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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
STUDY PLAN APPROVAL FORM

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Study Plan Number 8.3.1.2.3.3

Study Plan Title SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Revision Number 0

Prepared by: U. S. GEOLOGICAL SURVEY

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Approved:

J. Timothy Sullivan for 1/14/93
Director, Regulatory and Site Evaluation Division / Date

Effective Date: 1/14/93

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RECORD OF REVISIONS

REVISION NUMBER	*REVISION*	*DATE*
R0	Study rationale and plans for three activities: Conceptualization of saturated-zone flow models within the boundaries of the accessible environment (Section 3.1) Development of fracture-network model (Section 3.2) Calculations of flow paths, fluxes, and velocities within the saturated zone to the accessible environment (Section 3.3)	8-28-92

ABSTRACT

This study plan describes the plans for three site-characterization activities whose objectives are to synthesize concepts of the site saturated-zone at Yucca Mountain, and to employ numerical modeling techniques to describe its flow regime. The study will incorporate site hydrologic data from other studies into a conceptual model, and use the conceptual model as the basis for a numerical model that will quantitatively describe site saturated-zone flow. The results of the numerical modeling will be important hydrologic-parameter input for the resolution of performance issues. The activities include

- Conceptualization of saturated-zone flow models within the boundaries of the accessible environment (Section 3.1),
- Development of fracture-network model (Section 3.2), and
- Calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment (Section 3.3).

The rationale of the overall site saturated-zone 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, and the selected and alternate methods considered. Section 4 summarizes the application of the study results to other site-characterization investigations, and Section 5 presents the schedules and associated milestones.

SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

YMP - USGS - SP 8.3.1.2.3.3, R0

STUDY PLAN

AUGUST 1992

August 28, 1992

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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 USGS 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 U.S. Department of Energy (DOE) to demonstrate in its environmental-impact statement and license application whether or not the MGDS will meet the requirements of federal regulations 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191.

The study plan describes the plans for synthesizing and modeling the site saturated-zone system. The study is organized into three activities:

- 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the accessible environment,
- 8.3.1.2.3.3.2 - Development of fracture-network model, and
- 8.3.1.2.3.3.3 - Calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment.

Note that the numbers (e.g., 8.3.1.2.3.3.1) 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 the study within the SCP geohydrology program. The site saturated-zone hydrologic-system synthesis and modeling study is one of three studies in the site saturated-zone hydrologic-system investigation, whose overall purpose is to develop a model of the Yucca Mountain saturated-zone hydrologic system, which will assist in assessing the suitability of the site for containment and isolation of high-level nuclear waste. The two preceding studies in the investigation characterize the site saturated-zone ground-water flow system and the site saturated-zone hydrochemistry, respectively. (The activities comprising these studies are not shown in Figure 1.1-1.) The three activities in the present study were selected on the basis of various factors. Time and schedule requirements were considered in determining the number and types of analyses chosen to obtain the required data. Analyses were designed on the basis of performance-parameter needs and available analytical methods. These factors are described in Sections 2 and 3.

Other studies under the Geohydrology program (SCP Section 8.3.1.2) that will contribute to understanding the site ground-water flow system are the Regional Hydrology Investigation (8.3.1.2.1) and the Site Unsaturated-Zone

Hydrology Investigation (8.3.1.2.2). Specifically, under the Regional Hydrology Investigation, Study 8.3.1.2.1.4, Regional Hydrologic System Synthesis and Modeling, will support the present study by providing information on initial conditions and boundary conditions for ground-water flow modeling. The Site Saturated-zone Mod ling will be coordinated with Study 8.3.1.2.1.4. In addition, the Site Unsaturated-Zone Modeling and Synthesis (Study 8.3.1.2.2.9) will contribute information on fluxes from and the effect of faults in the unsaturated zone to the present study.

The plans for each activity are presented in Section 3. Plans for the conceptual saturated-zone flow model, the development of a fracture-networkmodel, and the calculation of flow, fluxes, and velocities within the saturated zone are described in Sections 3.1, 3.2, and 3.3, respectively. The descriptions include (a) objectives and parameters, (b) technical rationale, and (c) tests and analyses. Cross references are provided for quality-assurance level assignments.

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 matrix accompanied by quality-assurance level-assignment sheets for the study is presented in Section 7.

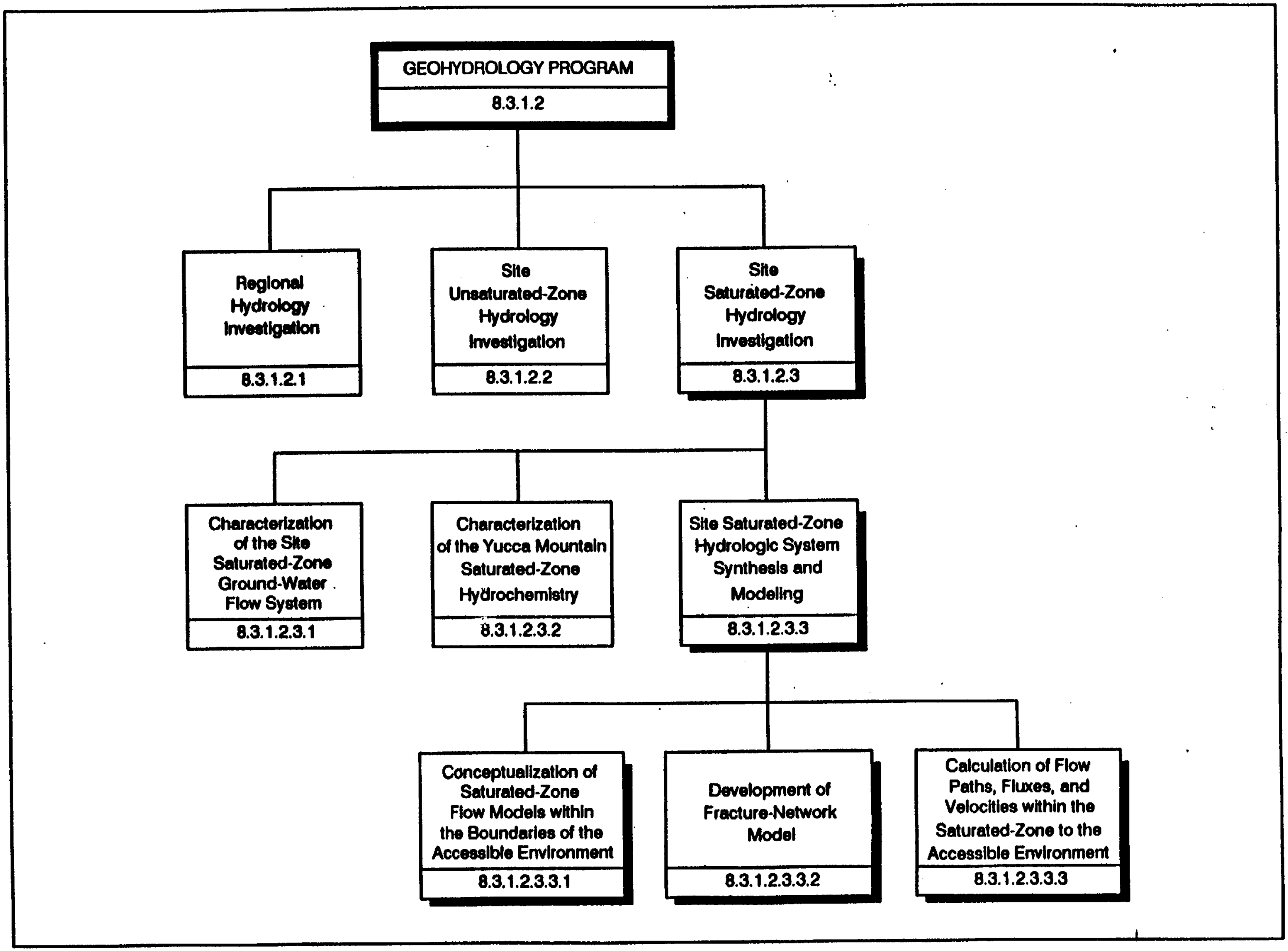

Figure 1.1-1. Diagram showing the location of study within the site saturated-zone hydrology investigation and organization of the geohydrologic-characterization program.

1.2 Objectives of study

Hydrologic evaluation of the site-saturated zone will be conducted as an integrated set of subsurface data-collection activities and modeling activities that have the common objective of providing an understanding of the present flow regime in the saturated zone at Yucca Mountain.

The objectives of the present study are to synthesize available data into appropriate models, to make qualitative analyses of system operation and to perform a quantitative analysis of hydrogeologic data pertaining to the site saturated-zone ground-water flow system in a comprehensive flow model.

Activity 8.3.1.2.3.3.1 is designed to meet study objectives by producing a conceptual model that will represent the site saturated-zone flow system as well as possible within the limits of available data, using equivalent-porous-media concepts. Activity 8.3.1.2.3.3.2 is designed to meet study objectives by refining and validating hydrologic models of fracture networks through the prediction and analysis of results of multiple-well hydrologic tests. Activity 8.3.1.2.3.3.3 is designed to meet study objectives by providing a comprehensive description of aquifer properties that can be used for calculation of ground-water velocity at the scale of Yucca Mountain, and by development of conceptual and numerical models, combining fracture flow and equivalent porous media concepts for ground-water flow and conservative solute transport also at the scale of Yucca Mountain. The role of matrix diffusion will be considered in this activity and will probably be incorporated in the flow and transport calculations.

1.3 Regulatory rationale and justification

The results of the site saturated-zone hydrologic-system synthesis and modeling study will be used to provide hydrologic data for performance-assessment calculations of saturated-zone ground-water travel time, which in turn is used in predictions of radionuclide releases to the accessible environment.

The overall regulatory-technical relations between the SCP performance-assessment information needs and the data collected in this study are presented in the geohydrology testing strategy presented in SCP Section 8.3.1.2 and the issue-resolution strategies (performance assessment) presented in SCP Section 8.3.5. The description presented below provides a more specific identification of these relations as they apply to this study. A detailed tabulation of parameter relations is presented in Table 7.2-1.

In this and other study plans, it has been useful to group the measured or calculated 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 design and performance issues. This demonstration is made in Table 7.2-1 in Appendix 7.2. In the case of the site saturated-zone synthesis and modeling study, the activity parameters (presented in the figures and tables of Sections 3.1, 3.2, and 3.3) can be grouped under a set of characterization parameters as follows in Table 1.1-1:

Activity	Title	Characterization Parameters
8.3.1.2.3.3.1	Conceptualization of saturated-zone flow models within the boundaries of the accessible environment	Hydraulic conductivity Hydraulic gradient Effective porosity Ground-water flux Water chemistry Storage properties Potentiometric surface configuration
8.3.1.2.3.3.2	Development of fracture-network model	Hydraulic conductivity Hydraulic gradient Storage coefficient Effective porosity Conservative solute transport

Table 1.1-1 Activities of the study and their characterization parameters

8.3.1.2.3.3.3	Calculation of flow paths, fluxes and velocities within the saturated zones to the accessible environment	Hydraulic conductivity Hydraulic gradient Storage coefficient Effective porosity Conservative solute transport

The grouping of activity parameters according to characterization parameters is given in Table 2.3-1 of Section 2, and also in the logic diagrams accompanying the activity descriptions of Sections 3.1, 3.2, and 3.3.

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

Information derived from this study principally will support the performance determinations of pre-waste-emplacement ground-water travel time (Issue 1.6) and the predictions of radionuclide releases to the accessible environment (Issue 1.1). Through contributions to Issue 1.6 performance parameters, the study will support the resolution of NRC siting criteria (Issue 1.8), higher-level findings (Issue 1.9), and special sources of ground water (Issue 1.3).

The following portion of this section summarizes from the SCP the study-level interfaces between this study and the performance and design 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)

Issue 1.6 addresses the question of whether or not the candidate repository site can meet the Nuclear Regulatory Commission (NRC) performance objective for ground-water travel time. The performance objective is that the geologic repository shall be located so that the pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 yr (or such other time approved or specified by the NRC). Briefly, the qualitative description of the disturbed zone is the part of the controlled area where physical and chemical properties are expected to change due to underground facilities construction or the effects of waste-generated heat, such that the properties changes may have a significant effect on repository performance. The controlled area is a location which on the surface encompasses no more than 100 km^2 and extends no further than 5 km from the outer boundary of the radioactive wastes, and which includes the subsurface underlying the area defined by these limits. The accessible

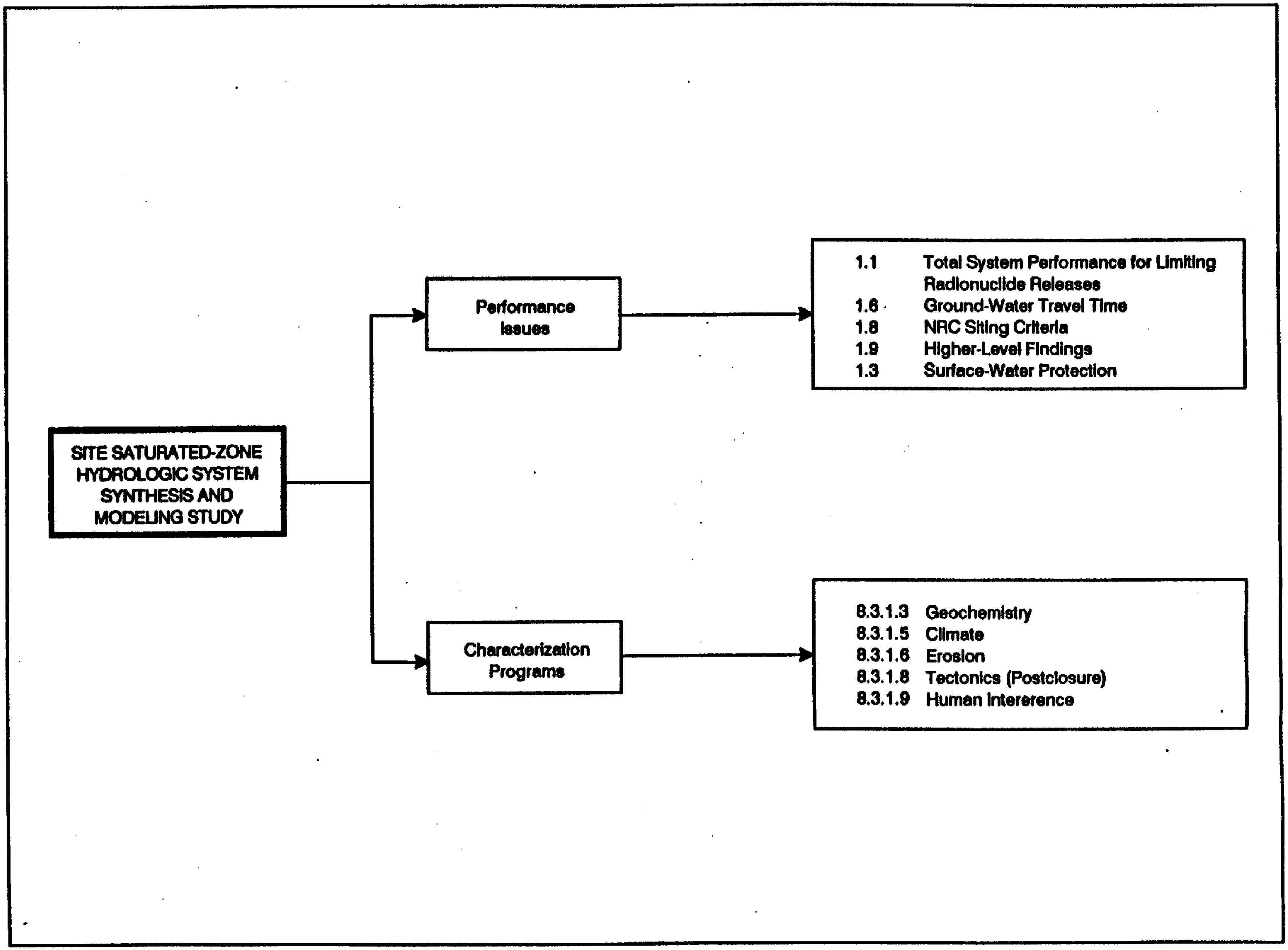

Figure 1.3-1. Diagram showing interfaces of site saturated-zone hydrologic system synthesis and modeling study with YMP performance issues and other site-characterization programs.

environment is the atmosphere, the land surface, surface water, oceans, and the portion of the lithosphere that is outside the controlled area.

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. The site saturated-zone modeling in the present study will be coordinated with the saturated-zone flow analysis in Issue 1.6, one of whose objectives is to determine which sets of hydrologic flow paths in the saturated zone will be used in ground-water travel-time calculations. The saturated-zone analyses to be performed as part of the scope of Issue 1.6 are detailed in Section 8.3.5.12 of the Site Characterization Plan. The contributions of the present study to the information needs for the issue (Information Needs 1.6.1 through 1.6.4) are discussed in the following paragraphs.

In SCP Table 8.3.5.12-2, the ground-water travel-time goal, between the disturbed zone and the accessible environment, in the saturated zone has been established 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) have been calculated. If these goal values are realized, they would establish a bounding basis for concluding with reasonable confidence that travel time in the saturated zone will exceed 1,000 years.

Meeting the values for the above goals, however, would not be sufficient to calculate a cumulative distribution of ground-water travel time in the saturated zone if portions of some flow paths included fracture flow (as is expected), or if travel is sensitive (as is expected also) 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 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 probablistic performance measure expressed as a cumulative distribution function of travel time. The relations of site-characterization parameters from the study 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 pre-waste-emplacement site data in the categories of material property values, initial and boundary conditions, and model validation. Site saturated-zone modeling activities reduce measured site data to the parameters amenable for direct use in ground-water travel-time calculations. The process of data reduction through modeling analyses is described in Sections 1 and 3. Critical data required from the study by Issue 1.6 includes 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.

Issue 1.6 supporting parameters, fed by 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 validation in the 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 contributes (1) site-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, are important requirements 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 the present study. Modification of existing numerical models will be performed through comparison with other models having different levels of sophistication, geohydrology program field tests about the conceptual assumptions of existing models, and results of sensitivity analyses. It is described in SCP Section 8.3.5.12 (Issue 1.6), under Subactivity 1.6.2.2.2 (Validation of models) of Activity 1.6.2.2 (Verification and validation).

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), saturated-zone flow analysis will simulate flow paths in the saturated zone. This effort will be coordinated with the saturated-zone modeling performed in the present study.

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 dependent on the conceptual and, therefore, the numerical, hydrologic models for the saturated zone, formulated in the present study. Uncertainties in the existing conceptual model will be addressed in the calculation of the ground-water travel-time 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. 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 which the 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 flow) that are supported by the available information. This class is associated with anticipated or expected conditions, and it 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 as a backup. SCP Table 8.3.5.13-9 is a description 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, 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, effective porosity, and possibly matrix diffusion parameters of saturated-zone units in the controlled area. Site data from the present study can also contribute to these supporting parameters, which are also cited in Table 7.2-1.

Two of the disturbed-case classes concern the possible failure of unsaturated-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 head gradients, or changed rock, hydrologic, or chemical properties in the saturated zone. The effects of possible future climate change, tectonic and igneous activity, and human interference upon the saturated zone are considered in these scenarios, with the known and expected saturated-zone regime behavior being the baseline case. Because the present study contributes to baseline knowledge through 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 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 rock-hydrologic properties are needed from the study as are required to resolve Issue 1.6 (see Table 7.2-1). This information need requires calculational models of the saturated zone that are capable of predicting time-dependent specific discharge in at least two dimensions. It also requires from the present study 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 support the issue-resolution strategy for ground-water travel time in Issue 1.6. The data will include rock-hydrologic properties, average saturated-zone discharge, and lengths of flow paths.

The present study, by providing a baseline description of the site saturated-zone flow regime in the form of a numerical model, is an associated study in evaluations of the following PACs and their potential consequences. The associations of the study 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 from the present study.

In the following paragraphs, the qualifying and disqualifying conditions are briefly summarized with 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 through provision of saturated-zone site-characterization data (e.g., flux, pressure head, saturated permeability, and potentiometric surface) to Issue 1.6. By providing a saturated-zone model to be used as a baseline for evaluating possible disturbed case scenarios, the study supports the higher-level finding through Issue 1.1.

- o 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 providing a 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.

- o 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 study by the provision of a 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.

- o Rock characteristics qualifying condition - The present and expected characteristics of the host rock and surrounding units shall be capable of accommodating the thermal, mechanical, and radiation stresses expected to be induced by repository construction, operation, and closure and by expected interactions among the waste, host rock, ground water, and engineered components.

The higher-level finding for this condition is supported by the study by the provision (through the site saturated-zone model) of effective porosity to Issue 1.1, and effective porosity and saturated-zone effective thickness to Issue 1.6.

- o 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 supported by the study through the provision of a site saturated-zone model to Issue 1.1, to be used as a baseline from which to evaluate effects of future climatic conditions on water-table altitude and saturated-zone head gradients, and on the possible occurrence of new surficial-discharge points.

- o 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 supported by the study through the provision of a site saturated-zone model to Issue 1.1, to be used as a baseline from which to evaluate the possible effects of tectonic activity on water-table altitude, hydraulic gradients, and flow pathways.

- 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 supported by the study through the provision of a site saturated-zone model to Issue 1.1, to be used as a baseline from which to evaluate the possible effects of irrigation, ground-water withdrawal, and construction of surface and subsurface impoundments on water-table altitudes and saturated-zone head gradients.

In Issue 1.9(b), two evaluations are required to predict releases for 100,000 years after repository closure. The first evaluation will emphasize performance of the 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 hydrologic and geochemical conditions at the site; and (3) take credit for the expected performance of all other engineered components of the repository system. The natural processes and events considered will be only those considered likely to occur over the next 100,000 years.

To resolve Issue 1.9b, Scenario E (the nominal or expected class) will be expanded to take in events that can reasonably be expected to occur over the next 100,000 years. All of the scenarios are related to future climate change; they are listed in SCP Table 8.3.5.18-9. The present study supports the resolution of Issue 1.9b by providing a site saturated-zone model to be used as a baseline from which to model the effects of future climate changes on water-table altitude, or the appearance of surficial discharge points in the controlled area, and an increased water-table gradient in the controlled area over the next 100,000 years.

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

The present study supports this issue through its contribution to the resolution of Issue 1.6. 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 greater than 1,000 yr, Issue 1.3 is affirmatively resolved.

2. RATIONALE FOR STUDY

2.1 Technical rationale and justification

2.1.1 Role of study in the Geohydrology Program

The relationship of this study to the SCP Geohydrology Program is shown in Figure 1.1-1. Activities associated with this study are: (1) conceptualization of the saturated-zone flow models, (2) development of the fracture-network model, and (3) calculation of flow paths, fluxes and velocities within the saturated zone.

The rationale for using a combined conceptual and numerical model approach with the above activities to analyze the site-saturated zone consists of the following reasons:

1. The saturated-zone hydrologic system is complex and most probably behaves like a three-dimensional system. This system is heterogeneous and anisotropic. Flow is controlled by faults, fracture systems, and joints. In addition, complex boundary conditions may exist at the site. For these reasons, and the fact that no analytical solutions to this complex situation exist, the approach best suited to the study of the site is formulation of a conceptual model (or models) and translation of the conceptual model(s) to a mathematical/numerical model.

2. Numerical modeling is the most efficient, and least subjective, way to test hydrologic hypotheses for incorporation into the conceptual model(s).

3. Modeling will aid in data synthesis and, in turn, will provide feedback to data-gathering activities as to the number, types, and locations of tests performed and data to be collected.

4. Equivalent porous-media assumptions have not been able to adequately simulate well-test results at the site. A study of the impact of fractures on flow is necessary to represent the site accurately.

2.1.2 Technical background for the study

The saturated-zone ground-water flow system beneath Yucca Mountain is part of the Alkali Flat-Furnace Creek Ranch ground-water basin (Waddell, 1982) that extends approximately 90 km from Timber Mountain in the north to Alkali Flat and possibly to Furnace Creek Ranch in the south. The east-west extent of this flow system is poorly defined but probably varies spatially from 20 to 50 km (Figure 2.1-1). The subregional flow system is part of the Death Valley regional ground-water basin (Hunt and others, 1966) (Figure 2.1-2).

Although the general trend of flow in the subregional system is from north to south (Figure 2.1-1), the potentiometric surface in the

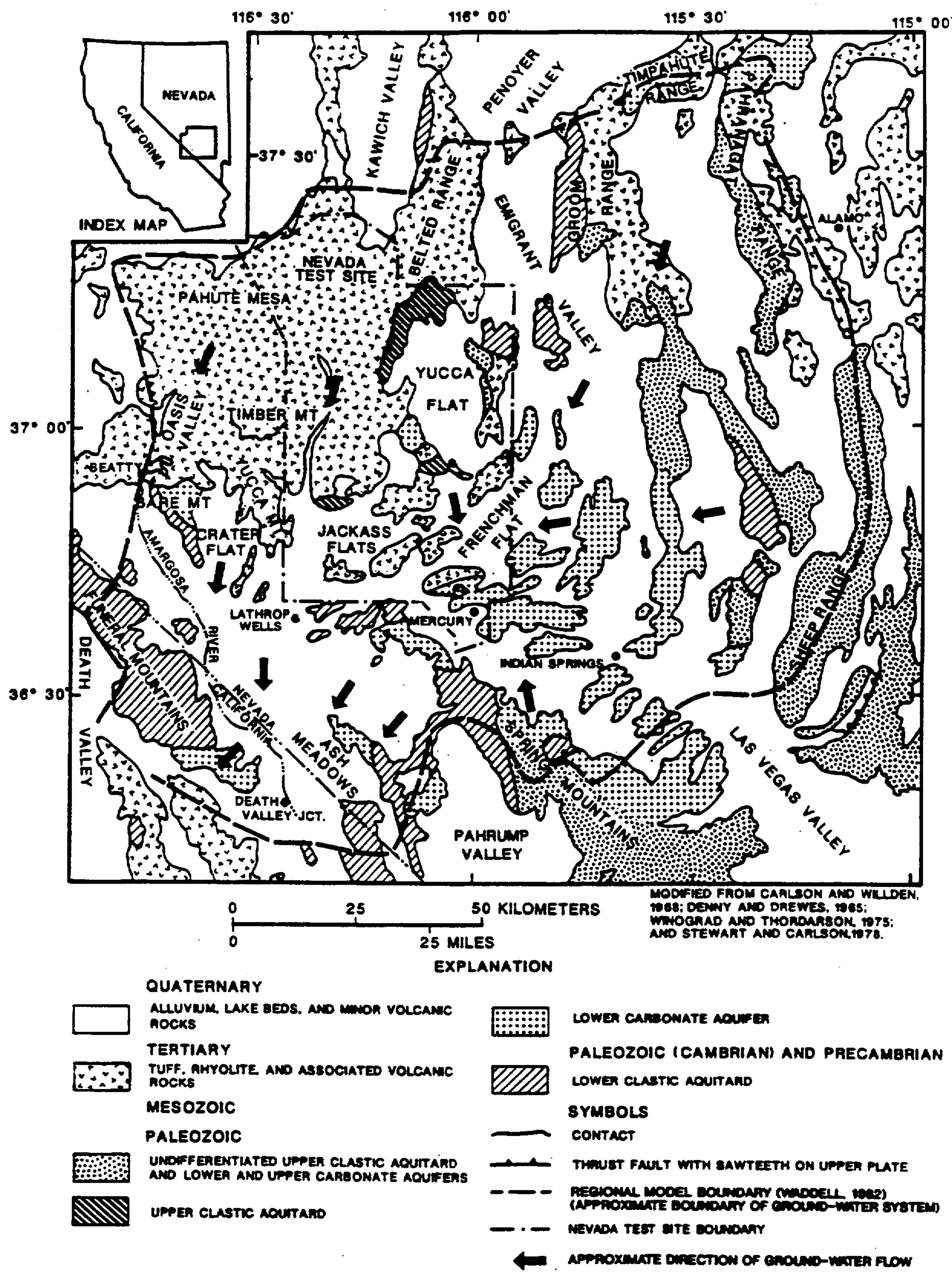

Figure 2.1-1. Location of the regional ground-water flow system.

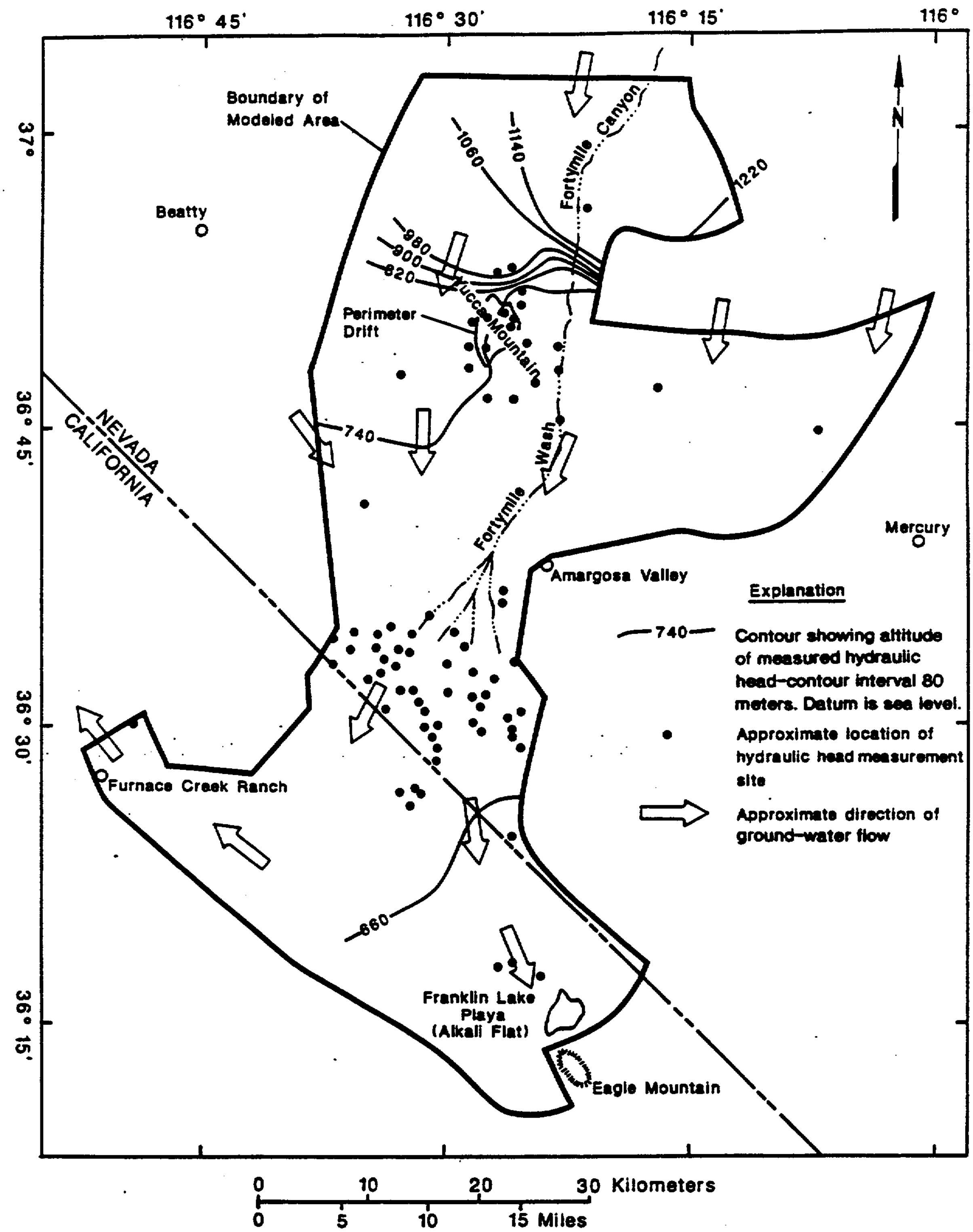

Figure 2.1-2. Subregional ground-water flow system, showing general directions of ground-water flow (modified from Czarnecki and Waddell, 1984).

vicinity of Yucca Mountain (Robison, 1984) indicates a probable west-to-east flow component. Very small gradients to the south and east of Yucca Mountain make it difficult to define the direction of flow. Gradients in this area are as small as 1 m/km. This is in contrast to gradients as large as 150 m/km at the north end of Yucca Mountain.

Ground-water flow at Yucca Mountain is hypothesized to be complexly three-dimensional, with rates and directions of flow controlled in large part by secondary permeability (as fracture systems and faults). The upper part of the flow system at the site occurs in a series of bedded and welded tuffs of Tertiary age (Figure 2.1-3). The spatial distribution of interconnected fractures is poorly understood but appears to decrease with depth in the tuffs of Tertiary age. In the lower part of the flow system (Winograd and Thordarson, 1975), ground water flows through Paleozoic carbonate rocks at considerable depth (>1,000 m) below the site. Carbonate rocks were encountered at depth during the drilling of exploratory borehole UE-25p #1. The carbonate rocks are highly transmissive as a result of secondary permeability. The areal extent of carbonate rocks in the subsurface is poorly understood. Secondary vertical permeability caused by faults probably provides the primary vertical link between the upper and lower parts of the flow system. Limited hydraulic-head data indicate an upward hydraulic gradient within the flow system.

The degree of hydraulic communication between the upper and lower parts of the flow system could have a major impact on horizontal hydraulic gradients in the upper part of the flow system. It is important to understand why the gradients are large in some places and small in other places.

2.1.3 Functions of the activities

The conceptualization of saturated-zone flow models within the boundaries of the accessible environment (Activity 8.3.1.2.3.3.1) will serve to improve the confidence levels in the conceptual model elements: the hydrogeologic framework, hydrologic properties, and initial and boundary conditions. Data from various studies will be synthesized, with consideration given to scale dependence of parameters and spatial variability, into a conceptual model of the saturated-zone at the site. Equivalent-porous-media concepts will be used in this activity to perform hypothesis testing and for testing of the initial conceptual model. The scale of study for this activity is 10's of km.

The development of the fracture-network model (Activity 8.3.1.2.3.3.2) proposes and tests methods for simulating ground-water flow and conservative solute transport in the saturated zone at the site on a multiple-well scale, using fracture-flow concepts. (At the UE25C hole complex, the multiple well complex where the fracture-network model will be developed and tested, the three wells are 30, 61 and 76 m apart.) Flow and transport characteristics resulting from the fracture-network model will be incorporated into the site-wide conceptual and numerical model in the next activity.

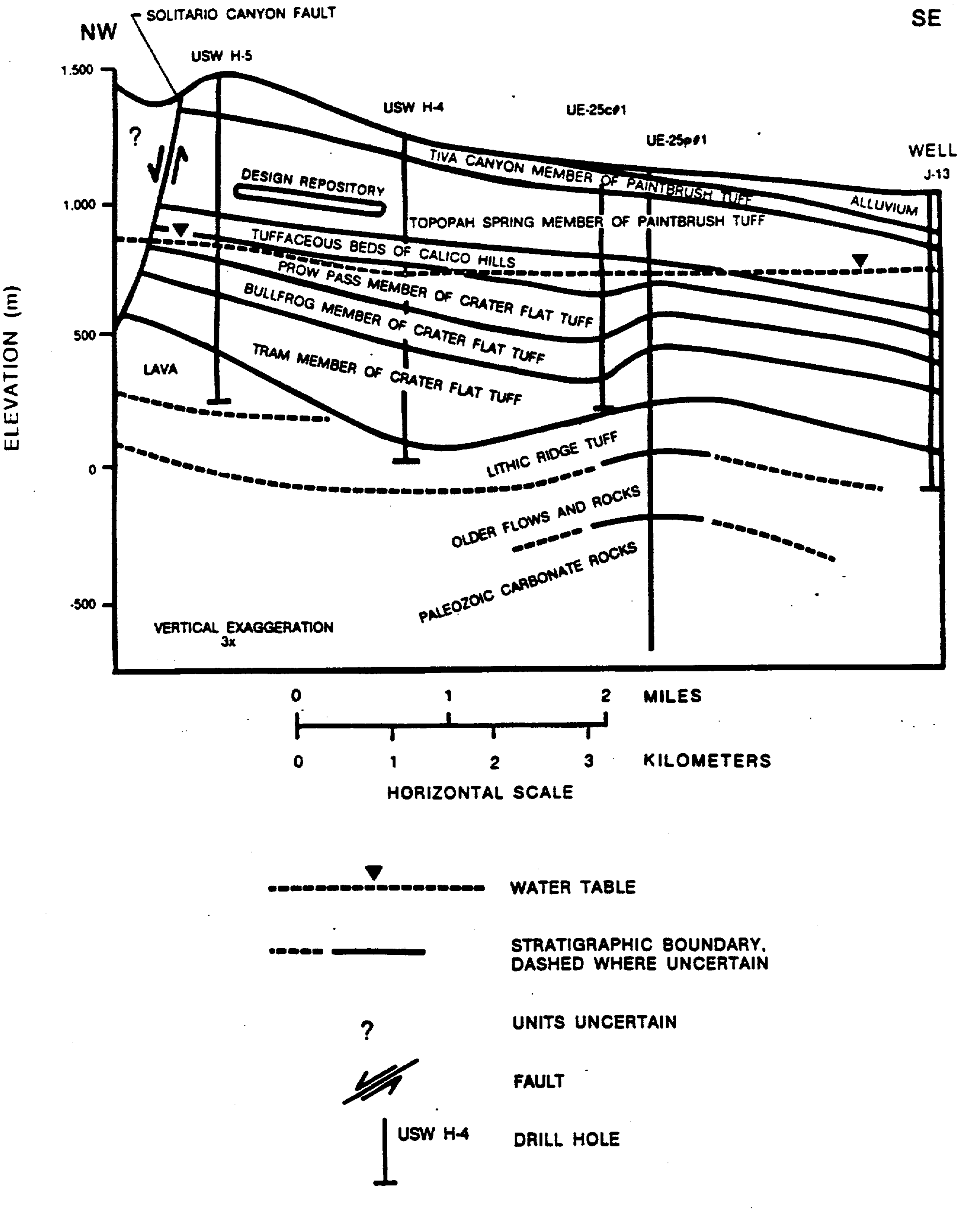

Figure 2.1-3. Simplified stratigraphy of section across Yucca Mountain, showing stratigraphic relations (U.S. Department of Energy, 1988).

The calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment (Activity 8.3.1.2.3.3.3) is the culminating effort of the saturated-zone investigation. In this activity, equivalent porous media and fracture-flow concepts generated from the previous activities will be combined to form a ground-water flow and conservative transport model at the scale of Yucca Mountain. The resulting conceptual model will be translated to a mathematical/numerical model and will be used to calculate flow paths, fluxes, and ground-water travel times in the saturated zone at the site scale (10's of km in the vicinity of Yucca Mountain).

2.1.4 Parameters and modeling strategies

In SCP usage (U.S. Department of Energy, 1988) hydrologic activity parameters are those parameters that are generated by testing and analysis in the field, laboratory, or office; 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. The activity parameters associated with activities of this study also appear in the figures and tables of Section 3 of this study plan. Parameter categories serve to group similar types of performance and design parameters supporting performance-assessment and design 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 2.1-4, the parameter categories are shown supporting specific model components that make up the site 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.

Table 2.1-1 groups the activity parameters of the present 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 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-

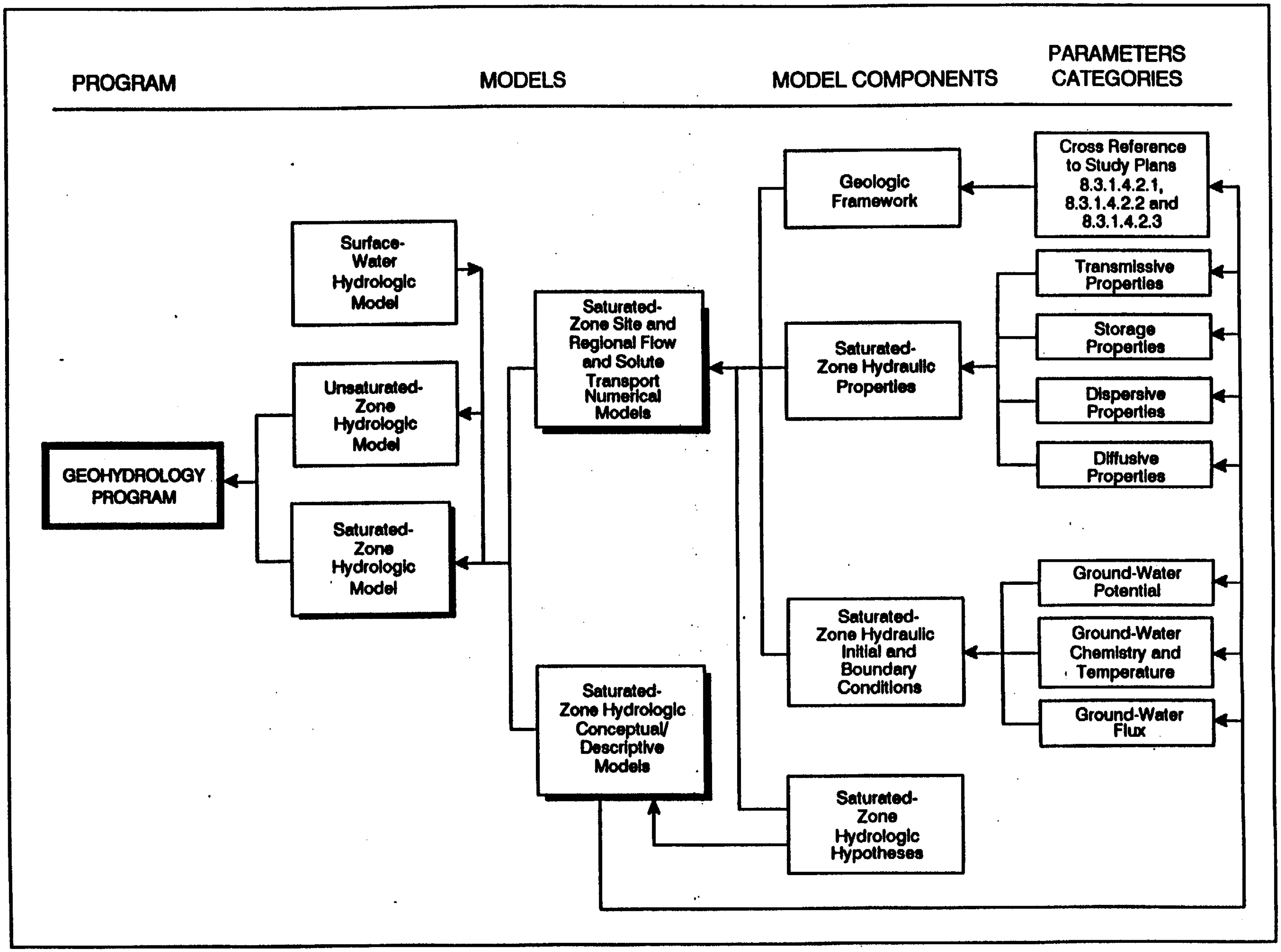

Figure 2.1-4. Logic diagram of the saturated-zone hydrology component of the geohydrology program.

Table 2.1-1 Association of measured activity parameters with site-characterization parameters

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
Activity 8.3.1.2.3.1 Conceptualization of saturated-zone flow models within the boundaries of the accessible environment	Hydraulic conductivity	Hydraulic conductivity, spatial distribution, assumptions for site conceptual model
		Sensitivity, transmissive properties
	Hydraulic gradient	Sensitivity, potentiometric surface
	Effective porosity	Sensitivity Spatial distribution, assumptions for site
		Conceptual model
	Ground-water flux	Ground-eater flux, assumptions for site conceptual model
	Water chemistry	Spatial distribution, assumptions for Site conceptual model
	Storage properties	Sensitivity, Spatial distribution, assumptions for Site conceptual model
	Potentiometric surface configuration	Spatial distribution, assumptions for Site Conceptual model
Activity 8.3.1.2.3.3.2 - Development of fracture network model	Hydraulic conductivity	Hydraulic conductivity, fracture networks
		Hydraulic conductivity, effective, variation with fracture geometry

Table 2.1-1 Association of measured activity parameters with site-characterization parameters

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
	Hydraulic gradient	Hydraulic gradients, fracture networks
	Storage coefficient	Storage coefficient, fracture networks
	Ground-water flux	Ground-water flux in fracture networks, steady-state and transient
		Relations between fracture geometry characteristics and hydrologic response
		Relations between geophysical and hydrologic models
	Ground-solute transport	Conservative-solute transport, fracture networks, steady-state and transient
		Hydrodynamic dispersion, fracture networks
Activity 8.3.1.2.3.3.3 - Calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment	Hydraulic conductivity	Hydraulic conductivity, spatial distribution
	Hydraulic gradient	Potentiometric surface, site
	Storage coefficient	Storage coefficient, spatial distribution
	Effective porosity	Effective porosity, spatial distribution

Table 2.1-1 Association of measured activity parameters with site-characterization parameters

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
	Ground-water flux	Groundwater-water flow paths, scale of Yucca Mountain
		Ground-water flow velocities, scale of Yucca Mountain
		Matrix diffusive properties, spatial distribution
		Ground-water flux, scale of Yucca Mountain
	Conservative-solute transport	Conservative-solute transport, scale of Yucca Mountain, matrix diffusive properties, spatial distribution

assessment analyses. Hydrologic analyses generated in this study can be traced from activity parameters through characterization parameters and to their intended use in satisfying performance-assessment 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 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 performance parameters, the activity parameters listed in Table 2.1-1 and Section 3 are needed to test hypotheses that support conceptual models and model components. 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 magnitude of a parameter by different means. The combined effect of using multiple approaches (or analyses) 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 analytical 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.

2.1.5 Current representation of the saturated-zone and alternate hypotheses

SCP Table 8.3.1.2-2b lists certain current and alternate hypotheses concerning the saturated-zone hydrologic regime. These will contribute to the hydrologic hypotheses developed in the saturated-zone hydrologic model. In conducting preliminary performance and design analyses, assumptions must be made regarding the values of some parameters and hydrologic processes and conditions. These preliminary analyses may include assumptions involving values of such parameters as hydraulic conductivity, effective porosity, and hydraulic gradient including assumptions regarding the dimensionality of the problem, scaling of variables, and closeness of the system to equilibrium. The on-going process of hypothesis testing helps to increase confidence that the assumptions made in preliminary analyses are reasonable.

2.1.6 Hydrologic modeling

The following definitions will be used throughout this study plan:

1. Hydrologic Hypotheses - proposed explanations of flow system behavior based on available data that are tested by mathematical/numerical modeling. Hypotheses that are tenable are considered working hypotheses and are incorporated into the conceptual model.

2. Conceptual model - a collection of working hypotheses that describe a system, in general referring to the site saturated-zone hydrologic system, but also applicable to any system being described, such as a geological conceptual model as defined by geophysical information. The conceptual model is a way of abstracting and simplifying natural phenomena (Bear, 1972, p. 83).

3. Mathematical/Numerical Model - the mathematical equations and resulting numerical model that are derived from the conceptual model. Often the mathematical equations cannot be solved directly, so numerical techniques are utilized.

4. Calibration Process - comparison of the simulated numerical model results with observed data in order to best represent the system under study. Calibration is a process and is dependent on the quantity and quality of available data and observations. Qualitative or quantitative methods, including professional judgment, may be used to assess the adequacy of the calibration process and may have a stochastic, deterministic, or empirical basis. Criteria can be used to judge calibration, such as the minimum sum of squared residuals between calculated and observed hydraulic head. In addition, the calibration process will involve an examination of the observed versus predicted water levels, gradients, fluxes and possibly geochemistry produced from the flow model. In deterministic ground-water flow models, calibration often involves a trial and error process of adjusting the input parameters within their ranges of uncertainty to produce a better fit with observed data. Any solution, however, must be considered to be non-unique because the nature of a ground-water system is that it is poorly constrained.

5. Verification - the process of testing that the mathematical equations embodied in the numerical code are correct and adequately represent the processes being modeled. In addition, the verification process assumes that the particular numerical model has been tested under different cases and its results compared with analytical solution or laboratory results for the same problem.

6. Validation - tests the ability of the conceptual and numerical models to correctly represent the significant physical processes of the system being studied. Model validation is closely linked to the calibration process and sensitivity analyses. In the validation process, once a model is calibrated by adjusting model variables within their range of certainty to reduce differences between predicted and observed values, model results are compared to another set of data with varying boundary, hydrologic or initial conditions for the same system. Cross validation (discussed below) may be performed if an additional data set is not available. Determination of error acceptable in the modeling process is governed by objectives of the modeling and how the model will be applied, including the influence of errors on the ground-water system's ability to meet certain criteria, such as the minimum ground-water travel time. It is envisioned that probabilistic error calculations will be made for each model discussed in this study and that uncertainty in the modeling will be quantified to the extent possible. Model error also is dependent on errors associated with data that support the model. These cumulative errors derived from related studies will be addressed as modeling proceeds.

   Further methods of validation include the ability of the model to accurately predict future well-test results (tests are described in Study 8.3.1.2.3.1, Site saturated-zone flow system) and new data such as hydraulic head and discharge. Inherent in these comparisons is uncertainty related to the system geometry. Sometimes, extensive field validation is not possible and validation efforts may rely on peer review of the conceptual and numerical models.

7. Cross Validation - this process involves using all the data except data from one point and then predicting that value with the resultant model. A prediction error can be calculated for the observed versus predicted values. The process is repeated, leaving each data point out, in order to obtain a distribution of prediction that can be used to estimate the overall prediction error for a model given the complete data set.

8. Sensitivity Analyses - these analyses consist of measuring the response of the numerical model to changes in the value of a model parameter, and may be performed by varying one or more model parameters over the range of probable uncertainty. Model parameter sensitivity may be evaluated using a variety of different methods such as deterministic, stochastic, empirical or qualitative methods. The sensitivity analysis will indicate the relative ranking of variables based on current assumptions showing which variables have the greatest effect on model results. Another use of sensitivity analyses will be to identify those locations at which more data or tests (described in SP 8.3.1.2.3.1) are needed to reduce uncertainty.

Because of flow-system complexity at the site and because there will never be enough data to define the system exactly in a deterministic manner, it is likely that the models discussed in the study may have multiple possible solutions and, therefore, may not be unique. The less known about the system, the more assumptions must be made. These assumptions can be tested and confidence in the model can be built by predicting future tests, performing cross-validation, and submitting the model to peer review. The ultimate goals of modeling will be to narrow the range of uncertainty in the solutions, to minimize prediction error and to provide feedback to data gathering studies such as Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system).

2.1.7 Contributions from other studies

The contributions of other site-characterization studies to the site saturated-zone synthesis and modeling study are outlined below, and are treated in more detail in Sections 3.1, 3.2, and 3.3.

Study 8.3.1.4.2.1 (Vertical and lateral distribution of stratigraphic units within the site area) will contribute data on the spatial variations of the Crater Flat Tuff and other saturated-zone units to the present study.

Study 8.3.1.4.2.2 (Structural features within the site area) will contribute the following to the present study: fracture-network geometry of the Paintbrush Tuff from outcrops; borehole fracture data; shaft- and drift-wall fracture data; and fracture location, density, and orientation from cross-hole tomography and vertical seismic profiles between wells.

Study 8.3.1.4.2.3 (Three-dimensional geologic model) will contribute the following to the present study: a geologic model for the Crater Flat Tuff; geological and geophysical data for fracture-network model development; an integrated geological/geophysical model for fracture-network geometry in the saturated zone at Yucca Mountain; and other stratigraphic and structural data pertinent to site hydrogeology.

Study 8.3.1.4.3.2 (Three-dimensional rock-characteristics models) will contribute the following to the present study: spatial distribution of rock-characteristics data, including measured hydrologic properties; and geological and geophysical data for fracture-network model development.

Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system) will contribute the following to the present study: hydrogeologic and hydrologic-properties data from previous and planned future hydraulic-stress and tracer tests, to be used in the calibration and validation processes for the site saturated-zone modeling effort.

Study 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling) will support the present study, in that the regional saturated-zone flow system must be understood in order to define the present and expected boundary conditions and initial conditions for the site saturated-zone model. In addition to providing the results of the regional modeling effort to the present study, Study 8.3.1.2.1.4 may also contribute interpretations of the hydrogeologic setting in support of the site modeling effort.

Study 8.3.1.5.2.1 (Quaternary regional hydrology) will contribute information on the geologic framework, saturated-zone hydraulic properties, initial conditions, boundary conditions, and hydrologic hypotheses (including changes over time in the flow regime) to the present study.

Study 8.3.1.5.2.2 (Future regional hydrology due to climate changes) will also contribute information on the impacts of changes in climate and tectonics on recharge, discharge, and flow paths, to this study.

Study 8.3.1.2.2.9 (Site unsaturated zone modeling and synthesis) will contribute information on how water moves through unsaturated zone to the saturated zone and what range of flux might be expected from the unsaturated zone.

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 greatly depend on data generated from other studies and activities as site characterization proceeds, as well as on pre-existing data from earlier studies. These data will be synthesized to formulate one or more conceptual models, and later one or more mathematical/numerical models of site saturated-zone ground-water flow. Therefore, representativeness of these models with respect to the repository site will depend on the quantity and quality of the input data. The models will be checked frequently for agreement and representativeness of the site as new data become available, and preliminary modeling will be performed in order to assess data-gathering needs, including numbers, types and locations of tests discussed in YMP-USGS SP 8.3.1.2.3.1. Based on the professional judgement of the investigator(s), and criteria described in Sections 3.1.3.2, 3.2.3.1.3, 3.2 [illegible].2.2; and 3.3.3.2 of this document, the conceptual and numerical models will be assessed as to whether or not they adequately represent the ground-water flow system at the site. These criteria will be used to determine data-collection needs and to help decide when enough data have been collected. As conceptual and mathematical/numerical model development proceeds, it is expected that system characteristics which have only minimal influence on the system response will be recognized and perhaps deleted from the model(s); thus the model(s) may incorporate only the most dominant processes contributing to the behavior of the hydrologic system. Simplification of conceptual and numerical models is a common practice. "In each case, the simplification is carried to the point where the model is still amenable to mathmatical treatment, yet is not so simple as to miss those features of the studied phenomena it is intended to describe ..."(Bear, 1972, p. 83).

2.2.2 Accuracy and precision of methods

Selected methods for testing in each activity are summarized in tables at the end of each activity section (Section 3). These methods were selected on the basis of their precision and accuracy, duration, and interference with other tests and analyses. The accuracy and precision of the modeling analyses are difficult to quantify prior to any implementation of the testing methods. However, when the results of the modeling are reported the accuracy and/or precision of the results will be described. The degree of accuracy and/or precision of the modeling is a qualitative, relative judgement based on current knowledge and familiarity with modeling methodology. The accuracy and precision of the information required for performance assessment has not been specified. Consequently, the accuracy and precision required from the results of the modeling cannot be specified.

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. 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 from these outside studies will be further discussed within their respective study plans.

2.2.4 Time required versus time available

Current schedules of the tasks and deliverables within the three activities of this study are shown in Section 5.1. The three activities rely heavily upon the data-gathering activities of other studies, particularly Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system). Therefore the schedules for the modeling efforts of the present study are dependent on schedules for hydrologic data collection. The principal investigator and USGS-HIP management have formulated the schedules to consider this constraint and also to provide sufficient time for model development and testing.

2.2.5 Limits of modeling methods

Although numerical modeling of tests planned in this study will be performed, the problem remains of identifying parameters in a distributed system with many degrees of freedom available. Measurements in the tests will be made at a few locations in a system in which the numerical mesh of the model may have thousands of unknowns. The use of all available data can reduce uncertainty, but some uncertainty will remain. Uncertainty analyses, such as parameter estimation and other geostatistical techniques, may be used to aid in quantifying the uncertainty, if enough data are available.

2.2.6 Potential for interference among activities

Because of the nature of modeling activities, the analyses in this study will have little or no interference among themselves or other site-characterization activities.

3. DESCRIPTION OF ACTIVITIES

This study is organized into three activities:

- 8.3.1.2.3.3.1 - Conceptualization of saturated-zone flow models within the boundaries of the accessible environment;
- 8.3.1.2.3.3.2 - Development of fracture-network model; and
- 8.3.1.2.3.3.3 - Calculation of flow, fluxes, and velocities within the saturated zone to the accessible environment.

The plans for these activities are described in Section 3.1 through 3.3.

3.1 Conceptualization of saturated-zone flow models within the boundaries of the accessible environment

3.1.1 Objectives

The objectives of this activity are:

(1) to synthesize the available data into a conceptual and mathematical/numerical model, and

(2) to make a qualitative analysis of how the saturated-zone system is functioning.

3.1.2 Rationale for activity selection

The goal of this activity is to conceptualize a saturated-zone flow model at the Yucca Mountain site. Numerical simulation of flow and transport within the saturated zone typically consists of mathematical equations which describe the present hydrologic and transport processes (governing equations) and a computer code to solve the governing equations using numerical techniques. Defining the governing equations for a particular system, however, requires knowledge of the system characteristics and a conceptual model of the system. The conceptual model cannot be formulated without preliminary hypothesis proposal and testing.

Hydrologic hypotheses for the saturated zone at Yucca Mountain are proposed explanations of the system behavior. These hypotheses are supported, qualitatively, by observations and data and will be subject to change as the site saturated-zone database is updated during site characterization.

3.1.3 General approach and summary of analyses

All reliable data and reasonable interpretations of the data will be assimilated into a description of the flow system in an area surrounding and including the site to be determined by the investigator(s) based on available data, modeling considerations, and professional judgement. This description will include the physical and hydraulic characteristics of the rock units and structural features, as well as the likely ways that the flow system operates within this framework. The data will contain information obtained from the published literature and the YMP activities. This description of the flow system will be used to formulate hydrologic hypotheses which will be tested by mathematical/numerical modeling. Hypotheses that are judged by the investigator(s) to be tenable will be incorporated into the one or more conceptual models. The conceptual model(s) will be evaluated by a derived mathematical/numerical model that may or may not be the same numerical modeling code as used in analysis of the various hypotheses, based on the professional judgement of the investigator(s). The resulting mathematical/numerical model will undergo a validation process as discussed in Section 2.1.6.

Water mass-balance data primarily will originate from Study 8.3.1.5.2.1 (Quaternary regional hydrology). Activities 8.3.1.5.2.1.3 (Evaluation of past-discharge areas) and 8.3.1.5.2.1.4 (Analog-recharge studies) will provide information on rates of evapotranspiration and recharge for different climatic conditions representative of past and present conditions at the site. Methods to be used include hydrologic-budget modeling and chloride-ion, mass balance modeling cross checked by an examination of geochemistry associated with arid-zone infiltration. Information about recharge fluxes through the unsaturated zone will be provided from Study 8.3.1.2.2.9 (Site unsaturated-zone modeling and synthesis).

Changes in the saturated-zone system with time will be addressed in Studies 8.3.1.5.2.1 (Quaternary regional hydrology) and 8.3.1.5 2.2 (Future regional hydrology due to climatic changes). Data gathered under these studies regarding transient changes in the hydrologic regime will be incorporated into the site model(s) discussed in the present study.

Boundary conditions (fluxes) and initial conditions for numerical modeling at the site scale will be derived from Studies 8.3.1.5.2.1 (Quaternary regional hydrology) and 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling). Physical boundaries will be selected specific to this study, but fluxes across those boundaries will be calculated from the regional models.

Additional hydrogeologic data contributing to the present study will be drawn from other studies in the Geohydrology Program, including 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling), 8.3.1.5.2.1 (Quaternary regional hydrology) and 8.3.1.5 2.2 (Future regional hydrology due to climatic changes).

Hydrologic hypotheses will be assessed from a number of studies including 8.3.1.5.2.1 (Quaternary regional hydrology), 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling) and 8.3.1.2.3.1 (Site saturated-zone ground-water flow system).

Hydraulic and hydrogeologic data for this study primarily will come from Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system). Data to be contributed from that study include hydraulic-property estimates from well-stress tests and conservative tracer tests (hydraulic conductivity, effective porosity, estimates of dispersion coefficients, matrix diffusion, and storage coefficients), hydraulic characteristics of selected faults, water levels at individual wells and hydraulic gradients between wells, characterization of the type of flow (linear, radial, spherical, fractal, fissure, porous) that occurs at single- and multiple-well scales, identification of the degree of vertical flow between different strata, at the small scale, evaluation of equivalent-porous-medium concepts at the scale of the tests, and definition of solute-transport properties and their relation to fracture characteristics and suitability of single- versus multiple-well tests to characterize transport properties. Information on matrix diffusion will come through analyses discussed in YMP-USGS SP 8.3.1.2.3.1 (Site saturated-zone ground-water flow system) of experiments to be performed at the C-well complex described in detail in Study Plan 8.3.1.2.3.1.7 (Reactive tracer experiments in the C-wells). In addition, Study 8.3.1.2.3.1 will address spatial variability in transport properties by hydraulic and tracer tests and scale dependency of different hydraulic parameters by conducting well tests at different scales (under varying hydraulic stresses and radii of influence).

The source for stratigraphic and structural data pertinent to the hydrogeology will be Study 8.3.1.4.2.3 (Three-dimensional geologic model). The source for the spatial distribution of rock-characteristics data, including measured hydrologic properties, will be Study 8.3.1.4.3.2 (Three-dimensional rock-characteristics models). The above two studies together are the culmination of the Rock Characteristics Program.

Three analyses used in modeling the site saturated zone are described in this activity: (1) data synthesis and preliminary hypothesis testing, (2) model development and validation, and (3) sensitivity and uncertainty analyses. The first analysis consists of data synthesis and preliminary hypothesis testing that lay the groundwork for development of a conceptual model by indicating hypotheses and concepts that are consistent with observations made and data available of the saturated-zone flow system at Yucca Mountain, and provides feedback to data-gathering activities (described in Study 8.3.1.2.3.1) as to the location, type, length, and number of tests needed in the saturated zone. The results of the hypotheses testing generally lead to a new or revised set of hypotheses which are again tested. The second analysis is comprised of conceptual model development, derivation of a mathematical/numerical model from the conceptual model, and validation of the mathematical/numerical model using hypotheses tested in the preliminary hypotheses testing stage to form one or more conceptual models for the saturated-zone flow system. As part of this step, the conceptual model(s) will be translated into a mathematical/numerical model(s). Calibration and validation will be performed to the extent possible given the amount of data available. In the third analysis, sensitivity and uncertainty analyses are performed to measure the relative importance of the major components of the conceptual model and to characterize uncertainty if possible. These analyses begin after the conceptual model(s) has undergone the validation process because the sensitivity is likely to be a function of the conceptual model.

Figure 3.1-1 summarizes the organization of the conceptualization of saturated-zone flow models. A descriptive heading for each analysis appears in the shadowed boxes of the second row. Below each analysis are the individual methods that will be utilized during analysis. Figure 3.1-2 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 analysis boxes, respectively, in Figure 3.1-2.

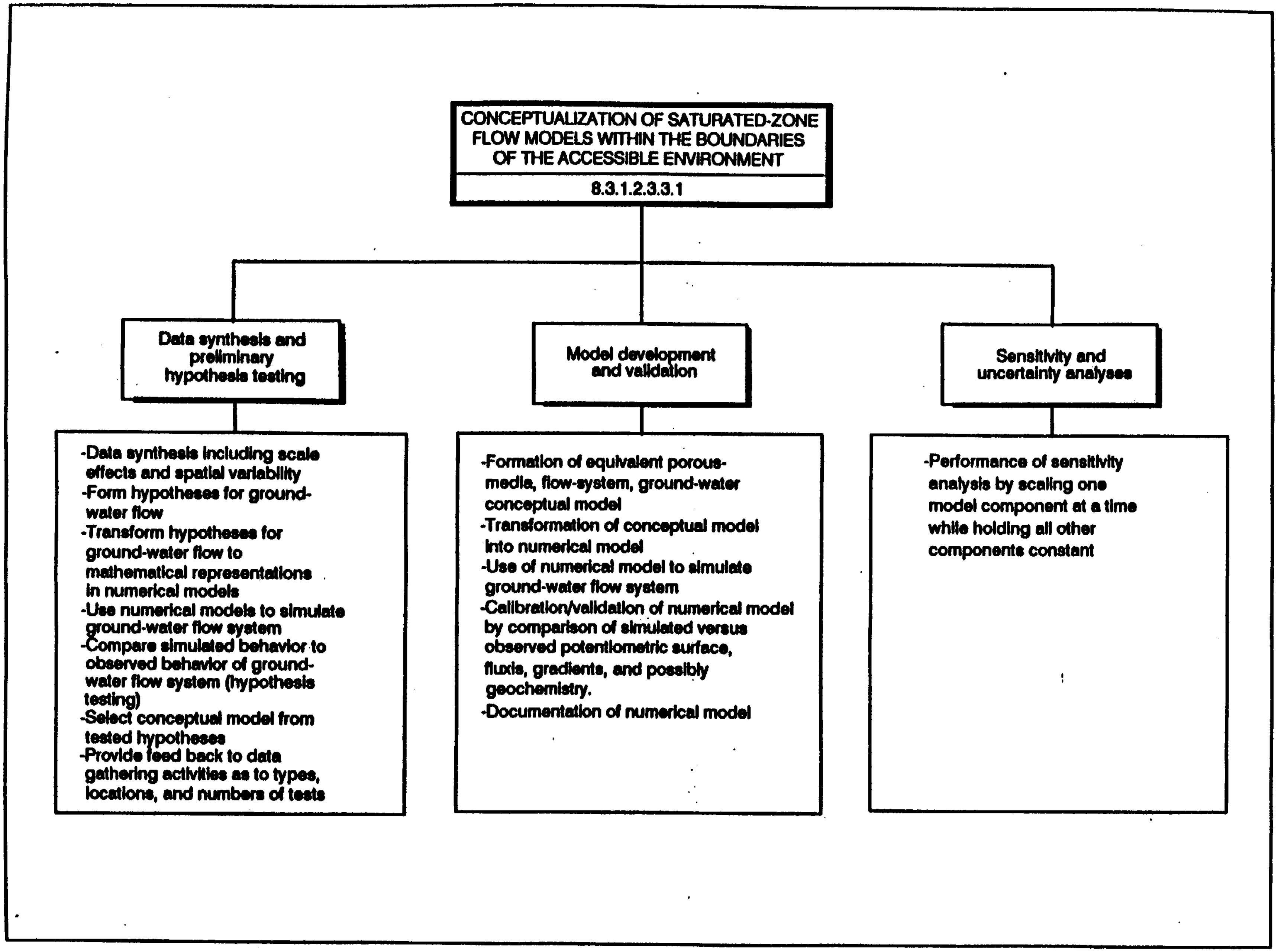

Figure 3.1-1. Logic diagram of conceptualization of saturated-zone flow-models activity, showing tests, analyses, and methods.

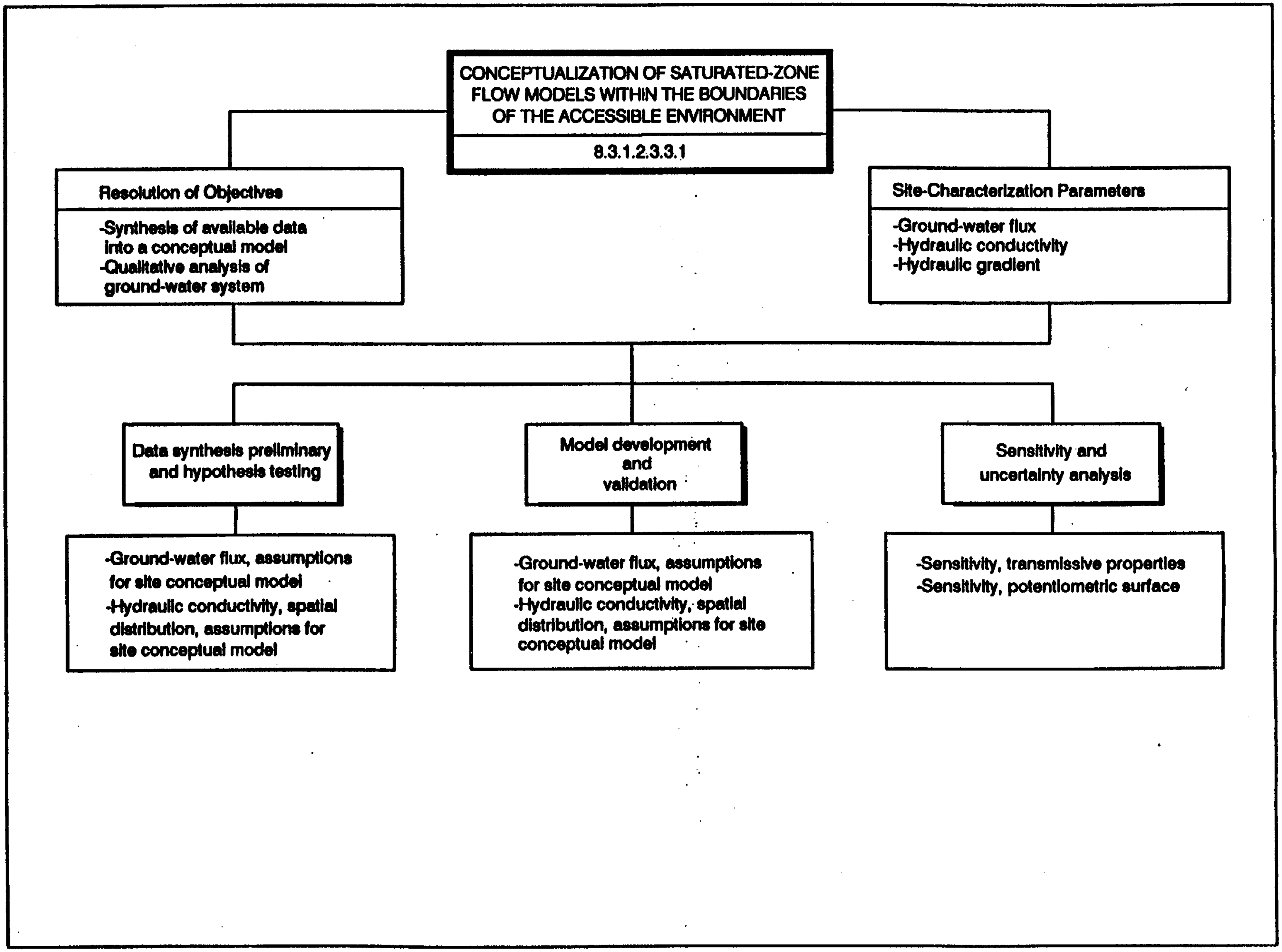

Figure 3.1-2. Logic diagram of conceptualization of saturated-zone flow-models activity, showing tests, analyses and activity parameters.

The two figures summarize the overall structure of the planned activity in terms of methods to be employed and measurements to be made. 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 activity 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 Data synthesis and preliminary hypothesis testing

The flow system within the saturated zone at Yucca Mountain is quite complex. Flow may be controlled by a combination of flow through the rock matrix, flow through fracture systems, and flow through (or impairment of flow by) fault systems. The stratigraphy and structure at and near the site is also quite complex. The hydraulic characteristics that affect ground-water flow may vary drastically between and within individual stratigraphic units. Not all items equally influence the flow system, however. Conceptual model development will include a three-dimensional layered approach that incorporates structural geology as observed from geophysical and borehole evidence. This approach will examine the influence of the underlying Paleozoic aquifer on the Tertiary tuff aquifer and the impact of large-scale structural features on ground-water flow. At present, the paucity of borehole data is a limiting factor in determining how the regional Paleozoic aquifer is conceptualized in the vicinity of Yucca Mountain. In addition, little information is available on the occurrence of faults in the subsurface. Numerical modeling (described in Section 3.1.3.2) via posing alternative conceptual models, may be able to address questions of what is geologically feasible and may be able to guide data collection activities.

To be able to ultimately conceptualize the flow system at Yucca Mountain, the system must be simplified. The essential physical processes must be included, but incidental processes must be ignored. The essential processes will be defined during this study. It is necessary to make simplifying assumptions about the operation of the flow system. In addition, the hydraulic characteristics must be estimated through analysis of aquifer stress tests and water-level fluctuations. Synthesis of the available data and preliminary hypotheses testing will lead to a description of the flow system that will become the conceptual model (or models).

The data used to form hydrologic hypotheses consist of both geologic and hydrologic data. The geologic data are useful in defining the geologic framework (e.g., site geometry, spatial location of faults and fracture networks, physical boundary conditions), whereas the hydrologic data consist of parameters such as hydraulic conductivity, hydraulic gradient, effective porosity, matrix diffusion, flux, water chemistry, and media storage properties. Therefore, formulation of hydrologic hypotheses and subsequent conceptual models will continually be refined as site characterization proceeds and the geohydrologic data base increases.

Data synthesis will be an important component of this first analysis. Scaling difficulties are expected in the synthesis process. Translation of data from the measured scale to the site scale could be addressed by the application of several new stochastic techniques, such as the definition of effective properties (Bakr and others, 1978; Gutjahr and others, 1978; and Dagan, 1981). Effective conductivities can be derived by these techniques given the variation in local-scale conductivity. Other ways in which to incorporate scale effects are described by Smith and Freeze (1979), Rubin and Gomez-Hernandez (1990) and Desbarats (1987), who employed heuristic upscaling rules via computer simulations and Monte Carlo techniques to define block conductivities.

Spatial variation of hydrologic parameters is also of concern in this study. Geostatistical procedures may aid in the analysis of hydraulic parameter spatial variability. However, these procedures require a certain amount of data, often a large number of measurement pairs for each point, to construct a semivariogram for the parameter under consideration. A common problem is that there are not enough data to adequately describe the shape of the semivariogram. The only parameter for which there is a large enough data set is hydraulic head. All other hydrologic parameters are characterized by sparse data. One way in which to address this difficulty is to incorporate soft information into the analysis. Such soft information might include results from geologic and seismic work, where the parameter values may not be well known and which may be inexactly located within a certain volume of material. An example of this kind of information might be knowledge of the general location and orientation of high-conductivity features. These features can be incorporated into the geostatistical process as soft information to create a synthetic semivariogram along with available data.

Another way to assess data needs is to construct a meaningful semivariogram by numerically generating a hydraulic conductivity field possessing an assumed spatial structure. A set of point measurements would then be sampled from this field equal to the number of expected sampling locations. This method would be a way in which to test that data density is sufficient to recreate the initial conductivity field. A problem with this approach is that the assumed variances and ranges, used to create the initial conductivity field, may not adequately represent the degree of spatial variability that actually exists in the field. Monte Carlo analysis could aid in the testing of possible spatial distributions of hydrologic parameters under study. Lack of data, again, may prove to be the limiting factor in this analysis.

Data synthesis may be aided by use of a three-dimensional geoscientific information system, (GSIS), described by Turner and others (1991). Advantages of using GSIS are: the management and integration of data, including the incorporation of soft data; the ability to rapidly develop, test, and visualize alternate conceptualizations of the system under study; and ease of data input to the mathematical/numerical modeling process.

After preliminary hypotheses about the flow system have been formulated, they will be tested with a numerical model. The numerical model will be used to simulate the flow system and calculate the expected behavior of the system, based on the preliminary hypotheses. These simulated results will be examined in light of the observed behavior of the flow system to see if the preliminary hypotheses are reasonable.

In addition, the data synthesis and testing phase will be used to provide input to data-collecting and testing activities (described in YMP-USGS SP 8.3.1.2.3.1). This feedback process will address additional data and tests to characterize the system and may indicate the appropriate scale for data collection.

Figure 3.1-3 illustrates the feedback process involved in data synthesis and preliminary hypotheses testing. The process of developing hypotheses, simulating the flow system, and comparing the simulated and observed behavior of the system generally leads to revised hypotheses. This process of revising hypotheses, simulating the system, and comparing the observed and simulated behavior of the system continues iteratively until the simulated behavior of the system approaches the observed behavior of the system. At this point, the preliminary hypotheses about the system are ready to become the conceptual model of the ground-water flow system at the site.

3.1.3.2 Model development and validation

The preliminary hypotheses testing will gradually eliminate any untenable hypotheses about the flow system within the saturated zone at Yucca Mountain and will lead to development of one or more conceptual models of the flow system. The conceptual models will include the essential processes that control the ground-water flow system, the boundary conditions at the perimeter of the flow system, and quantitative descriptions of the appropriate hydraulic parameters. In this activity, an assumption that will be made in the conceptual model described is the ground-water flow system can be represented by equivalent porous-media concepts. Major structural features such as the Solitario Canyon fault may be represented as zones of different hydraulic characteristics, whereas minor features will be incorporated into the equivalent porous-media concept. The boundaries of the conceptual model, which probably will be on the order of 10's of km, will become a combination of specified-water-level and/or specified-flow boundaries derived from information generated by Studies 8.3.1.5.2.1 (Quaternary regional hydrology), 8.3.1.5.2.2 (Future regional hydrology due to climate changes), and 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling). The hydraulic parameters specified in the conceptual model will be the porous-media-equivalent parameters for the flow system generated from the above studies in addition to Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system). These

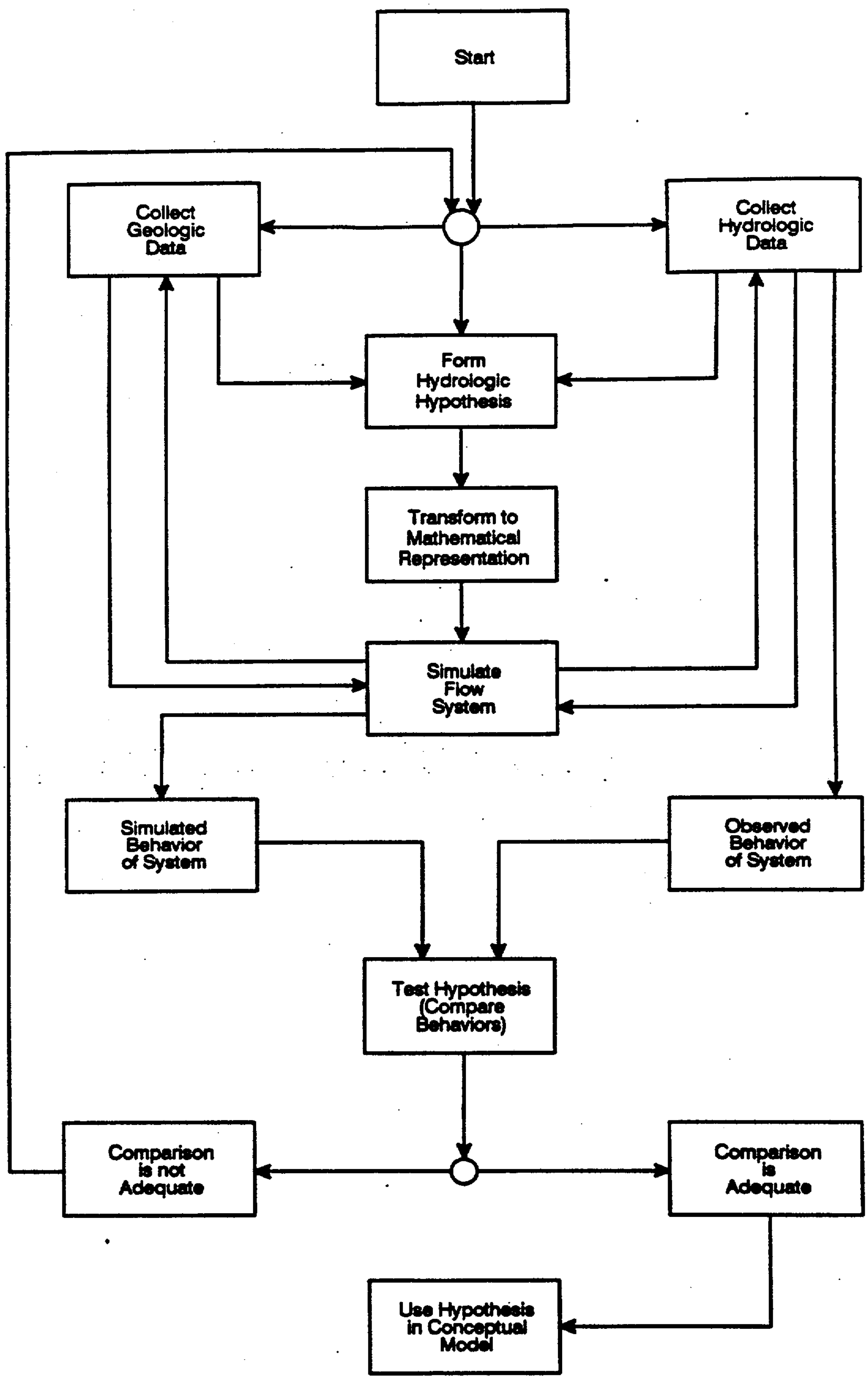

Figure 3.1-3. Feedback process used in preliminary hypothesis testing.

parameters probably will depend on the scale of the model, as discussed previously in Section 3.1.3.1, and may or may not be closely related to the parameters that are measured at the boreholes, particularly because equivalent-porous-media concepts are being assumed on a site scale in this first activity. Flow on the local scale (for example, the C-well complex) may not be adequately represented by equivalent-porous-media concepts, whereas for flow at the site scale, porous media representation of the fracture formations may be acceptable.

The conceptual model must be transformed into a mathematical/ numerical model before it can be used to simulate the flow system. The numerical model probably will be three-dimensional and will consider steady-state flow conditions. Initially, steady-state conditions will be assumed and transient conditions will not be simulated because of the preliminary nature of the modeling and the need to understand first-order effects before adding complexity to the model. Little data may be available at this point of the modeling process to support modeling in transient mode. Therefore, under present-day conditions, boundary conditions and fluxes can initially be described as invariant with time. In monitoring over almost 10 years, minimal changes in the water levels have been observed. In addition, there is little pumping or stress on the system in the present day. Later modeling, under this activity, if the data are available, and under Activity 8.3.1.2.3.3.3 will address transient conditions.

The choice of the numerical code to perform the simulations may or may not be the same as the numerical model used to test the hypotheses. This model will use standard finite-mathematical techniques (finite difference or finite element) to represent the ground-water flow equation. Existing ground-water flow codes will be evaluated for their applicability for use in simulating flow at Yucca Mountain. Codes to be examined include the USGS Modular Model (MODFLOW) (McDonald and Harbaugh, 1988) and the Lawrence Berkeley Lab TOUGH2a Code. Factors to be considered in selecting an existing ground-water flow code include the models' ability to simulate three-dimensional flow and complex geometry, whether or not the model has undergone verification (for the definition of verification see Section 2.1.6), the acceptance of the model by the modeling community, integration with other models currently being used on Yucca Mountain (such as models on the site scale for the unsaturated-zone studies, Study 8.3.1.2.9.9), and the availability and quality of documentation. Other models will be evaluated as needed, but numerical code development will not be undertaken unless there is a demonstrable need. The numerical-model mesh will be fine enough so that the major features of the system can be represented.

All of the components of the conceptual model will be integrated into the numerical model to simulate the flow system. The primary outputs from the numerical model will be simulated water levels which will be compared to the observed water levels to test how well the conceptual model describes the flow system. Matching of simulated versus observed hydraulic heads, fluxes, gradients, and possibly geochemistry, and comparison of model results with past data will constitute the calibration process. Closeness of the simulated model results to the observed data will be judged by the investigators and by methods discussed in Section 2.1.6. If the comparison is not adequate, more data may need to be collected and the conceptual model(s) modified. As discussed previously also in Section 2.1.6, the solution to the model(s) may not be unique because of the complexity of the flow system and data available to characterize the site.

Validation of model results will be addressed to the degree possible. There probably will not be enough data to have separate data sets for the calibration and validation processes. If this is the case, the model(s) may be used to predict future, planned tests, at the appropriate scale described in Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow) as a form of validation. Peer review of the model(s) will also constitute part of the validation process.

Once calibration and validation have been performed, to the extent possible, and results are judged to be satisfactory by the investigators and the peer reviewers, the conceptual model(s) will be considered to be the best representation of the saturated flow system at the site. The simulated water levels can be used to calculate ground-water flux and will be used in the analysis of flow paths and ground-water travel times.

Both the conceptual model and its mathematical representation will be documented. The documentation will include the physical processes simulated; the boundary conditions imposed; the finite mathematical technique used, including its associated mesh; and the porous-media equivalent hydraulic parameters utilized. The documentation will show the simulated and observed water levels and discuss the differences where appropriate.

3.1.3.3 Sensitivity and uncertainty analyses

After the numerical model presents the best available representation of the saturated-zone flow system at Yucca Mountain, given the porous-media equivalent assumption, sensitivity analyses will be performed. The numerical representation of the conceptual model assumes that all parameters, stresses, and boundary conditions (herein called "model variables") are known. Even though some model variables are better known than are others, no model component is known with complete certainty. Sensitivity analyses will address some of this uncertainty and were previously described in Section 2.1. These analyses will be used to identify parameters and areas where more data are needed to reduce uncertainty. Parameters to be analyzed include: saturated thickness, hydraulic conductivity, recharge, discharge, and boundary conditions. If transient simulations are performed, the sensitivity of the model to effective porosity, storage coefficients, and initial conditions will be evaluated.

Further uncertainty analyses may be conducted especially to examine model sensitivity to the spatial structure of various parameters. If enough data are available, Monte Carlo simulations may be made to evaluate the effect of changing a component's spatial distribution.

3.1.3.4 Methods summary

The activity parameters to be evaluated by the tests and analyses described in the above sections are summarized in Table 3.1-1. Also listed are the selected methods for evaluating the parameters. Alternate methods may be utilized if a selected method is impractical to estimate the parameter(s) of interest. The selected methods in Table 3.1-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the parameters of interest. Models and analytical techniques have been or will be developed to be consistent with data developed in this and contributing studies.

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 2.1.7) for which quality assurance levels have been set.

Table 3.1-1 Summary of tests and methods for the conceptualization of saturated-zone flow-models activity (SCP 8.3.1.2.3.3.1)

Methods	Site-characterization parameter
Preliminary hypothesis testing	
Form hypotheses for ground-water flow (selected)	Ground-water flux, assumptions for site conceptual model
"	Hydraulic conductivity, spatial distribution, assumptions for site conceptual model
Transform hypotheses for ground-water flow to mathematical representations in numerical models (selected)	(Does not directly address activity parameter)
Use numerical models to simulate ground-water flow system (selected)	Ground-water flux, assumptions for site conceptual model, hydraulic gradient
"	Hydraulic conductivity, spatial distribution, assumptions for site flow model
Compare simulated behavior to observed behavior of ground-water flow system (hypothesis testing) (selected)	Ground-water flux, assumptions for site conceptual model, hydraulic gradient
"	Hydraulic conductivity, spatial distribution, assumptions for site flow model
Select conceptual model from tested hypotheses (selected)	(Does not directly address activity parameter)
Conceptual-model development and validation	
Formation of equivalent porous-media flow system ground-water conceptual model (selected)	Ground-water flux, assumptions for site conceptual model
"	Hydraulic conductivity, spatial distribution, assumptions for site flow model

Table 3.1-1 Summary of tests and methods for the conceptualization of saturated-zone flow-models activity (SCP 8.3.1.2.3.3.1)

Methods	Site-characterization parameter
Conceptual-model development and validation (continued)	
Transformation of conceptual model into numerical model (selected)	(Does not directly address activity parameter)
Use of numerical model to simulate ground-water flow system (selected)	Ground-water flux, assumptions for site conceptual model, hydraulic gradient
Comparison fo simulated potentiometric surface with observed potentiometric surface (model validation) (selected)	"
Documentation of numerical model (selected)	(Does not directly address activity parameter)
Sensitivity analysis	
Performance of sensitivity analysis by scaling one model component at a time while holding all other components constant (selected)	Sensitivity, potentiometric surface, hydraulic gradient
"	Sensitivity, transmissive properties, hydraulic gradient

3.2 Development of fracture-network model

3.2.1 Objectives

The principal objectives of the hydrologic analysis of fracture networks are:

(1) to develop and evaluate methods for simulating ground-water flow and conservative-solute transport in saturated-fractured rock beneath Yucca Mountain,

(2) to relate results of hydraulic and conservative-tracer tests in wells to fracture-network characteristics.

This activity will result in descriptions of various flow and transport characteristics needed to predict rates and directions of ground-water and radionuclide migration. Flow characteristics include the transmissive and storage properties of the fractured rock. Solute-transport characteristics include effective porosity hydrodynamic dispersion, and matrix diffusion properties.

3.2.2 Rationale for activity selection

Flow at Yucca Mountain is theorized to be dominated by the presence of fractures. On the scale of the site (km by km) it is doubtful whether or not porous-media equivalency will be able to be established in order to describe the flow system as completely as possible. This activity has been selected to develop methodology and models to describe fracture flow. The models will be initially tested at the C-well complex. This modeling will be performed concurrently with stress tests and conservative tracer tests planned at the C-well complex (Study 8.3.1.2.3.1). Information from the testing will help refine the fracture-flow models and the modeling will provide feedback to data collection activities.

3.2.3 General approach and summary of analyses

The hydrologic analysis of fracture networks described in this document emphasizes the development and testing of various models to define the degree to which they can be verified as representative of real conditions.

Major technical components of the hydrologic analysis of fracture networks are broadly placed into two analyses. The first analysis (preliminary model development) emphasizes model development and evaluation using existing data or data that can be readily obtained from geological, geophysical, and hydrologic studies. Much of this data will originate outside the present study, specifically from Study 8.3.1.4.2.2 (Structural features within the site area) and Study 8.3.1.4.2.3 (Three-dimensional geologic model). The second analysis (analysis of well tests) emphasizes model refinement and validation at multiple-well locations in the saturated zone beneath Yucca Mountain.

Part of the data on fracture geometry will originate in activities of the Rock Characteristics Program. In Activity 8.3.1.4.2.2.2 (Surface-fracture network studies), fracture-network geometry of two-dimensional surfaces through three-dimensional networks of the Paintbrush Tuff will be mapped. This information will be compared to data collected in the Crater Flat Tuff and will be supplemented by borehole fracture data collected in Activity 8.3.1.4.2.2.3 (Borehole evaluation of faults and fractures) and drift fracture data collected in Activity 8.3.1.4.2.2.4 (Geologic mapping of the exploratory shaft and drifts). These activities are described in YMP-USGS-SP 8.3.1.4.2.2 (Structural features within the site area). The spatial variations of the Crater Flat Tuff and other saturated-zone units will be investigated in the activities of Study 8.3.1.4.2.1 (Vertical and lateral distribution of stratigraphic units within the site area) and under the present study and Study 8.3.1.2.3.1 (Site saturated-zone hydrologic system). The generation of a geologic model for the Crater Flat Tuff and a geologic model for the fracture networks at Yucca Mountain will in part be performed in Study 8.3.1.4.2.3 (Three-dimensional geologic model).

Because of the multi-disciplinary approach used in the hydrologic analysis of fracture networks, the activity will involve scientists from Lawrence Berkeley Laboratory (LBL) and the U.S. Geological Survey (USGS). The complementary nature of most tasks and the interrelated nature of all disciplines will require significant organizational sharing of responsibilities. Because the USGS has ultimate responsibility for hydrologic characterization of Yucca Mountain, work undertaken by LBL scientists and USGS geologists will require a significant amount of assistance and direction from hydrologists, especially the Principal Investigator, to ensure that work meets USGS needs. As a general guideline, USGS geologists will be responsible for geologic studies, LBL will be responsible for development of computer codes for flow and transport in fracture networks, and USGS hydrologists will be responsible for designing and conducting hydrologic well tests. Geophysical investigations will be undertaken cooperatively by LBL and USGS. Interpretation of hydrologic well tests also will be undertaken cooperatively by LBL and USGS. Development of appropriate conceptual models of flow and transport in fracture networks beneath Yucca Mountain will be the responsibility of USGS hydrologists. This task, however, will be the result of contributions and ideas from all scientists involved to minimize potentially biased influences from one or a few individuals. Work undertaken by both organizations, as part of the hydrologic analysis of fracture networks, will be completed within the framework of the USGS Quality Assurance Plan.

Figure 3.2-1 summarizes the organization of the development of fracture-network tests. A descriptive heading for each analysis appears in the shadowed boxes of the second row. Below each analysis are the individual methods that will be utilized. Figure 3.2-2 summarizes the objectives of the activity, characterization parameters, and activity parameters which are addressed by the activity. These categories appear in the boxes in the top left side, top right side, and below the shadowed analysis boxes, respectively, in Figure 3.2-2.

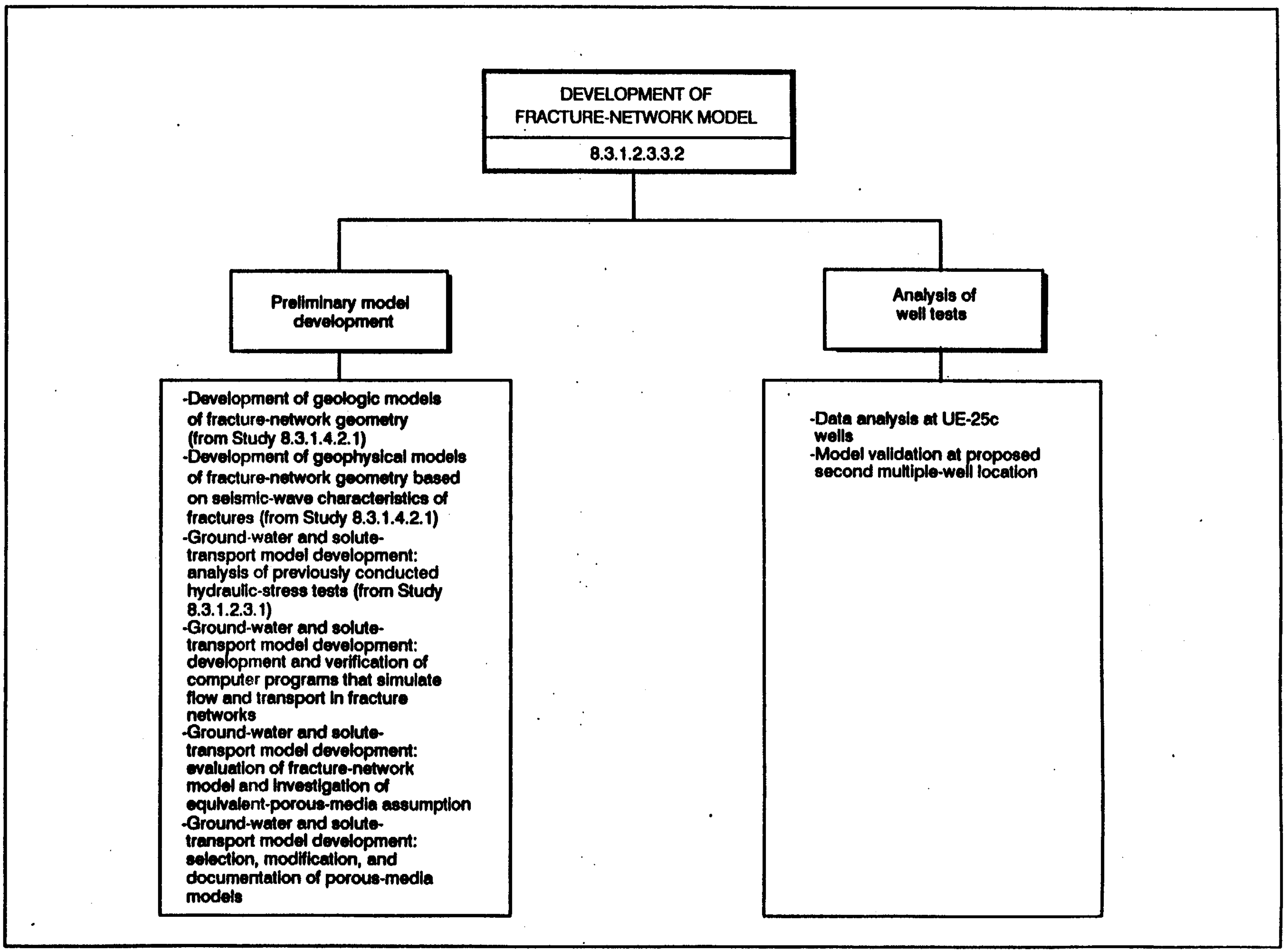

Figure 3.2-1. Logic diagram of development of fracture-network model activity, showing tests, analyses, and methods.

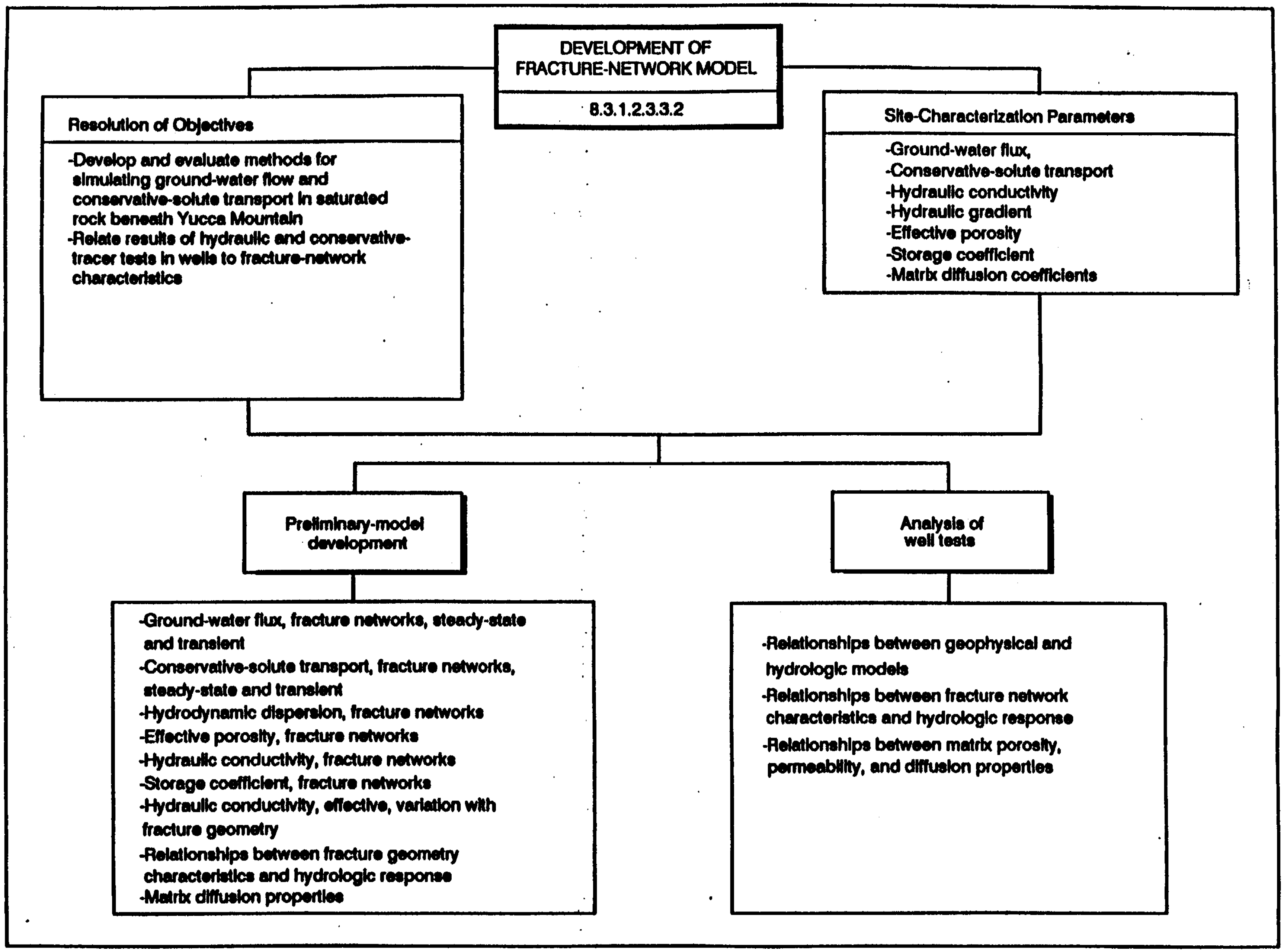

Figure 3.2-2. Logic diagram of development of fracture-network model activity, showing tests, analyses, and activity parameters.

The two figures summarize the overall structure of the planned activity in terms of methods to be employed and measurements to be made. 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 activity 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.

3.2.3.1 Preliminary model development

The understanding of water movement through fractured rock beneath Yucca Mountain is very limited. It is recognized that rates and directions of movement are probably dominated by fractures, but no models specific to the site have been developed to date to estimate rates of movement as a function of fracture spacing, size, orientation, etc. Developing a comprehensive understanding of ground-water movement in fracture networks requires a geologic model that correctly describes the geometry of fracture networks, a geophysical model that correctly estimates spatial variations in fracture geometry in deeply buried rock not amenable to fracture mapping, and a hydrologic model that correctly predicts ground-water flow and conservative-solute transport.

The purpose of this analysis is to develop and evaluate geologic, geophysical, and hydrologic models of fracture networks that could be applied to interpretation of hydrologic well tests. For each model (geologic, geophysical, and hydrologic), development and evaluation can be subdivided into (1) conceptual-model development with existing data or data that result from prototype testing; (2) translation of conceptual models into mathematical/numerical models, including development of computer programs; and (3) refinement of the hydrologic models. For the geologic model of fracture geometry, data collected from outcrop studies and borehole fracture surveys will be used for model refinement. Site-characterization data obtained during well tests will be used to validate and refine geophysical and hydrologic models. Validation of geophysical and hydrologic models is described in Section 3.2.3.2.

The fracture-network models developed for geology (described in Section 3.2.3.1.1 and performed in Studies 8.3.1.4.2.2 and 8.3.1.2.3.1) and geophysics (described in Section 3.2.3.1.2 and performed in Studies 8.3.1.4.2.2, 8.3.1.2.3.1, and 8.3.1.4.2.3) will serve as input, to the hydrologic fracture network model. Statistical analysis of data, including fractal analysis, will be completed in order to develop a conceptual model of fracture-network geometry.

3.2.3.1.1 Development of geologic models of fracture-network geometry

The development of models of fracture-network geometry will be performed by USGS investigators as part of Study 8.3.1.4.2.2 (Structural features within the site area), Study 8.3.1.2.3.1 (Site saturated-zone hydrologic system) and possibly under this activity. Also included are surface mapping of large structural features, borehole evaluation of fractures and stratigraphy from core and geophysical logs, and related structural investigations. These studies will provide information related to fracture-network characteristics, including fracture interconnections at the surface, because surface mapping alone will not provide sufficient information related to three-dimensional spatial variations in fracture characteristics. Effects of burial, changes in stress fields, relations between surface pavements, stratigraphy, and large structural features and changes in fracture-filling characteristics also need to be included in geologic models of fracture-network geometry.

Geologic models of fracture-network geometry will be based on detailed characterization of selected surface pavements and probably outcrop studies, whereas spatial variations in fracture density will be evaluated by less-detailed study of borehole-fracture data. Components of the geologic investigation important in a hydrologic analysis of fracture networks are (1) development of geologic models by surface mapping of geologic units at Yucca Mountain (primarily the Crater Flat Tuff), (2) description of spatial variations of fracture properties in Crater Flat Tuff and other stratigraphic units of importance in the saturated zone of Yucca Mountain, and (3) validation of geologic models for Crater Flat Tuff by fracture mapping of one or more surface pavements.

The intended results of statistical and geologic analysis are a conceptual model of fracture-network geometry and corresponding computer programs that can be used to generate fracture networks. The generated fracture networks are intended to be statistically similar to those of Yucca Mountain. Therefore, the measured statistics of the generated network will be compared to the statistics related to the pavement fracture network. This geologic fracture model will be evaluated in light of the geophysical and hydrologic work to be done in order to have the best representation possible of the fracture network for the hydrologic analysis.

It will not be possible to validate all components of the geologic model of fracture-network geometry by direct geologic mapping of Crater Flat Tuff at the surface. For example, effects of depth of burial cannot be validated. Similarly, borehole-fracture data cannot be used to validate the model because knowledge of fracture lengths and interconnections will not be available. Results of cross-hole seismic profiling and cross-hole hydraulic-stress and tracer tests, however, may serve as data for indirect validation of the geologic model.

3.2.3.1.2 Development of geophysical models of fracture-network geometry based on seismic-wave characteristics of fractures

The development of geophysical models of fracture-network geometry will be performed cooperatively by USGS Geologic Division and Lawrence Berkeley Laboratory investigators as part of Studies 8.3.1.4.2.2 (Structural features within the site area), 8.3.1.4.2.3 (Three-dimensional geologic model), and at the C-well complex in Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system). It is important to have an integrated geological/geophysical model of fracture-network geometry in developing a hydrologic model of ground-water flow in fractured rock in the saturated zone at Yucca Mountain.

The objective of geophysical conceptual-model development is to determine if stiffness theory, as described in Study 8.3.1.4.2.2, can be applied successfully at Yucca Mountain, and if appropriate, to refine the technique for mapping fracture properties between boreholes in the saturated zone. Cross-hole seismic profiling (cross-hole tomography) and hydrologic testing at the C-well complex and possibly at other multiple-well locations will be performed. Figure 3.2-3 shows the location of the C-wells. Stiffness theory, developed by Schoenberg (1980), states that fracture discontinuities will disrupt shear-wave velocity as a function of fracture stiffness. Attenuation of the sheer wave occurs as fracture stiffness decreases and the wave is absorbed by the configuration of the fracture asperity, voids, and mineral infilling. A three-dimensional seismic velocity map will be created by cross-hole tomography to examine vertical anisotropy as a result of the fractures in order to determine average fracture spacing. Anticipated results of the cross-hole tomography are three-dimensional maps of fracture location, orientation, and density. Data collected will be used to construct one possible geologic model of fracture locations at the C-well complex and will serve as input to the hydrologic model. This model will be compared to fracture data obtained from the proposed tracer and stress tests outlined in Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system.)

The geophysical-conceptual model will be implemented in a set of computer programs. A fracture-network generator will be used to describe the distribution of fractures within a block of rock. For preliminary-model evaluation, a fracture-network generator such as the one described by Long and Billaux (1987) will be used. The parameters of the fracture network developed on the basis of the geologic model of Yucca Mountain (described in Section 3.2.3.1.1) will be used also in the fracture-network generator.

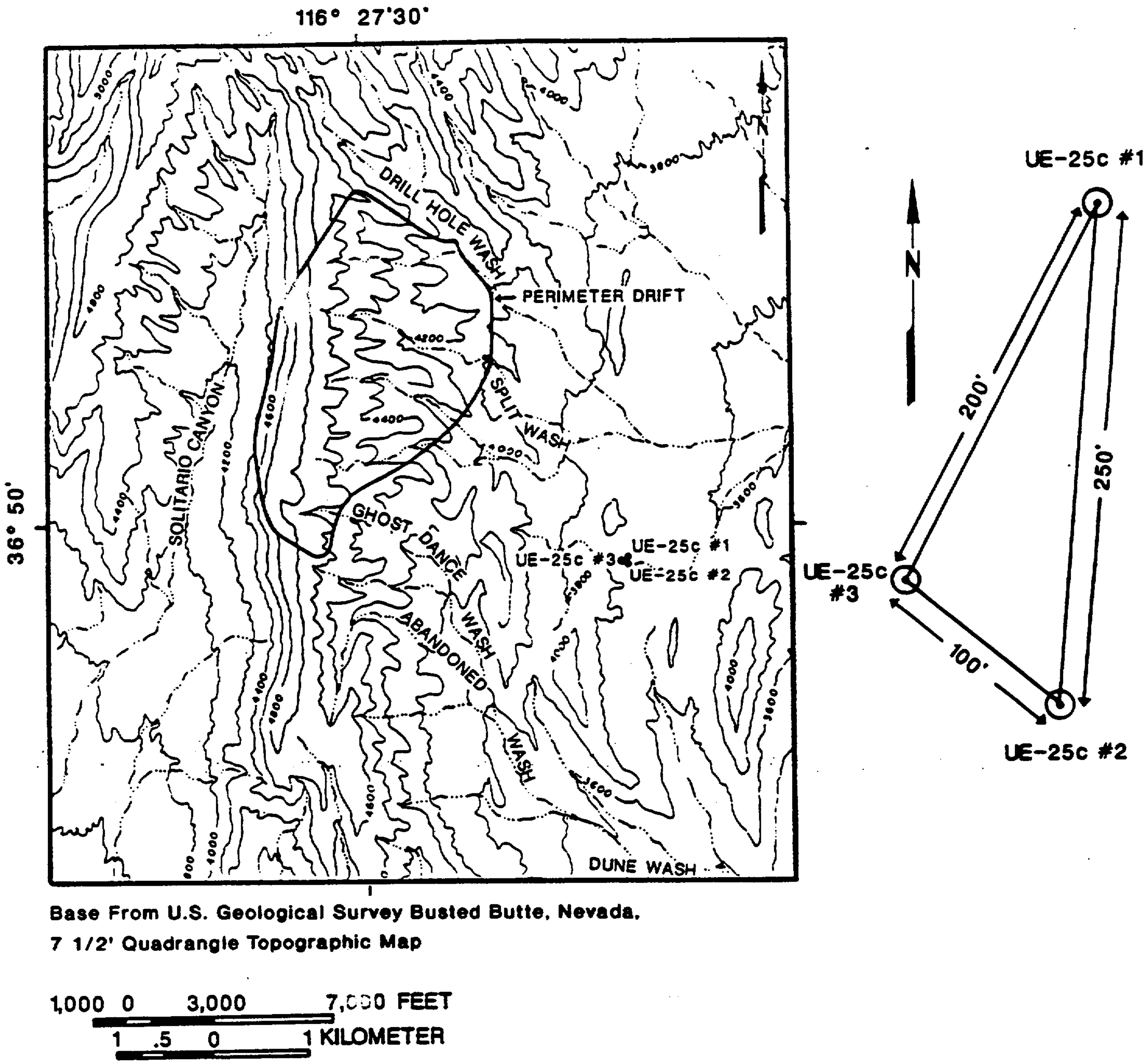

Figure 3.2-3. Location of the C-well complex (UE-25c wells).

The seismic results will be used to constrain the geometry of the fractures. Because the fracture-network geometry is unknown in the subsurface, programs that implement statistical procedures for estimating fracture-network geometry, the inverse problem, will be needed. Tomographic inversion of the travel time or amplitude of the signal is used to show the fractures that have been detected by the shear waves. These programs may include provisions for conditioning the solution with known fracture data (such as location and orientation of fractures in boreholes).

The seismic wave model will be verified in the other studies by calculating synthetic seismograms and then by using the inverse-solution technique to estimate the spatial distribution of fractures at several seismic-wave frequencies. The initial fracture network and the estimated fracture network will be compared statistically. The conceptual model will be revised and improved based on information gathered from the verification process. As part of the development and evaluation of the geophysical conceptual model, prototype testing with vertical seismic profiling will be conducted at well USW G-4. A detailed description of the prototype testing is given in YMP-USGS SP 8.3.1.4.2.2 (Structural features within the site area).

3.2.3.1.3 Development of hydrologic models of ground-water flow and conservative-solute transport in fractured rock

The development and evaluation of conceptual models to describe ground-water flow and conservative-solute transport in fractured rock will be accomplished through the combined efforts of three tasks:

(1) synthesis of previously conducted hydraulic-stress tests;

(2) development and verification of computer programs that simulate flow and transport in fracture networks;

(3) evaluation of the fracture-network model and comparison of the equivalent-porous-media assumption as utilized in Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system).

The first task, analysis of previously conducted hydraulic-stress tests, is described in detail in YMP-USGS-SP 8.3.1.2.3.1 (Site saturated-zone ground-water flow system). Characteristics considered to be important in porous-media models also are discussed in detail in that study plan under Activity 8.3.1.2.3.1.3 (Analysis of single- and multiple-well hydraulic-stress tests) and will be carried out under that activity. Therefore, the following section will emphasize the development and use of fracture-network models. Computer programs will be developed that are capable of simulating ground-water flow and conservative-solute transport in a discrete or stochastically derived fracture network. The programs will be used to simulate pumping and tracer tests at Yucca Mountain. Existing programs do not include well-boundary conditions that occur in pumping and tracer tests. Existing programs for discrete fracture networks also do not adequately model mass transport under well-test conditions where a wide range of Peclet numbers is expected. Peclet number is defined as vL/D, where v is the fluid velocity, L is the characteristic length of the fracture flow path, and D is the hydrodynamic dispersion coefficient. The fracture-network model will consist of two parts: (1) a fracture-network generator based on the geology, geophysics, and hydrology and (2) a hydrologic model for ground-water flow and solute transport.

The fracture-network generator will use statistical descriptions of fracture characteristics, including abutting and crosscutting relationships, to create a network of discrete fractures in an otherwise impermeable rock matrix. A network may consist of several sets of fractures. Each set of fractures most likely will be generated in accordance with probability-density functions of aperture, spacing, length, and orientation. Initially, fracture networks will be represented in a two-dimensional plane by parallel plates that are perpendicular to the plane. The fracture-network generator may be refined later to represent fractures as interconnected channels in three dimensions. A network of one-dimensional channels interconnected in three dimensions may be a more realistic representation of fractured rock.

The fracture-network model will be capable of simulating flow and transport in both steady-state and transient conditions, and will be capable of simulating well-bore boundary conditions. Problems of flow through the fracture network will be solved using the standard finite-element method with linear elements along each fracture. Each element is one dimensional, but the network of elements is three dimensional. Solute transport in each fracture will be modeled using a coupled Eulerian-Lagrangian method. Advective transport in a fracture will be modeled by the method of characteristics, and dispersion will be solved by the finite-element method. Forward tracking of advective transport will be used if the concentration front is sharp. Otherwise, backward tracking will be used. An adaptive grid system will be used within fractures in an attempt to avoid the effects of numerical dispersion. The adaptive grid system will permit nodes to be added in the vicinity of a sharp concentration front and deleted in areas where variations in solute concentration are smooth. Two methods, channeling and complete mixing, will be investigated for mixing solute at fracture intersections. Alternative methods such as the particle-tracking method will also be evaluated.

In developing the fracture-network model, initial focus will be only on flow that occurs in the fractures. This emphasis is because at the scale of the C-well complex (100's of m), preliminary data suggest that the fracture geometry is the first-order control on the flow and the transport. Matrix diffusion is considered to be a second-order effect which will be examined later in the fracture-network modeling. This process is envisioned as a staged approach. In the first stage, the physics of flow in fractures and translation of the physics into feasible and reliable numerical model will be performed. If this model cannot adequately explain the field data, as determined by professional judgement, obtained from the cross-hole interference stress and tracer tests explained in Study 8.3.1.2.3.1, inclusion of effects such as matrix diffusion will be considered.

Data needed on the permeability of the matrix blocks would arise from Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system) and Study 8.3.1.2.3.1.7 (Reactive tracer experiments in the C-wells).

The model will be verified by simulating appropriate flow and solute-transport problems and comparing simulation results to known solutions to other fracture-flow problems. The exact nature of simulations that will be done for purposes of model verification cannot be defined until the final model design is selected and programmed. If no independently derived solutions are available for verification, model results will be compared to the extent possible with results of existing fracture-network models such as those of Dershowitz and others (1989), Robinson (1984), and Endo (1984). Part of the validation process will be the prediction of results of hydraulic stress and tracer tests, conducting the tests (described in YMP-USGS SP 8.3.1.2.3.1), and comparing predicted with actual results. Documentation will include a discussion of numerical methods used in the program, input requirements and formats, results of program verification, and a discussion of appropriate procedures for using the program.

The fracture-network model will be evaluated by conducting a series of sensitivity analyses. In this activity, sensitivity analyses consist of a series of hydrologic simulations where one or a few parameters describing the fracture network (for example, average fracture length and standard deviation of fracture orientation) are varied in a prescribed manner. Boundary conditions will be constant for all simulations and will be a modification of those used by Long and others (1982) and Endo (1984). Long and others (1982) and Endo (1984) used the same boundary conditions to create a uniform gradient across a rectangular flow region. The eastern and western boundaries were specified by a uniform head of 0 and 1 respectively. The northern and southern model edges each were defined as linearly imposed boundary conditions from 0 to 1. Variations in hydrologic characteristics, such as effective hydraulic conductivity or average rates of solute migration, are related to variations in the fracture-network geometry. General purposes of sensitivity analyses were discussed in Section 2.1.6. In addition, these studies also are useful in identifying geologic conditions where it is valid to simulate fractured rock as an equivalent-porous medium.

Sensitivity studies will be done for two purposes.

1. The first is to evaluate the effects of fracture characteristics on results of well tests. Such studies may indicate important needs in field investigations (discussed in YMP-USGS SP 8.3.1.2.3.1), including needs for specific types of well tests. Test designs that are typically used in a porous medium may not be optimal for understanding the hydrologic nature of the fractured rock at Yucca Mountain. As a result of sensitivity analyses, it is anticipated that greater emphasis will be placed on collecting early-time well-test data and eliminating effects of well-bore storage. Early-time data are controlled by fracture geometry close to the borehole, but are needed for fracture definitions. Data are averaged over a wider area as later time data are collected.

2. The second is to evaluate the general hydrologic behavior of the saturated zone, to the extent that fracture statistics measured in boreholes at Yucca Mountain are representative of the saturated zone. Emphasis will be given to identifying scales where flow and transport in a fracture network can be simulated appropriately by analogy to an equivalent porous medium, and investigating the character of convective dispersion.

Fracture networks used in sensitivity analyses will bracket the range of reasonable uncertainty in fracture characteristics. During initial stages of the investigation, geologic and hydrologic data will be sparse or incompletely analyzed. Consequently, the range of values used in sensitivity analyses will be large. As additional fracture data become available, the range of values will be refined. Initial analyses also will emphasize data available from the C-well complex. As data become available, later sensitivity tests may be directed toward other locations. Fracture frequency and orientation have been measured in boreholes from TV logs and seisviewer logs; however, fracture data to describe the distribution of fracture lengths and fracture apertures are not available specific to the C-well complex. Therefore initial studies will consider fracture networks with uniform lengths and apertures.

Past investigation at USW-H4 (Erickson and Waddell, 1985) has identified flow-producing fractures or zones by comparing results of tracejector surveys, borehole-dilution tests, and temperature logs with fracture locations in boreholes. The use of tracejector surveys is described by Blankennagel (1967); static tracer tests and methodology to detect inflow areas from temperature logs are discussed in Erickson and Waddell (1985). Preliminary stress tests have been performed at the C-well complex and are reported by Geldon (in press). Future tests and drilling of an additional, inclined borehole are planned at the multiple well complex (as described in YMP-USGS-SP 8.3.1.2.3.1). Initial comparisons of the tracejector surveys, borehole-dilution tests, caliper logs and temperature logs have indicated a correlation between flow-producing zones and fractured intervals in the C wells. The results, however, are preliminary, and the additional work must be completed to further refine the interpretations. Although these investigations have aided in identifying flow-producing fractures, the limited understanding of fracture lengths, apertures, and interconnections has constrained efforts to understand why fractures conduct water selectively. As geologic data, primarily from surface-mapping studies, and seismic-profiling data become available, sensitivity analyses using distributed lengths and apertures will be conducted. By conducting these later studies, it may be possible to understand why only selected fractures conduct water.

Each fracture network that is generated will be used in the finite-element program to calculate rates of ground-water flow across the network. Rates of flow will be related to hydraulic conductivity of an equivalent porous medium using an approach similar to that described by Long and others (1982). An approach similar to that of Endo and Witherspoon (1985) may be used to relate flow rate to effective porosity. Methods described by Long and others (1982) also will be used to identify the scale of representative elementary volumes (REV) of fracture networks and hence to determine scales where a fracture network can be described by analogy to an equivalent-porous medium. The scale of an REV probably will be different for flow than for transport.

Sensitivity studies will be conducted to investigate hydrodynamic dispersion in fracture networks. The most significant dispersive mechanism in a fractured medium is the mechanical dispersion due to fracture network geometry. The effects of fracture characteristics on this mechanism will be investigated. The coefficient of variation of aperture and the correlation between aperture and length are among the parameters that may prove to be important.

It is possible that multiple-fracture networks generated from the same set of fracture statistics may have significantly different hydrologic character. If a fracture system has an REV and the scale of simulation is larger than the REV, by definition, multiple realizations should have reasonably similar hydrologic character. If the scale of simulation is smaller than the REV, the probability of significantly different hydrologic character depends on various parameters, of which fracture spacing and aperture are most critical.

The importance of generating multiple-fracture networks when applying the fracture-network model in well tests cannot be evaluated until preliminary sensitivity analyses are completed. If the preliminary analyses indicate that different realizations from the same set of fracture statistics have different hydrologic character, then later studies will be done with multiple realizations of fracture networks. The most appropriate method for generating fracture networks cannot be determined until preliminary studies are completed. Methods that may be considered for use include Monte Carlo simulation and an interpolation method called response-surface methodology (Box and Wilson, 1951).

If multiple realizations of fracture networks generated from a single set of fracture statistics have similar hydrologic response, the relationships between fracture characteristics and hydrologic response will be deterministic; otherwise, the relationships will be stochastic. If the relationships are stochastic, then sensitivity analyses will be used to estimate the likely range of the relationships. Depending on the method used to select fracture networks, it may be possible to estimate statistical confidence regions of the relations. Results of the fracture-network model developed under this activity will be compared in the third task with those for the equivalent-porous-media (epm) model utilized in Study 8.3.1.2.3.1 to analyze the stress and tracer tests.

3.2.3.2 Analysis of well tests

The primary objective of this analysis is to refine and validate geophysical and hydrologic models of fracture networks by predicting and analyzing results of multiple-well tests. Estimation of aquifer properties at well-test locations, although important for site characterization, is a secondary objective of this activity because aquifer-property estimates are no more reliable than the conceptual model used in making the estimates.

The analysis of well tests will be done in two phases. The first, involving testing at the C-well complex (Figure 3.2-3), will emphasize model refinement, particularly understanding relationships between geophysical and hydrologic models. Section 3.2.3.1 emphasized the use of existing data or data that could be readily obtained. It is expected that some aspects of the conceptual models developed on the basis of these data will prove incorrect or will not be sufficiently detailed when applied in deeply buried rocks of the saturated zone beneath Yucca Mountain. There also are no existing data that can be used to investigate possible relations between seismic and hydrologic models. Therefore, significant model refinement is expected as a result of interpreting well tests at the C-well complex. These well tests are described in YMP-USGS-SP 8.3.1.2.3.1. The second phase of this activity will emphasize model validation at other multiple-well locations. The second phase will be curtailed if other sets of multiple wells are not drilled. Drilling and subsequent hydrologic testing at one or more multi-well locations is described in YMP-USGS-SP 8.3.1.2.3.1.

3.2.3.2.1 Data analysis at C-well complex

Cross-hole seismic surveys will be conducted in the saturated zone in SCP Activity 8.3.1.4.2.2.5 (in YMP-USGS-SP 8.3.1.4.2.2) to estimate fracture location, density, and orientation in vertical planes between wells and in Study 8.3.1.2.3.1 at the C-well complex.

Descriptions of hydraulic and tracer tests planned at the C-well complex are given in YMP-USGS-SP 8.3.1.2.3.1. Methods for analyzing hydraulic and tracer tests within the framework of an equivalent-porous-medium are described in YMP-USGS-SP 8.3.1.2.3.1, and only the analysis by fracture-network models is described here. By combining aspects of both equivalent-porous-media models, and fracture-network models, such as double porosity models, into a single hybrid model, it may be possible to minimize the requirements for discrete fracture data, while avoiding the limitations of the equivalent-porous-media approach. Alternately, several models, bracketing the observed results of the hydraulic and tracer tests, may result.

After gaining experience in hydrologic simulations and interpretation of well-hydraulic tests (described in Section 3.2.3.2, Analysis of well tests), the fracture-mesh generator may be changed to create a network of discrete fractures imbedded within a porous matrix. Such a change would be appropriate if (1) several minor sets of fractures are present at Yucca Mountain and (2) hydrologic study shows that minor sets of fractures can realistically be replaced by an equivalent porous medium. Such a change could greatly reduce the amount of fracture data needed for hydrologic modeling while retaining discrete representation of critical fracture sets.

The hydrologic model of fracture networks will be used to interpret results of hydraulic and conservative-tracer tests at the C-well complex. Based on results of sensitivity studies and seismic modeling, a set of fracture networks will be generated that will bracket the range of uncertainty in fracture characteristics. These networks will be conditioned so that fractures observed in the boreholes will be represented. Components of the geologic model of fracture networks that are uncertain also will be considered in selecting fracture networks.

Because fracture-network characteristics probably cannot be determined uniquely by simulation of well-test results, statistical algorithms for determining likely fracture networks will be used. Statistical methods for estimating flow characteristics in porous media include those of Cooley (1983), Hoeksema and Kitanidis (1984), Dagan (1985), and Carrera and Neuman (1986). A statistical method for estimating solute transport characteristics in porous media is described by Wagner and Gorelick (1986). Very little work has been done in applying these or other statistically based parameter-estimation procedures to fracture networks. As part of the hydrologic analysis of fracture networks at Yucca Mountain, statistically based methods for estimating aquifer properties will be evaluated, and appropriate methods will be adapted for application on fractured rock. The methods will then be used to interpret results of well tests at the C-well complex. In addition to statistical methods originally developed for application in porous media, other statistical methods, including the method of simulated annealing (Press and others, 1986), will be evaluated. Those networks that best match measured results of hydraulic-stress and tracer tests will be considered representative of the fractured rock in the vicinity of the tested wells.

As a result of the experience gained in analyzing well tests at C-well complex, it probably will be apparent that conceptual models are inadequate in some respects. Therefore, analysis will be done concurrent with testing, with results of earlier tests used to revise conceptual models and computer programs. Results of later tests would be used to evaluate the revised models.

3.2.3.2.2 Model validation at other proposed multiple-well locations

Although the C-well complex is the only multiple-well location near Yucca Mountain, the plan for site characterization includes the option of drilling and testing other sets of multiple-wells. The decision to drill and test other multiple-well locations will depend on success in developing reliable conceptual models at the C-well complex and the ability of the single-well tests to give reliable estimates of hydraulic properties as compared to tests at the C-well complex. If other multiple-well locations are not drilled and tested, site-characterization beyond the C-well complex will be limited to hydraulic and tracer tests with single wells.

In addition to providing site-characterization data, the purpose of drilling and testing other multiple-well locations is to validate geophysical and hydrologic models. Validation will be attempted by predicting, conducting, and analyzing results of hydraulic and tracer tests. The remainder of this section describes the validation process. A description of planned drilling and testing activities is given in YMP-USGS-SP 8.3.1.2.3.1.

Model validation probably will be a four-step process. Because conceptual models have not been formulated in detail, it is not appropriate to speculate on detailed interpretive approaches until experience in testing and analysis at the C-well complex has been gained. The first step in validation will be to core-drill the wells and collect adequate seismic-profile data to use in geophysical and hydrologic modeling. It is emphasized here that it is important to core-drill the entire length of each borehole. Core data give much more reliable fracture information than do a televiewer and a TV camera. The second step is to design appropriate hydraulic and tracer tests and to predict test results. Geophysical and interborehole flow data will be used to select appropriate test designs. Geologic and geophysical models will be used to estimate fracture-network geometry. Hydrologic models, using the estimated fracture-network geometry as a basis, will predict test results. In addition, if the computed hydraulic conductivities derived from tests conducted in packed-off intervals in single-well tests are available, they will be used also in the validation and comparison process. Uncertainty in model analysis will be evaluated when predicting test results. Therefore, predictions probably will be expressed statistically, either as a range of probable results or as a best estimate of results and associated confidence regions. The third step will be to conduct the tests. The fourth step in validation will be to compare predicted test results with actual test results. Professional judgement will be used to decide when the comparison is adequate.

Because of uncertainty in model analysis, predicted results probably will not compare exactly with actual results. If the models are valid representations of the actual system, actual results should be bounded in a statistical sense by predicted results. The measurement scale at which field data are determined also may be a source of error. As Cushman (1986) notes, although smaller scale features may appear implicitly in larger scale measurements, it is not possible to determine heterogeneities on a scale smaller than that sampled.

3.2.3.3 Methods summary

The activity parameters to be evaluated by the analyses described in the above sections are summarized in Table 3.2-1. Also listed are the selected methods for evaluating the parameters and the current estimate of the parameter-value range. Alternate methods may be utilized if a selected method is impractical to estimate the parameter(s) of interest. The selected methods in Table 3.2-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the parameters of interest. Models and analytical techniques have been or will be developed to be consistent with data developed in this and contributing studies.

Table 3.2-1 Summary of tests and methods for the development of fracture-network model activity (SCP 8.3.1.2.3.3.2)

Methods	Site-characterization parameter
Preliminary-model development	
Development of geologic models of fracture-network geometry (selected)	(Supplied from outside present study)
Development of geophysical models of fracture-network geometry based on seismic-wave characteristics of fractures (selected)	"
Ground-water and solute-transport model development: analysis of previously conducted hydraulic-stress tests (selected)	Hydraulic conductivity, fracture networks
"	Storage coefficient, fracture networks
Ground-water and solute-transport model development: development and verification of computer programs that simulate flow and transport in fracture networks (selected)	Conservative-solute transport, fracture networks, steady-state and transient
"	Effective porosity, fracture networks
"	Ground-water flux, fracture networks, steady-state and transient
"	Hydraulic conductivity, fracture networks
"	Hydraulic gradient, fracture networks
"	Hydrodynamic dispersion, fracture networks
"	Storage coefficient, fracture networks
Ground-water and solute-transport model development: evaluation of fracture-network model and investigation of equivalent-porous-media assumption (selected)	Conservative-solute transport, fracture networks, steady-state and transient

Table 3.2-1 Summary of tests and methods for the development of fracture-network model activity (SCP 8.3.1.2.3.3.2)

Methods	Site-characterization parameter
	Preliminary-model development (continued)
"	Effective porosity, fracture networks
"	Ground-water flux, fracture networks, steady-state and transient
"	Hydraulic conductivity, fracture networks
"	Hydraulic gradient, fracture networks
"	Hydrodynamic dispersion, fracture networks
"	Storage coefficient, fracture networks
Ground-water and solute-transport model development: selection, modification, and documentation of porous-media models (selected)	Relationships between fracture-geometry characteristics and hydrologic response
	Analysis of well tests
Data analysis at UE-25c wells (selected)	Relationships between fracture-network characteristics and hydrologic response
"	Relationships between geophysical and hydrologic models
Model validation at proposed second multiple-sell location (selected)	Relationships between fracture-network characteristics and hydrologic response
"	Relationships between geophysical and hydrologic models

3.2.4 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 2.1.7) for which quality assurance levels have been set.

3.3 Calculation of flow paths, fluxes, and velocities within the saturated zone to the accessible environment

3.3.1 Objectives

The overall purpose of this activity is to provide a comprehensive description of aquifer properties that can be used when calculating ground-water velocity at a scale of 10's of km with emphasis on the ground water flow at Yucca Mountain. The comprehensive description will be provided by meeting the following objectives:

(1) to evaluate the equivalent porous-media concept and fracture-network concept for the calculation of flow paths, fluxes, and velocities, and

(2) to estimate ground-water flow direction and magnitude for input to travel-time calculations.

3.3.2 Rationale for activity selection

The calculations of ground-water flow paths, fluxes, and velocities have been assigned to a separate activity, because it is necessary to provide a comprehensive description of aquifer properties at the scale of Yucca Mountain and then to employ this description in conjunction with known potentiometric-surface data in order to calculate ground-water flow direction and magnitude at Yucca Mountain (10's of km) and vicinity. It is critical that a careful evaluation be made of the alternate concepts of equivalent-porous media and fracture networks, so that the model employed for calculations will be as representative as possible of the Yucca Mountain hydrogeologic regime.

3.3.3 General approach and summary of analyses

Two analyses will be performed in this activity at the scale of the site in order to meet the objectives mentioned previously: (1) characterization of spatial variation and scale effects in aquifer properties, and (2) development of a refined conceptual model(s) and translation to a mathematical/numerical model of ground-water flow and conservative solute transport.

The first analysis will involve using the results of hydraulic and tracer tests (discussed in Section 3.2.3.2.1 of this study plan and in YMP-USGS SP 8.3.1.2.3.1), in addition to geophysical data from cross-hole tomography and vertical seismic profiling as applied to the site scale. The second analysis will consist of conceptual and numerical modeling at the site scale by drawing together information gathered from the conceptualization activity (8.3.1.2.3.3.1) and the fracture-network model activity (8.3.1.2.3.3.2).

Data for these analyses primarily will come from the activities previously discussed in this study. Activity 8.3.1.2.3.3.1 (Conceptualization of saturated-zone flow models within the boundaries of the accessible environment) will provide the hydrogeologic framework, hydrogeologic properties, recharge and discharge data, and initial conditions and boundary conditions. Activity 8.3.1.2.3.3.2 (Development of the fracture-network model) will provide hydraulic parameters and fracture flow and transport on a multiple-well scale. Both activities will provide conceptual ideas for the final conceptual model.

Figure 3.3-1 summarizes the organization of the calculation of flow paths, fluxes, and velocities analyses. A descriptive heading for each analysis appears in the shadowed boxes of the second row. Below each analysis are the individual methods that will be utilized. Figure 3.3-2 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 analysis boxes, respectively, in Figure 3.3-2. The figures summarize the overall structure of the planned activity in terms of methods to be employed and measurements to be made. 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 activity 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. The integration of the two previous activities, Conceptualization of saturated-zone flow models within the boundaries of the accessible environment and Development of fracture-network model, into Calculation of flow-paths, fluxes and velocities within the saturated zone to the accessible environment is diagrammed in Figure 3.3-3.

3.3.3.1 Characterization of spatial variation and scale effects in aquifer properties

Three broad classes of data may be available for characterizing spatial variations in aquifer properties: (1) results of hydraulic and tracer tests in wells, (2) geophysical data, and (3) geological data. The type of hydrologic analysis that would be conducted depends on the type, quantity, and distribution of data that will be available. Results of well tests will represent average values over the hydraulically stressed volume of rock. At the scale of modeling in this activity (10's of km with emphasis on the ground-water flow system at Yucca Mountain), however, well-test results are essentially point estimates of aquifer properties. In addition, hydrologic well tests are conducted in a perturbed flow system, but large-scale models evaluate a relatively unperturbed system. The relationship between techniques applicable at the scale of hydrologic well tests and techniques applicable at regional scales has not been established for most fractured media. If the techniques described in Section 3.2.3.2 are able to simulate results of hydrologic-well tests, an attempt will be made to apply them on a theoretical basis for use in large-scale models. Scale dependence of many model parameters is expected.

Several types of hydraulic and tracer tests may be available. Borehole-flow surveys and falling-head injection tests are available at many boreholes near Yucca Mountain. If single-well tests prove

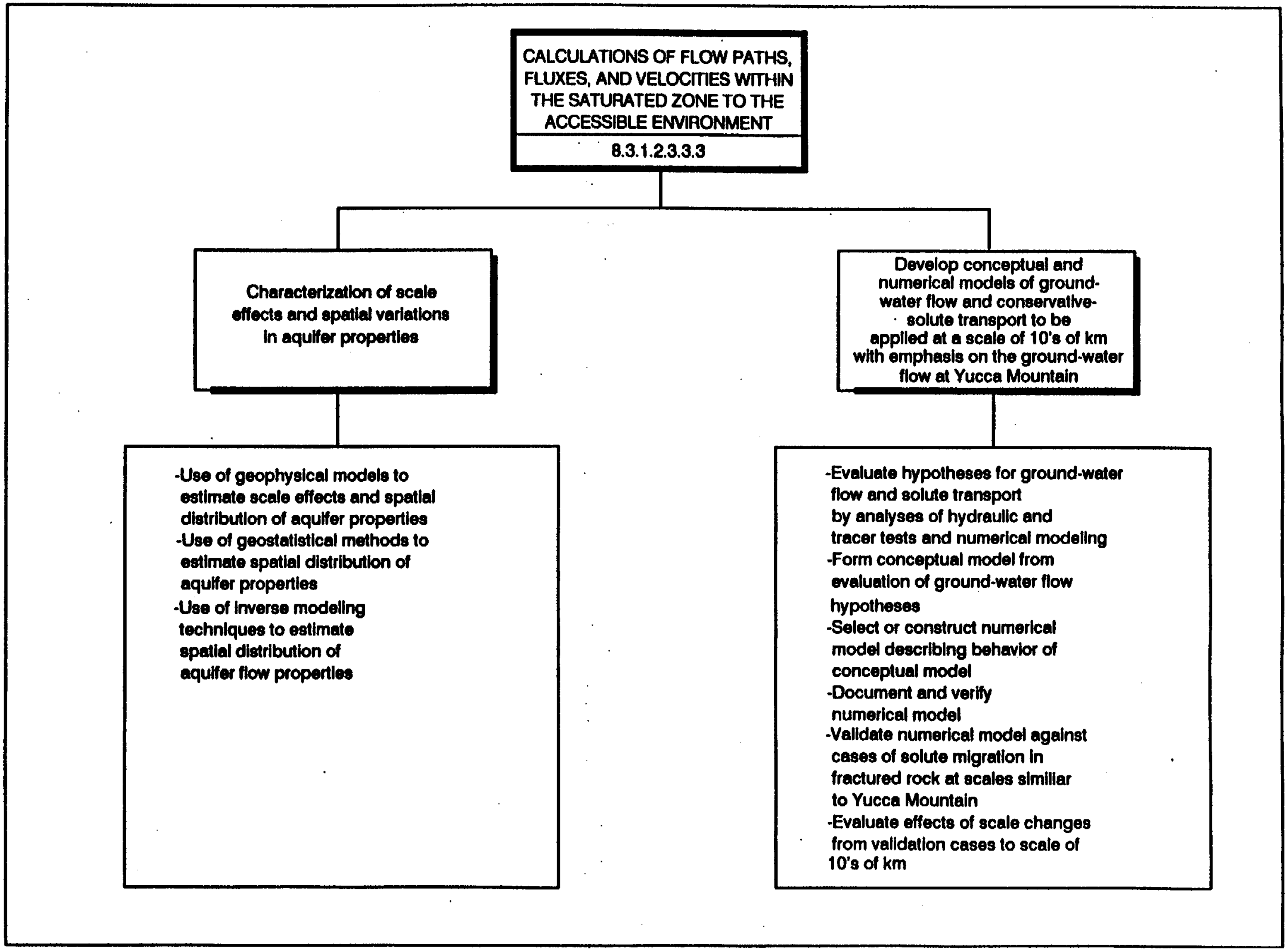

Figure 3.3-1. Logic diagram of calculation of flow paths, fluxes, and velocities activity, showing tests, analyses, and methods.

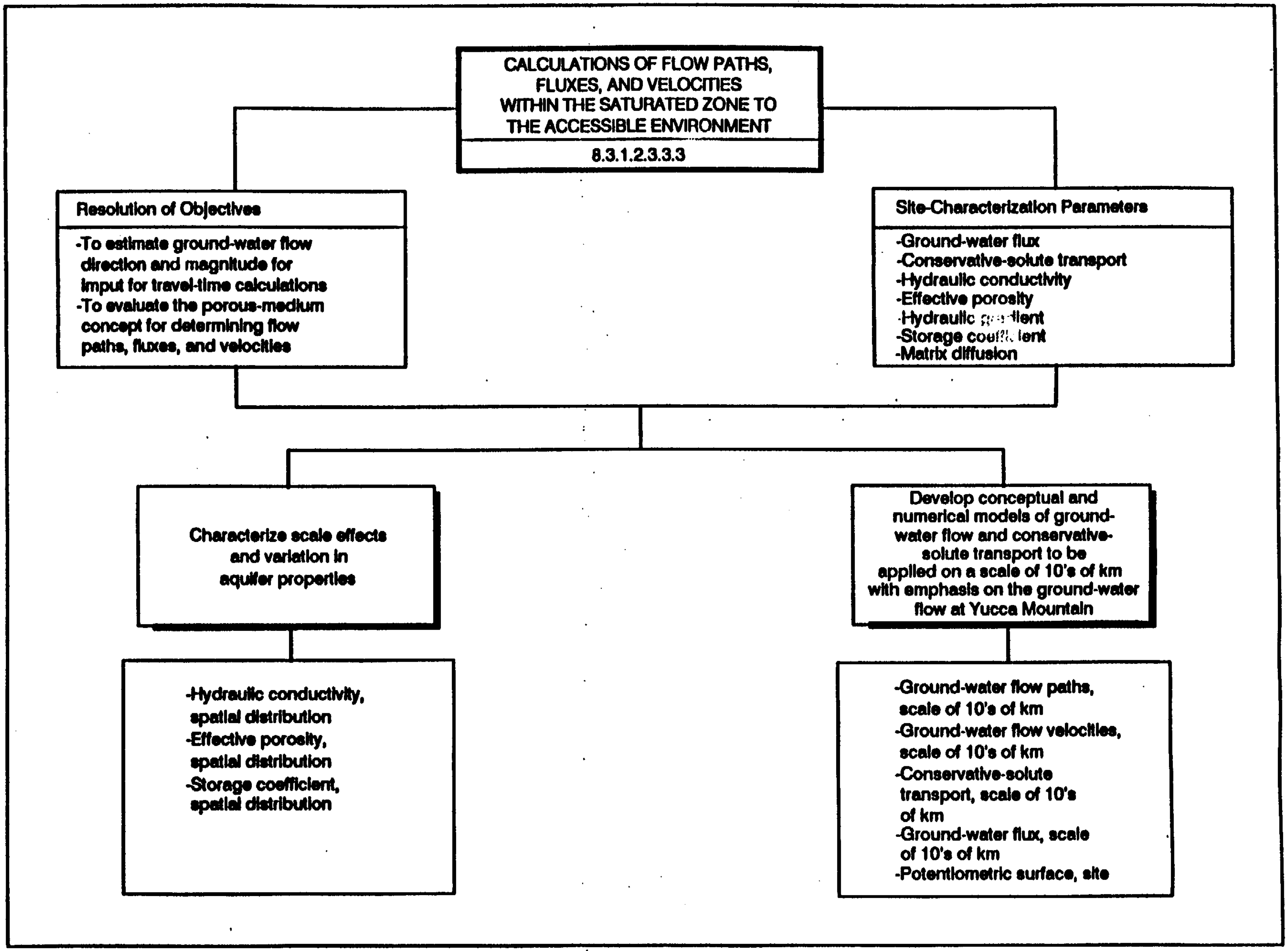

Figure 3.3-2. Logic diagram of calculation of flow paths, fluxes, and velocities activity, showing tests and activity parameters.

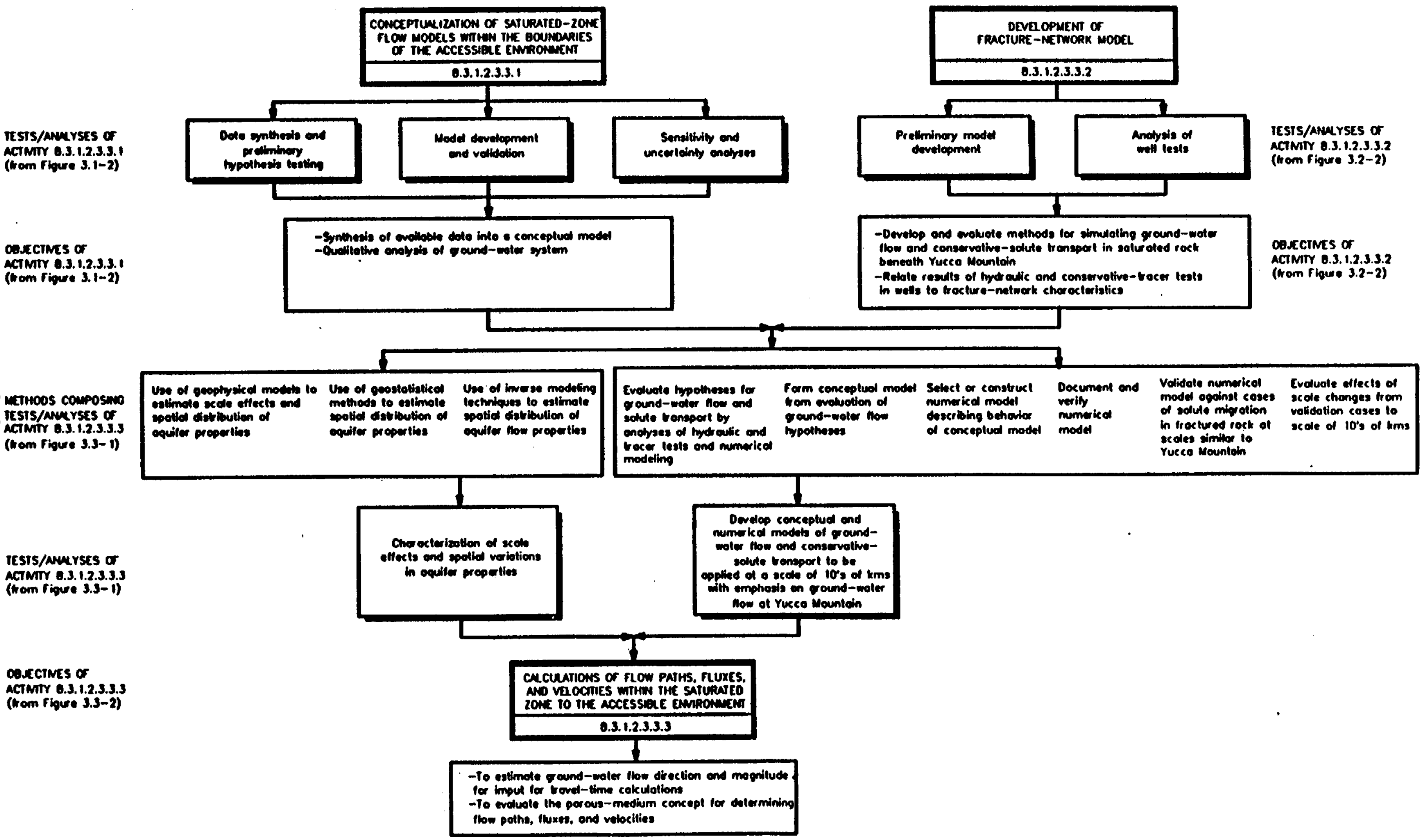

Figure 3.3-3. Integration of Activities 8.3.1.2.3.3.1 and 8.3.1.2.3.3.2 to achieve the objectives of Activity 8.3.1.2.3.3.3.

to be reliable methods for estimating aquifer properties, a number of single-well hydrologic tests probably will be conducted at existing well locations. The tests are described in YMP-USGS-SP 8.3.1.2.3.1. Water-level fluctuations as a result of earth tides and barometric effects also will provide estimates of effective porosity and perhaps hydraulic conductivity at existing well locations. Plans for monitoring and interpreting water-level fluctuations at Yucca Mountain are described in YMP-USGS-SP 8.3.1.2.3.1. Hydraulic stress and tracer tests planned at the C-well complex will test a volume of rock approximately 400,000 m^3. To determine hydraulic properties at a scale larger than the C-well complex a large-scale pumping test is planned (See Section 3.4.3.2 - YMP-USGS SP 8.3.1.2.3.1). In addition, aquifer-property estimates should be available at the C-hole complex and perhaps additional multiple-well locations.

In addition to hydrologic well tests, data from seismic tomography and vertical seismic profiling could be used for scaling. Without knowing the results of investigations described previously, it is not possible to provide detailed plans for studying the effects of changes in scale. An example is provided of how changes in scale could be studied, however. When using seismic-profiling data to estimate fracture-network geometry, the geometry could be estimated on the basis of data collected at several frequencies and spacings. The geometry estimated on the basis of large spacing would correspond to large features. Analysis of well tests by hydrologic models could be augmented using fracture networks inferred from seismic data collected at large spacing and fracture networks inferred from all seismic data. Differences in hydrologic analysis may represent errors associated with changes in scale.

If geophysical profiling at USW G-4 and the C-well complex proves to be helpful in estimating fracture-network geometry and aquifer properties, geophysical data could be collected at additional wells (Study 8.3.1.2.3.1).

The method for estimating aquifer properties in areas between boreholes would depend on the availability of cross-hole seismic-profiling data and success relating seismic-wave propagation to hydrologic properties. If data are available and relationships between seismic and hydrologic properties are demonstrated during investigation of multiple-well locations, geophysical models described previously would be used to estimate spatial variations in fracture networks. Results of geophysical models would be used in hydrologic models described previously to predict the spatial distribution of aquifer properties. Aquifer-property estimates obtained from hydrologic-well tests would be used to condition the predicted spatial distribution of aquifer properties. Geophysical data may provide information about the distribution of aquifer properties along cross sections between boreholes, and between boreholes and the land surface. Geologic data obtained in surface-pavement and outcrop studies at several locations and fracture data obtained in boreholes in addition to the fracture mapping planned for the exploratory shaft, may also give information on spatial variation of fracture characteristics.

If geophysical data are not collected or are insufficient to be used to interpolate aquifer properties between test locations with confidence, geostatistical methods might be used to estimate the spatial distribution of aquifer properties with well-test data. Geostatistical techniques such as kriging and conditional simulation may be appropriate if distances between point estimates of aquifer properties are less than the ranges of the corresponding semivariograms. A limitation of this method, as discussed previously in Section 3.1.3.1, is that there may not be enough data to construct a meaningful semivariogram. Several ways in which to address the lack of data for these analyses are the assumption of a synthetic variogram and subsequent testing of the assumed shape of the variogram, and(or) use of a numerically generated data distribution to test how well the point samples represent the actual system. A more detailed discussion of these analyses was given in Section 3.1.3.1. For flow properties, inverse modeling techniques (Cooley, 1983) may prove useful. For transport properties, including the distribution of velocity, no history of solute migration will be available for use with inverse models. If, as anticipated, the variance of aquifer-property estimates is large, confidence in the estimated distribution of transport parameters will be low. The inability to use geophysical methods also would result in reduced confidence in the estimated distribution of flow and transport parameters.

Synthesis and analysis of the data will probably be aided by use of a three-dimensional GSIS (Turner and others, 1991), previously discussed in Section 3.1.3.1.

Applicability of techniques proved successful at the scale of the above tests to large-scale problems will be evaluated by conducting sensitivity analyses and simulations of flow and transport in hypothetical flow systems. The hypothetical systems will be similar conceptually and will retain many of the important hydrologic characteristics of Yucca Mountain but will be simplified for transformation to a numerical model.

3.3.3.2 Development of conceptual and numerical models of ground-water flow and conservative solute transport to be applied at a scale of 10's of km with emphasis on the ground-water flow at Yucca Mountain

The conceptual model of the site hydrology will be refined from information gathered in the previous activities. Mathematical/numerical models derived from the revised conceptual model probably will be used to estimate flow paths and ground-water velocities at the scale of 10's of km focusing on Yucca Mountain. Numerical modeling represents a convenient method for synthesizing all available geologic, geophysical, and hydrologic information for consistency with the theories of ground-water flow and solute transport. Conventional equivalent-porous-medium models, although representing a practical approach to simulating ground-water flow and solute transport at the scale of the modeling, have important limitations and may not provide accurate estimates of ground-water solute transport (Endo and others, 1984). This approach is most applicable to systems where fracture spacing is small compared to the scale of the system under study. Results of well tests and parametric studies with the fracture-network model may indicate that representative elementary volumes (REV) cannot be identified for the fractured rock at Yucca Mountain. These results also may indicate that hydrodynamic dispersion cannot be simulated by analogy to Fickian diffusion. Conventional porous-medium models are based on the assumptions of an REV and Fickian diffusion, and they may provide misleading or unreliable estimates of travel time if applied to the flow system at Yucca Mountain.

Fracture-network models, although possibly having a better theoretical base than porous-medium models, have data requirements that are difficult to meet in simulations the size of Yucca Mountain and have not been applied to large problems. Much of the discussion in this document has been directed toward methods for evaluating fracture-network models at scales of well tests, incorporating data required by fracture-network models, and revising and validating the fracture-network models. Theories of flow and transport in fractured rock, however, are just recently being tested in field applications. In general, there are two approaches to flow and transport modeling in fractured rock. In the first, the fractured media are treated as equivalent porous media, the continuum approach. This approach is most useful when the spacing of fractures is small compared to the scale of the problem and most or all of the fractures are interconnected. Flow is calculated macroscopically without regard to the flow paths of individual particles. Dual-porosity models are derived from the continuum assumption. The fractures and the matrix each constitute a continuum with distinct properties (Warren and Root, 1963). The second approach consists of characterizing the fractures discretely, and is most useful when flow occurs in large fractures and not all fractures in the media are interconnected.

A disadvantage of the continuum approach to modeling fracture flow is that these models often cannot account adequately for dispersion. In many equivalent-porous-medium codes, dispersion is assumed to be isotropic (thereby negating contaminant spreading as a result of the fractures) and dispersivity values are unrelated to the hydraulic gradient (thereby negating the fact that fractures oriented parallel to the hydraulic gradient are more effective conduits for flow than fractures oriented in a different manner). Recently, Smith and others (1989) have developed a continuum model that includes anisotropic dispersion.

Problems exist with the discrete approach because it is nearly impossible to collect all the data needed to explicitly characterize fractures in a block of media and because of computer limitations. One solution to these difficulties is the use of statistical methods to characterize the fractures. Some models of fracture flow and transport combine the continuum and discreet approaches (van Genuchten and Dalton, 1986; Smith and others, 1989).

If fractured rock at Yucca Mountain can be represented by an equivalent-porous medium with aquifer properties that are statistically homogeneous at a local scale, a decision will be made by the investigators on how to incorporate contaminant dispersion into the model. If the REV is discovered to be different for flow and transport and if the spatial correlation of the hydraulic conductivity field relative to the scale of the flow domain indicates that transport would be dominated by non-normal behavior (Smith and Schwartz, 1980) then either a particle-tracking device or a model that can accommodate non-Gaussian behavior may be better suited to simulate transport.

If transport can be characterized by normal (Gaussian) behavior, a method by Winter and others (1984) may be able to be used. These authors recognized the scale dependence of dispersion and velocity but show that, at large scales in statistically homogeneous porous media, these parameters are approximately constant. Local-scale values and their correlation structure are discussed by Neuman (1987). Large-scale estimates are calculated from local-scale measurements of hydraulic conductivity and dispersion coefficient. It may be possible to estimate global scale dispersivity from the local-scale correlation structure.

If results of hydrologic well tests show that fractured rocks at Yucca Mountain are realistically represented by equivalent-porous media with aquifer properties that are statistically heterogeneous at a local scale or by a discrete fracture network, then a technique described by Schwartz and Smith (1985) will be evaluated. These authors describe the spread of contaminant in saturated, fracture rock as a random-walk process. To obtain the statistics for the random-walk process, particle motion is simulated in a smaller flow domain containing a discrete network of fractures.

If results of well tests and parametric studies indicate that flow-system analysis using the continuum approach and conventional porous-medium models is not appropriate, other methods to describe flow and transport in fractured rock will be investigated. A combination of the continuum and the discrete approach may be most applicable to this study. As discussed by Smith and others (1989) a discrete model, on a small scale, provides the fracture geometries and statistics needed for the larger domain. These statistics are extrapolated stochastically to the continuum model. Activities in this study are designed for such an approach. The fracture-network model described in Section 3.2 of this study plan will provide information on a small, local scale that can be validated and tested against well stress tests. Information from this discrete model could be extrapolated in the present activity to an acceptable continuum model that incorporates anisotropic dispersion. Although a detailed description of a numerical model cannot be given until previously described investigations are conducted, a general discussion of problems that need to be addressed when developing a model is appropriate.

Numerical code development will not be undertaken in any of the above cases unless there are no existing codes available. A thorough search of the modeling codes will be made prior to flow and/or transport code development.

Any numerical method based on the continuum, discrete, or combined approaches as developed for use in analyzing fracture flow and solute transport at the scale of Yucca Mountain (10's of km) will be based on appropriate conceptual models. At this point in project planning, a number of hypotheses can be proposed for ground-water flow and solute transport in fractured rock at Yucca Mountain. Hydraulic and tracer tests, and numerical modeling described previously will be used to evaluate these hypotheses.

Faults with traces measured in thousands of feet are common at Yucca Mountain, and several hypotheses can be developed to describe their influence on the aquifer system. Three of these hypotheses are listed here.

1. Flow and transport may occur primarily along faults and associated breccia. Scales where the concept of an REV is appropriate are not known but probably are too great for use when accurately estimating ground-water velocities. Therefore, numerical models of Yucca Mountain may need to include faults as discrete features.

2. The system of faults may not be sufficiently interconnected to influence flow and transport at the scale of Yucca Mountain, but it may act as boundaries for local flow systems within unfaulted blocks. For example, faults may permit rapid movement of water and solute along fault traces without contributing significantly to movement across faults.

3. The system of faults may be represented by an equivalent porous medium; however, aquifer properties of the fault network may be significantly different from fracture networks within fault blocks. A numerical method based on dual-porosity theory may be needed to describe transient flow or solute transport. In such a model, the system of faults would be represented by one porous medium, but the fracture network within the fault blocks would be represented by a second overlying porous medium.

In the preceding hypotheses, it is assumed that the system of faults and the fracture networks of intervening unfaulted blocks have different hydraulic and transport characteristics. This assumption may not be completely true; in which case, no unique hypothesis may be needed to describe flow and transport along faults.

Hypotheses describing flow and transport in fracture networks within fault blocks are at least as plentiful as those describing flow and transport in the system of faults. Many of the hydraulic and tracer tests planned at the C-well complex and elsewhere are designed to investigate these hypotheses. The most important hypotheses are listed here.

1. Fracture networks within fault blocks may act as equivalent-porous media. Characteristics of fracture networks and associated estimates of aquifer properties may or may not be related to stratigraphy. Whether or not fractures are related to stratigraphy, three-dimensional numerical models capable of reproducing complex heterogeneity may be needed.

2. Fracture networks may act as equivalent-porous media with respect to flow at scales required for accurate estimation of flow paths and Darcian fluxes, but not with respect to transport. Accurate estimation of velocities and dispersion characteristics may require a numerical model that includes discrete-fracture networks in some form.

3. The concept of an equivalent-porous medium may not be valid at any scale appropriate for estimating flow paths, Darcian fluxes, and ground-water velocities.

4. Fracture networks within fault blocks may act as dual-porosity media: where the rock is simulated by two overlapping porous media, one representing the fracture network and one representing the rock matrix. A unique set of aquifer-property estimates may exist for each medium. Dual-porosity theory may not be needed to describe steady-state flow but may be useful in transient-flow problems or solute-transport problems.

The most likely hypothesis is that fracture networks within fault blocks act as dual-porosity media (#4). If this supposition is verified by the hydraulic and tracer tests planned at the C-well complex, more complex conceptual and numerical models will be needed to describe the ground-water flow at Yucca Mountain. Any of the preceding hypotheses describing the system of faults can be combined with any of the hypotheses describing fracture networks within fault blocks to form a conceptual model of the aquifer system at the scale of Yucca Mountain. It is not practical to describe numerical methods that could be used with each possible model. A numerical method that may be appropriate for one conceptual model is given as an example. In addition to the method outlined here, additional investigation may suggest alternate approaches.

A conceptual model can be formed that corresponds to these hypotheses:

1. hydrologic characteristics of the system of faults are not significantly different from hydrologic characteristics of fracture systems within fault blocks, and

2. fracture networks can be simulated as equivalent porous media with respect to flow but not transport.

A numerical method corresponding to this conceptual model has been proposed by Schwartz and Smith (1985). The method would consist of a porous-medium model at the scale of Yucca Mountain with local-scale models of fracture networks used to describe the character of ground-water flow and solute transport within finite-difference blocks or finite elements of the continuum model.

As a result of the experience gained in predicting, conducting, and analyzing hydraulic and tracer tests at Yucca Mountain, it is likely that the conceptual model of flow and transport in fractured rock will be significantly refined. At that time, corresponding existing numerical methods will be evaluated, and a numerical model will be developed if necessary. New computer programs would be written, verified, and documented. A limited validation would be attempted, as described in the following paragraphs. The most important aspect of validation would be related to the change of scale from the scale of well tests (100's of m) to the scale of Yucca Mountain (10's of km).

Hydrologic models that are developed during this investigation probably would be most accurate when applied at the scale of well tests. The ultimate use of the model, however, would be at the scale of Yucca Mountain, where details measurable at the scale of well tests will not be measured. When collecting data and analyzing results at the scale of well tests, it will be necessary to consider the importance of this "lost" detail.

To the extent possible, well-documented cases of solute migration in fractured rock would be used to validate models at scales similar to those of Yucca Mountain (1 to 100 km^2). To form an appropriate model-validation exercise, the history of contamination and subsequent migration would need to be known, and the geologic framework would need to be similar to the geologic framework of Yucca Mountain. The geohydrologic data base for the validation exercise would need to be fairly complete. Limited data collection as part of Study 8.3.1.2.3.1, though, such as surface mapping of fractures or seismic profiling, may be required to support the validation. A survey of solute plumes to consider for validation exercises has not been completed but probably would include the well-documented case of tritium migration in fractured rock near the Idaho National Engineering Laboratory (Duffy and Harrison, 1987; and Lewis and Goldstein, 1982).

In addition to the validation-process, sensitivity and uncertainty analyses, as discussed in Section 2.1, will be performed.

Once these steps have been carried out to the extent possible and the results have been judged to be satisfactory by the investigators, the conceptual and numerical models will be used to estimate ground-water flow direction and magnitudes at the scale of the site. The model(s) may then be utilized in a transient mode.

3.3.3.3 Methods summary

The parameters to be evaluated by the analyses described in the above sections are summarized in Table 3.3-1. Also listed are the selected methods for evaluating the activity parameters. Alternate methods may be utilized if a selected method is impractical to estimate the parameters of interest. The selected methods in Table 3.3-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the parameters of interest. Models and analytical techniques have been or will be developed to be consistent with data developed in this and contributing studies.

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 (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 2.1.7) for which quality assurance levels have been set.

Table 3.3-1 Summary of tests and methods for the calculated flow paths, fluxes, and velocities activity (SCP 8.3.1.2.3.3.3)

Methods	Site-characterization parameter
Develop conceptual and numerical models of ground-water flow and conservative-solute transport to be applied at the scale of Yucca Mountain	
Evaluate hypotheses for ground-water flow and solute transport by analysis of hydraulic and tracer tests and numerical modeling (selected)	Conservative-solute transport, scale of Yucca Mountain
"	Ground-water flow paths, scale of Yucca Mountain
"	Ground-water flow velocities, scale of Yucca Mountain
"	Ground-water flux, scale of Yucca Mountain
Form conceptual model from evaluation of ground-water flow hypotheses (selected)	Conservative-solute transport, scale of Yucca Mountain
"	Ground-water flow paths, scale of Yucca Mountain
"	Ground-water flow velocities, scale of Yucca Mountain
"	Ground-water flux, scale of Yucca Mountain
"	Potentiometric surface, site
Select or construct numerical model describing behavior of conceptual model (selected)	(Does not directly address activity parameter)
Documentation and verification of numerical model (selected)	"

Table 3.3-1 Summary of tests and methods for the calculated flow paths, fluxes, and velocities activity (SCP 8.3.1.2.3.3)

Methods	Site-characterization parameter
Develop conceptual and numerical models of ground-water flow and conservative-solute transport to be applied at the scale of Yucca Mountain (continued)	
Validate numerical model against cases of solute migration in fractured rock at scales similar to Yucca Mountain	Conservative-solute transport, scale of Yucca Mountain
Validate numerical model against cases of solute migration in fractured rock at scales similar to Yucca Mountain (selected)	Ground-water flow paths, scale of Yucca Mountain
"	Ground-water flux velocities, scale of Yucca Mountain
"	Ground-water flux, scale of Yucca Mountain
Evaluate effects of scale changes from validation cases to scale of Yucca Mountain (selected)	Conservative-solute transport, scale of Yucca Mountain
"	Ground-water flow paths, scale of Yucca Mountain
"	Ground-water flow velocities, scale of Yucca Mountain
"	Ground-water flux, scale of Yucca Mountain
"	Potentiometric surface, site

Table 3.3-1 Summary of tests and methods for the calculated flow paths, fluxes, and velocities activity (SCP 8.3.1.2.3.3)

Methods	Site-characterization parameter
Characterize spatial variations in aquifer properties	
Use of geophysical models to estimate spatial distribution of aquifer properties (selected)	Effective porosity, spatial distribution
"	Hydraulic conductivity, spatial distribution
Use of geostatistical methods to estimate spatial distribution of aquifer properties (selected)	Effective porosity, spatial distribution
"	Hydraulic conductivity, spatial distribution
"	Storage coefficient, spatial distribution
Use of inverse modeling techniques to estimate spatial distribution of aquifer-flow properties (selected)	Hydraulic conductivity, spatial distribution

4. APPLICATION OF STUDY RESULTS

4.1 Application of results to resolution of performance issues

Site-characterization data generated in the present study will be employed in the following performance issues: Issue 1.6 (Ground-water travel time), Issue 1.1 (System performance objective for limiting radionuclide releases to the accessible environment), Issue 1.8 (NRC siting criteria), and Issue 1.9 (Higher-level findings), and Issue 1.3 (Special sources of ground water). These are discussed in SCP Sections 8.3.5.12, 8.3.5.13, 8.3.5.17, 8.3.5.18 and 8.3.5.15, respectively.

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. Logic diagrams and tables are used to summarize specific relationships between performance parameter needs and site-characterization parameters generated in this study. Section 7.2 provides additional detailed parameter relations.

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

The following paragraphs describe how data from the site saturated-zone flow-system synthesis and modeling study contributes to other site-characterization investigations.

- Investigation 8.3.1.3.2 (Studies to provide information on mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths). Within this investigation, the generalized parameters of hydrologic conditions and the geometry of ground-water flow paths in the saturated zone are required in order to evaluate the history of mineralogic and geochemical alteration at Yucca Mountain, and to project observed geochemical changes (mineral alteration) beyond the disturbed zone over the life of the repository.

- Investigation 8.3.1.3.4 (Studies to provide the information required on radionuclide retardation by sorption processes along flow paths to the accessible environment). Within this investigation, the geometry of ground-water flow paths and rates of ground-water flow in the saturated zone are required in order to evaluate the role that sorption plays in retarding the movement of radionuclides along flow paths to the accessible environment.

- Investigation 8.3.1.3.6 (Studies to provide the information required on radionuclide retardation by dispersive, diffusive, and advective transport processes along flow paths to the accessible environment). Within this investigation, the generalized parameters of hydrologic conditions and geometry of flow paths in the saturated zone are required in order to experimentally determine (1) the rate of movement by dispersive, diffusive, and advective processes, (2) retardation of radionuclides, and (3) the effective diffusivity of radionuclide species of each rock unit in the saturated zone.

- Investigation 8.3.1.3.7 (Studies to provide the information required on radionuclide retardation by all processes along flow paths to the accessible environment). Within this investigation, the potentiometric surface, geometry of ground-water flow paths, and ground-water flux in the saturated zone are required to perform calculations of radionuclide transport from the repository to the accessible environment using, as a basis, an integrated, conceptual geochemical-geophysical model of Yucca Mountain. The geohydrologic regime will be employed as a baseline condition starting from which transport calculations will be made for the nominal and disturbed cases.

- Investigation 8.3.1.5.2 (Studies to provide the information required on potential effects of future climatic conditions on hydrologic characteristics). In this investigation, the saturated-zone potentiometric surface and the geometry of ground-water flow paths at the present time are required in order to evaluate the response of the saturated zone to changes in recharge brought about by possible climatic change over the life of the repository. The present saturated-zone regime will be used as a baseline condition against which the effects of possible future increases in precipitation can be evaluated.

- Investigation 8.3.1.6.4 (Potential effects of erosion on hydrologic, geochemical, and rock characteristics). Within this investigation, the saturated-zone potentiometric surface and geometry of ground-water flow are required so that an assessment can be made as to whether future erosion at Yucca Mountain may be of sufficient magnitude to modify hydraulic gradients and locations of recharge and discharge areas and thus reduce ground-water travel time to the accessible environment. (The probability of this occurrence is considered very low.)

- Investigation 8.3.1.8.3 (Studies to provide information required on changes in unsaturated- and saturated-zone hydrology due to tectonic events). Within this investigation, the potentiometric surface, geometry of ground-water flow paths, and ground-water flux in the saturated zone under present conditions must be known from the saturated-zone flow model. Using these data as a baseline condition, the effects on water-table elevation, ground-water flux, and hydrologic properties from tectonic processes can be evaluated. These processes include faulting, folding, uplift and subsidence, volcanism, and igneous intrusion.

- Investigation 8.3.1.9.2 (Studies to provide the information required on present and future value of energy, mineral, land, and ground-water resources). Within this investigation, present-day aquifer characteristics, such as water-table elevation and distribution of hydrologic properties, will be required from the saturated-zone flow model in order to evaluate the current supply and demand situation for ground water in the region surrounding Yucca Mountain and to estimate the value of the ground-water resource.

- Investigation 8.3.1.9.3 (Studies to provide the information required on potential effects of exploiting natural resources on hydrologic, geochemical, and rock characteristics). Within this investigation, the saturated-zone flow model will provide the present saturated-zone potentiometric surface, flow-path geometry, and distribution of aquifer characteristics that will be used as a baseline for the evaluation of the potential effects of future ground-water withdrawals on the hydrologic system at Yucca Mountain.

5. SCHEDULES AND MILESTONES

5.1 Schedules

The proposed schedule presented in Figure 5.1-1 summarizes the logic network and reports for the three activities of this study. 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 or interferences from other studies, and also how the present study will contribute or may interfere with other studies.

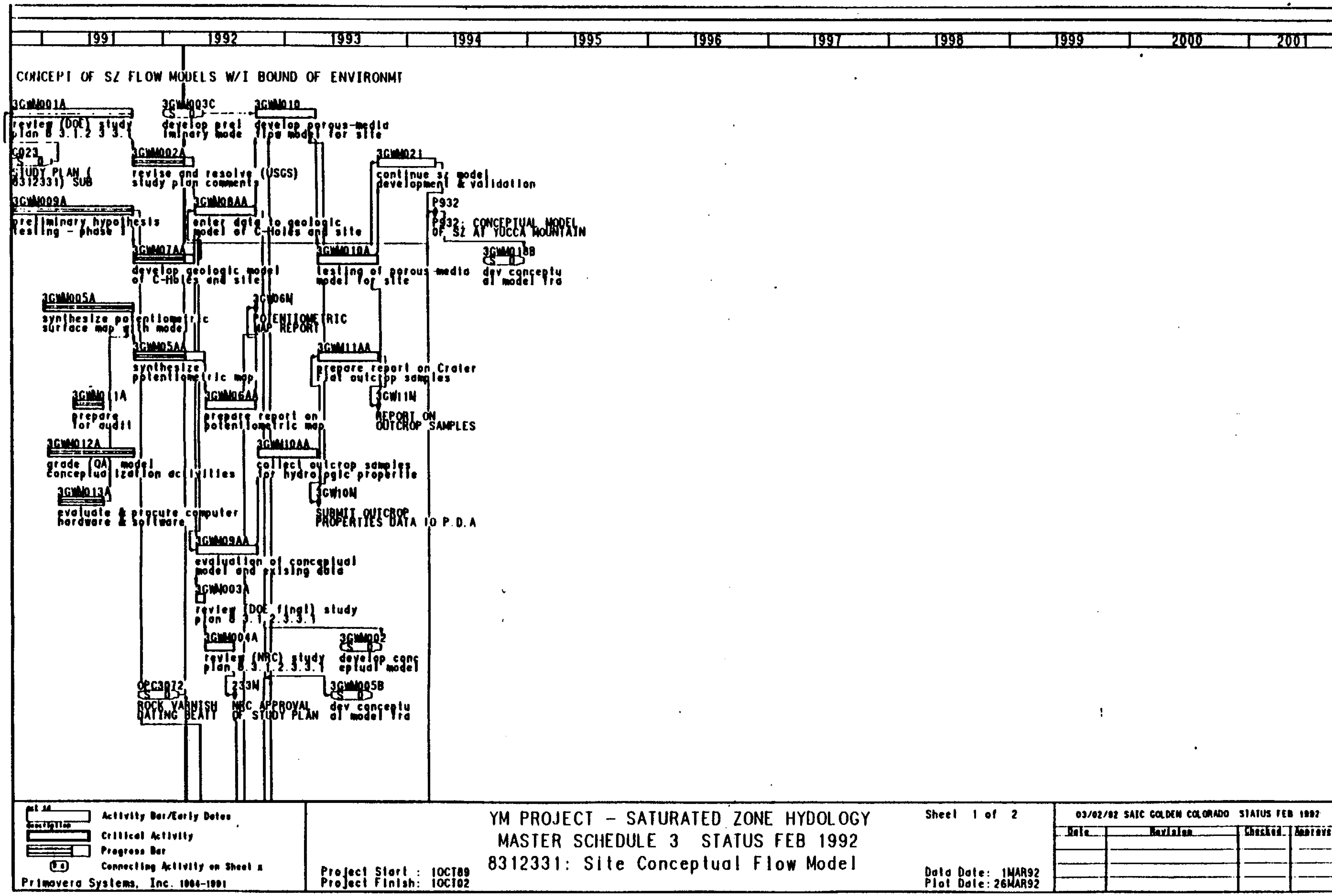

Figure 5.1-1a. Summary network of site saturated-zone hydrologic synthesis and modeling study.

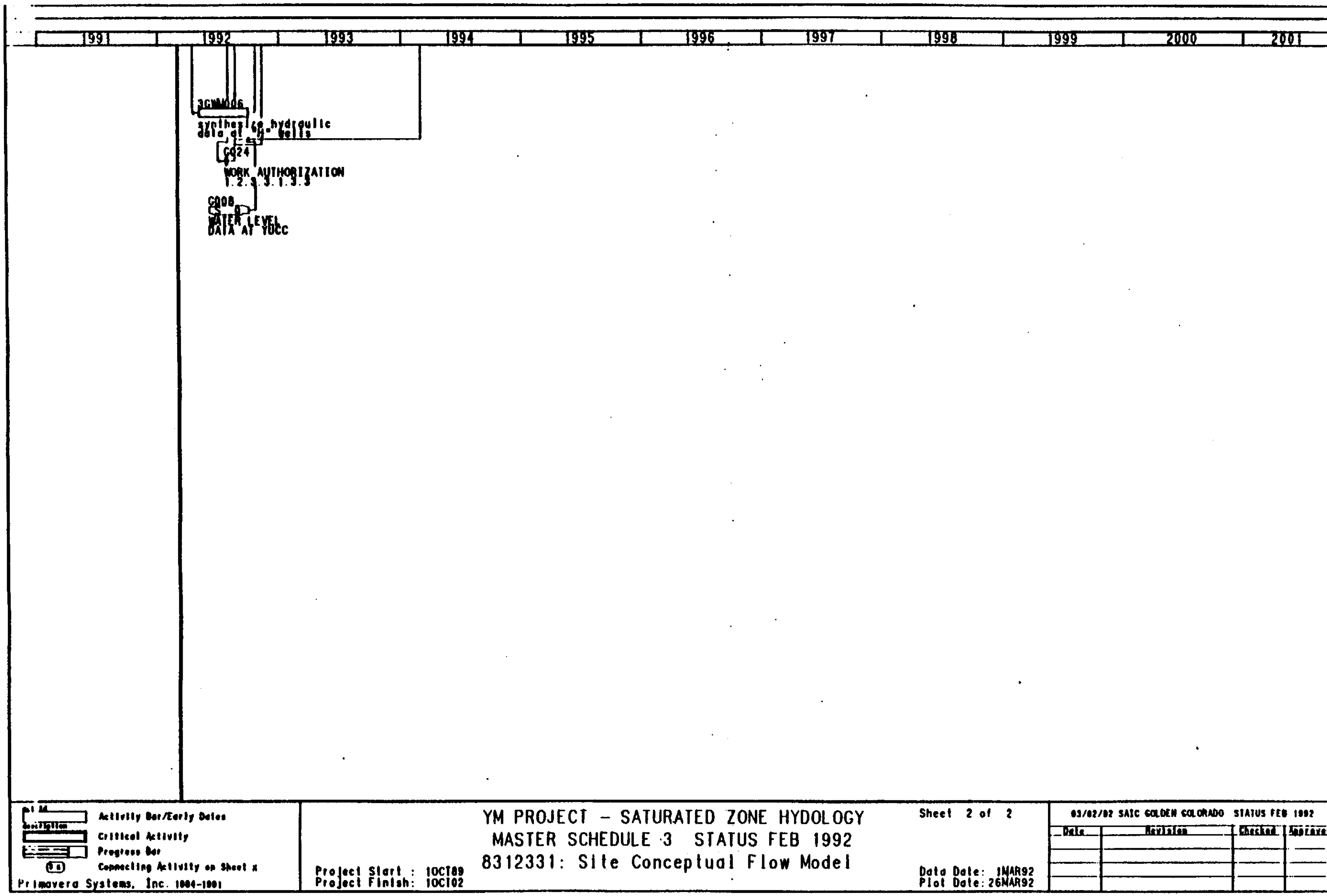

Figure 5.1-1b. Summary network of site saturated-zone hydrologic synthesis and modeling study.

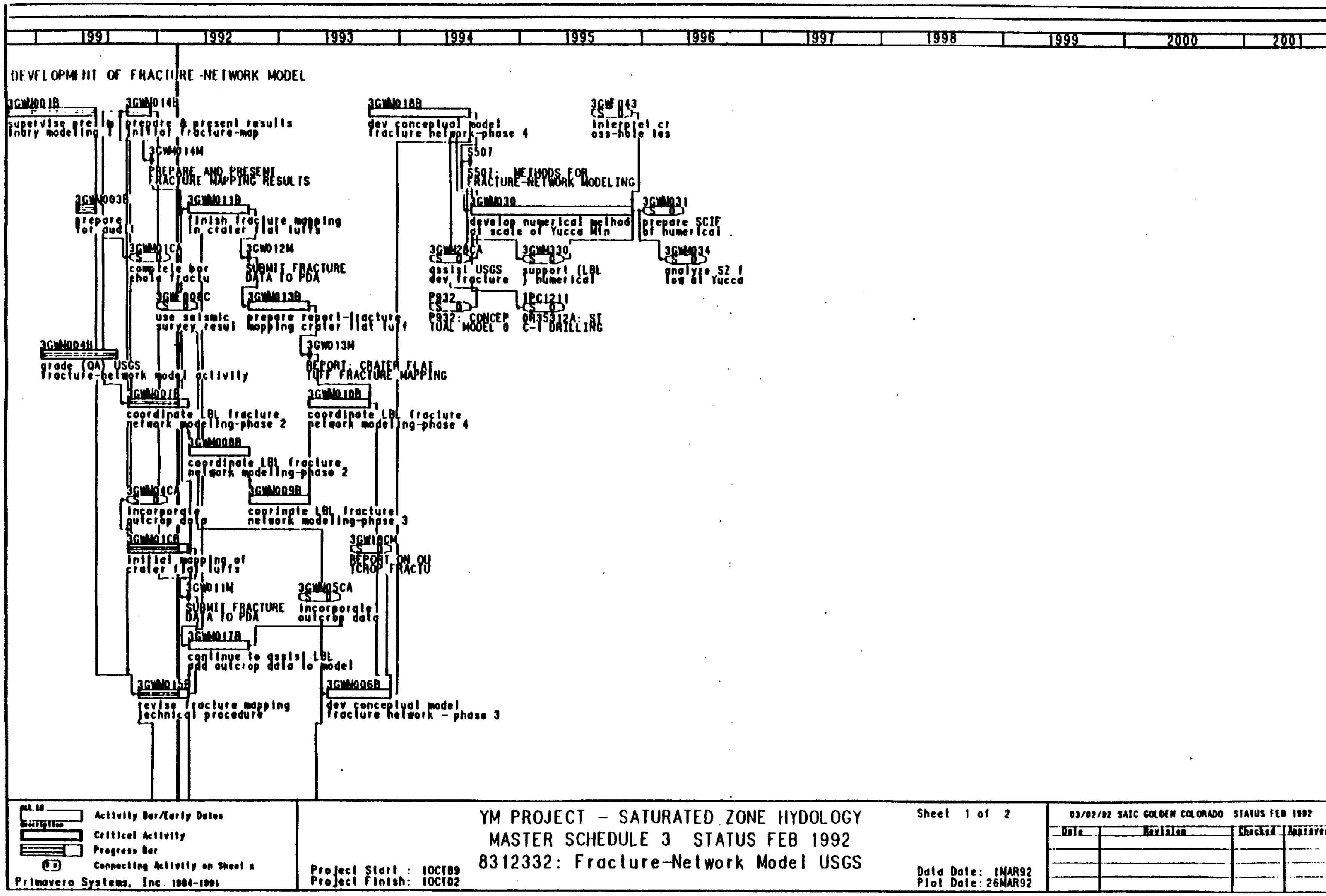

Figure 5.1-1c. Summary network of site saturated-zone hydrologic synthesis and modeling study.

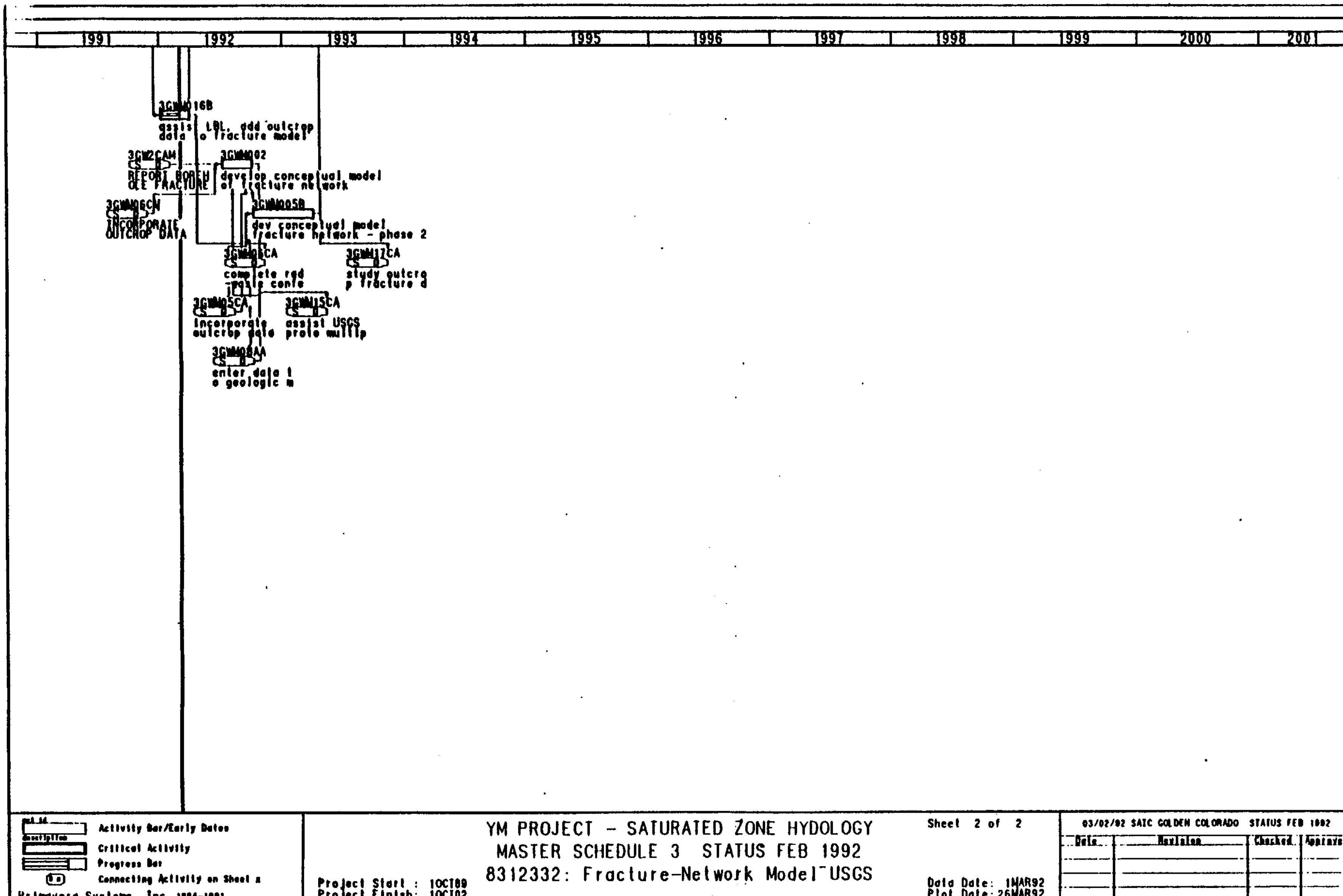

Figure 5.1-1d. Summary network of site saturated-zone hydrologic synthesis and modeling study.

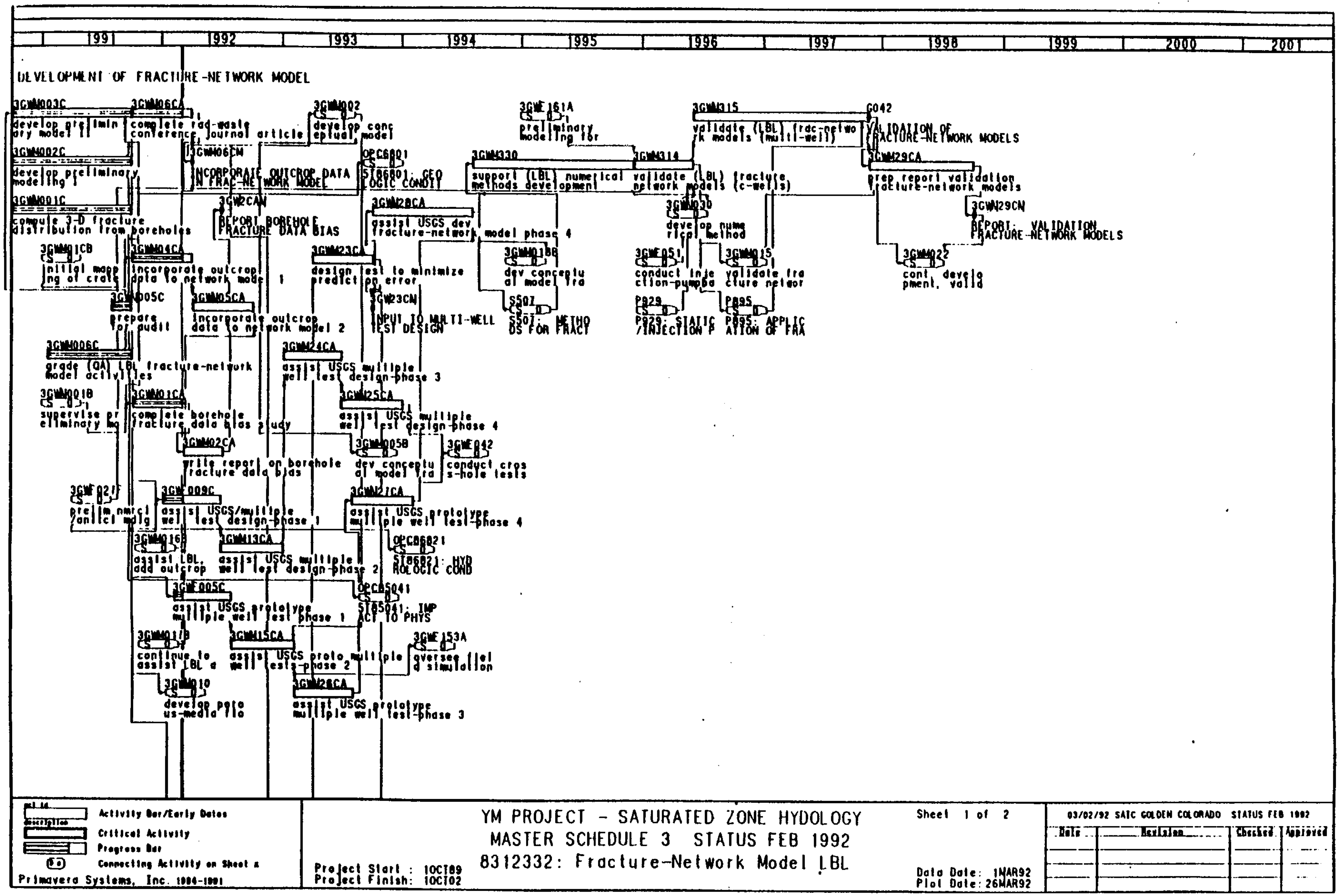

Figure 5.1-1e. Summary network of site saturated-zone hydrologic synthesis and modeling study.

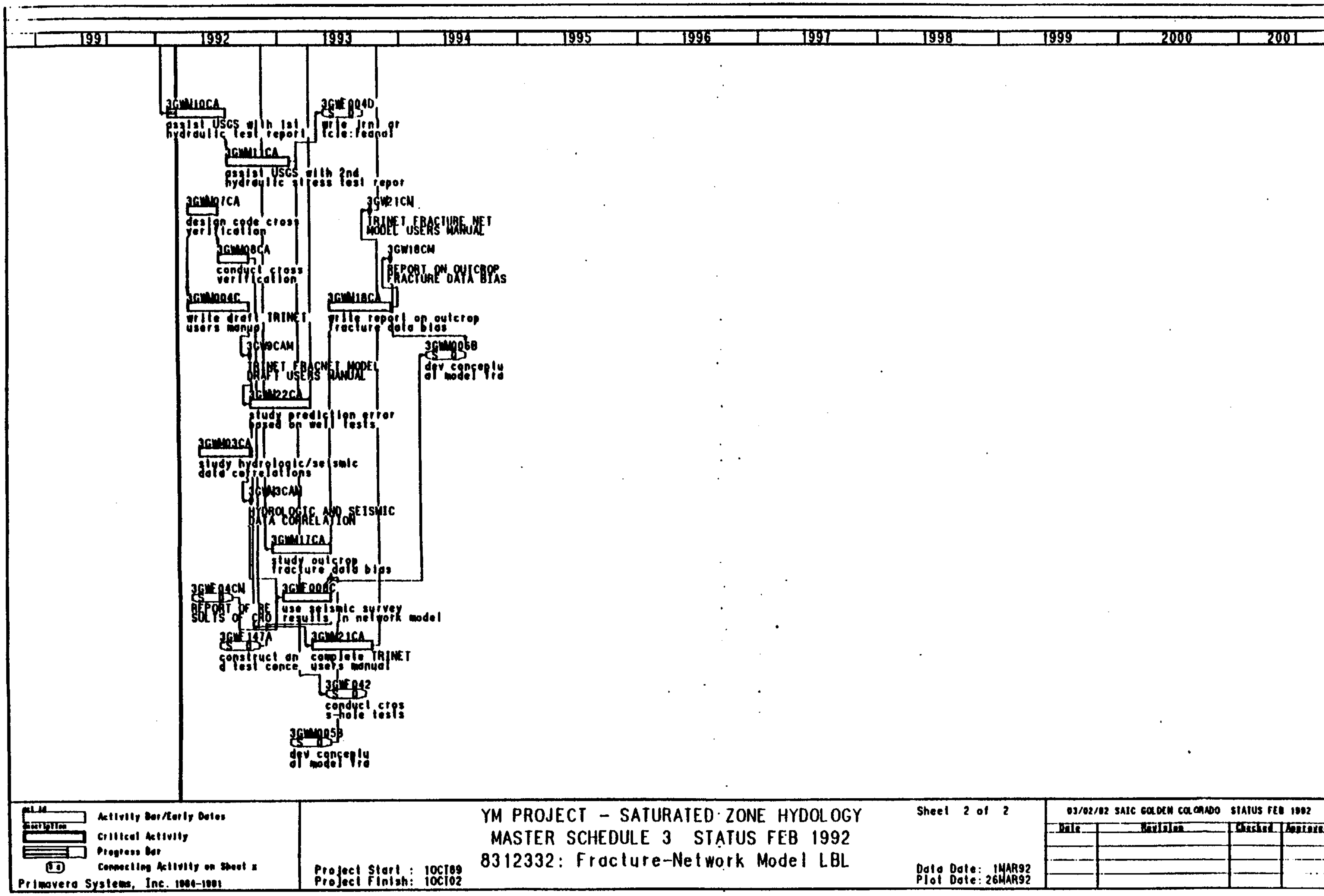

Figure 5.1-1f. Summary network of site saturated-zone hydrologic synthesis and modeling study.

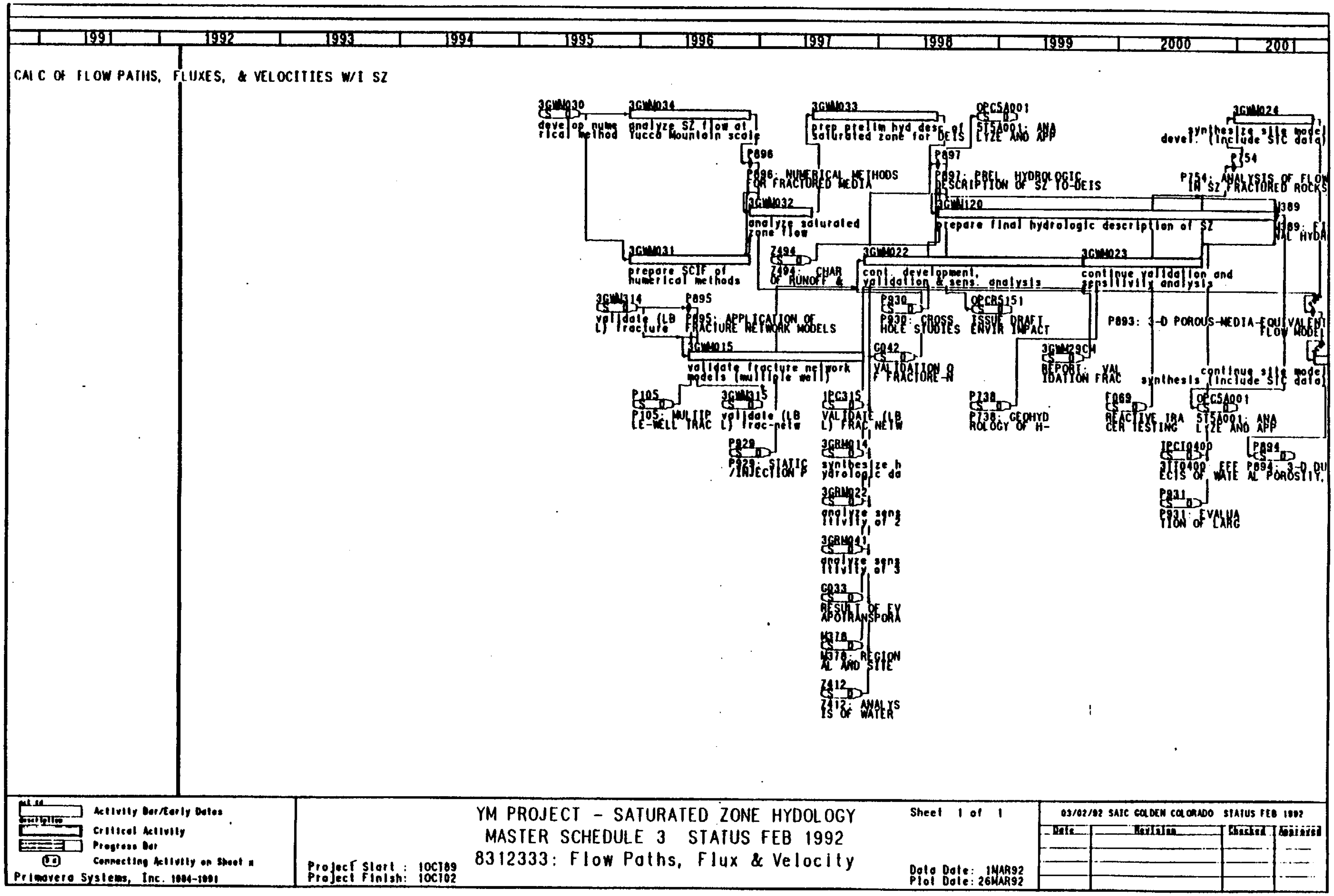

Figure 5.1-1g. Summary network of site saturated-zone hydrologic synthesis and modeling study.

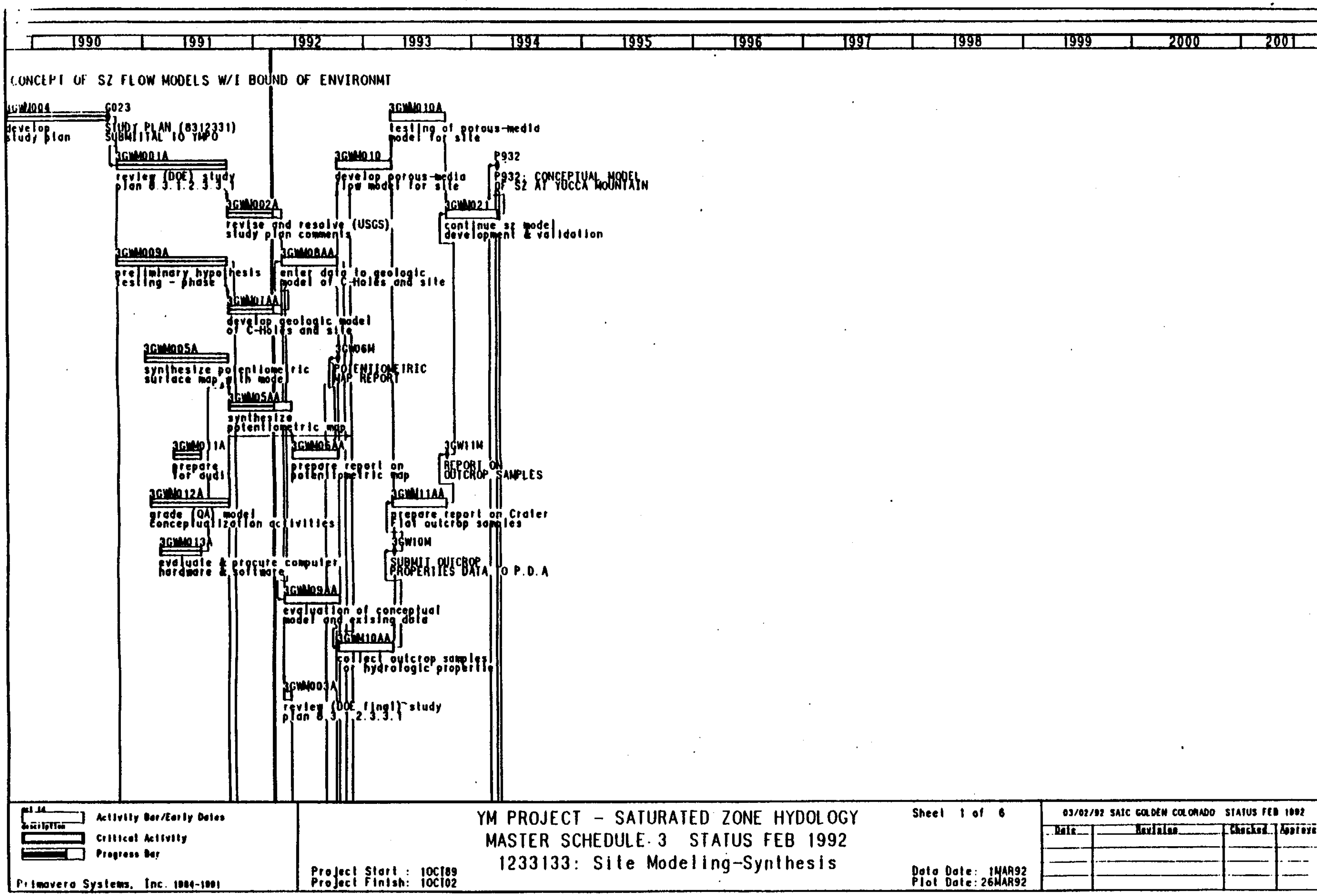

Figure 5.1-1h. Summary network of site saturated-zone hydrologic synthesis and modeling study.

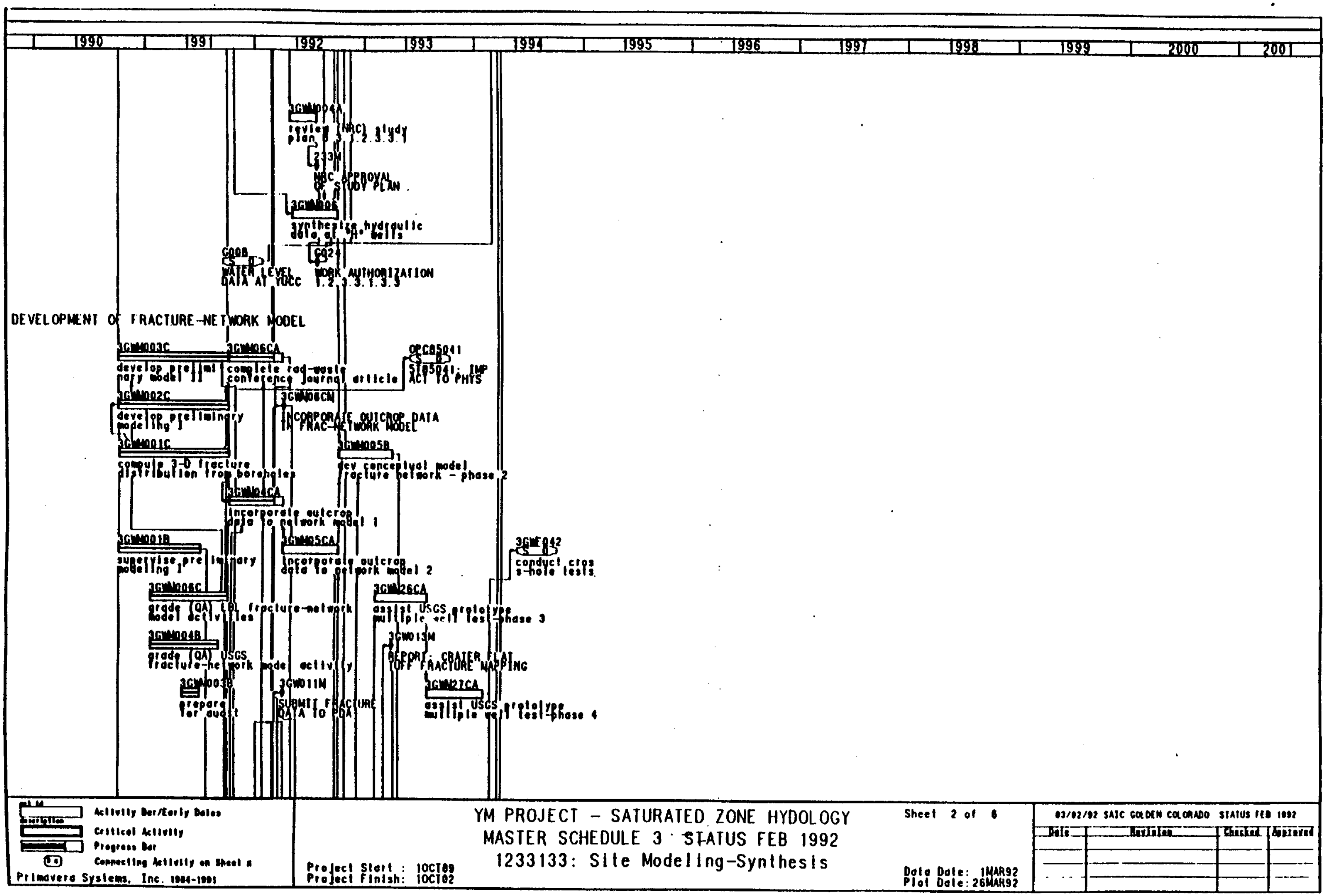

Figure 5.1-1i. Summary network of site saturated-zone hydrologic synthesis and modeling study.

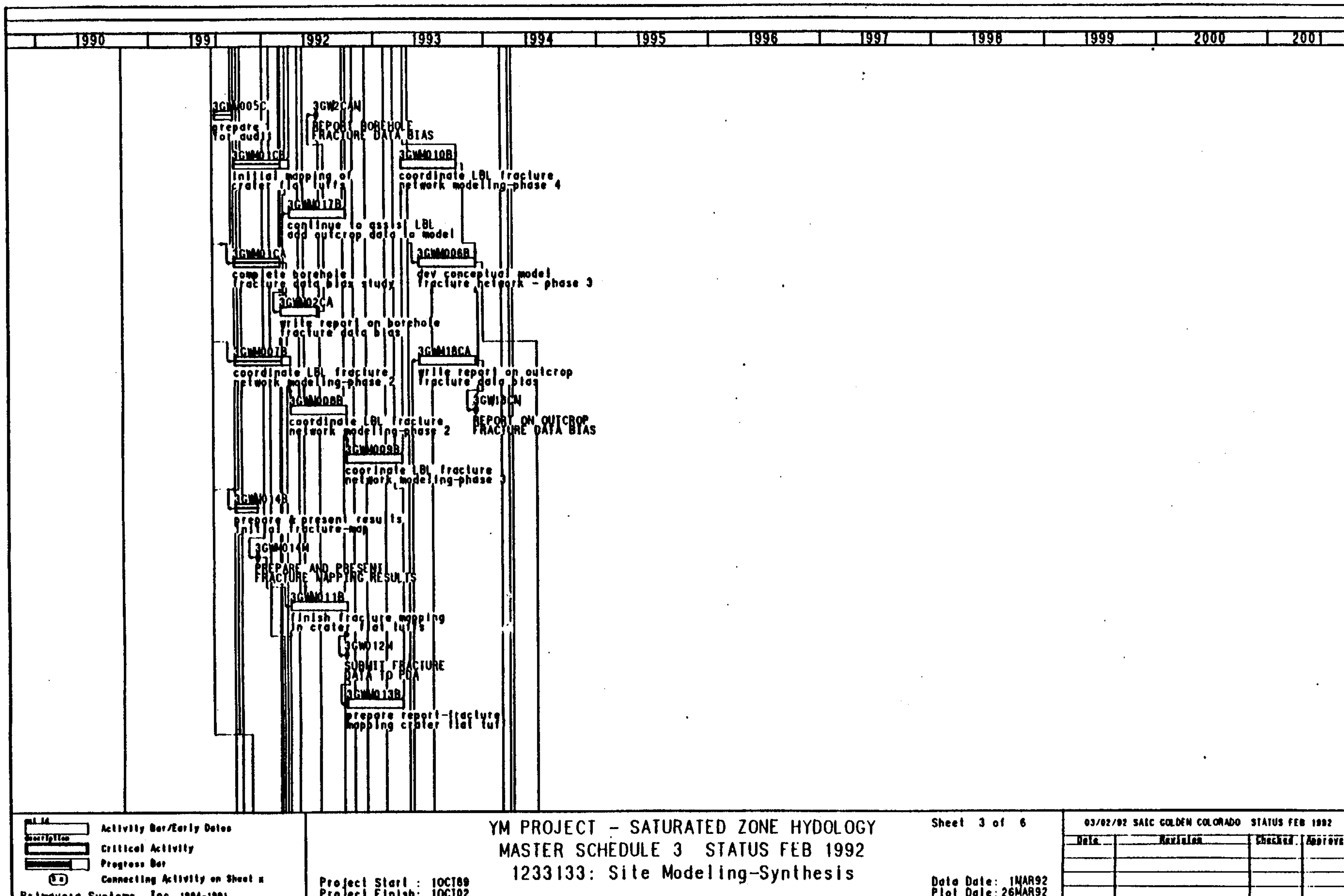

Figure 5.1-1j. Summary network of site saturated-zone hydrologic synthesis and modeling study.

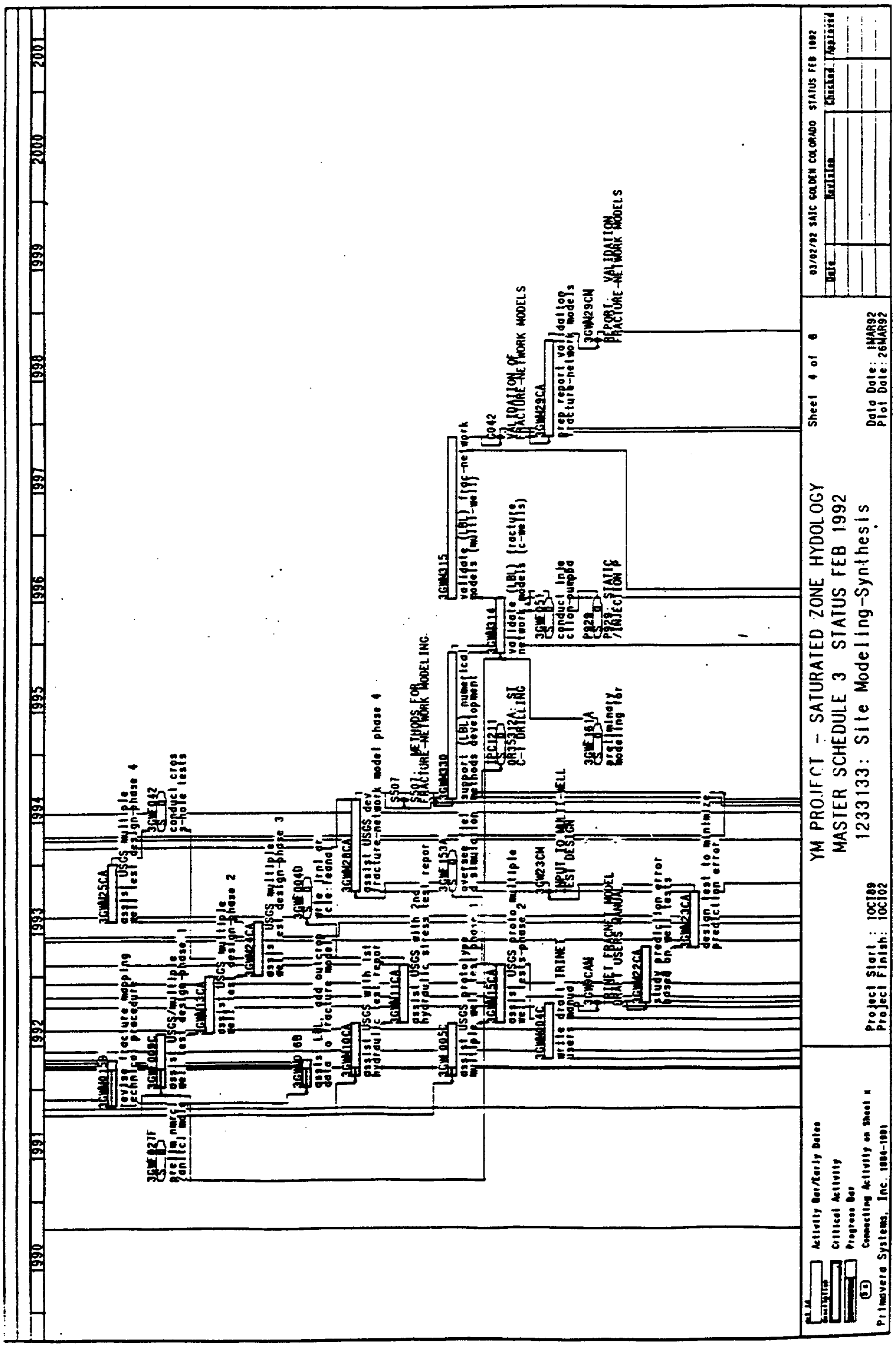

Figure 5.1-1k. Summary network of site saturated-zone hydrologic synthesis and modeling study.

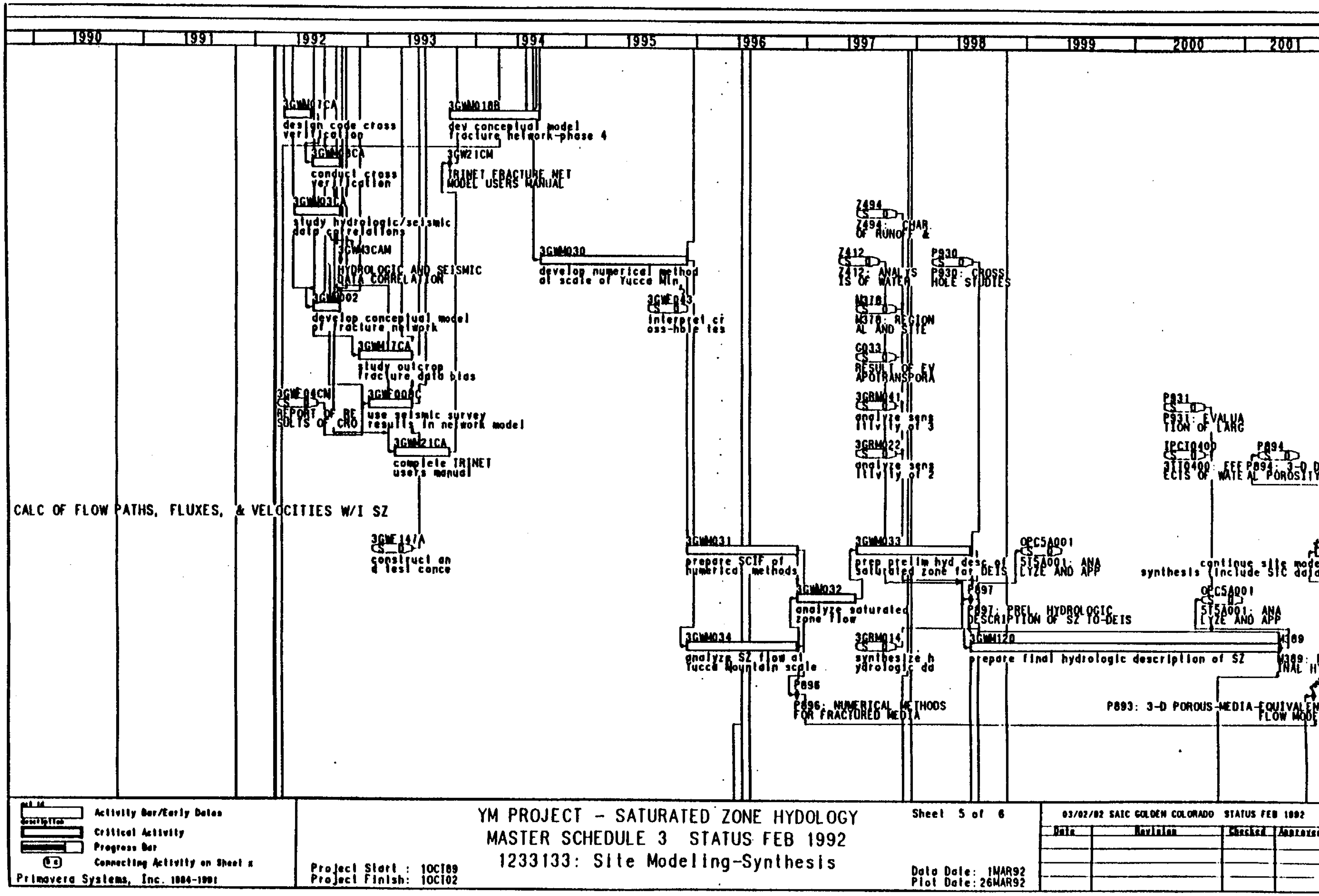

Figure 5.1-1l. Summary network of site saturated-zone hydrologic synthesis and modeling study.

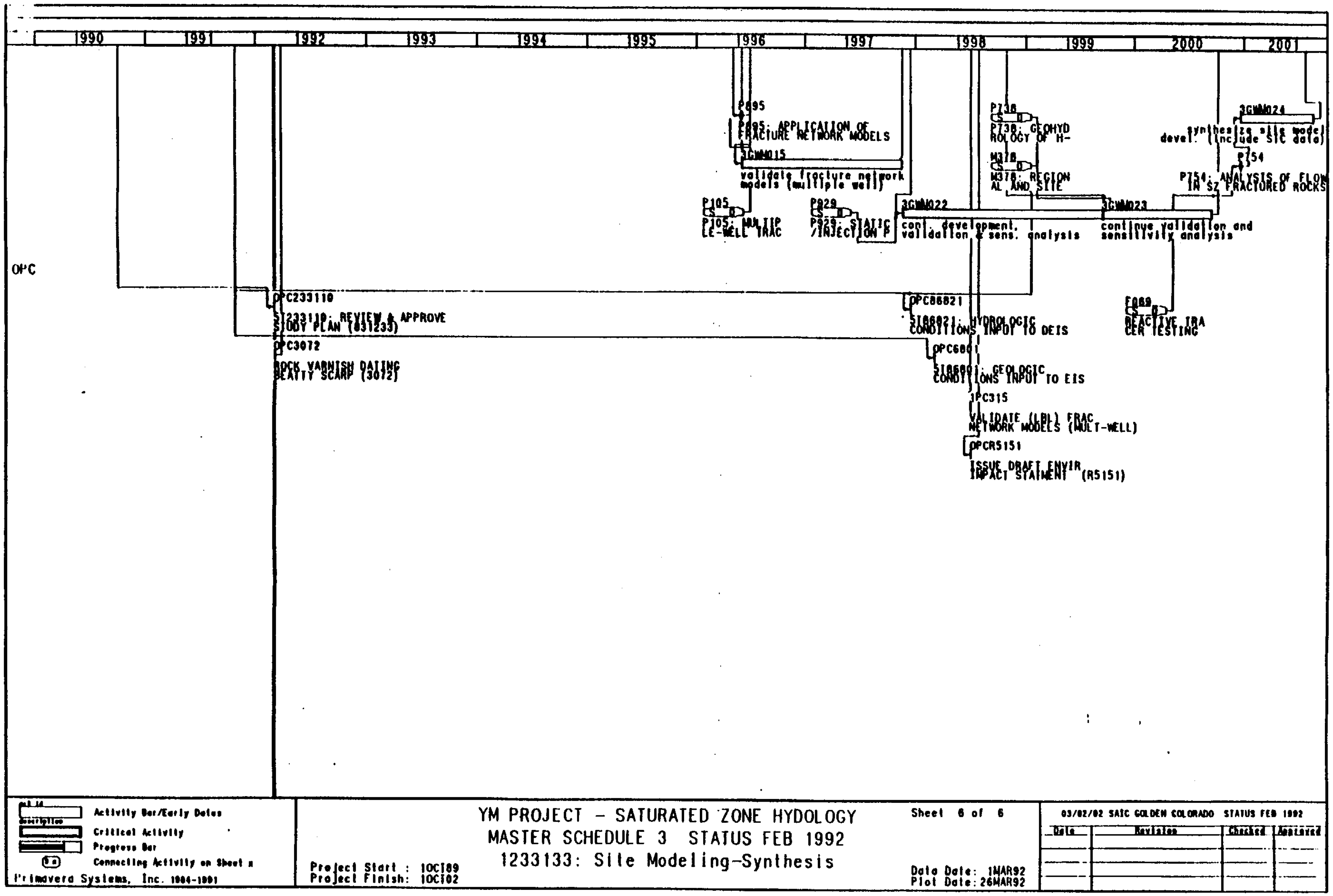

Figure 5.1-1m. Summary network of site saturated-zone hydrologic synthesis and modeling study.

5.2 Milestones

The milestone number, title, level, and corresponding work-breakdown-structure (WBS) number associated with the three activities of this study are summarized in Table 5.2-1.

The information presented in Table 5.2-1 represents major events or important summary milestones associated with the activities presented in this study plan 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 on-going planning efforts.

Table 5.2-1. Milestone list for work-breakdown structure number - 1.2.3.3.1.3.3 (SCP 8.3.1.2.3.3)

Milestone Number	Milestone	Milestone Level
Conceptualization of saturated-zone flow models: 8.3.1.2.3.3.1		
P932	Conceptual model of SZ at Yucca Mountain	2
233M	NRC approval of study plan	3
3GW06M	Potentiometric map report	3
3GW11M	Report on outcrop samples	3
G023	Study plan (8.3.1.2.3.3.) submittal to YMPO	3
G024	Work authorization 1.2.3.3.1.3.3	3
3GW10M	Submit outcrop properties data to PDA	4
Development of fracture-network model: 8.3.1.2.3.3.2 (USGS)		
3GW013M	Report: Crater Flat tuff fracture mapping	3
3GWM014M	Prepare and present fracture mapping results	3
S507	Methods for fracture-network modeling	3
3GW011M	Submit fracture data to PDA	4
3GW012M	Submit fracture data to PDA	4
Development of fracture-network model: 8.3.1.2.3.3.2 (LBL)		
3GW18CM	Report on outcrop fracture data bias	3
3GW21CM	Trinet fracture net model users manual	3
3GW2CAM	Report borehold fracture data bias	3
3GW23CM	Report: Validation fracture-network models	3
3GWM3CAM	Hydrologic and seismic data correlation	3
G042	Validation of fracture-network models	3
3GW23CM	Input to multi-well test design	4
3GW9CAM	Trinet fracnet model draft users manual	4
3GWM06CM	Incorporate outcrop data in frac-network model	4

Milestone Number	Milestone	Milestone Level
Calculations of flow paths, fluxes, and velocities: 8.3.1.2.3.3.3		
M389	Final hydrologic description of SZ	2
P897	Preliminary hydrologic description of SZ to DEIS	2
P754	Analysis of flow in SZ fractured rocks	3
P893	3-D porous-media-equivalent flow model	3
P894	3-D dual porosity, flow model of SZ at YM	3
P895	Application of fracture network models	3
P896	Numerical methods for fractured media	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.

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

Applicable NQA-1 criteria for Study 8.3.1.2.3.3 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 performance-parameters needs and characterization parameters to be determined in this study. The relations were developed using model-based parameter categories (See Figure 2.1-1) that provide common terminology and organization for evaluation of site and performance information relations.

All performance issues that 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 8.3.2 - 3.3.5). 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 characterization 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 (site 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 (characterization parameters) within a parameter category should <u>not</u> be made.

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance for limiting radionuclide releases to accessible environment				(SCP 8.3.5.13)
Performance Measures: EPPM , nominal case, release scenario class E, water pathway release; (Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.)					
		Parameter Category: Saturated-zone transmissive properties			
n_e: average effective matrix porosity, controlled area, saturated zone (scenario class E, nominal case) [1]	Controlled area; Saturated zone	Goal: >0.1 Current: Low Needed: Medium	Hydraulic conductivity	Yucca Mountain and surrounding region; Saturated-zone hydrogeologic system	8.3.1.2.3.3.1
Hydraulic conductivity (Rock matrix)	Controlled area; Saturated-zone units	Goal: Mean, Variance, Autocorrelation length Current: Medium Needed: High, Low, Low	Effective porosity	"	8.3.1.2.3.3.2
Hydraulic conductivity (fracture networks)	"	Goal: Mean, Variance, Autocorrelation length Current: Low Needed: High, Low, Low	Hydraulic conductivity	"	"
Effective porosity (Rock matrix)	"	Goal: Mean, Variance, Autocorrelation length Current: Low, Low, Low Needed: Medium, Medium, Low	Effective porosity	"	8.3.1.2.3.3.3

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance for limiting radionuclide releases to accessible environment				(SCP 8.3.5.13)
		Parameter Category: Saturated-zone transmissive properties			
Effective porosity (Fracture networks)	Controlled area; Saturated-zone units	Goal: Mean, Variance, Autocorrelation length Current: Low, Low, Low Needed: Medium, Medium, Low	Hydraulic conductivity	Yucca Mountain and surrounding region; Saturated-zone hydrogeologic system	8.3.1.2.3.3.3
		Parameter Category: Saturated-zone water potential			
d_s: average length of flow paths, through saturated zone from controlled area to accessible environment boundary (scenario class E, nominal case) (1)	Controlled area; Saturated zone	Goal: >5000 m Current: Low Needed: Medium	Hydraulic gradient	Yucca Mountain and surrounding area; Saturated-zone hydrogeologic system	8.3.1.2.3.3.1
Altitude of water table, ambient, as a function of lateral spatial location	Controlled area; Saturated-zone units	Goal: Mean, Variance Current: Medium, Medium Needed: High, Medium	"	Yucca Mountain and surrounding region; Saturated-zone hydrogeologic system	8.3.1.2.3.3.2
Effective thickness of saturated zone; as a function of lateral spatial location	"	Goal: Mean Current: Low Needed: Low	"	"	8.3.1.2.3.3.3

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance for limiting radionuclide releases to accessible environment				(SCP 8.3.5.13)
		Parameter Category: Saturated-zone ground-water flux			
q_s: average discharge in saturated zone under controlled area (scenario class E, nominal case) (1)	Controlled area; Saturated zone	Goal: <32 mm/yr Current: Low Needed: Medium	Ground-water flux	Yucca Mountain and surrounding region; Saturated-zone hydrogeologic system	8.3.1.2.3.3.1
			Conservative-solute transport	"	8.3.1.2.3.3.2
			Ground-water flux	"	"
			Conservative-solute transport	"	8.3.1.2.3.3.3
			Ground-water flux	"	"

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement ground-water travel time				(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 transmissive properties					
Effective porosity[1]	Controlled area; Saturated zone	Goal: >0.01 Current: Low Needed: Low	Hydraulic conductivity	Yucca Mountain and surrounding region; Saturated-zone hydrogeologic system	8.3.1.2.3.3.1
Permeability, saturated (Fault zones)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low	Effective porosity	"	8.3.1.2.3.3.2
Permeability, saturated (Fractures)	"	Goal: Mean, SCor, SDev Current: Low, NA, NA Needed: Medium, Low, Medium	Hydraulic conductivity	"	"
Permeability, saturated (Rock mass)	"	"	Effective porosity	"	8.3.1.2.3.3.3
Permeability, saturated (Rock matrix)	"	Goal: Mean, SDev Current: Medium, NA Needed: Medium, Low	Hydraulic conductivity	"	"

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement ground-water travel time				(SCP 8.3.5.12)
		Parameter Category: Saturated-zone transmissive properties			
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			
Porosity, total (Fractures)	"	Goal: Mean, SCor, SDev Current: NA, NA, NA Needed: Medium, Low, Medium			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement ground-water travel time				(SCP 8.3.5.12)
		Parameter Category: Saturated-zone transmissive properties			
Porosity, total (Rock mass)	Controlled area; Saturated zone, each litho unit in upper 100 m	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			
		Parameter Category: Saturated-zone water potential			
dh/dl (gradient)(1)	Controlled area; Saturated zone	Goal: <0.001 Current: Low Needed: Low	Hydraulic gradient	Yucca Mountain and surrounding area; Saturated-zone hydrogeologic system	8.3.1.2.3.3.1
Distance along flow paths(1)	"	Goal: 1000 m Current: Low Needed: Medium	"	Yucca Mountain and surrounding region; Saturated-zone hydrogeologic system	8.3.1.2.3.3.2

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement ground-water travel time				(SCP 8.3.5.12)
		Parameter Category: Saturated-zone water potential			
Pressure head, function of depth (Ground water)	Controlled area; Saturated zone, upper 100 m	Goal: Mean Current: Low Needed: Medium	Hydraulic gradient	Yucca Mountain and surrounding region; Saturated-zone hydrogeologic system	8.3.1.2.3.3.3
Water-table altitude (Ground water)	Controlled area; Saturated zone, water table level	Goal: Mean, SDev Current: Medium;NA Needed: High, Low			
		Parameter Category: Saturated-zone ground-water flux			
K_s where K_s is hydraulic conductivity of saturated-matrix zones[(1)]	Controlled area; Saturated zone	Goal: <10 m/yr Current: Low Needed: Low	Ground-water flux	Yucca Mountain and surrounding region; Saturated-zone hydrogeologic system	8.3.1.2.3.3.1
Flux, flow rate (Rock mass)	Controlled area; Saturated zone, upper 100 m	Goal: Mean Current: Low Needed: Medium	Conservative-solute transport	"	8.3.1.2.3.3.2
			Ground-water flux	"	"
			Conservative-solute transport	"	8.3.1.2.3.3.3

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement ground-water travel time				(SCP 8.3.5.12)
		Parameter Category: Saturated-zone ground-water flux			
			Ground-water flux	Yucca Mountain and surrounding region; Saturated-zone hydrogeologic system	8.3.1.2.3.3.3

(1) Performance parameter; all other parameters cited are supporting parameters.