity showing methods and analyses.

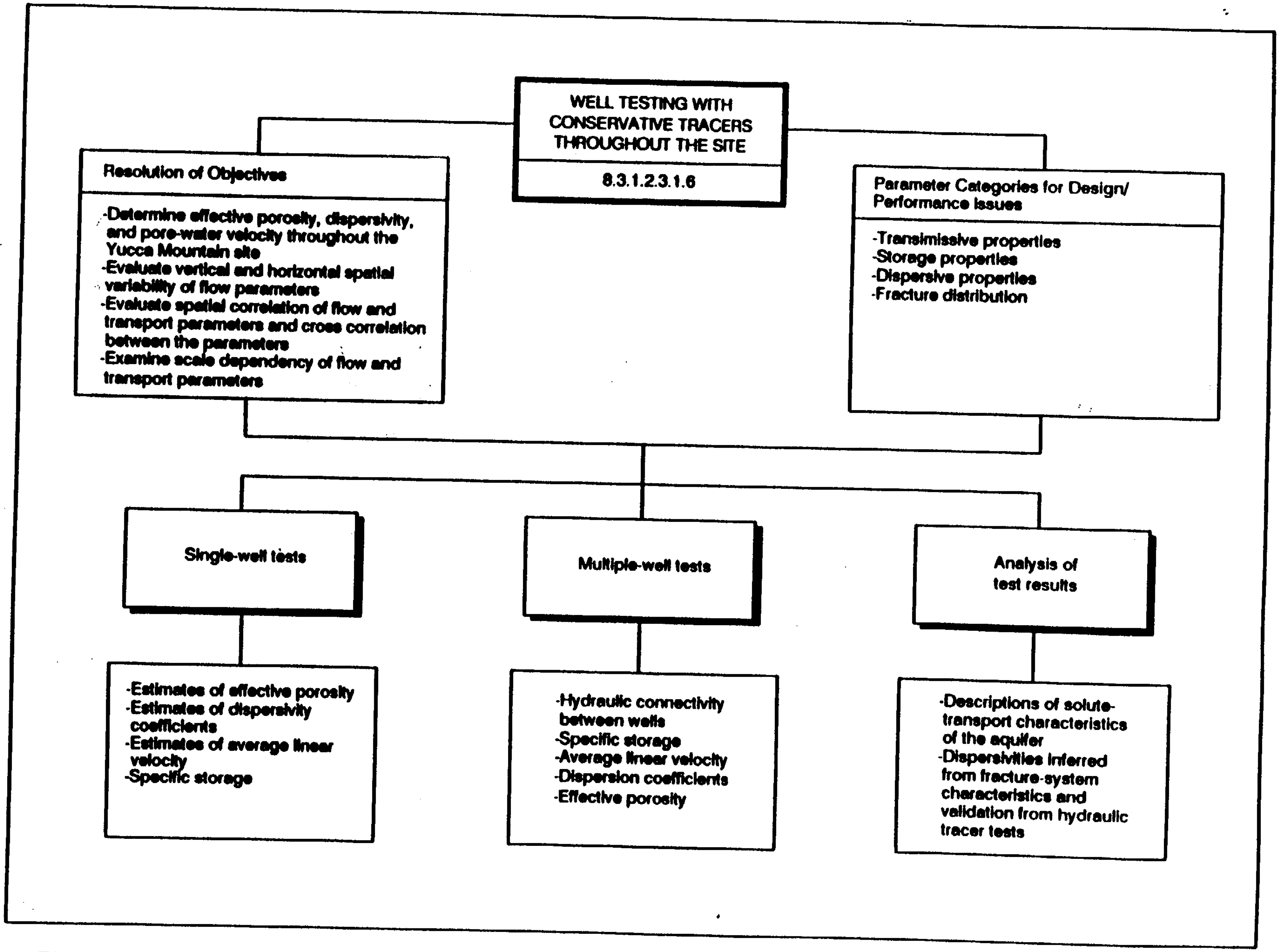

Figure 3.6-2. Logic diagram of the Yucca Mountain site conservative-tracer activity showing methods, analyses, and site-characterization parameters

3.6.3.1 Single-well tests

Approximately 5 to 10 wells will be selected for testing. The exact number and location of wells to be tested will be based on preliminary model results discussed in SP 8.3.1.2.3.3, and other available information. Existing geophysical logs for all hydrologic wells penetrating the saturated zone will be reviewed. The statistical characteristics of fractures intercepted by the boreholes (from borehole TV logs, acoustic televiewer logs, or other geophysical logs) will be used to identify several intervals in each well where tracer tests will be conducted.

Hydraulic tests would be conducted in each well if hydraulic tests have not been conducted previously. Packers would be installed to isolate intervals that would be used in tracer tests. Pressure transducers would be installed in the well to be pumped and any nearby wells that may respond to pumping. A pump would be installed, water withdrawn from the isolated test interval, and pressure response measured. Collection of pressure-response data during the early part of each test would be emphasized because the data may be useful in understanding the average distance a tracer would need to move before entering the fracture network near the well. Pumping would continue for approximately 3 to 5 days. Pressure-recovery data would be collected for a period at least equal to the pumping period.

Within each well, injection-pumpback tests would be conducted in two intervals that have large hydraulic conductivity. A conservative tracer would be injected into the formation at the selected intervals. Single well injection/pumpback tests may not yield reliable estimates of dispersivity coefficients, effective porosity, and average linear velocity, although we hope to obtain rough estimates of these parameters. Pretest sensitivity analysis would identify reasonable periods of time for the injection phase of tests. The injection phase would be sufficiently long to permit tracer movement out of the fractures that intercept the borehole into the fracture network. In this manner, the influence of individual fractures on seepage velocity would be minimized.

A pump would be installed and water withdrawn from the test interval to begin the pumpback phase of the test. The rate of pumping and temperature of the water would be monitored. Samples of pumped water would be collected and analyzed for tracer concentration. Pumping would continue for at least 3 days or until virtually all tracer is recovered. Effective porosity, longitudinal dispersivity, and average linear velocity will be determined at each well tested. Methods of analysis are described in Section 3.6.3.3 (Analyses of test results) and in Study Plan 8.3.1.2.2.7. Porous-media and/or fracture network techniques will be used to interpret the results of these injection-pumpback tests. Interpretive techniques to be used in tracer studies at the c-well complex will be compared to identify the appropriate techniques for application throughout the site.

3.6.3.2 Multiple-well tests

If results of tracer studies at the c-well complex show that single-well tests do not give reliable estimates of hydraulic properties, then additional multiple-well locations downgradient of the repository would be selected. Wells would be drilled and hydraulic and tracer tests conducted. The wells would be located as close to the repository as practical where the physical rock properties are different from those of the c-well complex. New wells would be drilled to depths of approximately 350 meters below the water table. Well construction and completion would be similar to that for the c-wells. Spacing of the wells cannot be stated exactly, but some change from the spacing of the c-wells can be expected. Geophysical logs would be run and interpreted to characterize fractures and identify appropriate testing intervals.

Hydraulic tests would be conducted to determine the nature of hydraulic connection among wells. Packers would be installed to isolate intervals that would be used in tracer tests. Pressure transducers would be installed in any wells that may respond to pumping. In each test, a pump would be installed, water would be withdrawn from the isolated test interval at a predetermined rate, and the pressure response would be monitored. Collection of pressure-response data during the early part of each test would be emphasized, because the data may be useful in understanding the average distance a tracer would need to move before entering the fracture network near the well. Pumping would continue for approximately 3 to 5 days or until steady-state flow is established. The pump would be turned off, and pressure-recovery data would be collected for a period at least equal to the pumping period.

Two-well recirculating tests or multiple-well convergent tests would be conducted in hydrogeologic intervals that have large hydraulic conductivity. Methods used to conduct the tracer tests would be similar to methods used at the c-well complex (Section 3.5). Some deviation in methods may be needed, however. Deviation would be based on the unique hydrologic characteristics of the complex location and experience gained in conducting tests at the c-well complex.

3.6.3.3 Analyses of test results

Hydraulic and conservative-tracer tests would be interpreted using porous-media and/or fracture-network techniques that proved successful when applied to test results at the c-well complex (Section 3.5.3.4). If the techniques cannot be applied successfully, modification of the techniques may be needed. In general, the strategy for test analysis would be similar to the strategy used in analyzing test results at the c-well complex. More detailed plans for analysis of test results cannot be made until analysis of test results at the c-well complex is complete.

Matrix diffusion will be addressed in the analysis of the tracer tests based on information gained from experiments using polystyrene microspheres. These experiments will be performed at the c-hole complex and are described in detail in Study Plan 8.3.1.2.3.1.7, Study Plan For Reactive Tracer Experiments in the C-Wells.

3.6.3.4 Methods summary

The parameters to be determined by the tests described above are summarized in Table 3.6-1. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be used if the primary (selected) method is impractical to measure the parameters of interest. In some cases, only the most common methods are included in the table. The selected methods in Table 3.6-1 were chosen primarily on the basis of accuracy, precision, duration of methods, expected range, and lack of interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site parameter. The expected ranges of the site parameter have been bracketed by previous data collection and computer modeling and are shown in Table 3.6-1.

3.6.4 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires documentation of technical procedures for all technical activities that require quality assurance.

Table 3.6-2 provides a tabulation of technical procedures applicable to this activity. Procedures that are not identified with an effective date will be completed and available 30 days (for standard procedures) or 60 days (for non-standard procedures) before the associated testing is started; these procedures are also identified with a "TBD" (To Be Determined) technical procedure number. Approved procedures are identified with a USGS procedure number and an effective date. Some of the listed technical procedures are primarily outside the objectives of the subject activity (Well testing with conservative tracers throughout the site) or study (Characterization of the Yucca Mountain site saturated-zone flow system), but are included for general information and ease of cross-referencing. Approved technical procedures not listed may be used during the activity, should that be appropriate, and listed procedures may be revised or replaced with other procedures, as needed.

All procedures listed are currently classified as "standard", as they represent modifications of methods and equipment with established

Table 3.6-1. Summary of tests and methods for the Yucca Mountain site conservative-tracer tests activity (SCP 8.3.1.2.3.1.6)
[Dashes (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Single-well tests	
Single-well injection-pumpback tests (selected)	Estimates of dispersion coefficients	.01 m to 10 m
Single-well drift-pumpback tests (alternate)	"	"
Single-well injection-pumpback tests (selected)	Estimates of effective porosity	0.01 to 0.10
Single-well drift-pumpback tests (alternate)	"	"
Single-well injection-pumpback tests (selected)	Specific storage	10^{-10} to 10^{-8} cm^{-1}
Single-well drift-pumpback tests (alternate)	"	"
Single-well injection-pumpback tests (selected)	Estimates of average linear velocity	--
Single-well drift-pumpback tests (alternate)	"	--
	Multiple-well tests	
Two-well recirculating tracer tests (selected)	Dispersion coefficients	0.1 m to 100 m
Two-well convergent tracer tests (selected)	"	0.1 m to 10 m
Two-well recirculating tracer tests (selected)	Effective porosity	0.01 to 0.1
Two-well convergent tracer tests (selected)	"	"

Table 3.6-1. Summary of tests and methods for the Yucca Mountain site conservative-tracer tests activity (SCP 8.3.1.2.3.1.6)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Multiple-well tests--Continued	
Two-well recirculating tracer tests (selected)	Specific storage	10^{-10} to 10^{-8} cm^{-1}
Multiple well convergent tracer tests (selected)	"	"
Two-well recirculating tracer tests (selected)	Average linear velocity	--
Multiple well convergent tracer tests (selected)	"	--
	Analysis of conservative tracer tests	
Techniques based on analogy to equivalent porous medium (selected)	Permeability and transmissivity, characteristics of fracture systems	--
Fracture network models (selected)	"	--
Comparison of multiple-well tests to single-well tests (selected)	"	--
Techniques based on analog to equivalent porous medium (selected)	Dispersion coefficients	0 m to 1000 m
Fracture network models (selected)	"	0.1 m to 10 m
Comparison of multiple-well tests to single-well tests (selected)	"	0 to 100 m

Table 3.6-1. Summary of tests and methods for the Yucca Mountain site conservative-tracer tests activity (SCP 8.3.1.2.3.1.6)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Analysis of conservative tracer tests--Continued		
Solution techniques based on analogy to equivalent porous medium (selected)	Effective porosity	0.01 to 0.1
Fracture network models (selected)	"	"
Comparison of multiple-well tests to single-well tests (selected)	"	"
Solution techniques based on analog to equivalent porous media (selected)	Specific storage	10^{-10} to 10^{-8} cm^{-1}
Fracture network models (selected)	"	"
Comparison of multiple-well tests to single well tests (selected)	"	"
Solution techniques based on analog to equivalent porous media (selected)	Average linear velocity	--
Fracture network models (selected)	"	--
Comparison of multiple-well tests to single well tests (selected)	"	--

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Table 3.6-2. Technical procedures for the well testing with conservative tracers throughout the site (SCP Activity 8.3.1.2.3.1.6)
[Dashes (--) indicate information is not available and to be determined.

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Single-well tests	
HP-06	Hydrologic pumping test	01/11/82
HP-23	Collection and field analysis of saturated-zone ground-water samples	11/04/83
HP-34	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	05/15/85
HP-60	Method for monitoring water-level changes using pressure transducers	05/04/88
HP-71	Method for monitoring water-level changes using a Campbell Scientific 21X Micrologger	09/01/87
HP-75	Method for measuring water levels in wells using reeled (2,600-ft and 2,800-ft) steel tape	06/22/87
HP-121	Installing and retrieving information from a Setra pressure transducer	--
TBD	Method for measuring discharge of a pumping well with an in-line flow meter	--
TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	--
TBD	Calibration and use of a pressure transducer in a well with a multiple-packer system	--
TBD	Calibration and use of a thermister to monitor water temperature	--
TBD	Method for conducting a large-scale pumping test	--
TBD	Method for injecting a tracer solution in selected intervals of deep wells	--

Table 3.6-2. Technical procedures for the well testing with conservative tracers throughout the site (SCP Activity 8.3.1.2.3.1.6)--Continued

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Single-well tests--Continued	
TBD	Collection of water samples (saturated zone) in wells equipped with a multiple-packer system	--
TBD	Long-term storage of water samples	--
TBD	Method for conducting injection-pumpback tests	--
	Multiple-well tests	
HP-23	Collection and field analysis of saturated-zone ground-water samples	11/04/83
HP-34	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container	05/15/85
HP-60	Method for monitoring water-level changes using pressure transducers	05/04/88
HP-75	Method for measuring water levels in wells using reeled (2,600-ft and 2,800-ft) steel tape	06/22/87
TBD	Method for measuring discharge of a pumping well with an in-line flow meter	--
TBD	Method for measuring discharge of a pumping well with an end-line orifice plate	--
TBD	Calibration and use of a pressure transducer in a well with a multiple-packer system	--
TBD	Calibration and use of a thermister to monitor water temperature	--

Table 3.6-2. Technical procedures for the well testing with conservative tracers throughout the site (SCP Activity 8.3.1.2.3.1.6)--Continued

Technical procedure number (NWM-USGS-)	Technical procedure	Technical (NWM-USGS-)
	Multiple-well tests--Continued	
TBD	Method for conducting a cross-hole hydraulic test	--
TBD	Method for injecting a tracer solution in selected intervals of deep wells	--
TBD	Collection of water samples (saturated zone) in wells equipped with a multiple-packer system	--
TBD	Long-term storage of water samples	--
TBD	Method for conducting a two-well recirculating tracer test	--
TBD	Method for conducting a convergent tracer test	--

records of use and reliability. Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and stepwise procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Applicable quality-assurance procedures are presented in Appendix 7.1.

4 APPLICATION OF STUDY RESULTS

4.1 Application of results to resolution of design and performance issues

The results of this study will be used in the resolution of YMP performance and design issues concerned with saturated-zone flow regimes at Yucca Mountain and vicinity. The principal applications will be in assessments of ground-water travel time (Issue 1.6), overall system performance (Issue 1.1), configuration of underground facilities (Issue 1.11), characteristics and configurations of shaft and borehole seals (Issue 1.12), and adequacy of repository construction, operation, closure, and decommissioning technologies (Issue 4.4). Secondary uses of the information will occur in protection of special sources of ground water (Issue 1.3), favorable and potentially adverse conditions (Issue 1.8) and higher-level findings postclosure system technical guidelines (Issue 1.9).

The application of site information from this study to design- and performance-parameter needs required for the resolution of design and performance issues is addressed in Section 1.3. Sections 2 and 3 use logic diagrams and tables to summarize specific relation between tests and analyses methodologies and site-characterization parameters determined from this study. Section 7.2 provides additional parameter relations.

4.2 Application of results to support other site-characterization investigations and studies

Data collected in this study will be employed in other studies in Investigation 8.3.1.2.3 (Description of the saturated-zone hydrologic system at the site), as well as studies in the following investigations:

- 8.3.1.2.1 Studies to provide a description of the regional hydrologic system,
- 8.3.1.3.1 Studies to provide the information on water chemistry within the potential emplacement horizon and along potential flow paths,
- 8.3.1.3.7 Studies to provide the information required on radionuclide retardation by all processes along flow paths to the accessible environment,
- 8.3.1.4.2 Geologic framework of the Yucca Mountain site,
- 8.3.1.4.3 Development of three-dimensional models of rock characteristics at the repository site, and
- 8.3.1.8.3 Studies to provide information required on changes in unsaturated- and saturated-zone hydrology due to tectonic events.

The site saturated-zone hydrologic system investigation (8.3.1.2.3) is directed at solving problems associated with the fundamentals of saturated flow and transport beneath Yucca Mountain. The three studies that have been developed to solve this problem are the (1) Characterization of the site saturated-zone ground-water flow system (8.3.1.2.3.1), (2) Characterization of the saturated-zone hydrochemistry (8.3.1.2.3.2), and (3) Saturated-zone hydrologic system synthesis and modeling (8.3.1.2.3.3). These three studies are closely interrelated and will provide information to one another.

These studies, especially the modeling and synthesis, will provide data for performance assessment (Section 8.3.5 of the Site Characterization Plan). Within performance assessment, a decision will have to be made as to whether the data and the model are sufficient to adequately address performance assessment issues. If performance assessment defines needs for additional data, then another phase of data collection may result. This study plan represents possibly only the first phase of data collection.

The activities within this study are closely interrelated and will provide information to one another. For example, information determined during Site Potentiometric Level Evaluation pointed to the need for the Solitario Canyon Fault study. An even stronger relationship exists between the fifth and sixth activities, testing of the c-well complex with conservative tracers and well testing with conservation tracers throughout the site. Tests that prove feasible in the fifth activity will be used in the sixth activity. There also is a very strong link between the fifth and sixth activities in this study plan and two activities that are part of the

LANL study plan (see Section 1.1). These two activities will use reactive tracers (much more like radionuclides) at the c-well complex and throughout the site.

The site saturated-zone flow-system study interfaces with several other investigations to provide an understanding of the hydrology, chemistry, stratigraphy, and structure of the saturated zone beneath Yucca Mountain.

Results from the site saturated-zone flow study will be applicable to studies providing a description of the regional hydrologic system (8.3.1.2.1). Within Study 8.3.1.2.1.3 (Characterization of the regional ground-water flow system) the spatial distribution of the hydraulic properties of the rock units in the saturated zone and the areal distribution of flux will be determined. Information from the Solitario Canyon borehole study (8.3.1.2.3.1.1) and the Site-potentiometric level evaluation (8.3.1.2.3.1.2) at the site will be applicable to characterizing regional ground-water flow. Site data on water levels, hydraulic gradients, hydraulic properties, and hydrochemical samples (see 8.3.1.2.3.2 for chemistry) will provide useful input for regional studies. Similarly, water samples from the site saturated-zone flow-system study will be used for water-chemistry investigations and ground-water chemistry modeling (8.3.1.3.1). Investigation 8.3.1.3.1 addresses water chemistry within the potential emplacement horizon and along potential flow paths to the accessible environment. Investigation 8.3.1.3.1 will use ground-water chemistry data already available and to be obtained by activities in this study plan and 8.3.1.2.3.2 (Characterization of the saturated-zone hydrochemistry).

Conservative-tracer tests and the description of flow paths, fluxes, permeabilities, effective porosities, and dispersivities determined by this study will be useful in Investigation 8.3.1.3.7 (Radionuclide retardation by all processes along flow paths to the accessible environment). In particular, 8.3.1.3.7.1.1 (Analysis of physical/chemical processes affecting transport) needs data from the c-well complex tracer tests to provide input for determining how the physical processes of dispersion and advection will affect radionuclide transport. Geophysical data and data on preferential flow paths, structural controls on liquid flow, and fracture characteristics of rock units will be valuable in assessing the stratigraphy and structure necessary to locate the underground facility (8.3.1.4.2) and the potential effects of tectonic activity on hydrologic characteristics (8.3.1.8.3). In Investigation 8.3.1.4.2, Study 8.3.1.4.2.1 (Characterization of the vertical and lateral distribution of stratigraphic units within the site area) is the pertinent study. Activity 8.3.1.4.2.1.1 (Surface and subsurface stratigraphic studies of the host rock and surrounding units) will use data, pending on the integration of the drilling and geophysical activities (8.3.1.4.1), from the saturated-zone drillholes. Several drillholes may be continuously cored in the vicinity of the site to better explain inferred geologic and geophysical anomalies and to help determine the lithologic variability in the Paintbrush Tuff, tuffaceous beds of the Calico Hills, and Crater Flat Tuff. Activity 8.3.1.4.2.1.3 (Borehole geophysical surveys) will obtain a suite of commercially available geophysical logs (as described in 3.1 and 3.2 of this study plan) in saturated-zone boreholes drilled in the vicinity of Yucca Mountain.

In Investigation 8.3.1.8.3, Study 8.3.1.8.3.2 (Analysis of the effects of tectonic processes and events on changes in water-table elevation) will receive input from this study to assess the probability of tectonic events resulting in significant changes in elevation of the water table or potentiometric surface, changes in the hydraulic gradient, or the creation of perched aquifers in the controlled area.

Finally, geohydrologic, geophysical data, fracture data, and data from drill cuttings and core will be integrated into the development of three-dimensional models of hydrologic and physical properties at Yucca Mountain (see 8.3.1.2.3.3, 8.3.1.4.2.3, 8.3.1.4.3.1, and 8.3.1.4.3.2).

5 SCHEDULES AND MILESTONES

5.1 Schedules

The proposed schedules presented in Figures 5.1-1 and 5.1-2 summarize the logic network and reports for the six activities of the site saturated-zone flow system. These figures represent a summary of the schedule information which includes the sequencing, interrelations, and relative durations of the activities described in this study. In particular, Figures 5.1-1 presents the summary network for the Solitario Canyon and potentiometric-level activities, and shows the integrated drilling schedule for comparison. Figure 5.1-2 presents the summary network for the hydraulic and conservative tracer tests. Specific durations, and start and finish dates for the activities are being developed as part of ongoing planning efforts. The development of the schedule for the present study has taken into account how the study will be affected by contributions of data or interferences from other studies, and also how the present study will contribute to, or interfere with, other studies.

The testing of the saturated zone for flow-system as described in this study plan will be dependent on the drilling schedules of the water-table holes. Accurate characterization of the site saturated-zone flow system will require several years of sampling and monitoring. Because of the relatively long period of time needed, the planned activities provide little time for delay.

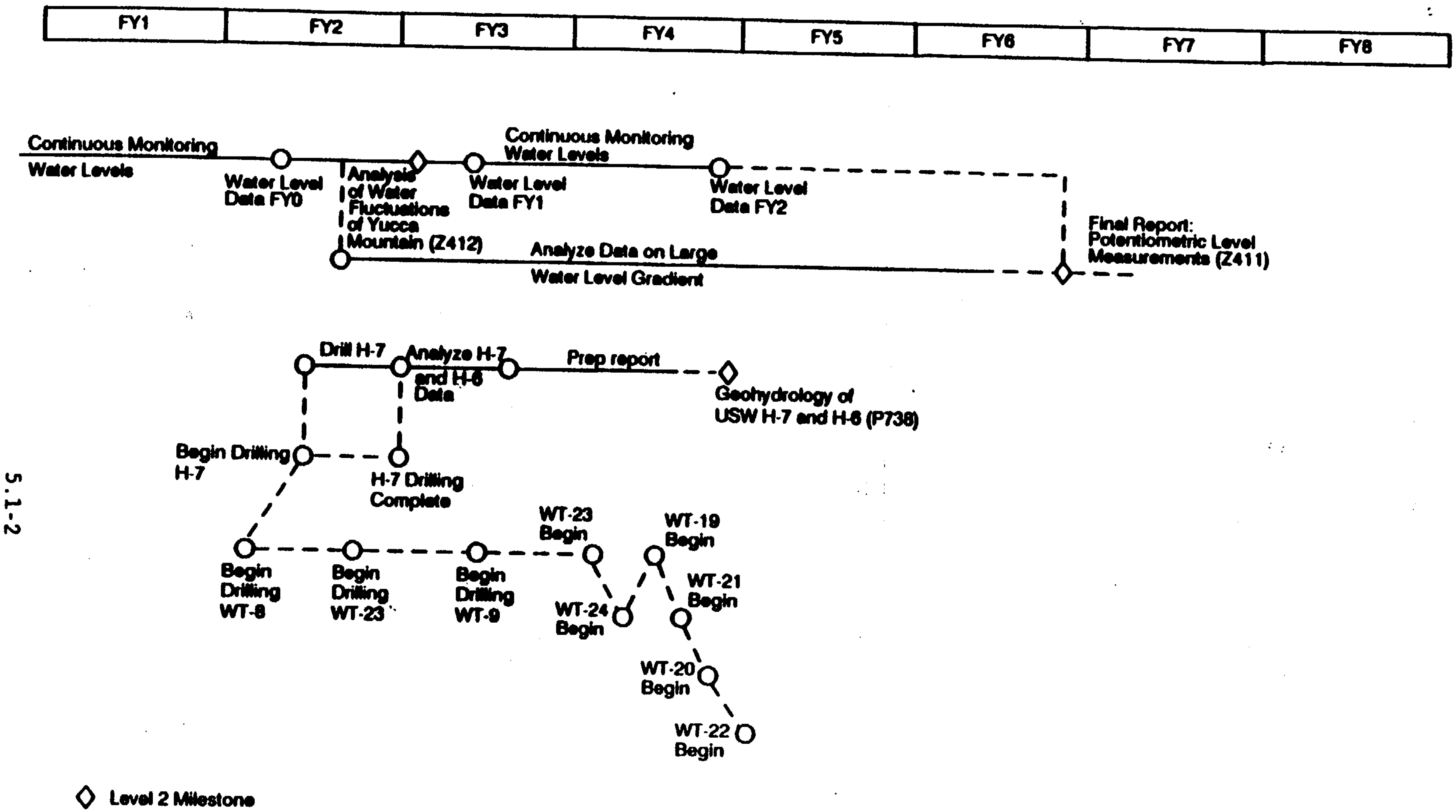

Figure 5.1-1. Summary network for Solitario Canyon and potentiometric-level activities showing integrated drilling schedule.

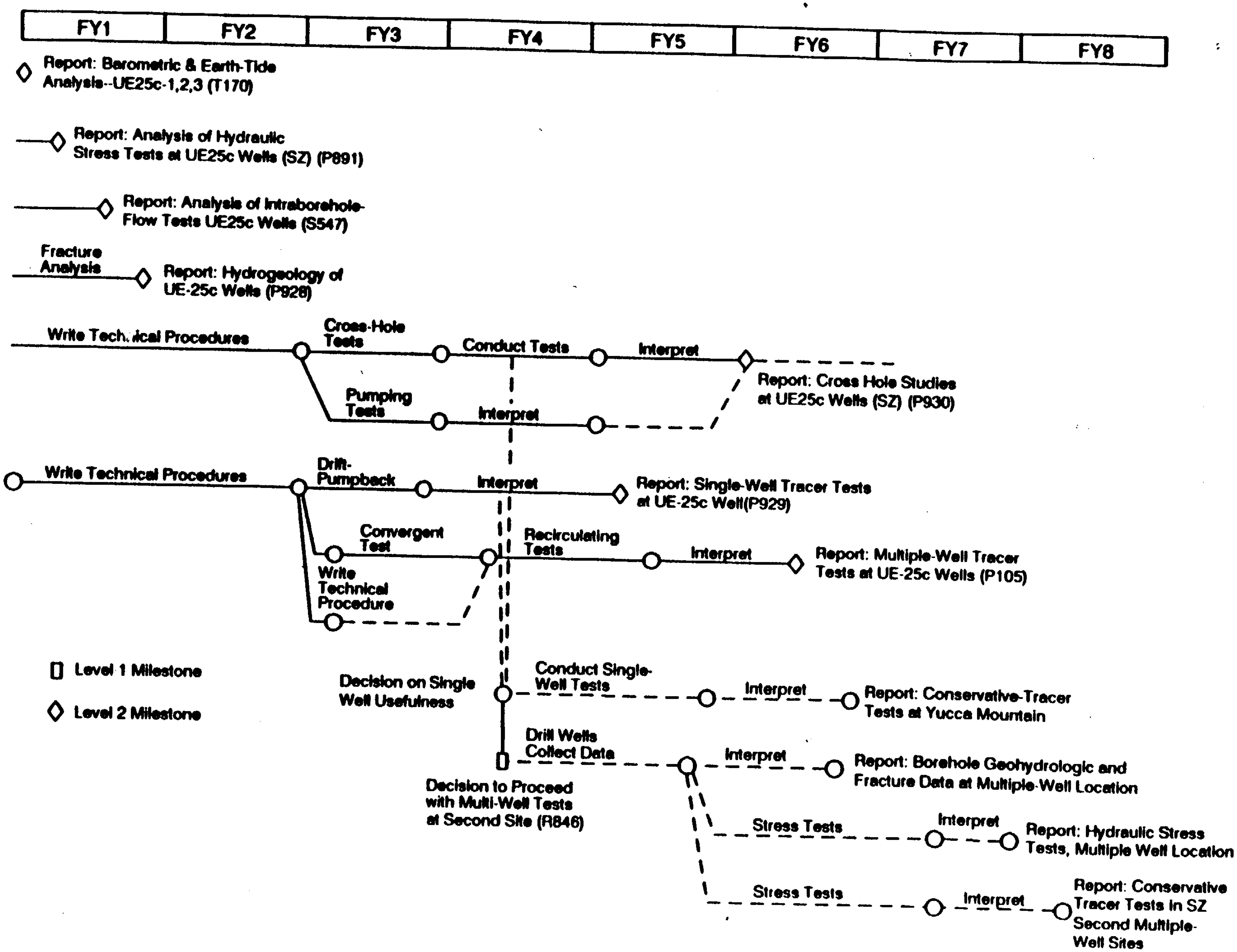

Figure 5.1-2. Summary network for hydraulic and conservative tracer tests

5.2 Milestones

The level, number, and title of milestones associated with the six activities of the characterization of the site-saturated zone ground-water flow system study are summarized in Table 5.2-1.

The information presented in Table 5.2-1 represents major events or important summary milestones associated with the activities presented in this study plan. Specific dates for the milestones are not included in the tables, as project schedules have been revised from those originally stated in Section 8.5 of the SCP, and are subject to further change due to ongoing planning efforts.

Table 5.2-1. Milestone list for work-breakdown structure number-1.2.3.3.1.3.1 (SCP 8.3.1.2.3.1)

[Milestone dates are unavailable at this time.]

Milestone number	Milestone	Milestone level
Solitario Canyon fault study in the saturated zone: 8.3.1.2.3.1.1		
P738	Report: Geohydrology of USW H-6 & H-7	2
Site potentiometric-level evaluation: 8.3.1.2.3.1.2		
Z411	Project Issue Report: Potentiometric surface of Yucca Mountain	2
Z412	Issue Report: Analysis of water fluctuations of Yucca Mtn.	2
Analysis of single- and multiple-well hydraulic-stress tests: 8.3.1.2.3.1.3		
P928	Issue Report: Hydrogeology of UE25c wells	2
P891	Issue Report: Analysis of hydrologic stress at UE25c wells	2
S547	Issue Report: Analysis of intraborehole-flow tersts - test wells UE25c1, c2, c3	2
T170	Report: Preliminary estimates of aquifer characteristics from water level fluctuations induced by earth tides and barometric fluctuations	2
Multiple-well interference testing: 8.3.1.2.3.1.4		
P930	Report: Cross hole studies at UE25c wells (SZ)	2
P105	Issue Report: Multiple-well tracer tests in SZ at UE25c wells	2
P929	Issue Report: Single-well tracer tests in SZ at UE25c wells	2
Well testing with conservative tracers throughout the site: 8.3.1.2.3.1.6		
R846	Decision to proceed with multiple-well tracer tests at second site	1

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7 APPENDICES

7.1 Quality-assurance requirements

7.1.1 Quality-assurance requirements matrix

Quality-assurance requirements

Determination of the quality status for the activities of this study will be made separately, according to AP-6.17Q, "Determination of the Importance of Items and Activities", which implements NUREG-1318, "Technical Position on Items and Activities in the High-Level Waste Geologic Repository Program Subject to Quality Assurance Requirements". The results of that determination will be contained in the Q-List, Quality Activities List and Non-Selection Record, which will be controlled documents.

QA grading packages for the activities of this study plan will be prepared separately, according to AP-5.28Q, "Quality Assurance Grading". The resultant Quality Assurance Grading Report will be issued as a controlled document.

Applicable NQA-1 criteria for Study 8.3.1.2.3.1 and how they will be satisfied

NQA-1 Criteria #	Documents addressing these requirements
1. Organization and interfaces	The organization of the OCRWM program is described in the Mission Plan (DOE/RW-005, June 1985) and further described in Section 8.6 of the SCP. Organization of the USGS-YMP is described in the following: QMP-1.01 (Organization Procedure)
2. Quality-assurance program	The Quality-Assurance Programs for the OCRWM are described in YMP-QA Plan-88-9, and OGR/83, for the Project Office and HQ, respectively. The USGS QA Program is described in the following: QMP-2.01 (Management Assessment of the YMP-USGS Quality-Assurance Program) QMP-2.02 (Personnel Qualification and Training Program)

	QMP-2.05 (Qualification of Audit and Surveillance Personnel)
	QMP-2.06 (Control of Readiness Review)
	QMP-2.07 (Development and Conduct of Training)
	Each of these QA programs contains Quality Implementing Procedures further defining the program requirements. An overall description of the QA Program for site characterization activities is described in Section 8.6 of the SCP.
3. Scientific investigation control and design	This study is a scientific investigation. The following QA implementing procedures apply:
	QMP-3.02 (USGS QA Levels Assignment [QALA])
	QMP-3.03 (Scientific and Engineering Software)
	QMP-3.04 (Technical Review of YMP-USGS Publications)
	QMP-3.05 (Work Request for NTS Contractor Services [Criteria Letter])
	QMP-3.06 (Scientific Investigation Plan)
	QMP-3.07 (Technical Review Procedure)
	QMP-3.09 (Preparation of Draft Study Plans)
	QMP-3.10 (Close-out Verification for Scientific Investigations)
	QMP-3.11 (Peer Review)
4. Administrative operations and procurement	QMP-4.01 (Procurement Document Control)
	QMP-4.02 (Acquisition of Internal Services)
5. Instructions, procedures, plans, and drawings	The activities in this study are performed according to the technical procedures listed in Section 3 of this study plan, and the QA administrative procedures referenced in this table for criterion 3.

	QMP-5.01 (Preparation of Technical Procedures)
	QMP-5.02 (Preparation and Control of Drawings and Sketches)
	QMP-5.03 (Development and Maintenance of Management Procedures)
	QMP-5.04 (Preparation and Control of the USGS QA Program Plan)
6. Document control	QMP-6.01 (Document Control);
7. Control of purchased items and services	QMP-7.01 (Supplier Evaluation, Selection and Control)
8. Identification and control of items, samples, and data	QMP-8.01 (Identification and Control of Samples)
	QMP-8.03 (Control of Data)
9. Control of processes	Not applicable
10. Inspection	Not applicable
11. Test control	Not applicable
12. Control of measuring and test equipment	QMP-12.01 (Instrument Calibration)
13. Handling, shipping, and storage	QMP-13.01 (Handling, Storage, and Shipping of Instruments)
14. Inspection, test, and operating status	Not applicable
15. Control of nonconforming items	QMP-15.01 (Control of Nonconforming Items)
16. Corrective action	QMP-16.01 (Control of Corrective Action Reports)
	QMP-16.02 (Control of Stop-Work Orders)
	QMP-16-03 (Trend Analysis)

17. Records management	QMP-17.01 (YMP-USGS Records Management)
	QMP-17.02 (Acceptance of Data Not Developed Under the YMP QA Plan)
18. Audits	QMP-18.01 (Audits)
	QMP-18.02 (Surveillance)

NQA-1 requires that tools, gages, instruments, and test equipment used for activities affecting quality shall be controlled and, at specified periods, calibrated and adjusted to maintain accuracy within the necessary limits. Since this recalibration is not always possible when instruments are permanently sealed into the rock being tested, redundancy and other methods for mitigation are being evaluated and included in experimental design. Instruments and test-equipment calibration are controlled by USGS QMP-12.01 noted above.

Sample management is controlled by USGS QMP-8.01 noted above. More specific procedures for the handling and storage of samples (to ensure sample control and traceability) are being developed for use by the YMP Sample Management Facility and by the USGS in its technical procedures.

7.2 Relations between the site information to be developed in this study and the design and performance information needs specified in the SCP

This section tabulates in Table 7.2-1 the specific technical information relations between SCP design- and performance-parameters needs and site parameters to be determined in this study. The relations were developed using model-based parameter categories (see Figure 2.1-1) that provide common terminology and organization for evaluation of site, design, and performance information relations.

All design and performance issues that obtain data from this study are noted in the table. For each issue, the site parameters (from SCP 8.3.1.2) are related to the design and performance parameters reported in the performance allocation tables (from SCP 8.3.2 - 8.3.5). At the beginning of each issue group, the performance measures addressed by the design or performance parameters for the issue are listed. Parameter categories, as noted above, are used to group the design and performance parameters with the site parameters so that comparisons of information requirement (design and performance) with information source (site study) can be made.

For each design and performance parameter noted in the table, the associated goal and confidence (current and needed) and site location are listed. For each parameter category, the associated site parameters are listed with information about the site location and the site activity providing the information.

Note - Comparison of the information relations (site parameters with design/performance parameters) must be done as sets of parameters in a given parameter category. Line-by-line comparisons from the left side of the table (design/performance parameters) with the right side of the table (site parameters) within a parameter category should <u>not</u> be made.

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.13)
Performance Measures: EPPM[a], nominal case, release scenario class E, water pathway release (Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.)					
Parameter Category: Saturated-zone transmissive properties					
n_f: average effective matrix porosity, controlled area, saturated zone (scenario class E, nominal case)[b]	Controlled area; Saturated zone	Goal: >0.1 Current: Low Needed: Medium	Transmissivity and hydraulic conductivity, fault zone and wall rocks	USW H-7; USW WT-8; USW WT-9; Solitario Canyon fault	8.3.1.2.3.1.1
Hydraulic conductivity (Rock matrix)	Controlled area; Saturated-zone units	Goal: Mean, Variance, Autocorrelation length Current: Medium Needed: High, Low, Low	Hydraulic conductivity	USW WT-22; USW WT-21; USW WT-23; USW WT-9; USW WT-8; USW WT-24; UE-25 WT #19; UE-25 WT #20; Saturated zone	8.3.1.2.3.1.2
Hydraulic conductivity (Fracture networks)	"	Goal: Mean, Variance, Autocorrelation length Current: Low Needed: High, Low, Low	Effective porosity, bulk; estimates from earth-tide analysis of water levels	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone	8.3.1.2.3.1.3
Effective porosity (Rock matrix)	"	Goal: Mean, Variance, Autocorrelation length Current: Low, Low, Low Needed: Medium, Medium, Low	Transmissivity, bulk; estimates at multiple-well test locations	"	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.13)
Performance Measures: (Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.) EPPM[a], nominal case, release scenario class E, water pathway release					
		Parameter Category: Saturated-zone transmissive properties			
Effective porosity (Fracture networks)	Controlled area; Saturated-zone units	Goal: Mean, Variance, Autocorrelation length Current: Low, Low, Low Needed: Medium, Medium, Low	Fracture transmissivity (apertures), inferred from hydraulic tests, matrix properties, geophysical logs	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone; Straddle packers at different depths (to be determined)	8.3.1.2.3.1.4
			Hydraulic-conductivity tensor, equivalent porous media, multiple-well test locations	"	"
			Average linear velocity, pore water and tracers	Pumping test in C-boreholes (UE-25c #1, 2, 3); Saturated zone	8.3.1.2.3.1.5
			Effective porosity, single- and multiple-well tests	Yucca Mountain site; UE-25c#1, 2, 3; Saturated zone	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.13)
Performance Measures: EPPM[a], nominal case, release scenario class E, water pathway release (Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.)					
		Parameter Category: Saturated-zone transmissive properties			
			Average linear velocity, pore water and tracers	Yucca Mountain site, subregional test holes and intervals to be determined; Saturated zone; Hydrologic wells, to be determined	8.3.1.2.3.1.6
			Effective porosity; single- and multiple-well tests	"	"
			Hydraulic conductivity; well-test locations throughout the site; conservative tracers	"	"
			Permeability and transmissivity, characteristics of fracture systems, inferred from hydraulic packer and tracer tests	Yucca Mountain site, subregional test holes and intervals to be determined; Saturated zone; hydrologic wells, to be determined	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.13)
Performance Measures: EPPM[a], nominal case, release scenario class E, water pathway release (Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.)					
Parameter Category: Saturated-zone water potential					
d_s: average length of flow paths, through saturated zone from controlled area to accessible environment boundary (scenario class E, nominal case)[b]	Controlled area; Saturated zone	Goal: >5000 m Current: Low Needed: Medium	Hydraulic gradient	USW H-7; USW WT-8; USW WT-9; Solitario Canyon fault	8.3.1.2.3.1.1
Altitude of water table, ambient, as a function of lateral spatial location	Controlled area; Saturated-zone units	Goal: Mean, Variance Current: Medium, Medium Needed: High, Medium	Hydraulic gradients	USW WT-22; USW WT-21; USW WT-23; USW WT-9; USW WT-8; USW WT-24; UE-25 WT #19; UE-25 WT #20; Saturated zone	8.3.1.2.3.1.2
Effective thickness of saturated zone;as a function of lateral-spatial location	"	Goal: Mean Current: Low Needed: Low	Hydraulic gradients, relative	Yucca Mountain site, UE-25c #1, 2, 3; Saturated zone	8.3.1.2.3.1.3

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.13)
Performance Measures: EPPM[a], nominal case, release scenario class E, water pathway release					
Parameter Category: Saturated-zone ground-water flux					
q_s: average discharge in saturated zone under controlled area (scenario class E, nominal case)[b]	Controlled area; Saturated zone	Goal: <32 mm/yr Current: Low Needed: Medium	Flow rates, intraborehole	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone	8.3.1.2.3.1.3
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 CRR 191.16?				(SCP 8.3.5.15)
Performance Measures: Existence of special sources of ground water					
Parameter Category: Saturated-zone hydrologic conceptual/descriptive models					
Existence of aquifers within 5 km of controlled area	Valley fill; Tuff; Lower carbonate	Goal: NA, NA, NA Current: High, High, High Needed: High, High, High	Hydraulic boundaries and conduits, at scale of well tests and type of flow	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone	8.3.1.2.3.1.3

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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 CRR 191.16?			(SCP 8.3.5.15)	
Performance Measures:					
		Parameter Category: Saturated-zone hydrologic conceptual/descriptive models			
			Aquifer heterogeneity and spatial distribution	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone; Straddle packers at different depths (to be determined)	8.3.1.2.3.1.4
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?			(SCP 8.3.5.12)	
Performance Measures:	(Supporting parameters used in calculating performance parameters for ground-water travel time.) Ground-water travel time[e], Saturated zone (secondary reliance) Boundary of repository-induced changes in effective fracture porosity				
		Parameter Category: Rock-unit mineralogy/petrology and physical properties			
Density, bulk (Fault zones)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SDev Current: NA, NA Needed: Low, Low	Matrix compressibility, inferred from barometric and earth-tide analysis	Yucca Mountain site, subregional; Saturated zone	8.3.1.2.3.1.3

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.12)
Performance Measures:	(Supporting parameters used in calculating performance parameters for ground-water travel time.) Ground-water travel time[e], Saturated zone (secondary reliance) Boundary of repository-induced changes in effective fracture porosity				
		Parameter Category: Rock-unit mineralogy/petrology and physical properties			
Density, bulk (Rock matrix)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SCor, SDev Current: Medium, NA, NA Needed: Medium, Medium, Medium			
		Parameter Category: Saturated-zone transmissive properties			
Effective porosity	Controlled area; Saturated zone	Goal: >0.01 Current: Low Needed: Low	Transmissivity and hydraulic conductivity, fault zone and wall rocks	USW H-7; USW WT-8; USW WT-9; Solitario Canyon fault	8.3.1.2.3.1.1
Permeability, saturated (Fault zones)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low	Hydraulic conductivity	USW WT-22; USW WT-21; USW WT-23; USW WT-9; USW WT-8; USW WT-24; UE-25 WT #19; UE-25 WT #20; Saturated zone	8.3.1.2.3.1.2

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.12)
Performance Measures: (Supporting parameters used in calculating performance parameters for ground-water travel time.) Ground-water travel time*, Saturated zone (secondary reliance) Boundary of repository-induced changes in effective fracture porosity					
Parameter Category: Saturated-zone transmissive properties					
Permeability, saturated (Fractures)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SCor, SDev Current: Low, NA, NA Needed: Medium, Low, Medium	Effective porosity, bulk; estimates from earth-tide analysis of water levels	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone	8.3.1.2.3.1.3
Permeability, saturated (Rock mass)	"	"	Transmissivity, bulk; estimates at multiple-well test locations	"	"
Permeability, saturated (Rock matrix)	"	Goal: Mean, SDev Current: Medium, NA Needed: Medium, Low	Fracture transmissivity (apertures), inferred from hydraulic tests, matrix properties, geophysical logs	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone; Straddle packers at different depths (to be determined)	8.3.1.2.3.1.4
Porosity, effective (Fault zones)	"	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low	Hydraulic-conductivity tensor, equivalent porous media, multiple-well test locations	"	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.12)
Performance Measures: (Supporting parameters used in calculating performance parameters for ground-water travel time.) Ground-water travel time*, Saturated zone (secondary reliance) Boundary of repository-induced changes in effective fracture porosity					
Parameter Category: Saturated-zone transmissive properties					
Porosity, effective (Fractures)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SCor;SDev Current: Low, NA, NA Needed: Medium, Low, Medium	Average linear velocity, pore water and tracers	Pumping test in C-boreholes (UE-25c #1, 2, 3); Saturated zone	8.3.1.2.3.1.5
Porosity, effective (Rock Mass)	"	"	Effective porosity, single- and multiple-well tests	Yucca Mountain site; UE-25c#1, 2, 3; Saturated zone	"
Porosity, effective (Rock Matrix)	"	Goal: Mean, SDev Current: Low, NA Needed: Low, Low	Average linear velocity, pore water and tracers	Yucca Mountain site, subregional test holes and intervals to be determined; Saturated zone; Hydrologic wells, to be determined	8.3.1.2.3.1.6
Porosity, total (Fault zones)	"	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low	Effective porosity; single- and multiple-well tests	"	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.12)
Performance Measures:	(Supporting parameters used in calculating performance parameters for ground-water travel time.) Ground-water travel time*, Saturated zone (secondary reliance) Boundary of repository-induced changes in effective fracture porosity				
		Parameter Category: Saturated-zone transmissive properties			
Porosity, total (Fractures)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SCor, SDev Current: NA, NA, NA Needed: Medium, Low, Medium	Hydraulic conductivity; well-test locations throughout the site; conservative tracers	Yucca Mountain site, subregional test holes and intervals to be determined; Saturated zone; Hydrologic wells, to be determined	8.3.1.2.3.1.6
Porosity, total (Rock mass)	"	Goal: Mean, SCor, SDev Current: Low, NA, NA Needed: Medium, Low, Medium	Permeability and transmissivity, characteristics of fracture systems, inferred from hydraulic packer and tracer tests	Yucca Mountain site, subregional test holes and intervals to be determined; Saturated zone; hydrologic wells, to be determined	"
Porosity, total (Rock matrix)	"	Goal: Mean, Scor, SCor Current: Medium, NA, Medium Needed: Medium, Medium, Medium			

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.12)
Performance Measures:	Ground-water travel time*, Saturated zone (secondary reliance) (Supporting parameters used in calculating performance parameters for ground-water travel time.) Boundary of repository-induced changes in effective fracture porosity				
		Parameter Category: Saturated-zone water potential			
dh/dl (gradient)	Controlled area; Saturated zone	Goal: <0.001 Current: Low Needed: Low	Hydraulic gradient	USW H-7; USW WT-8; USW WT-9; Solitario Canyon fault	8.3.1.2.3.1.1
Distance along flow paths	"	Goal: 1000 m Current: Low Needed: Medium	Hydraulic gradients	USW WT-22; USW WT-21; USW WT-23; USW WT-9; USW WT-8; USW WT-24; UE-25 WT #19; UE-25 WT #20; Saturated zone	8.3.1.2.3.1.2
Pressure head, function of depth (Ground water)	Controlled area; Saturated zone, upper 100 m	Goal: Mean Current: Low Needed: Medium	Hydraulic gradients, relative	Yucca Mountain site, UE-25c #1, 2, 3; Saturated zone	8.3.1.2.3.1.3
Water-table altitude (Ground water)	Controlled area; Saturated zone, water table level	Goal: Mean, SDev Current: Medium;NA Needed: High, Low			

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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?				(SCP 8.3.5.12)
Performance Measures:	Ground-water travel time[e], Saturated zone (secondary reliance) (Supporting parameters used in calculating performance parameters for ground-water travel time.) Boundary of repository-induced changes in effective fracture porosity				
Parameter Category: Saturated-zone ground-water flux					
q/K_s where K_s is hydraulic conductivity of saturated-matrix zones	Controlled area; Saturated zone	Goal: <10 m/yr Current: Low Needed: Low	Flow rates, intraborehole	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone	8.3.1.2.3.1.3
Flux, flow rate (Rock mass)	Controlled area; Saturated zone, upper 100 m	Goal: Mean Current: Low Needed: Medium			
Parameter Category: Saturated-zone hydrologic conceptual/descriptive models					
Altitude of the water table	Repository area; Subsurface	Goal: -- Current: -- Needed: --	Hydraulic boundaries and conduits, at scale of well tests and type of flow	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone	8.3.1.2.3.1.3
			Aquifer heterogeneity and spatial distribution	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone; Straddle packers at different depths (to be determined)	8.3.1.2.3.1.4

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.11	Have the characteristics and configurations of the repository and repository engineered barriers been adequately established to show compliance with postclosure design criteria (10CFR 60.133) and provide information for the resolution of the issues				(SCP 8.3.2.2)
Performance Measures: Usable area: Is usable area adequate for 70,000 metric tons of uranium (MTU) waste?					
Parameter Category: Saturated-zone water potential					
Water-table elevation (Contour map of water table in primary area and extensions)	Primary area and extensions; Water table	Goal: Contours accurate to +/- 7.5 m Current: Medium Needed: Medium	Hydraulic gradient	USW H-7; USW WT-8; USW WT-9; Solitario Canyon fault	8.3.1.2.3.1.1
Water-table elevation (Contour map of water table in areas with minimum ground-water travel time)	"	Goal: Contours accurate to +/- 10 m Current: Medium Needed: High	Hydraulic gradients	USW WT-22; USW WT-21; USW WT-23; USW WT-9; USW WT-8; USW WT-24; UE-25 WT #19; UE-25 WT #20; Saturated zone	8.3.1.2.3.1.2
			Hydraulic gradients, relative	Yucca Mountain site, UE-25c #1, 2, 3; Saturated zone	8.3.1.2.3.1.3

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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				(SCP 8.3.3.2)
Performance Measures: Drainage capacity					
		Parameter Category: Saturated-zone transmissive properties			
Saturated, bulk-rock hydraulic conductivity	At base of ES-1 and in boreholes; CHn1	Goal: Saturated, bulk-rock hydraulic conductivity $k_{SAT} > 1 \times 10^{-5}$ cm/s Current: Low Needed: Low	Transmissivity and hydraulic conductivity, fault zone and wall rocks	USW H-7; USW WT-8; USW WT-9; Solitario Canyon fault	8.3.1.2.3.1.1
			Hydraulic conductivity	USW WT-22; USW WT-21; USW WT-23; USW WT-9; USW WT-8; USW WT-24; UE-25 WT #19; UE-25 WT #20; Saturated zone	8.3.1.2.3.1.2
			Effective porosity, bulk; estimates from earth-tide analysis of water levels	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone	8.3.1.2.3.1.3
			Transmissivity, bulk; estimates at multiple-well test locations	"	"

Table 7.2-1 Design and performance issues and parameters supported by results of this study

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
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				(SCP 8.3.3.2)
Performance Measures:					
Parameter Category: Saturated-zone transmissive properties					
			Fracture transmissivity (apertures), inferred from hydraulic tests, matrix properties, geophysical logs	Yucca Mountain site; UE-25c #1, 2, 3; Saturated zone; Straddle packers at different depths (to be determined)	8.3.1.2.3.1.4
			Hydraulic-conductivity tensor, equivalent porous media, multiple-well test locations	"	"
			Average linear velocity, pore water and tracers	Pumping test in C-boreholes (UE-25c #1, 2, 3); Saturated zone	8.3.1.2.3.1.5
			Effective porosity, single- and multiple-well tests	Yucca Mountain site; UE-25c#1, 2, 3; Saturated zone	"