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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
STUDY PLAN APPROVAL FORM

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Study Plan Number 8.3.1.5.2.2

Study Plan Title Characterization of Future Regional Hydrology due to Climate Changes

Revision Number 0

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Director, Regulatory and Site Evaluation Division / Date

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RECORD OF REVISIONS

REVISION NUMBER	REVISION	DATE
R0	Study rationale and plans for two activities: Analysis of future surface-water hydrology due to climate changes (Section 3.1) Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated-zone hydrology (Section 3.3)	4-30-92

ABSTRACT

This study plan describes the site-characterization activities to be performed for the evaluation of the effects of possible future climate and geologic changes on the surface-water and saturated-zone hydrologic regimes at Yucca Mountain and the surrounding region. Results from this study will provide hydrologic parameter input for the resolution of performance and design issues. The two activities of this study are:

- o Analysis of future surface-water hydrology due to climate changes; and
- o Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated-zone hydrology.

The rationale for the effects of future climate on hydrology study is described in Sections 1 (regulatory rationale) and 2 (technical rationale). Section 3 describes the specific plans for the activities, including the analyses to be performed and the selected and alternative methods considered. Section 4 summarizes the application of study results, and Section 5 presents the schedules and associated milestones.

CHARACTERIZATION OF THE FUTURE
REGIONAL HYDROLOGY DUE TO CLIMATE CHANGES

YMP-USGS SP 8.3.1.5.2.2, R0

STUDY PLAN

APRIL 1992

April 30, 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 studies are to provide hydrologic and geologic information to evaluate the suitability of Yucca Mountain for development as a high-level nuclear-waste repository, and the ability of the mined geologic-disposal system (MGDS) to isolate the waste in compliance with regulatory requirements. In particular, the project is designed to acquire information necessary for the Department of Energy (DOE) to demonstrate in its environmental-impact statement and license application that the MGDS will meet the requirements of federal regulations 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191.

The purpose of the study plan is to describe and outline strategies for evaluating the effects of possible future climate changes upon the surface-water and saturated-zone hydrology of Yucca Mountain and the surrounding region. The study is organized into two activities:

- 8.3.1.5.2.2.1 - Analysis of future surface hydrology due to climate changes, and
- 8.3.1.5.2.2.3 - Evaluation of possible future changes in climate and regional geologic framework on regional saturated-zone hydrology.

Note that the numbers (e.g., 8.3.1.5.2.2.1) 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.

The SCP description of the present study contains a separate activity for the evaluation of hydrologic effects of possible future climate changes upon the site unsaturated zone (Activity 8.3.1.5.2.2.2, Analysis of future unsaturated-zone hydrology due to climate changes). This activity has not been included in the study plan because its scientific content has been incorporated in YMP-USGS SP 8.3.1.2.2.9 (Site unsaturated-zone modeling and synthesis). The logic for this change is explained in Section 1.2.

Figure 1.1-1 illustrates the location of the study within the SCP Climate Program. The future regional hydrology study is one of eight studies planned to characterize paleoclimatic history, evaluate expected future climatic scenarios, define relations between paleoclimate and paleohydrology, and evaluate the response of the future Yucca Mountain hydrologic regime to possible changes in future climate, or to changes in the future geologic framework if results of various studies demonstrate a need to do so. The two activities in this study were selected based on 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 design/performance-parameter

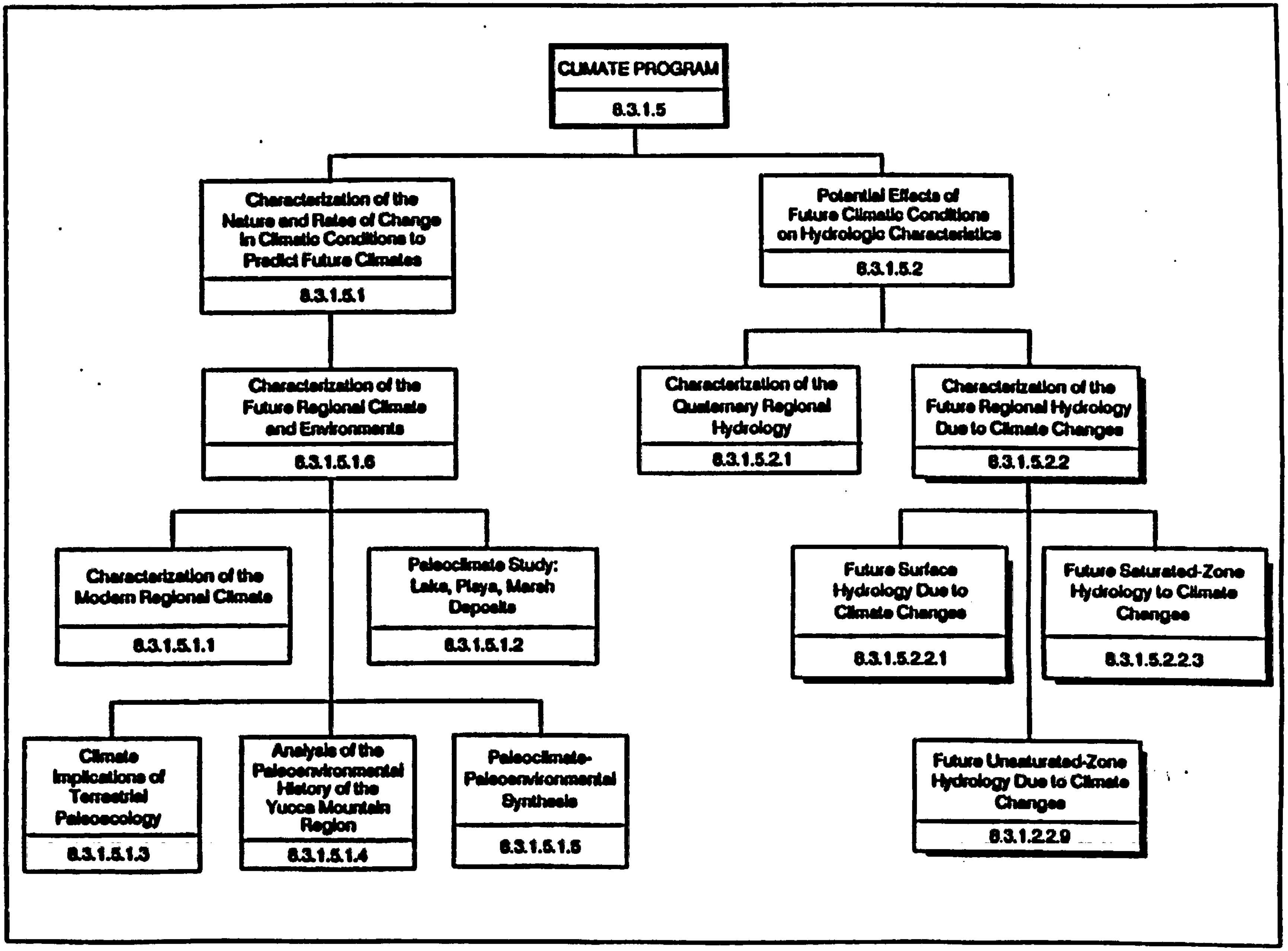

Figure 1.1-1. Location of study within the future climate/hydrology investigation and organization of the C mate Program.

needs, available analytical methods, and test scale. These factors are described in Sections 2 and 3. The analyses were also designed such that resulting data will be comprehensive enough to permit interpretations according to alternate hypotheses for the natural systems that the analyses are investigating.

The descriptions and plans for both activities are presented in Section 3. Plans for the analysis of future surface-water hydrology are discussed in Section 3.1, and plans for the synthesis of possible future recharge and changes in geologic framework on the Yucca Mountain saturated zone are in Section 3.3. 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 quality-assurance requirements are discussed in Section 7.1.

1.2 Objectives of study

The objective of this study is to characterize the impacts of potential future climate changes on the regional and site surface-water system, and the impacts of potential future climate changes and changes in the regional geologic framework on the regional saturated-zone hydrology. The modeling of the site unsaturated zone under conditions of greater-than-present effective precipitation (SCP Activity 8.3.1.5.2.2.2) is not included in this study; it will be performed in Study 8.3.1.2.2.9 (YMP-USGS SP 8.3.1.2.2.9, Site unsaturated-zone modeling and synthesis), and this effort will be integrated as appropriate with the efforts of the present study.

The scientific approach to meeting the study objective will be to apply numerical hydrologic modeling techniques to the hydrologic regimes of Yucca Mountain and vicinity. This strategy will allow the evaluation of the effects of a range of possible future climatic conditions (e.g., variations in precipitation and temperature) upon site and regional hydrology, during climatic scenarios postulated in the Yucca Mountain region over the next 10,000 and 100,000 yr.

Figure 1.2-1 shows the future regional hydrology study as the culminating effort in the Climate Program. Three components of site characterization converge in the study and make possible the evaluation of future hydrology due to climate change. They are: 1) conceptual and numerical hydrologic models of the surface-water (from the Geohydrology Program) and the saturated-zone hydrologic regimes (from the Geohydrology Program and the present study); 2) current climatology and future climatic scenarios (from the Climate Program); and 3) synthesis of paleohydrology and paleoclimate (a part of the present study). In the third component, evidence about the nature of Quaternary regional hydrology will be correlated with the paleoclimatic history (from Investigation 8.3.1.5.1) of the Yucca Mountain region and with changes in the geologic framework. The results of this reconstruction will guide modeling efforts in evaluating the effects of possible future climatic changes and(or) changes in the geologic framework.

The future surface-water activity (8.3.1.5.2.2.1) is expected to provide estimates on the magnitudes and frequencies of future runoff and streamflow events. The unsaturated-zone modeling efforts of Study 8.3.1.2.2.9 are expected to provide a range of estimates for possible values of future infiltration, percolation, and saturation. The future saturated-zone activity (Activity 8.3.1.5.2.2.3) is expected to provide an evaluation of the response of the saturated-zone water table, flow paths, and fluxes to possible future climatic conditions and changes in the regional geologic framework.

1.3 Regulatory rationale and justification

In this study, evaluations of the effects of possible future climate changes upon the surface-water and saturated-zone hydrology will contribute directly to the resolution of applicable elements of Issue 1.1 (Limiting radionuclide releases to the accessible environment) and Issue 1.9b (Higher-level findings, 100,000-yr condition). The SCP (U.S. Department of Energy, 1988, p. 8.3.1.5-3) states that for the regulatory period of 10,000 years, the site-characterization data from this study needed to satisfy Issue 1.1 will be sufficient for the resolutions of the applicable elements of Issues 1.8 (NRC siting criteria), 1.9a (Higher-level findings, 10,000-yr condition), 1.10 (Characteristics and configurations of waste package), 1.11 (Characteristics and configurations of repository and engineered barriers), and 1.12 (Characteristics and configurations of shaft and borehole seals). The unsaturated-zone modeling (under conditions of greater-than-present effective precipitation) of Study 8.3.1.2.2.9 (Site unsaturated-zone modeling and synthesis) will also contribute to issues resolution by the path described above.

SCP Table 8.3.1.5-1 is a listing of the four specific repository performance scenarios related to possible future climatic changes and their effects upon the hydrology of Yucca Mountain and environs. These scenarios are summarized below:

- Climatic changes cause an increase in infiltration over the controlled area;
- Climatic changes cause an increase in altitude of the water table;
- Climatic changes cause an increase in the gradient of the water table within the controlled area; and
- Climatic changes cause the appearance of surficial discharge points within the controlled area.

In addition to the SCP scenarios, climate changes can cause a change in the form of precipitation or precipitation amounts, resulting in an increase in infiltration over the controlled area.

Each of these scenarios is accompanied in the table by a performance measure and performance parameters. For example, the performance measure for the third scenario is radionuclide transport time through the saturated zone to the accessible environment boundary. The accessible environment is the atmosphere, land surfaces, surface waters, oceans, and lithosphere beyond the controlled area. The controlled area will extend horizontally no more than 5 km in any direction from the outer boundary of the original location of the radioactive wastes. The performance parameters for the scenario are the expected magnitudes of the changes in water-table gradient due to climatic changes over the next 10,000 yr (for Issue 1.1) and 100,000 yr (Issue 1.9b), respectively.

Values for the performance parameters for all four of the scenarios will be provided by the characterization-parameter data generated by the future surface-water modeling of Activity 8.3.1.5.2.2.1, the unsaturated-zone

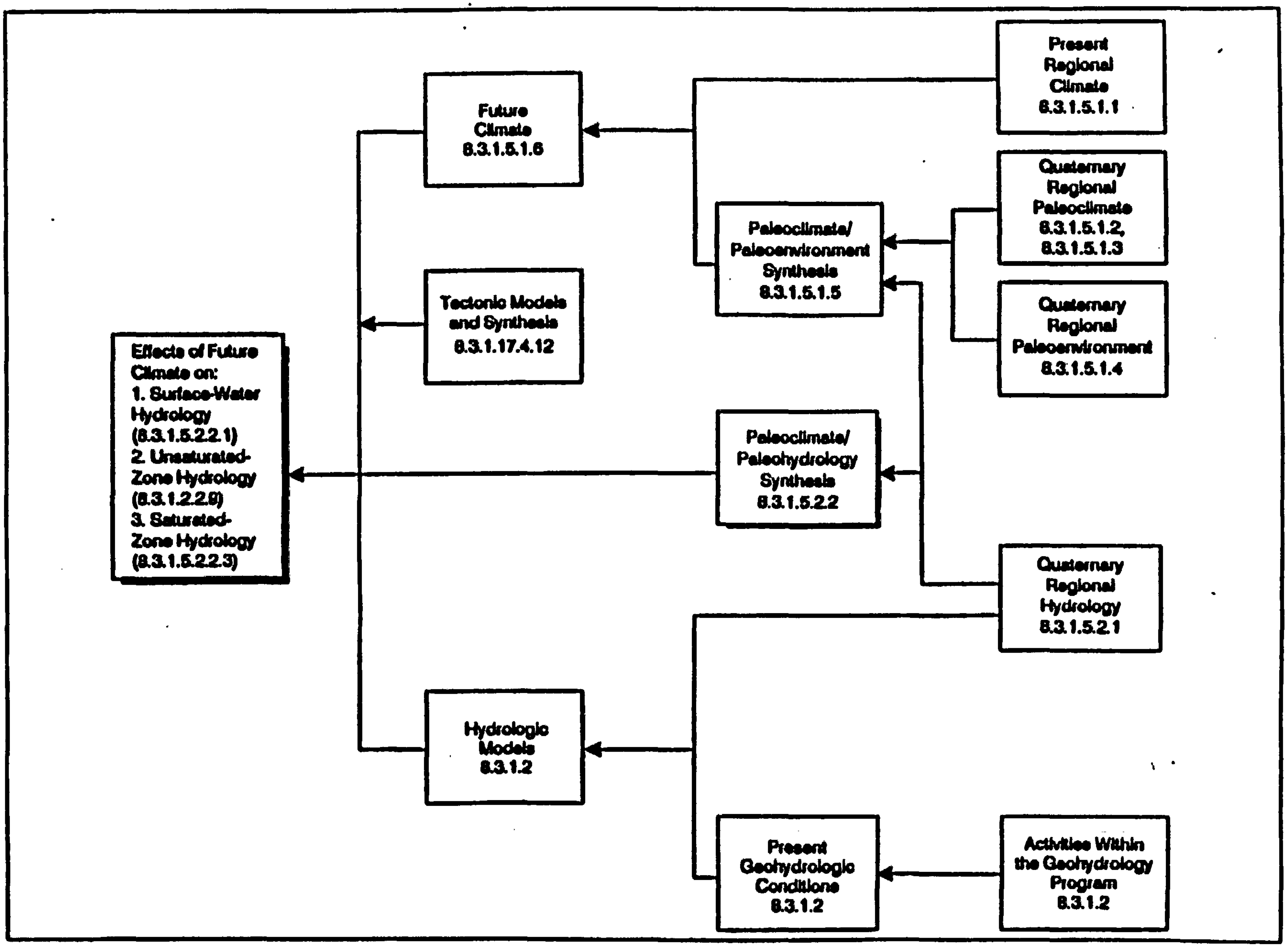

Figure 1.2-1. Logic diagram showing the present study as the culmination of the climate program.

modeling (under conditions of greater-than-present effective precipitation) of Study 8.3.1.2.2.9 (described in YMP-USGS SP 8.3.1.2.2.9, Site unsaturated-zone modeling and synthesis), and the future saturated-zone modeling of Activity 8.3.1.5.2.2.3. It is through this process that the elements of repository performance and design issues relating to future climatic effects upon hydrology will be addressed.

The overall regulatory-technical relations between the SCP performance-assessment issues and the analyses generated in this study are presented in the testing strategy presented in SCP Section 8.3.1.5 and the issue-resolution strategies presented in SCP Sections 8.3.2 through 8.3.5. The description presented below provides a more specific identification of these relations as they apply to this study. A tabulation of parameter relations between performance and design parameters and the characterization parameters of this study is presented in Appendix 7.2 (Table 7.2-1).

The purpose of the following text is to clarify the path that site-characterization data will follow from its origin in this study to its use in the resolution of repository performance and design issues. In other study plans, it has been useful to group the measured parameters of the various activities (activity parameters) into a limited set of characterization parameters, more broadly defined parameters that encompass activity-parameter data collected in the field and laboratory, or generated by modeling. It should be noted that because the present study is the culminating study of the Climate Program, it generates only characterization parameters. By using characterization parameters, it becomes easier to demonstrate how the study relates to satisfying the information requirements of parameters in the performance issues. This demonstration is made in Table 7.2-1. This study generates the following set of characterization parameters:

Activity	Characterization Parameter
Activity 8.3.1.5.2.2.1 - Future surface-water hydrology	Future runoff and streamflow
Activity 8.3.1.5.2.2.3 - Future saturated-zone hydrology	Future saturated-zone hydrologic conditions

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

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

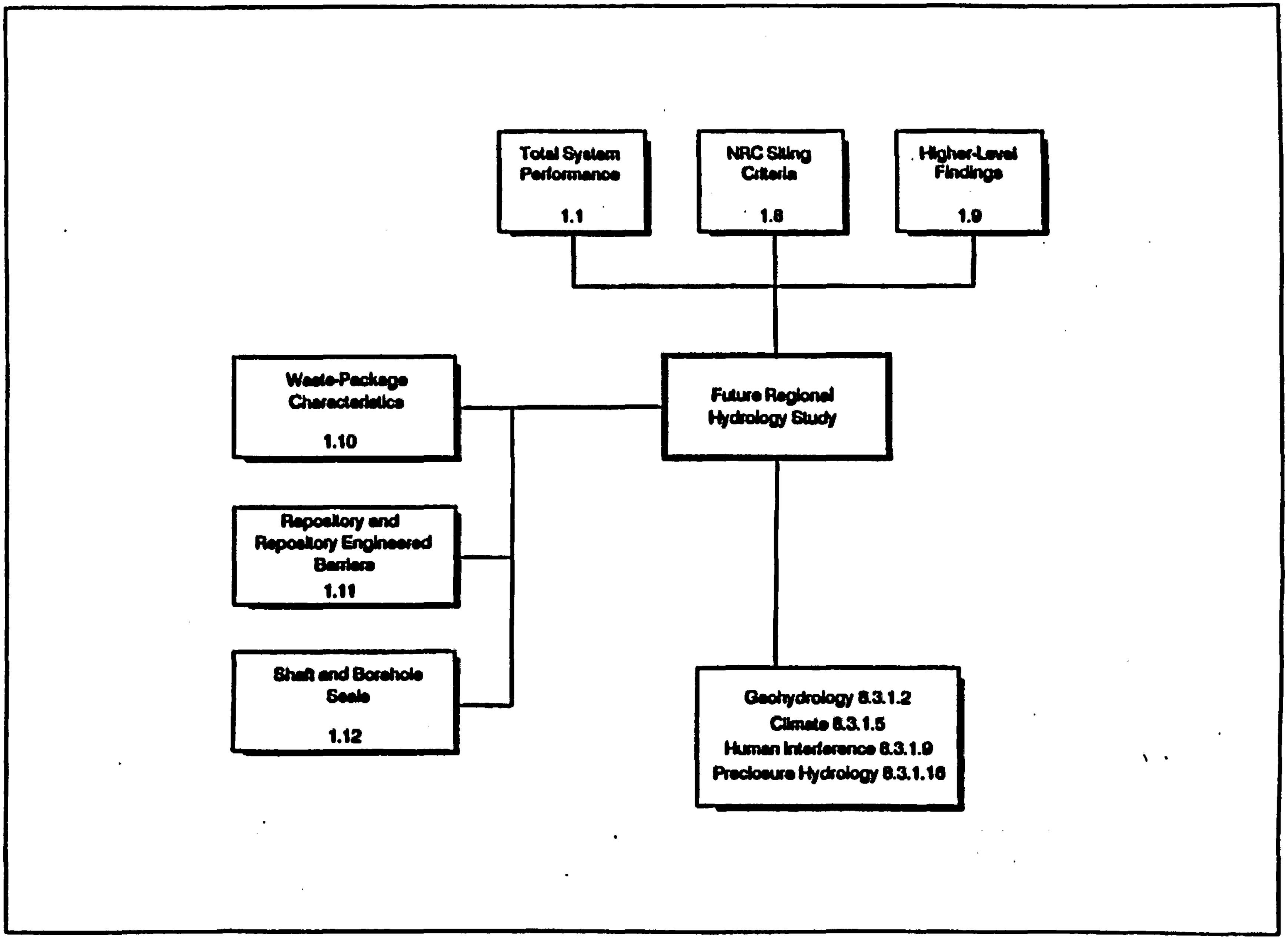

Figure 1.3-1. Diagram showing interfaces of the study with YMP performance and design issues and other s' -characterizations programs.

2 RATIONALE FOR STUDY

2.1 Technical rationale and justification

The technical rationale for the study is that climate changes impact surface, unsaturated-zone, and saturated zone hydrology and these impacts may affect the performance of the repository.

If it is shown that percolation would increase through the repository block in response to a wetter-than-present episode of future climate, it is possible that radionuclide-transport time from the repository to the accessible environment could be shortened. The potential for radionuclide release would be enhanced if the waste canisters were submerged by a water table rising through the 165-m (540-ft) interval between the proposed repository and the existing water table. A more humid climate will increase the fracture flow in the unsaturated zone, but will not flood the repository; however, increased fracture flow coupled with a raised water table may decrease ground-water travel time.

The water-table elevation beneath the repository horizon reflects an interaction of many factors, among which are (1) the local recharge rate; (2) the lateral flux in the saturated zone resulting from recharge in upgradient areas; (3) vestiges from prior climatic regimes that persist because of storage effects; (4) distance to, and elevation of, regional discharge boundaries; and especially (5) the distribution of hydraulic conductivities and geologic structures in the saturated zone. The modeling of future hydrologic response to possible climate changes will allow a prediction of water-table elevation changes due to changes in input values of any one (or more) variable(s).

2.1.1 Role of study in the Climate Program

The location of the future climatic effects on hydrology study within the SCP Climate Program is shown in Figure 1.1-1. Activities planned for the study include: (1) an analysis of future surface hydrology as a result of climatic changes, and (2) evaluation of possible future changes in climate and regional geologic framework on regional saturated-zone hydrology. (The analysis of future unsaturated-zone hydrology due to climatic changes will be performed as part of Study 8.3.1.2.2.9, Site unsaturated-zone modeling and synthesis.)

For analysis of future surface hydrology as a result of climatic changes, the rationale for employing a combined conceptual and numerical approach is that the response of a watershed to changes in climate is complex and climatic change is not always directly reflected by changes in watershed response. The complexity of the response of the surface-water regime to climatic change precludes the use of analytical solutions for the problem. Numerical simulation is thus the most efficient and dependable method for evaluating possible conditions in the future surface-water regime.

2.1.2 General modeling approach

Previously gathered data, published data, and site-characterization data gathered concurrently with modeling studies will be used in evaluating the response of the Yucca Mountain hydrology to possible future climatic changes. Data are limited throughout the study area, and, therefore, an assessment of uncertainty will be made through standard methods such as sensitivity analyses.

For the purposes of this study plan, the definitions of computer software verification and model validation are those given in the U.S. DOE OCRWM Quality Assurance Manual (1990), Section 19.2.

The following are steps in the modeling process (adapted from Bear (1972); they are shown schematically in Figure 2.1-1.

1. Formulate a conceptual model (a set of working hypothesis) of the hydrologic system. The conceptual model must incorporate as many features and processes of the natural system as possible, and should incorporate all available data, observations, and interpretations of the data and observations. Any assumptions about the natural system should be a part of the conceptual model. In the analysis of future surface hydrology as a result of climatic changes, an example of a conceptual model to be tested by a numerical model could be the observation that the longer-term arid cycles may be out of phase with selected short-term precipitation events. In the analysis of future saturated-zone hydrology as a result of climatic changes, an example of a conceptual model could be that recharge reaching the water table through the unsaturated zone has only a negligible effect on water-table elevation.

2. Construct and calibrate a numerical model of the present-day hydrologic system, based on the conceptual model and attendant assumptions. The first procedure in model construction is the discretization of the study area. Model mesh design depends on the geohydrologic setting of the study area, the equations used to describe ground-water flow (based on the conceptual model), and the scale of the model. Model scale is dependent on the selected representative elementary volume (REV) or information provided by a statistical evaluation of the measured values from the aquifer systems under study. Time must be discretized for transient simulations. The second procedure is estimation of model variables throughout the mesh area, and incorporation of measured values directly into the model. Estimates are derived from data and observations or may be derived deterministically, stochastically, empirically, or qualitatively. The third procedure is calibration of the numerical model. This process consists of comparison of simulation results with observations and measured data. If the comparison is considered acceptable based on professional judgment, then the process is finished; if not, model values, boundary conditions, or the conceptual model may be modified and the simulation repeated. The simulation/modification process continues until acceptable agreement exists between the numerical model and the field observations or measurements. Final simulation results

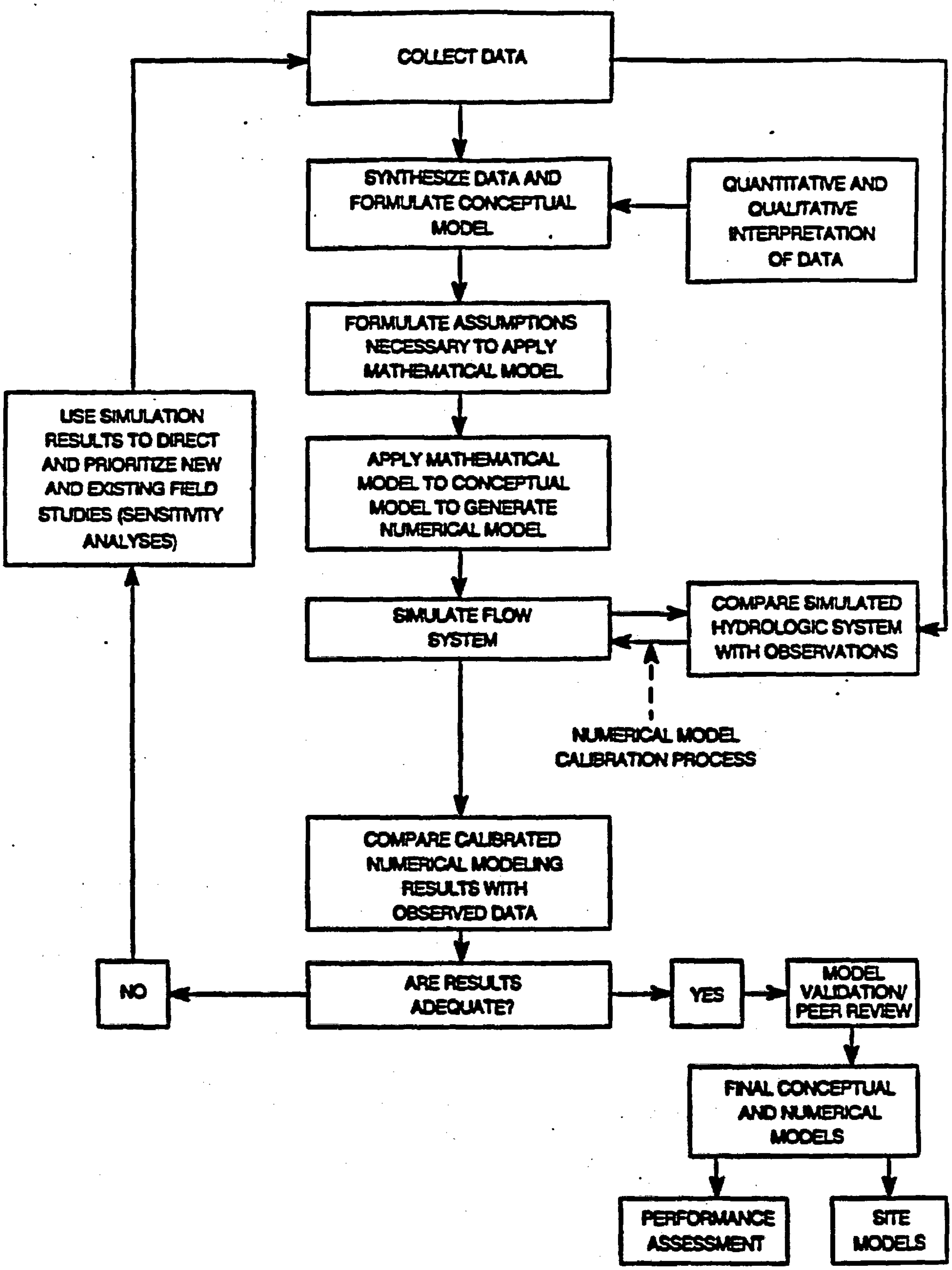

Figure 2.1-1. The conceptual-numerical modeling process.

are those of the calibrated numerical model. The model is judged, by the investigator, to be calibrated based, in part, on predetermined criteria, such as the minimum sum of squared residuals between calculated and observed hydraulic head. In the analysis of future saturated-zone hydrology due to climate changes, the model will be calibrated to inferred values of precipitation and water-table elevation for specific time intervals in the Quaternary.

In the analysis of future surface hydrology due to climatic changes, the numerical model must be calibrated to historical data for precipitation, temperature, and solar radiation. Optimization in this activity is the automatic (program-controlled) adjustment of a specified set of parameters to obtain better agreement between observed and predicted runoff. Selected parameters are adjusted within user-defined limits until the best agreement between observed and predicted runoff possible is obtained. Several different optimization techniques are currently available with the Precipitation-Runoff Modeling System (PRMS) (Leavesley and others, 1983, p. 46-57).

3. Compare final simulation results with observations and measured data. If the comparison is judged to be adequate by the investigator, the process is complete; otherwise collect more data and observations, and modify the conceptual model. Studies in which additional data and observations would be collected include Study 8.3.1.4.2.1 (Vertical and lateral distribution of stratigraphic units in the site area), 8.3.1.4.2.2 (Structural features within the site area), 8.3.1.4.2.3 (Three-dimensional geologic models), 8.3.1.4.3.2 (Three-dimensional rock-characteristics models), 8.3.1.2.1.3 (Regional ground-water flow system), 8.3.1.5.2.1 (Quaternary regional hydrology), 8.3.1.2.1.1 (Meteorology for regional hydrology), and 8.3.1.2.1.2 (Regional surface-water runoff and streamflow).

4. Validate model results to the extent possible. In the future surface-water activity, field validation will incorporate new test data that may become available during the development, testing, and calibration of the model. Measurable data, which will include streamflow, hydraulic head, infiltration, and discharge, will be used as they become available as checks against model results. In addition, peer review will be used to support model validation.

   In the analysis of future saturated-zone hydrology, a validation of the numerical model is planned. The model will be run forward in time from an interval in the Quaternary (to which it has been calibrated) to the present, and the position of the modeled water table will be compared against the present observed water table. The calibration will be made using Quaternary positions of the water table assembled in YMP-USGS SP 8.3.1.5.2.1 (Quaternary regional hydrology). The validation will be made against the present-day position of the water table as assembled in YMP-USGS SP 8.3.1.2.1.3 (Regional ground-water flow system), and YMP-USGS SP 8.3.1.2.3.3 (Site saturated-zone ground-water flow system). Validation of the modeled water table in response to possible future-climatic scenarios will not be possible.

Steps (1), (2) and (3) are repeated until an adequate representation of the hydrologic system is obtained. Modeling may give a better understanding of the natural hydrologic system and the features and factors that affect it.

Sensitivity analyses may also be done after the model calibration process is complete. The final sensitivity analyses will be used to identify parameters and areas where more data are needed to reduce uncertainty.

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

In the future surface-water activity, sensitivity analysis produces information that allows the user to determine the extent to which uncertainty in the parameters results in uncertainty in the predicted runoff, and to assess the magnitude of parameter errors and parameter intercorrelations when an optimization is performed. This information points out where the greatest returns might be for more detailed measurements or information.

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

Because of the regional and large-scale nature of the modeling effort, numerical modeling of the saturated zone in this study will assume that equivalent porous-media (EPM) concepts and Darcy's Law apply to the ground-water flow systems. (Other analytical concepts for ground-water flow will be applied if appropriate.) That is, the numerical models will be based on Darcy's Law and the various forms of the partial differential equation that describes transient ground-water flow (the diffusion equation; Freeze and Cherry, 1979). The diffusion equation can be used to approximate flow through fractured media if the smallest volume considered in a numerical model is larger than the representative elementary volume (REV). The REV must include a sufficient number of pores (or discontinuities such as fractures) to permit the meaningful statistical average to be calculated as required by the continuum approach (Freeze and Cherry, 1979 p. 70; Bear, 1972). The REV concept or approach is not as general, in application, as the statistical approach and suffers from several limitations (Dagan, 1986). Both approaches will be investigated for use in the simulation modeling of Yucca Mountain. Faults will be simulated in the model by linear or planar features of higher or lower permeability than the surrounding geologic units, depending on the results of other tests and studies (such as Study 8.3.1.2.3.1, Characterization of the site saturated-zone ground-water flow system).

Data synthesis will be an important component of this analysis. Scaling difficulties are expected in the synthesis process. Translation of data from the measured scale to the regional 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 measurements for each point, to construct a semivariogram for the parameter under consideration. A common problem is that these are not enough data to adequately describe the shape of the semivariogram. The only parameter for which these are enough data is hydraulic head. All other hydrologic parameters are characterized by sparse data. One way in which to address this difficulty is to incorporate qualitative information into the analysis. Such 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 qualitative information to create a synthetic semivariogram along with available data.

Another way to assess data needs to construct a meaningful semivariogram might be to numerically generate 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). Advantages of using GSIS are: the management and integration of data, including the incorporation of qualitative 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.

2.1.3 Parameters and analytical strategies

In SCP usage (U.S. Department of Energy, 1988) activity parameters are those parameters that are generated by field and laboratory testing activities; in the Climate Program they represent the most basic measurements that will be used to characterize the climate and climate/hydrologic relationships of Yucca Mountain and vicinity. Many of the activity parameters are building blocks to support various aspects of the project. Some support design and performance issues directly. Others primarily provide bases for analyses and evaluations to be conducted within the Climate Program or within other characterization programs.

In SCP Table 8.3.1.5-2, activity parameters for the Climate Program are listed according to parameter categories. In many studies, parameter categories serve to group similar types of activity parameters with corresponding design and performance parameters needed for issues resolution. However, the two activities of this study generate only 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. The hydrologic modeling activities of this study (for the surface-water and saturated-zone regimes) can be traced from their characterization parameters directly to the performance parameters listed in SCP Table 8.3.1.5-1. This relation is shown in Table 7.2-1.

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

The approaches to modeling analysis selected for the present study have been chosen to minimize uncertainty in parameter values and in the understanding of parameter interrelations, within the constraints of available resources. Where possible, multiple approaches within an activity are directed toward evaluating the value of a parameter by different means. The combined effect of using multiple approaches 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 evaluation of repository performance. 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.

2.1.4 Interactions with other studies

The following studies will contribute data necessary for the calibration of the precipitation-runoff model of Activity 8.3.1.5.2.2.1: Study 8.3.1.2.1.1 (Meteorology for regional hydrology), Study 8.3.1.2.1.2 (Regional runoff and streamflow), Study 8.3.1.2.2.1 (Unsaturated-zone infiltration), Study 8.3.1.16.1.1 (Flood potential and debris hazards), and Study 8.3.1.5.1.1 (Present regional climate). Study 8.3.1.5.1.6 (Future regional climate and environments) will provide a range of possible future climatic conditions that will be used as input for the precipitation-runoff model. The regional paleoflooding and analog-recharge activities of Study 8.3.1.5.2.1 (Quaternary regional hydrology), and the Fortymile Wash activity of Study 8.3.1.2.1.3 (Regional ground-water flow system) will have two applications for the present study. First, they will provide checks on the validity of precipitation-runoff model predictions. Second, these studies may employ the calibrated precipitation-runoff model developed in this study for independent analyses.

The present study will interact with several other studies to achieve the evaluation of future climate effects and changes in the regional geologic framework on saturated-zone hydrology in Activity 8.3.1.5.2.2.3. Study 8.3.1.5.2.1 (Quaternary regional hydrology) addresses how Quaternary hydrologic conditions have differed from present conditions because of climatic or geologic change. Study 8.3.1.5.1.6 (Future regional climate and environments) will contribute a set of expected future climatic scenarios whose effects will be modeled in the present study; scenario data will include estimated timing, probability of occurrence, and meteorological characteristics. Study 8.3.1.2.2.9 (Site unsaturated-zone synthesis and modeling) will generate a model describing flow paths, fluxes, and velocities within the unsaturated zone. In that study, the model will be run under conditions of higher-than-present effective precipitation, both to evaluate future climatic changes on the unsaturated zone, and to provide estimates of possible future vertical recharge reaching the water table through the unsaturated zone. Study 8.3.1.2.1.4 (Regional saturated-zone synthesis and modeling) will provide subregional and regional saturated-zone models that will be used to evaluate future climate and geologic effects. Study 8.3.1.2.3.3 (Site saturated-zone synthesis and modeling) will generate a site saturated-zone model that may play a role in assessing future climate effects specific to the repository site. Conceptual models for possible changes in the regional geologic framework will be contributed by Study 8.3.1.17.4.12 (Tectonic models and synthesis). The above studies are (or will be) treated in detail in their respective study plans.

2.2 Constraints on the study

2.2.1 Representativeness of repository scale and correlation to repository conditions

The calculation methods for calibrating the precipitation-runoff model will use meteorology and streamflow data collected from drainages at, and peripheral to, the Yucca Mountain site. Thus, the modeling will be undertaken at full scale using data representative of the site.

The calculation method for the regional saturated-zone flow model will use all of the applicable data and information collected by the YMP site-characterization program. The geologic and hydrologic information will be analyzed using a Geoscientific Information System (GSIS) to supply data sets for digital models at full-scale representation of the regional, subregional, and possibly the repository block areas.

2.2.2 Accuracy and precision of methods

The data used in this study will be collected by studies listed in Section 2.1.4 of this study plan. Discussions of the accuracy and precision of these data are contained in the appropriate study plans covering these studies. Sensitivity analyses will be used to evaluate these levels of accuracy and precision with respect to confidence levels assigned to conclusions resulting from the current study.

It is impossible to measure every hydrologic aspect of a watershed or ground-water flow system that affect surface- or ground-water models. Therefore, simplification of the hydrologic system will be necessary. This will involve assigning average conditions to large units being modeled, representation of complex processes by simple algorithms, and interpolation and extrapolation of data to broad areas.

2.2.3 Potential impacts of activities on the site

No field activity is required by this study, and there will therefore be no impacts on the Yucca Mountain site.

2.2.4 Time required versus time available

Section 5.1 describes a proposed schedule for the activities described in Section 3. Because the methods in the activity are mostly analytical, it is expected that they will be accomplished within the time scheduled for them. However, the data upon which the analyses of this study are based, notably runoff and streamflow data (Study 8.3.1.2.1.2, Regional runoff and streamflow), meteorological data (Study 8.3.1.2.1.1, Meteorology for regional hydrology), unsaturated-zone infiltration data (Study 8.3.1.2.2.1, Unsaturated-zone infiltration), paleohydrologic data (Study 8.3.1.5.2.1, Quaternary regional hydrology), recharge changes in response to climatic changes (Study 8.3.1.5.2.1), and changes in geologic framework (Study 8.3.1.17.4.12, Tectonic models and synthesis) require ample time for collection. The reliability of surface-water change due to climate change predictions and changes in recharge due to climatic changes are dependent upon the quantity and ranges of hydrologic and meteorologic data collected. For these reasons, it is anticipated that final modeling will not be conducted until several years of continuous data are collected, even though preliminary modeling is already underway for the future saturated zone activity.

2.2.5 Potential for interference among activities

The selected analyses of this study will have no interference with tests of other activities.

3 DESCRIPTION OF ACTIVITIES

The study contains two activities:

- 8.3.1.5.2.2.1 - Analysis of future surface-water hydrology due to climate changes
- 8.3.1.5.2.2.3 - Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated-zone hydrology

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

3.1 Analysis of future surface-water hydrology due to climate changes

3.1.1 Objectives

The objectives of this activity are: (1) to simulate past changes in runoff and surface-water storage (lakes) resulting from past climatic change, and (2) to predict the impact of future climatic conditions on surface-water hydrology at the Yucca Mountain site. The activity will use a computer modeling approach and information relating past, present, and future climatic conditions from Investigation 8.3.1.5.1 to "characterize the impacts of potential future climate changes on the regional and site surface-water system ..." (Site Characterization Plan [SCP], Volume V, Part B, p. 8.3.1.5-118, 1988). Of particular importance to this study is the relationship between paleoclimatic and paleo-surface-water conditions, as will be determined by Activity 8.3.1.5.1.5.1 (Paleoclimate-paleoenvironmental synthesis). These data, and data from other studies in Investigation 8.3.1.5.1, will ultimately be used to simulate past changes in runoff and surface-water storage and to establish potential relationships between future precipitation and runoff at the site.

3.1.2 Rationale

The analysis of future surface hydrology due to climate changes activity is designed to provide "a determination of future precipitation-runoff relationships to be used by the erosion program (8.3.1.6)" (SCP, Volume V, Part B, p. 8.3.1.5-16, 1988). As such, surface-water runoff models of past, present, and future hydrologic conditions in the Yucca Mountain area are needed. Modern surface-water runoff data generated by SCP meteorologic investigations (Study 8.3.1.2.1.1), the streamflow gaging and precipitation programs (Study 8.3.1.2.1.2), rainfall-runoff modeling at Fortymile Wash (Activity 8.3.1.2.1.3.3), and evapotranspiration studies (Activity 8.3.1.2.1.3.4) will be used to establish present hydrologic conditions. Data from investigations of Quaternary regional hydrology (Study 8.3.1.5.2.1) and regional paleoflooding (Activity 8.3.1.5.2.1.1) will, on the other hand, be used to simulate past hydrologic conditions. The information generated by past and present modeling activities will then be combined with data from the future climatic change program (Investigation 8.3.1.5.1) to determine the effects of climatic change on surface-runoff conditions at Yucca Mountain.

Because the nature and timing of future climatic change can not be precisely known, it will be necessary to develop a series of models to show the range of likely combinations of precipitation-runoff conditions that may occur due to future changes in climate; the latter to be established by Activity 8.3.1.5.1.5.1 (Paleoclimate-paleoenvironmental synthesis). The rationale adopted in this study therefore embraces a hydrologic modeling approach that can assess the surface hydrologic effects of all plausible future changes in precipitation, temperature, and (or) solar radiation. As set forth by the performance parameters of the climate program (Section 8.3.1.5), a number of hydrologic scenarios must be developed to assess the effects of all possible climatic events that may occur during the next 10,000 and 100,000 years.

3.1.3 Overview of study area

The hydrologic system at Yucca Mountain involves precipitation inputs from rain and snow, and evapotranspiration, infiltration, and surface-water runoff outputs. On average, precipitation in the area amounts to 92.2 to 153.0 mm/yr. However, only periodic stream flow occurs because moisture output due to evapotranspiration alone can be as high as 1,500 to 1,700 mm/yr (U.S. DOE, 1988, Table 5-4 and p. 3-8). The result of this moisture budget deficit is that streamflow occurs only in response to precipitation from strong summer thunderstorms or infrequent and prolonged winter storms. Under these conditions surface-water runoff in the form of overland sheetfloods and channelized streamflows is generated and flooding can occur.

Water that does reach one of the entrenched river channels (arroyos) in the area can flow for some distance downstream before being lost into the porous alluvial channel bed. Some streamflow events can be particularly extensive, especially when the rate of moisture input greatly exceeds output due to infiltration or evapotranspiration. For example, a flash flood will occur in response to a torrential downpour when the infiltration capacity of the unconsolidated materials of the channel bed and surrounding slopes is greatly exceeded. Similarly, flooding can also occur during less intense, but longer duration storms that frequently occur during the winter months. In this case the infiltration capacity of the landscape is more slowly exceeded before runoff occurs.

Climatic and landscape conditions are particularly important to surface-water runoff modeling efforts in an arid environment. Complex relationships exist between climatic and landscape factors. A number of parameters may become particularly significant because of variations in these factors. For modeling purposes, the following will therefore need to be considered: (1) the frequency and magnitude of the precipitation event that generates surface runoff, (2) the infiltration rate and capacity of the channel bed and surrounding slopes, (3) the amount of surface water lost to the unsaturated zone due to infiltration, and (4) the amount of surface water lost to the atmosphere as a result of evapotranspiration; the latter related both to climatic conditions and vegetation cover type.

In a perennial stream environment these parameters can be easily and accurately measured. For example, precipitation and streamflow gaging networks of perennial streams, many of which have been in place for some time, can be used to derive data needed to calibrate surface-water runoff models. For the arid, ephemeral system of Yucca Mountain, however, streamflow that occurs only during flood events can be much more difficult to measure. In addition, the present streamflow gaging network (Activity 8.3.1.2.1.2.1) has been in place for too short a time to adequately establish long-range hydrologic modeling parameters.

An additional problem is that the response of an arid watershed, or more generally its hydrologic environment, to changes in climate can be inordinately complex and indirect. Yair and Berkowicz (1989) found, for example, that in some circumstances aridity may be entirely out of phase with precipitation. They found that in areas of rocky soils (desert pavement) that soil moisture was considerably greater than in areas having greater amounts of precipitation but less surface (rock) cover.

3.1.4 General approach and methods

As a preliminary modeling effort for future surface-water runoff conditions at Yucca Mountain, an evaluation of potentially applicable models will be undertaken. During this phase of the investigation a number of computer models and modeling schemes will be evaluated in terms of their suitability for simulating precipitation-runoff relations in the arid region. As a result, prospective models will be chosen for testing using recorded hydrologic and atmospheric data from either Yucca Mountain or a comparable arid-lands ecosystem. The tests will involve production of a series of simulations that can be compared with known historic and prehistoric flood data. The model that performs best under this array of tests will then be chosen and calibrated (or modified) for use by this site-characterization activity at Yucca Mountain.

Figure 3.1-1 gives a summary of the objectives, characterization parameters, and steps required by this modeling investigation. A descriptive heading for each step of the activity appears in the shadowed boxes (second row). Below these are the individual methods that will be used. An outline of the overall structure of the activity, including the methods, estimates, and results, is also given.

The USGS investigators will select modeling approaches for this and related activities that they believe are suitable for providing accurate and reliable data within the expected ranges of the parameters. Alternative approaches may be used if the selected procedures presented here prove ineffective in terms of measuring the site characterization parameters of interest.

3.1.5 Potentially applicable models

At present a number of precipitation-runoff models are available and potentially applicable for use by this activity. Those models that are supported by the USGS Office of Surface Water and have adequate documentation are: (1) PRMS (Precipitation-Runoff Modeling System) (Leavesley and others, 1983), (2) HSPF (Hydrological Simulation Program) (Donigian and others, 1984; Johanson and others, 1984), and (3) DR3M (Distributed Routing Rainfall-Runoff Model) (Alley and Smith, 1982). All are distributed-parameter models which allow a watershed to be divided into "homogeneous" landscape units on the basis of such features as slope, aspect, elevation, vegetation type, soil type, and the distribution of precipitation. Thus, each watershed unit is homogeneous with respect to a set of dominant attributes. A watershed can additionally be further subdivided into flow planes and channel segments for routing storm flows. In this case, the flow planes are conceptual surfaces having a width equal to the length of the channel into which they flow, and a length equal to average hillslope length. Surface runoff can therefore be routed across the flow planes using a finite-difference approximation of the continuity equation, and the kinematic wave approximation to overland flow (Leavesley and others, 1983, p. 28), into conceptually uniform channel segments having a specific width, length, roughness, and slope. Channel-flow routing uses the same approach as that for overland-flow computations (Leavesley and others, 1983, p. 34-36).

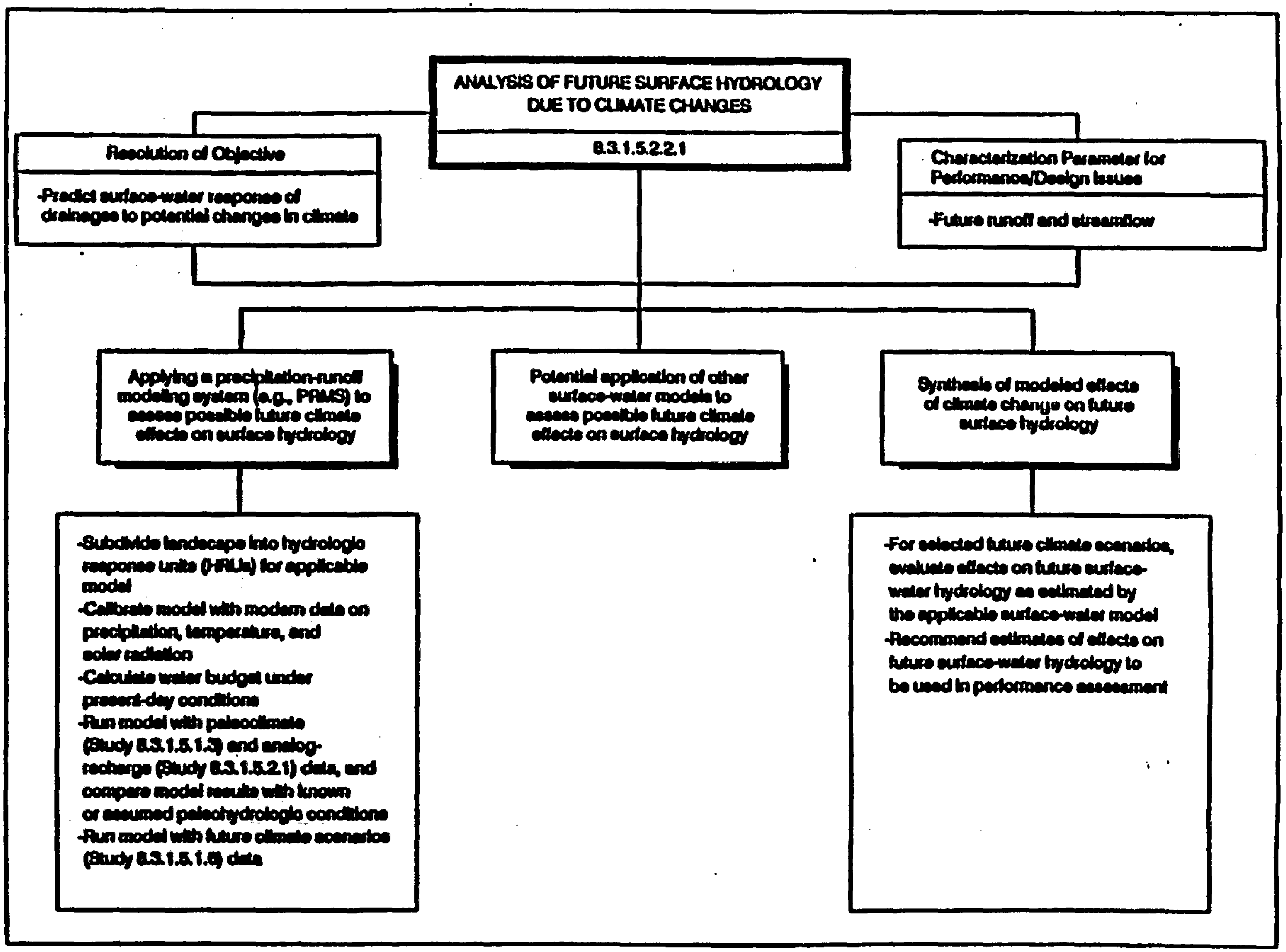

Figure 3.1-1 Logic diagram of future surface-water activity, showing analyses, methods, and characterization parameter.

The DR3M model operates only in storm mode and does not generate daily or low flow conditions. The HSPF and PRMS models are similar in many ways, although, the HSPF model has the advantage of being able to route sediment and dissolved constituents, and additionally uses channel-routing routines during low-flow periods. The PRMS model, on the other hand, uses channel routing only during storm periods. A problem with the HSPF model, as it is currently maintained by the USGS and the Environmental Protection Agency (EPA), is that it is difficult to modify.

A group of models, represented by TOPMODEL (Beven and others, 1984), uses the concept of variable contributing area, an approach also supported by the PRMS model when it is operated in daily mode. In this approach, streamflow is generated by excess soil moisture from a time-variable area of saturated soil in addition to rainfall in excess of infiltration capacity. The USGS, however, does not currently (January, 1992) support TOPMODEL.

Another class of watershed models uses flow planes of variable width to represent hillslopes. The best known of these models is IHDM (Institute of Hydrology Distributed Model) (Beven and others, 1987). Like TOPMODEL, IHDM also makes use of variable contributing area, but it has the added advantage of modeling converging surface and subsurface flow. In this approach, subsurface flow (i.e., flow through the soil layers) is modeled in a two-dimensional, vertical grid having variable width.

Grid models, such as SHE (Systeme Hydrologique Europeen) (Beven and others, 1980; Abbott and others, 1986a; 1986b), have the advantage of treating hillslope processes in finer detail than do flow-plane-oriented models. However, detailed information for soils, topography, and precipitation is commonly not available to warrant watershed modeling at such a large scale (e.g., 0.5- to 2.0-km grid spacing). While some areas in the vicinity of Yucca Mountain are planned for precipitation-data collection at a grid spacing of about 2 km, most of the Fortymile Wash drainage basin will be monitored by precipitation gages spaced at about 30 km.

3.1.5.1 Example of Precipitation-Runoff Modeling System (PRMS)

The PRMS model is a potential candidate for future surface-water runoff modeling activities because it has many desirable features and is now used and supported by the USGS. It is a modular-designed, deterministic, physical-process modeling system that was developed to evaluate the impacts of various combinations of precipitation, climate, and landuse on surface-water runoff, sediment yields, and general basin hydrology (Leavesley and others, 1983). PRMS is considered a distributed-parameter model in that it uses homogeneous response units to route overland streamflow through the watershed. Each component of the hydrologic cycle including precipitation, evapotranspiration, infiltration, and runoff is represented by one of several possible library subroutines (modules) that were designed to be as independent as possible from one another. The model's modular design provides two advantages. The first is that each module can be easily modified for a particular set of conditions. The second is that supplementary, area-specific modules can be added. The modular design of the PRMS model therefore enable adjustment for a specific set of conditions that might exist in the watershed.

3.1.5.1.1 PRMS operation

The PRMS model represents hydrologic processes deterministically. Each component of the hydrologic cycle is expressed in the form of known physical laws or empirical relationships that have some physical interpretation based on measurable watershed attributes. However, input data required for explicit modeling of hydrologic processes are commonly not available, or require complex computations. For this reason, there are several options for representing a process depending on the availability of input data and the importance of the process relative to the desired results. For example, if one were interested in a detailed accounting of soil moisture and had only daily temperature, humidity, and solar radiation input data, the Jensen and Haise (1963) procedure could be used to compute evapotranspiration. On the other hand, if one were concerned only with total-monthly runoff, pan evaporation data from a station in the region could be used (Leavesley and others, 1983, p. 21).

In operation the PRMS model involves relatively simple water-budget accounting of a complex hydrologic system. The watershed is partitioned (subdivided) into a number of homogeneous landscape units, known as hydrologic response units (HRUs). Surface water is then routed through the watershed by the model on the basis of HRU parameters. For each HRU, for example, precipitation input is interpolated based on the elevation of the HRU relative to the elevations of the nearest precipitation gages. The type of the precipitation input (rain or snow) is also simply determined from daily minimum and maximum air temperature and the month of the year. Other more complex computations are required, however, for solar radiation and precipitation interception. For example, solar radiation is adjusted using the mean slope and aspect of each HRU, while precipitation interception is adjusted by vegetation type and season. Some of the ways in which the PRMS model handles the required input parameters and computations are presented below.

3.1.5.1.2 Input parameters and computations

3.1.5.1.2.1 Soil moisture

Soil-moisture accounting is performed as the algebraic summation of all moisture accretions (rainfall and snowfall) to, and depletions (evapotranspiration, infiltration, and subsurface and ground-water reservoirs recharge) from, the active soil zone. Although the soil moisture algorithm may be a simplification of unsaturated-zone processes, it has been found to adequately predict surface-water response (Leavesley and others, 1983).

3.1.5.1.2.2 Evapotranspiration

Site-specific values of evapotranspiration may be available from Activity 8.3.1.5.2.1.4 (Analog recharge studies) or Activity 8.3.1.2.2.1.2 (Natural infiltration) for use by this surface-water runoff modeling investigation. In the event that these data are not available, or that they prove insufficient to cover the region of study, estimates of potential evapotranspiration can be made using one of two methods. The first estimates potential evapotranspiration based on monthly adjustments of daily pan-evaporation loss, daily mean air temperature, and possible hours of sunshine (Hammon, 1961). The second uses only daily mean air temperature and monthly solar radiation measurements (Jensen and Haise, 1963).

3.1.5.1.2.3 Infiltration

Infiltration computations vary depending on the time interval and the form of the precipitation input. For daily computations, infiltration is computed as the excess from surface runoff. For storm computations, infiltration is computed using the Green-Ampt equation (Green and Ampt, 1911). In this computation infiltration is determined according to the hydraulic conductivity of the soil, the effective value of the product of capillary drive and moisture deficit, and the antecedent infiltration of the area.

3.1.5.1.2.4 Surface runoff

Surface runoff computations can be made using daily or storm data. In the daily computation, snowmelt contributes to surface runoff only after the soil zone has reached its maximum water-holding capacity. Rainfall, on the other hand, is apportioned to surface runoff using a variable contributing-area concept, where the area contributing to surface runoff varies according to the antecedent moisture. No routing of surface runoff occurs in the daily computation mode. In storm mode, however, precipitation in excess of infiltration is routed over hillslopes as overland flow and through channel segments as streamflow.

3.1.5.1.2.5 Streamflow

Total surface-water discharge in an area is the sum of streamflow contributions from all HRUs and subsurface- and ground-water reservoirs. When a watershed is sufficiently large that daily streamflow is sensitive to transit times from upstream to downstream locations, lag times can be incorporated through the use of channel reservoirs. Since only average daily streamflow is considered, however, flood peaks (storm flows) are not defined. Instead, storm-flow routing is accomplished by considering the drainage network as a series of channel segments and junctions. For each channel segment, flow is routed using a finite-difference approximation of the continuity equation and the kinematic wave approximation relating discharge and cross-sectional area (Leavesley and others, 1983, p. 34-36).

3.1.5.1.2.6 Subsurface and ground-water flow

Subsurface flow, defined as the relatively rapid migration of water from a shallow or perched water zone to a stream channel, and ground-water flow are treated using the continuity of mass equation and user-defined storage routing coefficients. These coefficients are generally estimated, and subsequently refined, through the use of model optimization procedures. Data obtained from the relatively dense network of stream gages planned for Yucca Mountain (Study 8.3.1.2.1.2, Regional runoff and streamflow) can be used to define these parameters during the calibration phase of this modeling activity.

3.1.5.1.2.7 Streambed infiltration

Streambed infiltration is a key connection between the two activities of the present study. Water that percolates from the surface must pass through the unsaturated zone before recharge of the saturated zone can occur. Thus, since an important component of recharge is infiltration from streamflow losses to the porous alluvial channel bed, conceptual models of streambed infiltration are currently being developed by SCP Activity 8.3.1.2.1.3.3 (Fortymile Wash recharge). These data are particularly important to future surface-water runoff modeling activities in that hydrologic simulations will have to account for the volume percentage of water loss to streambed infiltration, which can be a potentially large value. Therefore, if the PRMS model is selected for this investigation, the streambed infiltration model, or models, developed by Activity 8.3.1.2.1.3.3 will be incorporated as a supplementary PRMS software module.

3.1.5.1.3 Data needed to calibrate the model

3.1.5.1.3.1 Hydrologic response units (HRUs)

HRUs for the watershed to be modeled are developed on the basis of slope, mean elevation, latitude, dominant vegetation type (e.g., bare, grasses, shrubs, trees, etc.), and dominant soil type (e.g., sand, loam, or clay). Much of the required data can be obtained directly from published maps including topographic, vegetation, soils, and geologic maps. In addition, a geographic information system (GIS) can be implemented to compile the requisite information from existing computer databases. For example, a digital elevation model, which consists of a regular grid of elevation values, could be used to retrieve and compute the average elevation, slope, and aspect of each HRU. Similarly, computer databases of vegetation and soil types, or other needed information, can be searched and retrieved to set up HRUs on the basis of a common collection of "homogeneous" landscape characteristics. Software for retrieving this watershed modeling information from existing computer databases is now under development by Jenson and Domingue (1988) and Leavesley and Stannard (1990).

3.1.5.1.3.2 Overland flow planes

To route surface-water runoff over overland flow planes, the roughness of the flow planes will need to be calculated. Data for these calculations should be available from SCP Activity 8.3.1.2.2.1.3 (Evaluation of artificial infiltration) in YMP-USGS SP 8.3.1.2.2.1 (Unsaturated-zone infiltration), otherwise some assumptions will have to be made. The slope of overland flow planes, on the other hand, can be directly measured from topographic maps, or from a digital elevation model using a GIS approach similar to that used to retrieve other HRU information.

3.1.5.1.3.3 Stream channels

To route surface-water runoff through stream channels, the roughness of the channel bed, as well as other physical parameters of the channels' bed-material, will need to be established. These data should be available from Study 8.3.1.2.1.2 (Regional surface-water runoff and streamflow), otherwise some assumptions will have to be made. The slope, width, and shape of the stream channels, on the other hand, can be directly measured from topographic maps, measured in the field (Study 8.3.1.2.1.2), or derived from a digital elevation model using a GIS approach similar to that used to retrieve other HRU information.

3.1.5.1.3.4 Climatic data

Three climatic parameters related to past and present surface-water runoff conditions at Yucca Mountain will be needed during the calibration phase of this investigation. They are: (1) precipitation, (2) temperature, and (3) solar radiation. These data will be used to test the simulation potential of the model and establish calibration standards and modeling coefficients. In addition, these data may be useful for modifying existing software modules, or adding new, site-specific modules to the modeling program.

Of the three data sets, precipitation is of greatest importance because it is most directly related to surface-water runoff. Daily minimum and maximum air temperature values, variations in temperature with elevation, and observed solar radiation are also needed, however, to compute temperature-dependent lapse rates for snowmelt, to derive evapotranspiration values, and to make climatic adjustments for the HRUs of the watershed.

Present, site-specific climatic information will be collected by Study 8.3.1.2.1.1 (Characterization of the meteorology for regional hydrology) "to provide input into the rainfall-runoff model development effort," (SCP, Volume IV, Part B, p. 8.3.1.2-97, 1988). Precipitation data, for example, will be collected in increments of 1 mm on an event basis using tipping-bucket and accumulated-by-storage gages. The modeling effort will use these data in a reduced format as total precipitation per unit time (e.g., 5, 10, or 15 minutes) depending on the application and the character of the storm, and as total daily precipitation. Ultimately, precipitation values will be interpolated for each HRU by adjusting the measured precipitation values at nearby gages by a correction factor that accounts for the influences of elevation, spatial variation in topography, and gage-catch efficiency. Correction coefficients needed by the model can then be established for daily- and storm-precipitation amounts. Similar interpolation and adjustment procedures will also be used to establish temperature and solar radiation parameters for each HRU in the watershed.

Past climatic data will be collected or estimated by Activity 8.3.1.5.1.5.1 (Paleoclimate-paleoenvironmental synthesis). The logic here is that known (or estimated) climatic parameters - that is, those that generated past surface-water runoff events - can be used as inputs to the model. Subsequent hydrologic simulations can then be run and the results compared with known surface-water runoff events of the past. The diversity of climatic change that occurred during the late Quaternary should be adequate to account for the full range of climatic variations that may occur in the future.

Together, these past and present climatic data will afford essential modeling parameters for this activity. A model's performance can then be evaluated, calibrations can be made, and new or modified modeling algorithms (modules) can be developed to improve the model's effectiveness for simulating future surface-water runoff events under changing climatic conditions at Yucca Mountain.

3.1.6 Data needed to assess the effects of climatic change

To predict the hydrologic effects of future climatic change, data from several SCP climatic, paleoclimatic, and hydrologic activities will be used. Data appropriate for future surface-water modeling efforts at Yucca Mountain will be gathered, analyzed, and subsequently used to simulate future surface-water runoff relationships. These data should be available from: (1) global and regional climate modeling activities of SCP Study 8.3.1.5.1.6 (Characterization of the future regional climate and environments), (2) estimates of the conditions responsible for paleoecological assemblages from SCP Study 8.3.1.5.1.3 (Climatic implications of terrestrial paleoecology), (3) actual conditions at analog-recharge sites from SCP Activity 8.3.1.5.2.1.4 (Analog-recharge studies), (4) paleohydrologic investigations of the region from SCP Study 8.3.1.5.2.1 (Quaternary regional hydrology), and (5) experimental modeling attempts to simulate estimated paleohydrologic conditions using paleo-streamflow and paleoflood data from SCP Activity 8.3.1.5.2.1.1 (Regional paleoflood evaluation). In the event that these data prove inadequate for modeling purposes, data sets from other sources may also need to be used. One example is the more than 20 years of precipitation data for the Basin and Range Province that has been collected by researchers at the University of Nevada, Reno (Mackay School of Mines), and the Desert Research Institute.

Ideally, a data set of known meteorological and hydrologic conditions should be used to run, test, and calibrate the model prior to actual future runoff simulations. Simulated precipitation variances should consider changes in the seasonality, intensity, and type of precipitation (rain or snow), as well as the magnitude and frequency of catastrophic storms and the consequences of sustained drought. The model should also address daily and seasonal temperature variations, mean annual temperature change, and the effects of changes in solar radiation. Paleohydrologic modeling should similarly be conducted using known or estimated data which foremost represent past meteorologic and hydrologic conditions at Yucca Mountain.

As a consequence of these activities, the overall effect of future climatic change on surface-water runoff conditions in the Yucca Mountain area can be established. Although topographic and (or) geologic change is difficult to account for, additional hydrologic scenarios may be needed to model such change. Possible future topographic and tectonic scenarios may be contributed from Activity 8.3.1.5.2.2.3 (Future saturated-zone hydrology), Study 8.3.1.17.4.9 (Tectonic geomorphology of the Yucca Mountain region), and Study 8.3.1.17.4.12 (Tectonic models and synthesis). Similarly, future climatic variations that may induce floral assemblage changes in the watershed would also need to be accounted for by the model, since such changes may ultimately affect the area's water budget due to differences in the evapotranspiration rates of the plant species involved.

3.1.7 Possible problems

3.1.7.1 Modeling surface-water runoff in an arid area

Although PRMS and other runoff models supported by the USGS (e.g., HSPF and DR3M) are potential candidates for modeling the effects of future climatic change on surface-water runoff conditions at Yucca Mountain, these models have not been thoroughly tested for accuracy, efficiency, or effectiveness in an arid hydrologic environment. Three potential problems are: (1) the models were developed principally for perennial stream systems where daily runoff occurs and is measurable, conditions that do not exist at Yucca Mountain; (2) the models consider snowpack a vital precipitation input parameter, while in the Yucca Mountain area streamflow occurs primarily due to infrequent, high magnitude rain storms; and (3) the models either do not account for or only partially account for stream losses due to channel bed infiltration, a condition that can adversely alter streamflow in the arid hydrologic system.

In the arid Yucca Mountain area, channel bed infiltration can substantially reduce streamflow during storm-generated runoff events. Measurements or estimates of infiltration along various segments of the channel in question will therefore have to be considered by the model to account for the loss. Another problem is that flash floods, which can cause an ephemeral stream such as Fortymile Wash to go from a totally desiccated state to one of bank-full flooding, are not directly accounted for by the models. It may be possible, however, to overcome this problem by operating the model in storm mode, a feature that is provided by PRMS.

The model used in this activity, whether PRMS or some other more appropriate model, will undoubtedly need to be modified to effectively simulate runoff due to future climatic change in the arid region of Yucca Mountain. Modification of the module (or modules) that account for storm-generated runoff, for example, could be made to account for infiltration losses using recorded infiltration data from the Fortymile Wash recharge study (Activity 8.3.1.2.1.3.3). Estimates can then be made of the infiltration capacity of all other ephemeral stream channels in the watershed on the basis of these parameters. Similarly, snow-pack measurements, which will be collected as part of site-characterization Studies 8.3.1.2.1.1 and 8.3.1.2.1.2, can be used as supplemental input parameters to more accurately model runoff conditions. In addition, the model can be modified and/or calibrated to consider these, or other site-specific conditions, that may improve simulations of future runoff conditions of the Yucca Mountain area watershed.

3.1.7.2 Effects of geomorphic change

Variations in the surface-water hydrology of the region due to future climatic change can alter the morphology of stream channels. These alterations can, in turn, produce further changes in the surface-water hydrology of the watershed. As a result, a feedback mechanism of hydrologic imbalance can occur.

Geomorphic events, or more importantly, man-made changes, can have far-reaching and oftentimes detrimental consequences on the hydrologic regime of a watershed. An increase in the delivery rate of sediment from headwater hillslopes or point sources such as a landslide, for example, can engulf major stream channels and divert normal flow (Bryan, 1928). Similarly, a debris flow can alter the roughness, width, and sinuosity of a stream channel (Janda and Meyer, 1986; Meyer and Martinson, 1989), while a change in the frequency of high-magnitude streamflows can cause unusually intense erosion (Hereford, 1984). In Las Vegas Valley, for instance, the results of a man-induced increase in stream discharge were found to have had profound consequences. The prolonged perennial discharge of municipal waste water into Las Vegas Wash, a previously ephemeral stream, caused unusually rapid incision and enlargement of the wash. The results of these man-made changes to the watershed were: (1) the stream entrenched itself deep enough to intersect and contaminate the local ground-water table, (2) erosion produced a deep, narrow channel having very different hydraulic characteristics and far-reaching consequences for its tributary streams, and (3) stream erosion along the wash has removed about 3,000,000 m^3 of alluvium (Glancy and Whitney, 1989). Thus, while man-made hydrologic changes such as these to the Yucca Mountain watershed would need to be accounted for when developing hydrologic scenarios of the future, such changes would be difficult to anticipate without some prior knowledge of the change.

3.1.7.3 Effects of catastrophic events

Several non-climatic, catastrophic events can have significant short- or long-term effect on the surface-water hydrology of the region. These include volcanic tephra deposition, fire, and overgrazing. The effects of these events, however, can be assessed by varying the infiltration and roughness characteristics of hillslopes and channels to appropriate values for the model.

3.1.8 Synthesis of products and considerations related to future surface-water modeling

The surface-water model employed for this activity will, for each run, yield predicted hydrographs of recharge to ground water from hillslopes, surface-water discharge, and stream discharge. Surface-water discharge can be computed from each flow plane in storm mode, and from each HRU for daily mode. Stream discharge, on the other hand, can be established from each channel in storm mode, and from the entire drainage basin in daily mode. These individual predictions, however, would provide only a partial description of surface-water conditions. Thus, a complete numerical description of possible future surface-water conditions will need to be developed to show the seasonality and frequency of flow events, as well as the shape and magnitude of the hydrograph. These statistical values will be dependent on (1) the seasonality and frequency of the associated input conditions, that is the frequency of precipitation events and temperature conditions, and (2) adjustments that occur during the transformation from precipitation to runoff and streamflow.

A synthesis of future surface-water hydrology would consist of predictions of the frequency, seasonality, and magnitude of runoff and streamflow for each of a range of selected climatic (precipitation, temperature, and solar radiation) input conditions. For selected climatic parameters, the response of the hydrologic system to predicted catastrophic events would also be analyzed, as would the geomorphic response of the system to changes in climate and catastrophic events.

3.1.9 Quality-assurance requirements

Quality assurance requirements that apply to this activity include the following: (1) documentation and control of the quality of software used for modeling, subject to the requirements set forth in YMP-USGS QMP-3.03 (Software quality assurance), and (2) technical review, as set forth in YMP-USGS-QMP-3.04 (Technical review, approval, and distribution of YMP-USGS publications). Technical procedures are in place for data that are collected under other studies for which quality assurance requirements have been set. There are no specific technical procedures that apply to this activity.

3.2 Analysis of future unsaturated-zone hydrology due to climate changes

The modeling of the future unsaturated-zone hydrology due to climate changes is described in Section 3.5 (Site unsaturated-zone integration and synthesis) of YMP-USGS SP 8.3.1.2.2.9 (Site unsaturated-zone modeling and synthesis). Activity 8.3.1.5.2.2.2 has been omitted from the present study plan for this reason.

3.3 Evaluation of possible future changes of the climate and regional geologic framework on the regional saturated-zone hydrology

3.3.1 Objectives

The objectives of this activity are to:

1) Reconstruct paleohydrologic conditions in the Yucca Mountain and surrounding area and use these conditions, together with the paleoclimatic conditions reconstructed under Investigation 8.3.1.5.1, as a basis to predict the impact of future climatic and tectonic conditions on the saturated-zone hydrologic system.

2) Synthesize the existing paleohydrologic data through the use of numerical simulation techniques to determine the effects that lesser or greater recharge would have on water levels, ground-water flow paths, and hydraulic gradients in the Yucca Mountain region.

3) Evaluate possible regional tectonic and thermal events that may produce prolonged or transient effects on the regional water level.

3.3.2 Rationale for activity selection

Meeting the activity objective will require the investigators to complete the following steps: 1) assembling and evaluating present-day and paleohydrologic data using Geoscientific Information Systems (GSIS) and geohydrologic models, and 2) quantifying the response of the Yucca Mountain region saturated zone to expected future-climate scenarios coupled with possible changes in the geologic framework. The success of the first step will depend upon the experience and scientific judgement of the investigators in analyzing data from many sources within the site-characterization program. The second will depend upon the above factors coupled with the application of numerical hydrologic modeling techniques. These steps comprise the culmination of the Climate Program insofar as it is directed toward saturated-zone hydrology, and for this reason the above work has been designated as a separate activity.

3.3.3 General approach and summary of analyses

The approach emphasized in this activity is a synthesis that will draw upon data and interpretations of data from several other site-characterization studies (see Section 2.1.4) in order to evaluate probable responses of the Yucca Mountain saturated-zone hydrologic system to: 1) changes in recharge and discharge that may result from possible future climatic scenarios; and 2) changes in the regional geologic framework that could result from possible changes in the regional tectonic and thermal regimes that may result in prolonged effects on water levels.

The mechanism that will be central to the synthesis will be either the subregional saturated-zone model or the regional three-dimensional saturated-zone model to be developed under the scope of Study

8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling). The conceptualization and development of this model, and its calibration to the present-day hydrologic system, will be a cooperative effort among geohydrologists of both the Paleohydrology Group and the Saturated-Zone Section of the USGS Hydrologic Investigations Program (HIP). The investigators will employ a Geoscientific Information System (GSIS) for data management in the present activity for the process of paleoclimate/paleohydrology synthesis and for the use of the model in assessing the hydrologic effects of possible changes in future climate and in the regional tectonic and thermal regimes.

Although the primary approach to evaluating the future hydrology of the Yucca Mountain saturated zone will be three-dimensional modeling on a regional scale, the investigators will leave open the use of supplemental modeling approaches for future conditions. These supplemental approaches might include a scaled-down subregional three-dimensional approach, and subregional two-dimensional cross-sectional and(or) areal approaches.

Numerical models developed under Study 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling) have the potential to be applied to examine the response of the saturated-zone ground-water flow system of Yucca Mountain and vicinity to potential changes in boundary conditions resulting from climatic or geologic change. Several different models of the saturated zone will be developed (or modified from existing models) under Study 8.3.1.2.1.4: (1) an areal subregional two-dimensional finite-element model with the capability of being converted directly into a fully three-dimensional model; (2) one or more cross-sectional finite-element or finite-difference models; and (3) a regional three-dimensional finite-difference, finite-element, or boundary-element model. The site saturated-zone model of Study 8.3.1.2.3.3 (Synthesis and modeling of the site saturated-zone hydrologic system) may be employed, using input from the regional saturated-zone model, to evaluate possible future climate effects on the saturated zone specific to the repository site.

Specific issues to be addressed by the modeling effort will include:

1) the importance of recharge along Fortymile Wash; and

2) changes in the gradients between areas of contrasting permeability.

The future saturated-zone activity will have as one of its tasks the completion of the paleoclimate/paleohydrology synthesis. The synthesis will address the reconstruction of the response of the saturated-zone hydrologic regime to the time series of Quaternary climatic changes (as provided by Investigation 8.3.1.5.1, Nature and rates of changes in climatic conditions to predict future climates). Assessing the relationships between Quaternary paleoclimate and Quaternary paleohydrology, the paleoclimate/paleohydrology synthesis, is not an independent study or activity, but rather occurs within each of the paleohydrology activities of Investigation 8.3.1.5.2 (Potential effects of future climatic conditions on hydrologic characteristics). Examples of such relationships would be the magnitudes of paleoflooding events, unsaturated-zone storage and flux, and position of the water table associated with a Quaternary pluvial episode. Paleohydrology/ paleoclimate relations will be evaluated in the present study. One of the objectives of the hydrologic modeling of the saturated zone will be to assess the sensitivity of the flow regime to possible variations in the climatic parameters. Model output will include quantitative estimates of the changes in water levels, gradient, flux distribution, and velocity field of the Yucca Mountain saturated zone that could result from possible future climate scenarios.

The regional three-dimensional saturated-zone model will have undergone a calibration process as part of Study 8.3.1.2.1.4. Before the model is employed to evaluate the possible future hydrology of the regional saturated zone, it will also undergo a validation process against evidence resulting from the synthesis of Quaternary paleoclimatic and paleohydrologic data collected in Investigation 8.3.1.5.1 (Nature and rates of changes in climatic conditions) and Study 8.3.1.5.2.1 (Quaternary regional hydrology). An expected principal result of the paleoclimate/paleohydrology synthesis will be correlations between paleoclimate parameters, such as annual precipitation and air temperature, and the regional water level, determined by locations of past-discharge points, at particular intervals of Quaternary time. For time intervals and locations where sufficient confidence can be placed in these correlations, the model can be tested to see how well the past water levels can be reproduced. Disagreements will be evaluated with consideration of possible effects of geologic variables, such as tectonic events. Data on Quaternary water levels will be generated in Activity 8.3.1.5.2.1.3 (Past-discharge studies). Values of recharge to be used in the input process may be derived or estimated using several methods including, but not limited to, the following: 1) analog-recharge studies (in Study 8.3.1.5.2.1), 2) Fortymile Wash recharge studies (in Study 8.3.1.2.1.3), 3) modeling of Quaternary and future surface-water hydrology (Section 3.1 of the present study plan), and 4) the unsaturated-zone models developed under Study 8.3.1.2.2.8 (Fluid flow in unsaturated, fractured rock) and applied in Study 8.3.1.2.2.9 (Site unsaturated-zone modeling and synthesis). The model will then be run forward in time to see how well the present-day water level can be reproduced. The model will be used to evaluate the effects on the saturated-zone hydrologic regime of selected possible future climate scenarios generated in Study 8.3.1.5.1.6 (Future regional climate and environments). The model input for probable changes in the future regional geologic framework will be derived from interpretations of probable future tectonic settings to be undertaken in Study 8.3.1.17.4.12 (Tectonic models and synthesis).

Experience with the regional modeling process indicates that a likely sequence of model application will be to first apply the model and then look for validating evidence; a preliminary effort along this line is described in Czarnecki (1985; 1990) and also in Downey (1984; 1986). Possible next steps would be to incorporate refinements to the model, based on new data, or to the recharge mechanisms; and to test boundary and(or) initial conditions to evaluate alternate hypotheses. An example might be to cut off recharge from the throughflow thought to originate across Timber Mountain, and to eliminate throughflow across the Funeral Mountains toward Death Valley. If a calibrated model could be constructed under these conditions, similar analyses may be repeated to look at water-level rise and resultant discharge throughout the flow system during possible wetter climatic conditions in the future. Again, a much more variable than expected set of fluxes would be specified, which would provide *de facto* sensitivity analyses.

Additionally, results of studies to evaluate the position and timing of past water-table elevations beneath Yucca Mountain (Study 8.3.1.3.2.2, History of mineralogic and geochemical alteration of Yucca Mountain; Los Alamos National Laboratory), as well as in downgradient areas, particularly within the Amargosa Desert (past discharge activity in Study 8.3.1.5.2.1), will provide additional data for calibration and validation of a regional model.

Figure 3.3-1 summarizes the organization of the future saturated-zone activity. 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 employed during the analysis. Figure 3.3-1 also summarizes the objective of the activity and the characterization parameter addressed by the activity. These appear in the boxes of the top left side and top right side, respectively. The figure summarizes the overall structure of the planned acti·.ty in terms of methods to be employed, and the descriptions of the following sections are organized on the basis of this chart. Methodology and parameter information are tabulated as a means of summarizing the relations among (1) the characterization parameter to be evaluated, (2) the information needs of performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

3.3.3.1 Applying a regional three-dimensional saturated-zone model to assess possible future climate effects on the saturated zone

3.3.3.1.1 Previous work in modeling the regional saturated-zone hydrology

Detailed discussions of the regional ground-water flow system may be found in YMP-USGS SP 8.3.1.2.1.3 (Characterization of the regional ground-water flow system) and in papers by Winograd and Thordarson (1975), Waddell (1982), Rice (1984), and Downey and Sinton (written comm., 1992). Papers that are more specific to modeling of ground-water flow of Yucca Mountain and vicinity include Czarnecki and Waddell (1984), Czarnecki (1985), Downey and others (1990), and Kolm and Downey (written comm. (1992).

Extensive marsh deposits occur in the central Amargosa Desert, west of the Ash Meadows discharge area (Hoover, 1989). These sediments are generally coincident with locations of discharge under simulated wetter conditions, providing possible evidence that could be used in model validation against paleohydrologic conditions.

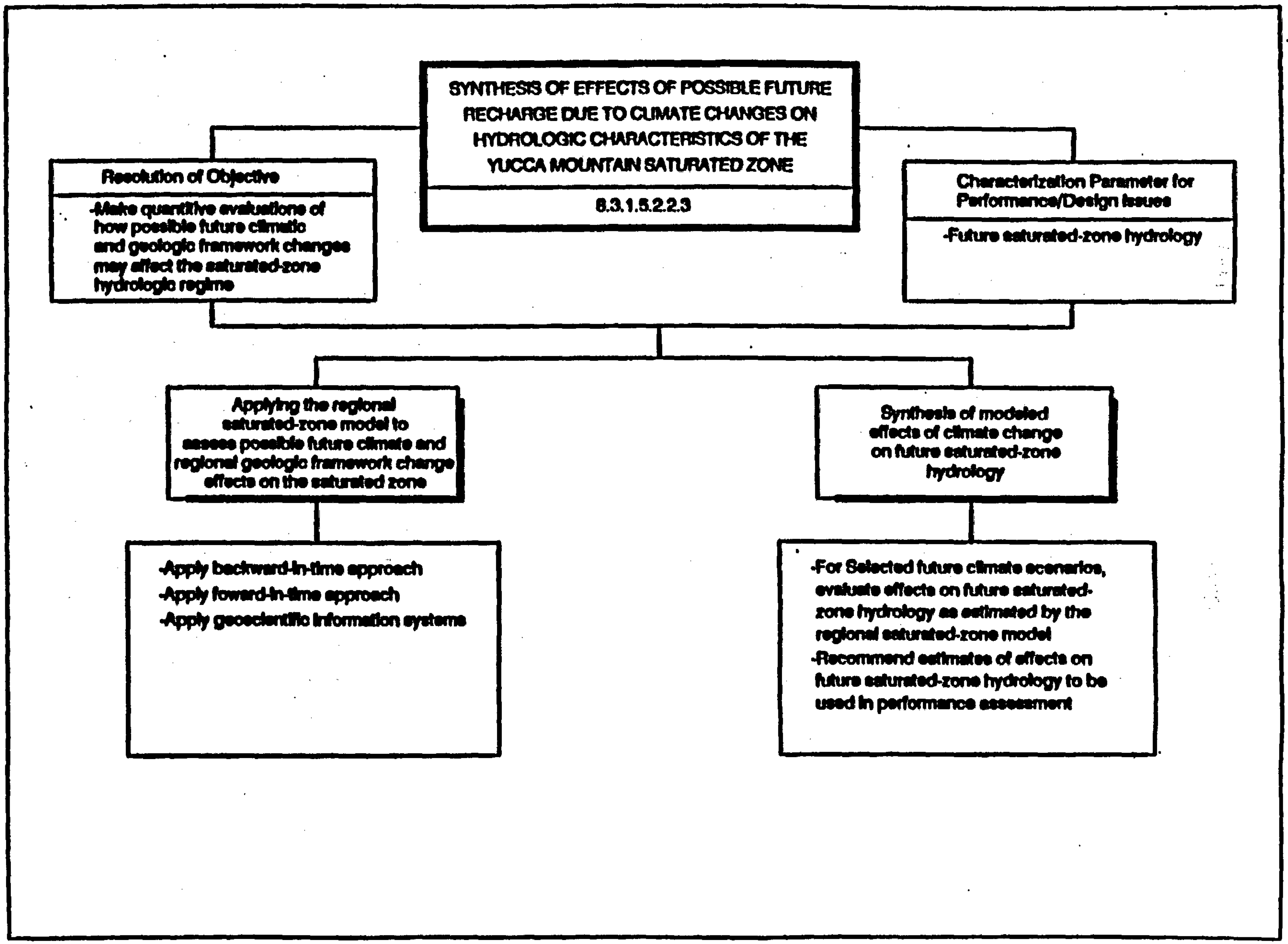

Figure 3.3-1. Logic diagram of future saturated-zone activity, showing analyses, methods, and characterization parameter.

3.3.3.1.2 Role of three-dimensional geoscientific information systems (GSISs) in applying the model

True three-dimensional GSIS can greatly assist hydrologic modeling in four ways: (1) by assisting data management and QA documentation, (2) through integration of diverse data sources and types, (3) in visualization of alternative conceptual models for rapid testing, and (4) in integration of numerical models with evolving data and model development (Turner, 1989; Turner and others, in press, 1992). Thus, the use of GSIS can support the simulation of effects of possible future climatic and geologic framework changes more efficaciously than other more traditional means of computer interaction and output.

GSIS differs from the better known GIS in that GIS reduces three-dimensional problems to two-dimensional representations through the use of surfaces. These surfaces, such as bedding planes, can then be contoured or displayed isometrically. However, in this representation, elevation of a surface is not an independent variable, and as such the quasi three-dimensional system can only accept a single elevation for a surface at a given point in x-y space. Accordingly, geologic structures such as folds or reverse faults that cause repetition of a single geologic horizon or hydrologic unit at a given location cannot be represented.

In contrast, the true three-dimensional systems can accept repeated occurrences of the same surface at any given location, and more importantly, they can accept variability within a given hydrologic unit as a function of both depth and lateral position. For models in which actual flow paths and consequent travel times may be critically dependent on such intraformational variability, the power of GSIS may be indispensable.

Hydrologic models that are currently in use are capable of calculating the flow regime of a given three-dimensional geologic setting, provided that a suitably accurate distribution of hydrologic properties is available. However, the geologic characterization of the model volume in three dimensions or the transient interaction with changing boundary conditions can be difficult to visualize and check. The present generation of hydrologic models has exceeded the ability of model users to supply the necessary input data by traditional methods. The use of GSIS systems with data and communication linkages between the system and ground-water models may help solve spatial visualization and data-management problems, by enhancing the efficiency of rock-characteristics data entry to the models and by making it easier to insure that the model is using the distribution of rock characteristics intended by the investigator.

3.3.3.1.3 General approach to applying the model for the regional saturated zone

The basis of the numerical modeling efforts will be the conceptual models of the Quaternary, present, and future hydrologic systems. These conceptual models will be developed in Study 8.3.1.2.1.4 on the basis of published data, such as that used by other authors to develop other conceptual and numerical models, and standard parameter evaluation techniques. Development of conceptual models will be coupled with periodic reviews of field evidence and may benefit from an additional search for data. In addition, stochastic hydrologic methods, as described by Hofmann (1965) will be investigated as possible sources of support of the deterministic models. Stochastic methods (Bates and Jackson, 1987) involve the statistical manipulation of hydrogeological variables to provide information about the probabilities of the occurrence of hydrologic events. A stochastic variable, in this context, is one whose value is determined by a probability function. An example of the application of stochastic methods, as cited by Hofmann (1965), is "the rearrangement of the time sequences of historic hydrologic events and the generation of representative non-historic sequences." This approach could possibly be applied to the evaluation of future regional saturated-zone hydrology.

To date, the works of Czarnecki (1985) and Downey and Sinton (written comm., 1992) have been the major effort in simulating the effects of possible increased recharge on the saturated zone in the region surrounding Yucca Mountain. This work is discussed in Section 3.3.3.1.1. The position of the water table in response to increased recharge was numerically modeled and probable discharge areas were identified. However, one of the major limitations in this work is the lack of a reliable method for estimating present-day and future recharge. The method used relied on the work of Rush (1970) which used an empirical method developed by Eakin and others (1951). The technique of Eakin and others (1951) was compared by Crosthwaite (1969) and Watson and others (1976) to other methods of estimating recharge. They concluded that the method was suitable for obtaining only a very approximate estimate of recharge. No method was considered to be fully reliable in predicting recharge, although the method of Eakin and others (1951) has been used extensively in basin studies in Nevada.

Additional work is needed to determine recharge mechanisms and rates, and to establish analytical expressions for relationships between precipitation rates and associated ground-water recharge rates. This need is in part treated in Study 8.3.1.2.2.1 (Unsaturated-zone infiltration) and in part by Activity 8.3.1.5.2.1.4 (Analog recharge studies). Recharge studies related to Fortymile Wash are contained within Study 8.3.1.2.1.3 (Regional ground-water flow system). Information from these studies will be critical to the final model used to evaluate future hydrologic responses to climate changes.

A three-dimensional, finite difference model was used by Downey and Sinton (written comm., 1992) to simulate the steady-state ground-water flow system in the Yucca Mountain area. This model was developed using the data sets and boundary conditions of Czarnecki and Waddell (1984). The model was utilized in the evaluation of three-dimensional ground water flow simulations versus the two-dimensional approach. The three-dimensional model included two aquifer layers, which represent an upper unit composed mainly of volcanic, alluvial, and marsh deposits while the lower unit is composed primarily of carbonate rocks of the regional aquifer system. Horizontal flow was simulated within the aquifer layers, and vertical flow simulated between the two aquifers. In general, ground water flows to the south and west from the recharge areas to discharge areas in the vicinity of Death Valley, California. Model simulations indicate that the spatial distribution of hydrologic units of lower permeability and the distribution or magnitude of recharge and discharge fluxes are the primary controls on the flow of ground water in the study area. Vertical variations in hydraulic head are the result of one or more of the following: discharge, recharge, and lower vertical permeability. Model simulations indicate that complex flow patterns may exist in the Yucca Mountain area and are the result of interactions between recharge and the transmissivity of the upper and lower aquifer layers. Discharge at Ash Meadows, Alkali Flat, and recharge along Fortymile Wash and Pahute Mesa are important to the understanding of the geohydrology of the Yucca Mountain area.

Two general modeling approaches, one backward-in-time and one forward-in-time, will be utilized to build upon past modeling efforts. Information from both will be used to estimate the effects of future climate and geologic framework change on the saturated-zone geohydrologic system in the Yucca Mountain, Nevada, region.

(1) "Backward-in-time" approach: This approach employs a model of present (1992) hydrologic conditions developed in Study 8.3.1.2.1.4 (Regional saturated-zone synthesis and modeling). Using numerical modeling techniques and GSISs, these conditions will be stressed to simulate paleohydrological conditions at various points in past time and will be compared to the hydrologic conditions near the end of the Pleistocene, about 23,000 years ago (Spaulding, 1985).

(2) "Forward-in-time" approach: This approach synthesizes paleohydrological conditions using numerical modeling techniques from a point in time about 23,000 years ago to the present day. The objective is to simulate present (1992) hydrologic conditions using paleohydrologic data; however, simulated paleohydrological conditions will be compared at points in time where hydrologic data are available.

Both approaches should produce validated geohydrologic models that may be used to simulate future hydrological conditions in the Yucca Mountain, Nevada, region and should converge on the same answer. Future hydrologic conditions will use climate predictions, possible tectonic changes, and projected water-use information. In model validation, features in the geologic record, such as past-discharge points (as determined in Study 8.3.1.5.2.1, Quaternary regional hydrology), that differ from predictions of the models, will have to be evaluated in the context of possible tectonic effects. It is predicted that a short-term warmer and drier period, followed by a long-term, colder and wetter period may occur in the Yucca Mountain region of southern Nevada during the next 7,000 to 10,000 yr (Spaulding, 1985). However, other scenarios will be used as input to the simulation models if data are available. The modeling efforts in both approaches will employ the three-dimensional numerical model codes used in Study 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling). The investigators realize that there is a considerable overlap between the forward-in-time and the backward-in-time approaches. This overlap provides a form of cross-checking between the two methods forcing the investigators to keep in mind the many interactions and relationships present in the geohydrologic system of southern Nevada. Both methods should provide the same answer at the same point in time; however, the two approaches are not designed to provide exact answers or calibration points because of data limitations of the field of paleohydrology. The two approaches are also data-limited and highly depended on other project functions, such as Study 8.3.1.5.2.1 (Quaternary regional hydrology), to provide sufficient data in a timely manner to accomplish the objectives of this project.

3.3.3.1.3.1 Backward-in-time approach

Starting with the present-day (1992) geohydrologic and climatic conditions, modeling will be "backward-in-time" using paleohydrologic and geologic data as verification points along the time line. The objective is to simulate hydrologic conditions at various points in time in the past to demonstrate that the numerical model can reproduce known paleohydrological conditions at these time points, thus providing a measure of model validation for the time period from present day to about 23,000 years ago. Figure 3.3-2 illustrates the modeling process for the backward-in-time and forward-in-time approaches.

In the backward-in-time approach, the meaning of "validation" is that the simulated potentiometric surface for a particular interval of time in the Quaternary would be judged to have an acceptable match, as defined by professional judgment, with the inferred or estimated potentiometric surface for that same interval of time, based on paleohydrologic evidence. Deviations will be examined for new information as to unrecognized climatic effects and effects of a changing tectonic and geologic framework.

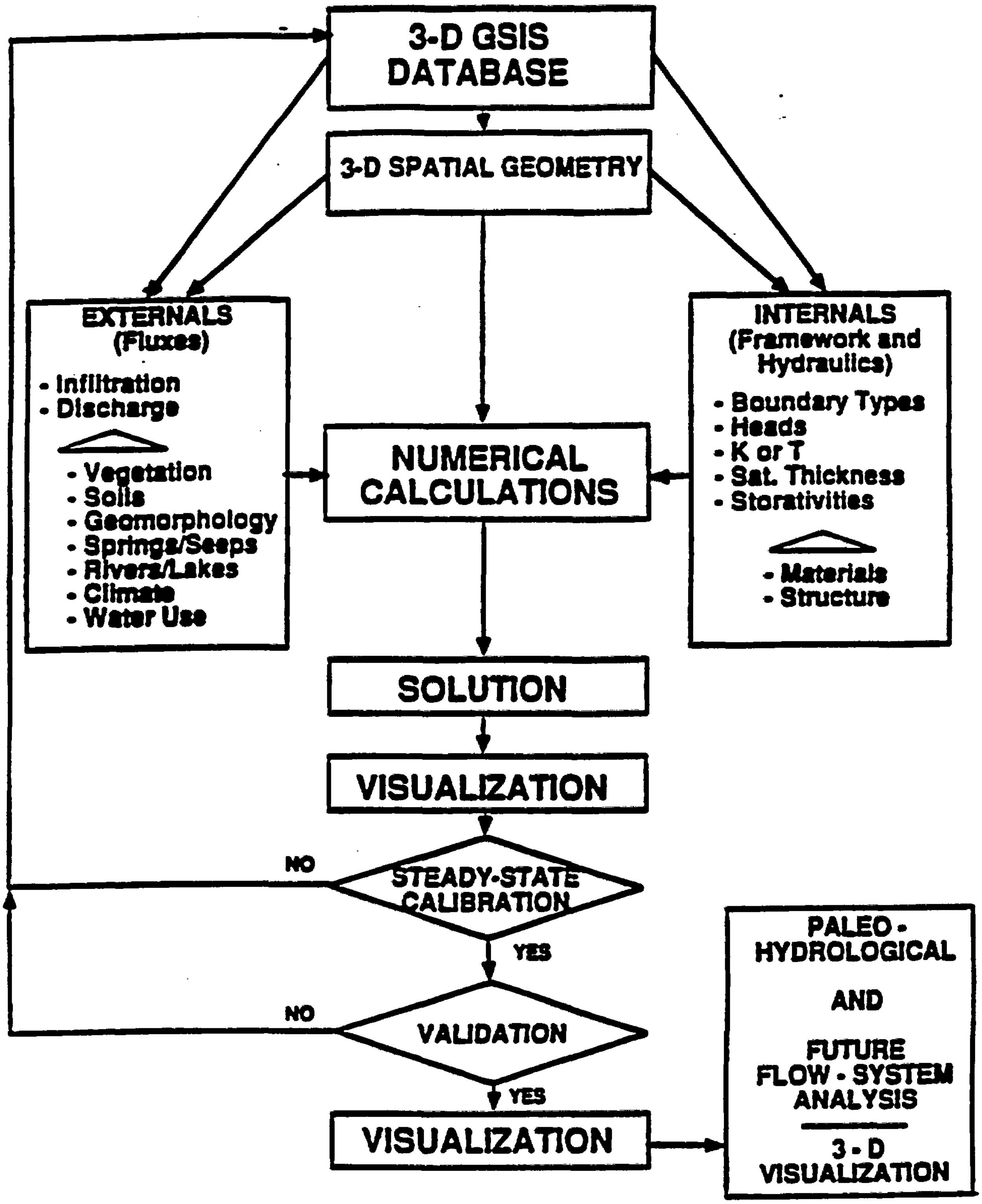

Figure 3.3-2. Logic diagram for modeling for the backward-in-time and foward-in-time approaches.

Data sets for the simulation model of modern-day hydrologic conditions will be derived from observations, measurements, and interpretations made during other portions of the subject. The model variables or parameters have been termed internals or externals as shown in Figure 3.3-2. The externals consist of geology, geomorphology, climate, vegetation types and distribution, and topography. The internals, or information dealing with the subsurface environment, consist of the hydraulic head, transmissivity or hydraulic conductivity, storativity, and boundary conditions.

The model will be stressed by making the climate wetter and colder, and by reconfiguring the geologic framework based on the geologic record. Figure 3.3-3 illustrates the transient modeling process for the backward-in-time and forward-in-time approaches. The simulation model will be calibrated using geologic information (Figure 3.3-2) such as paleolake or playa deposits, spring deposits, and marsh deposits. Vegetation evidence, such as pollen records or pack-rat middens, pedogenic features, and geomorphic land forms will also be used in the model calibration.

Model variables, classed as externals, are derived from field evidence and data analysis as part of the past-discharge activity (in Study 8.3.1.5.2.1, Quaternary regional hydrology), climate studies (Investigation 8.3.1.5.1), and unsaturated-zone studies (Study 8.3.1.2.2.9, Unsaturated-zone synthesis and modeling). These variables will then be used to estimate those variables classed as model internals, such as water levels and boundary conditions. Evidence and analysis derived from tectonics studies (Study 8.3.1.8.3.2, Effect of tectonic processes on water-table elevation; and Study 8.3.1.17.4.12, Tectonic models and synthesis) will be used to estimate aquifer geometry.

Model calibration, verification, and validation procedures (discussed in Section 2.1.2) will be completed using geologic and biologic evidence from which the hydrologic evidence was derived for each time period (Figure 3.3-3). GSIS (discussed in Section 3.3.3.1.2) will be utilized for data management and visualization of model results.

In order to simulate future climatic conditions, Study 8.3.1.5.1.6 (Future regional climate and environment.) will generate a set of expected future climate scenarios for the next 100,000 years, with special emphasis on the next 10,000 years. These climate scenarios will provide estimated parameters for input (for example, recharge to the simulation model that will allow evaluation of the future climate effects on the saturated zone) in the Yucca Mountain region.

If the geologic record (Study 8.3.1.5.2.1) suggests that tectonics have affected the paleoflow regime, future tectonic effects on the water table will have to be considered. For

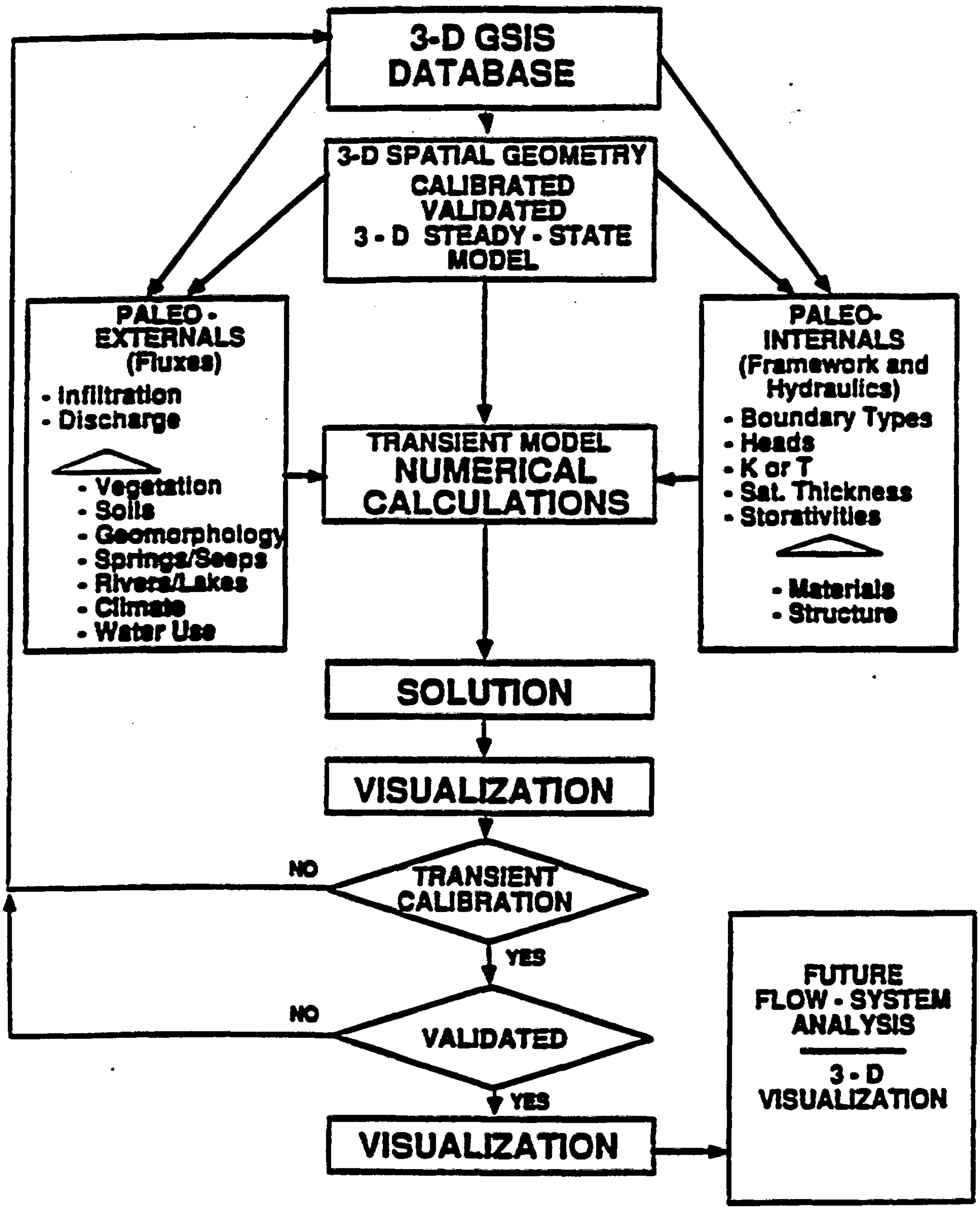

Figure 3.3-3. Logic diagram for transient modeling for the backward-in-time and foward-in-time approaches.

geohydrologic model simulations of future tectonic conditions, Studies 8.3.1.8.3.2 (Effect of tectonic processes on water-table elevation) and 8.3.1.17.4.12 (Tectonic models and synthesis) will provide input as to the effects of tectonic events on the saturated-zone geologic framework.

3.3.3.1.3.2 Forward-in-time approach

Starting with the geohydrologic climate conditions at a point in time about 23,000 years ago, transient model simulations will be made "forward in time" using paleohydrological and geological data for verification at various points in time to the present day (about 1988). The objective of this approach is to simulate the present-day geohydrologic conditions in the Yucca Mountain region using the available paleohydrologic and geologic information, as well as the present-day geologic and climatic data. This approach may provide a long-term form of model validation not available from other techniques.

Model input data sets will be developed based on geologic deposits, discharge deposits, and vegetation evidence, such as pollen records and pack-rat middens. Pedogenic features and geomorphic deposits will also provide input to the simulation model. Both the "forward-in-time" and "backward-in-time" approaches should provide the same general results.

In order to simulate the future geologic framework conditions, Study 8.3.1.17.4.12 (Tectonic models and synthesis) will provide input for the modeling of tectonic effects on changes in framework in the saturated zone.

3.3.3.2 Synthesis of modeled effects of climate change on future saturated-zone hydrology

Because the end results of this activity are intended for the resolution of performance issues, particularly for the assessment of "disturbed-case" scenarios in Issue 1.1, it will be necessary for the USGS investigators to recommend specific modeling results for use in performance assessment. Finalizing these recommendations will be accomplished by peer review within USGS-HIP, incorporation of objective reviews by USGS scientists not involved in the Yucca Mountain Project (YMP), and(or) the assistance of non-USGS scientists from the fields of climatology and hydrologic modeling.

3.3.3.3 Methods summary

The characterization parameter to be evaluated by the analyses described in the above sections appears in Figure 3.3-1. The selected methods for evaluating the parameter are also summarized in this figure. Alternate methods may be employed if selected methods should prove impractical to evaluate the parameter of interest. The USGS investigators have selected modeling approaches which they believe are suitable to provide data within the expected ranges of model output.

3.3.4 Quality-assurance requirements

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

4 APPLICATION OF STUDY RESULTS

4.1 Application of results to resolution of performance and design issues

Site information from the present study will be employed in the following performance issues: Issue 1.1 (Limiting radionuclide releases to the accessible environment), Issue 1.8 (NRC siting criteria); and Issue 1.9 (Higher-level findings). It will also be applied in the following design issues: Issue 1.10 (Waste-package characteristics), Issue 1.11 (Characteristics and configuration of repository and repository-engineered barrier systems), and Issue 1.12 (Characteristics and configurations of shaft and borehole seals.

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

4.2 Application of results to support other site-characterization studies

Results from Activity 8.3.1.5.2.2.1 (Future surface-water hydrology) will be used in two additional activities, Activity 8.3.1.5.2.2.3 (Future climate effects on the saturated zone), and Activity 8.3.1.16.1.1.1 (Site flood and debris-hazards studies).

Activity 8.3.1.5.2.2.3 (Future climate effects on the saturated zone) will assess the the effects of changes in climate and in the regional geologic framework could induce changes in the amount of ground-water recharge to the regional ground-water table. Large rates of evapotranspiration relative to precipitation cause very little infiltration from hillslopes to the ground water. Although flow in channels is the most likely source of ground-water recharge, the infiltration response of ridges, slopes, and upland areas to changes in climate, as modeled in the future surface water activity, will also be considered in recharge estimates for Activity 8.3.1.5.2.2.3. Thus, in order to predict changes n ground-water recharge due to climate changes, the response of streamflow must first be predicted.

Activity 8.3.1.16.1.1.1 (Site flood and debris-hazards studies) will assess the magnitude and frequency of potential floods during the pre-closure period. Because little historic data is available to determine the potential for future flooding with a high degree of accuracy, alternative methods of flood magnitude and frequency assessment are required. One alternative is to use meteorological conditions with known probabilities as input into a surface-water model originating in Activity 8.3.1.5.2.2.1. The resulting streamflow can thereby be predicted. This approach to flood estimation has the advantage over analysis of peak-flow data of being able to predict not only the peak discharge of a flood, but also the shape and duration of the entire hydrograph, and the antecedent soil-moisture conditions. This can in turn be used to assess the debris hazards associated with a hypothetical flood.

Results from Activity 8.3.1.5.2.2.3 (Future climate effects on the saturated zone) may be used to guide the data-collection efforts of Activity 8.3.1.5.2.1.3 (Evaluation of past-discharge areas).

5 SCHEDULES AND MILESTONES

5.1 Schedules

The proposed schedule presented in Figure 5.1-1 summarizes the logic network and reports for Study 8.3.1.5.2.2. This figure represents a summary of the schedule information which includes the sequencing, interrelations, and relative durations of the activities described in this study. Specific durations and start and finish dates for the activities are being developed as part of ongoing planning efforts. The development of the schedule for the present study has taken into account how the study will be affected by contributions of data from other studies, and also how the present study will contribute to or may interfere with other studies. Milestones shown on the schedule include the major milestones cited in SCP Table 8.3.1.5-6 (Major events and planned completion dates for studies in the Climate Program). Figure 5.1-1 reflects the most recently available project participant schedule.

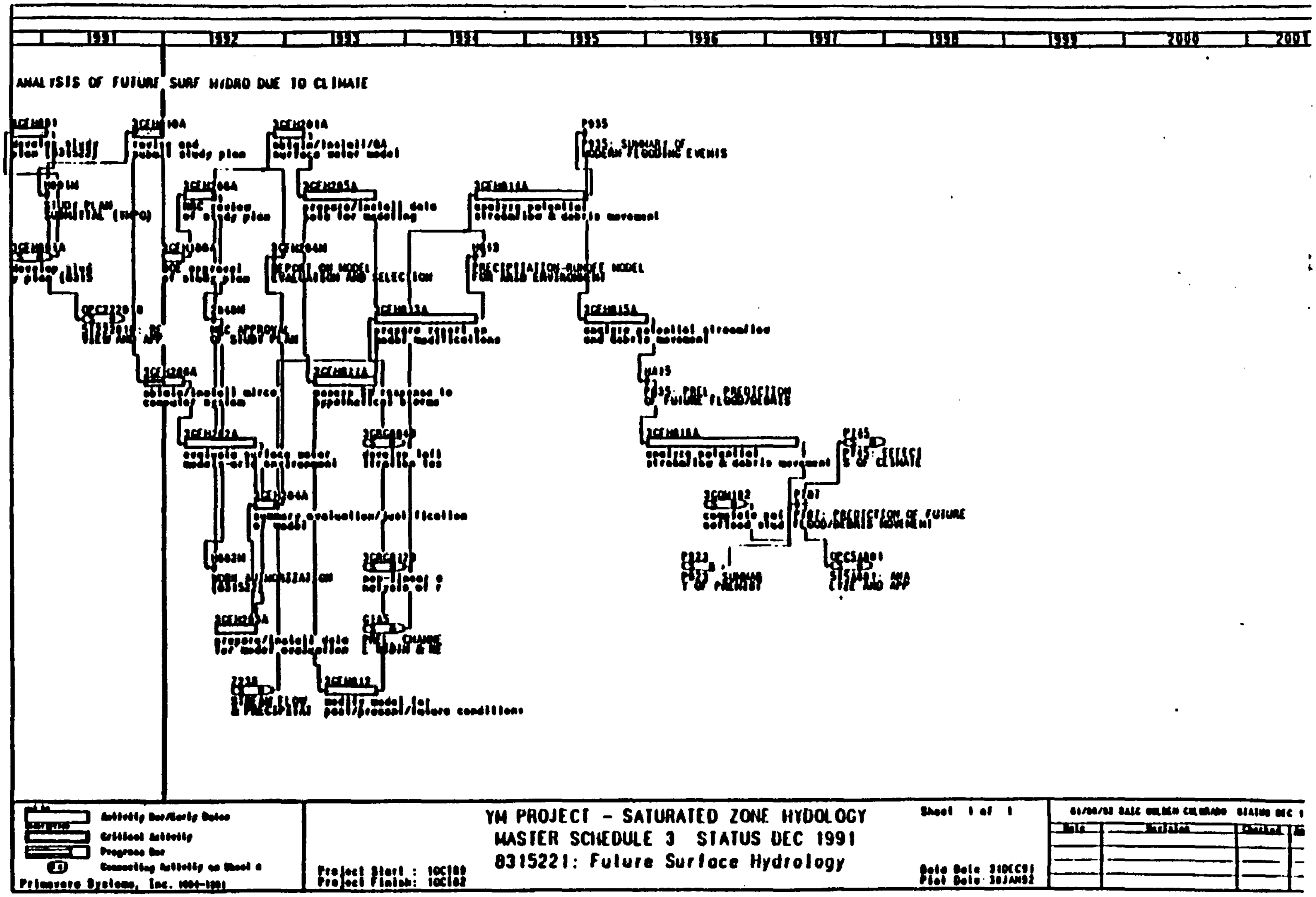

Figure 5.1-1a. Summary network for future regional hydrology study.

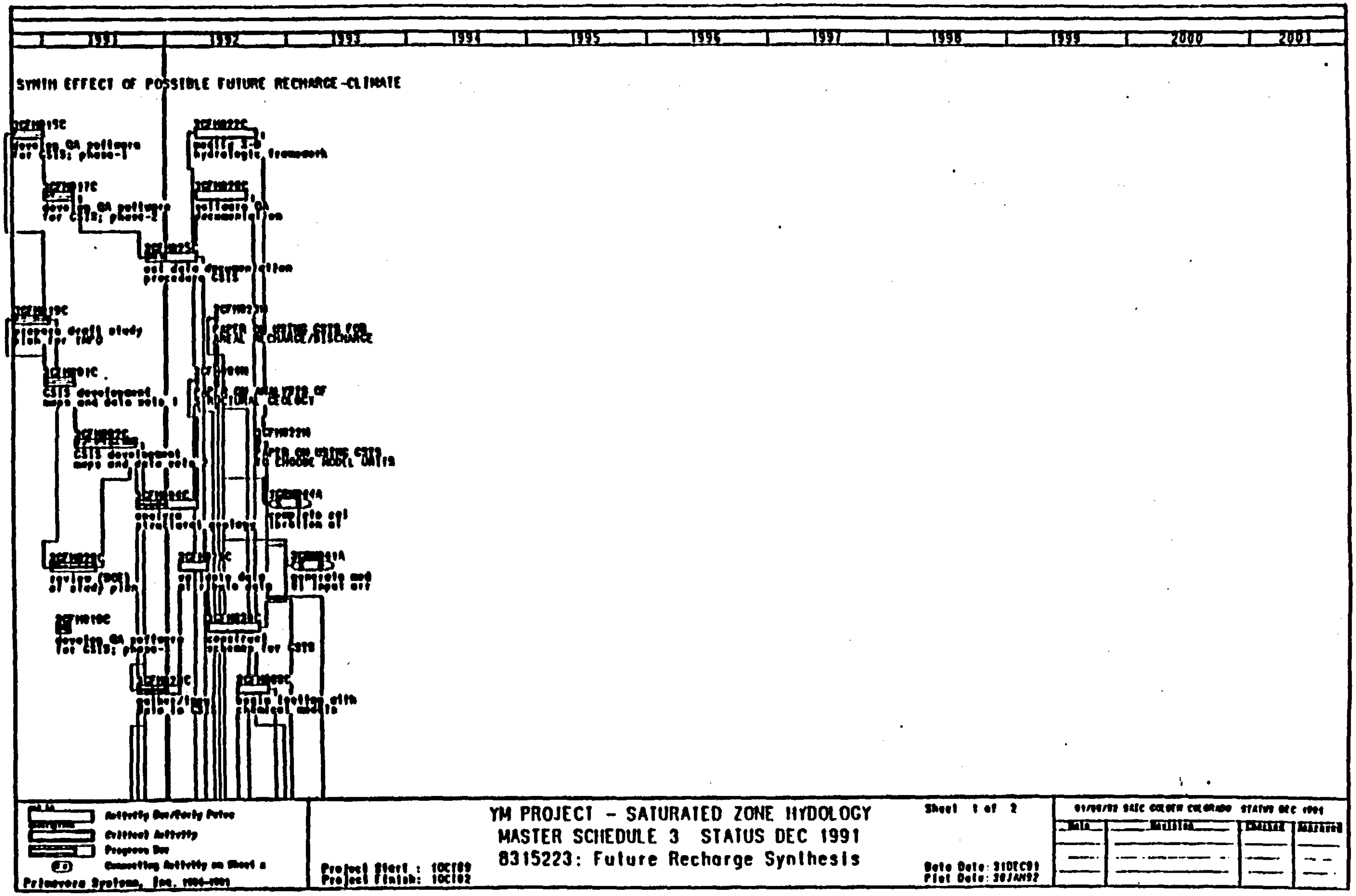

Figure 5.1-1b. Summary network for future regional hydrology study.

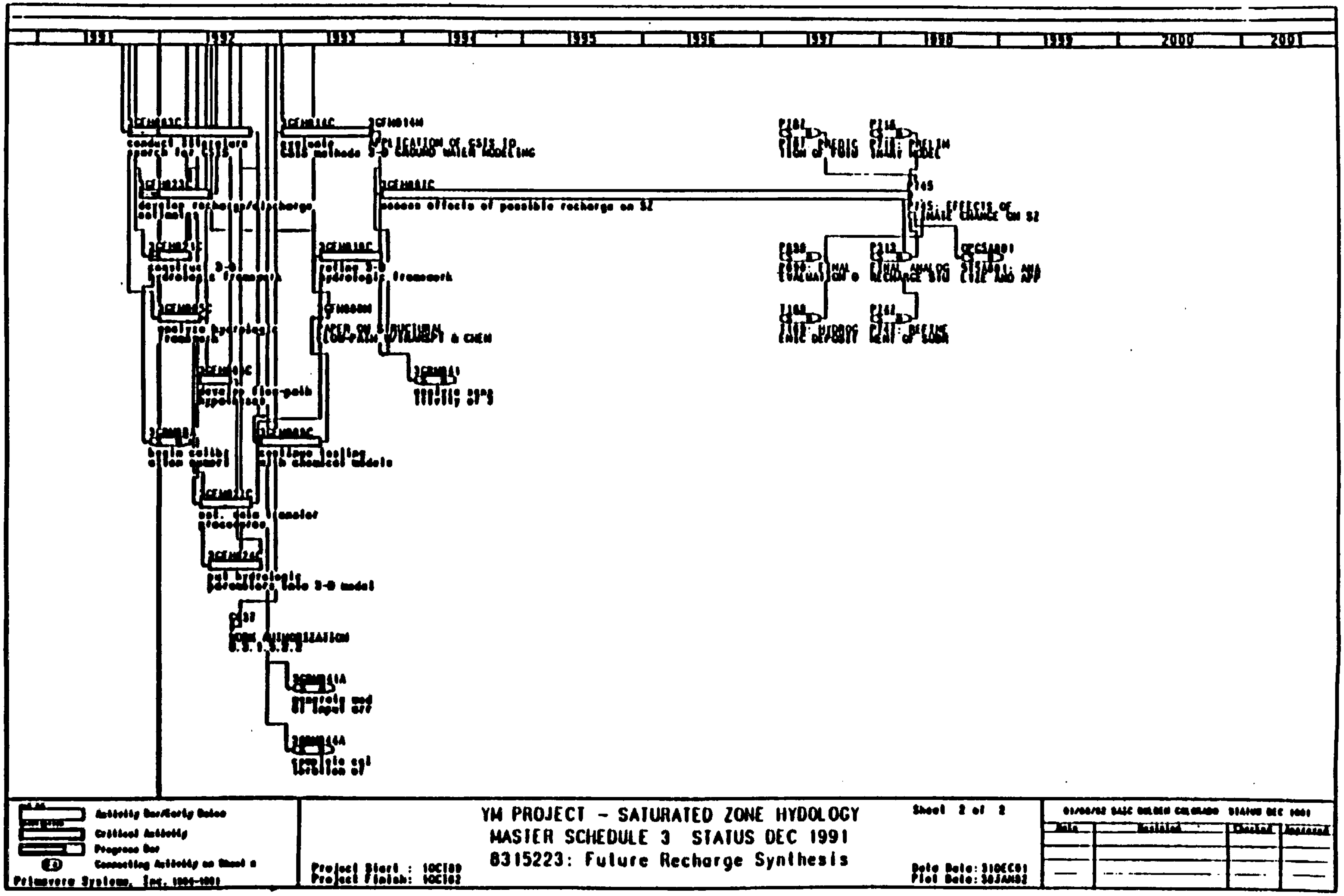

Figure 5.1-1c. Summary network for future regional hydrology study.

5.2 Milestones

The milestone numbers, titles, and levels associated with Study 8.3.1.5.2.2 appear in Table 5.2-1. The information presented in the table represents major events or important summary milestones associated with the activities presented in this study plan as shown in Figure 5.1-1. Specific dates for the milestones are not included in the tables, as these dates are subject to change due to ongoing planning efforts.

Table 5.2-1. Milestone list for work-breakdown structure number - 1.2.3.6.2.2.2 (SCP 8.3.1.5.2.2)

Milestone Number	Milestone	Milestone Level
Future surface water: 8.3.1.5.2.2.1		
2040M	NRC approval of study plan	3
H001M	Study plan submittal (YMPO)	3
H002M	Work authorization (831522)	3
H013	Precipitation-runoff model for arid environment	3
HA15	P835: Preliminary prediction of future flood/debris	3
P787	P787: Prediction of future flood/debris movement	3
P935	P935: Summary of modern flooding events	3
3GFH204M	Report on model evaluation and selection	4
Future saturated zone: 8.3.1.5.2.2.3		
P745	P745: Effects of climate change on SZ	2
3GFH004M	Paper on analysis of structural geology	3
3GFH009M	Paper on structural flow-path with transport and chemistry	3
3GFH014M	Application of GSIS to 3-D ground water modeling	3
3GFH022M	Paper on using GSIS to choose model units	3
3GFH023M	Paper on using GSIS for areal recharge/discharge	3
G037	Work authorization 8.3.1.5.2.2	3

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7 APPENDICES

7.1 Quality-assurance requirements

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

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

7.1.1 Quality-assurance requirements matrix

Applicable NQA-1 criteria for Study 8.3.1.5.2.2 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 and design information needs specified in the SCP

This section tabulates in Table 7.2.1 the specific technical information relations between SCP and performance-parameters needs and characterization parameters to be evaluated in this study. The relations were developed using model-based parameter categories that provide common terminology and organization for evaluation of site, design, and performance information relations.

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

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

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

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

Issue 1.1 Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13? (SCP 8.3.5.13)

Performance Measures: EPPM[a], disturbed case C-1, increased water flux through unsaturated zone
EPPM[a], disturbed case C-2, foreshortening of unsaturated zone, water pathway
EPPM[a], disturbed case C-3, altered unsaturated-zone rock properties and geochemistry, water pathway
EPPM[a], disturbed case D-1, foreshortening of water flow paths in unsaturated zone
EPPM[a], disturbed case D-2, altered saturated-zone head gradients, rock hydrologic properties, and geochemistry

Parameter Category: Paleohydrology/future-hydrology hypotheses

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Expected magnitude of flux change due to climatic changes over next 10,000 yr; quantitative confidence bounds on expected magnitude of change (scenario class C-1, local or extensive increases in unsaturated-zone percolation flux)	Repository area; Unsaturated zone	Goal: Flux change will be 0.5 mm/yr with 67% confidence or more Current: Low Needed: High	Future runoff and streamflow		8.3.1.5.2.2

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

Issue 1.1 Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13? (SCP 8.3.5.13)

Performance Measures: EPPM[a], disturbed case C-2, foreshortening of unsaturated zone, water pathway
EPPM[a], disturbed case C-3, altered unsaturated-zone rock properties and geochemistry, water pathway
EPPM[a], disturbed case D-1, foreshortening of water flow paths in unsaturated zone
EPPM[a], disturbed case D-2, altered saturated-zone head gradients, rock hydrologic properties, and geochemistry

Parameter Category: Paleohydrology/future-hydrology hypotheses

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Expected magnitude of change in water-table level due to climatic changes over the next 10,000 yr (scenario class C-2, foreshortening of unsaturated zone)	Controlled area; Water table	Goal: Expected magnitude of change in water-table altitude will not bring water table to within 100 m of repository horizon in 10,000 yr Current: Low Needed: High	Future saturated-zone hydrologic conditions		8.3.1.5.2.2
Degree of mineralogic change in the controlled area resulting from changes in water-table level or flow paths in 10,000 yr (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties)	Controlled area; Unsaturated zone	Goal: Adverse changes in mineralogy will not occur Current: Low Needed: Low			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity

Issue 1.1 Will the mined geologic disposal system meet the system performance objective for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13? (SCP 8.3.5.13)

Performance Measures: EPPM®, disturbed case D-1, foreshortening of water flow paths in unsaturated zone
EPPM®, disturbed case D-2, altered saturated-zone head gradients, rock hydrologic properties, and geochemistry

Parameter Category: Paleohydrology/future-hydrology hypotheses

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Expected locations of surficial discharge points within controlled-area over next 10,000 yr (scenario class D-1, appearance of surficial discharge points within controlled area, foreshortening of saturated zone)	Controlled area; Saturated zone	Goal: That no surficial discharge points could appear within controlled-area given a water table rise < 160 m Current: Low Needed: Medium			
Expected magnitude of change in water-table gradient due to climatic change over the next 10,000 yr (scenario class D-2, increased head gradients or changed rock, hydrologic, or geochemical properties in saturated zone)	"	Goal: Gradients change less than a factor of 4 Current: Low Needed: 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 Loc

Issue 1.9 Can higher-level findings be made for disqualifying and qualifying conditions of technical guidelines fo geohydrology, geochemistry, rock characteristics, human interference ect. and can comparative evaluatio required by 10 CFR Part 960.3-1-5 be made?

Performance Measures:

Parameter Category: Paleohydrology/future-hydrology hypotheses

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Loc
Expected magnitude of flux change due to climatic changes over 100,000 yr	Controlled area;	Goal: Show expected flux change will be < 5 mm/yr Current: -- Needed: High	Future runoff and streamflow	
Expected magnitude of change in water-table level due to climatic changes over next 100,000 yr	"	Goal: Show expected magnitude of change in water-table altitude will be <+100 m Current: -- Needed: Moderate	Future saturated-zone hydrologic conditions	
Expected magnitude of change in water-table gradient due to climatic change over next 100,000 yr	"	Goal: Show change will be $< 2 \times 10^{-3}$ Current: -- Needed: Moderrate		

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 1.9	Can higher-level findings be made for disqualifying and qualifying conditions of technical guidelines for geohydrology, geochemistry, rock characteristics, human interference ect. and can comparative evaluations required by 10 CFR Part 960.3-1-5 be made?				(SCP 8.3.5.18)
Performance Measures:					
Parameter Category: Paleohydrology/future-hydrology hypotheses					
Expected locations of surficial discharge points within the controlled zone due to climatic change over the next 100,000 yr	Controlled area;	Goal: Show that no significant surficial discharge points could appear within C-area, given a water-table rise <=160 m Current: -- Needed: Moderate			