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Study Plan for
Study 8.3.1.2.1.4

Regional Hydrologic System Synthesis and Modeling

Revision 0

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

Prepared by
U.S Geological Survey

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STUDY PLAN APPROVAL FORM

Study Plan Number 8.3.1.2.1.4

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Revision Number 0

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RECORD OF REVISIONS

REVISION NUMBER	*REVISION*	*DATE*
RO	**Study rationale and plans for four activities:** Conceptualization of regional hydrologic flow models (Section 3.1) Subregional two-dimensional areal hydrologic modeling (Section 3.2) Subregional two-dimensional cross-sectional hydrologic modeling (Section 3.3) Regional three-dimensional hydrologic modeling (Section 3.4)	

ABSTRACT

This study plan describes four activities to be performed in the Yucca Mountain region as part of the Geohydrology Program. The overall objectives of these activities are to synthesize existing and new regional saturated-zone hydrogeological data into regional and subregional ground-water flow system models, and to construct and calibrate numerical models of these flow systems based on the conceptual models. The activities include:

- Conceptualization of the regional hydrologic flow models,
- Subregional two-dimensional areal hydrologic modeling,
- Subregional two-dimensional cross-sectional hydrologic modeling, and
- Regional three-dimensional hydrologic modeling.

The rationale of the regional hydrologic system synthesis and modeling 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 study results to other investigations, and Section 5 presents the schedules and associated milestones.

REGIONAL HYDROLOGIC SYSTEM SYNTHESIS

AND MODELING

YMP - USGS - SP 8.3.1.2.1.4, RO

STUDY PLAN

JULY 1991

July 1, 1991

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1 PURPOSE AND OBJECTIVES OF STUDY

1.1 Purpose of the study plan

The U.S. Geological Survey (USGS) is conducting studies at Yucca Mountain, Nevada, as part of the Yucca Mountain Project (YMP). The purposes of the studies are to provide hydrologic and geologic information 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 Department of Energy (DOE) to demonstrate in its environmental-impact statement and license application that the MGDS will meet the requirements of federal regulations 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191.

The purpose of the study plan is to describe and outline strategies for synthesizing and modeling the regional saturated-zone hydrologic system. The study is organized into four activities:

- 8.3.1.2.1.4.1 - Conceptualization of regional hydrologic flow models;
- 8.3.1.2.1.4.2 - Subregional two-dimensional areal hydrologic modeling;
- 8.3.1.2.1.4.3 - Subregional two-dimensional cross-sectional hydrologic modeling; and
- 8.3.1.2.1.4.4 - Regional three-dimensional hydrologic modeling.

Note that the numbers (e.g., 8.3.1.2.1.4.1) used throughout this plan 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.

Figure 1.1-1 illustrates the location of this study plan within the SCP geohydrology program. The regional hydrologic system synthesis and modeling study is one of four studies in the regional hydrologic system investigation, whose overall purpose is to develop a conceptual model of the regional hydrologic system to assist in assessing the suitability of the Yucca Mountain site to contain and isolate waste. The three preceding studies in the investigation characterize the meteorology for regional hydrology, regional and site runoff and streamflow, and the regional ground-water flow system. (Figure 1.1-2 illustrates the location of the regional, subregional, and site ground-water flow systems.) The four activities in the present study were selected on the basis of various factors and are described in Sections 2 and 3. Time and schedule requirements were considered in determining the number and types of activities chosen to obtain the required results. Activities were designed on the basis of

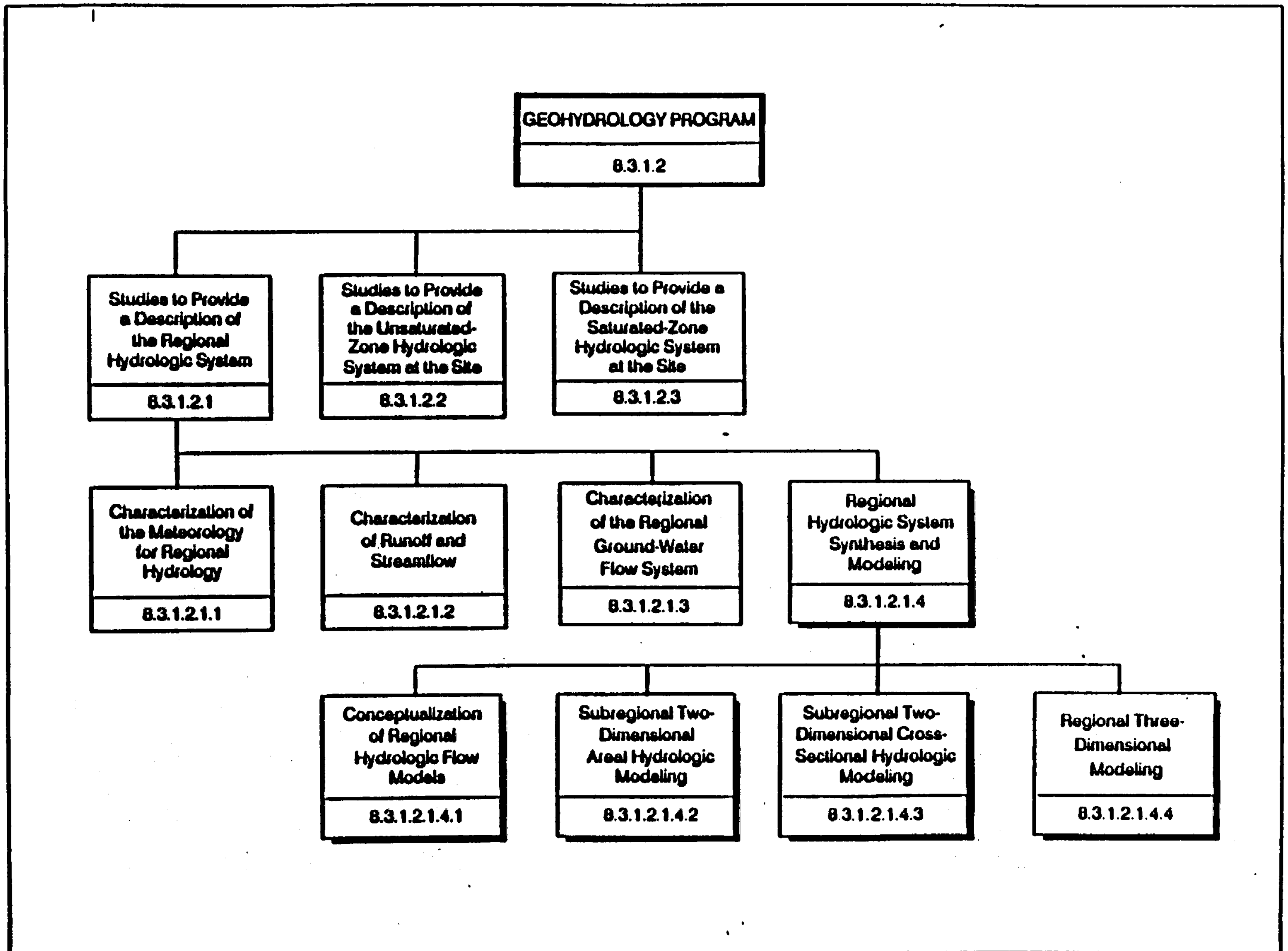

Figure 1.1-1. Diagram showing the location of study within the site saturated-zone hydrology investigations and organization of the geohydrology program.

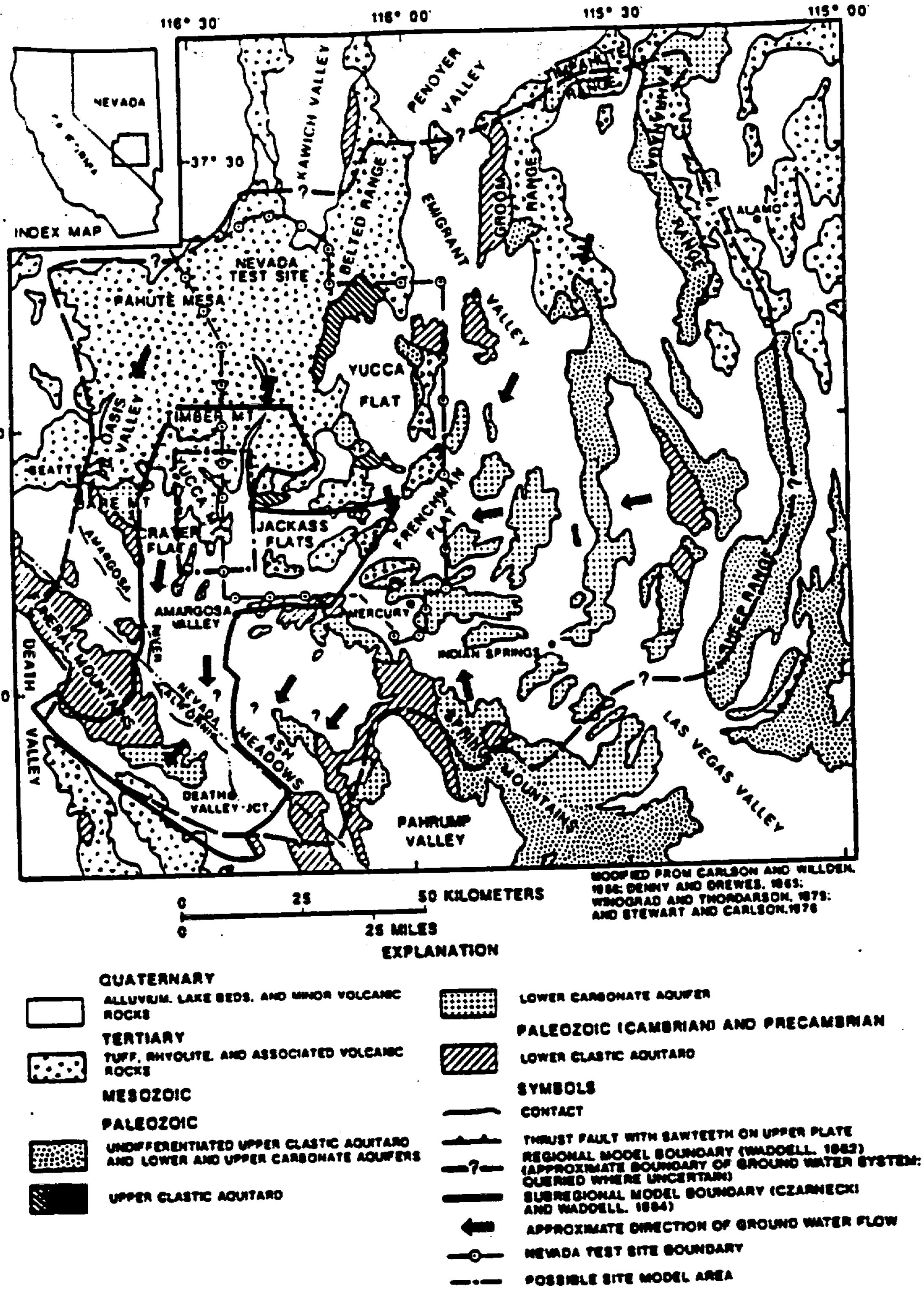

Figure 1.1-2. Location of the regional, subregional, and site ground-water flow systems. (modified from Czarnecki and Waddel, 1984, fig. 1).

design and performance parameter needs and available analytical methods. These factors are described in Sections 1.3, 2, and 3.

The descriptions and plans for each activity are presented in Section 3. Plans for the conceptualization of regional hydrologic flow models are discussed in Section 3.1, plans for subregional two-dimensional areal hydrologic monitoring are in Section 3.2, plans for subregional two-dimensional cross-sectional modeling are in Section 3.3, and plans for regional three-dimensional hydrologic modeling are in Section 3.4. The descriptions include (a) objectives and parameters, (b) technical rationale, and (c) general modeling approach and analytical techniques. Alternate methods are summarized, and cross references are provided for quality-assurance levels.

Application of the study results is summarized in Sections 1.3 and 4, study and activity schedules and milestones are presented in Section 5, a study-plan reference list is presented in Section 6, and a quality-assurance appendix is presented in Section 7.1.

1.2 Objectives of study

The objectives of the study are:

(1) to synthesize all existing and new data (collected as part of the site-characterization process) into conceptual models of the regional and subregional ground-water flow systems, and

(2) to construct numerical models of the ground-water flow systems based on the conceptual models.

The resulting conceptual models will incorporate, as much as possible, alternative hypotheses of the ground-water flow systems. In addition, each activity may generate more than one numerical model if no clear choice exists between alternative hypotheses concerning the ground-water flow systems. Previously developed numerical models will be evaluated and revised in the context of new information and current conceptual models.

The expected results and uses of the numerical models are:

(1) to test hypotheses incorporated in the conceptual models (test alternative conceptual models);

(2) to estimate present-day values of:

   (a) the direction and magnitude of ground-water flow throughout the regional and subregional ground-water flow systems;

   (b) horizontal and vertical saturated-zone hydraulic gradients;

   (c) hydraulic properties of rocks, sediments, and structural features; and

   (d) the distribution and rate of ground-water recharge, discharge, and vertical leakage between ground-water flow systems;

(3) to perform sensitivity analyses for the purpose of aiding in planning and direction of future data-collecting activities associated with other studies, and for identifying the effects of changing key model variable values. Concurrent data collection and model development are essential to the site-characterization process, because models are the most effective means of identifying those areas and parameters that are critical to site characterization;

(4) to provide initial and boundary conditions for the site model(s); and

(5) to assist (in other investigations) in predicting ground-water flow system response to climatic change, tectonic deformation, changes in ground-water pumping (human interference), and other unidentified processes that may be affecting the ground-water flow system.

The regional hydrology synthesis and modeling study is aimed at resolving several uncertainties about the regional/subregional ground-water flow systems. For example, large horizontal hydraulic gradients exist directly north and northeast of the proposed repository location, and may be of hydrologic significance to the site-scale ground-water flow system. The cause of these anomalous gradients is uncertain. The study also is aimed at refining the boundary conditions for the Yucca Mountain regional study area. The distribution, rate, and mechanisms of ground-water recharge are not well known. Modeling studies are aimed at estimating and evaluating hypotheses concerning recharge in conjunction with data-collecting activities. The distribution and rate of ground-water discharge is fairly well known but probably will require further study. Finally, the geohydrologic significance of lineaments and regional fracture zones can be assessed, in part, using numerical models of ground-water flow.

1.3 Regulatory rationale and justification

The analyses of the regional hydrologic regime generated by this study, through contributions to the site saturated-zone synthesis and modeling study (YMP-USGS SP 8.3.1.2.3.3), will provide input for the resolution of Issue 1.6 (Pre-waste-emplacement ground-water travel time). The present study will directly and indirectly support the resolution of Issue 1.1 (Limiting radionuclide releases to the accessible environment). Through contributions to Issues 1.6 and 1.1, the study will support the resolutions of Issue 1.8 (NRC siting criteria) and Issue 1.9 (Higher-level findings). Through contributions to Issue 1.6, the study will support the resolution of Issue 1.3 (Protection of special sources of ground water).

The results of the regional hydrologic system synthesis and modeling study are not intended to directly estimate ground-water travel time within the saturated zone from the repository to the accessible environment. Rather, the regional modeling results will be used as a basis for specifying boundary conditions for more detailed models of ground-water flow at the site (YMP-USGS SP 8.3.1.2.3.3), and as a basis (in other site-characterization studies; see Section 4.2) for evaluating the possible effects of future climate, tectonic activity, and human interference upon the regional ground-water flow system. The models of this study may also provide confirmatory evidence for ground-water travel-time evaluation, an approach that would be consistent with the convergence of information by multiple techniques for performance assessment.

The regional hydrologic flow system must be understood in order to define the present and expected boundary conditions for the site saturated-zone ground-water models, and the hydrogeologic setting in which the site occurs. The regional hydrologic system synthesis and modeling study assists in meeting requirements of performance issues through the provision of saturated-zone hydrogeologic data for the site saturated-zone hydrologic system synthesis and modeling study, and may also provide confirmatory evidence for ground-water travel-time calculations.

The overall regulatory-technical relations between the SCP performance-assessment issues and the analyses generated in this study are presented in the geohydrology testing strategy presented in SCP Section 8.3.1.2 (Table 8.3.1.2-1) and the issue-resolution strategies presented in SCP Sections 8.3.2 through 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 between performance parameters of Issues 1.1 and 1.6 and characterization parameters of this study is presented in Appendix 7.2 (Table 7.2-1).

In this and other study plans, it has been useful to group the measured parameters of the various activities (activity parameters) into a limited set of characterization parameters, more broadly defined parameters that encompass activity-parameter data collected in the field and laboratory, or generated by modeling. By introducing these parameters, it becomes easier to demonstrate how the study relates to satisfying the information requirements of parameters in the performance issues. This demonstration is made in Table 7.2-1. In the case of the regional hydrologic system synthesis and modeling study, the activity parameters (presented in the figures of Sections 3.2 through 3.4) can be grouped under a set of characterization parameters that is identical for the four activities of the study. The group consists of:

Ground-water flux
Hydraulic conductivity
Hydraulic gradients
Storage coefficient

The grouping of activity parameters according to characterization parameters is given in Table 2.1-1 of Section 2. Characterization parameters are also shown in the logic diagrams accompanying the activity descriptions of Sections 3.2, 3.3, and 3.4.

Project-organization interfaces between the regional saturated-zone synthesis and modeling study and YMP performance issues are illustrated in Figure 1.3-1. The figure also indicates project interfaces with other studies; these relations are described further in Section 4.2. The relations between the performance issues noted later in this section and the regulatory requirements of 10 CFR 60 and 10 CFR 960 are described in SCP Section 8.2.1.

The following portion of this section summarizes from the SCP the study-level interfaces between this study and the performance issues. The discussion of the uses of site-characterization data from this study in resolving those issues is based upon performance measures and performance parameters identified in SCP Section 8.3.5.

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

One of the requirements for resolving Issue 1.6 is the confirmation and refinement of conceptual models of flow through the saturated zone at the Yucca Mountain site. Regional saturated-zone modeling in this study supports the site saturated-zone modeling, which will be coordinated with the saturated-zone flow analysis in Issue 1.6. One of the objectives of that analysis is to determine what ground-water flow paths will be used in saturated zone ground-water travel-time calculations. The regional and subregional models of this study, while not being the primary contribution to performance assessment, may provide confirmatory evidence for the evaluation of ground-water travel time. This approach would be consistent with the convergence of information by multiple techniques for the performance assessment.

In SCP Section 8.3.5.12, a required minimum ground-water travel-time value from the disturbed zone to the accessible environment has been set at 1,000 years, and values for goals for the performance parameters of hydraulic gradient (dh/dl), saturated hydraulic conductivity (K_s), effective porosity (n_e), and flow-path distance (d) are listed. If these goal values for the saturated zone are realized, they would establish a partial basis for concluding with reasonable confidence that total ground-water travel time will exceed 1,000 years.

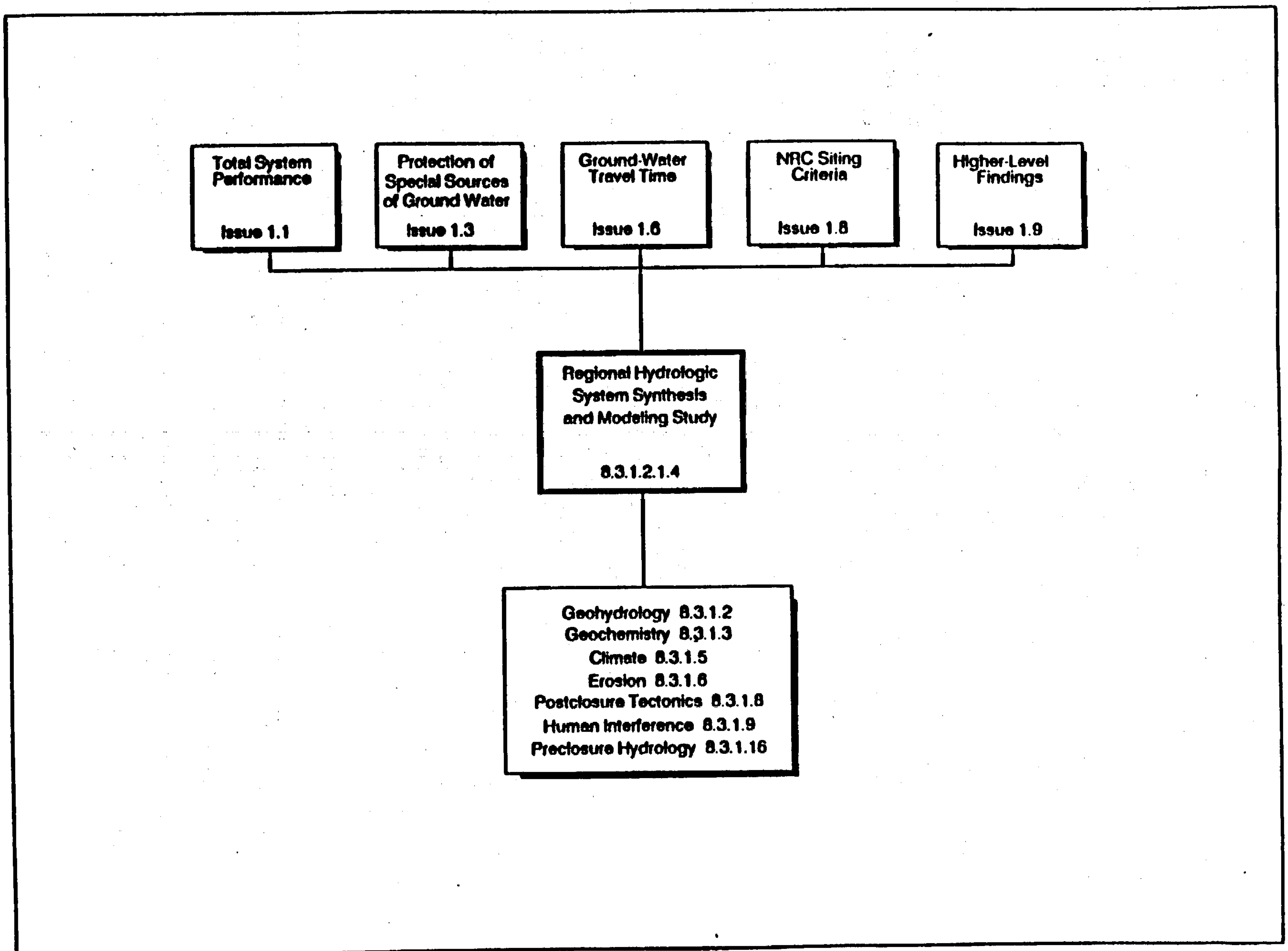

Figure 1.3-1. Diagram showing interfaces of regional hydrology synthesis and modeling study with YMP performance issues and other site-characterization programs.

However, meeting the required values for the above goals would not be sufficient to calculate a cumulative probability distribution of ground-water travel time in the saturated zone if portions of some flow paths were to include fracture flow, or if travel time is sensitive (as is expected) to the variability of the performance parameters within ranges that are bounded by the performance goals. Therefore in Issue 1.6 (SCP Table 8.3.5.12-3) a set of supporting performance parameters based on the elements of the general flow equations has been identified, for which no quantitative goals have been set. Instead, the goals are defined in terms of relative confidence desired in the probability distributions of the parameters.

Issue 1.6 thus contains two categories of parameters: (1) the performance parameters identified for establishing bounds on the travel time for comparison to goals, and (2) the supporting performance parameters identified for developing a probabilistic performance measure expressed as a cumulative probability distribution function of travel time. The relations of characterization parameters from the study (through its support of Study 8.3.1.2.3.3) to Issue 1.6 performance and supporting performance parameters are shown in Table 7.2-1.

In Information Need 1.6.1 (Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path), the present study contributes (through Study 8.3.1.2.3.3) pre-waste-emplacement regional and subregional data in the categories of material property values, initial and boundary conditions, and model verification. Site saturated-zone modeling activities, supported by the present study, reduce measured site data to the parameters amenable to direct use in ground-water travel-time calculations. (This process of data reduction through modeling analyses is described in Section 3 of YMP-USGS-SP 8.3.1.2.3.3.) Critical data required from the site saturated-zone modeling study by Issue 1.6, and augmented by the present study, include conceptual-model descriptions and associated uncertainties for the site saturated-zone flow system. The validation of flow models is also a critical requirement. Meeting the requirements of performance-parameter data results from using saturated-zone conceptual flow models as a basis for predicting the spatial distribution of material properties, gradients, and flow paths. (This process is described in Section 3 of this study plan and Section 3 of YMP-USGS-SP 8.3.1.2.3.3.)

Issue 1.6 supporting parameters, receiving data from site-characterization parameters in the categories of material property values and initial and boundary conditions, provide specific input for the solution of the general equations for ground-water travel time. Model verification in the site saturated-zone synthesis and modeling study tests the adequacy of the equations used for travel-time calculation.

In Information Need 1.6.2 (Calculational models to predict ground-water times between the disturbed zone and the accessible environment), the present study supports Study 8.3.1.2.3.3 in contributing (1) characterization parameters (as described for Information need 1.6.1), and (2) conceptual models of site saturated-zone flow. The definition of conceptual hydrologic models for the site saturated zone, and their relative likelihood, is an important requirement for evaluating ground-water travel times in Issue 1.6. Also within this information need, the development of calculational (numerical) models to estimate ground-water travel time will take into account local saturated-zone flow models resulting from Study 8.3.1.2.3.3, as supported by the present study. Modification of existing numerical models will be performed through comparison with other models having different levels of complexity, geohydrology-program field tests of the assumptions and alternatives for existing conceptual models, and results of sensitivity analyses.

In Information Need 1.6.3 (Identification of the paths of likely radionuclide travel from the disturbed zone to the accessible environment and identification of the fastest path), numerical models of saturated-zone flow will simulate flow paths in the saturated zone. This effort will be coordinated with the site saturated-zone modeling activities in Study 8.3.1.2.3.3, as supported by the present study. Site saturated-zone flow models will contribute to defining the boundary of the accessible environment.

In Information Need 1.6.4 (Determination of the pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment) the calculated ground-water travel-time values will be based on the conceptual model of the site saturated zone, formulated in Study 8.3.1.2.3.3 and augmented by the present study. Uncertainties in the site conceptual model will be addressed in the calculation of the ground-water travel-time cumulative distribution function.

Performance Issue 1.1
(Limiting radionuclide releases to the accessible environment)

In calculating the complementary cumulative distribution function (CCDF) for estimating radionuclide releases after repository closure, the DOE intends to take into account all those natural processes and events that are sufficiently credible to warrant consideration. (The calculation of the CCDF is discussed in SCP Section 8.3.5.13.) Impacts of processes and events initiated by human activities will also be considered in the system performance assessments for Issue 1.1. Selection of processes and events considered credible enough to affect future repository performance has resulted in the identification of a set of scenarios grouped in scenario classes, according to features that the individual scenarios have in common. The expected partial performance measure (EPPM) for a scenario class is a term that expresses the probability of occurrence of that scenario class. Significant scenario classes are those which have the highest EPPM values. (A detailed treatment of scenario classes and the EPPM concept appears in SCP Section 8.3.5.13.)

Scenario Class E, also called the nominal case, describes the undisturbed performance of the repository. It takes into account the legitimate, distinguishable alternative conceptual models (including those for site saturated-zone ground-water flow) that are supported by the available information. This class is associated with anticipated or expected conditions, and describes the predicted behavior of the repository and the uncertainties in predicted behavior, considering only likely natural events.

Disruptive scenario classes (disturbed cases) are also developed in Issue 1.1. These classes are considered sufficiently credible to warrant consideration, but are outside the range of probability considered for the nominal case.

In Scenario Class E, the unsaturated and saturated zones are considered the primary barriers to radionuclide migration, and the engineered barrier system is considered to be a backup element. SCP Table 8.3.5.13-9 is a listing of the performance parameters for this scenario. Saturated-zone performance parameters for the nominal case, to which site-characterization data from the present study can contribute through Study 8.3.1.2.3.3, appear in Table 7.2-1. These include saturated-zone average discharge, average effective matrix porosity, and average lengths of flow paths in the controlled area. Supporting performance parameters needed to evaluate the nominal case and to serve as baseline data for the disturbed cases are listed in SCP Table 8.3.5.13-17. Supporting parameters pertaining to the saturated zone include effective thickness, hydraulic conductivity, and effective porosity of saturated-zone units in the controlled area. Site data from the present study can also contribute (through Study 8.3.1.2.3.3) to these supporting parameters, which are also cited in Table 7.2-1.

Two of the disturbed-case classes concern the possible failure of saturated-zone barriers. Scenario Class D-1 concerns the appearance of surficial-discharge points within the controlled area, and foreshortening of the saturated zone. Scenario Class D-2 concerns the possibility of increased hydraulic gradients, or changes in rock, hydrologic, or chemical properties of units in the saturated zone. The effects of possible future climate change, tectonic and igneous activity, and human interference on the hydraulic properties of the saturated zone are considered in these scenarios, with known and expected saturated-zone conditions being the baseline case. Because the present study contributes (through Study 8.3.1.2.3.3) to baseline knowledge by helping to define Scenario Class E, it also contributes to assessing these two disturbed cases.

In Information Need 1.1.1 (Site information needed to calculate releases to the accessible environment), the present study assists (through Study 8.3.1.2.3.3) in satisfying the need by providing site-characterization data to the performance parameters cited in Table 7.2-1.

Information Need 1.1.2 (A set of potentially significant release scenario classes that address all events and processes that may affect the geologic repository) is addressed by the present study in the same manner as is Information need 1.1.1. The SCP states that all data and interpretive information arising from the site-characterization program are potentially relevant to the identification of release-scenario classes.

In Information Need 1.1.3 (Calculational models for predicting releases to the accessible environment attending realizations of the potentially significant release-scenario classes), the same hydraulic properties are needed from the present study as are required to resolve Issue 1.6 (see

Table 7.2-1). This information need requires calculational (numerical) models of the saturated zone that are capable of predicting time-dependent specific discharge in at least two dimensions. It also requires from Study 8.3.1.2.3.3 the final conceptual models of the saturated-zone hydrologic system.

Performance Issue 1.8
(NRC siting criteria)

This performance issue addresses the NRC siting criteria of two sets of conditions that describe human activities and natural conditions, processes, and events. The first set consists of favorable conditions (FC) that, if present, enhance the ability of the site to isolate waste. The second set consists of potentially adverse conditions (PAC), that, if present, could adversely affect the ability of the site to isolate waste. Siting criteria require that demonstrations be made regarding each of these conditions.

Through support of Issue 1.6, the present study indirectly addresses the following favorable condition:

- FC 7: Pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment that substantially exceeds 1,000 yr.

Site-characterization data from the present study will indirectly support the issue-resolution strategy for ground-water travel time in Issue 1.6. These data include: (1) transmissive and storage properties of rocks in the saturated zone, (2) specific discharge (Darcy velocity) through these rocks, (3) effective saturated thickness, and (4) ground-water flow-path length.

The present study, by providing conceptual and numerical models of regional and subregional ground-water flow, and by supporting Study 8.3.1.2.3.3 in providing a baseline description of the site saturated-zone flow system, is an associated study in evaluations of the following PACs and their potential consequences. (The associations of the present study and Study 8.3.1.2.3.3 with various PACs are tabulated in SCP Section 8.3.5.17.)

- PAC 2: Potential for human activity to adversely affect the ground-water flow system, such as ground-water withdrawal, extensive irrigation, subsurface injection of fluids, underground pumped storage, military activity, or construction of large-scale surface-water impoundments.

- PAC 4: Structural deformation such as uplift, subsidence, folding or faulting, that may adversely affect the regional ground-water flow system.

- PAC 5: Potential for changes in hydrologic conditions that would affect the migration of radionuclides to the accessible environment, such as changes in hydraulic gradient, average interstitial velocity, storage coefficient, hydraulic conductivity, natural recharge, potentiometric levels, and discharge points.

- PAC 6: Potential for changes in hydrologic conditions resulting from reasonably foreseeable climatic changes.

- PAC 8: Geochemical processes that would reduce sorption of radionuclides, result in degradation of the rock strength, or adversely affect the performance of the engineered barrier system.

- PAC 11: Structural deformation, such as uplift, subsidence, folding, and faulting, during the Quaternary period.

- PAC 15: Evidence of igneous activity since the end of the Quaternary period.

- PAC 22: Potential for the water table to rise sufficiently so as to cause saturation of an underground facility located in the unsaturated zone.

Performance Issue 1.9
(Higher-level findings)

Performance Issue 1.9 is concerned with DOE postclosure guidelines (Issue 1.9a) and with the two evaluations of repository performance over 100,000 years (Issue 1.9b).

In Issue 1.9a, either a positive or negative higher-level finding is determined for each qualifying and disqualifying condition associated with postclosure repository performance. The findings are determined from the resolutions of the performance issues, of which Issues 1.1 and 1.6 receive site-characterization data (through Study 8.3.1.2.3.3) from the present study.

In the following paragraphs, the applicable qualifying and disqualifying conditions are briefly summarized, followed by explanations of how the present study applies to each.

- System guideline qualifying condition - The geologic setting at the site shall allow for the physical separation of radioactive waste from the accessible environment after closure.

The higher-level finding for this condition will be indirectly supported by the present study by specification (through Study 8.3.1.2.3.3) of saturated-zone site-characterization data (e.g. ground-water flux, hydraulic head, and saturated hydraulic conductivity) to Issue 1.6. By providing baseline conditions for the site for evaluating possible disturbed case scenarios, the study supports the higher-level finding through Issue 1.1.

- Geohydrology disqualifying condition - A site shall be disqualified if the pre-waste-emplacement ground-water travel time to the accessible environment is less than 1,000 years.

The present study contributes to the higher-level finding for this condition by augmenting the site saturated-zone model that will be used in Issue 1.6 for calculations of ground-water travel time along likely paths of radionuclide migration, and by providing confirmatory evidence for calculations of ground-water travel time.

- Geochemistry qualifying condition - The present and expected geochemical characteristics of a site shall be compatible with waste containment and isolation.

The higher-level finding for this condition is supported by the present study by contributions to the site saturated-zone model to be used as a baseline against which to evaluate, in Issue 1.1, effects of possible disturbed-case scenarios on saturated-zone hydraulic conductivity, and the consequences of such effects on geochemical characteristics.

- Climate qualifying condition - The site shall be located where future climatic conditions will not be likely to lead to radionuclide releases greater than those allowable under regulatory requirements.

The higher-level finding for this condition is indirectly supported by the present study by contributions to the site saturated-zone modeling activities for Issue 1.1, which are to be used as a baseline from which to evaluate the effects of future climatic conditions on water-table altitude and saturated-zone hydraulic gradients, and on the possible occurrence of new ground-water discharge points.

- Tectonics qualifying condition - The site shall be located in a geologic setting where future tectonic processes or events will not be likely to lead to radionuclide releases greater than those allowable under regulatory requirements.

The higher-level finding for this condition is indirectly supported by the present study by contributions to the site saturated-zone modeling activities for Issue 1.1, which are to be used as a baseline from which to evaluate the possible effects of tectonic activity on water-table altitude, saturated-zone hydraulic gradients, and ground-water flow paths.

- Natural resources qualifying condition - The site shall be located such that the natural resources, including ground water suitable for crop irrigation or human consumption without treatment, present at or near the site will not be likely to give rise to interference activities that would lead to radionuclide releases greater than those allowable under regulatory requirements.

The higher-level finding for this condition is indirectly supported by the present study by contributions to the site saturated-zone modeling activities for Issue 1.1, which are to be used as a baseline from which to evaluate the possible effects of irrigation, ground-water withdrawal, the construction of surface and subsurface impoundments, and other forms of human interference on water-table altitudes and ground-water flow direction and magnitude.

In Issue 1.9(b), two performance evaluations are required to predict radionuclide releases 100,000 years after repository closure. The first evaluation will emphasize the performance of site natural barriers. The second will: (1) consider the expected performance of the repository system; (2) be based on the expected performance of waste packages and waste forms, and expected geohydrologic and geochemical conditions at the site; and (3) take into account the expected performance of all other engineered components of the repository system. The natural processes and events considered will only be those likely to occur 100,000 years after repository closure.

To resolve Issue 1.9b, Scenario E (the nominal case) will be expanded to accommodate probable events that can be expected to occur 100,000 years after repository closure. All of the scenarios are related to future climate change, and are listed in SCP Table 8.3.5.18-9. The present study indirectly supports the resolution of Issue 1.9b by contributions to the site saturated-zone modeling activities which are to be used as a baseline from which to evaluate the effects of future climate changes on water table altitude, possible ground-water discharge points in the vicinity of the controlled area, and saturated-zone hydraulic gradients in the controlled area 100,000 years after repository closure.

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

The resolution of Issue 1.3 is structured to first ascertain whether any aquifers in the vicinity of Yucca Mountain meet the EPA criteria for Class I aquifers, and the 40 CFR 191.12 criteria for special sources of ground water. If special sources of ground water exist, and if ground-water travel time from the repository to special sources of ground water is shown (through the resolution of Issue 1.6) to be less than 1,000 yrs, Issue 1.3 is affirmatively resolved. The present study supports the resolution of Issue 1.3 through its indirect contribution to Issue 1.6 through Study 8.3.1.2.3.3.

2 RATIONALE FOR STUDY

2.1 Technical rationale and justification

2.1.1 Role of study in the geohydrology program

The location of the regional saturated-zone synthesis and modeling study within the SCP Geohydrology Program is shown in Figure 1.1-1. Activities planned for this study include: (1) conceptualization of regional and subregional ground-water flow models; (2) subregional two-dimensional areal ground-water flow modeling; (3) subregional two-dimensional cross-sectional ground-water flow modeling; and (4) regional three-dimensional ground-water flow modeling. Figure 2.1-1 shows the relationship between modeling studies and site characterization.

The rationale for employing a combined conceptual and numerical approach to analyzing regional saturated-zone ground-water flow is explained below.

1. The ground-water flow system is geohydrologically complex. It is a multilayered system with complex structure, heterogeneous and anisotropic conditions, both confined and unconfined conditions, and complex boundary conditions.

2. No analytical solutions exist for the conceptual models because of the complexity of the ground-water flow system.

3. Numerical simulation is the most efficient and accurate method for ground-water flow system analysis and for prediction of future hydrologic conditions.

The objective of this study is to construct consistent regional models (conceptual and numerical) of ground-water flow for the following purposes: (1) synthesis of available data with conceptual models of the flow system; (2) estimation of ground-water flow system parameters (e.g. hydraulic head, hydraulic conductivity, etc.); (3) testing of alternate hypotheses; (4) sensitivity analyses that aid in data-collection planning; (5) specification of initial conditions and, reliable estimates of site-model boundary conditions; and (6) prediction (in subsequent investigations) of future ground-water flow-system conditions. Other studies that may be able to use these models include Study 8.3.1.5.2.1 (Quaternary regional hydrology) and Study 8.3.1.5.2.2 (Future regional hydrology due to climate changes).

Since an understanding of the saturated-zone hydrologic system is required for evaluation of pathways to the accessible environment, studies of flow paths and specific discharge are needed. Regional ground-water flow models provide a valuable synthesis of available hydrogeologic data as well as estimates of ground-water flow paths, fluxes, and specific discharge. The present study contributes in providing modeling efforts directed to this end.

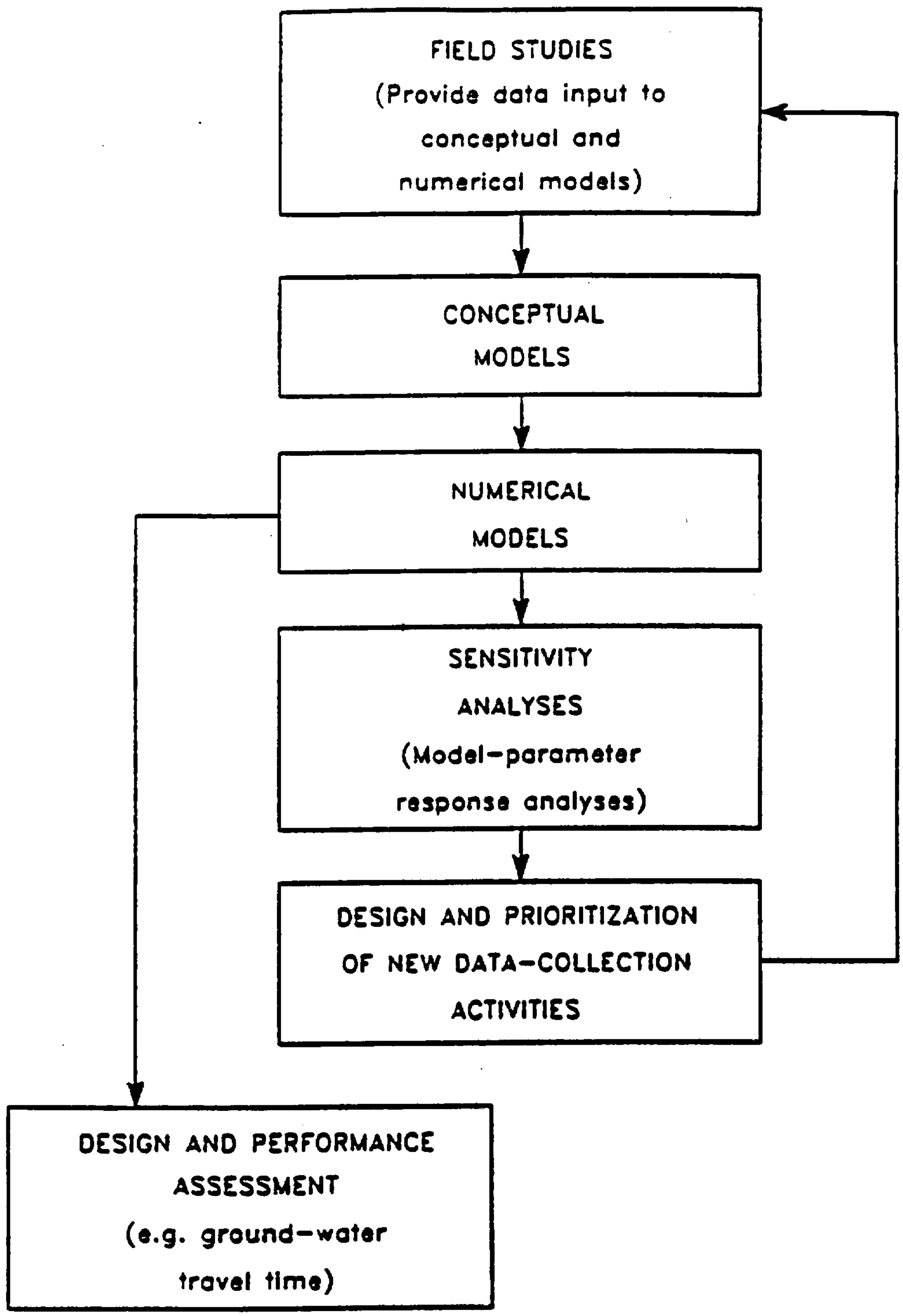

Figure 2.1-1. Schematic diagram showing the relation of modeling studies to site characterization.

Saturated-zone variables (parameters) to be estimated in this study using numerical models include: (a) the spatial distribution of transmissivity (hydraulic conductivity and saturated thickness); (b) hydraulic gradient; (c) the magnitude and direction of ground-water flux; (d) recharge, discharge, and vertical leakage rates and distribution; and (e) storage coefficient and effective porosity.

The conceptual models of the ground-water flow system will incorporate alternate hypotheses where appropriate. Testing alternate hypotheses, for the purpose of assessing relative significance, can be achieved by developing more than one numerical ground-water flow model (when appropriate), and by using numerical-model sensitivity analysis methods. Key hypotheses, variables, and assumptions for the conceptual models will be identified for use in data-collection activities.

Numerous hydrogeologic investigations that have been conducted during the last few decades in and around the NTS have provided a broad understanding of the regional hydrogeologic framework (for example, Winograd and Thordarson, 1975). Regional and subregional groundwater flow modeling (Waddell, 1982; Czarnecki and Waddell, 1984; Sinton, P. O., and Downey, J. S., written communication, 1990), based on such investigations, has incorporated regional heterogeneities of various hydrogeologic units, and has acceptably represented the ground-water flow systems under specified assumptions. Major assumptions inherent in regional models pertain to the location and magnitude of recharge and discharge boundary conditions and regional transmissivities. Recharge estimates across model boundaries are often crude, because of the lack of sufficient hydraulic gradient and transmissivity data. However, prioritization of data collection may be facilitated through sensitivity analyses of models of ground-water flow. The task is to prioritize data collection and reduce the potential range of key model variable values used in the regional flow models; therefore, these models are useful for directing additional data collection by indicating areas and parameters that need further study.

The saturated zone beneath and downgradient from the site may serve as the final segment of the flow path for ground-water flow and transport to the accessible environment. Evaluation of the regional saturated-zone flow system will provide knowledge of the boundary conditions at the site. Estimates of the hydraulic properties of units in the saturated zone, hydraulic gradients, and ground-water flux are needed to specify boundary conditions for site-area models; therefore, one objective of the modeling study is to assign reliable boundary conditions to the more critical site model (YMP-USGS-SP 8.3.1.2.3.3, Site saturated-zone hydrologic system synthesis and modeling). Results from these modeling activities are not intended to directly estimate ground-water travel time from the repository to the accessible environment. They may provide confirmatory evidence for the evaluation of ground-water travel time.

The baseline studies of the regional hydrologic conditions will serve as a means for predicting future ground-water flow system conditions beneath the Yucca Mountain site and vicinity. Regional models provide tools for analyzing (in subsequent investigations) changes in future stresses to the hydrologic system, such as increased recharge resulting from future climatic changes, potential increased withdrawal of ground water (human interference), and changes in hydrogeologic properties resulting from tectonic events.

2.1.2 General modeling approach

Previously gathered data, published data, and site-characterization data gathered concurrently with modeling studies that will be used in formulation of the ground-water flow system conceptual model are: (1) measurements and estimates of recharge, discharge and boundary fluxes; (2) measurements of hydraulic head within and proximal to the boundaries of the ground-water flow system; (3) measurements and estimates of transmissivity values (hydraulic conductivity and saturated thickness); (4) measurements and estimates of storage coefficient and porosity values; (5) geological data (horizontal and vertical distribution of lithology and structure) and interpretations; (6) geophysical data (including remote-sensing data) and interpretations; (7) hydrochemical data and interpretations; and (8) geobotanical data and interpretations. The studies providing these data are listed in Section 2.1.6.

Data are limited throughout the study area. Uncertainty is inversely proportional to data availability and may be ranked from lowest to highest for the following types of data: (1) hydraulic head (these data are most abundant), (2) ground-water discharge (direct measurements have been made through ET measurements and spring-discharge gauging), (3) transmissivity (difficulties exist in interpreting tests in fractured rock, limiting useful results), (4) storage coefficient (few reliable aquifer tests are available), (5) effective porosity in fractured media (this varies over several orders of magnitude), and (6) recharge (mechanisms are poorly understood for arid settings).

The only data that is abundant enough to allow geostatistical analysis is hydraulic head data. By kriging this data one may not only obtain interpolated and extrapolated estimates of hydraulic head, but also estimates of the error associated with the kriged estimate. This, of course, assumes that the measured values of hydraulic head are error-free, which is unlikely due to potential sources of error such as borehole deviation, composite head over the entire borehole, instrument malfunction, and operator error. This error estimate may be used to "weight" the confidence in the estimate if used in a parameter-estimation model such as the one described in Czarnecki and Waddell (1984). Parameter estimation then allows the derivation of large-scale values of transmissivity or flux (but usually not both), and may be a suitable alternative to manual model variable adjustment to obtain optimum model-variable values.

For the purposes of this study plan, the following definitions are used:

1. Conceptual model - According to Bear (1972) a conceptual model is a method "for abstracting and simplifying natural phenomena", such as

a ground-water flow system, so that "the model is amenable to mathematical treatment, yet not so simple that it ignores those features it is intended to describe. According to this approach a complicated physical phenomenon or system (ground-water flow system), the mathematical treatment of which is practically impossible, is replaced by some fictitious, simpler phenomena or system (the conceptual model), that is amenable to mathematical treatment" (Bear, 1972, p. 83).

2. Mathematical model - The equations derived from the mathematical treatment of a conceptual model constitute a mathematical model.

3. Numerical model - A model that is derived from the application of methods that transform or approximate a mathematical model, that cannot be directly solved, to a new set of solvable equations is a numerical model. An example would be a finite-difference approximation of the three-dimensional, steady-state ground-water flow equation based on Darcy's Law (see Wang and Anderson, 1982). The resulting set of solvable equations is usually embodied in a computer code.

4. Calibration process - The calibration process is completed when a numerical model adequately represents the natural ground-water flow system, given the quantity and quality of available data and observations. Qualitative or quantitative methods may be used to assess the adequacy of the calibration process, and may have a stochastic, deterministic, or empirical basis. "Calibration" in this study plan is used to mean a calibration process.

5. Verification - Verification is testing to demonstrate that the numerical model performs its arithmetic and logical operations correctly.

6. Validation - Validation is the assurance that the physical model as embodied in software is a correct representation of the intended physical system or process.

The following are steps in the modeling process (adapted from Bear (1972); shown schematically in Figure 2.1-2.

1. Formulate a conceptual model of the ground-water flow system. The conceptual model should incorporate as many features and processes of the natural system as possible. The conceptual model should incorporate all available data, observations, and interpretations of the data and observations. A set of assumptions about the natural system must accompany the conceptual model.

2. Construct and calibrate a numerical model of the ground-water flow system, based solely on the conceptual model and attendant assumptions (the basis of the numerical model will be discussed below). Final simulation results are those of the calibrated numerical model. The model is judged to be calibrated based in part on predetermined criteria (such as the minimum sum of squared

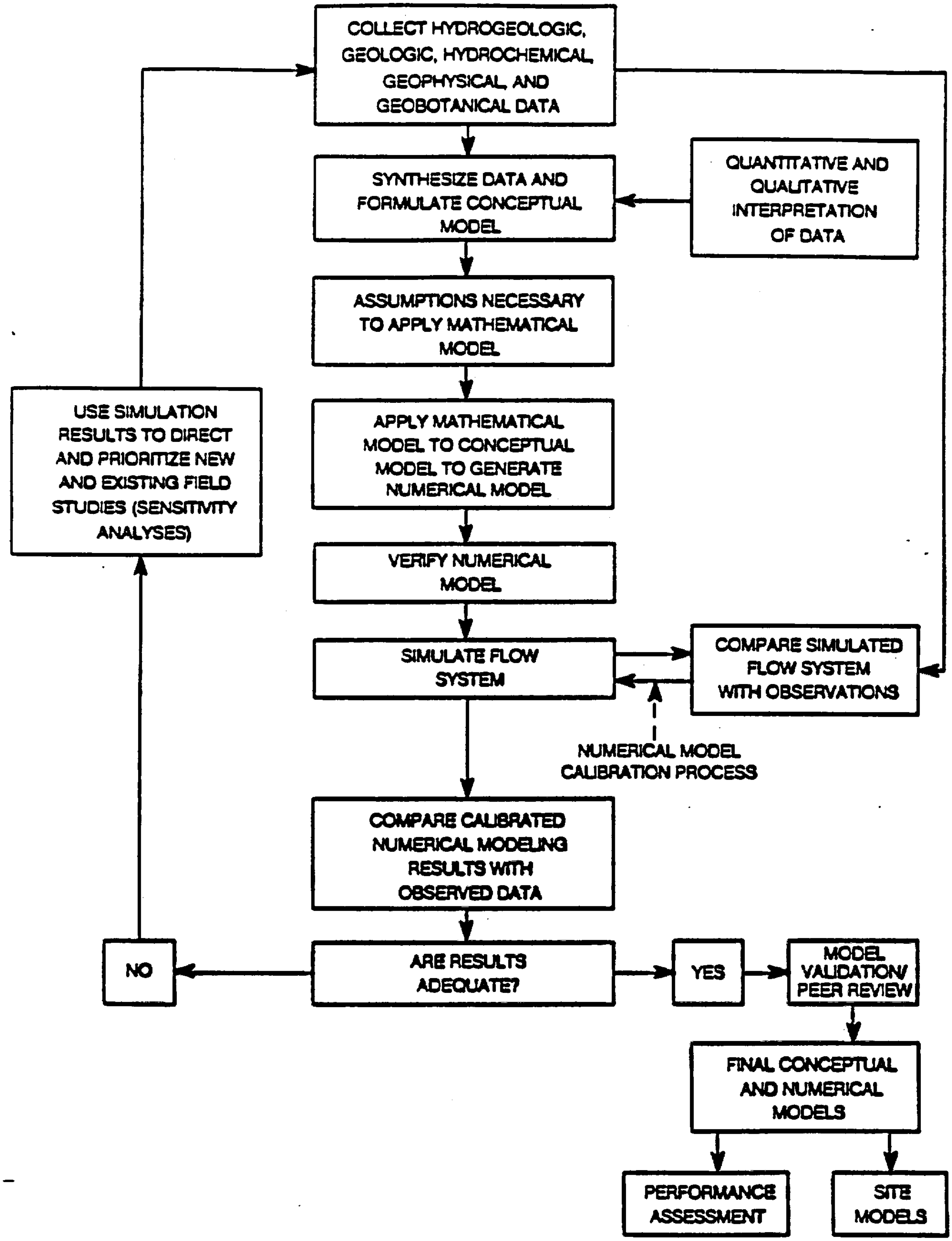

Figure 2.1-2. The conceptual-numerical modeling process.

residuals between calculated and observed hydraulic head). However, because of the nature of any solution to a poorly constrained ground-water flow system, the solution should be considered non-unique.

3. Compare final simulation results with observations and measured data. If the comparison is adequate then the process is complete; otherwise collect more data and observations, and modify the conceptual model appropriately.

4. Validate model results to the extent possible. Field validation might incorporate new test data not available during model development. For example, hydraulic head, transmissivity, and discharge all can be measured and might be available for use as checks against model results. Often this will not be possible and review by competent peers is the only suitable recourse to validate the model.

Steps (1), (2) and (3) are repeated until an adequate representation of the ground-water flow system is obtained (calibrated model). Modeling gives a better understanding of the natural ground-water flow system and the features and factors that affect it.

Sensitivity analyses will also be done after the model calibration process is complete. The final sensitivity analyses will be used to identify parameters and areas where more data are needed to reduce uncertainty. Examples of parameters that might be analyzed in this way include: (1) saturated thickness, (2) hydraulic conductivity, (3) recharge, (4) discharge, and (5) boundary conditions.

There are several methods for doing sensitivity analyses. Quantitative sensitivity analyses involve the calculation of parameter sensitivities ("parameters" here refers to numerical ground-water flow-model parameters or variables). Parameter sensitivities are a measure of the sensitivity or response of the numerical ground-water flow model to changes in the value of a model parameter. Numerical methods will probably be used to calculate parameter sensitivities; sensitivities may be evaluated by deterministic, stochastic, or empirical methods, or by qualitative and interpretive methods. Qualitative sensitivity analyses (the relative ranking of variables) may also be used during the activity. The calculation and interpretation of sensitivities constitutes the process of sensitivity analysis.

New data that are obtained after a model has undergone the calibration process will be used to evaluate model results. For example, if transmissivity estimates become available for a region within the modeled area, then transmissivity estimates used in the model will be compared to those obtained from field testing. In this case an exact match would be unlikely; rather a "match" (sometimes to within an order of magnitude) between observed and model-simulated values may be considered acceptable based on professional judgment.

Numerical modeling activities in this study will assume that porous-media concepts and Darcy's Law apply to the regional and subregional ground-water flow systems. That is, the numerical models will be based on Darcy's Law and the various forms of the partial differential equation that describes transient ground-water flow (the diffusion equation, Freeze and Cherry, 1979). The diffusion equation can be used to approximate flow through fractured media if the smallest volume considered in a numerical model is larger than the representative elementary volume (REV). The REV "must include a sufficient number of pores (or discontinuities such as fractures) to permit the meaningful statistical average required by the continuum approach" (Freeze and Cherry, 1979 p. 70; Bear, 1972). No viable alternatives to the porous-media continuum approach have yet been developed; however, it is possible that modeling activities in this study may attempt to apply methods currently under development (see, for example, Long and others, 1985).

All ground-water numerical modeling studies have several basic features and methods in common. The general methodology is as follows.

1. Discretization of study area - Model mesh design depends on the geohydrologic setting of the study area, the equations used to describe ground-water flow (based on conceptual model), and the scale of the model. Time must be discretized for transient simulations.

2. Estimation of model variables (such as transmissivity, recharge, discharge, etc.) throughout the mesh area, and incorporation of measured values directly into the model - Estimates are derived from data and observations included in the conceptual model, and may be derived deterministically, stochastically, empirically, or qualitatively.

3. Process of calibration of the numerical model - This process consists of comparison of simulation results with observations and measured data. If the comparison is adequate, then the process is finished; if not, model variable values must be modified and the simulation repeated. The simulation/modification process continues until acceptable agreement exists between the numerical model and the field observations (or measurements).

2.1.3 Functions of the activities

The conceptualization of regional hydrologic flow models activity (8.3.1.2.1.4.1) is designed to provide a basis for subsequent numerical models of ground-water flow developed during the study. The conceptualization process is the first step toward developing quantitative models of ground-water flow. This process includes: (1) evaluation and synthesis of data into a conceptual model; and (2) identification of flow system boundaries, structural controls, and hydrologic properties.

The activities of the study have been defined according to the areal coverage and types of the models to be employed. The spatial relation among the three modeling activities in the present study plan is designed for overlap. The two-dimensional areal model covers an area smaller than that of the regional three-dimensional model, but larger than the three-dimensional model of the site (Study 8.3.1.2.3.3, Site hydrologic system synthesis and modeling). The cross-sectional model will, because of its size, be capable of looking at more discrete vertical layers than the regional three-dimensional model. The two-dimensional areal model (which is also capable of being converted to three-dimensions) will permit greater refinement in the vicinity of Yucca Mountain. The designation of three-dimensional modeling as a regional effort is not absolute, because three-dimensional modeling at the subregional scale will also be done if the geologic and hydrologic data are sufficient to permit it.

The subregional two-dimensional areal hydrologic modeling activity (8.3.1.2.1.4.2) is designed to fulfill several functions. First, the activity will test alternate hypotheses incorporated in the conceptual model(s). Second, the activity will estimate present-day values of: (1) direction and magnitude of ground-water flow throughout the subregional ground-water flow systems; (2) horizontal saturated-zone hydraulic gradients; (3) hydraulic properties of rocks, sediments, and structural features; and (4) the distribution and rate of ground-water recharge and discharge. Third, sensitivity analyses will be done to evaluate the effects of different flow system variables and boundary conditions on properties of interest, such as ground-water flow direction and magnitude. Fourth, sensitivity analyses will be done for the purpose of aiding in planning and direction of future data-collecting activities associated with other studies. Concurrent data-collection and model development are essential to the site-characterization process, because models are the most effective means of identifying those areas and parameters that are critical to site-characterization. Fifth, the activity will provide initial and boundary conditions for the site model(s) of Study 8.3.1.2.3.3. Sixth, the regional model will be employed in other investigations (described in Section 4.2) to evaluate ground-water flow-system response to possible future climatic changes, tectonic deformation, human interference, and, possibly, other unidentified processes that may affect the ground-water system.

The subregional two-dimensional cross-sectional hydrologic modeling activity (8.3.1.2.1.4.3) is designed to assess vertical variations in hydraulic gradients, ground-water flux and flow paths, and material properties along ground-water flow paths through the site. Sensitivity analyses will be done to examine the effect that changes or uncertainty in model variables, including boundary conditions, have on ground-water flow direction and magnitude, and on simulated hydraulic head. The cross-sectional modeling activity will also be used to test alternate hypotheses and, possibly (in subsequent investigations), to predict ground-water flow system response to possible future changes in boundary conditions.

The regional three-dimensional hydrologic modeling activity (8.3.1.2.1.4.4) is designed to perform essentially the same functions as Activity 8.3.1.2.1.4.2, but in a three-dimensional context. Modeling done within this activity will be important for: (1) establishing appropriate boundary conditions for models at the site scale, and (2) testing alternative conceptual models. Sensitivity analyses will be done to examine the effect that changes or uncertainty in model variables, including boundary conditions, have on ground-water flow direction and magnitude, and on simulated hydraulic head. The three-dimensional modeling activity will synthesize the geohydrologic properties and conditions of Paleozoic and Proterozoic units, Tertiary volcanic rocks, and Tertiary and younger basin-fill sediments within the regional flow system.

The general approach in each of the modeling activities will be to emphasize the use of multiple conceptual models (i.e., working hypotheses) for the behavior of the flow system. Within each modeling activity, several models will be constructed to test different conceptual models against observed and measured geologic and hydrologic data. The planned result is that the combined conceptual/numerical models for the regional and subregional flow systems will be those that have the best accord with the known hydrogeologic setting.

2.1.4 Parameters and analytical strategies

In SCP usage (DOE, 1988) hydrologic activity parameters are those parameters that are generated by field and laboratory testing activities; they represent the most basic measurements that will be used to characterize the geohydrology of Yucca Mountain and vicinity. Many of the activity parameters are building blocks to support various aspects of the project. Some, such as hydraulic conductivity, support design and performance issues directly. Others primarily provide bases for analyses and evaluations to be conducted within the geohydrology program or within other characterization programs.

In SCP Table 8.3.1.2-1, activity parameters for the geohydrology program are grouped according to parameter categories, which also appear in Table 7.2-1. The activity parameters associated with each activity also appear in the figures of Section 3. Parameter categories serve to group similar types of performance and design parameters supporting design and performance-assessment issues resolutions (SCP Sections 8.3.2-8.3.5) and match them with groups of similar types of activity or characterization parameters to be obtained during site characterization. Parameter categories in the SCP were introduced as a classification scheme to aid in assessing the appropriateness and completeness of the data collection program. In Figure 2.1-1, the parameter categories are shown supporting specific model components that make up the saturated-zone model. This figure corresponds to SCP Figure 8.3.1.2-4, and in that document is accompanied by parallel logic diagrams for the surface-water and unsaturated-zone components of the geohydrology program. Parameter categories are associated with the characterization parameters of this study in Table 7.2-1.

Table 2.1-1 groups the activity parameters of the study according to characterization parameters. In SCP usage, a characterization parameter is a parameter, obtained by a characterization program, that has a logical, direct tie to a performance or design parameter, and for which a testing basis can be defined. Most characterization parameters will be developed from some combination of activity parameters, and will be the products of data reduction, tests and analyses, and modeling. Some of the activity parameters listed in Table 2.1-1, although not required directly for resolving performance or design issues, are required to accomplish satisfactory hydrologic modeling, which in turn increases confidence in the accuracy of the characterization parameters that are required for performance and design analyses. Hydrologic analyses generated in this study can be traced from activity parameters through characterization parameters and to their intended use in satisfying performance and design-parameter requirements for issues resolutions. This last step is addressed by Table 7.2-1.

Characterization parameters will be expressed as functions of space and (or) time and will be presented in formats that will facilitate use of the data in resolving design and performance issues. In future SCP progress reports, a testing basis will be developed for each characterization parameter, and will consist of some means of expressing the goals, confidence limits, and accuracy associated with each characterization parameter, so that requirements of performance and design parameters can be satisfied. An example of a testing basis could be that some statistical measure of the parameter, such as the mean, be known to a specific degree of accuracy.

In addition to supporting design and performance parameters, the activity parameters listed in Table 2.1-1 and Section 3 are needed to test hypotheses that support conceptual models. A sufficient level of confidence in parameter values must exist for the analyses of this study to be employed for this purpose. The approaches to modeling analysis selected for the present study have been chosen to minimize uncertainty in parameter values and in the understanding of parameter interrelations, within the constraints of available resources. Where possible, multiple approaches within an activity are directed toward evaluating the value of a parameter by different means. The combined effect of using multiple approaches (or tests) will be to increase the level of confidence in the parameter, because reliance will not be placed exclusively in one approach. Within a particular activity, some approaches may provide only partial information, while others will provide extensive information necessary for modeling analysis. By combining the test results and studying their relations, a greater understanding and confidence of modeling results can be achieved.

Because of the nonstandard nature of some of the analyses, the possibility that one or more analyses may fail in achieving the desired objectives is recognized. The use of multiple approaches for modeling analysis increases confidence that the failure or the partial failure of one or more analyses will not severely inhibit the ability of the characterization activities in providing the required information.

Table 2.1-1 Association of activity parameters with characterization parameters

Activity	Characterization Parameter	Activity Parameters
Activity 8.3.1.2.1.4.1 - Conceptualization of regional hydrologic flow models	(Activity does not directly generate characterization parameters.)	(Activity does not directly generate activity parameters.)
Activity 8.3.1.2.1.4.2 - Subregional two-dimensional areal hydrologic modeling	Ground-water flux	Ground-water flow: direction and magnitude
		Ground-water flux: areal distribution
		Ground-water flux: specified boundaries
	Hydraulic conductivity	Transmissivity: areal distribution
		Hydraulic conductivity: areal distribution
	Hydraulic gradients	Potentiometric surface
	Storage coefficient	Storage coefficient: areal distribution

Table 2.1-1 Association of activity parameters with characterization parameters (Continued)

Activity	Characterization Parameter	Activity Parameters
Activity 8.3.1.2.1.4.3 - Subregional two-dimensional cross-sectional hydrologic modeling	Ground-water flux	Ground-water flow: direction and magnitude
		Ground-water flux: vertical distribution
		Ground-water flux: specified boundaries
	Hydraulic conductivity	Transmissivity: vertical distribution
		Hydraulic conductivity: vertical distribution
	Hydraulic gradients	Potentiometric surface
		Hydraulic head: vertical distribution
	Storage coefficient	Storage coefficient: vertical distribution

Table 2.1-1 Association of activity parameters with characterization parameters (Continued)

Activity	Characterization Parameter	Activity Parameters
Activity 8.3.1.2.1.4.4 - Regional three-dimensional hydrologic modeling	Ground-water flux	Ground-water flow: direction and magnitude
		Ground-water flux: areal and vertical distribution
		Ground-water flux: specified boundaries
	Hydraulic conductivity	Transmissivity: areal and vertical distribution
		Hydraulic conductivity: areal and vertical distribution
	Hydraulic gradients	Potentiometric surface
		Hydraulic head: areal and vertical distribution
	Storage coefficient	Storage coefficient: areal and vertical distribution

2.1.5 Hydrologic hypotheses

Saturated-zone hydrologic hypotheses describe the manner in which water moves through the saturated zone. The testing and refinement of hypotheses provide a logical and systematic approach to the ultimate definition of how the geohydrologic system functions. The results may constitute an improved conceptual model of the system that, in turn, leads to increased confidence in the geohydrologic evaluation of the repository site.

Figure 2.1-3, the logic diagram of the saturated-zone component of the Geohydrology Program (adapted from SCP Section 8.3.1.2), shows the relation of saturated-zone hydrologic hypotheses to model components. Hydrologic hypotheses for the saturated zone are discussed at the beginning of SCP Section 8.3.1.2. The current representation and alternate hypotheses for the saturated-zone hydrologic system conceptual models appear in SCP Table 8.3.1.2-2b.

During preliminary performance and design analyses, assumptions must be made regarding parameters and hydrologic processes and conditions. These preliminary analyses may include assumptions involving parameters such as flow paths, velocities, fluxes, gradients, conductivities, anisotropies, boundary conditions, and structural and geohydrologic-unit controls on saturated and unsaturated zone flow. The ongoing process of hypothesis testing helps to increase confidence that the assumptions made in preliminary analyses are either reasonable or not.

2.1.6 Interaction with other studies

The principal application of the activity parameters estimated in the present study is in the evaluation of the regional/subregional saturated-zone hydrology. These parameters are used in models of present-day geohydrologic conditions. The models will then be used for: (1) hydraulic-property estimation; (2) hypothesis testing; (3) sensitivity analyses; (4) data-collection planning; (5) input to site models; and (6) prediction of future hydrologic conditions (Study 8.3.1.5.2.2, Future regional hydrology due to climate changes).

However, the information pertaining to ground-water hydrology developed during this study can also be applied to the development of surface-water, unsaturated-zone, and site saturated-zone models describing present hydrologic regimes.

The Geohydrology Program will consist of two geohydrologic models that will describe two distinct zones of the hydrologic system: the unsaturated zone and the saturated zone. Each of these zones is impacted by surface water; thus a surface-water model will also be developed (in Study 8.3.1.2.1.2, Regional surface-water runoff and streamflow) to provide input to the geohydrologic models. The geohydrologic models will be used at many stages to perform preliminary analyses, to design and analyze tests and experiments, and analyze and interpret field data. The principal hydrologic-modeling effort,

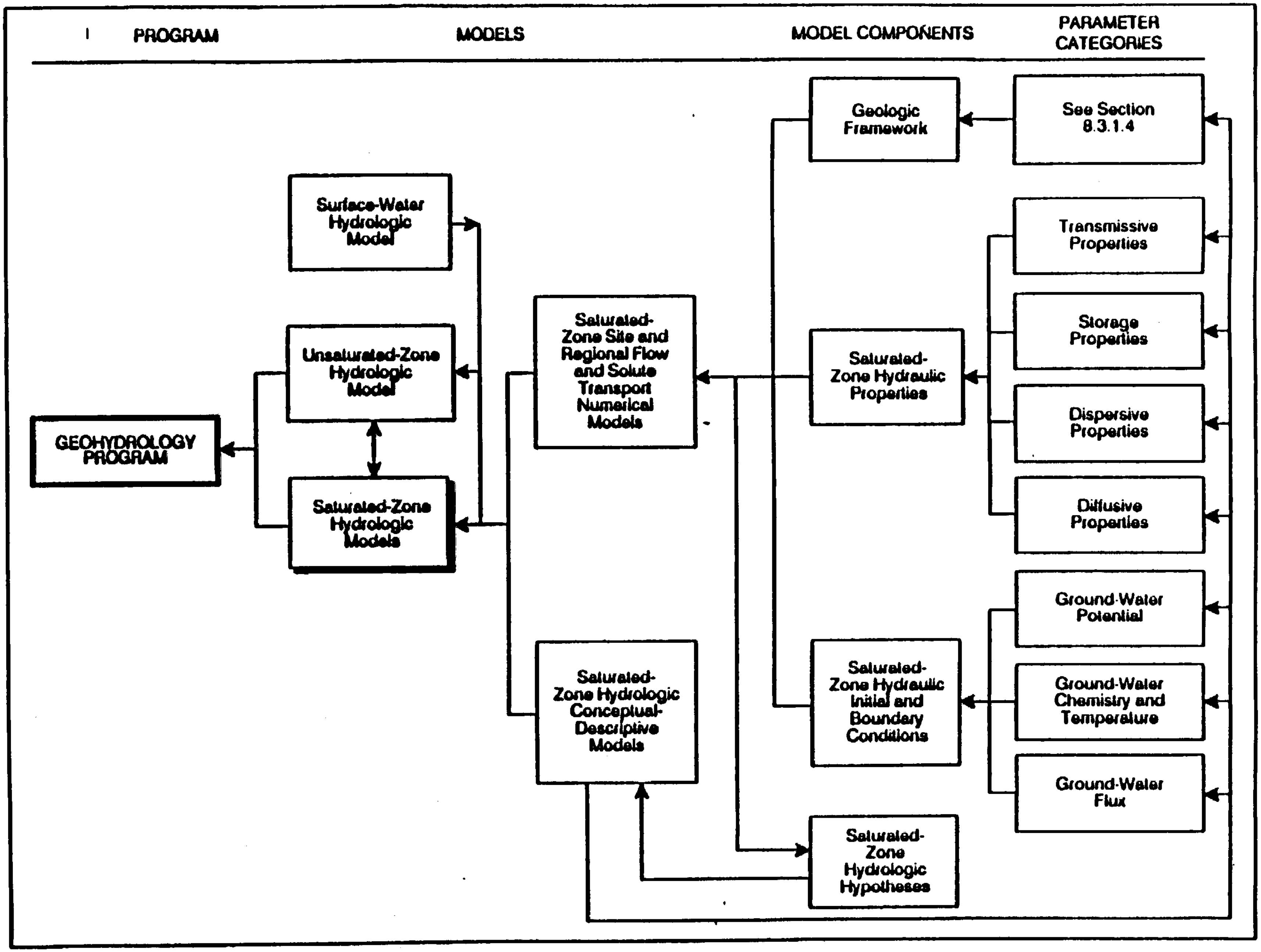

Figure 2.1-3. Logic diagram of the saturated-zone hydrology component of the geohydrology program.

however, is to develop conceptual and numerical representations to simulate the present and expected future geohydrologic system and its components. The use of site information from Geohydrology Program data collection in the saturated-zone hydrologic models is illustrated in Figure 2.1-3.

The saturated-zone geohydrologic models contain four major components: (1) geohydrologic framework (lithology and structure), (2) hydraulic properties of rocks and sediments in the saturated zone, (3) initial and boundary conditions, and (4) alternate hypotheses and assumptions. The first three components form the basis for developing the numerical models that quantitatively describe various aspects of the saturated zone. These components also support the fourth component, the hypotheses of conditions, parameters, and processes.

Each of the modeling activities described in this study plan, and by extension, the geohydrologic models mentioned above, will use data obtained from the following sources: (1) artificial infiltration tests (in Study 8.3.1.2.2.1, Unsaturated-zone infiltration); (2) natural infiltration monitoring (in Study 8.3.1.2.2.1); (3) characterization of percolation in the unsaturated zone (in Studies 8.3.1.2.2.3, Unsaturated-zone percolation - surface-based studies, and 8.3.1.2.2.4, Unsaturated-zone percolation - ESF studies); (4) conceptualization of the unsaturated-zone hydrologic flow system (in Study 8.3.1.2.2.8, Fluid flow in unsaturated, fractured rock); (5) site potentiometric-levels evaluation (in Study 8.3.1.2.3.1, Site saturated-zone ground-water flow); (6) conceptualization of the saturated-zone flow models within the boundaries of the accessible environment (in Study 8.3.1.2.3.3, Site saturated-zone hydrologic system synthesis and modeling); (7) regional hydrochemical tests and analyses (in Study 8.3.1.2.3.2, Saturated-zone hydrochemistry); (8) surface-water runoff studies (in Study 8.3.1.2.1.2, Regional surface-water runoff and streamflow); (9) meteorological monitoring (in Study 8.3.1.2.1.1, Meteorology for regional hydrology); (10) regional seismic refraction studies (in Study 8.3.1.4.2.1, Vertical and lateral distribution of stratigraphic units within the site area); (11) regional-potentiometric levels studies (in Study 8.3.1.2.1.3, Regional ground-water flow system); and (12) regional evapotranspiration studies (in Study 8.3.1.2.1.3). Data from each of these studies will be incorporated into the regional and subregional hydrologic models as it becomes available.

2.2 Constraints on the study

2.2.1 Representativeness of repository scale and correlation to repository conditions

Model development of the site saturated zone will rely on data generated from other studies and activities as site characterization proceeds. Model development will also rely heavily on data from earlier studies. These data will be synthesized to formulate conceptual models of regional and subregional ground-water flow. Therefore, representativeness of these conceptual models with respect to the repository site will depend solely on the quantity and quality of the data. The models (both conceptual and numerical) will continually be checked for agreement and representativeness of the region as new data become available.

2.2.2 Accuracy and precision of methods

Selected methods for testing in each activity are summarized in figures at the end of the activity descriptions. These 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 regional synthesis and modeling activities is difficult to quantify prior to the implementation of the methods. The degree of accuracy and/or precision of each test and method within activities is a qualitative, relative judgement based on the investigators' assessment of the applicability of the methods.

2.2.3 Potential impacts of activities on the site

The activities in the present study do not directly have an impact on the site. The activities do, however, rely on various data-gathering activities which may or may not impact the site (see Section 2.1.6). In addition, results from this study will influence the direction of some activities within other studies as deficiencies in the data base are found. Site impacts of other studies are discussed in their respective study plans.

2.2.4 Time required versus time available

The duration of modeling activities may be months to years. The methods, however, have been selected so that the parameters of interest can be evaluated reasonably within the schedule of the study (Section 5.1). The conceptual modeling activity will last throughout the study. Furthermore, the total duration of the activity is dependent on the number of times the conceptual model is revised, which is dependent on the spatial variability of a parameter within or among geohydrologic units, the desired level of accuracy and precision required for performance assessment, and the desired level of confidence in reproducibility of the modeling activity.

2.2.5 Potential for interference among activities

Because each of the numerical models (Activities 8.3.1.2.1.4.2, 8.3.1.2.1.4.3, and 8.3.1.2.1.4.4) will be based on the conceptual model (Activity 8.3.1.2.1.4.1), internal consistency will be maintained, and the activities of this study will not interfere with each other. Because of the interpretive, non-data-collecting nature of this study, none of the activities of this study will interfere with other site-characterization activities.

3 DESCRIPTION OF ACTIVITIES

This study is organized into four activities:

- 8.3.1.2.1.4.1 - Conceptualization of regional hydrologic flow models,
- 8.3.1.2.1.4.2 - Subregional two-dimensional areal hydrologic modeling,
- 8.3.1.2.1.4.3 - Subregional two-dimensional cross-sectional hydrologic modeling, and
- 8.3.1.2.1.4.4 - Regional three-dimensional hydrologic modeling.

The plans for these activities are described in Sections 3.1, 3.2, 3.3, and 3.4 respectively.

3.1 Conceptualization of regional hydrologic flow models

3.1.1 Objectives

The objectives of this activity are to synthesize available data into a conceptual model that incorporates alternate hypotheses and (or) existing hypotheses, and to make a qualitative analysis of how the regional and subregional ground-water flow systems function.

The primary result of this activity will be a complete, concise, qualitative description of the regional saturated-zone ground-water flow system, given the limitations of the data incorporated into the conceptual model.

Meeting the objectives will provide the framework or basis for development of numerical models of ground-water flow. Data to be incorporated and synthesized in the conceptual model include (1) geohydrologic data, (2) geologic data (lithology and structure, bedrock and surficial geology), (3) geophysical data, (4) geochemical data, and (5) botanical distribution data. The conceptual model will consist of the above data and a series of hypotheses; where more than one hypothesis for a model component is possible, all will be included in the conceptual model and subsequent numerical models. To meet the objectives, the activity will address evaluation of the ground-water flow system boundaries, hydraulic properties of rocks and sediments, structural and stratigraphic features, recharge, discharge, and vertical leakage rates and distribution.

3.1.2 Rationale for activity selection

Conceptual and numerical models of regional ground-water flow currently exist for the Nevada Test Site region and for Yucca Mountain and vicinity (Winograd and Thordarson, 1975; Waddell, 1982; Czarnecki and Waddell, 1984; Sinton, P. O., and Downey, J. S., written communication, 1990). Each of the conceptual models was based on data existing at the time of model development. New or additional data may or may not fit the existing conceptual models, the latter case causing a need to re-evaluate the existing models in the context of new data. Conceptual models (and resultant numerical models) are by necessity a simplification of complex physical properties and processes, based on an incomplete data set. The development and evaluation of conceptual models of regional ground-water flow forms the basis for use and modifications of numerical models of ground-water flow.

A conceptual model of the regional hydrologic system is necessary to assess the suitability of the site for the containment and isolation of waste, because the conceptual model will provide the basis for subsequent numerical models of regional and subregional ground-water flow, and contribute to the geohydrologic framework for site conceptual and numerical models.

3.1.3 General approach and summary of tests and analyses

All reliable data (hydrologic, geologic, and geophysical) will be assimilated into a description of the regional/subregional ground-water flow system. This description may incorporate, to the extent practical: (1) the physical and hydraulic characteristics of sediments, rock-units, and major structural features (faults, fracture zones, lineaments, etc); (2) the distribution, rates, and mechanisms of recharge, discharge, and vertical leakage; (3) measurements of hydraulic head; (4) hydrochemical data; (5) results from geophysical surveys; (6) remote-sensing data; (7) surficial geology (spring deposits and potential recharge areas); and (8) geobotanical relationships (plant mapping to delineate discharge and recharge areas). The data will contain information obtained from the published literature and from site-characterization activities. This conceptual description of the flow system will be used to revise existing regional and subregional ground-water flow models (Waddell, 1982; Czarnecki and Waddell, 1984; Sinton, P. O., and Downey, J. S., written communication, 1990), and to develop new numerical models of ground-water flow. The regional conceptual model will provide the framework for the conceptual model of ground-water flow at the site.

Figure 3.1-1 summarizes the organization of the regional hydrologic flow model conceptualization activity. A descriptive heading for each step/analysis appears in the shadowed boxes of the second row. Below each step/analysis are the individual methods that will be used during testing. The figure summarizes the overall structure of the planned activity in terms of the methods to be employed. The descriptions of 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 information needs of the performance issues, (3) the technical objectives of the activity, and (4) the methods to be used.

3.1.3.1 Synthesis of data

Data, observations, and interpretative results will be gathered from other studies as they become available, and stored in a common data base or a geographic information system (GIS) for subsequent retrieval. Data may be displayed in the form of contour maps, images, random-point plots, or three-dimensional block diagrams (all referred to as "plots"). Composite data sets and plots may be generated, as well as derivative data sets and maps. A derivative data set is one that contains data derived from one or more sets of data by qualitative or quantitative interpretation. For example, the distribution of saturated thickness in an unconfined aquifer can be obtained from ground-water level measurements, stratigraphic thickness data, and land surface altitude data.

Data will be collected as part of Study 8.3.1.2.1.3 (Regional ground-water flow system) and other studies listed in Section 2.1.6. Data from each of these studies will be incorporated into the regional and subregional hydrologic models as it becomes available.

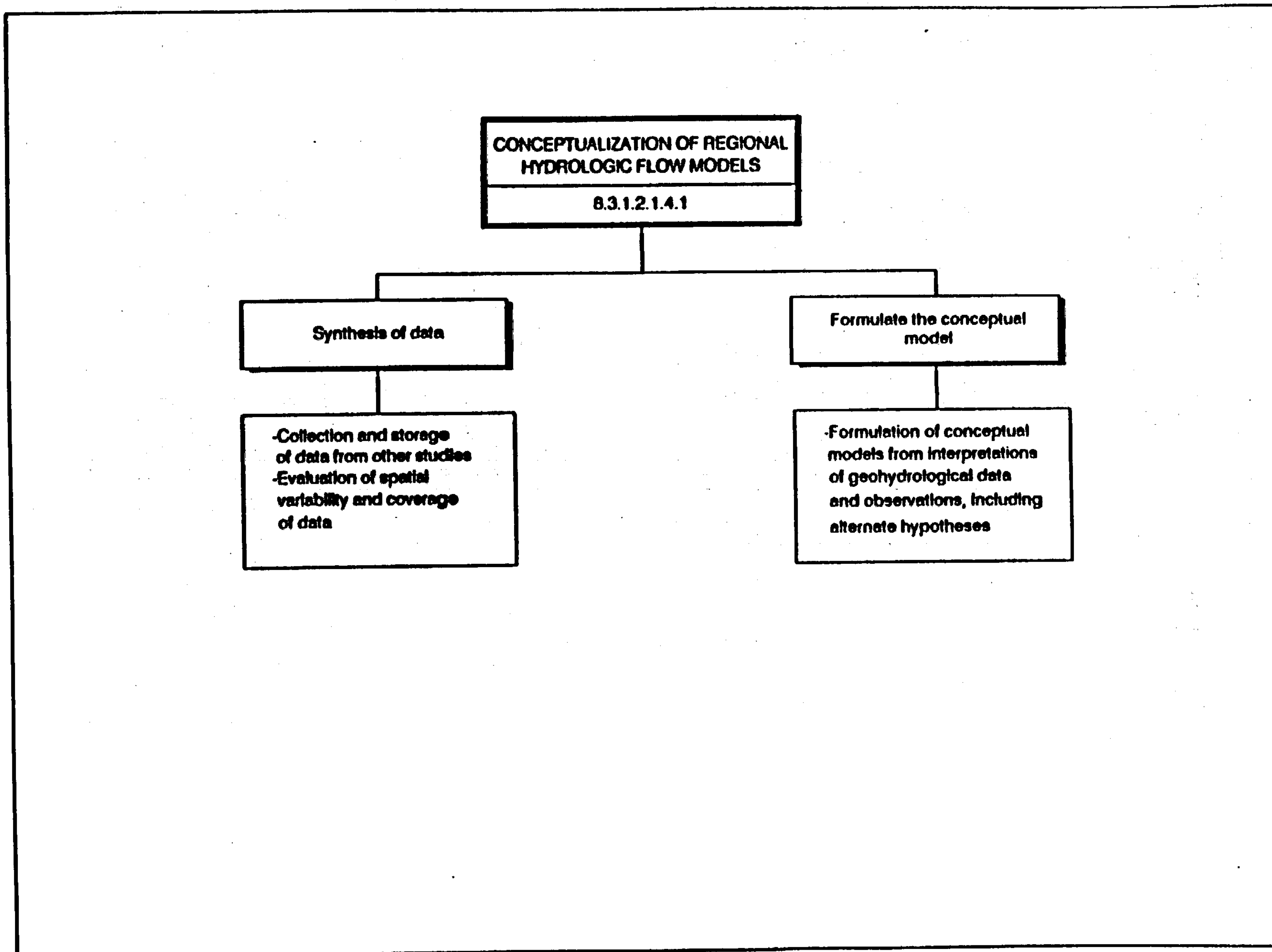

Figure 3.1-1. Organization diagram of conceptualization of regional hydrologic flow models activity, showing tests, analysis, and methods.

Data synthesis will be assisted by the use of geostatistical analysis (such as kriging) for interpolation and extrapolation of hydraulic-head values, and parameter-estimation models for derivation of large-scale values of transmissivity or flux. (See Section 2.1.2 for a more detailed treatment of these methods.) Additional lab or field data may be used or referred to in order to distinguish alternative hypotheses.

3.1.3.2 Formulation of the conceptual model

Concurrent with data synthesis, a conceptual model that incorporates alternate hypotheses will be derived from the data. The conceptual model will incorporate as many of the significant features of the ground-water flow system as possible, but will simplify the ground-water flow system such that numerical models can be applied to the conceptual model. Because the conceptual model will incorporate alternate hypotheses, more than one numerical model may be necessary to adequately describe the conceptual model. Numerical models, in conjunction with the data, will be used to assess the various alternate hypotheses, and choose those hypotheses that are most probable. The conceptual model will be based on data, observations, and interpretations of the data and observations. No specific method exists for formulation of conceptual models because of the interpretive nature of the process; the conceptual modeling process will be based on a mixture of qualitative and quantitative methods.

3.1.3.3 Methods summary

The analyses described in the above sections are summarized in Figure 3.1-1. The synthesis of geohydrologic data and the conceptualization of the regional and subregional geohydrologic system will be accomplished through the use of alternate approaches (i.e., multiple working hypotheses) to explain the observed and measured geologic and hydrologic data. The nature of this activity is such that it will not directly generate activity parameters; this activity is the basis for their generation in the subsequent three activities of the study.

3.1.4 Quality-assurance requirements

Technical procedures do not apply to this activity because: (1) documentation and control of the quality of software used for modeling are subject to the requirements set forth in YMP-USGS QMP-3.03 (Quality Assurance Software); (2) modeling is an analytical and interpretive process, the appropriate application of which is assured by technical review as set forth in YMP-USGS QMP-3.04 (Technical Review, Approval, and Distribution of YMP-USGS Publications); and (3) data used in modeling are collected under other studies (listed in Section 2.1.6) for which technical procedures are assigned.

3.2 Subregional two-dimensional areal hydrologic modeling

3.2.1 Objectives

The overall objective of this activity is to incorporate additional geohydrologic data into previous models of the subregional flow system of Yucca Mountain and vicinity, and modify them as necessary.

Subordinate objectives of the activity are:

(1) to evaluate alternate hypotheses of how the ground-water flow system functions;

(2) to provide a synthesis of the hydrogeological framework and boundary conditions for site models;

(3) to improve estimates of the direction and magnitude of regional ground-water flow and estimates of the hydraulic properties of geologic materials by using a numerical model; and

(4) to perform sensitivity analyses for the purpose of identifying key ground-water flow-system parameters, for the purpose of directing future data-collection activities.

The two-dimensional areal hydrologic model will also be used, as part of other studies (see Section 4.2), for predictive simulations that will be used to evaluate the response of the ground-water flow system to changes in climate, human interference, and tectonic deformation.

3.2.2 Summary of previous work

Regional hydrogeologic data delimit an elongated ground-water basin crossing several topographic divides. It extends from Pahute Mesa 145 kilometers (90 miles) south to the Amargosa Desert and Death Valley. Yucca Mountain lies near the center of the basin. Due to the great depths to the water table in the central and northern part of the basin, and to the highly complex nature of the hydrogeology of the basin, data are limited and interpretive uncertainty is great.

Hydraulic properties of rocks and sediments have been measured in many deep drillholes in the vicinity of the Nevada Test Site (Winograd and Thordarson, 1975). Many uncertainties remain, limiting the degree of accuracy available in site-specific applications. The hydraulic properties of the hydrogeologic units vary greatly within the ground-water basin. These units include volcanic-rock, carbonate-rock, and basin-fill aquifers as well as clastic and crystalline units of low permeability. These low-permeability units probably act as major barriers to ground-water flow and have a major impact on regional and subregional ground-water flow direction and magnitude. In addition, faults, fracture zones, and lineaments within the ground-water basin may act either as barriers or conduits to ground-water flow, and may explain anomalously large hydraulic gradients and unusual ground-water flow paths found in certain locations, such as north-northeast of the design repository area.

Regional and subregional ground-water flow modeling (Waddell, 1982; Czarnecki and Waddell, 1984; Czarnecki, 1985; Sinton, P. O., and Downey, J. S., written communication, 1990) has incorporated regional heterogeneities of the various hydrogeologic units, and has acceptably represented the ground-water flow system under specified assumptions. (Boundaries of regional and subregional ground-water flow systems are shown in Figure 1.1-2.) Major assumptions inherent in regional models pertain to the distribution and rates of ground-water recharge and discharge, and distribution of regional transmissivities. Recharge estimates across model boundaries are often crude, because of the lack of sufficient hydraulic gradient data and hydraulic properties data for the hydrogeologic units.

A subregional, finite-element model of two-dimensional ground-water flow has been developed by Czarnecki and Waddell (1984) to estimate ground-water flow direction and magnitude. Since the time that these model results were published, numerous additional studies and data collection activities have occurred in and around the modeled area (Figure 3.2-1). Additional drillholes have been constructed in the study area, yielding further potentiometric data and information about hydraulic properties. Potentiometric data are used, in part, as a basis for model calibration. They are also used as an indicator of changes in hydraulic properties, based on changes in hydraulic gradients.

3.2.3 Rationale for activity election

A subregional areal numerical model of ground-water flow will be constructed or an existing numerical model (Czarnecki and Waddell, 1984) will be revised in terms of the current conceptual model. The subregional areal numerical model of ground-water flow will be used to specify reliable boundary conditions for the more critical site-area models (Study 8.3.1.2.3.3, Site saturated-zone hydrologic system synthesis and modeling) embedded within the subregional model. To do so, fluxes and hydraulic heads at boundaries of the regional system are required, as well as the regional hydraulic properties of rocks and sediments. The subregional areal numerical model will also provide input to the two-dimensional cross-sectional numerical model (Section 3.3). This input will consist of boundary conditions, material properties, and selection of the horizontal flow path or paths that the cross-sectional model will simulate.

Two-dimensional areal modeling will be performed in parallel with the two-dimensional cross-sectional modeling of Activity 8.3.1.2.1.4.3 (Section 3.3). The validity of areal modeling will be tested by the results of the cross-sectional modeling, and the investigators recognize that the applicability of the areal approach depends upon the results of the cross-sectional approach (i.e., whether or not vertical flow is a major or minor component of ground-water flux).

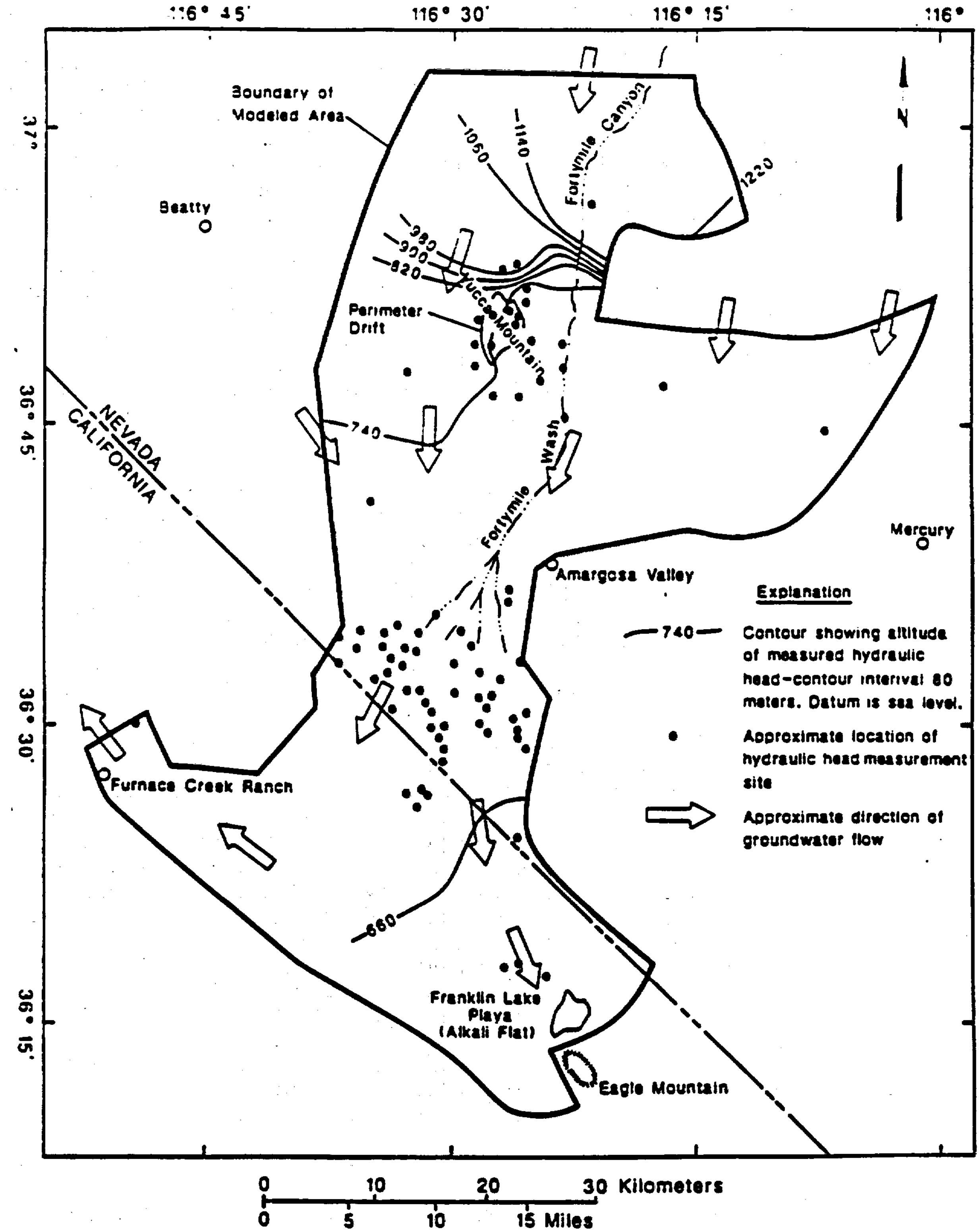

Figure 3.2-1. Subregional ground-water flow system showing general directions of ground-water flow.

The subregional areal numerical model may be used to predict future hydrologic conditions resulting from climate change, human interference, and tectonic deformation (see Section 4.2). Before predictive simulations can be done, the model must be calibrated; this requires reliable estimates of the hydraulic properties of materials and boundary conditions. Data from paleohydrologic studies, tectonic studies, paleoclimatic studies, and estimates of possible future ground-water use will be used as a basis for the predictive simulations. Use of numerical ground-water flow models is the most efficient and accurate method for assessment of future hydrologic conditions.

Data collection is a major part of the site-characterization process, and, although modeling activities do not collect or measure parameters, sensitivity analyses of numerical models provide a powerful technique for identifying key ground-water flow-system parameters. Sensitivity analyses will be performed to aid in the model calibration process, and, after the model is calibrated as much as it can be, given available data, to direct and prioritize future data-collection activities.

This activity will also provide quantitative evaluations of alternate hypotheses incorporated in the conceptual model. New numerical models will be constructed, if necessary, so that the alternatives can be assessed. For example, if there is strong evidence that thermal convection plays a significant role in the flow of ground water on the subregional scale, then numerical modeling will be performed to evaluate this potential alternate hypothesis.

3.2.4 General modeling approach and summary of tests and analyses

All ground-water numerical modeling studies have several basic features and methods in common; the general methodology to be employed in this activity is described in Section 2.1.2. As explained in that section, numerical models produced during this activity will probably assume the diffusion equation adequately describes the flow of ground water through rocks and sediments underlying the subregional area. Conceptual models formulated in Activity 8.3.1.2.1.4.1 (Section 3.1) and data used to support such models will be used as the basis for the subregional two-dimensional areal numerical model. The data and interpretations required for subregional two-dimensional areal hydrologic modeling are the same as those required for Activity 8.3.1.2.1.4.1, and are discussed at the beginning of Section 3.1.3. Data will be collected as part of Study 8.3.1.2.1.3 (Regional ground-water flow system) and other studies listed in Section 2.1.6. Data from each of these studies will be incorporated into the subregional hydrologic model as it becomes available.

Figure 3.2-2 summarizes the steps (analyses) in the subregional two-dimensional areal modeling process. A descriptive heading for each modeling step appears in the shadowed boxes of the second and fourth rows. Below each step are the individual methods that will be used during testing. Figure 3.2-3 summarizes the objectives of the activity, the characterization parameters, and the activity parameters which are

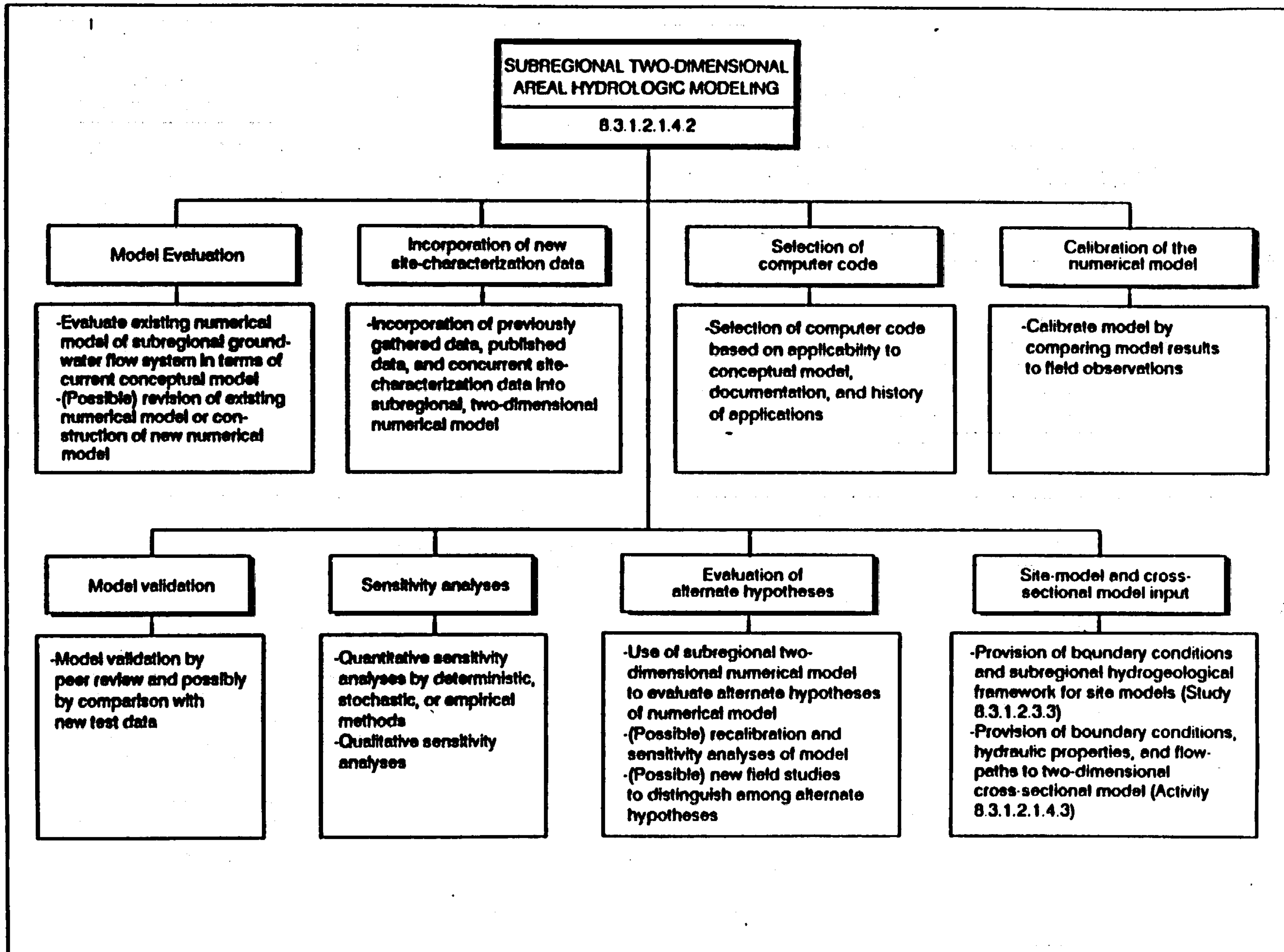

Figure 3.2-2. Organization diagram of subregional two-dimensional areal hydrologic modeling activity, showing tests, analyses, and methods.

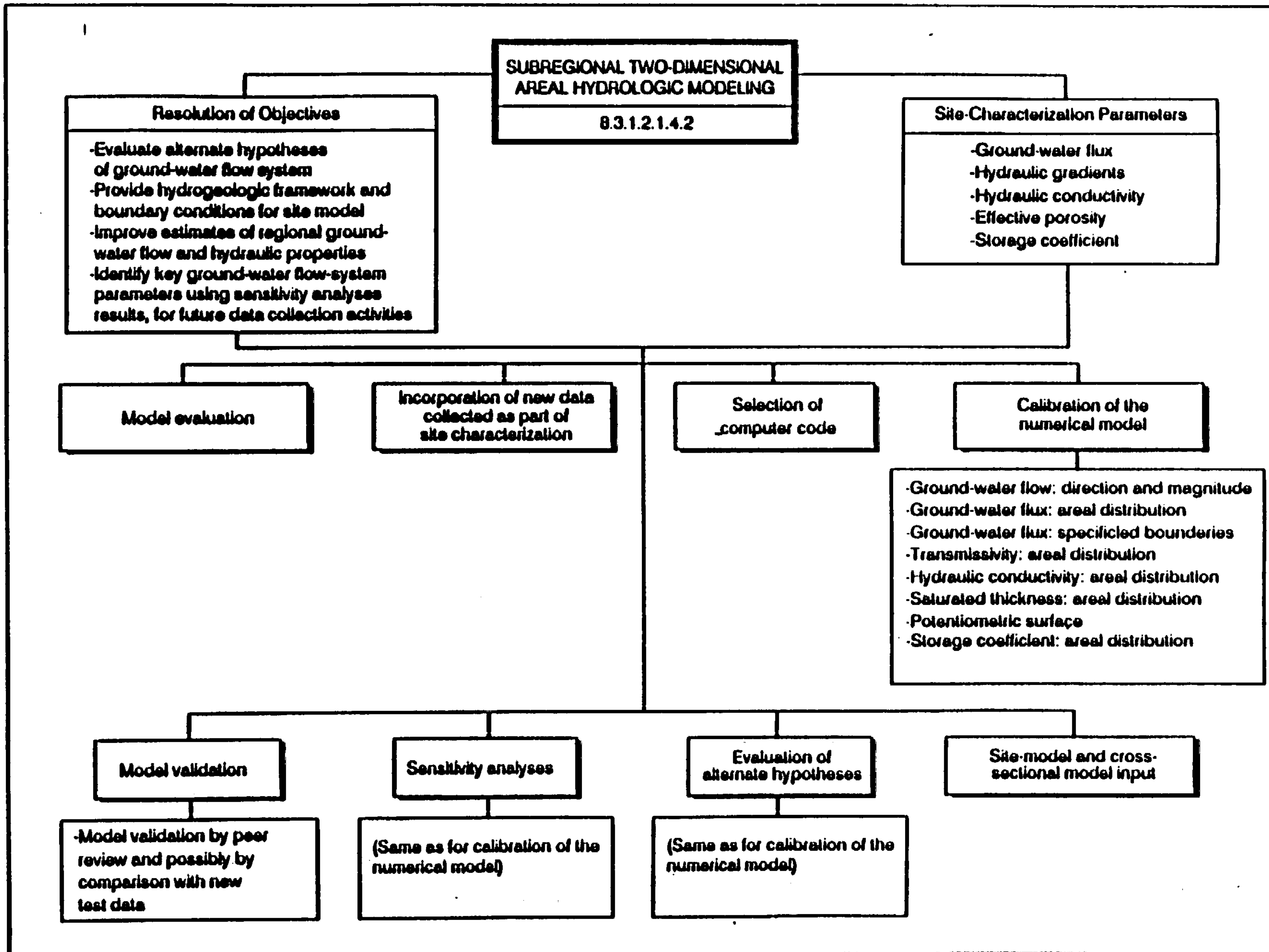

Figure 3.2-3. Organiza... n diagram of subregional two-dimensional areal hydrologic modeling activity, showing tests, and activity parameters.

addressed by the activity. These appear in the boxes in the top left side, top right side, and, below the shadowed modeling-step boxes, respectively, in Figure 3.2-3. The two figures summarize the overall structure of the planned activity in terms of methods to be employed and estimates and results to be obtained. The descriptions of 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 information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

3.2.4.1 Model evaluation

An existing numerical model of the subregional ground-water flow system (Czarnecki and Waddell, 1984) will be evaluated in terms of the current conceptual model of the subregional ground-water flow system. Depending on the outcome of the evaluation, the existing model may be revised according to the current conceptual model or a new numerical model may be constructed.

3.2.4.2 Incorporation of new site-characterization data

Conceptual models formulated in Activity 8.3.1.2.1.4.1 (Section 3.1) and data used to support such models will be used as the basis for the subregional areal numerical model. Previously gathered data, published data, and site-characterization data gathered concurrently with modeling studies that will be used in construction of the subregional areal numerical model are discussed in Section 3.1.3. Data collected during the modeling process (Section 2.1.2) will be considered and evaluated in the context of the existing model. New data of particular interest are discussed below.

Geophysical studies have produced additional information regarding stratigraphic and structural features in and around the site. Of particular utility is seismic refraction work that the USGS has performed and will be performing (Study 8.3.1.4.2.1, Vertical and lateral distribution of stratigraphic units within the site area) to define the location, type, and distribution of structural and stratigraphic units, in and around the study area, that may affect ground-water flow. While hydraulic properties in the vertical dimension are lumped when used in the areal two-dimensional ground-water flow model, information such as effective saturated thickness can be combined with model ground-water flux estimates to yield estimates of ground-water travel times. Data collected in the vertical dimension also aids in the development of three-dimensional models of groundwater flow. Other geophysical studies that will produce results that may be incorporated into the model include: resistivity surveys, gravity surveys, aeromagnetic surveys, seismic reflection surveys, and borehole geophysical surveys. All these various activities have the potential for providing additional data on the distribution, type, and properties of stratigraphic and structural units, for use in the subregional areal ground-water flow model. Results from these various activities will be reviewed as they become available, and incorporated into the model as appropriate.

Additional hydrogeologic data will be provided from the analyses of drillhole cuttings from exploration boreholes constructed in the Amargosa Desert by a commercial mining company (potentiometric levels evaluation in Study 8.3.1.2.1.3, Regional ground-water flow system). These analyses will provide further knowledge of the areal and vertical distributions of hydraulic conductivity, porosity, bulk density, lithology, and stratigraphy. Additional estimates of hydraulic conductivity will be provided by monitoring the recovery of water levels in wells and piezometers after they have been pumped for hydrochemical samples (Study 8.3.1.2.3.2, Saturated-zone hydrochemistry). The need for additional information on the distribution of hydrogeologic properties will be evaluated as part of a regional data-needs assessment in Study 8.3.1.2.1.3.

Annual evapotranspiration estimates in Study 8.3.1.2.1.3 have been made at Franklin Lake playa (Czarnecki, 1990). The need for these estimates stemmed from the sensitivity analyses done by Czarnecki and Waddell (1984). These improved estimates will be used in the two-dimensional subregional areal model as one of the discharge boundary conditions. In addition, recharge estimates made at Fortymile Wash (Study 8.3.1.2.1.3) will be used in the model; other refinements in recharge estimates throughout the study area will also be used.

Hydrochemical studies at site and regional scales (Study 8.3.1.2.3.2) will provide additional data that will be incorporated into modeling activities. Analyses of hydrochemical samples will help to define the flow paths of ground water through various lithologies, to account for the evolution of various water chemistries and ages. This hydrochemical perspective is often used as a partial basis for conceptual models of ground-water flow.

3.2.4.3 Selection of computer code

The selection of the computer code or codes to be used during this activity will be based on (1) the applicability of the computer code to the conceptual model, (2) the degree of documentation associated with the code, and (3) the number of times and the types of ground-water flow system problems to which the computer code has been applied. A selected code must apply to the conceptual model on which the numerical model is to based. Well documented codes are more desirable for the purposes of quality assurance and traceability. Computer codes that have been verified in modeling studies outside the site-characterization program are also desirable for the purposes of quality assurance and traceability. One possibility is the USGS MODFE code (Torak, L. J., in press); however, other computer codes will be considered. An advantage to using the finite element code, MODFE, is that it can readily be used to simulate three-dimensional ground-water flow by adding vertical layers to an existing areal two-dimensional configuration. This flexibility is useful but is tempered by the lack of reliable three-dimensional hydrogeologic data throughout the flow system. As data become available, they will be used to the extent possible in this activity and in Activity 8.3.1.2.1.4.4 (Regional three-dimensional hydrologic modeling).

3.2.4.4 Calibration of the numerical model

The numerical model will be calibrated to the extent possible by adjusting model variables to minimize differences between simulated hydraulic head, transmissivity, and recharge and discharge with measured or estimated field values. Adjustment of model variables (such as transmissivity) is done within the context or constraints of the hydrogeologic framework developed as part of the conceptual model. (The calibration process is defined in Section 2.1.2.) Simulation results will include estimates of hydraulic properties, boundary conditions, horizontal hydraulic gradients, and the magnitude and direction of ground-water flow.

3.2.4.5 Model validation

The numerical model will undergo validation by competent peer review and by comparison with new field test data, as described in Section 2.1.2.

3.2.4.6 Sensitivity analyses

Sensitivity analyses will be used during the model-calibration process, as discussed in Section 2.1.2, to determine the effects of changing key model variables values.

3.2.4.7 Evaluation of alternate hypotheses

Alternate hypotheses incorporated into the conceptual model will be evaluated using the numerical model. The evaluation process may require re-calibration of the model and new sensitivity analyses. Field studies may be designed to distinguish between alternative hypotheses, based on the new sensitivity analyses. This implies a cyclic process: new data collected from other studies may require changes in the conceptual model and the numerical model, and numerical modeling results may indicate what types of new data and where new data should be collected to distinguish between the various alternate hypotheses.

3.2.4.8 Site-model and cross-sectional model input

After the numerical model has been calibrated, estimates of boundary conditions will be provided for the site model. In addition, this activity will also provide the subregional hydrogeological framework for the site model.

The subregional two-dimensional cross-sectional hydrologic modeling activity (Section 3.3) will also receive data from the two-dimensional areal numerical model. Boundary conditions and estimates of the hydraulic properties of materials from this activity may be used in the cross-sectional model. The selection of appropriate ground-water flow paths for the cross-sectional model may be based on results from this activity.

3.2.4.9 Methods summary

The activity parameters to be determined by the tests and analyses described in the above sections, and the selected methods for evaluating the parameters, are summarized in Figures 3.2-2 and 3.2-3. Alternate methods may be utilized only if selected methods are impractical to measure the parameter(s) of interest. The USGS investigators have selected modeling approaches which they believe are suitable to provide reliable data within the expected ranges of the activity parameters.

3.2.5 Quality-assurance requirements

Technical procedures do not apply to this activity because: (1) documentation and control of the quality of software used for modeling are subject to the requirements set forth in YMP-USGS QMP-3.03 (Software Quality Assurance); (2) modeling is an analysis and interpretation activity, the appropriate application of which is assured by technical review as set forth in YMP-USGS-QMP-3.04 (Technical Review, Approval, and Distribution of YMP-USGS Publications); and (3) data used in modeling are collected under other studies (listed in Section 2.1.6) for which technical procedures are assigned.

3.3 Subregional two-dimensional cross-sectional hydrologic modeling

3.3.1 Objectives

The main objective of this activity is to estimate the ground-water flow direction and magnitude along a possible ground-water flow path in the saturated zone beneath the potential repository area to the accessible environment. The model will be constructed to evaluate the vertical component of ground-water flux and to examine the hydraulic significance of heterogeneities that may be caused by structural features (such as faults and fracture zones). The model will also evaluate the vertical component of ground-water flux in the saturated zone. An additional cross-sectional model for the area of large hydraulic gradient may also be constructed. The subordinate objectives stated in Section 3.2.1 also apply to this activity.

The two-dimensional cross-sectional hydrologic model will also be used, as part of other studies (see Section 4.2), for predictive simulations that will be used to evaluate the response of the ground-water flow system to climate changes, human interference, and tectonic deformation.

3.3.2 Rationale for activity selection

The subregional two-dimensional cross-sectional hydrologic modeling activity will provide an assessment of ground-water flow direction and magnitude along a ground-water flow path through the site. The activity will also be used to test hypotheses and, possibly (in later investigations), to predict ground-water flow system response to potential changes in future boundary conditions and material properties.

The objectives of the this activity will be accomplished by developing a two-dimensional cross-sectional numerical model of ground-water flow along a flow line from areas upgradient from the potential repository area to the discharge area in the vicinity of Franklin Lake playa. This cross-sectional model will be based on the current conceptual model and data incorporated into the conceptual model. The possible smaller cross-sectional model in the large-gradient area would also assist in meeting activity objectives.

Sensitivity analyses will be done to evaluate the effect of saturated thickness distribution and vertical heterogeneities on the magnitude and direction of ground-water flow. These analyses will provide insight regarding the ground-water flow system, despite the fact that horizontal ground-water flow components in the plane of the cross section (horizontal cross-flow) may affect the validity of the model. Ground-water flow-paths will be selected such that horizontal cross-flow effects will be minimized.

The cross-sectional line shown in Figure 3.3-1 is based on a potential flow path estimated by Czarnecki and Waddell (1984) using a two-dimensional areal, numerical ground-water flow model. The boundaries of the conceptual models are based merely on a flow path

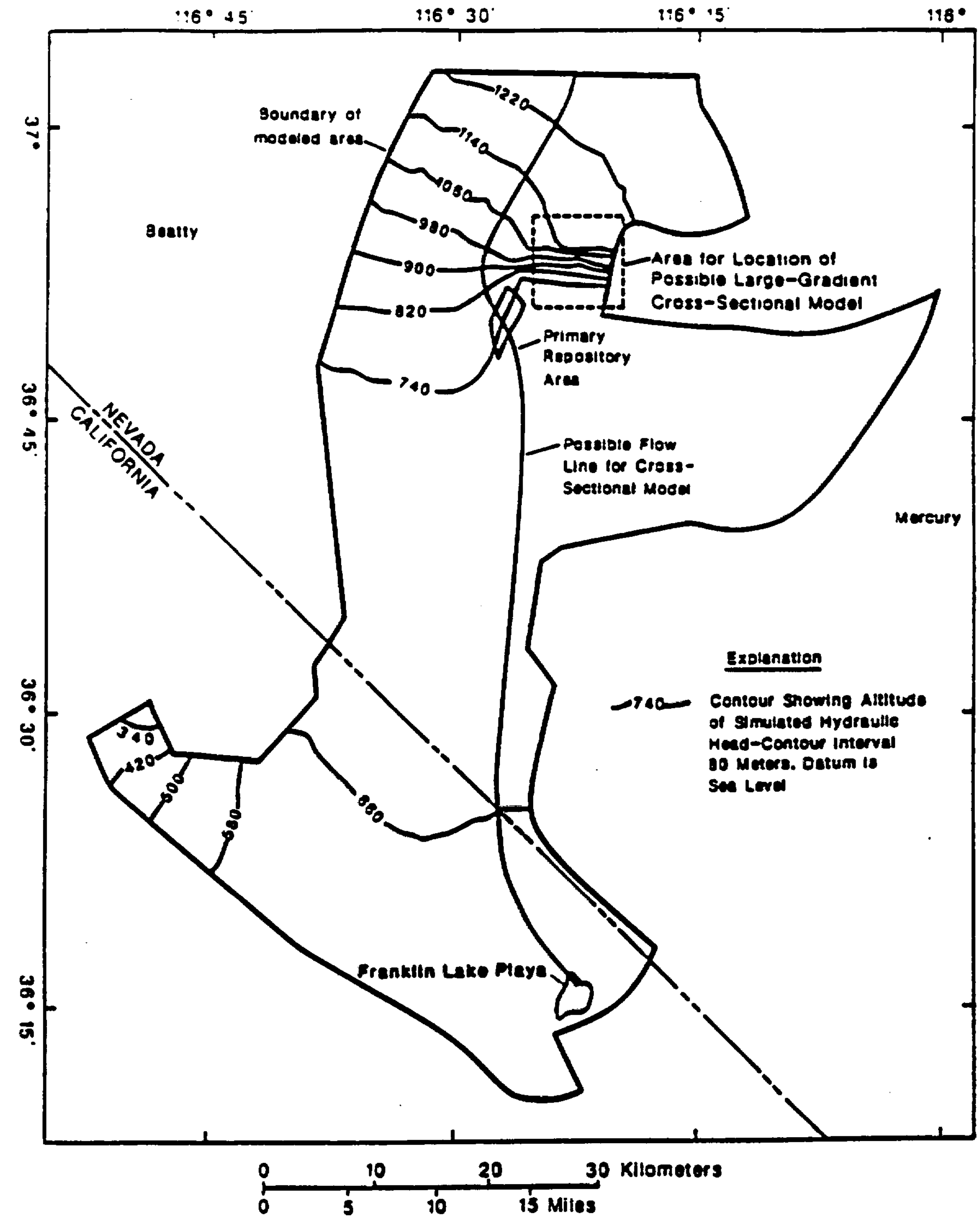

Figure 3.3-1. Possible location of two-dimensional cross-sectional model.

constructed from the two-dimensional model. One of the basic assumptions made in using the areal model is that ground-water flow is strictly horizontal. By modeling along a cross section, this assumption can be tested, particularly from the repository block to the accessible environment. If the vertical component is minor, then the two-dimensional areal modeling approach may be valid. A vertical component of ground-water flow would lengthen the ground-water flow path, and possibly increase ground-water travel time. A three-dimensional representation of the flow system at the scale of the site is necessary to properly characterize solute transport processes. Detailed three-dimensional modeling is discussed in YMP-USGS SP 8.3.1.2.3.3 (Site saturated-zone hydrologic system synthesis and modeling).

Results from the two-dimensional cross-sectional model may be used, in conjunction with other models and studies that are designed to estimate effective porosity at the site, as a basis for estimating ground-water travel time from the site to the accessible environment. Because the model will be used principally to identify in a qualitative sense the significance of vertical flow components, isotropic conditions will be assumed throughout the model section; however, anisotropic conditions may be incorporated in the model if warranted.

3.3.3 General modeling approach and summary of tests and analyses

All ground-water numerical modeling studies have several basic features and methods in common; the general methodology to be employed in this activity is described in Section 2.1.2. As stated in that section, numerical models produced during this activity will probably assume that the diffusion equation adequately describes the flow of ground-water through rocks and sediments underlying the subregional area. Conceptual models formulated in the conceptualization of regional hydrologic flow models activity (Section 3.1) and data used to support such models will be used as the basis for the subregional cross-sectional numerical model. The data and interpretations required for subregional two-dimensional cross-sectional hydrologic modeling are the same as those required for Activity 8.3.1.2.1.4.1, and are discussed at the beginning of Section 3.1.3. Data will be collected as part of Study 8.3.1.2.1.3 (Regional ground-water flow system) and other studies listed in Section 2.1.6. Data from each of these studies will be incorporated into the subregional cross-sectional model as it becomes available.

Figure 3.3-2 summarizes the steps (analyses) in the two-dimensional cross-sectional modeling process. A descriptive heading for each modeling step appears in the shadowed boxes of the second and fourth rows. Below each step are the individual methods that will be used during testing. Figure 3.3-3 summarizes the objectives of the activity, characterization parameters, and activity parameters which are addressed by the activity. These appear in the boxes in the top left side, top right side, and, below the shadowed modeling-step boxes, respectively, in Figure 3.3-3. The two figures summarize the overall structure of the planned activity in terms of methods to be employed and estimates and results to be obtained. The descriptions of the following sections are organized on the basis of these charts. Methodology and parameter

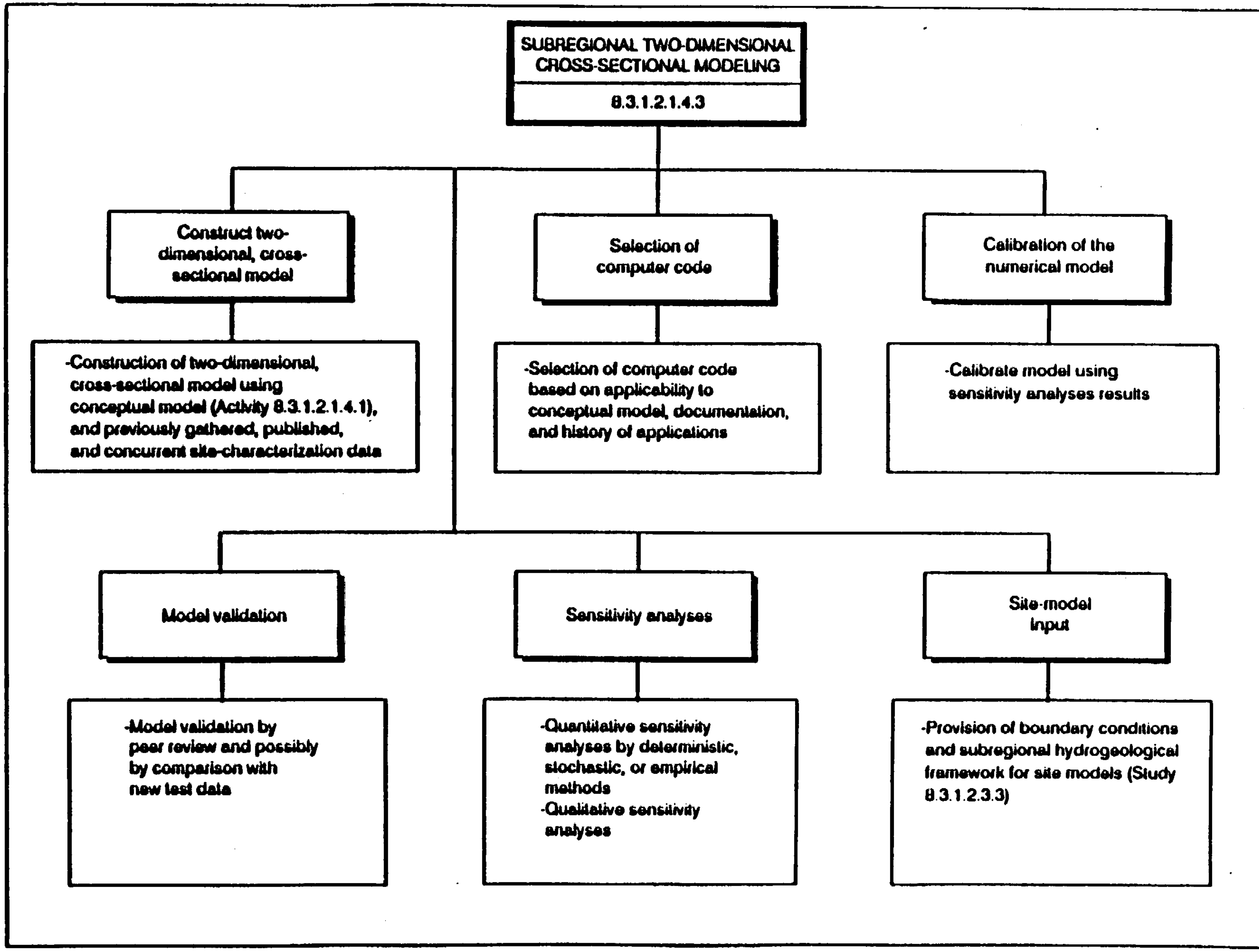

Figure 3.3-2. Organization diagram of subregional two-dimensional cross-sectional modeling activity, showing tests, analyses, and methods.

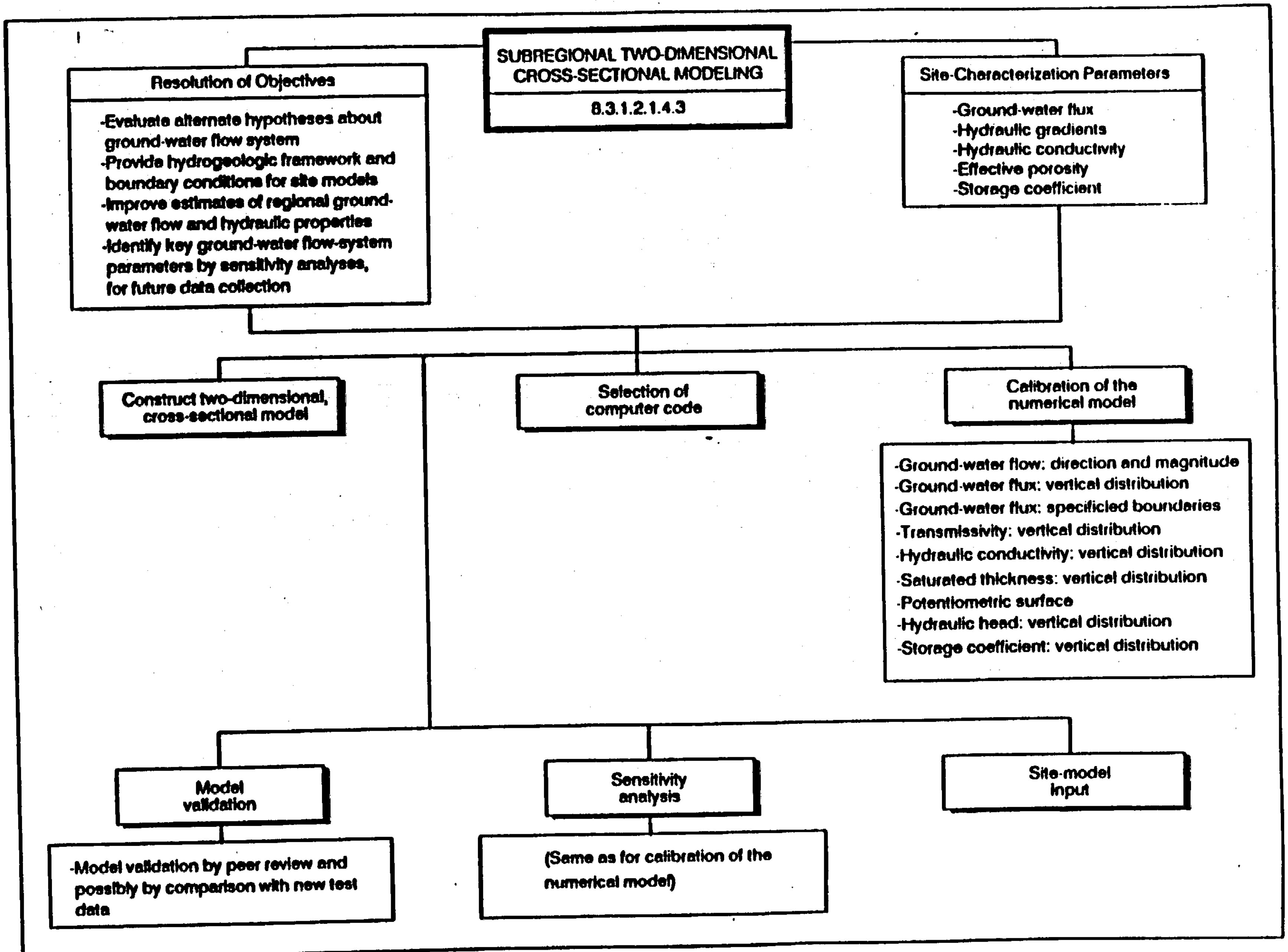

Figure 3.3-3. Organization diagram of subregional two-dimensional cross-sectional modeling activity, showing tests, and activity parameters.

information are tabulated as a means of summarizing the pertinent relations among (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.

3.3.3.1 Construct two-dimensional, cross-sectional model

Conceptual models formulated in the conceptualization of regional hydrologic flow models activity (Section 3.1) and data used to support such models will be used as the basis for the cross-sectional numerical model. Previously gathered data, published data, and site-characterization data gathered concurrently with modeling studies that will be used in construction of the subregional ground-water flow system cross-sectional model are discussed in Sections 2.1.2 and 3.1.3. New data of particular interest (geophysical, geohydrological, and hydrochemical) are those detailed earlier in Section 3.2.4.2.

A two-dimensional, cross-sectional model of ground-water flow in the saturated zone will be constructed along a potential flow line through Yucca Mountain (Figure 3.3-1). The line of cross section shown in Figure 3.3-1 was obtained by following vectors of ground-water flow from Plate 2 of Czarnecki and Waddell (1984). A shorter two-dimensional cross-sectional model may also be constructed through the area of large hydraulic gradient (dashed area in Figure 3.3-1). However, this effort will likely encounter problems in specifying boundary fluxes, and with calculational difficulties in the model code. Steady-state conditions will be evaluated in the model; however, transient conditions may also be simulated.

3.3.3.2 Selection of computer code

The selection of the computer code or codes to be used during this activity will be based on the criteria described in Section 3.2.4.3.

3.3.3.3 Calibration of the numerical model

The numerical model will be calibrated to the extent possible by adjusting model variables to minimize differences between simulated hydraulic head, transmissivity, recharge and discharge with measured or estimated field values. Adjustment of model variables (such as transmissivity) is done within the context or constraints of the hydrogeology framework developed as part of the conceptual model. (The calibration process is defined in Section 2.1.2.) Sensitivity analyses are useful for identifying and characterizing key model variables, and indicate relations between model variables. Sensitivity analyses provide a quantitative technique for efficient and accurate model calibration. Simulation results will include estimates of hydraulic properties, boundary conditions, horizontal and vertical hydraulic gradients, and the magnitude and direction of ground-water flow along the flow path.

3.3.3.4 Model validation

The numerical model will undergo validation by competent peer review and by comparison with new field test data, as described in Section 2.1.2.

3.3.3.5 Sensitivity analyses

Sensitivity analyses will be used during the model-calibration process, as discussed in Section 2.1.2, to determine the effects of changing key model variables values.

3.3.3.6 Site-model input

After the numerical model has been calibrated, estimates of boundary conditions will be provided for the site models. In addition, this activity will also provide the subregional geohydrological framework for the site models.

3.3.3.7 Methods summary

The activity parameters to be determined by the tests and analyses described in the above sections, and the selected methods for evaluating the parameters, are summarized in Figures 3.3-2 and 3.3-3. Also listed are the selected methods for determining the parameters. Alternate methods may be utilized only if selected methods are impractical to measure the parameter(s) of interest. The USGS investigators have selected modeling approaches which they believe are suitable to provide reliable data within the expected ranges of the activity parameters.

3.3.4 Quality-assurance requirements

Technical procedures do not apply to this activity because: (1) documentation and control of the quality of software used for modeling are subject to the requirements set forth in YMP-USGS QMP-3.03 (Software Quality Assurance); (2) modeling is an analysis and interpretation activity, the appropriate application of which is assured by technical review as set forth in YMP-USGS QMP-3.04 (Technical Review, Approval, and Distribution of YMP-USGS Publications); and (3) data used in modeling are collected partly under other activities (listed in Section 2.1.6) for which technical procedures are assigned.

3.4 Regional three-dimensional hydrologic modeling

3.4.1 Objectives

The objective of this activity is to construct a three-dimensional model of the regional ground-water flow system of Yucca Mountain and vicinity. The subordinate objectives stated in Section 3.2.1 also apply to this activity.

The three-dimensional hydrologic model will also be used, as part of other studies, for predictive simulations that will be used to evaluate the response of the ground-water flow system to changes in climate, human interference, and tectonic deformation (see Section 4.2).

3.4.2 Summary of previous work

Previous work on the geohydrology of the Yucca Mountain region is summarized in Section 3.2.2..

A preliminary quasi-three-dimensional, finite-difference, steady-state model of the regional ground-water flow system in the vicinity of Yucca Mountain, Nevada, has been developed (Sinton and Downey, written communication). This model used the USGS Modular Model computer code (McDonald and Harbaugh, 1988). There are other potential computer codes that could be used to simulate ground-water flow in three dimensions (SUTRA, HST3D, etc.). The Modular Model is one of the best documented computer programs available for the simulation of saturated ground-water flow in three dimensions. The areal extent of the model generally coincides with that used by Waddell (1982) (Figure 1.1-2). By using a quasi-three-dimensional model to simulate regional ground-water flow, a full accounting of the water budget can be made, and flow within discrete hydrogeologic units can be analyzed. Specifying boundary conditions at ground-water basin margins serves two purposes: (1) boundary conditions can be specified in a spatially correct manner; and (2) boundaries will have less effect on the interior parts of the modeled area. In addition, a refinement in the finite-difference grid can be utilized to more accurately simulate large gradients in the vicinity of Yucca Mountain.

The preliminary model contained two layers that simulated horizontal flow in each of two major hydrogeologic units in the study area: (1) a combination of the Plio-Pleistocene deposits and the Miocene volcanic rocks, and (2) the Paleozoic carbonate rocks. Proterozoic rocks were treated as no-flow units. Vertical flow between the two hydrogeologic units was simulated by a leakance layer in the model. The leakance layer represented the composite effects of upper and lower layer thicknesses, vertical hydraulic conductivities, and any intervening low-permeability zones present. The technical basis for using the leakance layer in the quasi-three-dimensional model is discussed in McDonald and Harbaugh (1988). With the existing data base, use of more than two layers to represent the regional ground-water-flow system is not expected to be justified because of a sparsity of data on the three-dimensional hydrogeologic properties of the system. This quasi-three-dimensional (or layered) simulation of the saturated zone is needed because of the differences in hydraulic properties between the two major hydrogeologic units and the differences in potentiometric head (50 to 60 ft, 16 to 20 m) between the two units. These differences in hydraulic properties and potentiometric head could not be simulated with a single-layered, two-dimensional model.

Since the time that this preliminary modeling study was completed, numerous additional studies and data collection activities have occurred in and around the modeled area (Figure 1.1-2). Additional drillholes have been constructed in the study area, yielding further potentiometric data and information about hydraulic properties. Potentiometric data are used, in part, as a basis for the model calibration process. These data also may be used to indicate changes in transmissivity, based on changes in hydraulic gradients.

3.4.3 Rationale for activity selection

A regional three-dimensional numerical model of ground-water flow will be constructed or an existing numerical model (Sinton and Downey, written communication) will be revised to incorporate the changes in conceptual model. The digital model will be used to provide: (1) a synthesis of the available hydrogeologic data, estimates of the direction and magnitude of ground-water flow and hydraulic properties of the hydrogeologic units; (2) necessity and type of additional data collection (as indicated by sensitivity analyses); (3) a quantitative method for evaluating alternate hypotheses; (4) boundary conditions and hydrogeologic framework for site models; and (5) means for analyzing (in other investigations; see Section 4.2) the possible effects of changes in future stresses on the hydrologic system such as increased recharge resulting from future climatic changes, potential increased ground water pumping and other human interference, and changes in hydrogeologic properties resulting from tectonic deformation.

Data synthesis will be assisted by the use of geostatistical analysis for interpolation and extrapolation of hydraulic-head values, and parameter-estimation models for derivation of large-scale values of transmissivity or flux. (See Section 2.1.2 for a more detailed treatment of these methods.)

The need for the development of a three-dimensional model is derived from various factors. Large hydraulic gradients have been documented at Yucca Mountain, indicating the potential for a significant component of vertical flow. Other areas with large gradients include Yucca Flat, Pahute Mesa, and Ash Meadows; see SCP Figure 3-9, modified from Waddell (1984). Vertical gradients also exist in areas of recharge, discharge, and vertical leakage. Two-dimensional areal models assume strictly horizontal flow and ignore the affects of horizontal cross-flow. Even when a cross-sectional model is oriented along a streamline, there is no assurance that the streamline remains within the vertical cross-section. Also, estimates of the areal distribution of recharge, discharge, and vertical leakage are difficult to obtain because several cross-sectional models must be constructed. Thus, three-dimensional modeling offers a possible solution to the shortcomings of two-dimensional modeling.

Several hydrostratigraphic units are present in the study area and comprise a multi-layered flow system. Two-dimensional areal ground-water flow models lump all the hydrostratigraphic units into one composite unit, making it impossible to analyze flow within distinct layers. Various configurations of structure and stratigraphy can be analyzed using a three-dimensional model that cannot be directly assessed using a two-dimensional model. For instance, analysis of the suspected small-permeability barrier along the north and west sides of Yucca Mountain (which may reside in the volcanic section, or the carbonate section, or both) can be done only with a three-dimensional model.

The regional numerical model of ground-water flow will be used to specify reliable boundary conditions for the more critical site-area model embedded within the subregional model. To do so, fluxes and hydraulic heads at boundaries of the regional system are required, as well as the regional hydraulic properties of rocks and sediments. The regional numerical model developed under this activity will also provide input to the two-dimensional cross-sectional numerical model. This input will consist of boundary conditions, material properties, and possibly the selection of the horizontal flow-path that the cross-sectional model is to simulate. Sensitivity analyses pertaining to these variables are also needed to prioritize additional data collection.

The numerical model will be utilized (in Study 8.3.1.5.2.2, Effects of future climate on hydrology; see Section 4.2) to predict future hydrologic conditions. Before predictive simulations can be done, the model must be calibrated, which requires reliable estimates of the hydraulic properties of materials and boundary conditions. Data from paleohydrologic studies, tectonic studies, paleoclimatic studies, and estimates of possible future ground-water use will then be combined with model data and used as a basis for the predictive simulations. Use of numerical ground-water flow models is the most efficient and accurate method for assessment of future hydrologic conditions.

Data collection is a major part of the site-characterization process, and, although modeling activities do not collect or measure parameters, sensitivity analyses of numerical models provide a powerful technique for identifying key ground-water flow system parameters. Sensitivity analyses will be done to aid in model calibration and, after the model is calibrated, to direct and prioritize future data-collection activities.

This activity will also provide quantitative evaluations of alternate hypotheses incorporated in the conceptual model. New numerical models will be constructed, if necessary, so that the alternatives can be assessed.

3.4.4 General modeling approach and summary of tests and analyses

All ground-water numerical modeling studies have several basic features and methods in common; the general methodology to be employed in this activity is described in Section 2.1.2. As stated in that section, numerical models produced during this activity will probably assume that the diffusion equation adequately describes the flow of ground-water through rocks and sediments underlying the subregional area. Conceptual models formulated in the conceptualization of regional hydrologic flow models activity (Section 3.1) and data used to support such models will be used as the basis for regional three-dimensional hydrologic modeling. The data and interpretations required for regional three-dimensional hydrologic modeling are the same as those required for Activity 8.3.1.2.1.4.1, and are discussed in Section 2.1.2 and in Section 3.1.3. Specifically, data will be collected as part of Study 8.3.1.2.1.3 (Regional ground-water flow system) and other studies listed in Section 2.1.6. Data from each of these studies will be incorporated into the subregional hydrologic model as it becomes available.

Figure 3.4-1 summarizes the steps in the regional three-dimensional modeling process. A descriptive heading for each modeling step appears in the shadowed boxes of the second and fourth rows. Below each step are the individual methods that will be used during testing. Figure 3.4-2 summarizes the objectives of the activity, site-characterization parameters, and activity parameters which are addressed by the activity. These appear in the boxes in the top left side, top right side, and, below the shadowed modeling-step boxes, respectively, in Figure 3.4-2. The two figures summarize the overall structure of the planned activity in terms of methods to be employed and estimates and results to be obtained. The descriptions of 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 information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

3.4.4.1 Model evaluation

An existing three-dimensional numerical model of the regional ground-water flow system (Sinton, P. O., and Downey, J. S., written communication, 1990) will be evaluated in terms of the current conceptual model of the regional ground-water flow system. Prior to refinement, however, it will be decided, based on results from the two-dimensional areal and cross-sectional modeling activities, whether it is necessary to use the three-dimensional model to adequately characterize the regional ground-water flow system, based on the magnitude of the vertical component of flow. Depending on the outcome of the evaluation, the existing model may be revised according to the current conceptual model, a new numerical model may be constructed, or three-dimensional modeling may not be done.

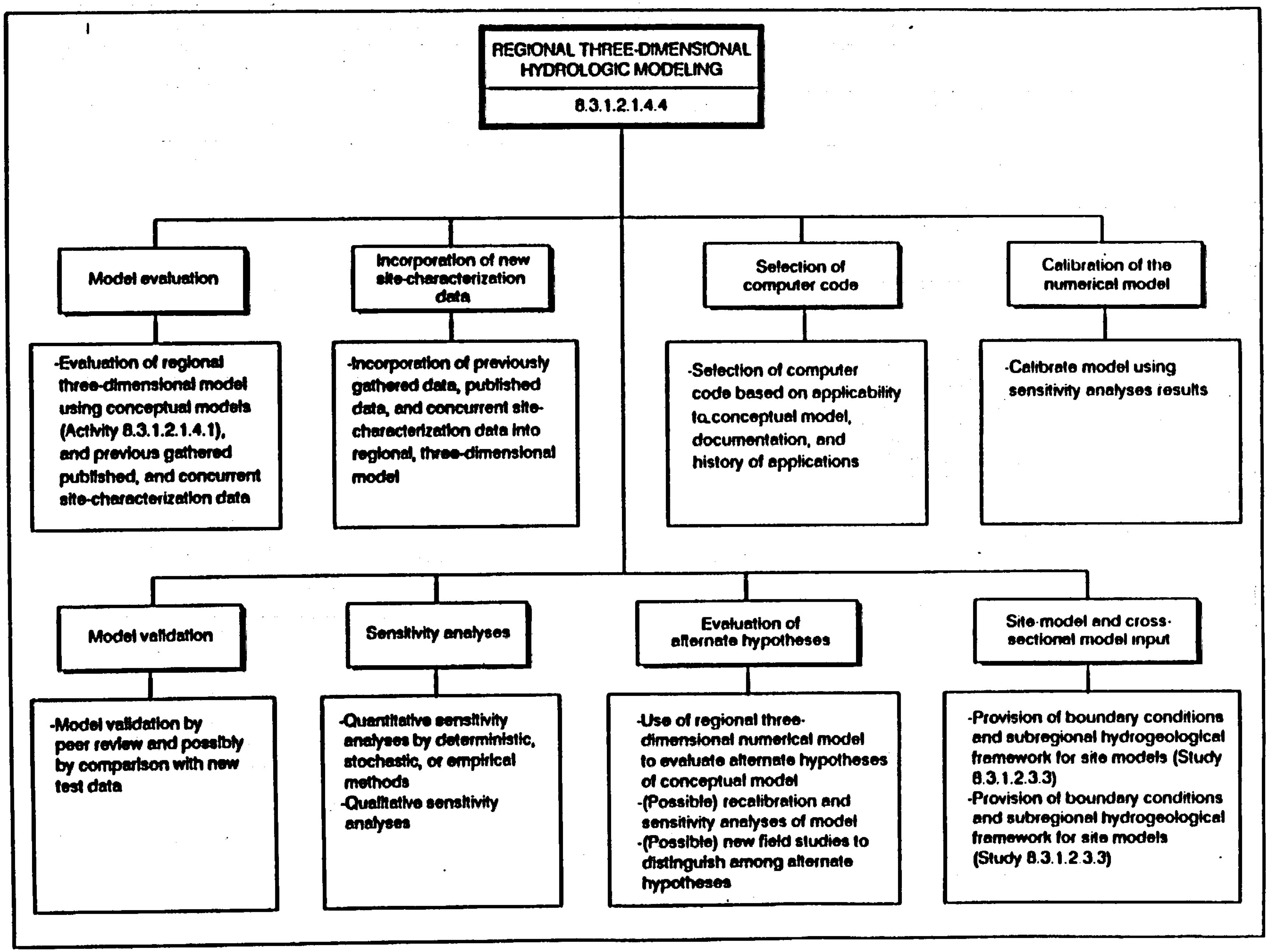

Figure 3.4-1. Organization diagram of regional three-dimensional hydrologic modeling activity, showing tests, analyses, and methods.

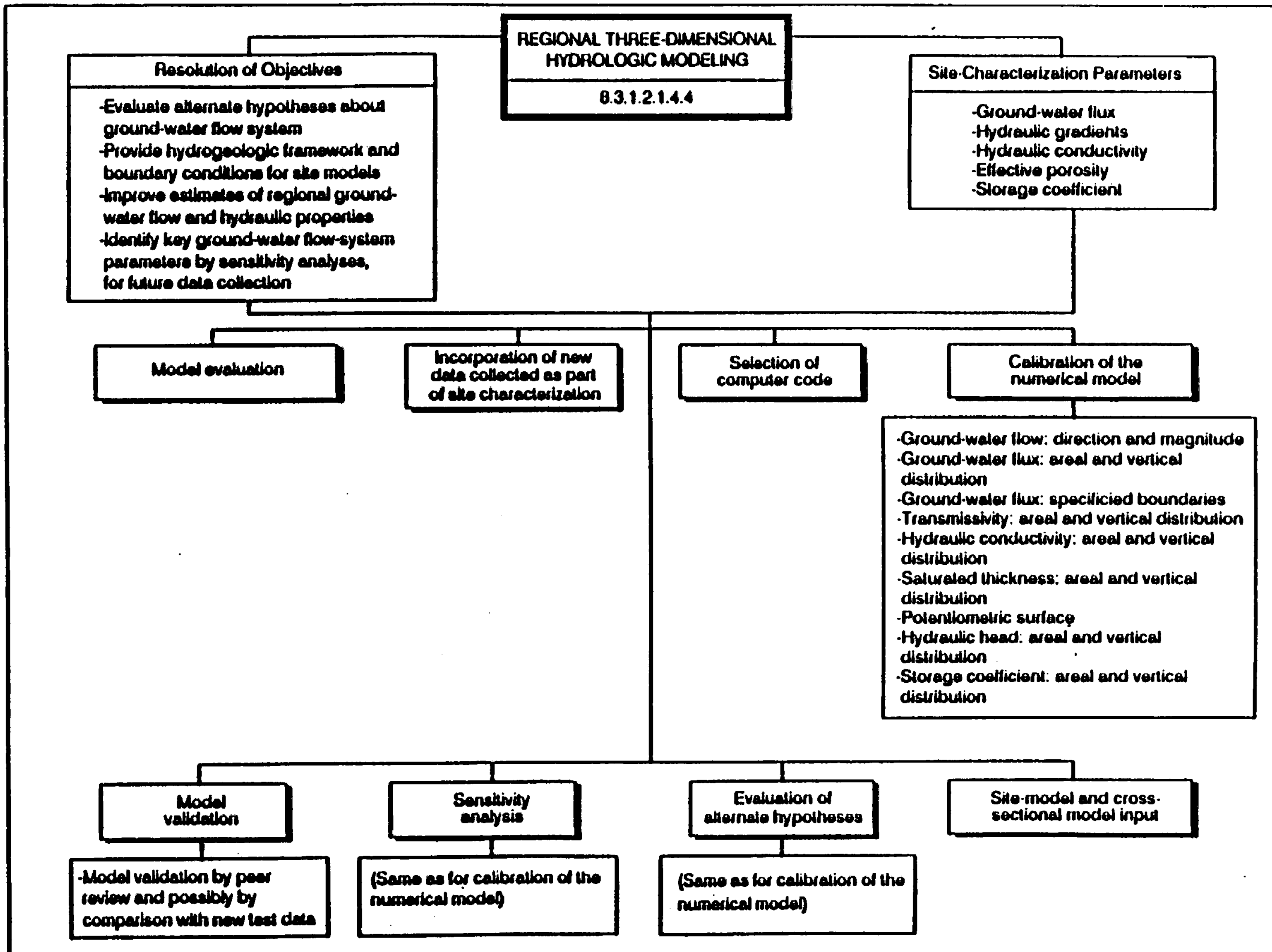

Figure 3.4-2. Organization diagram of regional three-dimensional hydrologic modeling activity, showing tests, and activity parameters.

3.4.4.2 Incorporation of new site-characterization data

Conceptual models formulated in the conceptualization of regional hydrologic flow models activity (Section 3.1) and data used to support such models will be used as the basis for the regional three-dimensional numerical model. Previously gathered data, published data, and site-characterization data gathered concurrently with modeling studies that will be used in construction of the subregional ground-water flow system numerical model are discussed in Section 3.1.3. New data of particular interest (geophysical, geohydrological, and hydrochemical) are those detailed earlier in Section 3.2.4.2.

Few data exist regarding vertical hydraulic conductivity of hydrogeologic units within the flow system. Tests are planned to characterize fracture flow at Yucca Mountain (Study 8.3.1.2.3.1, Site saturated-zone ground-water flow), which will include estimating vertical hydraulic conductivity. These test results will be used in comparison with values used in the ground-water flow models discussed in this study to bracket possible model values. The units will probably be modeled as isotropic, and sensitivity analyses will be done to evaluate the impacts of this assumption.

3.4.4.3 Selection of computer code

The selection of the computer code or codes to be used during this activity will be based on the criteria described in Section 3.2.4.3. A likely computer code for selection in this activity is the USGS Modular Model (McDonald and Harbaugh, 1988). The Modular Model is one of the best documented computer programs available for the simulation of saturated ground-water flow in three dimensions; however, other computer codes will be considered.

3.4.4.4 Calibration of the numerical model

The numerical model will be calibrated to the extent possible by adjusting model variables to minimize differences between simulated hydraulic head, transmissivity, recharge, and discharge with measured or estimated field values. Adjustment of model variables (such as transmissivity) is done within the context or constraints of the hydrogeologic framework developed as part of the conceptual model. (The calibration process is defined in Section 2.1.2.)

As an ongoing activity, the model may be revised and recalibrated using data from the regional and site saturated-zone studies and other geological studies. As the data base improves, an attempt may be made to improve the regional model by adding several additional layers to the model, in order to simulate flow in the saturated zone in more detail as more hydrogeologic data become available.

3.4.4.5 Model validation

The numerical model will undergo validation by competent peer review and by comparison with new field test data, as described in Section 2.1.2.

3.4.4.6 Sensitivity analyses

Sensitivity analyses will be used during the model-calibration process, as discussed in Section 2.1.2, to determine the effects of changing key model variables values.

3.4.4.7 Evaluation of alternate hypotheses

Alternative hypotheses incorporated into the conceptual model will be evaluated using the numerical model. This process is described in Section 3.2.4.7.

3.4.4.8 Site-model and cross-sectional model input

After the numerical model has been calibrated, estimates of boundary conditions will be provided for the site models. In addition, this activity will also provide the regional hydrogeological framework for the site models.

Boundary conditions and estimates of the hydraulic properties of materials from this activity may be used in the cross-sectional model (Section 3.3). The selection of appropriate ground-water flow paths for the cross-sectional model may be based on results from this activity.

3.4.4.9 Methods summary

The activity parameters to be determined by the tests and analyses described in the above sections, and the selected methods for evaluating the parameters, are summarized in Figures 3.4-1 and 3.4-2. Alternate methods may be utilized only if selected methods are impractical to measure the parameter(s) of interest. The USGS investigators have selected modeling approaches which they believe are suitable to provide accurate data within the expected ranges of the activity parameters.

3.4.5 Quality-assurance requirements

Technical procedures do not apply to this activity because: (1) documentation and control of the quality of software used for modeling are subject to the requirements set forth in YMP-USGS QMP-3.03 (Software Quality Assurance); (2) modeling is an analysis and interpretation activity, the appropriate application of which is assured by technical review as set forth in YMP-USGS-QMP-3.04 (Technical Review, Approval, and Distribution of YMP-USGS Publications); and (3) data used in modeling are collected under other studies (listed in Section 2.1.6) for which quality assurance levels have been set.

4 APPLICATION OF STUDY RESULTS

4.1 Application of results to resolution of performance issues

Site information from the present study will be employed in the following performance issues: Issue 1.6 (Ground-water travel time), Issue 1.1 (Limiting radionuclide releases to the accessible environment), Issue 1.8 (NRC siting criteria), and Issue 1.9 (Higher-level findings), and Issue 1.3 (Protection of special sources of ground water).

The application of site information from this study to performance parameter needs required for the resolution of performance issues is addressed in Section 1.3. Table 7.2-1 summarizes specific relationships between performance parameter needs and the characterization parameters of this study.

4.2 Application of results to support other site-characterization studies

The regional saturated-zone synthesis and modeling study will support other site-characterization studies in the Geohydrology, Geochemistry, Climate, Postclosure Tectonics, and Human Interference Programs. The following is a summary of how the present study will support those efforts.

In Study 8.3.1.2.3.3 (Site saturated-zone hydrologic system synthesis and modeling), the regional and subregional flow models of the present study provide the regional context in which the site model is to be constructed. The models in the present study will be used to provide: (1) a synthesis of available hydrogeologic data; (2) direction for and prioritization of additional data collection; and (3) estimates of ground-water flow paths, fluxes, and specific discharge. These modeling results will be used as a basis for specifying boundary conditions for more detailed models of ground-water flow at the Yucca Mountain site. The present study contributes to the performance issues of ground-water travel time (Issue 1.6) and total system performance (Issue 1.1) through Study 8.3.1.2.3.3.

In Study 8.3.1.2.1.3 (Regional ground-water flow system), sensitivity analyses done during the modeling process of the present study may indicate needs for additional regional hydrologic data. Such data may include potentiometric data, hydraulic conductivity, saturated thickness, transmissivity, porosity, and storage coefficient.

In Study 8.3.1.2.2.1 (Unsaturated-zone infiltration), parameters are needed for infiltration characteristics and spatial distribution of the physical and hydraulic properties of the surficial hydrogeologic units at Yucca Mountain. The present study may support these needs by evaluating estimates of the distribution and rates of ground-water recharge to the site unsaturated zone as part of model-variable input specification and calibration.

In the Geochemistry Program, Study 8.3.1.3.7.1 (Retardation sensitivity analysis) contains data requirements for recharge rates, potentiometric levels, and ground-water flow paths and fluxes. The present study will provide part of the hydrologic data required by the retardation sensitivity analysis.

In the Climate Program, Study 8.3.1.5.2.2 (Future regional hydrology due to climate changes) ground-water flow models from the present study will be used to test the response of the ground-water flow system to possible future climatic conditions. Future climate in the study area could be considerably wetter than the present climate, resulting in greater amounts of ground-water recharge. The three-dimensional regional model developed during the present study will be used to evaluate changes in water-table altitude, ground-water flow rates, and ground-water flow directions at Yucca Mountain that could result from such wetter conditions (increased recharge).

In the Erosion Program, Study 8.3.1.6.4.1 (Development of a topical report to address the effects of erosion on the hydrologic, geochemical, and rock characteristics of Yucca Mountain), the regional and subregional models from the present study (together with the site models of Study 8.3.1.2.3.3) will provide potentiometric data and ground-water flow-path data for Yucca Mountain and vicinity. These data will constitute a baseline against which the possible effects of future erosion can be evaluated.

In the Postclosure Tectonics Program, Study 8.3.1.8.3.2 (Analysis of the effects of tectonic processes and events on changes in water-table elevation), the position of the present-day (1989) water table in the regional and subregional models of the present study (together with the site models of Study 8.3.1.2.3.3) will constitute a baseline condition at Yucca Mountain and vicinity, against which possible future tectonic effects on water-table elevation can be evaluated. Tectonic processes that will be evaluated include igneous intrusion, strain changes, folding, uplift/subsidence, and faulting. For instance, future movement along faults in the vicinity of Yucca Mountain could change the hydraulic properties of geohydrologic units so as to either impede or enhance ground-water flow.

In the Human Interference Program, Study 8.3.1.9.3.2 (An evaluation of the potential effects of exploration for, and extraction of, natural resources on the hydrologic characteristics at Yucca Mountain), and in the Preclosure Hydrology Program, Study 8.3.1.16.2.1 (Location of adequate water supply for construction, operation, closure, and decommissioning of a mined geologic disposal system at Yucca Mountain, Nevada), the regional and subregional models from the present study (together with the site models from Study 8.3.1.2.3.3) will provide water-table elevation and ground-water flow-path data for Yucca Mountain and vicinity. These data will constitute a baseline against which the possible effects of ground-water withdrawal on the local geohydrologic system can be evaluated.

5 SCHEDULES AND MILESTONES

5.1 Schedules

The proposed schedule presented in Figure 5.1-1 summarizes the logic network and reports for Study 8.3.1.2.1.4. This figure represents a summary of the schedule information which includes the sequencing, interrelations, and relative durations of the activities described in this study. 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 from other studies, and also how the present study will contribute to or may interfere with other studies. Milestones shown on the schedule include the major milestones cited in SCP Table 8.3.1.2-11 (Major events and planned completion dates for studies in the geohydrology program). Figure 5.1-1 reflects the most recently available project participant schedule.

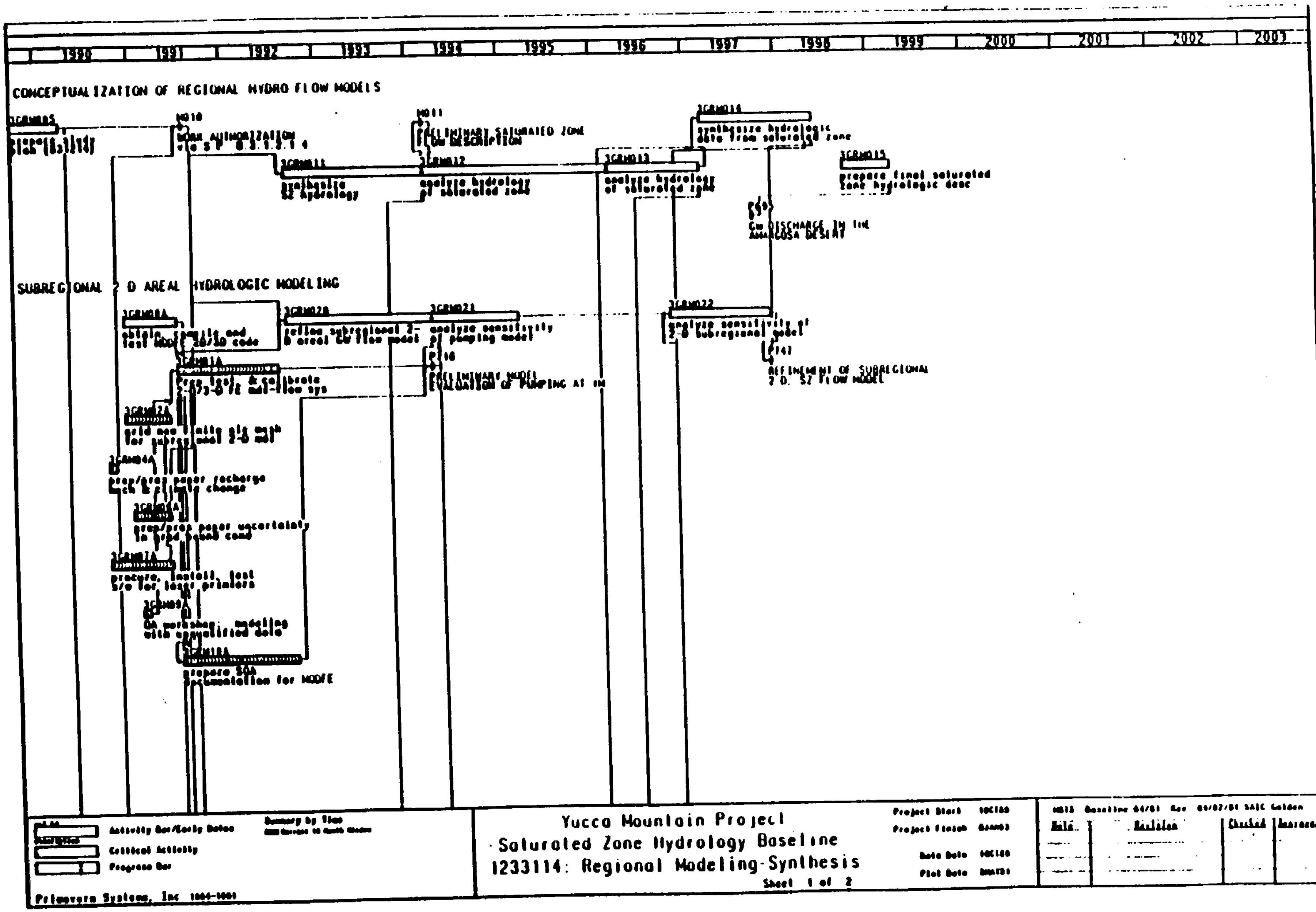

Figure 5.1-1a. Summary network of regional hydrology synthesis and modeling study.

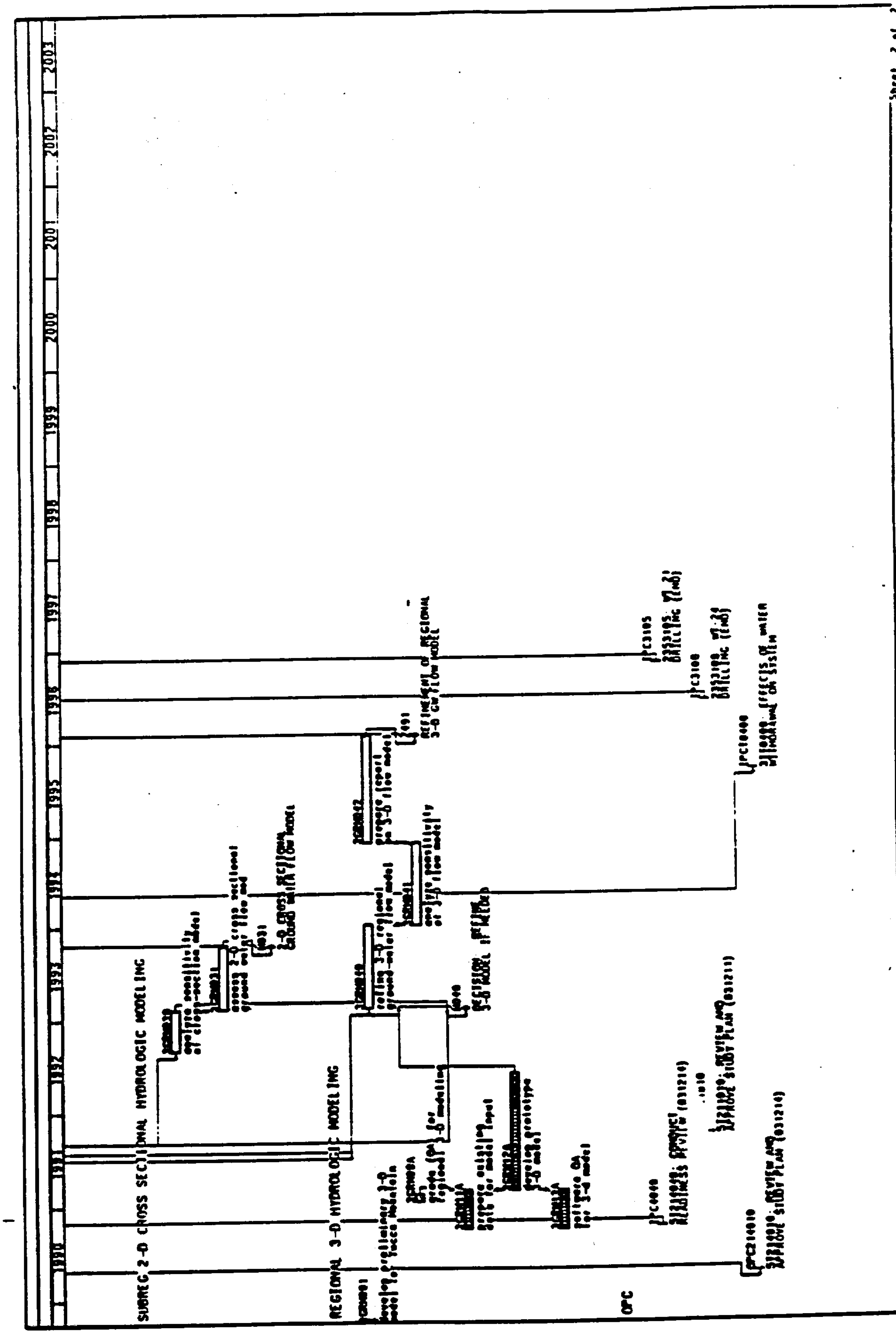

Figure 5.1-1b. Summary network of regional hydrology synthesis and modeling study.

5.2 Milestones

The milestone numbers and titles associated with Study 8.3.1.2.1.4 appear in Table 5.2-1. The information presented in the table represents major events or important summary milestones associated with the activities presented in this study plan as shown in Figure 5.1-1. Specific dates for the milestones are not included in the tables, as these dates are subject to change due to ongoing planning efforts.

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Table 5.2-1. Milestone list for work-breakdown structure number-1.2.3.3.1.1.4 (SCP 8.3.1.2.1.4)
[Milestone dates are unavailable at this time.]

Milestone number	Milestone	Milestone level
Conceptualization of regional hydrologic flow models: 8.3.1.2.1.4.1		
P936	Project Issue Report: Hydrologic description of SZ	1
P932	Project Issues Report: Conceptual model, SZ at Yucca Mountain	2
3J87	Submit Study Plan 8.3.1.2.1.4 to YMPO	3
8C20	Submit Study Plan 8.3.1.2.1.4 for DOE audit review	3
8C22	Demonstrate feasibility of enhanced MODFE for sensitivity analyses	4
8C21	[Conduct current MODFE code to run on microcomputer-convert modeling software for laser printer]	4
Subregional two-dimensional areal hydrologic modeling: 8.3.1.2.1.4.2		
P747	Issue Report: Refinement of sub-regional 2-D, SZ flow model	2
P716	Issue Report: Preliminary model evaluation of pumping at Yucca Mountain	2
Subregional two-dimensional cross-sectional hydrologic modeling: 8.3.1.2.1.4.3		
Z243	Issue Report: 2-D cross-sectional ground-water flow model	2
Regional three-dimensional hydrologic modeling: 8.3.1.2.1.4.4		
M389	Project Issues Report: Final hydrologic description of SZ	1
Z491	Issue Report: Refinement of regional 3-D ground-water flow model	2
P695	Issue Report: G-W discharge in the Amargosa Desert	2
3008	Decision: Refine 3-D model (if needed)	3

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7 APPENDICES

7.1 Quality-assurance requirements

7.1.1 Quality-assurance requirements matrix

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.

The QA grading package for this study was transmitted to the Project Office on January 30, 1991.

Applicable NQA-1 criteria for Study 8.3.1.2.1.4 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)

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

This section tabulates in Table 7.2.1 the specific technical information relations between SCP and performance-parameters needs and characterization parameters to be evaluated 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.

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

For each 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 characterization parameters are listed with information about the site location and the site activity providing the information.

Note - Comparison of the information relations (characterization parameters with 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 (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 Performance issues and parameters supported by results of this study

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, permeability

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
n_e: 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	Hydraulic conductivity	Regional and subregional ground-water flow systems; Saturated-zone geohydrologic units	8.3.1.2.1.4
Hydraulic conductivity (Rock matrix)	Controlled area; Saturated-zone units	Goal: Mean, Variance, Autocorrelation length Current: Medium Needed: High, Low, Low	Storage coefficient	"	"
Hydraulic conductivity (Fracture networks)	"	Goal: Mean, Variance, Autocorrelation length Current: Low Needed: High, Low, Low			
Effective porosity (Rock matrix)	"	Goal: Mean, Variance, Autocorrelation length Current: Low, Low, Low Needed: Medium, Medium, Low			

Table 7.2-1 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, permeability

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Effective porosity (fracture networks)	Controlled area; Saturated-zone units	Goal: Mean, Variance, Autocorrelation length Current: Low, Low, Low Needed: Medium, Medium, Low			

Parameter Category: Saturated-zone hydraulic gradient

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
d_a: 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 gradients	Regional and subregional ground-water flow systems; Saturated-zone geohydrologic units	8.3.1.2.1.4
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			

Table 7.2-1 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 hydraulic gradient					
Effective thickness of saturated zone;as a function of lateral-spatial location	Controlled area; Saturated-zone units	Goal: Mean Current: Low Needed: Low			
Parameter Category: Saturated-zone radiochemistry					
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	Ground-water flux	Regional and subregional ground-water flow systems; Saturated-zone geohydrologic units	8.3.1.2.1.4

Table 7.2-1 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[a], Saturated zone (secondary reliance) (Supporting parameters used in calculating performance parameters for ground-water travel time.)					
Parameter Category: Saturated-zone, permeability					
Effective porosity	Controlled area; Saturated zone	Goal: >0.01 Current: Low Needed: Low	Hydraulic conductivity	Regional and subregional ground-water flow systems; Saturated-zone geohydrologic units	8.3.1.2.1.4
Permeability, saturated (Fault zones)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low	Storage coefficient	"	"
Permeability, saturated (Fractures)	"	Goal: Mean, SCor, SDev Current: Low, NA, NA Needed: Medium, Low, Medium			
Permeability, saturated (Rock mass)	"	"			
Permeability, saturated (Rock matrix)	"	Goal: Mean, SDev Current: Medium, NA Needed: Medium, Low			

Table 7.2-1 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[a], Saturated zone (secondary reliance)

Parameter Category: Saturated-zone, permeability

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Porosity, effective (Fault zones)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low			
Porosity, effective (Fractures)	"	Goal: Mean, SCor;SDev Current: Low, NA, NA Needed: Medium, Low, Medium			
Porosity, effective (Rock Mass)	"	"			
Porosity, effective (Rock Matrix)	"	Goal: Mean, SDev Current: Low, NA Needed: Low, Low			
Porosity, total (Fault zones)	"	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low			

Table 7.2-1 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)					
Parameter Category: Saturated-zone, permeability					
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			
Porosity, total (Rock mass)	"	Goal: Mean, SCor, SDev Current: Low, NA, NA Needed: Medium, Low, Medium			
Porosity, total (Rock matrix)	"	Goal: Mean, Scor, SCor Current: Medium, NA, Medium Needed: Medium, Medium, Medium			

Table 7.2-1 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.)					
Parameter Category: Saturated-zone hydraulic gradient					
dh/dl (gradient)	Controlled area; Saturated zone	Goal: <0.001 Current: Low Needed: Low	Hydraulic gradients	Regional and subregional ground-water flow systems; Saturated-zone geohydrologic units	8.3.1.2.1.4
Distance along flow paths	*	Goal: 1000 m Current: Low Needed: Medium			
Pressure head, function of depth (Ground water)	Controlled area; Saturated zone, upper 100 m	Goal: Mean Current: Low Needed: Medium			
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 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[a], Saturated zone (secondary reliance) (Supporting parameters used in calculating performance parameters for ground-water travel time.)					
Parameter Category: Saturated-zone radiochemistry					
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	Ground-water flux	Regional and subregional ground-water flow systems; Saturated-zone geohydrologic units	8.3.1.2.1.4
Flux, flow rate (Rock mass)	Controlled area; Saturated zone, upper 100 m	Goal: Mean Current: Low Needed: Medium			

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