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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
STUDY PLAN APPROVAL FORM

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Study Plan Number 8.3.1.5.2.1

Study Plan Title CHARACTERIZATION OF YUCCA MOUNTAIN QUATERNARY REGIONAL HYDROLOGY

Revision Number 2

Prepared by: U. S. GEOLOGICAL SURVEY

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Approved:

J. Timothy Sullivan for 11/10/92
Director, Regulatory and Site Evaluation Division / Date

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CHARACTERIZATION OF THE YUCCA MOUNTAIN QUATERNARY REGIONAL HYDROLOGY

YMP - USGS - SP 8.3.1.5.2.1, R2

STUDY PLAN

MARCH 1992

March 31, 1992

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1 PURPOSE AND OBJECTIVES OF STUDY

1.1 Purpose of the study plan

The U.S. Geological Survey (USGS) is conducting studies at Yucca Mountain, Nevada, as part of the Yucca Mountain Project (YMP). The purposes of the USGS studies are to provide hydrologic and geologic information to evaluate the suitability of Yucca Mountain for development as a high-level nuclear-waste repository, and the ability of the mined geologic-disposal system (MGDS) to isolate the waste in compliance with regulatory requirements. In particular, the project is designed to acquire information necessary for the 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.

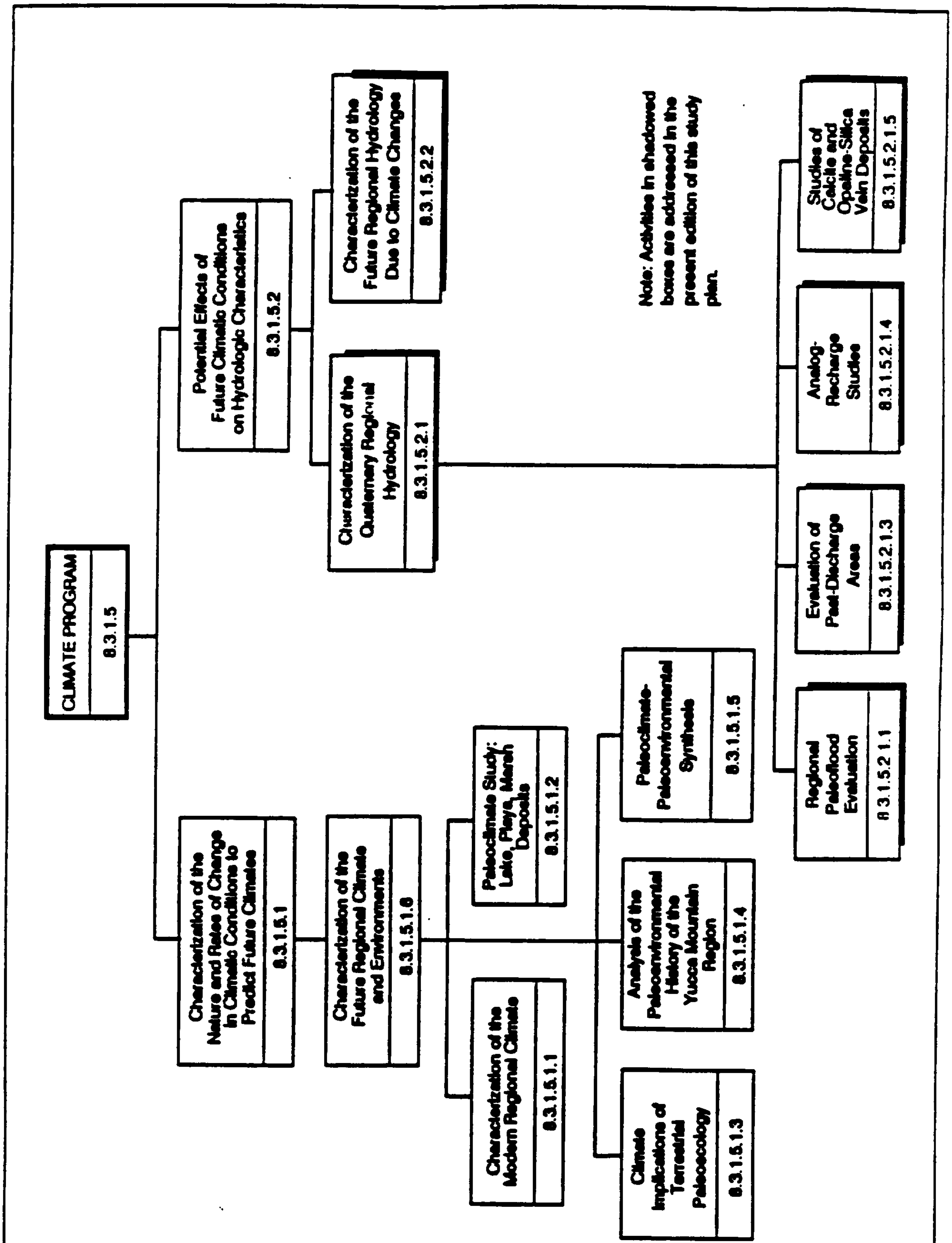
This study plan describes the USGS plans for characterizing the Quaternary hydrology of the Yucca Mountain region. The study is organized into four activities:

- 8.3.1.5.2.1.1 - Regional paleoflood evaluation,
- 8.3.1.5.2.1.3 - Evaluation of past-discharge areas,
- 8.3.1.5.2.1.4 - Analog-recharge studies, and
- 8.3.1.5.2.1.5 - Studies of calcite and opaline-silica vein deposits.

Note that the numbers (e.g., 8.3.1.5.2.1.1) used throughout this plan serve as references to specific sections of the YMP Site Characterization Plan (SCP). The SCP (U.S. DOE, 1988) describes the technical rationale of the overall site-characterization program and provides general descriptions of the activities described in detail in Section 3 of this study plan.

Figure 1.1-1 illustrates the location of the study within the SCP climate program. The Quaternary regional hydrology study is one of eight planned to characterize paleoclimatic history, evaluate expected future climate scenarios, define relations between paleoclimate and paleohydrology, and evaluate the response of the future Yucca Mountain hydrologic regime to changes in future climate. The four activities in the study were selected on the basis of various factors. Time and schedule requirements were considered in determining the number and types of tests chosen to obtain the required data. Tests were designed on the basis of design/performance-parameter needs, available test/analysis methods, and test scale. These factors are described in Sections 2 and 3. The tests and 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 tests/analyses are investigating.

The plans for each activity are presented in Section 3. Plans for the paleoflooding, past-discharge areas, analog-recharge, and calcite and opaline-silica vein deposits activities are described in Sections 3.1, 3.3, 3.4, and 3.5, respectively. The descriptions include (a) objectives and parameters, (b) technical rationale, and (c) tests and analyses. Alternate



...re 1.1-1. Location of study within the future c... e/hydrology investigation and organization of it ...te program.

test and analysis methods are summarized, and cross references are provided for quality-assurance requirements and technical procedures.

Application of the study results is summarized in Sections 1.3 and 4, study and activity schedules and milestones are presented in Section 5, a study-plan reference list is presented in Section 6, and a quality-assurance appendix is presented in Section 7.

1.2 Objectives of study

This study is primarily designed to identify those hydrologic conditions in the Yucca Mountain area which, during the Quaternary and more especially over the past 20,000 years (which includes the last pluvial cycle), have been significantly different from present conditions, owing to paleoclimatic changes or possibly changes in the geologic framework. The study will generate data that will allow the project to develop and test various models that describe the ancient hydrologic conditions, and it is expected to result in a characterization of the Quaternary regional hydrology at Yucca Mountain and environs. This characterization, in conjunction with results of paleoclimate and hydrology Investigations 8.3.1.5.1, Nature and rates of climate change; 8.3.1.2.2, Unsaturated-zone hydrologic system; and 8.3.1.2.1 and 8.3.1.2.3, Regional and site saturated-zone hydrologic systems, respectively, will contribute to an evaluation of the effects of future climate episodes over the next 10,000 and 100,000 years on the regional ground-water regime and on the unsaturated- and saturated-zone systems in and near Yucca Mountain. Major aspects of the present study are (1) the climatological conditions necessary for severe runoff events in the Quaternary, (2) characterization of Quaternary infiltration and recharge, (3) identification of areas of paleorecharge and paleodischarge, and (4) Quaternary fluctuations of water-table elevation. It is important to note that paleodischarge sites will be looked for without regard to possible causes of discharge and that as such, data developed can be used in any alternative conceptual model for paleohydrology or future hydrology. The study is secondarily designed, through some of the efforts of the calcite and opaline-silica vein deposits study, to contribute to evaluating the probability of future volcanic activity (Study 8.3.1.8.1.1, Probability of volcanic eruption penetrating the repository), evaluating the probabilities of future tectonic activity (Study 8.3.1.8.3.1, Effects of tectonics on hydrology), and also to evaluating the potential for economic-mineral deposits at Yucca Mountain (Study 8.3.1.9.2.1, Natural-resource assessment).

The regional Quaternary paleoclimate constitutes one of three components necessary to assess future hydrology due to future climate change. The other two are (1) numerical hydrologic models of the unsaturated and saturated zones (from the geohydrology program) and (2) the climatology of anticipated and unanticipated future climate scenarios (from the paleoclimatology program). The three components converge in Study 8.3.1.5.2.2 (Characterization of the future regional hydrology due to climate changes) in which paleohydrology/paleoclimate relations are evaluated, and in which sensitivity analyses are to be performed with the hydrologic models to evaluate the sensitivity of the hydrologic regime to variations in the climatic parameters. Output from the sensitivity analyses is expected to include estimates for infiltration, percolation, and saturation, along with estimates of changes in discharge rates or flow velocities within the system. For the saturated zone, output would include ground-water flux maps and potentiometric-surface maps, showing alterations in the flow regime and in the water-table level and gradient attributable to future climate change.

Three areas are of special concern to the paleohydrology study: (1) the maximum altitude of the water table during episodes of the Pleistocene when effective recharge was greater than at present, (2) the effects of water-table rises on shortening of ground-water flow paths to accessible environment, and (3) the magnitude of increases in percolation and recharge during episodes of greater effective precipitation.

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. If the water table does not rise high enough to flood the repository, the effect of wetter climate on radionuclide release may not be as significant.

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 sensitivity analyses performed on the hydrologic models will allow a prediction of water-table elevation changes due to changes in input values of any one (or more) variable(s), if the models have been calibrated and verified against known conditions. The conductivities in the flow field will be obtained from the geohydrology program (8.3.1.2) and the geometry (stratigraphy and structure) of the system from the rock-characteristics program (8.3.1.4). The activities described in this study plan will provide information required to describe past water-table fluctuations and to develop reasonable hypotheses for their causes. This will be accomplished by (1) interpretation of geomorphic and stratigraphic evidence of paleofloods; (2) hydrochemical evidence of waters that infiltrated during the Quaternary; (3) locating past points of ground-water discharge as evidenced by former springs, mineral vein fillings, and other deposits registering past higher water levels; (4) evaluation of analog-recharge sites to estimate past, present, and future infiltration characteristics; and (5) identification of past tectonic events that have modified the hydrologic system.

1.3 Rationale and justification

For this section to draw the relations between site-characterization data collected in this study and design and performance parameters, it is necessary to anticipate somewhat the more detailed treatment of activity parameters that appears in Section 2.1.3.

The main objective of the present study is to define the paleohydrologic regime during the Quaternary with emphasis on the last 20,000 years, so that its relationship and response to paleoclimatic influences or possible changes in past geologic framework can be evaluated. Definition of the regional paleohydrologic regime, in both its qualitative and quantitative aspects, can be considered the culminating parameter of the study, in that all of the measurable activity parameters in the study activities lead into it either directly or indirectly through a scientific process of developing and then testing alternate concepts that explain the conditions of ground water in the Quaternary. Some of the activity parameters measured in the field or laboratory, however, are not obviously related to the goal of defining regional paleohydrology. Examples of indirect relationships can be found in all of the subsequently described activities. Nonetheless, the activity parameters can be traced logically upward from their origins in the field or laboratory to their contribution to defining regional paleohydrology.

In order to more easily relate the measured parameters in the various activities to the overall goal of defining regional paleohydrology, it is useful to introduce a limited set of site-characterization parameters, broad categories of information that encompass the measured-activity parameters collected in the field and laboratory or resulting from analysis of field and laboratory data. These site-characterization parameters have been defined to be clearly relatable logically to defining the regional paleohydrology. By introducing this category, it also becomes easier to demonstrate how the study contributes to satisfying design- and performance-parameter requirements of the various design and performance issues.

The site-characterization parameters for the activities described in this revision of the Quaternary regional hydrology study plan are listed below, along with the activities in which they originate:

Activity 8.3.1.5.2.1.1 - Regional paleoflood evaluation	Relations of paleoflood characteristics to modern flood characteristics
Activity 8.3.1.5.2.1.3 - Evaluation of past-discharge areas	Potentiometric surface, past Hydrologic properties, past Paleodischarge, locations and rates Ages, hydrogenic deposits

Activity 8.3.1.5.2.1.4 - Analog-recharge studies	Infiltration rate, past
	Recharge rate, past
Activity 8.3.1.5.2.1.5 - Studies of calcite and opaline-silica vein deposits	Paleohydrologic flow paths, hydrogenic deposits
	Ages, hydrogenic deposits
	Ages, fault movements
	Ages, volcanic events
	Economic potential, hydrogenic deposits

Figure 1.3-1 is a logic diagram (after SCP Figure 8.3.1.5-2) showing the position of the present study in contributing to the culminating goal of the climate program, which is to estimate the effects of future climate upon the surface-water regime and unsaturated- and saturated-zone ground-water regimes. The site-characterization parameters in the figure are those listed above. The relations between the measured parameters of the activities and the site-characterization parameters are shown in Figures 3.1-2, 3.3-2, 3.4-2, and 3.5-2 of the Section 3 activity descriptions, and are summarized in Table 2.1-1 in the discussion of parameters in Section 2.1.3.

The following portion of this section summarizes from the SCP the study-level interfaces between the site-characterization program and the design and performance issues. Figure 1.3-2 illustrates the interfaces of the Quaternary regional hydrology study with YMP performance and design issues and other site-characterization programs.

Table 1.3-1 (at the end of Section 1.3) shows how the site information collected in this study relates to information required by repository performance and design parameters. (The relations between design and performance issues and regulatory requirements of 10 CFR 60 and 10 CFR 960 are described in SCP Section 8.2.1.) It completes the tracing of the logical path from the collection of measured-activity parameters in the field or laboratory through the use of the site information in performance assessment and design activities. The path begins with the appearance of the activity parameters in the text, figures, and tables of the Section 3 activity descriptions, continues with the association of measured and site-characterization parameters in Table 2.1-1 of Section 2.1.3, and ends in Table 1.3-1. The relations of the table are based upon parameter categories assigned to each of the site-characterization parameters and to the performance and design parameters specified in Sections 8.3.2 through 8.3.5 of the SCP. Where a site-characterization parameter from the present study shares a parameter category with a design or performance parameter, the relationship is reported in Table 1.3-1. For both types of parameters, the table lists spatial/geographic and geohydrologic-unit/structural locations. Comparisons of the locations of measurements (site-characterization parameters versus design and performance parameters) were also used as a

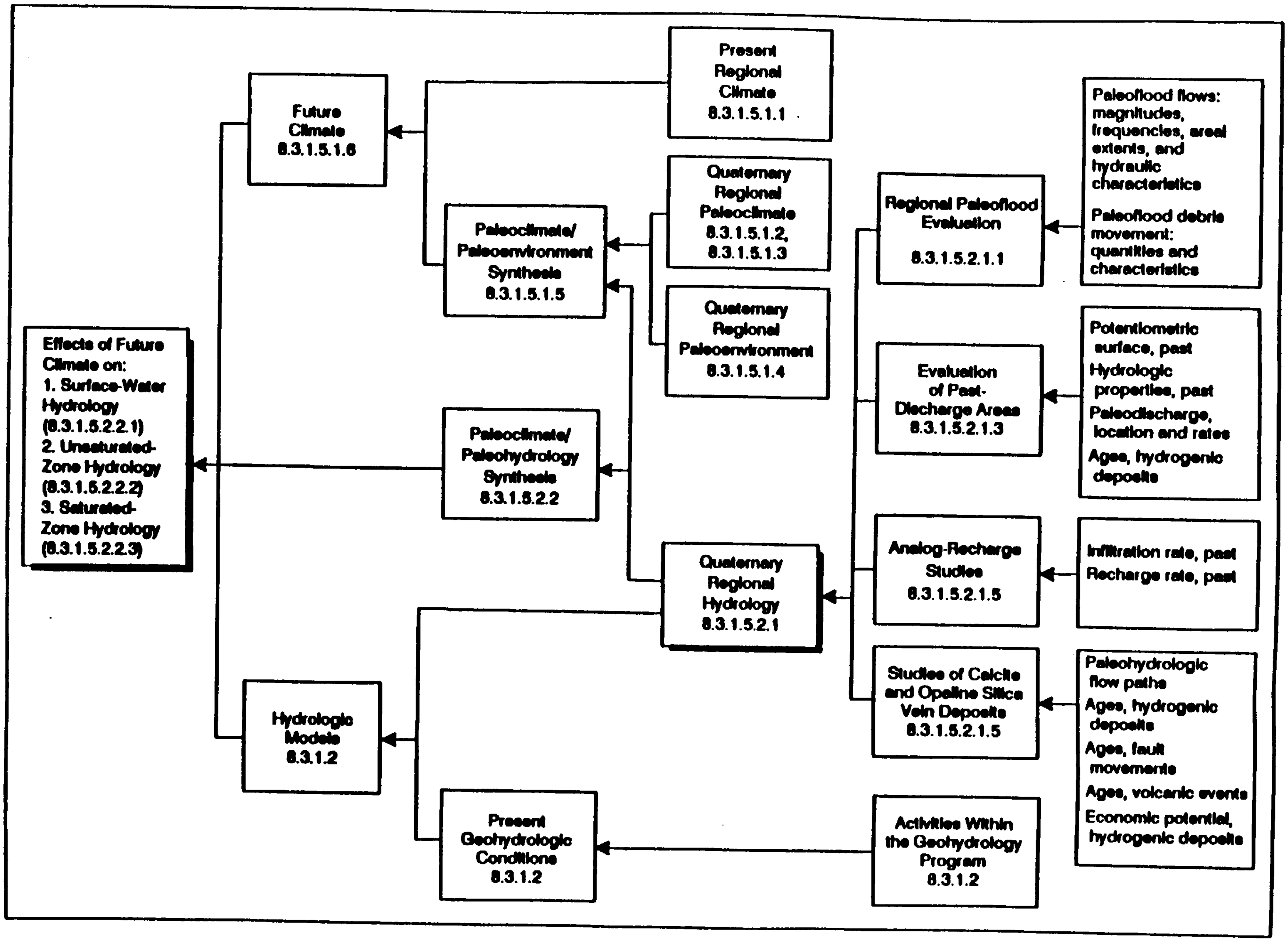


Figure 1.3-1. Logic diagram showing site-characterization parameters of this study in relation to the climate program.

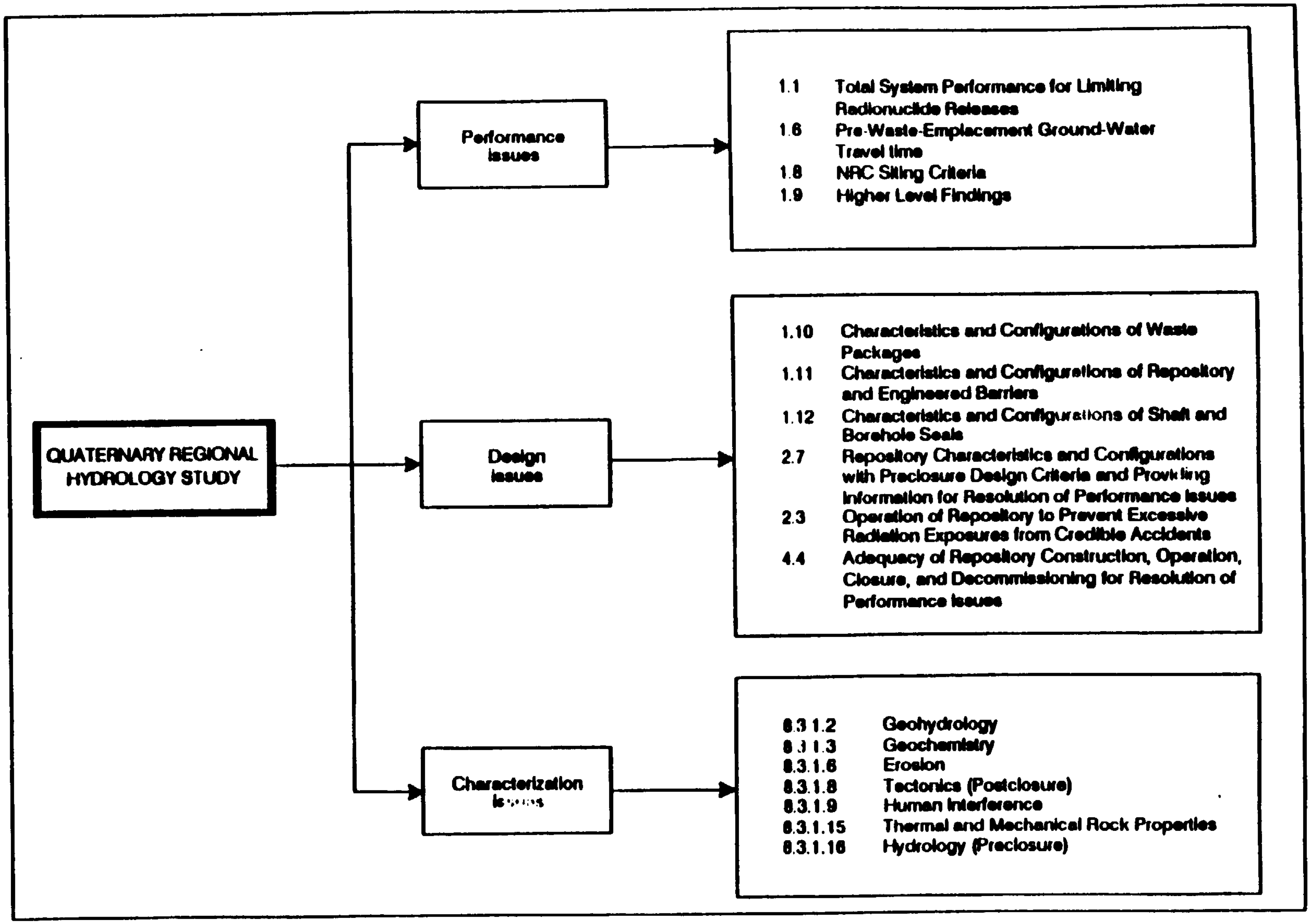


Figure 1.3-2. Interfaces of Quaternary regional hydrology study with YMP performance and design issues and other site-characterization programs.

means of constructing the relations shown in this table. For the site-characterization parameters, the originating activity is shown; for performance and design parameters, the SCP section requesting the information is shown. Note: the parameter relations of Table 1.3-1 must be evaluated as sets of parameters (site-characterization and design/performance) grouped by parameter category. Line-by-line comparisons within a parameter category should not be made.

Table 1.3-2 (also at the end of Section 1.3) is a listing of the performance and design parameters supported by this study (from Table 1.3-1) and includes additional information from the SCP performance-allocation tables on parameter goals, current and needed confidence levels in the parameter values, and expected parameter values. Additional discussion of these parameters are included in the issues-resolution strategies of SCP Section 8.3.1 through 8.3.5. Table 1.3-3 lists design and performance issues and parameters indirectly supported by Activity 8.3.1.5.2.2.1 (Regional paleoflood evaluation) by its contribution to Study 8.3.1.16.1.1 (Flood potential and debris hazards).

It is important to note in Table 1.3-1 that the relations between Quaternary regional hydrology and the performance parameters having to do with future climate/hydrology relations are indirect. As shown in Figure 1.3-1, the direct relation to performance parameters occurs through the evaluation of hydrological response to future climate in Study 8.3.1.5.2.2 For example, the performance parameter of expected locations of surficial-discharge points (the second performance parameter listed in Table 1.3-1) will be fulfilled from data resulting from sensitivity analyses of hydrologic models conducted in Study 8.3.1.5.2.2. Indirect as the relations may be between the present study and performance measures addressing future climate/hydrology relations, Table 1.3-1 serves the purpose of connecting the present study with repository design and performance.

In Table 1.3-1, in the site-characterization parameters for Activity 8.3.1.5.2.1.5, there are three entries that do not apply to future climate/hydrology relations: ages of fault movements, ages of volcanic events, and economic potential of hydrogenic deposits. These have been included to reflect the fact that the Trench 14 work will contribute to the tectonics and human-interference programs as well as to the climate program.

The following discussion of the uses of site-characterization data from this study in resolving performance and design issues is based upon performance measures and design and performance parameters identified in SCP Sections 8.3.2 through 8.3.5.

In SCP Table 8.3.1.5-2 (SCP Section 8.3.1.5, Climate program), Performance Issues 1.1 (Total-system performance) and 1.9 (Higher-level findings) are cited as the issues receiving support from data collected in this study. The following paragraphs discuss how the present study pertains to these issues. In this section, reference to Trench 14 should be understood to be an example of a broad group of localities to be studied.

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

This issue contains the most important applications for paleohydrologic and other data collected in the present study. Within this issue, the study relates primarily to performance parameters in Scenario Classes C-1, C-2, and C-3 and secondarily to other scenario classes.

For the expected partial performance measure (EPPM) for Scenario Class A-1 (extensive magmatic events), ages of volcanic events relate to the performance parameter of annual probability of volcanic eruption.

For the EPPM for Scenario Class A-2 (exploratory drilling), the economic potential of hydrogenic deposits relates to the performance parameters of the expected future drilling in the repository area, and the distribution of depths of exploratory drillings.

For the EPPM for Scenario Class C-1 (local or extensive increases in percolation flux through the unsaturated zone), the paleohydrologic regime relates to the performance parameter of expected magnitude of flux due to future climatic changes. Ages of fault movements relate to the performance parameters of probabilities of fault offset and changing of dip due to faulting. Ages of volcanic events relate to performance parameters of probabilities of volcanic events and igneous intrusions.

Through the support of the regional paleoflood evaluation (Activity 8.3.1.5.2.1.1) to the assessment of flood and debris hazards (Study 8.3.1.16.1.1), the present study will support a performance parameter of Scenario Class C-1 concerning the expected magnitude of local moisture-flux change caused by flooding through the access shafts. A more detailed treatment of the support of Study 8.3.1.16.1.1 to this performance parameter appears in YMP-USGS SP 8.3.1.16.1.1 (Flood potential and debris hazards at the Yucca Mountain site).

For the EPPM for Scenario Class C-2 (foreshortening of the unsaturated zone), the paleohydrologic regime relates to the performance parameter of expected change in water-table level due to future climatic changes. Ages of future fault movements relate to the performance parameter of probability of total offsets on faults exceeding 2.0 m (6.6 ft) in the controlled area. Ages of volcanic events relate to the performance parameter of probability of future igneous intrusion. Economic potential of hydrogenic deposits relates to the performance parameter of expected magnitude of water-level change as a consequence of future mining activity.

In the EPPM for Scenario Class C-3 (changes in unsaturated-zone rock hydrologic and geochemical properties), ages of fault movements relate to the performance parameter of probability of faulting events on Quaternary faults within 0.5 km (0.3 mi) of the controlled-area boundary, probability of controlled-area Quaternary faults within 2 km (1.2 mi) of the surface, and probability of faults within 0.5 km (0.3 mi) of the controlled area exceeding a 2.0-m offset.

Ages of volcanic events relate to the performance parameter of probability of significant igneous intrusion. For the EPPM for Scenario

Class D-1 (appearance of surficial discharge points within the controlled area), the paleohydrologic regime relates to the performance parameter of expected future locations of surficial discharge points within the controlled area. Ages of fault movements relate to the performance parameter of future fault offset exceeding 1.0 m (3.3 ft) within the controlled area. Ages of volcanic events relate to the performance parameter of probability of significant igneous intrusion within 5 km of the controlled area.

For the EPPM for Scenario Class D-2 (increased head gradients or changed rock hydrologic or geochemical properties in the saturated zone), the paleohydrologic regime relates to the performance parameter of expected magnitude of change in water-table gradient due to future climatic changes. Ages of fault movements relate to the performance parameter of probability of faults within the controlled area exceeding a total offset of 2 m (6.6 ft). Ages of volcanic events relate to the performance parameter of probability of significant igneous intrusion. Economic potential of hydrogenic deposits relates to the performance parameters of expected magnitude of changes in controlled-area water table due to mining activity, and expected magnitude of changes of distribution coefficients of saturated-zone units due to mining activity.

Performance Issue 1.9
(Higher-level findings)

Through the provision of site information for the resolution of Issue 1.1, the present study contributes to several higher-level findings for Issue 1.9a. The first, the qualifying condition for geohydrology, specifies that the present and expected geohydrologic setting of a site shall be compatible with waste containment and isolation; this condition is addressed in part by the characterization of future geohydrologic conditions resulting from Study 8.3.1.5.2.2, supported by this study. The second, the qualifying condition for tectonics, states that the repository shall be located where future tectonic events or processes are not likely to lead to radionuclide releases to the accessible environment greater than those allowed by regulation. Dating of calcite-silica veins in fault zones in Activity 8.3.1.5.2.1.5 will contribute to addressing this condition. The third, the qualifying condition for natural resources, states that the repository shall be located where a reasonable projection of the presence of natural resources will not likely be the causes of human interference resulting in radionuclide releases greater than those specified in the regulations. This condition will be addressed in part by geochemical tests of the calcite-silica vein deposits such as those exposed in Trench 14. This study, through its support of Study 8.3.1.5.2.2 in the characterization of response of the geohydrologic regime to future climate, also contributes to the resolution of Issue 9(b), evaluation over the next 100,000 years.

Auxiliary contributions of the study to Design Issues 2.7, 4.4, and 2.3 are also pointed out in Table 1.3-1, and are discussed below.

Design Issue 2.7
(Repository characteristics and configurations)

The Trench 14 work will provide ages of volcanic events, bearing upon the design parameter of volcanic-ash fall. This parameter relates to a variety of the performance measures, including the effects of credible natural phenomena and natural conditions on repository structures, systems, and components important to safety; ability of utilities important to safety to function; and disruption of waste-package configurations.

Through the support of the regional paleoflood evaluation (Activity 8.3.1.5.2.1.1) to the assessment of flood and debris hazards (Study 8.3.1.16.1.1), the present study will support certain design considerations of safety that pertain to potential flooding. These concern monitoring and controlling the dispersal of radioactive contamination; providing adequate ventilation to protect against radiation exposure; protecting repository structures, systems, and components against natural phenomena and environmental conditions; and others detailed in YMP-USGS SP 8.3.1.16.1.1 (Flood potential and debris hazards at the Yucca Mountain site).

Design Issue 4.4
(Adequacy of repository construction, operation, closure, and decommissioning)

Information about the ages of fault movements and volcanic events from Trench 14 bear upon the design parameters of probabilities of volcanic eruption and fault displacement, which apply to the performance measures of locations for surface facilities and sites for underground facilities.

Through the support of the regional paleoflood evaluation (Activity 8.3.1.5.2.1.1) to the assessment of flood and debris hazards (Study 8.3.1.16.1.1), the present study will support the design of the surface facilities for protection from the effects of possible flood events. A more detailed treatment of the support of Study 8.3.1.16.1.1 to surface-facilities design appears in YMP-USGS SP 8.3.1.16.1.1 (Flood potential and debris hazards at the Yucca Mountain site).

Design Issue 2.3
(Operation of the repository so that credible accidents do not result in excessive-radiation exposures to the public and workers)

Ages of volcanic events from Trench 14 bear upon the design parameter of volcanic-ash fall, which applies to the performance measure of consequences of credible site-related accidents.

Through the support of the regional paleoflood evaluation (Activity 8.3.1.5.2.1.1) to the assessment of flood and debris hazards (Study 8.3.1.16.1.1), the present study will support the assessment of consequences of credible site-related accidents related to possible flood events. A more detailed treatment of the support of Study 8.3.1.16.1.1 to this effort appears in YMP-USGS SP 8.3.1.16.1.1 (Flood potential and debris hazards at the Yucca Mountain site).

The study also has an important relation to Performance Issue 1.8, although the issue is not cited in Table 1.3-1 because it is not directly associated with design and performance parameters.

Performance Issue 1.8
(NRC siting criteria)

Through the site information provided for the resolution of Issue 1.1, the present study addresses some of the favorable and potentially adverse conditions of Issue 1.8. (The reader is referred to SCP Table 8.3.5.17-1 for a full listing of these conditions.) The future response of the hydrogeologic regime to future climate, estimated in Study 8.3.1.5.2.2 with the support of the present study, will address Favorable Condition 1, in which hydrogeologic and tectonic processes that have operated in the Quaternary period, when projected into the future, either will not affect or will favorably affect the ability of the repository to isolate the waste. Future hydrogeologic response to future climate also addresses one part of Favorable Condition 8: that the water table be sufficiently below the repository zone that fully saturated voids contiguous with the water table do not encounter the underground facility. The regional runoff and streamflow study (8.3.1.2.1.2) and flood-potential study (8.3.1.16.1.1) will use data from the regional paleoflood activity to address Potentially Adverse Condition (PAC) 1, Potential for flooding of the underground facility. The future hydrologic-response study (8.3.1.5.2.2) will draw upon several activities in the present study to address PAC 5, Potential for changes in hydrologic conditions that would effect radionuclide migration to the accessible environment; PAC 6, Potential for changes in hydrologic conditions resulting from reasonably foreseeable climatic changes; PAC 22, Potential for water table to rise sufficiently to saturate the underground facility; and PAC 23, Potential for existing or future perched-water bodies. Through the Trench 14 investigations pertaining to timing of fault movement, the present study will indirectly address PAC 4, Adverse effects of faulting on the regional ground-water flow system, and PAC 11, dealing with faulting during the Quaternary period. Through the dating and geochemistry of Trench 14 ash, the present study addresses PAC 15, Evidence of igneous activity since the start of the Quaternary period. Through geochemical aspects of the Trench 14 activity, the present study addresses PAC 17, Presence of naturally occurring minerals of economic interest.

There will be peripheral contributions from the Quaternary regional-hydrology study to several other design and performance issues. These have not been included in Table 1.3-1 so that the emphasis can be kept upon the primary contribution of the study in resolving the future climate/hydrology questions of Issue 1.1, and the secondary contributions to resolving the tectonic and human-interference questions of that issue.

Performance Issue 1.6
(Ground-water travel time)

The present study is expected to contribute indirectly to the estimation of present-day ground-water travel time by its contributions to Investigation 8.3.1.2.1 (Regional hydrologic system). An example occurs in Activity 8.3.1.5.2.1.3, where locations of present discharge areas, nature and extent of geohydrologic units, and hydrologic properties are collected. These apply to Study 8.3.1.2.1.3 as well as to the present study.

Design Issue 1.10
(Waste-package characteristics)

Through the provision of site information from Study 8.3.1.5.2.2 for the resolution of Issue 1.1, the Quaternary regional hydrology study addresses information required for waste-package, near-field environment. Evaluation of future geohydrologic response to future climate change applies indirectly to calculating the quantity of recharge water coming in contact with the waste canisters. Ages of fault movement resulting from the Trench 14 studies in Activity 8.3.1.5.2.1.5 apply indirectly to estimating the number of containers breached in the future by tectonic processes.

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

Through the provision of site information to Study 8.3.1.5.2.2, the Quaternary regional-hydrology study will indirectly address this issue. The characterization of geohydrologic response to future climate, particularly the future fluctuations of the water table, will apply to the performance requirement of maintaining 70 m (230 ft) between the repository disturbed zone and the water table.

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

The present study, through its use in Study 8.3.1.5.2.2, also indirectly addresses this issue. An unsaturated interval of the Topopah Spring Member below the repository zone is a component of seal design, and the continued existence of this interval over the next 10,000 years is contingent upon the response of the hydrologic regime to future climate. The amount of water entering the exploratory shaft, a performance parameter for this issue, will also be directly dependent upon the response of the hydrogeologic regime to future climate.

Through the support of the regional paleoflood evaluation (Activity 8.3.1.5.2.1.1) to the assessment of flood and debris hazards (Study 8.3.1.16.1.1), the present study will support certain design considerations for the repository anchor-to-bedrock plug/seal, general fill, and station plugs. A more detailed treatment of the support of Study 8.3.1.16.1.1 to shaft- and borehole-seals design appears in YMP-USGS SP 8.3.1.16.1.1 (Flood potential and debris hazards at the Yucca Mountain site).

In summary, all four activities in the present study are needed to understand the Quaternary hydrology of the Yucca Mountain region. This understanding is critical to defining the paleoclimate-paleohydrology relationship, which in turn is essential to the prediction of future geohydrologic response to future climate changes.

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Paleohydrology/future-hydrology hypotheses					
Expected magnitude of change in water-table gradient due to climatic change over next 100,000 yr (8.3.5.18)	Controlled area	--	Paleohydrologic flow paths, hydrogenic deposits (8.3.1.5.2.1.5)	Yucca Mountain and surrounding region	Tiva Canyon Member and other units hosting hydrogenic deposits
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) (8.3.5.13)	"	Water table	Potentiometric surface, past (8.3.1.5.2.1.3)	Yucca Mountain and surrrounding region	Unsaturated and saturated zones
Expected magnitude of change in water-table level due to climatic changes over next 100,000 yr (8.3.5.18)	"	--	Recharge rate, past (8.3.1.5.2.1.4)	"	Unsaturated zone

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Paleohydrology/future-hydrology hypotheses					
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) (8.3.5.13)	Repository area	Unsaturated zone			
Expected magnitude of flux change due to climatic changes over 100,000 yr (8.3.5.18)	Controlled area	--			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Faulting - recurrence and potential future activity, regional					
Annual probability of faulting events on Quaternary faults within 0.5 km of controlled-area boundary (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties) (8.3.5.13)	Controlled area	Unsaturated zone	Ages, fault movements (8.3.1.5.2.1.5)	Yucca Mountain and surrounding region	Tiva Canyon Member and other units hosting hydrogenic deposits
Identification and characterization of late-Quaternary faults in the repository block: probability of exceeding 7 cm displacement in areas of waste emplacement (8.3.2.5)	Yucca Mountain	Repository block			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Faulting - recurrence and potential future activity, regional					
Identification of a[illegible] fault within 100 m of FITS with greater than 1 chance in 100 of producing more than 5 cm of surface displacement in 100 yr probability of exceeding 5 cm displacement under FITS (8.3.2.5)	[illegible]tory support facility	Land surface			
Probability of changing dip >2 degrees in 10,000 yr by faulting (scenario class C-1, local or extensive increases in unsaturated-zone percolation flux) (8.3.5.13)	Repository area	Unsaturated zone			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Faulting - recurrence and potential future activity, regional					
Probability of movement within 2 km of surface and location of Quaternary faults in controlled-area (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties) (8.3.5.13)	Controlled area	Unsaturated zone			
Probability of offset >2 m on a fault in the controlled area in 10,000 yr (scenario class C-1, local or extensive increases in unsaturated-zone percolation flux) (8.3.5.13)	Repository area	"			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Faulting - recurrence and potential future activity, regional					
Probability of total offset >2.0 m in 10,000 yr on faults within 0.5 km of controlled-area (scenario class D-2, increased head gradients or changed rock, hydrologic, or geochemical properties in saturated zone) (8.3.5.13)	Controlled area	Saturated zone			
Probability of total offsets >1.0 m in 10,000 yr on faults within 0.5 km of controlled-area boundary (scenario class D-1, appearance of surficial discharge points within controlled area, foreshortening of saturated zone) (8.3.5.13)	"	"			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Faulting - recurrence and potential future activity, regional					
Probability of total offsets >2.0 m in 10,000 yr on faults within controlled-area boundary (scenario class C-2, foreshortening of unsaturated zone) (8.3.5.13)	Controlled area	Unsaturated zone			
Probability of total offsets >2.0 m in 10,000 yr on faults within 0.5 km of controlled-area boundary (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties) (8.3.5.13)	"	"			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Igneous probabilistic models					
Annual probability of a significant igneous intrusion within 0.5 km of the controlled-area boundary (scenario class D-2, increased head gradients or changed rock, hydrologic, or geochemical properties in saturated zone) (8.3.5.13)	Controlled area	Saturated zone	Ages,volcanic events (8.3.1.5.2.1.5)	Yucca Mountain and surrounding region	Tiva Canyon Member and other units hosting hydrogenic deposits
Annual probability of significant igneous intrusions in the controlled area (scenario class C-1, local or extensive increases in unsaturated-zone percolation flux) (8.3.5.13)	"	Unsaturated zone			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
		Igneous probabilistic models			
Annual probability of significant igneous intrusion within 0.5 km of controlled-area boundary (scenario class C-2, foreshortening of unsaturated zone) (8.3.5.13)	Controlled area	Unsaturated zone			
Annual probability of significant igneous intrusion within 0.5 km of controlled-area boundary (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties) (8.3.5.13)	"	"			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Igneous probabilistic models					
Annual probability of significant igneous intrusion within 0.5 km of controlled-area boundary (scenario class D-1, appearance of surficial discharge points within controlled area, foreshortening of saturated zone) (8.3.5.13)	Controlled area	Saturated zone			
Annual probability of significant igneous intrusion within 0.5 km of controlled-area boundary (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties) (8.3.5.13)	"	Unsaturated zone			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Igneous probabilistic models					
Annual probability of volcanic eruption, that penetrates the repository (scenario class A-1, extrusive magmatic events) (8.3.5.13)	Repository area	Unsaturated zone			
Annual probability of volcanic events within controlled area (scenario class C-1, local or extensive increases in unsaturated-zone percolation flux) (8.3.5.13)	Controlled area	"			
Frequency and magnitudes of volcanic ashfall (8.3.5.5)	At facility	Land surface			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Igneous probabilistic models					
Probability of volcanic eruption that would disrupt surface facilities (8.3.2.5)	Repository facilities	Land surface			
Probability of volcanic eruption through area of waste emplacement (8.3.2.5)	Yucca Mountain	Repository block			
Volcanic ash fall [At facility] (8.3.2.3)	Repository area	Land surface			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
		Potential effects of exploiting natural resources			
Expected magnitude of change in water-table level under controlled-area due to mine water usage or mine dewatering near controlled-area in next 10,000 yr (scenario class C-2, foreshortening of unsaturated zone) (8.3.5.13)	Controlled area	Water table	Economic potential, hydrogenic deposits (8.3.1.5.2.1.5)	Yucca Mountain and surrounding region	Tiva Canyon Member and other units hosting hydrogenic deposits
Expected magnitude of changes in distribution coefficients, solubilities and chemical reactivity of the EBS and unsaturated zone units due to mining activities near the controlled-area in next 10,000 yr (scenario class C-3) (8.3.5.13)	"	Unsaturated zone			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Potential effects of exploiting natural resources					
Expected magnitude of changes in distribution coefficients of saturated-zone units due to extensive surface or subsurface mining near controlled-area in next 10,000 yr (scenario class D-2) (8.3.5.13)	Controlled area	Saturated zone			
Expected magnitude of changes in gradients of water table under controlled area due to extensive surface or subsurface mining near controlled-area in next 10,000 yr (scenario class D-2) (8.3.5.13)	"	"			

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
Paleohydrology/future-hydrology hypotheses					
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) (8.3.5.13)	Controlled area	Unsaturated zone	Ages, hydrogenic deposits (8.3.1.5.2.1.5)	Yucca Mountain and surrounding region	Tiva Canyon Member and other units hosting hydrogenic deposits
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) (8.3.5.13)	"	Saturated zone	Hydrologic properties, past (8.3.1.5.2.1.3)	"	Unsaturated and saturated zones

Table 1.3-1 Relations between design- and performance-parameter needs and site-characterization parameter sources (grouped by parameter category) for this study

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Site-characterization parameter	Spatial/geographic location	Geohydrologic-unit/ structural location
		Paleohydrology/future-hydrology hypotheses			
Expected locations of surficial discharge points within the controlled zone due to climatic change over the next 100,000 yr (8.3.5.18)	Controlled area	--	Infiltration rate, past (8.3.1.5.2.1.4)	Yucca Mountain and surrounding region	Unsaturated zone
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) (8.3.5.13)	"	Saturated zone	Paleodischarge, locations and rates (8.3.1.5.2.1.3)	"	Unsaturated and saturated zones

Table 1.3-2. Design and performance parameters supported by the results of this study

Design and performance parameters	Spatial/geo-graphic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
Characteristics and configurations of the repository (preclosure); 8.3.2.3					
Volcanic ash fall (At facility)	Repository area	Land surface	To be evaluated in terms of frequency and consequence	Current - Data not available Needed - Medium	Data not available
Repository construction, operation, closure, and decommissioning technologies; 8.3.2.5					
Identification of any fault within 100 m of FITS with greater than 1 chance in 100 of producing more than 5 cm of surface displacement in 100 yr probability of exceeding 5 cm displacement under FITS	Repository support facility	Land surface	Probability of 5 cm displacement under FITS <.01 in 100 yr	Current - Low Needed - High	Probability <.01 in 100 yr
Probability of volcanic eruption that would disrupt surface facilities	Repository facilities	"	Probability <.0001 in 100 yr	Current - Medium to High Needed - High	Probability <.0001 in 100 yr

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geo-graphic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
Repository construction, operation, closure, and decommissioning technologies: 8.3.2.5					
Identification and characterization of late-Quaternary faults in the repository block: probability of exceeding 7 cm displacement in areas of waste emplacement	Yucca Mountain	Repository block	Probability of 7 cm displacement in waste emplacement area 1 change in 10 in 100 yr	Current - Low Needed - Medium	Probability <0.1 in 100 yr
Probability of volcanic eruption through area of waste emplacement	"	"	Probability <1 x 10^{-6} per yr	Current - Low Needed - High	Probability <1 x 10^{-6} per yr
Exposures to public (credible accidents): 8.3.5.5					
Frequency and magnitudes of volcanic ashfall	At facility	Land surface	Parameter goal to be evaluated in terms of frequency and consequence	Current - Data not available Needed - Medium	Data not available

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
			Total system performance; 8.3.5.13		
Annual probability of volcanic eruption, that penetrates the repository (scenario class A-1, extrusive magmatic events)	Repository area	Unsaturated zone	$<10^{-6}$ per yr	Current - Low Needed - High	SCP Section 1.5.1
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)	"	"	Flux change will be <5 mm/yr with 67% confidence or more	Current - Low Needed - High	SCP Section 3.9.3.3
Probability of offset >2 m on a fault in the controlled area in 10,000 yr (scenario class C-1, local or extensive increases in unsaturated-zone percolation flux)	"	"	$<10^{-1}$	Current - Low Needed - Medium	SCP Section 1.3.2.2

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geo-graphic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
			Total system performance; 8.3.5.13		
Probability of changing dip >2 degrees in 10,000 yr by faulting (scenario class C-1, local or extensive increases in unsaturated-zone percolation flux)	Repository area	Unsaturated zone	$<10^{-4}$ per 10,000 yr	Current - Low Needed - Low	None
Annual probability of volcanic events within controlled area (scenario class C-1, local or extensive increases in unsaturated-zone percolation flux)	Controlled area	"	$<10^{-5}$ per yr	Current - Low Needed - High	SCP Section 1.5.1
Annual probability of significant igneous intrusions in the controlled area (scenario class C-1, local or extensive increases in unsaturated-zone percolation flux)	"	"	"	Current - Low Needed - High	"

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
			Total system performance; 8.3.5.13		
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	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	SCP Sections 3.7.4, 3.9.8
Annual probability of significant igneous intrusion within 0.5 km of controlled-area boundary (scenario class C-2, foreshortening of unsaturated zone)	"	Unsaturated zone	$<10^{-5}$/yr	Current - Low Needed - Medium	SCP Section 1.5.1
Probability of total offsets >2.0 m in 10,000 yr on faults within controlled-area boundary (scenario class C-2, foreshortening of unsaturated zone)	"	"	$<10^{-1}$	Current - Low Needed - Medium	SCP Section 1.3.2.2

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
		Total system performance: 8.3.5.13			
Expected magnitude of change in water-table level under controlled-area due to mine water usage or mine dewatering near controlled-area in next 10,000 yr (scenario class C-2, foreshortening of unsaturated zone)	Controlled area	Water table	No goal (human activity)	Current - Not applicable Needed - Not applicable	None
Annual probability of significant igneous intrusion within 0.5 km of controlled-area boundary (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties)	"	Unsaturated zone	$<10^{-5}$/yr	Current - Low Needed - Medium	SCP Section 1.5.1

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
			Total system performance: 8.3.5.13		
Annual probability of significant igneous intrusion within 0.5 km of controlled-area boundary (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties)	Controlled area	Unsaturated zone	$<10^{-5}$/yr	Current - Low Needed - Medium	SCP Section 1.5.1
Annual probability of faulting events on Quaternary faults within 0.5 km of controlled-area boundary (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties)	"	"	$<10^{-4}$/yr	Current - Low Needed - Medium	SCP Section 1.3.2.2
Probability of movement within 2 km of surface and location of Quaternary faults in controlled-area (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties)	"	"	$<10^{-4}$/yr per fault	Current - Low Needed - Medium	"

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
			Total system performance: 8.3.5.13		
Probability of total offsets >2.0 m in 10,000 yr on faults within 0.5 km of controlled-area boundary (scenario class C-3, changes in unsaturated-zone rock, hydrologic, and geochemical properties)	Controlled area	Unsaturated zone	$<10^{-1}$	Current - Low Needed - Medium	SCP Section 1.3.2.2
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)	"	"	Adverse changes in mineralogy will not occur	Current - Low Needed - Low	None

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
			Total system performance; 8.3.5.13		
Expected magnitude of changes in distribution coefficients, solubilities and chemical reactivity of the EBS and unsaturated zone units due to mining activities near the controlled-area in next 10,000 yr (scenario class C-3)	Controlled area	Unsaturated zone	No goal (human activity)	Current - Not applicable Needed - Not applicable	None
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)	"	Saturated zone	That no surficial discharge points could appear within controlled-area given a water table rise < 160 m	Current - Low Needed - Medium	"

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
			Total system performance: 8.3.5.13		
Annual probability of significant igneous intrusion within 0.5 km of controlled-area boundary (scenario class D-1, appearance of surficial discharge points within controlled area, foreshortening of saturated zone)	Controlled area	Saturated zone	$<10^{-5}$/yr	Current - Low Needed - Medium	SCP Section 1.5.1
Probability of total offsets >1.0 m in 10,000 yr on faults within 0.5 km of controlled-area boundary (scenario class D-1, appearance of surficial discharge points within controlled area, foreshortening of saturated zone)	"	"	$<10^{-1}$	Current - Low Needed - High	SCP Section 1.3.2.2

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
		Total system performance: 8.3.5.13			
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)	--	Saturated zone	Gradients change less than a factor of 4	Current - Low Needed - Medium	SCP Section 3.7.1
Annual probability of a significant igneous intrusion within 0.5 km of the controlled-area boundary (scenario class D-2, increased head gradients or changed rock, hydrologic, or geochemical properties in saturated zone)	Controlled area	"	$<10^{-5}$/yr	Current - Low Needed - Medium	SCP Section 1.5.1

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
			Total system performance: 8.3.5.13		
Probability of total offset >2.0 m in 10,000 yr on faults within 0.5 km of controlled-area (scenario class D-2, increased head gradients or changed rock, hydrologic, or geochemical properties in saturated zone)	Controlled area	Saturated zone	$<10^{-1}$	Current - Low Needed - Medium	SCP Section 1.3.2.2
Expected magnitude of changes in gradients of water table under controlled area due to extensive surface or subsurface mining near controlled-area in next 10,000 yr (scenario class D-2)	"	"	No goal (human activity)	Current - Not applicable Needed - Not applicable	None

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
			Total system performance; 8.3.5.13		
Expected magnitude of changes in distribution coefficients of saturated-zone units due to extensive surface or subsurface mining near controlled-area in next 10,000 yr (scenario class D-2)	Controlled area	Saturated zone	No goal (human activity)	Current - Not applicable Needed - Not applicable	None
			Higher-level findings: geohydrology, geochemistry, rock characteristics, climate changes, erosion, dissolution, tectonics, and human interference; 8.3.5.18		
Expected magnitude of flux change due to climatic changes over 100,000 yr	Controlled area	--	Show expected flux change will be < 5 mm/yr	Current - -- Needed - High	--
Expected magnitude of change in water-table level due to climatic changes over next 100,000 yr	"	--	Show expected magnitude of change in water-table altitude will be <+100 m	Current - -- Needed - Moderate	--

Table 1.3-2. Design and performance parameters supported by the results of this study--Continued

Design and performance parameters	Spatial/geographic location	Geohydrologic-unit/ structural location	Parameter, goal	Parameter confidence, current and needed	Parameter, expected value
Higher-level findings: geohydrology, geochemistry, rock characteristics, climate changes, erosion, dissolution, tectonics, and human interference; 8.3.5.10					
Expected magnitude of change in water-table gradient due to climatic change over next 100,000 yr	Contorlled area	--	Show change will be < 2 x 10^{-3}	Current - -- Needed - Moderrate	--
Expected locations of surficial discharge points within the controlled zone due to climatic change over the next 100,000 yr	Controlled area	--	Show that no significant surficial discharge points could appear within C-area, given a water-table rise <+160 m	Current - -- Needed - Moderate	--

Table 1.3-3. Design and performance issues and parameters indirectly supported by Activity 8.3.1.5.2.2.1 (Regional paleoflood evaluation) by its contribution to Study 8.3.1.16.1.1 (Flood potential and debris hazards)

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 C-1, increased water flux through unsaturated zone

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters from Studies 8.3.1.16.1.1 and 8.3.1.2.1.2	Parameter Location	Site Activity	Contributing Site Parameters from Activity 8.3.1.5.2.1.1	Parameter Location
Parameter Category: Surface-water flood and runoff characteristics							
Expected magnitude of local flux change, and quantitative bounds on magnitude of flux change, due to flooding through access shafts (scenario class C-1, local or extensive increases in unsaturated-zone percolation flux)	Shaft locations; land surface	Goal: Show <25,000 m^3 per yr would pass through access shafts. Current: Low Needed: Medium	Potential for future flooding, magnitude and frequency of flooding at specific locations	Yucca Mountain and vicinity; land surface	8.3.1.16.1.1.1	Paleoflood flows: magnitudes, frequencies, areal extents, and hydraulic characteristics	Yucca Mountain region and site
			Runoff and streamflow, temporal, spatial, and physical characteristics (from Study 8.3.1.2.1.2)	Yucca Mountain; land surface			

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Table 1.3-3. Design and performance issues and parameters indirectly supported by Activity 8.3.1.5.2.2.1 (Regional paleoflood evaluation) by its contribution to Study 8.3.1.16.1.1 (Flood potential and debris hazards)

Issue 1.12 Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.134 and (b) provide information for the resolution of the performance issues? (SCP 8.3.3.2)

Performance Measures: Quantity of water
Drainage capacity

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters from Studies 8.3.1.16.1.1 and 8.3.1.2.1.2	Parameter Location	Site Activity	Contributing Site Parameters from Activity 8.3.1.5.2.1.1	Parameter Location
Parameter Category: Surface-water flood and runoff characteristics							
Quantity of water due to surface flooding events; 100 and 500 yr flood and probable maximum flood, including area of inundation and debris load of flows	Shaft, ramp, and borehole locations; Land surface	Goal: Inundation maps with elevation of inundated area to within +/-2 m Current: Low Needed: Medium	Potential for future flooding, magnitude and frequency of flooding at specific locations	Yucca Mountain and vicinity; Land surface	8.3.1.16.1.1.1	Paleoflood flows: magnitudes, frequencies, areal extents, and hydraulic characteristics	Yucca Mountain region and site
•	•	Goal: Determine topography of drainage area using 2 m contours Current: Medium Needed: Medium	Runoff and streamflow, temporal, spatial, and physical characteristics (from Study 8.3.1.2.1.2)	Yucca Mountain; Land surface			
Magnitude of water entering shafts	ES-1, ES-2, MM and EE shafts	Goal: <150 m^3/yr per shaft considering anticipated processes Current: Low Needed: Low					

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Table 1.3-3. Design and performance issues and parameters indirectly supported by Activity 8.3.1.5.2.2.1 (Regional paleoflood evaluation) by its contribution to Study 8.3.1.16.1.1 (Flood potential and debris hazards)

Issue 1.12 Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the postclosure design criteria of 10 CFR 60.134 and (b) provide information for the resolution of the performance issues? (SCP 8.3.3.2)

Performance Measures: Quantity of water

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters from Studies 8.3.1.16.1.1 and 8.3.1.2.1.2	Parameter Location	Site Activity	Contributing Site Parameters from Activity 8.3.1.5.2.1.1	Parameter Location
Parameter Category: Surface-water debris-transport characteristics							
Quantity of water due to surface flooding events; 100 and 500 yr flood & probable maximum flood, including area of inundation and debris load of flows	Shaft, ramp, and borehole locations; land surface	Goal: Estimates of debris quantity and category Current: Low Needed: Low	Debris transport: locations, quantities, and characteristics (from Study 8.3.1.2.1.2)	Yucca Mountain and surrounding region; land surface	8.3.1.16.1.1.1		
			Potential for future flooding, potential hazards of debris transported by flood flows	Yucca Mountain and vicinity; land surface		Paleoflood debris movement: quantities and characteristics	Yucca Mountain region and site

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Table 1.3-3. Design and performance issues and parameters indirectly supported by Activity 8.3.1.5.2.2.1 (Regional paleoflood evaluation) by its contribution to Study 8.3.1.16.1.1 (Flood potential and debris hazards)

Issue 2.1 During operation, closure, and decommissioning will radiation dose received by public within a highly populated area be less than a small fraction of the allowable limits and in unrestricted area are the limits as required by 10 CFR 60.111, 40 CFR 191? (SCP 8.3.5.3)

Performance Measures: Radionuclides concentrations in environmental media and individual doses

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters from Studies 8.3.1.16.1.1 and 8.3.1.2.1.2	Parameter Location	Site Activity	Contributing Site Parameters from Activity 8.3.1.5.2.1.1	Parameter Location
Parameter Category: Surface-water flood and runoff characteristics							
Volumetric flow of surface water to water bodies	80 km radius; land surface	Goal: Little or no surface runoff Current: Medium Needed: Medium	Potential for future flooding, magnitude and frequency of flooding at specific locations	Yucca Mountain and vicinity; land surface	8.3.1.16.1.1.1	Paleoflood flows: magnitudes, frequencies, areal extents, and hydraulic characteristics	Yucca Mountain region and site
			Runoff and streamflow, temporal, spatial, and physical characteristics (from Study 8.3.1.2.1.2)	Yucca Mountain; land surface	"		

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Table 1.3-3. Design and performance issues and parameters indirectly supported by Activity 8.3.1.5.2.2.1 (Regional paleoflood evaluation) by its contribution to Study 8.3.1.16.1.1 (Flood potential and debris hazards)

Issue 2.3 Can the repository be designed, operated, constructed, closed, and decommissioned in such a way that accidents do not result radiological exposures of the public at the nearest boundary of the area, or workers in the restricted area, in excess of limits? (SCP 8.3.5.5)

Performance Measures: Consequences of credible site-related accidents
Long-term dispersion, diffusion, and bioaccumulation characteristics of the site

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters from Studies 8.3.1.16.1.1 and 8.3.1.2.1.2	Parameter Location	Site Activity	Contributing Site Parameters from Activity 8.3.1.5.2.1.1	Parameter Location
		Parameter Category: ???					
Frequency and magnitudes of repository surface flooding	Repository facilities; land surface	Goal: PMF (Probable maximum flood) Current: Medium Needed: High	Potential for future flooding, magnitude and frequency of flooding at specific locations	Yucca Mountain and vicinity; land surface	8.3.1.16.1.1.1	Paleoflood flows: magnitudes, frequencies, areal extents, and hydraulic characteristics	Yucca Mountain region and site

Table 1.3-3. Design and performance issues and parameters indirectly supported by Activity 8.3.1.5.2.2.1 (Regional paleoflood evaluation) by its contribution to Study 8.3.1.16.1.1 (Flood potential and debris hazards)

Issue 2.3 Can the repository be designed, operated, constructed, closed, and decommissioned in such a way that accidents do not result radiological exposures of the public at the nearest boundary of the area, or workers in the restricted area, in excess of limits? (SCP 8.3.5.5)

Performance Measures: Long-term dispersion, diffusion, and bioaccumulation characteristics of the site

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters from Studies 8.3.1.16.1.1 and 8.3.1.2.1.2	Parameter Location	Site Activity	Contributing Site Parameters from Activity 8.3.1.5.2.1.1	Parameter Location
Parameter Category: Surface-water flood and runoff characteristics							
Volumetric flow of surface water to water bodies	80-km radius; Land surface	Goal: Little or no surface runoff Current: Medium Needed: Medium	Runoff and streamflow, temporal, spatial, and physical characteristics (from Study 8.3.1.2.1.2)	Yucca Mountain; land surface	8.3.1.16.1.1.1		

Table 1.3-3. Design and performance issues and parameters indirectly supported by Activity 8.3.1.5.2.2.1 (Regional paleoflood evaluation) by its contribution to Study 8.3.1.16.1.1 (Flood potential and debris hazards)

Issue 2.7 Have the characteristics and configurations of the repository been adequately established to (a) show compliance with preclosure design (b) provide information for the resolution of performance issues? (SCP 8.3.2.3)

Performance Measures: Ability to detect radioactive materials in repository effluent streams
Decontamination factor

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters from Studies 8.3.1.16.1.1 and 8.3.1.2.1.2	Parameter Location	Site Activity	Contributing Site Parameters from Activity 8.3.1.5.2.1.1	Parameter Location
		[illegible]					
Volumetric flow of surface water to water bodies (80 km radius)	Area within 80 km of site; land surface	Goal: Little or no surface runoff Current: Medium Needed: Medium	Potential for future flooding, magnitude and frequency of flooding at specific locations	Yucca Mountain and vicinity; land surface	8.3.1.16.1.1.1	Paleoflood flows: magnitudes, frequencies, areal extents, and hydraulic characteristics	Yucca Mountain region and site
Repository surface flooding (at facility)	Repository area; land surface	Goal: PMF Current: Medium Needed: High	Runoff and streamflow, temporal, spatial, and physical characteristics (from Study 8.3.1.2.1.2)	Yucca Mountain; land surface	•		

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Table 1.3-3. Design and performance issues and parameters indirectly supported by Activity 8.3.1.5.2.2.1 (Regional paleoflood evaluation) by its contribution to Study 8.3.1.16.1.1 (Flood potential and debris hazards)

Issue 4.4 Are the technologies of repository construction, operation, closure, and decommissioning adequately established for the resolution of the performance issues? (SCP 8.3.2.5)

Performance Measures: Location relative to floodplain
Soil and rock conditions

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters from Studies 8.3.1.16.1.1 and 8.3.1.2.1.2	Parameter Location	Site Activity	Contributing Site Parameters from Activity 8.3.1.5.2.1.1	Parameter Location
Parameter Category: Surface-water flood and runoff characteristics							
Surface hydrology for 10-, 25-, 50-, 100-, and 500-year flood and probable-maximum flood (PMF); area of inundation - maps with elevation of inundation	Repository area; Land surface	Goal: Inundation maps with elevation of inundation area to within +/- 2 m Current: Low Needed: High	Potential for future flooding, magnitude and frequency of flooding at specific locations	Yucca Mountain and vicinity; land surface	8.3.1.16.1.1.1	Paleoflood flows: magnitudes, frequencies, areal extents, and hydraulic characteristics	Yucca Mountain region and site
Surface hydrology for 10-, 25-, 50-, 100-, and 500-year flood and probable-maximum flood (PMF): topography of area of inundation and drainage area	•	Goal: Topography of drainage area 2-m contours Current: Medium Needed: Medium	Runoff and streamflow, temporal, spatial, and physical characteristics (from Study 8.3.1.2.1.2)	Yucca Mountain; land surface	•		
Favorable infiltration/runoff ratio	Yucca Mountain, vicinity of surface facilities; land surface	Goal: See SCP Section 8.3.1.2 (Geohydrology) Current: Low Needed: High					

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Table 1.3-3. Design and performance issues and parameters indirectly supported by Activity 8.3.1.5.2.2.1 (Regional paleoflood evaluation) by its contribution to Study 8.3.1.16.1.1 (Flood potential and debris hazards)

Issue 4.4 Are the technologies of repository construction, operation, closure, and decommissioning adequately established for the resolution of the performance issues? (SCP 8.3.2.5)

Performance Measures: Location relative to floodplain

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters from Studies 8.3.1.16.1.1 and 8.3.1.2.1.2	Parameter Location	Site Activity	Contributing Site Parameters from Activity 8.3.1.5.2.1.1	Parameter Location
Parameter Category: Surface-water debris-transport characteristics							
Surface hydrology for 10-, 25-, 50-, 100-, and 500-year flood and probable-maximum flood (PMF) area of inundation - debris quantity and category	Repository area; land surface	Goal: Debris quantity and category Current: Low Needed: Low	Debris transport: locations, quantities, and characteristics (from Study 8.3.1.2.1.2)	Yucca Mountain and surrounding region; land surface	8.3.1.16.1.1.1		
			Potential for future flooding, potential hazards of debris transported by flood flows	Yucca Mountain and vicinity; land surface	•	Paleoflood debris movement: quantities and characteristics	Yucca Mountain region and site

2 RATIONALE FOR STUDY

2.1 Technical rationale and justification

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

2.1.1 Role of study in assessing future climate effects on hydrologic regime

The primary objective of the climate program is the evaluation of the response of the ground-water regime to scenarios of expected future climate over the next 10,000 and 100,000 years. Understanding the Quaternary regional paleohydrologic regime at Yucca Mountain and vicinity by assessing the evidence (in the light of potential different explanations for past conditions) is essential to this evaluation, because a qualitative and quantitative estimate of the response of the surface-water and ground-water regimes to wetter (pluvial) climate episodes in the Quaternary is a necessary component in predicting the response of the ground-water flow regime to future climatic change. The two other components necessary in this prediction are (1) numerical models of the present ground-water regime, and (2) a prediction of expected future climate scenarios over the next 10,000 and 100,000 years.

To illustrate this approach, the following hypothetical example is offered.

(1) It may be concluded in the present study that at some past time the water table at Yucca Mountain was at a significantly higher elevation than at present, and that this stage correlates with a paleoclimate episode of greater precipitation (a pluvial episode).

(2) It may also be concluded in Study 8.3.1.5.1.6 (Characterization of the future regional climate and environments) that there is a moderate to high probability of the recurrence of a pluvial episode at a given future time and that the meteorological conditions can be estimated.

(3) The projected meteorological data for the future pluvial episode would be used as input to the model of present geohydrologic conditions. The model would be used to calculate the response of the present water table to future increased recharge and may calculate that ground-water travel time to the accessible environment would be shortened at some future time.

Evaluating the relationships between paleoclimate and paleohydrology defined in this study will be one of several components that will culminate in a study predicting the response of the geohydrologic regime to future changes in climate (see Figure 1.3-1). Study 8.3.1.5.1.6 will contribute data on the expected future climate scenarios, estimated timing and probability of occurrence, and meteorological characteristics. Investigation 8.3.1.2.2 (Unsaturated-zone hydrologic system) will result in a model defining flow paths, fluxes, and velocities within the unsaturated zone. Investigation 8.3.1.2.3 (Saturated-zone hydrologic system) will result in a model defining flow paths, fluxes, and velocities within the saturated zone to the accessible environment. Finally, in Study 8.3.1.5.2.2 (Characterization of the future regional hydrology due to climate changes), the above components (meteorology of future climate, paleohydrologic response to paleoclimate, and geohydrologic models) will be integrated to predict the impacts of future climatic change on the unsaturated- and saturated-zone hydrologic systems at Yucca Mountain. Chief among such impacts will be potential changes in the elevation and gradient of the water table and resulting changes in ground-water travel time from that calculated for the present.

The present study is designed to evaluate how Quaternary hydrologic conditions have differed significantly from present conditions because of climatic change. Areas that will be of particular interest are (1) the maximum altitude of the water table during Pleistocene pluvial episodes, (2) the degree to which ground-water flow paths to the accessible environment are shortened by rises in the water table, (3) the degree to which travel time to the accessible environment is reduced by increases in the saturation (i.e., effective permeability) of the unsaturated zone, and (4) the magnitude of increases in recharge during pluvial periods. Combined with future-climate scenarios and a geohydrologic model, the above data will be used in sensitivity analyses of the model to assess how great an infiltration flux might move through the repository in the future, and the possibility of repository flooding due to a rising water table during a future pluvial episode or major tectonic event.

Some of the information from the calcite-silica vein deposits studies, such as the presence of volcanic ash in fracture-filling materials and the relations of mineral-deposit dates to faulting, will apply to volcanic and tectonic site-characterization studies; and some of the Trench 14 geochemical data will bear upon the potential for economic mineralization. The main objective of the paleohydrology study, however, is to describe Quaternary hydrologic conditions so that they can be related (in Study 8.3.1.5.2.2) to the history of Quaternary paleoclimate.

2.1.2 Functions of the activities

The relationships between climate, infiltration, and recharge are of special interest to the paleohydrology study, and these relations will be developed on the basis of their constituent activities. Increased percolation flux in the repository block brought about by a return of pluvial climatic conditions could, if great enough, shorten the ground-water travel time from the repository to the accessible environment by producing a significant rise in water-table elevation in the saturated zone. A possible mechanism for this rise could be that increased infiltration/percolation would change the unsaturated-zone flow regime from predominantly matrix to predominantly fracture flow. In a worst case, the 165-m (540-ft) interval of unsaturated zone below the repository horizon would be saturated and the waste canisters submerged, thus speeding up the radionuclide-release rate. Lesser rises in the water table would not have such deleterious effects, although a shortening of flow paths to the water table would still result.

In order for the synthesis effort of Study 8.3.1.5.2.2 to reliably predict changes in water-table altitude, data will be required on past changes of recharge distribution and discharge positions, as well as sufficiently detailed geometry and hydraulic conductivities of units in the entire flow field (most of the geometry and hydrologic characteristics of units will originate in the geohydrology program - Section 8.3.1.2). The activities in this study have been formulated to provide the data needed to predict water-table fluctuations.

The regional paleoflood evaluation activity (8.3.1.5.2.1.1) is aimed at identifying the evidence and locations of paleofloods, investigating the hydraulic characteristics of selected paleoflood events, and comparing this general and specific evidence with the locations and characteristics of modern flooding and associated geomorphic processes. These findings and comparisons will improve the knowledge of the relationships between current and past flooding, and should be helpful in relating changes in flooding potential to climatic changes. The activity will also compare the characteristics and severity of paleoflooding and associated debris hazards with knowledge of current flood hazards to improve the assessment (in Study 8.3.1.16.1.1) of the potential for flood and debris hazards at the repository and along nearby transportation routes. Paleoflood data and interpretive results from the activity will also be useful for calibrating precipitation-runoff models employed in Activity 8.3.1.5.2.2.1 (Future surface-water hydrology) for evaluating the response of the surface-water regime to probable future climate changes.

The evaluation of past-discharge areas activity (8.3.1.5.2.1.3) will be aimed at gaining a further understanding of Quaternary ground-water conditions by studying these areas for evidence of prior water-table elevation, discharge, and temperature. Prior water-table gradients obtained in part from paleospring elevations are related to prior discharge. Fossil assemblages from paleospring deposits, when compared to the modern spring fauna, can indicate the temperature, water chemistry, and climate conditions at the time the fauna were extant. Flow-rate data of modern springs will be compared with the temperature and chemical data to determine if orifice discharge and pool/pond flushing rates can be expressed in relative temperature and chemical terms. Hypothetically, a spring that maintains a high, uniform, annual discharge rate should result in a pool and orifice whose chemistry and temperature are similar to each other throughout the year. A spring with low or seasonally variable discharge may not dominate the pool, and the pool will be subject to daily and seasonal changes, yielding pool water that is both thermally and chemically variable and thus different from the orifice. The greater the difference between orifice and pool, the lower or more variable the discharge rate. Because ostracodes have both orifice taxa, which include interstitial (hypogen) species, and pool taxa that are ecologically and mineralogically in thermal and chemical balance with their water, distinction of any difference between orifice and pool temperature and chemistry should be possible. Thus an analysis of the fossil ostracodes and knowledge of their life recuirements will allow qualitative estimates of paleodischarge rates anc quantities.

The analog recharge activity (8.3.1.5.2.1.4) is aimed at evaluating the infiltration versus precipitation relationships existing in the past and possibly in the future. By identifying modern settings whose climatic settings are similar to past climatic conditions at Yucca Mountain and studying their characteristics (e.g., meteorology, soils, geology, and plant communities) that are pertinent to infiltration conditions rates of ground-water recharge at these settings can be estimated. These recharge rates can then be applied to estimating recharge during a possible future recurrence of pluvial-climatic conditions.

The calcite and opaline-silica vein deposits activity (8.3.1.5.2.1.5) is principally aimed at acquiring a thorough understanding of the origin of calcite and opaline-silica deposits, such as those in the fault zone intersected by Trench 14, and understanding what these deposits imply about hydrologic conditions at repository depth. Data acquired to the present are consistent with a pedogenic origin for these deposits, but the possibility of origin by ascending waters cannot be ruled out. The data to be collected during the course of the activity will constitute an adequately complete physical description such that different explanations for the origin of the mineralization can be tested against the evidence. A secondary aim of the activity will be to examine the origin of the siliceous deposits in which calcite is absent or only a minor constituent. Some of these siliceous deposits are thought to be older than the calcite and opaline-silica-vein fillings and may be synvolcanic, but none of the ages or modes of origin is known. Several possible modes of origin have been proposed for the calcite and opaline-silica deposits such as those at Trench 14. These include deposition by cool downward-percolating meteoric water, by upward-moving cold or warm ground water, or by forcible injection as a result of a hydrotectonic event. These possible origins would bear upon the interpretation of the Quaternary hydrologic regime at Yucca Mountain and its response to past climatic episodes or tectonic events. Thus, the Yucca Mountain hydrogenic deposits would have a bearing on predictions of repository performance in the future and the possible release of radionuclides to the ground water or land surface. The geochronology of fault-zone fracture-filling materials in Trench 14 will bear upon evaluating the probability of future faulting, the composition and ages of ash stringers in the hydrogenic deposits will bear upon the probability of future volcanism, and the geochemistry of the hydrogenic materials will apply to the potential for economic mineral deposits.

2.1.3 Parameters

Parameters are used as a basis for developing the technical rationale of the planned work. A set of site-characterization parameters for Quaternary regional hydrology was introduced in Section 1.3. These have the purpose of making the results of this study more easily relatable to the overall logic of the climate program and to the requirements of repository design and performance parameters. Table 2.1-1 shows the correlation between the measurable (activity) parameters collected in the activities in the present edition of the study plan and the study parameters originating in those activities. The activity parameters are the same as those listed in the methods summary tables of Sections 3.1, 3.3, 3.4, and 3.5. The table assists in the tracing of site information logically from its origin in the activities, through the climate program, and to its employment in the resolution of design and performance issues (see Figure 1.3-1 and Table 1.3-1).

The measurable parameter information included in the right-hand side of Table 2.1-1 serves three principal purposes. It is needed (1) as indirect input to design and performance analyses, (2) to test hypotheses that support concepts of paleohydrologic conditions, and (3) as input to hydrologic numerical models (discussed in Section 2.1.4). A common requirement of the activity parameters is that sufficient confidence can be placed in their numerical values (where applicable) and in the understanding of their relationships for hypothesis testing. As discussed in Section 1.3, some of the activity parameters on the right-hand side of Table 2.1-1, although not required directly for resolving design and performance issues, are required for evaluating the broad aspects of regional paleohydrology (such as position of the past potentiometric surface) expressed in the site-characterization parameters listed on the left-hand side of Table 2.1-1. In the case of the climate program, the site-characterization parameters address the design and performance parameters through the overall evaluation of regional paleohydrology and subsequently through the evaluation of paleoclimate/paleo-hydrology relations.

A principal strategy of the study is to utilize approaches that minimize uncertainty in the values of the measurable activity parameters and in the understanding of their relations within the constraints of available resources. Some degree of uncertainty is inevitable, because parameters vary in space and time, measurements contain errors, and the parameters of paleohydrologic settings will mainly be results of inferences from measurements of factors influencing, or influenced by, the parameter. The strategy of the study, however, is to increase confidence by utilizing multiple approaches for determining parameters not readily amenable to measurement or analysis, and by testing hypotheses. Table 2.1-1 shows that some parameters listed are being generated by more than one activity (multiple approaches).

A major advantage to using multiple approaches for determining paleohydrologic parameters is that, in general, reliance is not placed on only one test to determine a value for a parameter. Some tests will provide only partial information, whereas others will provide extensive

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
Regional paleoflood evaluation (8.3.1.5.2.1.1)	Relations of paleoflood characteristics to modern flood characteristics	Location and areal extent of alluvial surfaces, erosion scars, and unconsolidated stream-channel deposits
		Lithology of alluvial deposits
		Particle-size distribution of alluvial deposits
		Thicknesses of alluvial deposits and strata
		Relative or absolute ages of deposits and geomorphic surfaces
		Areal distribution of surficial alluvial-deposit types
		Areal extent of surficial alluvial deposits
		Association of alluvial deposit types with particular fluvial processes
		Magnitudes and frequencies of late Quaternary flood-flow and debris-flow events
		Relative or absolute ages of deposits and geomorphic surfaces
		Location and areal extent, erosion scars and hillslope deposits
		Relative ages, alluvial surfaces and deposits
		Relative and absolute ages, alluvial surfaces and deposits

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
		Magnitudes and frequencies of Quaternary flood-flow and debris-flow events
		Hydraulic and debris-transport characteristics of past flood-flow and debris-flow events
Evaluation of past discharge areas (8.3.1.5.2.1.3)	Potentiometric surface, past	Potentiometric surface, modern
		Head, potentiometric, past
		Geohydrologic units: location, type, extent
		Head, potentiometric, present
		Storage coefficient
	Hydrologic properties, past	Correlation of surficial-materials properties (infiltration potential, grain-size distribution) with characteristic spectral responses from LANDSAT TM spectral data
		Estimated infiltration potentials for specific areas
		Geohydrologic units: location, type, extent
		Storage coefficient

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
	Paleodischarge, locations and rates	Locations, modern and past discharge deposits
		Estimated areas for evapotranspiration potentials
		Estimated discharge rates, modern and past discharge areas
		Geohydrologic units: location, type, extent
Evaluation of past discharge areas (8.3.1.5.2.1.3)	Paleodischarge, locations and rates	Chemistry, modern discharge waters
		Temperature, modern discharge waters
		Chemistry, past discharge waters
		Temperature, past discharge waters
		Partitioning coefficient as a function of salinity
		Salinity, past discharge waters
		Discharge rates, modern discharge areas
		Head, potentiometric, past
		Storage coefficient

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
Analog-recharge studies (8.3.1.5.2.1.4)	Infiltration rate, past	Climate, infiltration and recharge, relationships between parameters
		Runoff rate
		Chloride input to infiltrated water
		Infiltration rate
		Chemistry, unsaturated-zone water
Analog-recharge studies (8.3.1.5.2.1.4)	Recharge rate, past	Climate, infiltration and recharge, relationships between parameters
		Recharge rate
		Chemistry, unsaturated-zone water
Studies of calcite and opaline-silica vein deposits (8.3.1.5.2.1.5)	Paleohydrologic flow paths, hydrogenic deposits	Geometry, hydrogenic deposits
		Morphology, hydrogenic deposits
		Lateral and vertical variability, hydrogenic deposits
		Petrology, hydrogenic deposits
		Location and extent, hydrogenic deposits
		Clay mineralogy, hydrogenic deposits

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
Studies of calcite and opaline-silica vein deposits (8.3.1.5.2.1.5)	Paleohydrologic flow paths, hydrogenic deposits	Carbonate and silicate mineralogy, hydrogenic deposits
		Evolution of volatiles as a function of temperature
		Gas compositions, hydrogenic deposits
		Major-, minor-, and trace-element compositions, hydrogenic deposits
		pH, electroconductivity, hydrogenic deposits
		Particle-size distribution, hydrogenic deposits
		Density, hydrogenic deposits
		Temperature of formation, drusy quartz
		Isotopic composition, Trench 14-deposit source waters
		Ages, hydrogenic deposits
		Isotopic compositions, hydrogenic deposits
		Temperature of formation, hydrogenic deposits
		Chemistry, Trench 14-deposit source waters
		Major-, minor-, and trace-element compositions, spring waters

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
	Ages, hydrogenic deposits	Ages, hydrogenic deposits
		Isotopic compositions, hydrogenic deposits
	Ages, fault movements	Geometry, hydrogenic deposits
		Morphology, hydrogenic deposits
Studies of calcite and opaline-silica vein deposits (8.3.1.5.2.1.5)	Ages, fault movements	Petrology, hydrogenic deposits
		Clay mineralogy, hydrogenic deposits
		Carbonate and silicate mineralogy, hydrogenic deposits
		Ages, hydrogenic deposits
		Isotopic compositions, hydrogenic deposits
	Ages, volcanic events	Petrology, hydrogenic deposits
		Carbonate and silicate mineralogy, hydrogenic deposits
		Major-, minor-, and trace-element compositions, hydrogenic deposits

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
	Economic potential, hydrogenic deposits	Petrology, hydrogenic deposits
		Major-, minor-, and trace-element compositions, hydrogenic deposits
		Temperature of formation, hydrogenic deposits
		Paleohydrologic flow paths, hydrogenic deposits

information necessary for determination of a parameter. By combining the test results and studying their relations, a greater understanding of, and confidence in, any particular parameter can be achieved.

Paleo-water temperature is an example of a parameter that may be estimated or cross-checked using two different methods. The isotopic compositions of oxygen and hydrogen in some minerals deposited from ground water are temperature dependent, and mineral phases indicate a specific temperature range of deposition. Biological indicators, such as ostracodes, are also temperature dependent; some species live in a very restricted temperature environment. When both the biological indicator and the mineralogical indicators are present in the same sample, the temperature determined by all indicators should agree.

The possibility that one or more tests may fail in achieving the desired objectives is recognized; therefore, multiple approaches for determining parameters will be used to increase confidence that the failure or the partial failure of one or more tests will not severely inhibit the ability of the characterization activities in providing the information required.

Table 2.1-2 lists certain current hypotheses concerning the relationships between paleohydrology and Quaternary paleoclimate, particularly how past infiltration and recharge responded to past levels of precipitation.

In conducting preliminary performance and design analyses, assumptions must be made about the values of some parameters, and about paleohydrologic processes and conditions. The tests and analyses of the activities of the present study have been designed such that the collected evidence is sufficient to allow the weighing of alternate hypotheses. These preliminary analyses (for example, running the hydrologic models to predict the response of the water table to a predicted future climate scenario) may include assumptions involving values of such parameters as infiltration rates, recharge rates, and transmissivity of hydrogeologic units. The on-going process of hypothesis testing helps to increase confidence that the assumptions made in preliminary analyses are reasonable.

2.1.4 Contributions of the study to geohydrologic models

The principal function of the site-characterization parameters collected in the present study is the evaluation of the Quaternary regional paleohydrology. These parameters are subsequently associated with the regional paleoclimate history to establish a paleohydrology/paleoclimate history relationship, and this relationship is then synthesized with models of present-day geohydrology and predictions of future climate to estimate future hydrological response to future climate.

The information pertaining to surface- and ground-water hydrology developed during this study, however, can also be applied to the

Table 2.1-2. Relations between Quaternary regional hydrology hypotheses and the objectives of the activities of this Study (SCP Study 8.3.1.5.2.1)

Hypothesis	SCP number	Activity objectives
Flood magnitudes and frequencies have probably been irregular and episodic during recent geologic times	8.3.1.5.2.1.1.	To determine the correspondence between late Quaternary-age floods and climate events.
The regional ground-water flow system is located in an area of regional extensional stress, resulting in a tendency for many large fractures to remain open for long periods of time.	8.3.1.5.2.1.3.	To (1) determine location and geohydrologic characteristics of paleo-springs, (2) understand past and present discharge areas of regional hydrologic system to predict future saturated-zone hydrologic system at Yucca Mountain, (3) determine location, type, and extent of geohydrologic units, (4) determine past ground-water levels in carbonate caverns, (5) understand the past quantity and quality of water in discharge areas, and (6) determine location and amount of evapotranspiration
Faults, lineaments, and other fractures may be barriers to ground-water flow, depending upon relationship of ground-water flow direction and geologic stress.	8.3.1.5.2.1.3	•
Faults, lineaments, and other geologic structures are the principal routes for the movement of water from the recharge areas to discharge points south of Yucca Mountain	8.3.1.5.2.1.3	•
Increase or decrease of ground-water discharge will result in a change of water level beneath Yucca Mountain or a change in ground-water velocity.	8.3.1.5.2.1.3	•
Two or more subregional ground water flow systems exist in the area near Yucca Mountain, but because of geologic structure, such as major lineament systems, the subregional flow systems may be analyzed independently.	8.3.1.5.2.1.3	•
Knowledge of present-day recharge under different climatic conditions will provide information to estimate recharge during various Pleistocene climates.	8.3.1.5.2.1.4	To estimate recharge to the paleohydrologic regime in the Yucca Mountain vicinity under wetter climatic conditions.
Ground-water recharge and accumulation of various salts, such as chloride and carbonate, under similar vegetational, climatic, and geological regimes are not time dependent. Recharge during the late Pleistocene in pine forests with volcanic soil was the same as the present day under the same conditions.	8.3.1.5.2.1.4	•

Table 2.1-2. Relations between Quaternary regional hydrology hypotheses and the objectives of the activities of this Study (SCP Study 8.3.1.5.2.1)

Knowledge of Pleistocene recharge will provide information as to the effects of different recharge rates on the water table near Yucca Mountain.	8.3.1.5.2.1.4	To estimate recharge to the paleohydrologic regime in the Yucca Mountain vicinity under wetter climatic conditions.
Ground-water recharge and accumulation of various salts, such as chloride and carbonate, under similar vegetational, climatic, and geological regimes are not time dependent. Recharge during the late Pleistocene in volcanic soil was the same as the present day under the dame conditions.	8.3.1.5.2.1.4	To estimate recharge to the paleohydrologic regime in the Yucca Mountain vicinity under monsoonal conditions.
The calcite and opaline-silica vein deposits of Trench 14 were formed by upward-moving water forcibly injected as the result of a hydrotectonic event.	8.3.1.5.2.1.5	To determine the origin of the calcite and opaline-silica vein deposits at Trench 14 and other locations in the Yucca Mountain vicinity, and determine what bearing, if any, that origin would have on future hydrology at repository depth.
The calcite and opaline-silica vein deposits of Trench 14 were formed by upward movement of warm water from a deep hydrogeologic flow system.	8.3.1.5.2.1.5	•
The calcite and opaline-silica vein deposits of Trench 14 were formed by the upward movement of cold water from a shallow hydrogeologic flow system.	8.3.1.5.2.1.5	•
The calcite and opaline-silica vein deposits of Trench 14 are of pedogenic origin (downward-percolating cold water).	8.3.1.5.2.1.5	•

development of surface-water, unsaturated-zone, and saturated-zone models describing present hydrologic regimes.

The geohydrologic program will consist of two hydrologic models that will describe two distinct zones of the hydrologic system: the unsaturated zone and the saturated zone. Each of these zones is impacted by surface water, and so a surface-water model will be developed to provide connections with the other two hydrologic models. The hydrologic models will be used at many stages to perform preliminary analyses, to design and analyze tests and experiments, and to analyze and interpret field data. The principal hydrologic-modeling effort, however, is to construct mathematical representations to simulate the present and expected future geohydrologic system and its components.

Figures 2.1-1a through 2.1-1d are logic diagrams of the surface-water, unsaturated-zone, and saturated-zone hydrologic models (adapted from those in SCP Section 8.3.1.2). Their purpose is to illustrate the use of site information from the Quaternary regional hydrology study in the hydrologic models, which together constitute one component in evaluating future geohydrologic response to future climate changes.

The unsaturated-zone and saturated-zone hydrologic models contain four major components: (1) geohydrologic framework, (2) rock material properties, (3) initial and boundary conditions, and (4) hydrologic hypotheses. The first three components form the basis for developing the numerical models that quantitatively describe various aspects of the zone. These components also support the fourth component: the hypotheses of conditions, parameters, and processes.

Taking the logic diagram of the unsaturated zone (Figure 2.1-1c) as an example, it can be seen that the present study contributes site information to three of the model components: geologic framework, material properties, and initial and boundary conditions.

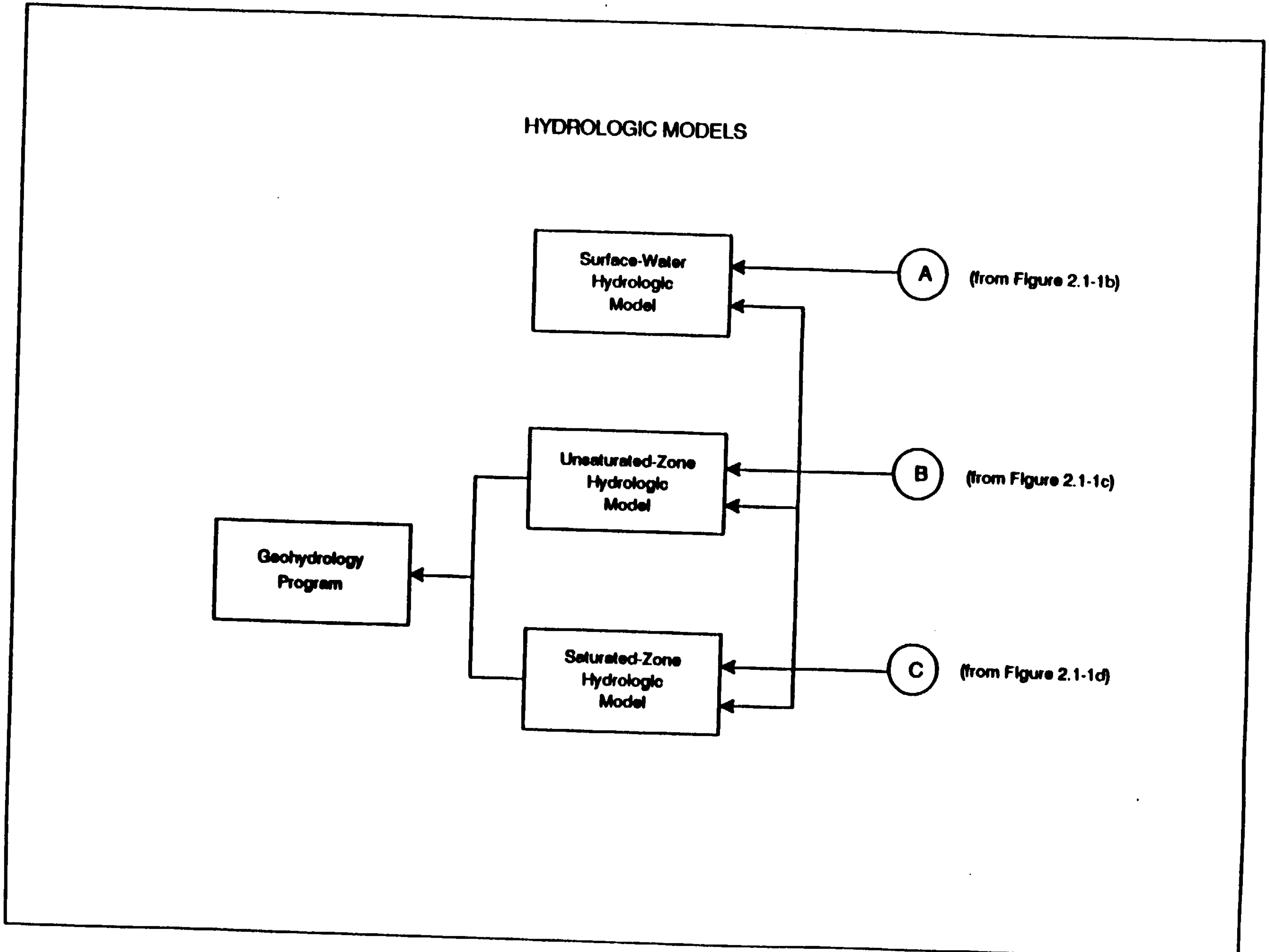


Figure 2.1-1a. Logic diagram showing contributions of Quaternary regional hydrology study to geohydrology-program models.

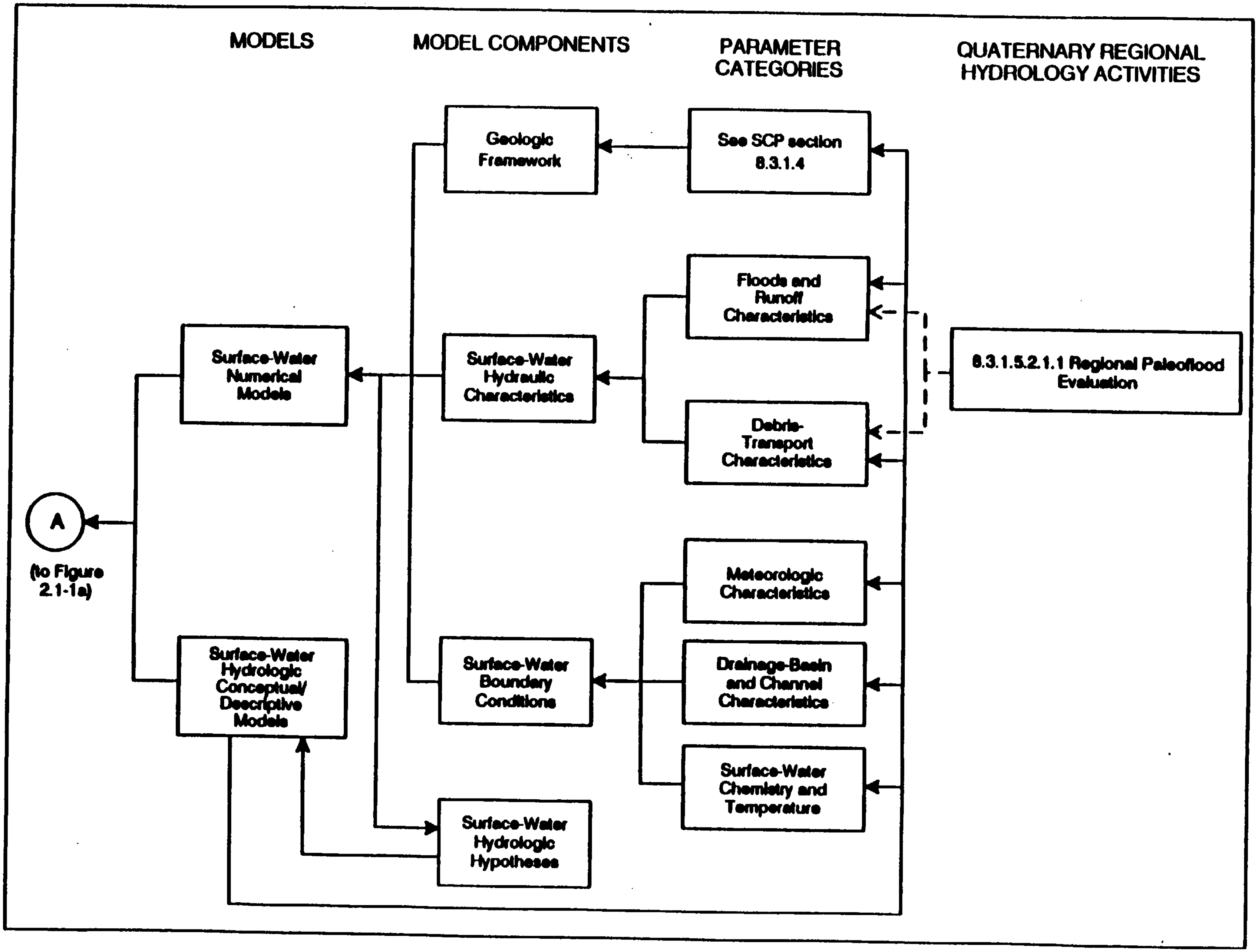


Figure 2.1-1b. Logic diagram showing contributions of Quaternary regional hydrology study to geohydrology-program models: Surface-water hydrologic model.

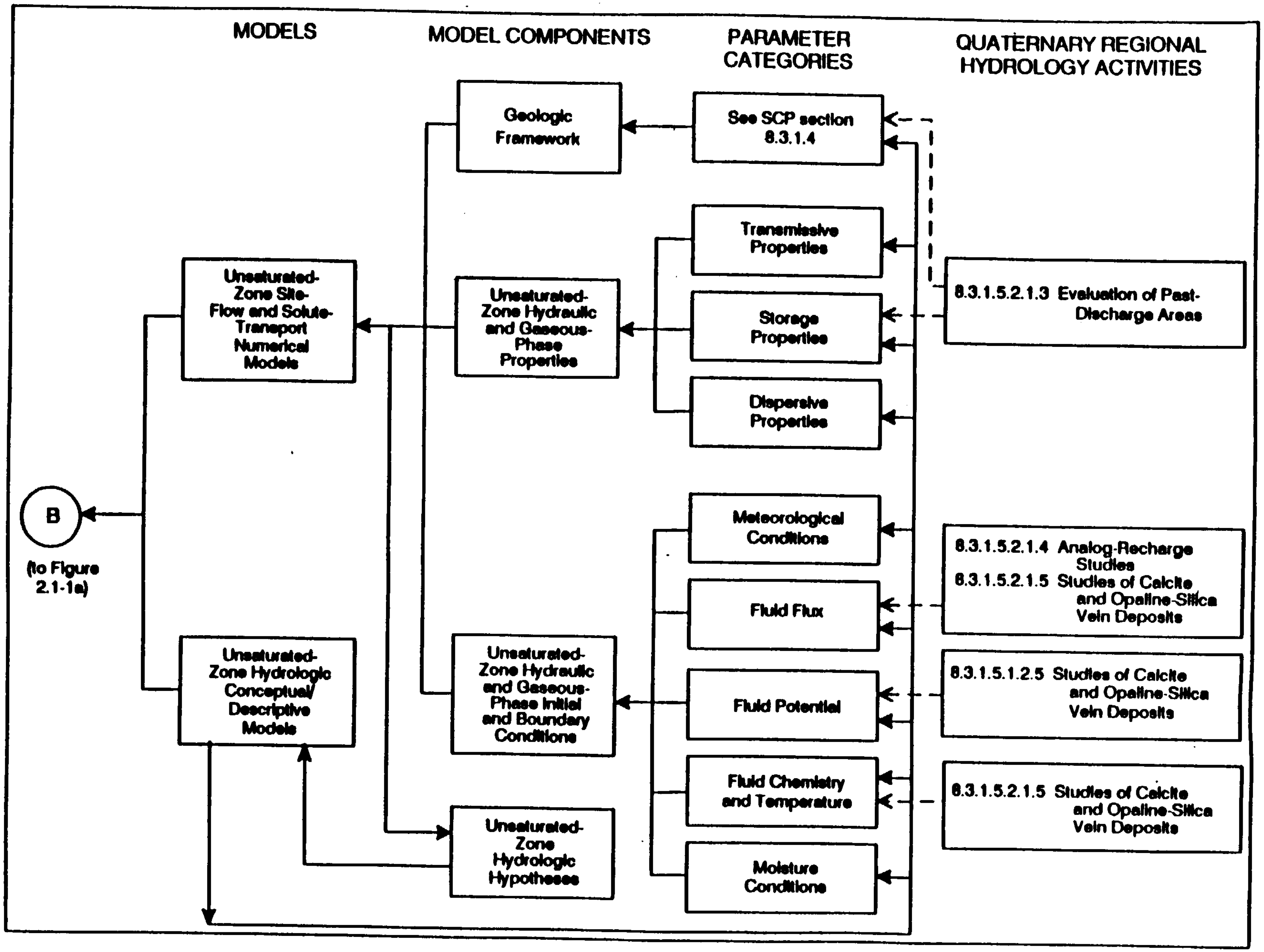


Figure 2.1-1c. Logic diagram showing contributions of Quaternary regional hydrology study to geohydrology-program models: Unsaturated-zone hydrologic model.

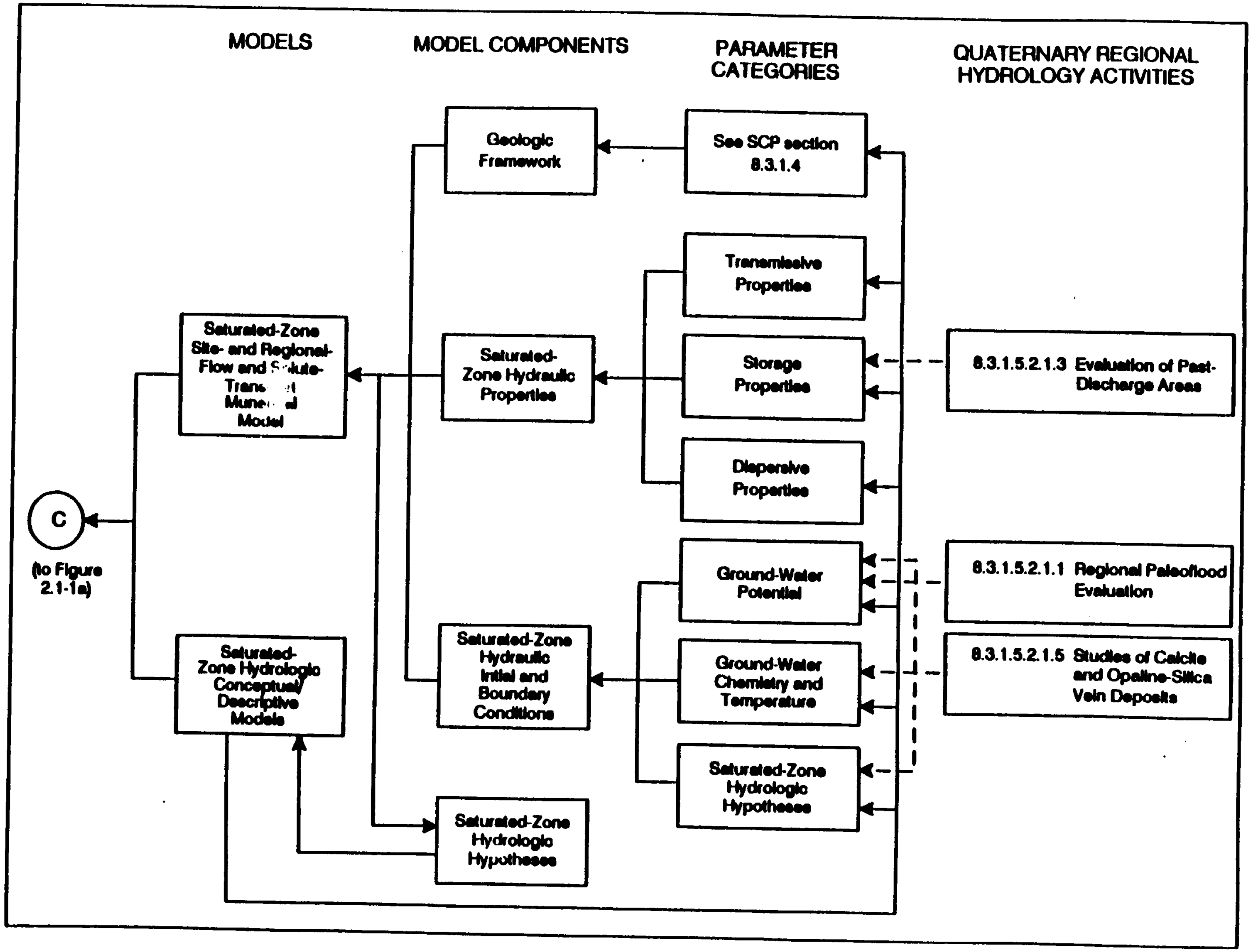


Figure 2.1-1d. Logic diagram showing contributions of Quaternary regional hydrology study to geohydrologic system models: Saturated-zone hydrologic model.

2.2 Constraints on the study

2.2.1 Representativeness of repository scale and correlation to repository conditions

In the regional paleoflood evaluation (Activity 8.3.1.5.2.1.1), a substantial amount of regional paleoflooding evidence is known to be contained within the Yucca Mountain region (for this activity, an arbitrary zone within an approximate 322-km (200-mi) radius from Yucca Mountain). The data collection may also encompass particular sites outside this zone, where the investigators can identify conditions that are analogous to paleoflooding at Yucca Mountain and environs. Thus the geomorphic and stratigraphic evidence assembled in the activity is expected to correlate with the hydrologic conditions of paleoflood events at Yucca Mountain.

Because the evaluation of past-discharge areas (Activity 8.3.1.5.2.1.3) and the analog-recharge activity (Activity 8.3.1.5.2.1.4) are regional efforts, they are not constrained by considerations of scale. The future regional hydrology study (8.3.1.5.2.2), the principal recipient of site information from the present study, will directly estimate future hydrologic conditions at the repository.

Considerations of scale apply to the evaluation of the hydrogenic deposits exposed at Trench 14. The processes responsible for the deposition of calcite and opaline silica and the consequent geohydrologic conditions will have to be projected to repository depth. Conditions at depth, associated with some origins, can be predicted with high confidence. For example, if the deposits represent a discharge point for a regional aquifer, the repository zone would have been saturated at the time the deposits formed. If the deposits represent a near-surface process (for example, pedogenic origin or discharge of a small perched system), conditions at repository depth cannot be projected with as much certainty. Conditions existing at the scale of the deposit at Trench 14 will also have to be projected to a larger scale so as to include deposits in other fractures that will not be investigated in as much detail. The confidence placed on these extrapolations will depend on the size and type of the data base available for the less-studied deposits.

2.2.2 Accuracy and precision of methods

Selected and alternate methods for testing in the activities are discussed in subsequent sections and are summarized in tables at the end of the activity sections. These methods were selected on the basis of their precision and accuracy, duration, and interference with other tests and analyses. The accuracy and precision of each of the techniques described in Section 3 are discussed in various publications describing the methods and will be defined, as appropriate, in the technical procedures developed for their implementation. The Yucca Mountain Quality Assurance Plan (QAP), NNWSI 88-9, Revision 2 requires that each technical procedure contain several types of information including, for example:

(1) requirements for precision and accuracy;

(2) acceptance and rejection criteria;

(3) calibration requirements;

(4) methods of documenting the precision and accuracy of the data;

(5) the means for ensuring that prerequisites were met; and

(6) potential sources of error and uncertainty in measurements and the means to control them.

The accuracy and precision of the various methods described in Section 3 have not been a constraint (i.e., have not been a discriminating factor) on their selection for use in this study. Each of the techniques has been judged to be adequate for the currently planned uses of the data (as described in Sections 1, 2 and 4). For most techniques, the actual accuracy and precision are affected by a combination of analytical and theoretical uncertainties which makes quantification of potential errors, in advance, difficult. The requirements for accuracy and precision of the various tests will be defined by the investigators, based on their experience and evaluation of the data obtained. Final uses of the data will, similarly, be constrained by the quality of the results obtained.

The analytical techniques to be used in the study are largely standard types of analyses. None of the proposed tests will require more than normal levels of accuracy or precision as compared to typical scientific investigations.

2.2.3 Potential impacts of activities on the site

The work described in this study plan will have no adverse affect on the capability of Yucca Mountain to isolate waste. The planned work for Activity 8.3.1.5.2.1.5 does include drilling of shallow holes, up to about 96 m (315 ft) in depth, and trenching within the controlled area at Yucca Mountain, but outside the repository block. Dry-drilling techniques will be utilized for all holes within the controlled zone, and analyses presented in SCP Section 8.4.3 indicate that surficial trenches and dry-drilled holes will not compromise the performance of the site.

The proposed work for Activity 8.3.1.5.2.1.1 calls for possible additional trenching in alluvial deposits in neighboring stream channels north and south of Coyote Wash, and at other as yet unspecified locations within the Nevada Test Site and the region surrounding Yucca Mountain. Any necessary permitting or environmental analysis required for trenching will be initiated when specific trench sites are selected.

The proposed work in Activities 8.3.1.5.2.1.3 and 8.3.1.5.2.1.4 occurs throughout the Yucca Mountain region outside of the controlled area for the proposed repository, and therefore will not affect repository performance.

The proposed work for Activity 8.3.1.5.2.1.5 should not affect the site in terms of either exploratory shaft or repository design. There are no known interferences with other studies. Samples taken from trenches, however, will have to be collected after mapping studies have been completed.

The study will not require any permitting or environmental analysis at the Nevada Test Site; however, some of the active springs that may provide the best sites to study possible analogs to the deposit in Trench 14 are located off the Nevada Test Site. Thus, special requirements between federal agencies may be necessary before samples can be collected at these sites.

2.2.4 Time required versus time available

The work for Activity 8.3.1.5.2.1.1 is constrained by time, and the reconnaissance phase may take several years to satisfactorily complete. The detailed-phase time schedule cannot be completed until the reconnaissance phase is complete because sites for detailed investigation will be selected through a process of screening the results of the reconnaissance effort. Therefore, the reconnaissance effort needs to be started as soon as possible.

The work for Activities 8.3.1.5.2.1.3 and 8.3.1.5.2.1.4 is also constrained by time. Efforts such as the analog-recharge studies require the collection of continuous data sets during a long period of time, in this case a minimum of five consecutive years at each site. The study of the paleodischarge areas will require at least five years from start, depending upon obtaining all necessary approvals for land entry, etc., early in the work. As with all scientific investigations exploring the unknown, time estimates will change as the study progresses.

The proposed work for Activity 8.3.1.5.2.1.5 needs to be started early. Each of the activity components described in Section 3.5 can be completed in less than 24 months, but several of the activities cannot be started until others are completed or at least underway.

Section 5.1 describes a proposed schedule for the four activities described in the next section.

3 DESCRIPTION OF ACTIVITIES

The study is organized into four activities:

- o 8.3.1.5.2.1.1 - Regional paleoflood evaluation,
- o 8.3.1.5.2.1.3 - Evaluation of past-discharge areas,
- o 8.3.1.5.2.1.4 - Analog-recharge studies, and
- o 8.3.1.5.2.1.5 - Studies of calcite and opaline-silica vein deposits.

SCP Activity 8.3.1.5.2.1.2 has been omitted from the study for reasons documented by a proposed change request.

3.1 Regional paleoflood evaluation

3.1.1 Objectives

The objectives of this activity are:

1. identify the locations and investigate the hydraulic characteristics of selected paleoflood events and compare this general and specific evidence with the locations, characteristics, and associated geomorphic processes of modern flooding. These findings and comparisons will improve knowledge of the relationships between current and past flooding, and will help relate changes in flooding potential to climatic changes; and

2. compare paleoflooding and associated debris hazards with current flood hazards to improve the assessment of the potential for flood and debris hazards at the repository and within the region during the preclosure period.

3.1.2 Rationale

The storage of high-level nuclear wastes requires long-term (10,000 yr or longer) protection of the environment from the hazards posed by the progressive decay of radioactive products. Long-term data collection for acceptable site characterization of current and future precipitation-runoff relations is therefore required. While site-characterization activities of the regional surface-water runoff and streamflow characteristics (Study 8.3.1.2.1.2) and assessments of the processes and products of flooding and associated debris transport (Study 8.3.1.16.1.1) attempt to characterize potential flood and debris hazards at Yucca Mountain, these data may not be adequate for characterizing possible events that may occur during the next 10,000 years or longer because runoff in the arid Yucca Mountain region is inherently too infrequent and erratic to fully develop such attributes.

For this reason, the regional paleoflood evaluation activity will attempt to supplement the modern hydrologic data base with evidence of past (prehistoric and historic) flooding and associated debris transport processes that may be derived from the arid geologic landscape of the Yucca Mountain region. This supplemental spatial and temporal information will effectively (1) broaden our understanding of the qualitative and quantitative relationships between floods and climatic events of the late Quaternary, (2) help to more fully describe modern-day streamflow and debris flow features that have been observed at the site, and (3) contribute useful parameters necessary for the calibration of the precipitation-runoff model that will be used to evaluate surface runoff conditions due to future climatic change (SCP Activity 8.3.1.5.2.2.1).

3.1.3 Approach

Paleofloods, as defined for this activity, are ancient streamflow and overland sheetflood events of Quaternary age. Although this investigation will primarily focus on erosional and depositional features generated by ancient (prehistoric) flood events, it will also concentrate on unrecorded (historic) floods that may have occurred prior to Yucca Mountain site-characterization activities (i.e., prior to 1983). The investigation will strive to discern information about both processes and products of severe surface-runoff events to improve understanding of past and present floods and their relationship to climatic events.

The regional paleoflood evaluation activity will interact with a variety of other Yucca Mountain site-characterization activities. These include: (1) Characterization of the Yucca Mountain regional surface-water runoff and streamflow (Study 8.3.1.2.1.2); (2) Studies to determine present locations and rates of surface erosion (Investigation 8.3.1.6.1); (3) Site flood and debris hazards (Study 8.3.1.16.1); (4) Analysis of the paleoenvironmental history of the Yucca Mountain region (Study 8.3.1.5.1.4); (5) Climatic implications of terrestrial paleoecology (Study 8.3.1.5.1.3); and (6) Future surface hydrology due to climate changes (Activity 8.3.1.5.2.2.1). Of these investigations, Activities 8.3.1.6.1.1.3 (Analysis of hillslope erosion at Yucca Mountain) and 8.3.1.16.1.1.1 (Site flood and debris hazards studies) are most closely related. For example, data on hillslope erosion will include information about the temporal and spatial characteristics of hillslope debris movement, which is essential information for assessing how past and present floods are related to climate.

3.1.4 Analysis products

An outline of the tasks anticipated for the regional paleoflood evaluation activity is presented in Figure 3.1-1. A descriptive heading for each task or analysis procedure is shown in the shadowed boxes (second row), as are individual methods for each task. Figure 3.1-2 summarizes the objectives of the study, and gives site-characterization parameters to be addressed, and activity parameters to be described or measured; these appear in boxes in the top left, top right, and below the shadowed task/analysis boxes, respectively.

The investigative strategy is dual phased. It consists of a regional reconnaissance phase and a more detailed, site-specific phase. Although the reconnaissance phase will generally precede the site-specific phase, the two can overlap.

During the regional reconnaissance phase, a geomorphologic inspection of the region surrounding Yucca Mountain will be conducted to record the locations and physical characteristics of past flooding, such as erosion scars and sedimentary deposits caused by the transport of debris by channelized fluvial processes and overland debris flows. The reconnaissance phase will yield a synoptic survey of regional paleoflood features and enable selection of appropriate sites (i.e., those considered valuable for their paleoflood information) for more detailed analysis. Ultimately, these sites will be more closely investigated during the site-specific phase of this study. At that time, geomorphic analyses of erosional and depositional evidence of past flood events will be evaluated and regional trends in flood magnitudes and (or) frequencies will be recorded. The information obtained from this dual-

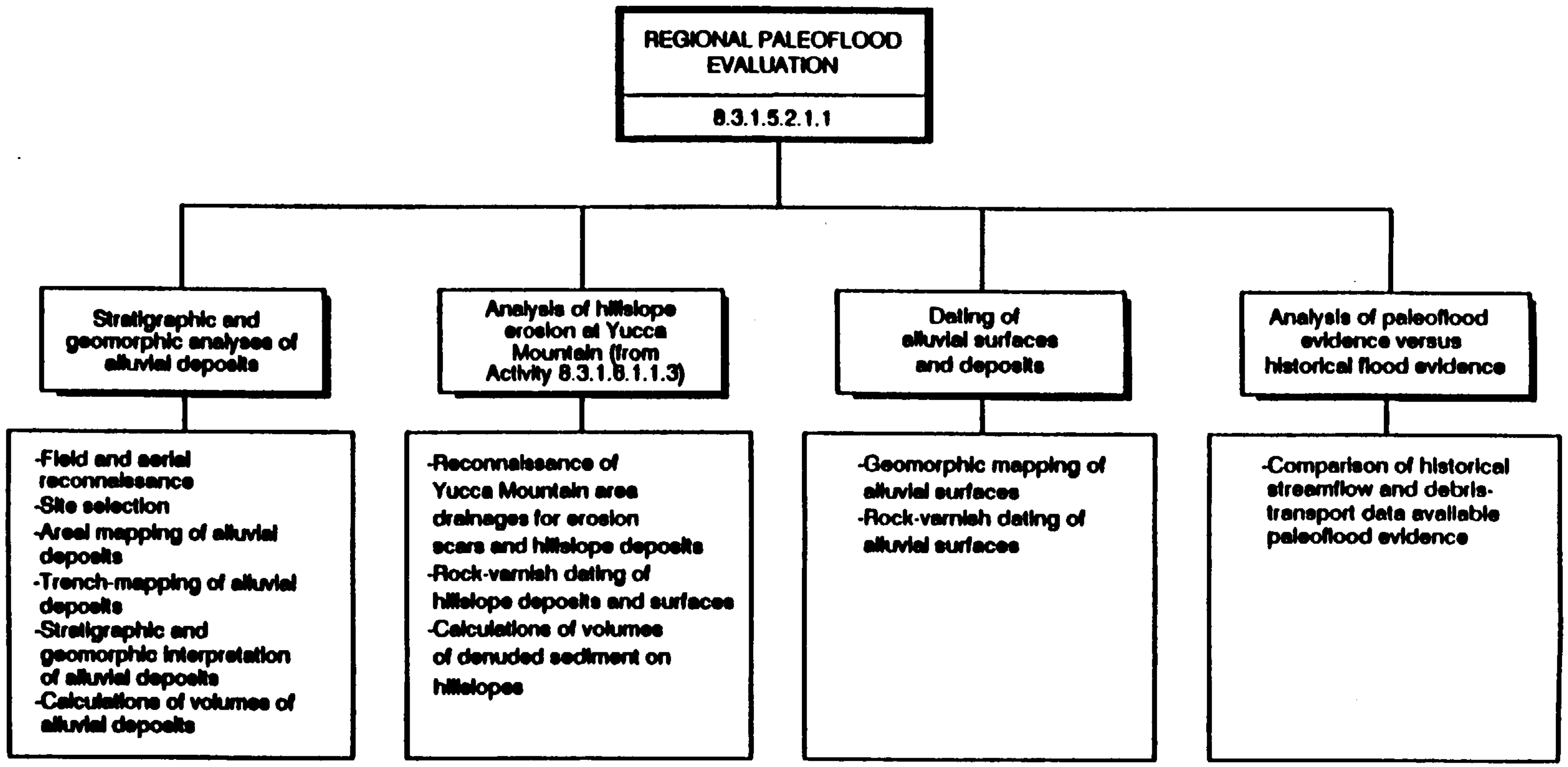
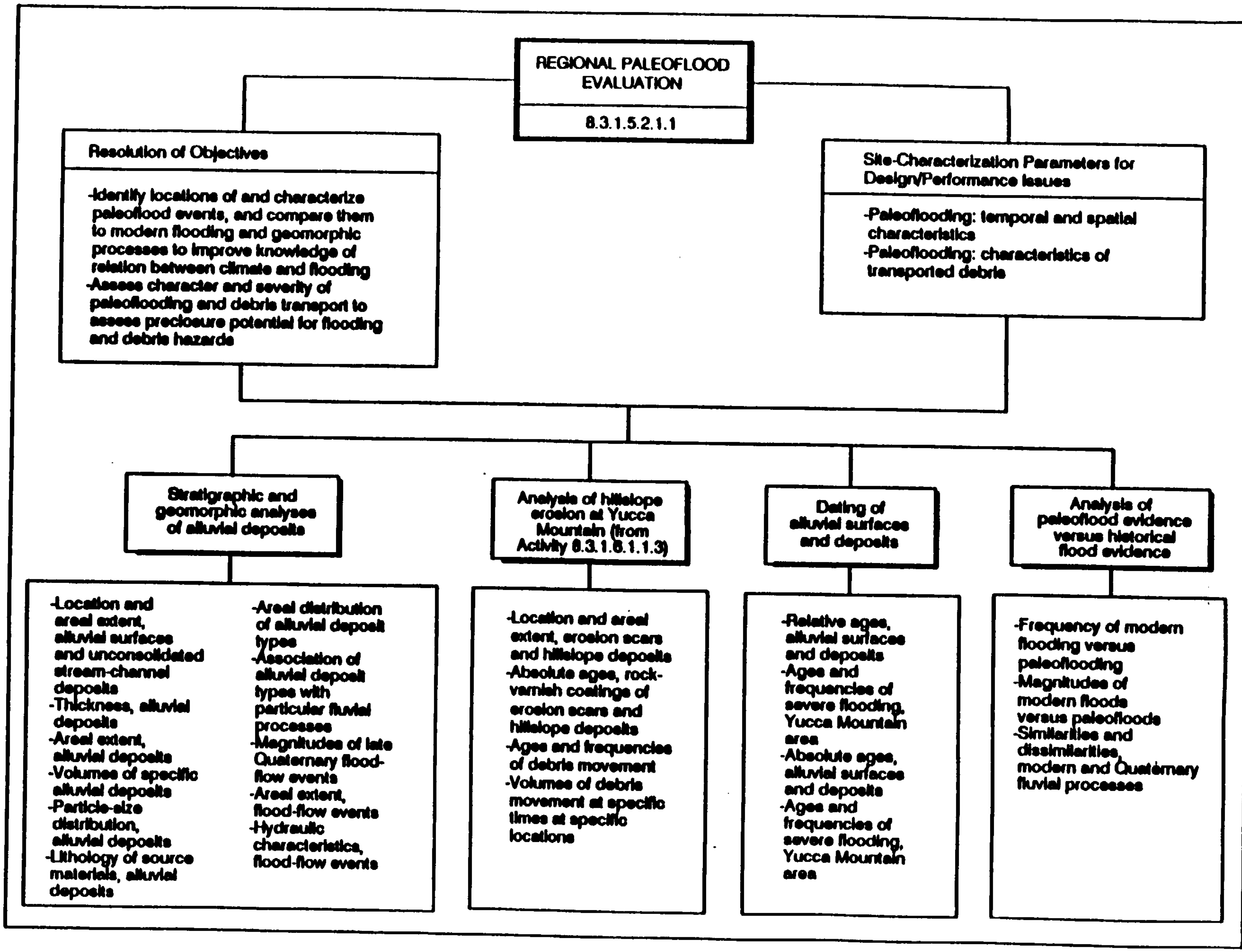


Figure 3.1-1. Logic diagram of regional paleoflood evaluation activity, showing tasks and methods.



F' 'ure 3.1-2. Logic diagram of regional paleoflood e 'uation activity, showing tasks and activity parame' phased investigation will constitute the scientific products of the regional paleoflood evaluation.

On the basis of knowledge about paleoclimatic conditions (Spaulding, 1983), it can be hypothesized that flood magnitudes and frequencies were probably irregular and episodic during late-Quaternary time. If the paleoflood record proves to be episodic in terms of the magnitudes and frequencies of flooding, as hypothesized, we will try to correlate these episodes with aspects of the paleoclimatic record for the region.

3.1.5 Study area

Reconnaissance efforts of the regional paleoflood evaluation will be conducted within a 200-mile radius surrounding Yucca Mountain (Figure 3.1-3). This area was chosen because it encompasses the geographically integral landscape of the southern Great Basin as defined by Fenneman (1931). The intensity of the reconnaissance activities, however, will not be uniform throughout this area. Instead, it will be more comprehensive nearest to Yucca Mountain and in those areas having comparable geologic and (or) hydrologic properties.

The study area is further divided into two areas to guide the investigation (Figure 3.1-3). The primary area, scheduled for more intensive reconnaissance and site-specific investigation, lies within 80.5 km (50 miles) of Yucca Mountain. A secondary area of somewhat less intensive investigation lies between the 80.5 km (50 mile) and 321.9 km (200 mile) radii boundaries. For example, the drainages of Coyote, Sever, and Drillhole Washes on the east-facing slope of Yucca Mountain are areas of critical interest within 80.5 km (50 miles) of Yucca Mountain. It should also be noted, however, that even if an area lies outside the 80.5 km (50 mile) boundary it may receive particular scrutiny if it is perceived to contain important paleoflood evidence. For example, while a major portion of the Amargosa River Basin lie farther than 80.5 km (50 miles) from Yucca Mountain, the entire river basin is of interest to this study because of its potential for supplying vital paleohydrologic information. Similarly, the Mojave River system will undoubtedly receive attention because it could contain important paleoflood information essential to this regional evaluation.

Thus, the study area boundaries are meant as flexible guides in that they set approximate limits for investigative planning and communications. We feel that an area's hydrologic similarity to Yucca Mountain is of foremost importance. For this reason, the most effective investigative strategies for the reconnaissance and site-specific activities will be developed to addresses the goals of this investigation. The more intensively studied sites will therefore undoubtedly lie near Yucca Mountain. It is anticipated, however, that important sites having comparable hydrologic and geomorphic features to Yucca Mountain will lie outside the 80.5 km (50 mile) boundary.

3.1.6 General analysis procedures

The reconnaissance effort will be geared to obtaining locational and physical evidence of regional paleofloods, debris flows, and other

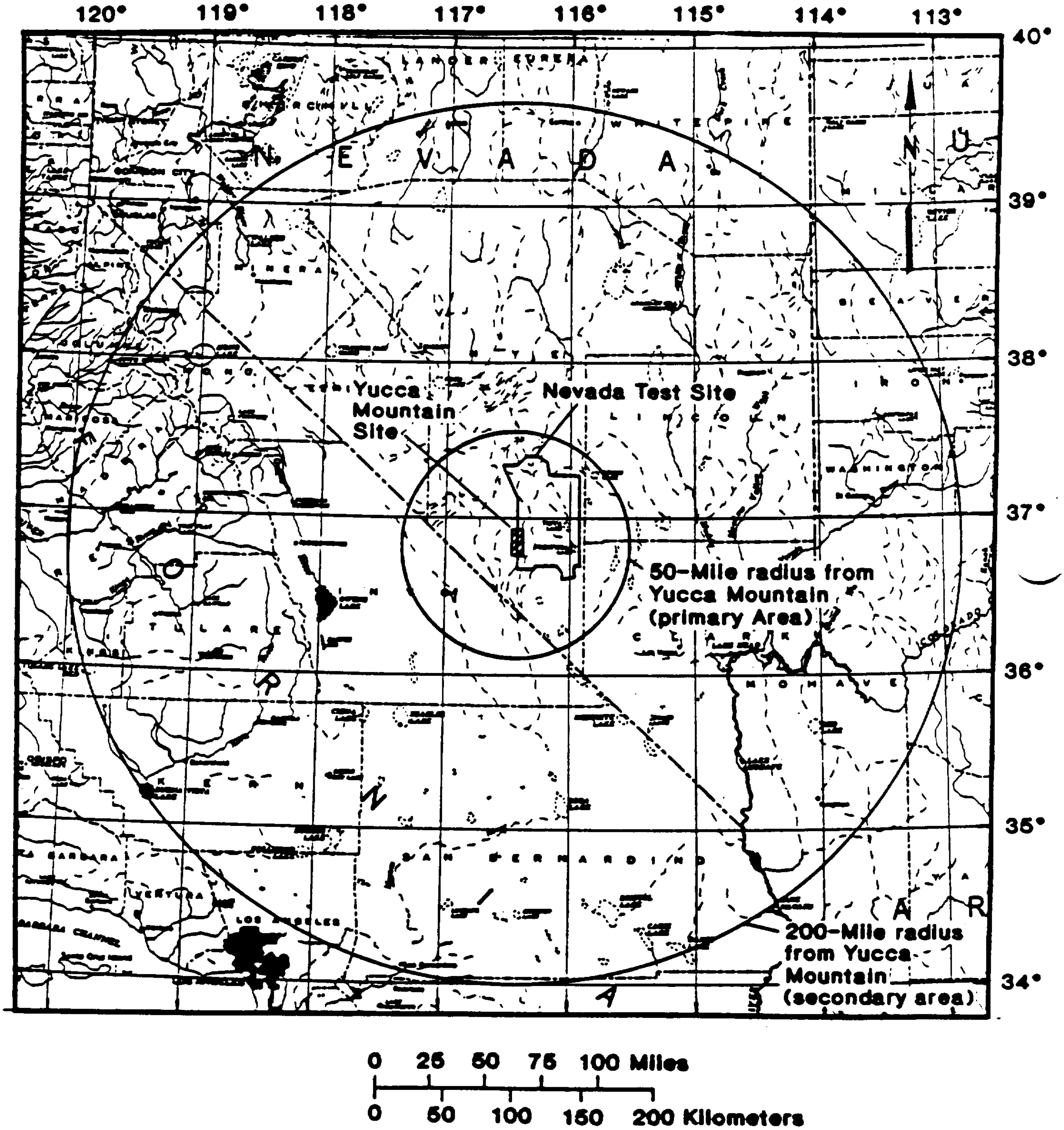


Figure 3.1-3. Primary and secondary areas for the paleoflood investigation.

unusual erosional and depositional features caused by surface-water runoff under changing climatic regimes of the late Quaternary. In addition, the reconnaissance effort will be used to screen newly discovered sites that may qualify for further site-specific analysis. Site selections will be made on the basis of an area's potential for contributing additional paleoflood information that will further our understanding of flood potentials, flood processes, and associated flood hazards at Yucca Mountain. Ultimately, many of these sites will be more intensively investigated during the site-specific phase of this study.

The site-specific phase will more fully address the objectives of this investigation. These investigations will identify (1) the paleoflood magnitudes and frequencies of paleofloods, (2) the geographic distributions of flood events, (3) certain landscape characteristics that may have contributed to the floods, (4) those hydraulic and geomorphic processes that may have caused the floods, and (5) the relative and (or) absolute ages of individual flood events. Through these site-specific investigations, information will be gained about the types, sizes, geographic distributions, and physical characteristics of past flood events. This information will then be compared with that for modern-day flood events in order to predict the potential of future flood events in the vicinity of Yucca Mountain.

3.1.6.1 Site selection

A number of sites will be selected for more detailed, site-specific analysis during the reconnaissance phase. Site selection will be based on whether a site can contribute additional, pertinent information about the region's paleoflood history or the potential of flood and debris flow hazards at Yucca Mountain. While the number of sites necessary to satisfy the objectives of this activity are currently unknown, the actual number of sites required, or available, will be established during late stages of the reconnaissance effort. At that time, selected sites will be assigned a priority based on (1) the degree of likelihood that a more detailed site-specific analysis will provide needed paleoflood information for the YMP, (2) the anticipated level of knowledge that can be gained for an acceptable level of expended effort, (3) the cost of conducting the investigation, (4) the perceived ease of data acquisition and personnel requirements in terms of both man hours and experience, (5) constraints that might be placed on the field inquiry by property owners, and (6) the degree and amount of land disturbance that may be potentially caused by the investigation.

Amongst the site selection criteria, the ease with which needed information can be collected and the cost of the investigation are of particular importance. For example, although the 1983 trenching at Coyote Wash yielded data needed to select a safer site for the proposed exploratory shaft, the trenches were quite expensive and the resulting disturbance to the landscape was particularly severe. In contrast, naturally exposed sedimentary deposits along the Amargosa River Canyon near Tecopa, California, would require little or no trenching, and the potential for these deposits to yield abundant stratigraphic data related to the paleoflood history of the region is very promising. For this reason, Amargosa Canyon present an opportunity that is both scientifically promising and economically feasible in that detailed studies of these deposits would not adversely degrade the landscape. In other areas where sedimentary strata are not as readily available for detailed investigation, however, supplementary trenches or bore holes may be needed.

3.1.6.2 Example of a site-specific investigation

As is apparent from the foregoing discussion, the reconnaissance phase will generally precede the more detailed, site-specific phase of this investigation. In some special cases, however, a detailed study may be needed before or during the reconnaissance phase. The following is an example of one such investigation, which is discussed in detail by Glancy (1991, in review).

Although the systematic reconnaissance phase had not yet begun in 1983, there was an immediate need to assess the potential hazards of flooding and associated debris transport to the site of a proposed exploratory shaft in Coyote Wash along the east flank of Yucca Mountain. A field investigation of the Coyote Wash drainage, upstream from the proposed shaft site, disclosed an area of fluvial sediments that was judged to be an acceptable candidate for a more detailed stratigraphic examination. It was also thought that these deposits might provide needed clues on the history of flooding within the drainage.

The investigation required excavating two trenches into the sedimentary deposits (Figure 3.1-4). The trenches exposed stream channel deposits that record a complex sequence of debris-flow and flood-flow events. A field examination of the stratigraphy of these deposits showed that flooding had occurred many times in Coyote Wash during Quaternary time. Old flood deposits, including debris-flows, that were exposed by the trenches provided evidence of the thicknesses and lithologic character of the emplaced debris and the hydraulic characteristics of the fluids that emplaced these deposits.

A significant finding of this study, which is also supported by reconnaissance observations of other nearby drainages, is that channels near Yucca Mountain have experienced both flooding and debris flows in the recent geologic past. The deposits document a series of flows of unknown magnitudes that range in age up to at least a few thousand years old. Also, the investigation gave a sense of the quantity and character of debris that is potentially available for remobilization by future floods. If these deposits were remobilized during future flood events, they would pose a significant potential hazard to planned downstream structures.

This added knowledge of the paleoflood history of Coyote Wash, and the quantity of debris available for future transport, thereby improved our understanding of the potential for future flood-related debris hazards to the site initially selected for the exploratory

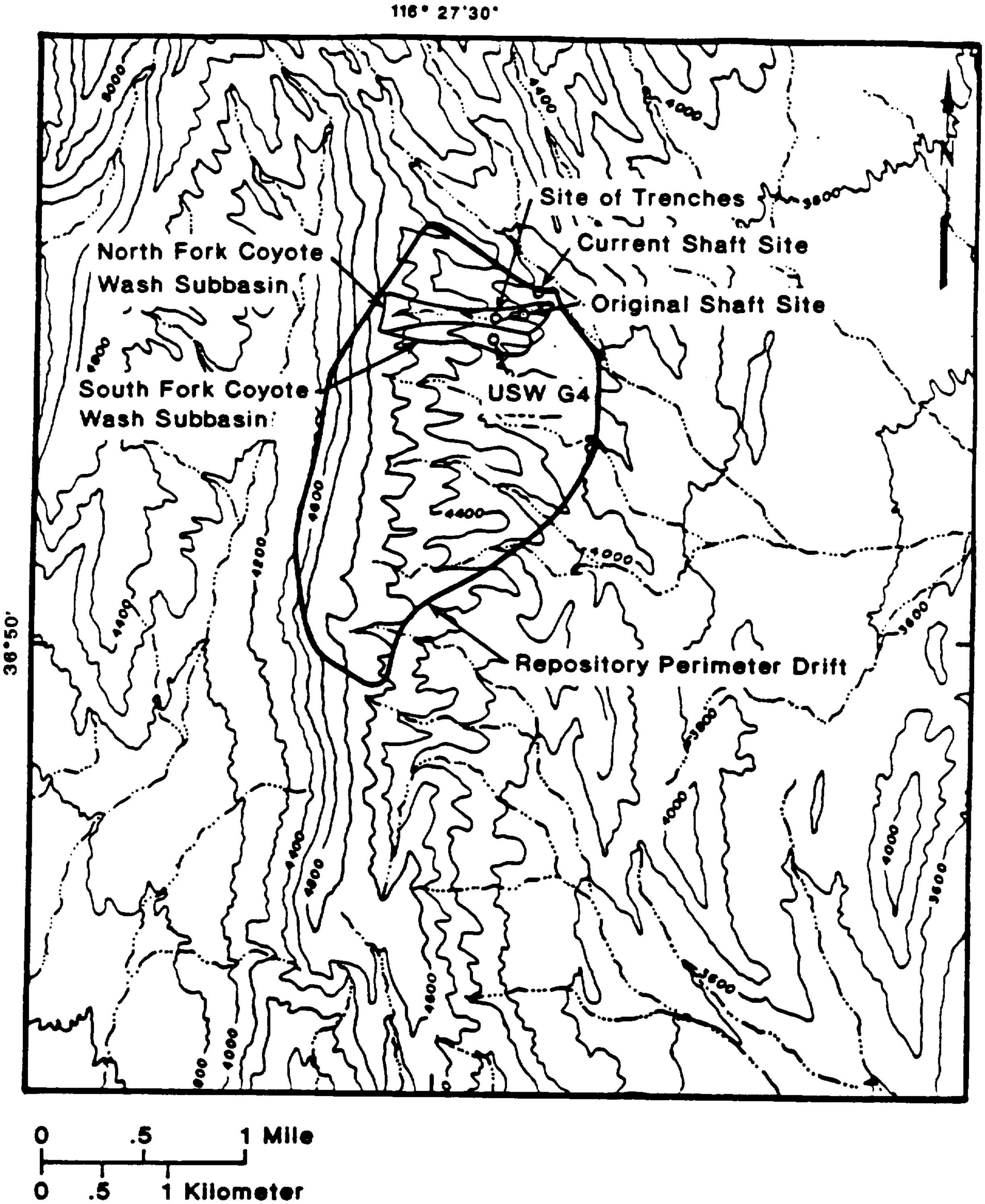


Figure 3.1-4. Location of trenches excavated to study streamflow deposits in Coyote Wash.

shaft. The location of the shaft site was subsequently moved to a site deemed safer by the combined results of this new information and other complementary flood-prediction work.

Although this more detailed study was done before the regional-reconnaissance phase, the data gathered were of a site-specific nature. The results would have undoubtedly been improved, however, by information that could have been gathered through a regional-reconnaissance phase followed by a more detailed, site-specific study. The immediate need for site-specific data and interpretations, however, could not await completion of the reconnaissance phase. The two-stage strategy presented in this study plan must therefore be flexible enough to meet the wide variety of needs and changing demands required by the Yucca Mountain Site Characterization Project.

3.1.7 Investigative strategy

3.1.7.1 Reconnaissance investigations

An initial effort of the regional paleoflood evaluation will involve a regional reconnaissance of the area surrounding Yucca Mountain (Figure 3.1-3). The study will focus on discovering evidence of Quaternary-age floods and debris flows that will provide needed information to satisfy the objectives of the Yucca Mountain Project. The reconnaissance effort will consist of an examination of the locations and geographic distributions of paleoflood features from digital landscape data, aerial photographs, multispectral satellite images, and field evidence. The combined aerial and field reconnaissance effort will provide a means for identifying and classifying paleoflood features throughout the region. From these investigations it will be possible to select candidate sites for more detailed, site-specific analysis using site selection criteria presented in Section 3.1.6.1 (Site selection, above).

Because the degree of complexity of the site analysis will not be known until the reconnaissance phase is well underway, much of the initial reconnaissance effort will focus on sites exhibiting obvious and easily recognizable paleoflood evidence. These sites will encompass large areas and contain deeply entrenched streams, prominent erosion scars, and extensive depositional landforms of strategically emplaced fluvial sedimentary deposits. Many of these larger sites will therefore be recognizable from satellite images or aerial photographs. In the vicinity of Yucca Mountain, for example, a number of unique sites of past flooding are obvious. One such site is the broad and deeply incised channel of Fortymile Wash. Other less obvious sites that can also contain equally meaningful data, however, may not be so easy to recognize. In these cases, subtle landscape expressions of past flooding, such as small erosional scars and depositional landforms or buried stratigraphic evidence, will need to be identified in the field. Thus, field reconnaissance activities will provide a means for inspecting sites identified by aerial reconnaissance techniques and permit discovery of smaller sites or sites containing subsurface stratigraphic evidence.

3.1.7.2 Site-specific investigations

The site-specific phase of this study will consist of a more detailed examination of stratigraphic and geomorphic evidence of paleoflooding at selected sites in the Yucca Mountain region. It will involve a detailed investigation using both aerial and field analysis methods. The aerial analysis approach will use computer mapping and image processing technologies to classify and measure the geographic distribution of erosional and depositional features, as well as landscape characteristics that may have contributed to paleoflooding in the area. Various data sets will be used including digital elevation and slope models, black-and-white and color-infrared aerial photographs, multispectral satellite images, and published map information. The field effort, on the other hand, will provide a means for field checking the aerial measurements, and will ascertain more detailed evidence about the physical, surface and subsurface characteristics of the features. It will therefore involve site-specific stratigraphic and geomorphic analyses of fluvial sedimentary deposits, investigation and documentation of hillslope erosion, and an analysis of the relative and absolute ages of such fluvial features as floodplains, terraces, and buried soil deposits that may provide evidence of the temporal nature of past flood events.

The level of detail of the site-specific investigations will inherently exceed that of the reconnaissance phase. At those sites exhibiting high potential for paleoflood evidence, or where an exhaustive search for evidence is necessary, the site-specific analysis effort will seek suitable physical exposures for detailed examination and measurement of stratigraphic evidence that may be concealed beneath the present-day land surface. While every attempt will be made to locate sites of natural stratigraphic exposure (e.g., cut river banks and exposed terrace edges), some sites will undoubtedly require excavation by trenching or boring equipment to expose essential geologic materials for further analysis.

3.1.7.2.1 Stratigraphic and geomorphic analyses

Analyses of stratigraphic and geomorphic evidence at selected sites will generate data on the thicknesses, particle-size distributions, and lithologies of paleoflood deposits, and provide a means for determining essential qualitative and quantitative characteristics of the flow or flows that generated the deposits. Where deposits are sufficiently continuous across valley or up and down valley, for example, estimates of peak discharge may be possible. Although estimates of the total flow volume will probably be impossible, these investigations should generate abundant data on the areal extent of surficial paleoflood landforms and their mode of deposition.

The stratigraphy and geomorphology of features described and mapped at various sites throughout the region will subsequently be interpreted to ascertain crucial information about regional paleoflooding. This information will include (1) the nature of the erosional and depositional processes responsible for the origin of paleoflood landforms, (2) the peak discharge of individual flood events, (3) the magnitudes and frequencies of late-Quaternary flooding, and (4) the relative and absolute ages of severe flood events. These interpretations will also attempt to establish estimates of the discharge characteristics, such as sediment concentration and presence or absence of yield strength, for individual flow events.

3.1.7.2.2 Analysis of hillslope erosion

Activity 8.3.1.6.1.1.3 (Analysis of hillslope erosion at Yucca Mountain) will contribute data on the effects of severe Quaternary runoff events on hillslope-debris transport. Drainage areas of concern will be examined for erosion scars and hillslope deposits. Erosion scars, stone stripes, and other debris deposits will also be studied to determine the geomorphic processes responsible for their formation. Features that may be products of past, extreme surface-water runoff events will be further examined and described, and their locations and areal extents recorded. The widespread presence of stone stripes on hillslopes near Yucca Mountain may provide evidence of past debris flows and related slope failures.

The abundance of cobbles and boulders covering much of the steeply sloping terrain around Yucca Mountain is of concern because these materials may become entrained during future hillslope erosional events and move downslope, in mass, as a debris flow. Improved knowledge of the age and genesis of these deposits would therefore confirm or allay concerns that they pose a potential future hazard. The results of this investigation will additionally be used by the Site flood and debris-hazards studies (Activity 8.3.1.16.1.1.1).

3.1.7.2.3 Dating of alluvial surfaces and deposits

During reconnaissance and site-specific investigations attempts will be made to date both unconsolidated alluvial surfaces (e.g., alluvial fan and terrace surfaces) and subsurface stream-channel deposits. Because much of the unconsolidated debris comprising alluvial surfaces in the region was emplaced by surface runoff events, a determination of the ages of these surfaces would provide valuable knowledge of the ages of past flood events. More specifically, these age dates will depict the recency of severe flooding and show whether severe runoff events at Yucca Mountain were episodic or continuous during the late Quaternary. Absolute age dates would additionally be useful in determining the recurrence interval of hillslope debris movement and channelized flood events that may, in the future, pose a threat to repository structures.

Relative and absolute chronologies of surface flow events will be determined based on surface and subsurface analyses of alluvial sediments and soils, regional and site-specific geomorphic mapping, and absolute dates derived using available radiometric techniques, such as the isotopic methods U-trend, U-series, Be, and C. In addition, the chronologies of alluvial surfaces and debris deposits may also be determined, or refined, on the basis of the newly developed rock-varnish dating technique described in SCP Section 8.3.1.6.1.1.3. The dating method(s) that will be used will be applied as specific conditions and technologies warrant. Attempts will also be made to develop additional methods or derive criteria for dating geomorphic features for the purpose of increasing the value of these erosional and depositional data with regard to their age and frequency.

3.1.7.2.4 Analysis of paleoflood evidence versus historical flood evidence

Activity 8.3.1.16.1.1 (Characterization of flood potential and debris hazards of the Yucca Mountain site) will compare the evidence of paleoflooding with the magnitudes and frequencies of historical floods. The streamflow and runoff information collected as part of Study 8.3.1.2.1.2 (Characterization of runoff and streamflow) will be used to assess the frequencies and magnitudes of present-day flooding at Yucca Mountain. Evidence and knowledge of paleoflooding will be compared with that developed for current flooding for the purpose of determining whether present-day floods are more or less frequent, or more or less severe, than those in the past. In addition, modern channel and hillslope processes and their resultant sedimentary deposits will also be compared with those of the past. These comparisons will enable determination of similarities and differences between present and past paleoflood processes and forms.

3.1.7.3 Methods summary

The parameters to be determined by the tasks and analyses described above and the selected methods for determining the parameters, are presented in Table 3.1-1. Alternative methods will be used to supplement these methods, where practical. In some cases there are several approaches to conducting a task. In those cases, only the most common methods are included in the table. The selected methods in Table 3.1-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range of results, and possible interference with other tasks and analyses.

The USGS investigators have selected methods that they believe to be suitable in providing the best possible data within the expected range of a parameter. Currently available analytical techniques will be used, when possible, to provide the required information. The development and use of new or better investigative techniques will be attempted when possible, and(or) when they are needed.

3.1.8 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires assignment, justification, and documentation of quality levels to activities that affect quality; and documentation of technical procedures for all technical activities that require quality assurance. Table 3.1-2 provides a complete tabulation of technical procedures applicable to this activity. Approved procedures are identified with USGS number.

Equipment requirements and instrument calibration are described in the technical procedures. Included in these documents are (1) lists of equipment and stepwise procedures for the use and calibration of equipment, (2) limits, accuracy, handling, and calibration needs, (3) quantitative or qualitative acceptance criteria of results, (4) description of data documentation, (5) identification, treatment and control of samples, and (6) records requirements.

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Table 3.1-1. Summary of tests and methods for the regional paleoflood evaluation activity (SCP 8.3.1.5.2.1.1)

Methods	Activity parameter
Discovery and study of paleoflood evidence in the Yucca Mountain region by reconnaissance	
Field and airphoto reconnaissance	Location and areal extent of alluvial surfaces, erosion scars, and unconsolidated stream-channel deposits
Screen and select candidate sites for subsequent detailed study	(Does not directly generate activity parameter)
Extract, compile, and interpret paleoflooding evidence	(Same activity parameters as for stratigraphic and geomorphic analyses of alluvial deposits)
Stratigraphic and geomorphic analyses of alluvial deposits	
Trench-mapping of alluvial deposits	Lithology of alluvial deposits
"	Particle-size distribution of alluvial deposits
"	Thicknesses of alluvial deposits and strata
"	Relative or absolute ages of deposits and geomorphic surfaces
Areal mapping of alluvial deposits	Areal distribution of surficial alluvial-deposit types
"	Areal extent of surficial alluvial deposits
Stratigraphic and geomorphic interpretation of alluvial deposits	Association of alluvial deposit types with particular fluvial processes

Table 3.1-1. Summary of tests and methods for the regional paleoflood evaluation activity (SCP 8.3.1.5.2.1.1)--Continued

Methods	Activity parameter
Stratigraphic and geomorphic analyses of alluvial deposits	
Stratigraphic and geomorphic interpretation of alluvial deposits	Magnitudes and frequencies of late Quaternary flood-flow and debris-flow events
"	Relative or absolute ages of deposits and geomorphic surfaces
Analysis of hillslope erosion	Location and areal extent, erosion scars and hillslope deposits
Geomorphic mapping of alluvial surfaces	Relative ages, alluvial surfaces and deposits
Dating of alluvial surfaces and deposits	Relative and absolute ages, alluvial surfaces and deposits
Analysis of paleoflood evidence versus historical flood evidence	
Compare paleoflood evidence with magnitudes and frequencies of historical floods	Magnitudes and frequencies of Quaternary flood-flow and debris-flow events
Compare past fluvial and hillslope deposits to modern channel and hillslope geomorphic processes	Hydraulic and debris-transport characteristics of past flood-flow and debris-flow events

Table 3.1-2. Technical procedures and quality-assurance level assignments for the regional paleoflood evaluation (SCP Activity 8.3.1.5.2.1.1)

Technical procedure number (NWM-USGS-)	Technical procedure
	Stratigraphic and geomorphic analyses of alluvial deposits
TBD	Techniques for measuring and characterizing fluvial-sediment deposits
TBD	Techniques for measuring stream-channel and hillslope erosion
TBD	Techniques for mapping surficially exposed fluvial deposits
GP-27	Trench wall and natural outcrop sampling for coordinated studies
TBD	Trench, map, and analyze stream-channels deposits
TBD	Sampling of alluvial surfaces and unconsolidated stream-channel deposits for dating and coordinated studies

3.2 Quaternary unsaturated-zone hydrochemical analysis

The investigations of Quaternary unsaturated-zone hydrochemistry which had been designated as falling under SCP Activity 8.3.1.5.2.1.2 lie within the scope of work on Study 8.3.1.2.2.7 (Unsaturated-zone hydrochemistry), and are described in YMP-USGS SP 8.3.1.2.2.7. Activity 8.3.1.5.2.1.2 has been omitted from the present study for this reason.

3.3 Evaluation of past-discharge areas

3.3.1 Objectives

The objectives of this activity are to

1. determine the location and hydrogeologic characteristics of paleo-spring deposits in the discharge areas, with special emphasis on differentiating regional and local aquifer discharge points;

2. understand the past- and present-discharge areas of the regional-hydrologic system in order to predict the future saturated-zone hydrologic system at Yucca Mountain;

3. determine (with the Study 8.3.1.2.1.3, Regional ground-water flow system) the location, type, and extent of geohydrologic units in the ground-water discharge areas of the Amargosa Desert and Death Valley;

4. determine past ground-water levels in carbonate caverns (such as those at Devil's Hole, Nevada) as evidence of past hydrologic conditions;

5. understand the past quantity and quality of water in the discharge areas of Franklin Lake, Amargosa Desert/River, and Peter's Playa and to determine the paleohydrologic significance of Peter's Playa and Franklin Lake as discharge areas; and

6. determine the location and amount of discharge by evapotranspiration that has occurred at past-discharge sites.

The above objectives were developed in order to guide data collection to provide information for testing the following hypotheses applying to the past, present, and future regional hydrologic regimes in the Yucca Mountain vicinity.

1. Faults, lineaments, and other geologic structures are the principal routes for the movement of water from the recharge areas to discharge points south of Yucca Mountain.

2. Faults, lineaments, and other fractures in earth material may be barriers to ground-water flow, depending upon the relationship of ground-water flow direction and geologic stress.

3. The regional ground-water flow system is located in an area of regional extensional stress, resulting in a tendency for many large fractures to remain open for long periods of time.

4. Increase or decrease of ground-water discharge will reflect a change of water level beneath Yucca Mountain or a change in ground-water velocity.

5. Two or more subregional ground-water flow systems exist in the area near Yucca Mountain, but because of geologic structures, such as major lineament systems, the subregional flow systems may be analyzed independently.

The study is also designed to collect as broad a data base as possible so that the conceptual model can be tested rigorously and so that alternative conceptual models, which may be proposed in the future, can be tested adequately. An important feature of this activity is that collecting of observational data is not guided by a single conceptual model.

3.3.2 Rationale for activity selection

Characterization of the Quaternary regional ground-water flow system in the Yucca Mountain area involves the application of several scientific disciplines. Information about the paleohydrologic system comes from the analysis of a large quantity of data, each of which supplies a part of the required hydrologic knowledge. In paleohydrologic studies, large quantities of data are analyzed and correlated in order to develop an overall understanding of the past hydrologic system.

Climate is one of the major conditions affecting any hydrologic system. If climate changes, recharge and discharge from the hydrologic system may change in response. Tectonics is another factor in determining the regime of a regional hydrologic system. Part of the effort in the present activity will be to attempt to recognize the influences of structural features (such as fault zones) upon the Quaternary regional hydrology. If it is shown that the location of certain ancient discharge areas or other features of the Quaternary hydrologic regime can be best explained by calling upon fault movement or other tectonic influences such as past zones of probable high strain, this conclusion would be important information in the assessment of changes in future hydrology due to tectonic events (Investigation 8.3.1.8.3). In particular, data on paleohydrologic response to Quaternary tectonism would apply to Study 8.3.1.8.3.1 (Effects of tectonic processes on average percolation rates) and Study 8.3.1.8.3.2 (Effect of tectonic processes and events on changes in water-table elevation). It is also probable that some structural-features data collected in the present study could contribute to the structural data required for Study 8.3.1.17.4.12 (Tectonic models and synthesis).

This activity approaches the problem of understanding the paleohydrologic system in and near Yucca Mountain during the Quaternary by developing an understanding of the changes in ground-water discharge resulting from changes in climate or tectonic events. The understanding developed by this activity will be further refined by using various hydrologic and climatic numerical models.

To understand Quaternary ground-water conditions in and near Yucca Mountain, paleo-discharge boundary conditions in the Paleozoic carbonate aquifer need to be defined. First, the discharge area of the regional ground-water basin will be searched for evidence that may be used to determine Quaternary water-table elevations. Prior water-table elevations of the deep carbonate aquifer may be demonstrated by fossil spring mounds, vein deposits, and other geologic features (Winograd and Doty, 1980). Surficial evidence of Quaternary water-table elevations includes the following:

1. paleo-spring mounds (point sources); sporadic sources along thrust areas or other point-source discontinuities;

2. lineament-controlled spring deposits (fracture or fault zone deposits);

3. vein deposits or "alteration zones" -- large areas of diffuse ground-water discharge in bedrock;

4. playa and lake beds (discharge along the playa rims, throughout the entire playa area, or in the playa centers); and

5. calcretes and caliche (deposited in areas of diffuse ground-water discharge; this type must be separated from the other types of calcretes and caliche).

The potentiometric surface in the deep carbonate aquifer is believed to be gentle in slope, and likely was gentle in slope during times past. Ground-water gradients obtained from study of paleospring elevations in the discharge area then will be projected to the Yucca Mountain site to provide estimates of prior potentiometric elevations in the underlying carbonate aquifer. Currently accepted models of the saturated-zone hydrologic regime will be used, in addition to paleohydrologic data, to estimate prior carbonate aquifer potentiometric elevations.

Ground-water gradients in Tertiary tuffaceous units and alluvial materials in and near Yucca Mountain are believed to be considerably steeper and more irregularly distributed than ground-water gradients in the underlying carbonate aquifer (see SCP Figure 3-28). The water-table gradients in the tuffaceous and alluvial materials near Yucca Mountain may therefore be more sensitive to temporal changes in recharge and discharge, and projections of past water-table elevation from discharge sites in these aquifers to points near Yucca Mountain may be less certain.

3.3.3 General approach and summary of tests and analyses

The general approach in this activity is to identify changes at (or of) discharge sites that reflect past ground-water levels. These past water levels will be used in hydrologic-flow models to project water-level changes at Yucca Mountain. Data collection in this activity will be coordinated with the regional potentiometric levels activity in Study Plan 8.3.1.2.1.3 (Characterization of the regional ground-water flow system).

Figure 3.3-1 summarizes the organization of the evaluation of past-discharge areas tests. A descriptive heading for each test and analysis

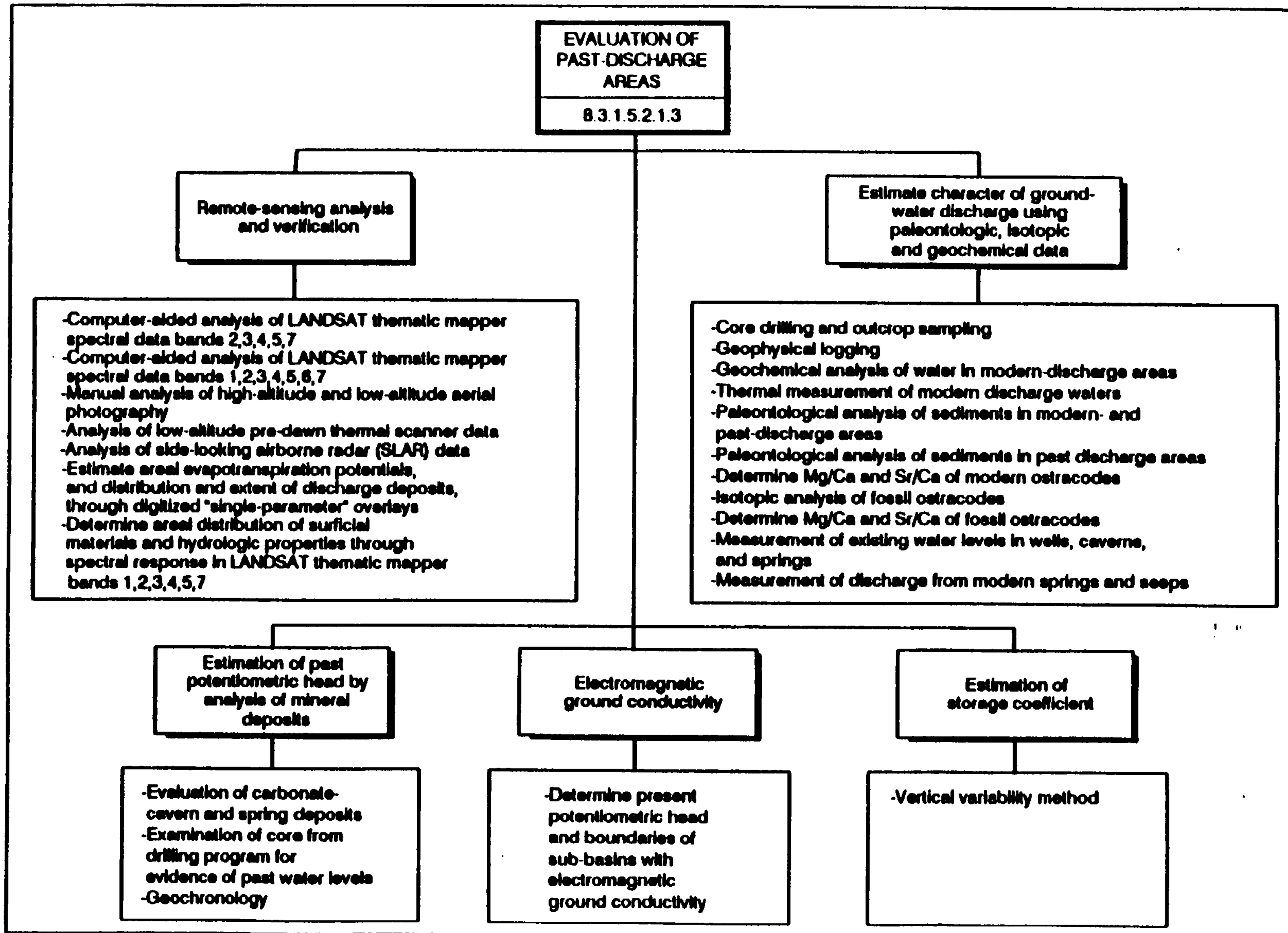

Figure 3.3-1. Logic diagram of past-discharge areas activity showing tests, analyses and methods.

appears in the shadowed boxes of the second and fourth rows. Below each test/analysis are the individual methods that will be utilized during testing. Figure 3.3-2 summarizes the objectives of the activity, site-characterization parameters which are addressed by the activity, and the activity parameters determined during testing. These appear in the boxes in the top left side, top right side, and below the shadowed test/analysis boxes, respectively, in Figure 3.3-2.

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

Figure 3.3-3 illustrates the selected areas for investigation of present and past discharge.

3.3.3.1 Remote-sensing analysis and verification

3.3.3.1.1 Objectives

Remote-sensing data and techniques will be used to provide support data for estimating values of potential infiltration and discharge, and for delineating regional fracture-zone hydrology. Support data will include

1. location of discharge deposits;

2. distribution of geomorphic/geologic deposits;

3. distribution of vegetation types and communities; and

4. location of hydrologically favorable geomorphic features, such as regional fracture zones (Fortymile Wash), playas, and fans.

This study will involve a training area of known features (Death Valley, California), a confirmation area (the Amargosa Valley, Nevada), and a site-specific area (Yucca Mountain, Nevada).

The objectives of this activity are to

1. support regional saturated-zone and paleohydrologic modeling of the ground-water systems in southern Nevada by providing additional accurate information regarding

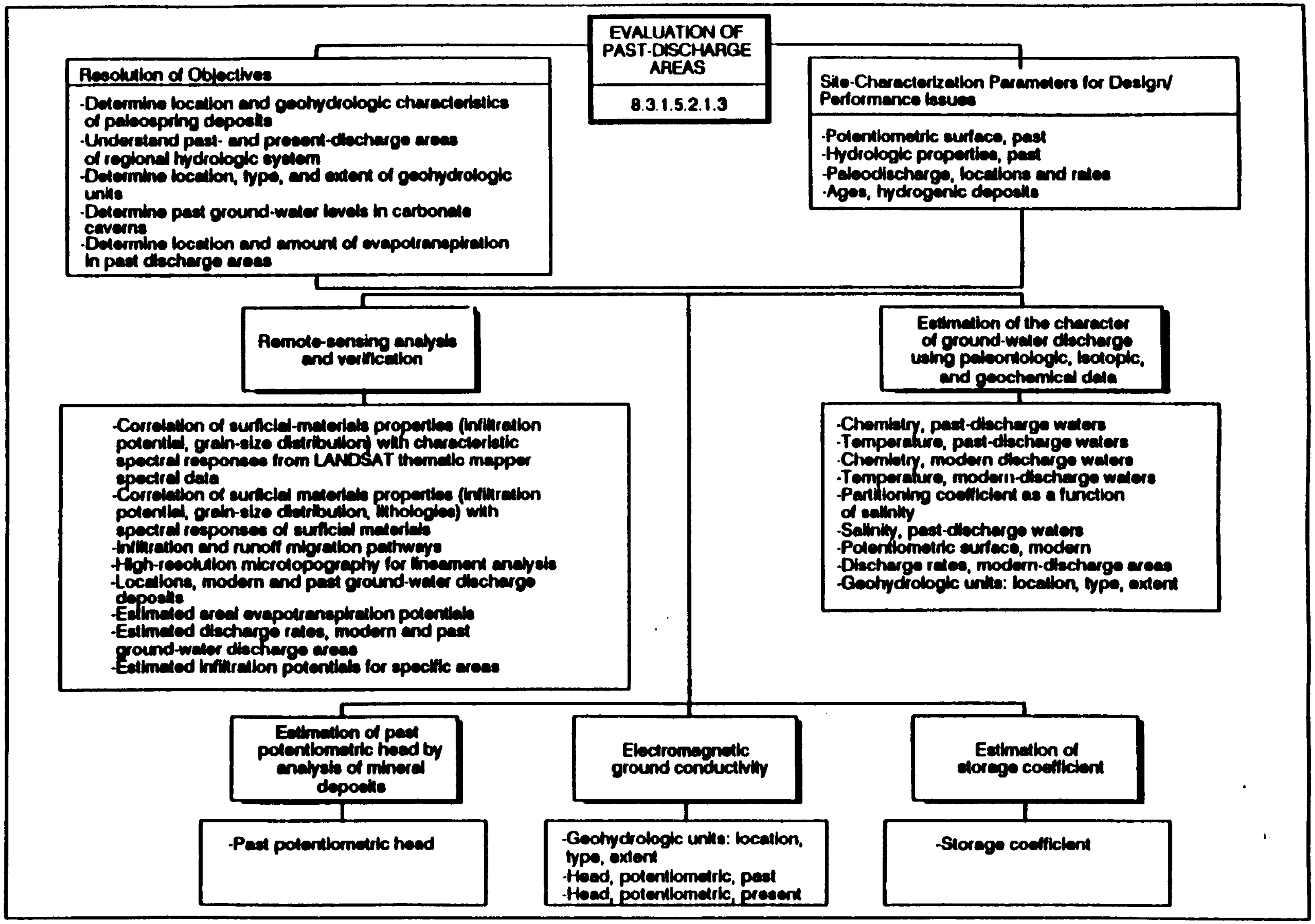

Figure 3.3-2. Logic diagram of past-discharge areas activity showing tests, analyses, and activity parameters.

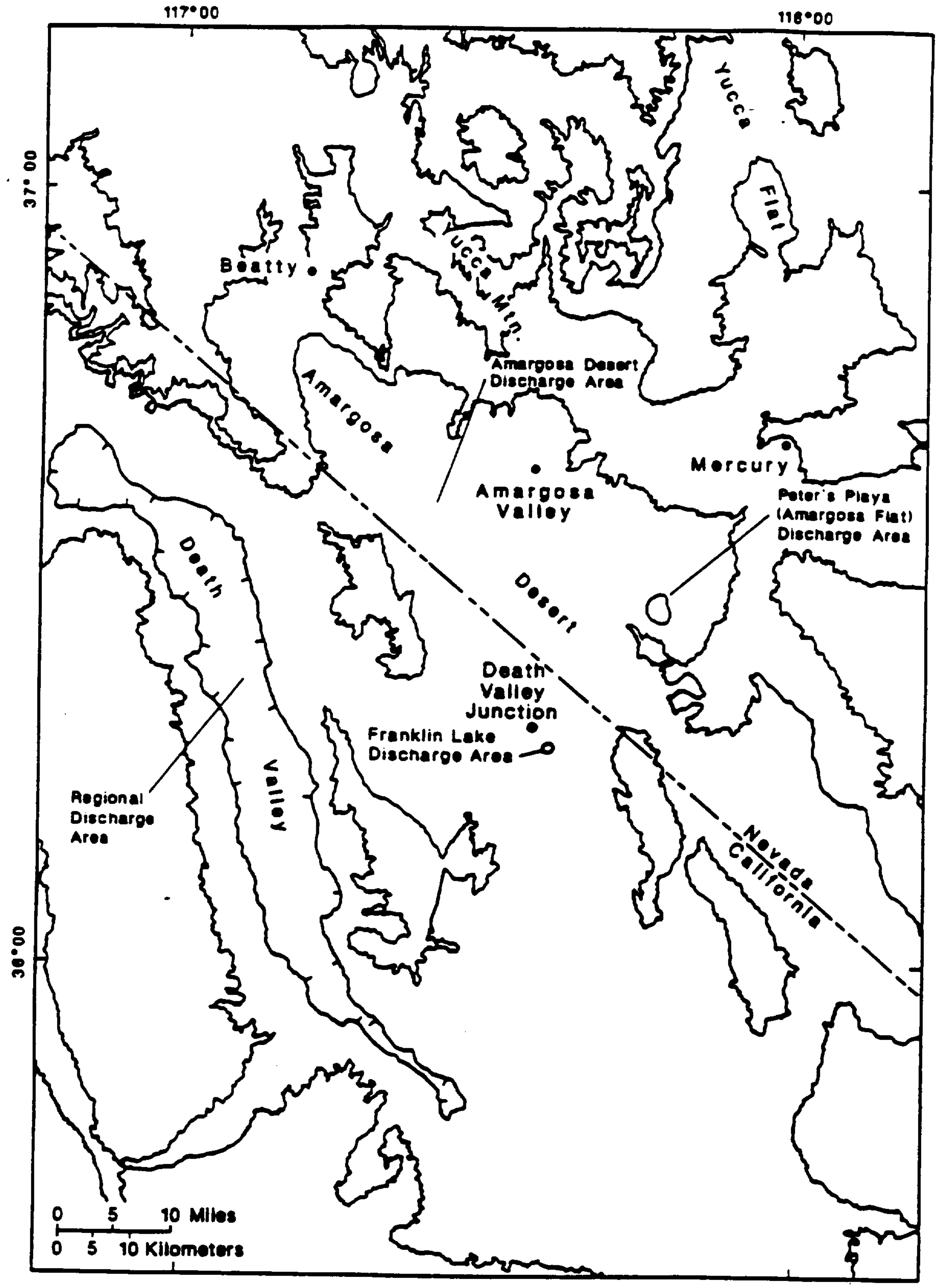

Figure 3.3-3. Selected present- and past-discharge areas addressed by activity 8.3.1.5.2.1.3.

location of discharge zones, estimates of infiltration or recharge, and regional fracture-zone hydrology; and

2. support on-site characterization of the Yucca Mountain repository area by providing additional accurate information regarding estimates of infiltration and discharge. (In support of this objective, infiltration and soil-moisture characteristics will be estimated using SLAR, thermal infrared data, and remote-sensing image processing and analysis techniques. This effort, which involves the development of new techniques, is included in Study 8.3.1.2.2.3 (Characterization of percolation in the unsaturated zone - surface-based study). Remote sensing will be done in conjunction with Study 8.3.1.17.4.7, Subsurface geometry, Quaternary faults, and Study 8.3.1.2.1.3, Regional ground-water flow system.)

The first objective has three goals. The first goal is to evaluate computer-aided enhancement and interpretation techniques for locating present- and past-discharge zones in parts of southern Nevada and California using LANDSAT Multispectral Scanner (MSS) and Thematic Mapper (TM) imagery. This goal will be achieved by

a. evaluating the applicability of previously published computer-aided enhancement and interpretation techniques using Multispectral Scanner (MSS) data, developed in other regions, for use in arid to semi-arid environments;

b. evaluating the applicability of existing techniques, as developed with MSS data, when used with TM data; and

c. developing and evaluating new computer-aided enhancement and interpretation techniques, where appropriate.

Landsat Thematic Mapper data are chosen for the following reasons:

1. good spatial resolution (30 X 30 meters)

2. good spectral resolution:

Band 1	.45-.53	m	Blue-green, visible
Band 2	.52-.60	m	Green, visible
Band 3	.63-.69	m	Red, visible
Band 4	.76-.90	m	Near-infrared
Band 5	1.55-1.75	m	Mid-infrared
Band 7	2.08-2.35	m	Mid-infrared
Band 6	10.4-12.5	m	Thermal IR

3. the regional nature of the study

Studies indicate that there is a direct relation between the characteristics of the ground-water discharge deposits, the water quality of the discharge, the local vegetation (Hunt, 1966; Hunt and others, 1966; and Beatley, 1976), and, to a lesser extent, the local soils (Bamburg and others, 1974; and Miller, 1977). Based on the relation between the deposits and the local soils and vegetation, the maximum contrast between the deposits and the vegetation would occur during the peak growing season (late April to mid-May in the study area), and the maximum contrast between the deposits and the soils would occur during the winter (minimum vegetation cover). Imagery from a wet spring is selected to enhance the vegetation discrimination, and imagery from a dry winter are selected to enhance the soil discrimination (Table 3.3-1).

Table 3.3-1 Data utilized for remote-sensing methods development

Data Type	Date	Remarks	Scene ID
MSS & TM	5/85	Wet spring	85045017512x0 & Y5045017512x0
TM	5/83	Dry spring	Y5041817515X0
MSS & TM	12/82	Dry winter	84015617493X0 & Y4015617492X0

Concurrent with digital data selection, all of the available traditional data sources, such as geologic maps, geochemical maps, and water resource reports, will be collected and initially evaluated for the Death Valley training area. The spectral analysis for discharge deposits will include image processing and analysis of digitized LANDSAT MSS and TM data using the Earth Resources Laboratory Applications Software (ELAS Version 416) computer program available from the Earth Observation Satellite Company (EOSAT) and the Earth Resources Observation Satellite (EROS) data center. The techniques to be used include digital enhancement techniques, such as band stretching, band filtering, band ratioing, and density slicing; classification techniques, such as supervised and unsupervised classification, maximum likelihood classification, and principal components analysis as summarized by Reeves and others (1975), Kolm (1985), and Satterwhite and Henley (1987); and topographic registration techniques.

Results from the initial digital processing of the Death Valley training data will be compared to traditional data bases and field checked; additional field mapping and sample collection will be conducted as appropriate. The processing techniques will be refined as necessary, and final field checks will be conducted. The refined techniques will then be applied to the entire regional study area, and a final evaluation will be performed.

The southern Death Valley region (Figure 3.3-3) was chosen as the training area because (1) there are active springs with associated discharge deposits; (2) there are numerous and often extensive areas of Miocene/Pliocene lake bed deposits; and (3) the Cottonball, Middle, and Badwater basins of Death Valley contain large, active playas with hydrologic input from surface and ground-water sources. Parts of these discharge areas have been mapped and analyzed for hydrochemical characteristics (Hunt and others, 1966). Results from the Death Valley training site will then be applied to the regional study area (Figure 3.3-3), including the Funeral Mountains, with exposures of volcanic and carbonate bedrock units; the Amargosa River Valley, including Franklin Lake Playa, Amargosa Flats, and active springs (for example, Devil's Hole spring); and the Amargosa Desert fluvial systems, characterized by dry washes, intermittently flowing channels, and pediment-fan systems containing discharge deposits.

The second goal of the first objective of this activity is to develop an alternative method for estimating regional infiltration/recharge and discharge based on remote sensing, soils, botany, geology, geomorphology, climate, and relief/topography. These estimates would be used in both the regional saturated-zone model (Study 8.3.1.2.1.4) and in paleohydrological studies in southern Nevada (Section 3.4).

The remote-sensing techniques and data types used in this activity will address (1) soils types and infiltration properties; (2) vegetation type, density, and distribution with respect to infiltration and discharge properties; (3) geomorphic features, including fluvial and eolian processes and materials, and fracture zones (lineaments); and (4) depth to water table and bedrock characteristics.

The current method for estimating regional infiltration/recharge is based on an estimate of the percentage of precipitation that infiltrates at given elevations of an area. This method is an excellent first approximation for these parameters; however, the proposed method activity may improve upon the accuracy of the estimates. If successful, this method will accommodate a variety of scales of grid or nodal size.

A literature search will be conducted to identify, locate, and acquire background information about the research area and techniques for analyzing the parameters. Background information about the research area includes the geology, hydrology, surficial and bedrock materials, vegetation patterns, physiology of the desert flora, paleoclimatic conditions, present climatic conditions, paleohydrology, and hydrologic properties of the surficial materials. Background information about analysis techniques includes (a) original studies utilizing the various parameters and (b) previous studies of the parameters in arid to semi-arid environments.

After the available data have been identified and located, an appropriate data base will be collected, consisting of remote-sensing data, climatic data, soil data, geomorphic data, vegetation data, and hydrologic data. Remote-sensing data will consist of black and white, color, and CIR photography; and Computer Compatible Tapes (CCT) of LANDSAT MSS and TM digital data. The digital data will be computer-enhanced where appropriate, and interpreted for incorporation into the general data base of the vegetation, soils, and geomorphic features data bases. Climatic data consist of CCT records of climatic variables including temperature, cloud cover, precipitation, wind speed and direction, humidity, and barometric pressure. Soil data consist of soil maps and descriptions, and the relationship to hydrologic properties.

Geomorphic data consist of geologic maps, structural maps, topographic data (topographic maps and CCT topographic data), slope-aspect information, a geomorphic features map, and materials properties maps. Vegetation data consist of vegetation maps, inventories, transects, and physiological studies of desert flora. Hydrologic data consist of gaging station records, well and borehole logs, water-table measurement records, ground-water geochemistry, and aquifer (pump) test records. These data bases will be integrated using a geographical information system (GIS), and the appropriate grid or nodal spacing will be selected (although the method will be developed so that any nodal size or shape may be accommodated). A model for infiltration, based on percentage of water passing, will be developed; the conceptual model is that each of these parameters will affect the infiltration sequentially: (1) initial infiltration into the surficial materials, (2) plant interactions and pedogenic soils-properties interactions, (3) thickness of deposits, and (4) thickness of unsaturated-zone fracture flow system (depth to water table). The ultimate results of the model would be a recharge estimate, for a given nodal size, to be incorporated into a regional ground-water model. If successful, parameters can be varied, based on analog studies, and the model can be used for paleo- and future-hydrology studies.

The third goal of the first objective is to predict the general hydrological characteristics of regional fracture zones and lineaments in southern Nevada determined from remote sensing, geologic, and hydrologic analysis. The activities include testing previously established lineament techniques and developing additional lineament analysis methods (quantitative and qualitative) to (1) locate regional zones of increased or decreased vertical or horizontal (or both) aquifer(s) transmissivity(ies), (2) locate areas of preferred vertical and horizontal ground-water flow paths, (3) locate areas of ground-water recharge and discharge, and (4) locate areas of ground-water mixing due to vertical leakage through confining layers. This study is discussed further in SCP Section 8.3.1.17.4.7 (Subsurface geometry and concealed extensions of Quaternary faults at Yucca Mountain) and Study Plan 8.3.1.2.1.3 (Characterization of the regional ground-water flow system).

The second objective is to apply the results obtained from the first objective to on-site studies at Yucca Mountain. More emphasis will be placed on the manual photo interpretation and geomorphic interpretation of available color and color infrared photography, large-scale black and white photography, and detailed geologic mapping as warranted by the site-specific scale. The precise area to be studied and the scale of mapping will depend upon preliminary results and needs identified by other tests.

In summary, the types of remote-sensing data bases being considered for use include (1) digitized LANDSAT Multispectral Scanner (MSS) and Thematic Mapper (TM) spectral data; (2) high-altitude and low-altitude aerial photography, to include black and white, color, and color infrared (CIR); (3) low-altitude pre-dawn thermal scanner data collected before, during, and after major storm events; and (4) side-looking airborne radar (SLAR). Figure 3.3-4 shows the location of proposed thermal scanner flight data collection. Detailed hydrologic properties of soils in this area will be determined as part of other studies. These results can be used to check the utility of the remote-sensing technique. A comprehensive literature search will be conducted to gather information from previous studies using these remote-sensing data bases and the techniques employed. Appropriate existing data bases will be obtained from national agencies and private contractors. If necessary, new data will be obtained to supplement the existing data.

3.3.3.1.2 General approach and discussion

The basic research on the spectral responses of rocks and minerals began with Clark's (1957) work with the visible and near infrared absorption spectra of silicates. The most extensive work on spectral responses of rocks and minerals in the visible and near infrared wavelengths has been done by Hunt (1977), Hunt and Ashley (1979), Hunt and Salisbury (1970, 1971, 1976a, 1976b), and Hunt and others (1971a, 1971b, 1972, 1973a, 1973b, 1973c, 1974).

The first major application of spectral responses to studies of rock types in the field using satellite data was performed by Rowan and others (1976); they discriminated between different rock types and hydrothermally altered areas in the Goldfield mining district of southern Nevada. Hussein (1982) applied similar techniques to studies of mineralization and sedimentary rock types in Egypt. Bothorel and others (1984) completed a similar study of three types of orebodies in southern Morocco.

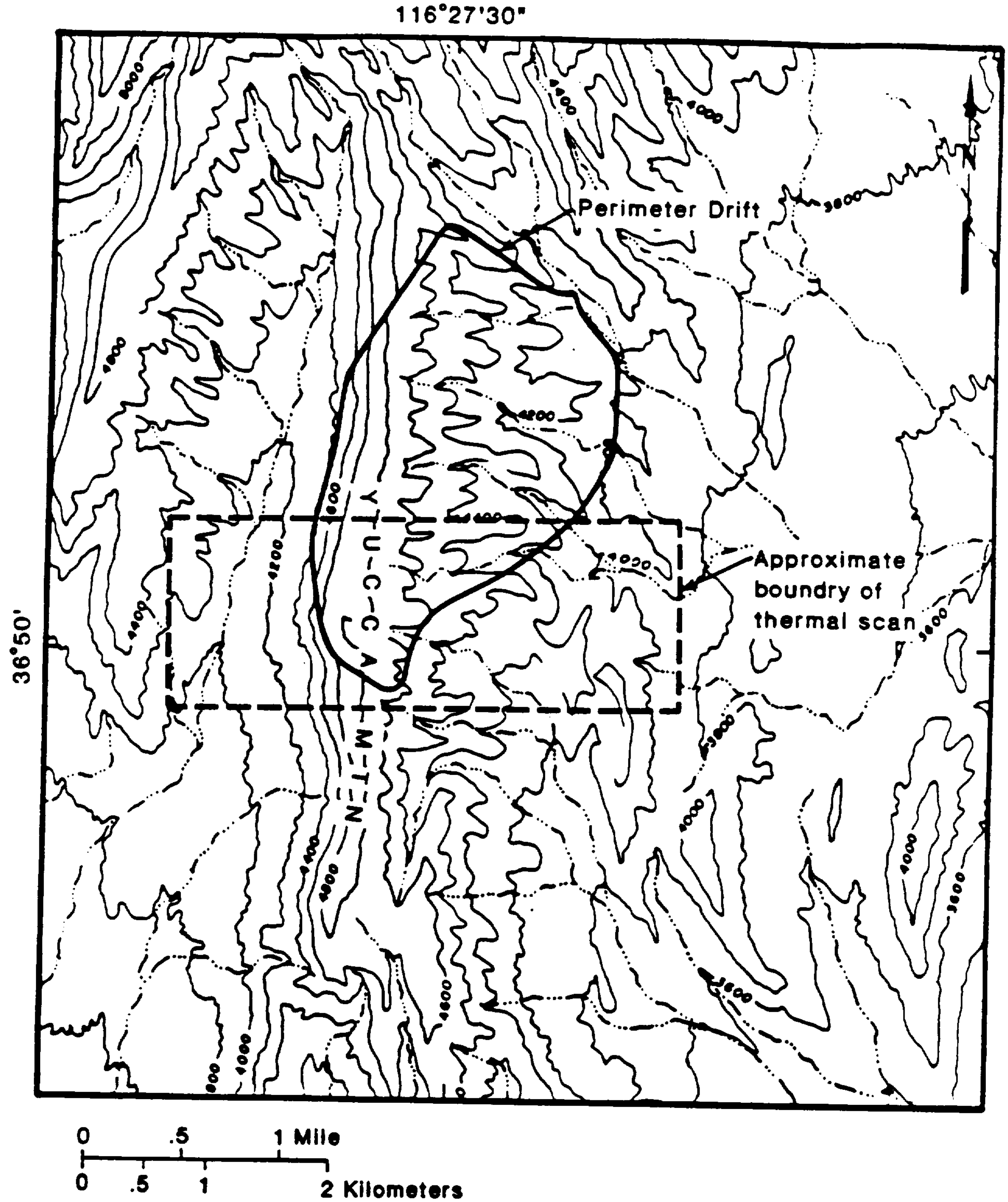

Figure 3.3-4. Location and topography of proposed thermal scanner flight data collection.

The vast majority of studies that have utilized digital satellite data for differentiating rock types have concentrated on hydrothermally altered rocks and zonations. The "Joint NASA/Geosat Test Case Project" by Abrams and others (1984) and Reeves and others (1975) are typical of these types of studies. Other than in hydrothermal alteration studies, digital satellite data are most often used in preparing geologic maps. Here the results of the satellite data analysis are not the primary goal, and therefore frequently they are not reported. Doyle (1975) presents a detailed summary of the uses of digital data for cartographic applications.

One of the most common nongeologic uses of digital satellite data is in crop/forest inventories and management. The majority of these types of studies are on irrigated croplands or forested areas. The goals of these studies are estimates of crop yields, renewable lumber resources, early detection of water-related plant stresses, and detection of insect or fungal infestations. Meyers (1975) summarized the use of Multispectral Scanner (MSS) data for evaluating crop types. Kolm's (1985) work is typical of the use of satellite data in estimating crop acreage and possible crop yields.

One of the first studies of desert vegetation using satellite data was by Ratliff (1972); he evaluated phreatophytic vegetation densities in the lower Truckee River drainage, Reno, Nevada. Johnson and others (1974) were able to identify 31 vegetation types in southern Arizona based on ERTS-1 (MSS) imager and the terrain and aspect relationships.

Regional flora inventories have been completed by Beatley (1976) and Munz (1974). Detailed studies of the physiologies of the local flora are currently being conducted by YMP, and detailed inventories of plant communities and distributions are planned for the near future.

The relationship between the physical properties and the water content and hydrologic properties of soils has been studied by Irani and Callis (1963), Childs (1969), Hillel (1971), and Nielsen and others (1972). Site-specific studies of the relationship between soil physical properties, hydrologic properties, and infiltration capacity are currently being conducted by YMP investigators (Schmidt, 1988; Schmidt and others, in progress).

Studies relating soil physical properties and moisture content to the thermal inertia of the soil, as determined from remotely sensed temperature fluctuations of the soil, began as early as 1971 and have been summarized by Van de Griend and others (1985). In general, these studies have concentrated on agricultural soils in the mid-west and eastern regions of the United States and in central and northern Europe. These soils tend to be homogeneous, aerated, and well supplied with either natural or irrigation water. Myers (1975) presented a summary of the use of satellite spectral data in evaluating soil types and moisture content. The first detailed study of the relationship between soil moisture and evaporation from nonsaturated soils in arid to semi-arid climates was done by Barton (1979) in Australia. The proposed work will expand on this study, using site-specific analogues as described in Section 3.4.3.2.

The spectral analysis for hydrogenic discharge deposits will include image processing and analysis of digitized LANDSAT TM data using the Earth Resources Laboratory Applications Software (ELAS) package available from Earth Observation Satellite Company (EDSAT) and the Earth Resources Observation Satellite (EROS) data center. The techniques that will be used include digital enhancements, principal component analysis, maximum likelihood classification, band ratioing, band stretching, and band filtering as summarized by Reeves and others (1975). The results of this work will be coordinated with the regional ground-water flow system studies (Study 8.3.1.2.1.3) and will be used to locate active and inactive ground-water discharge sites for use in estimating present and paleo (1) water-quality, (2) water-table elevations, and (3) discharge rates. This phase of the activity is particularly valuable in that data acquisition is not guided by any conceptual model, and, therefore, data applicable to any regional hydrologic model are collected with equal emphasis.

Manual analysis of high-altitude and low-altitude aerial photography and computer-aided analysis of digitized LANDSAT data will be coordinated with the hydrologic characterization studies of surficial materials being conducted by other investigators. The analysis of the spectral responses of the surficial materials will be correlated with the physical properties of the surficial materials, including grain-size distributions, infiltration capacities, lithologies, and geomorphic processes and response systems. Estimates of areal infiltration potentials will be based on the infiltration capacity, as determined from field studies, and the spatial distribution of spectral responses as determined from remote-sensing analysis. The types of surficial materials targeted will include residual and/or colluvial soils, bedrock alluvial/colluvial fan deposits, playas, and fluvial, eolian, and hydrogenic deposits.

Analysis of the vegetation types and spatial distributions from remote-sensing data will be coordinated with the physiographic studies and with the inventories of the southern Nevada flora. Using GIS techniques, these data will provide a means for rapid and cost-effective mapping of plant communities and relating the distribution of the communities to the topographic and hydrologic parameters of elevation, aspect, potential evapotranspiration (ET), bedrock lithology, surficial materials, infiltration capacities, and ground-water discharge. These relationships will be used as input for unsaturated-zone modeling, and to the extent that data from packrat middens and other fossil evidence can be used to determine Quaternary plant distributions, the above relationships will also be used in paleo recharge/discharge modeling efforts. A necessary assumption for the latter case is that the ecophysiology of modern plant communities is similar to their Quaternary counterparts (e.g., that a modern vegetation type, say a pinon-juniper woodland, growing in a given climate and soil, will transpire or otherwise function at similar rates as the same vegetation type growing in similar circumstances at 25,000 yr B.P.). The amount of actual plant uptake and transpiration of water from the unsaturated zone and shallow water tables will be studied by other investigators (see Section 3.4.3.2).

Results from the hydrogenic-deposits studies, the characterization of the surficial-materials responses, and the characterization of the vegetation responses will be integrated with the regional lineament studies (see Regional ground-water flow system, Study 8.3.1.2.1.3). Lineament analysis will provide information on the basement controls of surficial features, such as river channels, mountain blocks, and valley orientations. The lineament analyses could refine and modify, and be modified by, the analyses of the spectral data and ground studies and provide information on possible zones of upward or downward leakage of ground water and, therefore, zones of anomalous ground-water geochemistry.

On-site field inspections (ground truth) will be made to verify the classifications of surficial materials and vegetation communities obtained using remote-sensing techniques. Ground truth will consist of known surficial-material classification sites, infiltration study sites (SP 8.3.1.2.2.1), and vegetation study plots. These data are all being collected by other researchers. Where necessary, ground-based spectrometer data will be collected for direct correlation with the LANDSAT spectral responses of the surficial materials and vegetation communities.

The successful use of remote sensing in the above four applications will result in a series of remote-sensing techniques for (1) identifying past discharge areas; (2) estimating the infiltration properties of surficial materials; (3) estimating ET potentials based on climatic data, vegetation distributions, surficial materials, and slope angle/aspect/elevation relations; and (4) estimating infiltration potentials for specific areas in arid to semi-arid climates. These techniques will be used to develop a series of single- or multiple-factor digital overlay maps that will be combined to produce a regional digital overlay map of estimated infiltration and discharge rates for calibration and testing of the conceptual model for the regional ground-water flow system.

3.3.3.2 Estimation of the character of ground-water discharge using paleontologic, isotopic, and geochemical data

Yucca Mountain is surrounded by sedimentary deposits that contain paleontologic, isotopic, and geochemical records of past ground-water discharge. These deposits include the sediments in wet playas or former wet playas that are now dry playas, sediments associated with former or modern spring discharge from various aquifers (Winograd and Thordarson, 1975) and sediments deposited in the ponded water derived from alluvial aquifer discharge (Quade, 1986). The character of the proxy records available at any given site varies from relatively poor records such as dry-playa clastic, devoid of most fossils, to diverse records such as the fossiliferous marsh-pond deposits that contain biogenic and possibly abiotic sources of isotopic and geochemical information (^{13}C, ^{18}O, D/H, Sr/Ca). The records also include the relatively unusual carbonate vein fillings precipitated from deep aquifer discharge and containing a detailed isotopic record of past sources of recharge as well as climatic information (Winograd and others, 1985, 1987). Perched ground water can be distinguished from regional ground water by temperature and chemistry. Fossil species sensitive to temperature will be used to make this distinction.

The accuracy of locating paleodischarge points is predicated on the assumption that deposits created at discharge points have not been removed by erosion or buried by subsequent processes. This assumption is probably valid for the past 20,000 years and should be sound for the past 40,000 years, which is the age of the youngest dated surficial deposit (Rosholt and others, 1985). The assumption is much more tenuous for the early Quaternary.

The various deposits (10-100) will typically be cored in order to obtain detailed stratigraphic or other sample sets. Some deposits may be sampled directly from outcrop, such as the highly dissected marsh-pond deposits in the Las Vegas Valley (Quade, 1986) or the carbonate-opaline fracture fills in Trench 14. Details of coring and sampling strategy will depend on the deposit being studied, preliminary geophysical results, and the problem under consideration. Core sites and outcrops to be sampled will require a modest amount of exploration in order to find deposits that contain the best records with information about a particular problem. Thus, multiple cores need to be taken and studied in a preliminary way to assess the value and type of record that is present. Multiple records will also be needed to determine if environmental phenomena are of regional or of only local importance. Multiple records will also be necessary if alternate conceptual models are to be considered throughout the data-acquisition phase of the project.

Typically the length of sediment to be cored or studied will be relatively short (<100 ft), because this program is principally concerned with hydrologic variability over the past 65,000 years, because it includes the Wisconsin interglacial, the late Wisconsin glacial (pluvial maxima), and the present interglacial. The latter events should represent the major variations in climate that would be expected to result in hydrologic variability for the foreseeable future. In some instances, older records may be required in order to best evaluate the response of local hydrology to climate events such as higher levels of atmospheric CO_2. These records would need to come from deposits in the age range of 200,000 to 300,000 years or possibly from records as recent as 120,000 to 140,000 years. The latter periods are ones with elevated insolation and are recent enough so that a hydrologic response to those climates would be measured within the present tectonic setting. A few very deep holes (762 to 1524 m; 2,500 to 5,000 ft) may also be required in conjunction with the regional hydrology program in order to evaluate deep flow properties, or other aspects of the hydrogeology of particular aquifers that are of concern to this program.

Because climate is one of the major sources of hydrologic variability, most sites should be studied in cooperation with Investigation 8.3.1.5.1 (Future climate) so as to minimize costs and efforts needed to arrive at a satisfactory study. The other principal source of hydrologic variability in this region is related to tectonic activity, especially fracturing that provides a flow path for meteoric water as well as deep ground water. A major part of the sampling for hydrologic variability related to fracturing will be covered under the calcite and opaline-silica vein deposits activity (see Section 3.5).

Modern-day ground-water discharge from various aquifers and perched sources in this region can typically be differentiated by water chemistry and temperature (Winograd and Thordarson, 1975; Thompson and Chappell, 1984; Thompson and others, 1984). The character and source of paleodischarge should also reflect these properties. The principal sources of information that provide chemistry or temperature characteristics of past discharge are paleontologic and isotopic, or in some cases geochemical, records. Isotopic studies of low-temperature aqueous deposits are relatively well established and rely on assumed isotopic equilibrium between fluid and solid phases to be most useful. Examination of modern isotopic compositions (e.g. delta D, delta ^{13}C, and delta ^{18}O) of various waters and the minerals, especially biogenic carbonate, precipitated from them would comprise valuable baseline data. Paleontologic and some geochemical studies, such as the Sr/Ca ratio in biogenic carbonate, are not well calibrated in this area and require collection of baseline data under QA procedures in order to demonstrate the validity of this form of data for past interpretations.

Aquatic organisms that are environmentally sensitive and are often found as fossils in statistically useful numbers include ostracodes, diatoms, and chrysophyte cysts. Ostracodes have been shown to be sensitive indicators of both water temperature and chemistry (Delorme, 1969, 1972; Delorme and others, 1977; Forester, 1983, 1986, 1987), and these variables can be related to various sources of water, including surface, perched, and deep-aquifer origins. The studies by Delorme, though largely unpublished, involve 6,720 samples from more than 5,500 water bodies collected from a grid system placed over Canada. The data set from the United States is much smaller, about 400 water bodies including springs, but based on a recent comparative study (Forester and Delorme, unpublished data) is consistent in every respect with the larger data set from Canada. This comparative study also revealed, using thousands of samples as a study subset, that ostracode sensitivity to water chemistry is greatest in relatively low-salinity water, but especially below about 5 parts per thousand (ppt) total dissolved solids. Ostracode salinity tolerances are species specific and for saline water forms extend above 100 ppt for some taxa (see also DeDeckker, 1981). Most of the ground-water discharge in the region today and presumably in the past has a low salinity but is compositionally and thermally diverse.

A simple example of ostracode temperature sensitivity is shown in Figure 3.3-5. The various symbols indicate a live occurrence of the species indicated in springs that are known to remain thermally constant throughout the year or ones where flow is high enough to suggest that temperature is constant throughout the year. Thus the ranges of temperatures shown are temperatures required by the taxon to complete its life cycle. Some of these species, but not all, can tolerate temperature outside of the ranges shown. The general geography of these species supports the values shown in the diagram. For example, the taxa restricted to very warm water do not occur in any northern lake or spring or in any body of water where temperatures fall below 20 °C. These data and the recent data on sensitivity to water chemistry (R. M. Forester and L. D. Delorme, unpublished data) suggest that ostracodes may be ideal organisms to conduct paleohydrologic studies in Nevada. It also reveals that a modest number of modern samples must be collected under QA procedures to both strengthen the data base and provide enough samples to substantiate their sensitivity statistically.

Diatoms and chrysophyte cysts are the remains of different types of algae with each group exhibiting strong sensitivity to water chemistry and perhaps a sensitivity to temperature (Battarbee, 1986; Smol, 1980, 1988). Diatoms in particular often have different species assemblages in waters having different compositions and respond to the nutrient component of chemistry as well as major solutes. Like ostracodes, only a limited amount of information exists on the species compositions of diatoms or chrysophytes that live in the discharge of different aquifers in southern Nevada and nearby areas, and therefore modern collections must be made under QA procedures in order to develop a local data base suited to YMP studies.

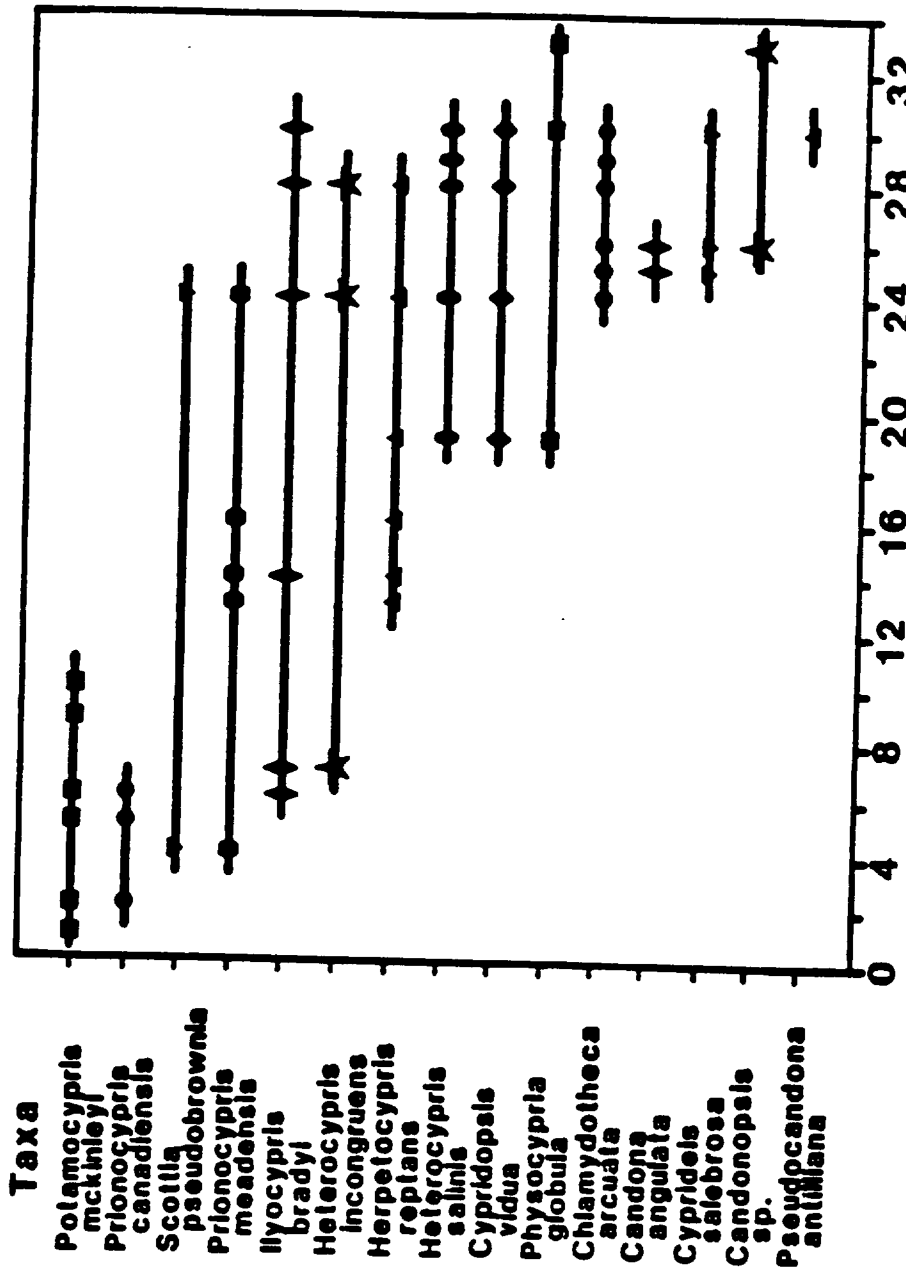

Figure 3.3-5. Ostracode temperature sensitivity.

Studies of modern ostracode ecology, along with studies of ostracode-valve chemistry, will be conducted at selected sites to provide baseline information about the relationship of these variables to the thermal and chemical properties of both discharging ground water and the pools, ponds, and marshes supported by that water. This modern ecologic study of present-day environmental conditions will use about 30 ground-water discharge environments within and surrounding the area of Yucca Mountain, and in southern Nevada, southeastern California, and parts of western Arizona (Table 3.3-2). (Inclusion of Arizona is necessary in order to insure accurate and complete coverage of species currently living in the southwestern Unites States and does not imply that Arizona is or will be affected by activities associated with the disposal of radioactive waste.) The selection of sites will be based upon acquiring modern examples of water upwelling from regional aquifers, water from or near recharge sites in the mountains, and water derived from perched ground water in the valleys. Site selection will emphasize thermal and chemical diversity of modern discharging ground water as well as the aquatic environments supported by the discharging ground water. The selected sites will be sampled at least on a quarterly basis, and a few key sites may be sampled more frequently. Sampling at each site will include multiple samples of each local subenvironment, such as spring vents, spring pools, and marshes, as well as the ground water itself at some sites. The expected sample set will be approximately 400 samples. The study and calibration of the Mg/Ca and Sr/Ca ratios in biogenic carbonate will be based upon living material collected from a limited number of sites, as well as upon laboratory cultures of material from those sites.

Studies of present-day ostracode ecology and valve chemistry, including isotopic composition of the ostracode valves will be conducted on material from all sampling sites. This will provide a measure of kinetic effects (vital effects) on trace-metal and isotopic fraction for various species under conditions of known temperature and total dissolved-solids conditions. Isotopic compositions should be useful in evaluating the degree of chemical equilibrium between waters and biogenic carbonate and may shed light on the status of isotopic equilibrium between waters and their host strata. In addition, detailed information will be collected about the physical and chemical properties of discharging ground water at the spring vents and of the pools, ponds, and marshes supported by that water. Detailed ecologic studies of the living ostracodes will provide the knowledge that will allow the use of modern and fossil ostracodes as indicators of paleohydrologic conditions.

The study and calibration of the Mg/Ca and Sr/Ca ratios observed in ostracode shells in southern Nevada will be based upon living material collected from sites in the Yucca Mountain area, and may include laboratory cultures of ostracodes. The data derived from the above collections will be organized in two ways: (1) a record of all environmental parameters (e.g., temperature, hydrochemistry) associated with a species living at the time of collection and (2)

Table 3.3-2 First set of springs to be investigated for paleodischarge studies

Name of Spring	Latitude	Longtitude	Temperature °C	Total Dissolved Solids mg/liter
Sandstone #1	36°03'47"	115°28'09"	17.00	290.00
Cave Spring	36°09'58"	115°35'52"	11.00	
White Rock Spring	36°10'27"	115°28'43"	25.00	450.00
Mazie Spring	36°14'26"	115°38'19"	3.00	130.00
Fletcher	36°16'26"	115°37'33"	11.50	310.00
Two Springs	36°17'28"	115°41'05"	4.00	76.00
Cave Spring 1	36°17'40"	115°39'55"	5.50	170.00
Grapevine	36°18'04"	115°29'25"	18.50	358.00
Deer Creek Point	36°18'33"	115°37'25"	8.00	230.00
Rogers Spring	36°22'39"	114°26'38"	30.50	
Blue Point Spring	36°23'21"	114°25'26"	30.00	
Dry Lake	36°27'18"	114°50'38"	29.00	960.00
Cow Camp Spring	36°35'01"	115°18'26"	14.50	290.00
White Rock	36°42'30"	115°14'20"	15.00	
Federson Hot Spring	36°42'53"	114°43'05"	32.00	860.00
Big Muddy	36°43'20"	114°42'48"	32.50	610.00
Grapevine	37°08'08"	114°42'02"	18.50	370.00
Little Ash	37°27'50"	115°11'30"	36.00	
Calico Mineral Hot Spring	37°36'47"	114°30'42"	48.00	380.00
Bennett Spring	37°47'03"	114°31'41"	24.00	280.00
Upper Conner Spring	37°54'10"	114°33'38"	8.00	290.00
Runoff Pine Spring	37°54'29"	114°32'56"	4.50	
Lime Spring	37°54'52"	114°32'25"	21.00	260.00
Deadman	37°55'07"	114°32'29"	9.50	430.00
Highland	37°55'16"	114°32'56"	10.00	390.00
Kwichup Spring	36°28'21"	116°02'16"	12.00	1300.00
Burrel Height	36°58'22"	116°43'10"	39.00	540.00
Tippipah	37°02'36"	116°12'26"	9.00	191.00
Tippipah 2	37°02'36"	116°12'26"	22.00	229.00
White Rock Spring	37°12'09"	116°07'52"	10.00	170.00

the absolute and relative abundances of all adult ostracodes found in one or more sediment samples taken from each environment. Both sets of information will be evaluated statistically as well as qualitatively and will form the baseline information needed to interpret taxa found in the fossil record. The valve chemistry data, including isotopic composition of the valve, will be used to establish Mg/Ca and Sr/Ca partitioning coefficients for common species to determine the potential temperature and salinity resolution of this method. The ostracode-ecologic and valve-chemistry data will be correlated with the modern ground-water hydrology in order to establish process-type relationships between all ostracode environmental data and known ground-water hydrology, thereby providing the basis for evaluating the nature of past discharge areas.

A comprehensive well inventory will be conducted in conjunction with work of the regional ground-water flow system study (8.3.1.2.1.3) in the regional-discharge area in order to compile geologic and hydrologic data that can be used to characterize the existing regional ground-water system. Water-level measurements will be made in existing wells, caverns, and springs and compared with measurements made in the past. Where necessary, sites will be selected for the installation of continuous recorders to provide a continuous record of water levels.

Where possible, discharge from springs and seeps in the ground-water discharge area located in the Amargosa Desert and Death Valley will be measured, using various methods as required by existing conditions.

An approach for estimation of discharge from ground-water-discharge areas by analyzing chemical precipitation and layering in discharge-area deposits was considered but not selected, because interpretation of data collected by this method would likely be too inexact to be useful due to lack of stratigraphic control. Similarly, an approach to discharge estimation by model calculation based on past-potentiometric head was considered but not selected. At present, this method seems too inexact to be useful, but it may be used in the future as an alternate approach to check results obtained by the methods described in the foregoing sections.

3.3.3.3 Estimation of past-potentiometric head by analysis of mineral deposits

The estimation of past-potentiometric head will be supported by evidence gathered in carbonate-cavern studies, in the drilling and coring program of this activity, and possibly from data gathered in the exploratory shaft.

The carbonate caverns such as those at Devil's Hole located in the discharge area south of Yucca Mountain contain evidence of past water levels in the regional hydrologic system; these changes cover many thousands of years. The water levels reflect the recharge-discharge relationships of the regional aquifer during this time period and can be used to infer the climatic conditions under which the recharge occurred. Regional water-level changes reflect changes in regional climate. The response of regional water levels to past regional climate can be used in addressing the question of how water levels at Yucca Mountain may respond to future climate changes.

Carbonate caverns in the ground-water-discharge areas south of Yucca Mountain provide convenient windows to the regional carbonate aquifer. The cavern deposits will be mapped, sampled, and analyzed. Previous studies of deposits from these caverns suggest a possible 300,000-yr record of carbon- and oxygen-isotope variation that will provide important information about the Quaternary geohydrologic and paleoclimatologic conditions at these sites and at Yucca Mountain (Winograd and others, 1988). Deposits on the cavern walls provide a record of water-level changes in the regional-carbonate aquifer dating back through the Quaternary. Biologic evidence from the cavern deposits also provides an association with ground-water chemistry.

Where possible, available caverns at Devil's Hole and any others found during field work will be entered, mapped, and sampled. Approximately 50 samples of the carbonate layers that formed in the saturated zone that are exposed on the cavern walls will be collected. The water in these caverns will also be sampled to provide information as to present-day water chemistry.

Previous studies (I. J. Winograd, personal communication, 1986) of carbonate-cavern deposits suggest a possible 30,000- to 50,000-year or greater water-level record, available from vein deposits, that will provide important information about the Quaternary geohydrologic and paleoclimatologic conditions at these sites and at Yucca Mountain. Deposits on the cavern walls provide a record of water-level changes in the regional-carbonate aquifer dating back through the Pleistocene. Biologic evidence from the cavern deposits may also provide an association with any changes in ground-water conditions. Fossilized and contemporary *Neotoma* sp. middens (packrat middens) may be present in some caverns. The location of the middens can be indicative of past maximum water levels, and the age of organic material in the middens can be used to assist in the reconstruction of water-level history.

The cavern-carbonate samples that formed in the saturated zone will be analyzed to determine mineralogic and biologic composition and age. Biological information such as ostracodes and diatoms incorporated into these deposits will be used to provide data about mode and environment of occurrence, including water chemistry. As many as 150 thin sections of carbonate samples may be analyzed to determine mineralogic variations that provide evidence of varying ground-water conditions. Scanning electron microscope (SEM) and X-ray techniques may also be used on up to 75 to 100 samples to determine the microscopic structure and composition of the banded carbonate units. Chemical, physical (e.g., grain size, texture, porosity, density), and isotopic analyses may be run on up to 50 samples to provide supporting information for various components of the study.

The samples of carbonate deposits and water will be analyzed to determine mineralogic, chemical, isotopic, and biologic composition. Samples will also be dated using various chemical or physical dating methods (as described in Section 3.5.3). Samples of tuff and other rocks will be analyzed to determine mineralogic variations or alterations that may provide evidence of varying ground-water conditions in the past. SEM and X-ray techniques will be used to determine the microscopic structure and composition of banded carbonate units. Radioisotopic analyses may be run on up to 50 water samples to attempt to determine the age of water in the aquifers starting with the 30 spring samples listed in Table 3.3-2.

Lithologic and mineralogic evidence from core and cuttings collected during the drilling program will be examined for indications of Quaternary water levels in the geologic section.

In the study-plan workshop, an approach to model calculation of past-potentiometric head using evidence of paleorecharge and paleodischarge was considered but not was selected, because interpretation of the data would likely be too inexact to be useful because of lack of stratigraphic control.

3.3.3.4 Electromagnetic (EM) ground conductivity

Electromagnetic (EM) ground-conductivity measurements may be made along and across surficial boundaries between ground-water subbasins in order to estimate the present water table at these locations. This work will be coordinated with regional ground-water flow-system work (Study 8.3.1.2.1.3) to map the water table in areas where well data are scarce. This effort will be done as a precursor to the drilling program. Water levels showing large vertical changes in small distances near the edges of ground-water basins may indicate changes in transmissivity, changes in saturated thickness, or both. They may also represent buried structural features. Furthermore, they will have to be investigated if alternate conceptual models for past and present regional hydrology are to be tested. Knowing the present water-table distribution at those boundaries between ground-water basins will help in reconstructing the position of the water table for past time periods and in predicting future water levels. With water-level data from wells, the distribution of the potentiometric contour lines between wells is inferred; by using EM techniques, the water-table surface can be mapped directly. Thus a more complete water-table configuration may assist in determining ground-water flow rates between subbasins (for the Regional hydrologic system investigation) and give clues to determining past and future flow rates.

Another application for EM ground-conductivity data is in supplementing site studies. It is postulated that the ostracode fauna found immediately above the clay deposits of the Moretti pit (near the southeast corner of Peter's Playa) represent the interstitial (hypogean) environment. Because the water level is being depressed at the site by a dewatering operation at the clay pit, it is difficult to know the true present water level at the fossil site. The EM ground-conductivity method, however, could show the extent of the water table and the lithology of that part of Peter's Playa. By mapping the water table along with information about the lithology, the water table could be mapped from the undisturbed area back to the dewatered clay pit. Resulting data would then be used to select a drill-coring site, from which data would be collected that would also address the needs of the Climate and Geohydrology programs for lithologic and climatic proxy data.

Radio-frequency (RF) ground conductivity was considered but will not be used at this time. If EM studies indicate a need for RF data, the technique will be added to the study.

An independent program of seismic reflection and refraction lines was selected as an concurrent approach to terrain ground conductivity. Seismic data from the tectonics program will also be employed in this activity to help assess water-table configuration and ground-water subbasin boundaries.

3.3.3.5 Estimation of storage coefficient

Storage coefficients for the geohydrologic modeling for calculations of present-day ground-water travel time will be provided by the geohydrology program. In order to model the response of future hydrology to future climate, however, (Study 8.3.1.5.2.2), the storage coefficients of units presently in the unsaturated zone, but which conceivably could become saturated in response to climatic change, will be estimated as part of the present activity. This estimation will be made from lithologic data provided both by the Geohydrology program and by the present study and will be done by the vertical variability method (Kolm and others, in review). This method uses the scientific judgement and experience of the hydrologist. Although the vertical-variability program was designed to compute transmissivity and storage depth for the saturated section utilizing gravity drainage, it can be modified to compute confined conditions. Thus, an estimate of storage coefficients can be obtained for material that is now not saturated but could have been in the past or could be in the future. The method evaluates vertical variability and uses unit thickness, saturated thickness, and estimates of hydraulic conductivity and specific yield applied to lithologic logs. The specific yield value multiplied by saturated thicknes. gives the parameter of storage depth. Input data for specific yield values are from aquifer tests and laboratory drainage tests for lithologic materials for the saturated zone. The values from the tests are for known lithologic materials and would then be applied to similar drillers' lithologic logs of like materials at sites where tests were not run.

A method of moments can be applied to aquifer-property estimation and can be used to evaluate vertical and areal variability of estimated aquifer-property distribution.

Specifically, this method may be applied to the vertical distribution of estimated hydraulic-conductivity and specific-yield values in fluvially derived aquifer systems to determine the vertical and areal distribution of these values and to determine the number of hydrologic layers in the aquifer system. The method also can be used to characterize unique geomorphic features, such as paleochannels or fracture-zone alignments that might correlate with areas of increased transmissivity. The method was initially tested on fluvial deposits, but it is generic; therefore, the method should work on all deposits with minimum modification.

Krumbein and Libby (1957) applied a method of moments to prepare maps showing values of the center of gravity (COG) and standard deviation for specific lithologic rock units. Meyboom (1960) applied the method of moments to determine the vertical variability of sandstone-bed thickness within a given stratigraphic section. Domenico and Stephenson (1964) applied quantitative geologic-mapping techniques that used the method of moments to determine thickness data for use in a hydrologic computer model of the Las Vegas Valley, Nevada. The application of vertical variability of hydraulic conductivity and specific yield, for weighted-average values between time steps for a multilayered-aquifer modeling program, was used for a test area in Texas County, Oklahoma, by Devries and Kent (1973). Winter (1975) used a similar method to study glacial-drift deposits in northwestern Minnesota.

Lappala (1978), using descriptive sample logs, computed and then applied vertically averaged values of hydraulic conductivity and drainable porosity (specific yield) to prepare maps of the High Plains aquifer in southwestern Nebraska. Gutentag and others (1984) analyzed 3,076 drillers' logs from the High Plains aquifer using a vertical-, areal-variability methods procedure. Bryn (1984) applied the method described in Gutentag and others (1984) to the High Plains aquifer of northeastern Colorado; she ascertained that determination of aquifer properties from interpretation of drillers' logs, which can be done at a reasonable cost, produces values that are reasonably accurate. Kolm and others (in review) developed a vertical and aerial variability technique to evaluate the accuracy of parameter estimation and variability of parameter distribution; the method was applied to two regional aquifer systems to reveal unique geomorphic features that control the ground-water flow paths and characteristics.

Before a computer model of ground-water flow can be applied, the vertical and areal distribution of lithologic types and associated hydraulic properties within the aquifer need to be determined. If all lithologies are equally likely to occur at any position in the vertical section, the aquifer can be modeled areally using average hydraulic-conductivity, transmissivity, and specific-yield values. If one lithology is more likely to occur at a particular position in the vertical section than any other lithologic type, the aquifer can be modeled by developing relations between vertical position and each aquifer property (for example, using a three-dimensional model instead of a two-dimensional model, or a one-layered model instead of a two-layered model).

A method that can be used to evaluate the vertical variability of aquifer properties uses the COG of the vertical distribution of aquifer properties estimated from lithologic logs. The COG of the distribution of any property (P) can be calculated from the following equation:

$$COG(P) = \sum_{i=1}^{n} P_i M_i / \sum_{i=1}^{n} P_i, \tag{1}$$

where the moment arm (M_i) is the distance from a reference plane (the base of aquifer is convenient to use) to the midpoint of the i^{th} lithologic unit that has a value P_i of the aquifer property.

The COG has the dimension of length and can be made dimensionless by dividing it by the total thickness of the aquifer. This number is referred to as the relative COG (RCOG) and is calculated by the following equation:

$$RCOG(P) = COG(P) / \sum_{i=1}^{n} t_i, \tag{2}$$

where t_i is the thickness of the i^{th} lithologic unit. To use equations 1 and 2, a lithologic log is divided into n lithologic units, and a value of the aquifer property is assigned to each unit.

The RCOG indicates the position of the centroid of distribution of the aquifer property within the lithologic section. Thus, a RCOG value of 0.5 $\pm$ 0.1 indicates that the aquifer property is distributed equally within the saturated lithologic section.

The COG value determined from a large number of lithologic logs can be analyzed to determine whether an aquifer property is distributed evenly or randomly about the middle of the aquifer throughout a given regional area. If the average RCOG value determined from a group of lithologic logs is not different from 0.5 $\pm$ 0.1, then the aquifer property (and the lithologies that control the property) is distributed laterally throughout the area.

3.3.3.6 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.3-3. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be utilized only if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, there are many approaches to conducting the test. In those cases, only the most common methods are included

Table 3.3-3. Summary of tests and methods for the past discharge areas activity (SCP 8.3.1.5.2.1.3)

[Note: Dashes (--) indicate information is not available and to be determined]

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Remote-sensing analysis and verification	
Computer-aided analysis of LANDSAT thematic mapper (TM) spectral data bands 2, 3, 4, 5, 6, 7 (selected)	Correlation of surficial materials properties (infiltration potential, grain-size distribution) with characteristic spectral responses from LANDSAT TM spectral data	Map products showing locations of discharge areas (measured)
Computer-aided analysis of LANDSAT thematic mapper (TM) spectral data bands 1, 2, 3, 4, 5, 7 (selected)	Locations, modern and past ground-water-discharge deposits	Color-enhanced imagery of surficial-material discriminations for data collection (measured)
Manual analysis of high-altitude and low-altitude aerial photography (selected)	Correlation of surficial materials properties (infiltration potential, grain-size distribution, lithologies) with spectral responses of surficial materials	Map products showing distribution of estimated infiltration potentials
Analysis of low-altitude pre-dawn thermal scanner data (selected)	Infiltration and runoff migration pathways	Map products showing zones of infiltration and runoff migration pathways
Analysis of side-looking airborne radar (SLAR) data (selected)	High-resolution microtopography for lineament analysis	Map products or photo images showing fracture patterns and linear features
Estimate evapotranspiration potentials based on climatic data, vegetation distibutions, surficial materials, and slope angle/aspect/elevation relations (selected)	Estimated areal-evapotranspiration potentials	Hunt (1966) reported 380 cm/yr PET for Death Valley, CA (measured, from literature)

Table 3.3-3. Summary of tests and methods for the past discharge areas activity (SCP 8.3.1.5.2.1.3)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Remote-sensing analysis and verification		
Estimate areal evapotranspiration potential, and distribution and extent of discharge deposits, through digitized "single-parameter" overlays (selected)	Estimated discharge rates, modern- and past-discharge areas	Near 0 to 1,000 liter/sec (estimated or theoretically determined)
Determine areal distribution of surficial materials and hydrologic properties through spectral response in LANDSAT TM bands 1, 2, 3, 4, 5, 7 (selected)	Estimated infiltration potentials for specific areas	Near 0 to 50 mm/day (estimated or theoretically determined)
Estimate character of ground-water discharge using paleontologic, isotopic, and geochemical data		
Core drilling and outcrop sampling (selected)	Geohydrologic units: location, type, extent	Depths 6 to 1520 m, contacts variable (estimated or theoretically determined)
Geophysical logging (selected)	"	Contacts variable (estimated or theoretically determined)
Geochemical analysis of water in modern-discharge areas (selected)	Chemistry, modern-discharge waters	Full range of natural waters is present in area (measured)
Thermal measurement of modern-discharge waters (selected)	Temperature, modern-discharge waters	+1 °C to about 100 °C (measured)
Paleontological analysis of sediments in modern- and past-discharge areas (selected)	Chemistry, past-discharge waters	Near 0 mg/liter to about 100,000 mg/liter (measured)
"	Temperature, past-discharge waters	+1 °C to about 100 °C (from literature)

Table 3.3-3. Summary of tests and methods for the past discharge areas activity (SCP 8.3.1.5.2.1.3)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Estimate character of ground-water discharge using paleontologic, isotopic, and geochemical data		
Determine Mg/Ca and Sr/Ca of modern ostracodes (selected)	Partitioning coefficient as function of salinity	Maximum = 1 (measured)
Isotopic analysis of fossil ostracodes (alternate)	Temperature, past-discharge waters	+1 °C to about 50 °C (upper range of microorganisms), (measured, estimated, or theoretically determined)
Isotopic analysis of modern ostracodes (alternate)	"	+1 °C to about 50 °C (upper range of microorganisms) (measured, estimated, or theoretically determined)
Measurement of existing water levels in caverns, wells, and springs (selected)	Potentiometric surface, modern	-100 m to greater than -3,000 m MSL of 1929 (measured)
Measurement of discharge from modern springs and seeps (selected)	Discharge rates, modern-discharge areas	Near 0 to 1,000 liters/sec (measured)
Determine Mg/Ca and Sr/Ca of fossil ostracodes (selected)	Salinity, past-discharge waters	Near 0 to 100,000 mg/liter (measured)
Estimation of past-potentiometric head by analysis of mineral deposits		
Evaluation of carbonate cavern and spring deposits (selected)	Head, potentiometric, past	-100 to -3,000 m MSL (measured)
Examination of core from drilling program for evidence of past water levels (selected)	"	Contact to +/- 0.2 m by drilling, +/- .1 m by coring (estimated or theoretically determined)

Table 3.3-3. Summary of tests and methods for the past discharge areas activity (SCP 8.3.1.5.2.1.3)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Estimation of past-potentiometric head by analysis of mineral deposits		
Geochronology (selected)	Head, potentiometric, past	-100 to -3,000 m MSL (measured)
Electromagnetic (EM) ground conductivity		
Determine present potentiometric head and boundaries of sub-basins with EM ground conductivity (in conjunction with regional ground-water flow-system study) (selected)	Geohydrologic units: location, type, extent	Depth and thickness of geohydrologic units in feet below land surface: 1 to 10 m (estimated or theoretically determined)
"	Head, potentiometric, past	-100 to -3,000 m MSL (measured)
"	Head, potentiometric, present	Depth of present water level in meters: +/- 0.3 m at 18 m
Extensive test-drilling program (alternate)	Geohydrologic units: location, type, extent	Depth and thickness of hydrogeologic units in meters below land surface +/- 0.3 m (measured)
"	Head, potentiometric, present	Depth of present water level in meters: -100 to -3,000 m MSL (measured)
Other surface geophysical methods (alternate)	Geohydrologic units: location, type, extent	Depth and thickness of hydrogeologic units in meters below land surface: +/- 0.1 m (measured)
"	Head, potentiometric, present	Depth of present water level in meters: -100 to -3,000 m MSL (measured)

Table 3.3-3. Summary of tests and methods for the past discharge areas activity (SCP 8.3.1.5.2.1.3)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Electromagnetic (EM) ground conductivity	
Modeling calibration to infer hydrogeologic boundaries of sub-basins (alternate)	Geohydrologic units: location, type, extent	Depth and thickness of hydrogeologic units in meters below land surface: +/- 0.1 m (measured)
"	Head, potentiometric, present	Depth of present water level in meters: -100 to -3,000 m MSL (measured)
	Estimation of storage coefficient	
Estimation of storage coefficient by vertical variability method (selected)	Storage coefficient	0.25 to 1 x 10^{-6} (naturally occurring range)
Estimation of storage coefficient by model analyses (alternate)	"	"

in the tables. The selected methods in Table 3.3-3 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The accuracy and precision of methods are difficult to quantify before actual testing and implementation of the methodology. Generally, for method selection, the accuracy and precision prediction is a relative judgement based on the USGS investigators' familiarity with, and understanding of, the method. For selected methods, if values of accuracy and precision exist, they will be listed within the USGS technical procedures.

Similarly, the duration of a method is difficult to quantify. The duration of some methods may be seconds, whereas the duration of others may be months. The methods, however, have been selected so that the parameters of interest can be evaluated reasonably within the schedule of the study (Section 5.1). The total duration of the method is dependent on the number of times it is implemented, which is dependent on the spatial variability of a parameter within or among geohydrologic units, the accuracy and precision of the method, the number of available samples, and desired level of confidence in reproducibility of the measurement.

The methods were also selected by considering their ranges of measurement. It would be senseless to select a method that could not provide accurate data within the expected range of the site-characterization parameter of interest. Again, the expected range of method is difficult to quantify without actual testing or implementation of the technique. The USGS investigators, however, have selected methods which they believe are suitable to provide accurate data within the expected range of the site-characterization parameter. Some of the expected ranges of site-characterization parameters have been bracketed by previous data collection and are shown in Table 3.3-3.

Finally, the interference of a given method with other tests in the site-characterization program was considered in selecting the method. Generally, the selected methods will have little or no interference with other tests and analyses. In cases where methods do interfere, the USGS investigators have planned their testing sequences accordingly, in order to maximize data collection and minimize interference.

3.3.4 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires assignment, justification, and documentation of quality levels to activities that affect quality; and documentation of technical procedures for all technical activities that require quality assurance.

The technical procedures which will be utilized in this activity are standard procedures derived from the scientific literature appropriate to the various techniques. These procedures have been adapted to compensate for site-specific conditions and incorporate the quality-assurance requirements of the Yucca Mountain Project.

Table 3.3-4 provides a tabulation of technical procedures applicable to this activity (technical procedures for chemical analyses for this activity appear in Table 3.5-2). The technical procedures are listed according to the tests/analyses of Table 3.3-3. Approved procedures are identified with a USGS number. Procedures that require preparation do not have procedure numbers. Procedures that are identified as "needed" in the table will be completed and available 30 days before the associated testing is started.

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

Table 3.3-4. Technical procedures for the past discharge areas activity (SCP Activity 8.3.1.5.2.1.3)
(At the discretion of the PI, approved technical procedures not listed may be used during the activity, should that be appropriate, and revised or replaced with other procedures as needed.)

Technical procedure number (YMP-USGS-)	Technical procedure
	Remote-sensing analysis and verification
HP-128	Development of methods to calibrate remote-sensing surficial data against hydrological and related properties of representative materials in a Southern-Nevada ground-water basin, Nevada and California
HP-158	Hydrology and hydraulic nature of fracture zones and lineaments determined from remote sensing and hydrologic analysis (tentative procedure)
HP-173	Data collection protocol for plant community analysis
HP-186	Methods for locating field sites on topographic maps for reconnaissance and site characterization activities
HP-203	Collection of soil samples for correlation with plant community data and with remote sensing analysis
HP-205T	Channel geometry data collection
HP-206T	Pedogenic carbonate sample collection
	Estimate character of ground-water discharge using paleontologic, isotopic, and geochemical data
GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
GCP-03	Uranium-series dating
GCP-08	Fission-track dating
HP-23	Collection and field analysis of saturated-zone ground-water samples
HP-25	Method for measuring water levels using a portable multiconductor

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Table 3.3-4. Technical procedures for the past discharge areas activity (SCP Activity 8.3.1.5.2.1.3)—*continued*

Technical procedure number (YMP-USGS-)	Technical procedure
HP-26	Method for calibrating water-level measurement equipment using the reference steel tape
HP-37	Preliminary procedure for drilling and coring of wet- and dry-lake sediments
HP-54	Water-flow measurements using weirs, flumes, and barrels
HP-76	Diatom enumeration studies
HP-78	Nonmarine calcareous-microfossil sample preparation and data acquisition procedures
HP-91	Collection and field analysis of surface-water samples
HP-99	Instruction for operation of a well sounder for measuring water levels
TWS-ESS-DP-16	Siemens X-ray diffraction procedure
TWS-ESS-DP-24	Calibration and alignment of the Siemens diffractometers
TWS-ESS-DP-25	Clay-mineral separation and preparation for X-ray diffraction analysis
TWS-ESS-DP-51	Mettler AE100 operating procedure (X-ray fluorescence analysis sample weighing procedure)
TWS-ESS-DP-52	Sample preparation for X-ray fluorescence analysis: fusing and lapping
TWS-ESS-DP-53	Pulverizing using the Rocklabs 3E shatterbox
GCP-17	Determination of the isotopic ratio H/D in water
GCP-12	Rb-Sr isotope geochemistry
HP-173	Data collection protocol for plant community analysis

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Table 3.3-4. Technical procedures for the past discharge areas activity (SCP Activity 8.3.1.5.2.1.3)—conn

Technical procedure number (YMP-USGS-)	Technical procedure
TWS-ESS-DP-112	Operating instructions for International Scientific Instrument Model DS-130 scanning electron microscope and TRACOR Northern Series II X-ray Analyzer for evaluation of YMP geologic materials
GCP-04	Uranium-trend dating
GCP-07	Mineral separation for geochemistry and isotopic analysis
HP-182	Collecting microvertebrate fossils by washing and sieving
HP-186	Methods for locating field sites on topographic maps for reconnaissance and site characterization activities
HP-203	Collection of soil samples for correlation with plant community data and with remote sensing analysis
HP-206T	Pedogenic carbonate sample collection
	Estimation of past potentiometric head by analysis of mineral deposits
GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
GCP-03	Uranium-series dating
GCP-08	Fission-track dating
HP-23	Collection and field analysis of saturated-zone ground-water samples
HP-37	Preliminary procedure for drilling and coring of wet- and dry-lake sediments
HP-78	Nonmarine calcarious-microfossil sample preparation and data acquisition procedures
HP-164	Processing of soil, sediment, and water samples for chrysophyte cysts

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Table 3.3-4. Technical procedures for the past discharge areas activity (SCP Activity 8.3.1.5.2.1.3)--continued

Technical procedure number (YMP-USGS-)	Technical procedure
GCP-04	Uranium-trend dating
GCP-07	Mineral separation for geochemistry and isotopic analysis
HP-186	Methods for locating field sites on topographic maps for reconnaissance and site characterization activities
GCP-22	Spike calibration for uranium-series and uranium-trend analysis
	Electromagnetic (EM) ground conductivity
HP-187	Terrain conductivity measurement using the Model EM-34-3
HP-186	Methods for locating field sites on topographic maps for reconnaissance and site characterization activities
	Estimation of storage coefficient
TBD	Storage coefficient estimation by vertical-variability method

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3.4 Analog recharge studies

3.4.1 Objectives

The primary objective of the analog recharge study is to estimate recharge to the paleohydrologic regime associated with ground water in the vicinity of Yucca Mountain under wetter climatic conditions. Knowledge of the paleohydrologic regime associated with the wetter conditions allows the determination of hydrologic effects of future climate change and estimates of possible future recharge and flow rates through the repository site under various climatic conditions.

The above objectives were developed in order to guide data collection to provide information for testing the following hypotheses.

1. Ground-water recharge or accumulation of various salts, such as chloride and carbonate, under similar vegetational, climatic, and geological regimes is not time dependent. Recharge during the late Pleistocene in pine forests with volcanic soil was the same as present day under the same conditions.

2. Knowledge of present-day recharge under different climate conditions will provide information to estimate recharge during various Pleistocene climates.

3. Knowledge of Pleistocene recharge will provide information as to the effects of different recharge rates on the water table near Yucca Mountain.

3.4.2 Rationale for activity selection

An analog study allows investigation of a paleoenvironment. Studying a modern system analogous to a paleosystem minimizes assumptions about parameter magnitude, variability, and the effects of parameter interaction. Pertinent unknowns can be directly measured at the analog site and, if the site is a true analog, assumed to be applicable to the paleosite.

3.4.3 General approach and summary of tests and analyses

Hydrologic budgets are commonly estimated from only general knowledge of a hydrologic regime (Eakin and others, 1951) or from energy-budget techniques (Leavesley and others, 1983). Both techniques are applicable to modeling paleohydrologic conditions. An energy budget will be used as a comparative method to an independent procedure such as the mass-balance technique. A chloride-ion mass-balance technique (Claassen and others, 1986) to determine effective moisture (or available moisture, which is precipitation less evapotranspiration) in a watershed is directly applicable to paleowatershed conditions. The model described by Claassen and others (1986) allows the effects of microclimate variability to be evaluated within a given ecologic zone, but it should be calibrated for each zone, primarily because rainfall amounts and seasonal distribution result in significant changes in chloride-ion concentration.

Figure 3.4-1 summarizes the organization of the evaluation of analog recharge tests. A descriptive heading for each test and analysis appears in the shadowed boxes of the second and fourth rows. Below each test/analysis are the individual methods that will be utilized during testing. Figure 3.4-2 summarizes the objectives of the activity, site-characterization parameters which are addressed by the activity, and the activity parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed test/analysis boxes, respectively, in Figure 3.4-2.

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

3.4.3.1 Site selection

Sites in Nevada, southern California, and Arizona have been evaluated, and four sites have been selected (and a fifth may be added at a later date) as analog recharge sites to represent the range of paleohydrologic conditions that, on the basis of paleoecological studies, may have existed during the late Pleistocene in the vicinity of Yucca Mountain. Evaluation of the selected analog sites will consist of characterizing the rock type, vegetation type, present microclimate, and topography. Sufficient data to define microclimatic conditions, hydrologic budget, and aqueous chemistry and isotopic composition will be collected for at least a 5-year period, with special emphasis on recharge rates. These data, in turn, will be used to determine the paleohydrologic regime associated with the ground water and vadose-zone water in the vicinity of Yucca Mountain, estimate possible paleo-recharge rates at Yucca Mountain, and provide a foundation for determination of possible future regimes at Yucca Mountain.

The evidence of the paleomonsoonal effects in the Mojave and Sonoran Deserts was put forth by Spaulding and Graumlich (1986). The implication of increased summer rains adds another climatic scenario for recharge. The present chloride mass-balance modeling effort assumes that significant recharge is the result of snowmelt. This may have been true only during the pluvial regime of the late Wisconsin. A second pluvial of the early Holocene resulting from monsoons would present different evapotranspiration, vegetation, and annual temperature distributions and, therefore, possibly different recharge mechanics and amounts not predicted by the subalpine and pine-juniper climate analog sites. Locations of Nevada analog sites are shown in Figure 3.4-3.

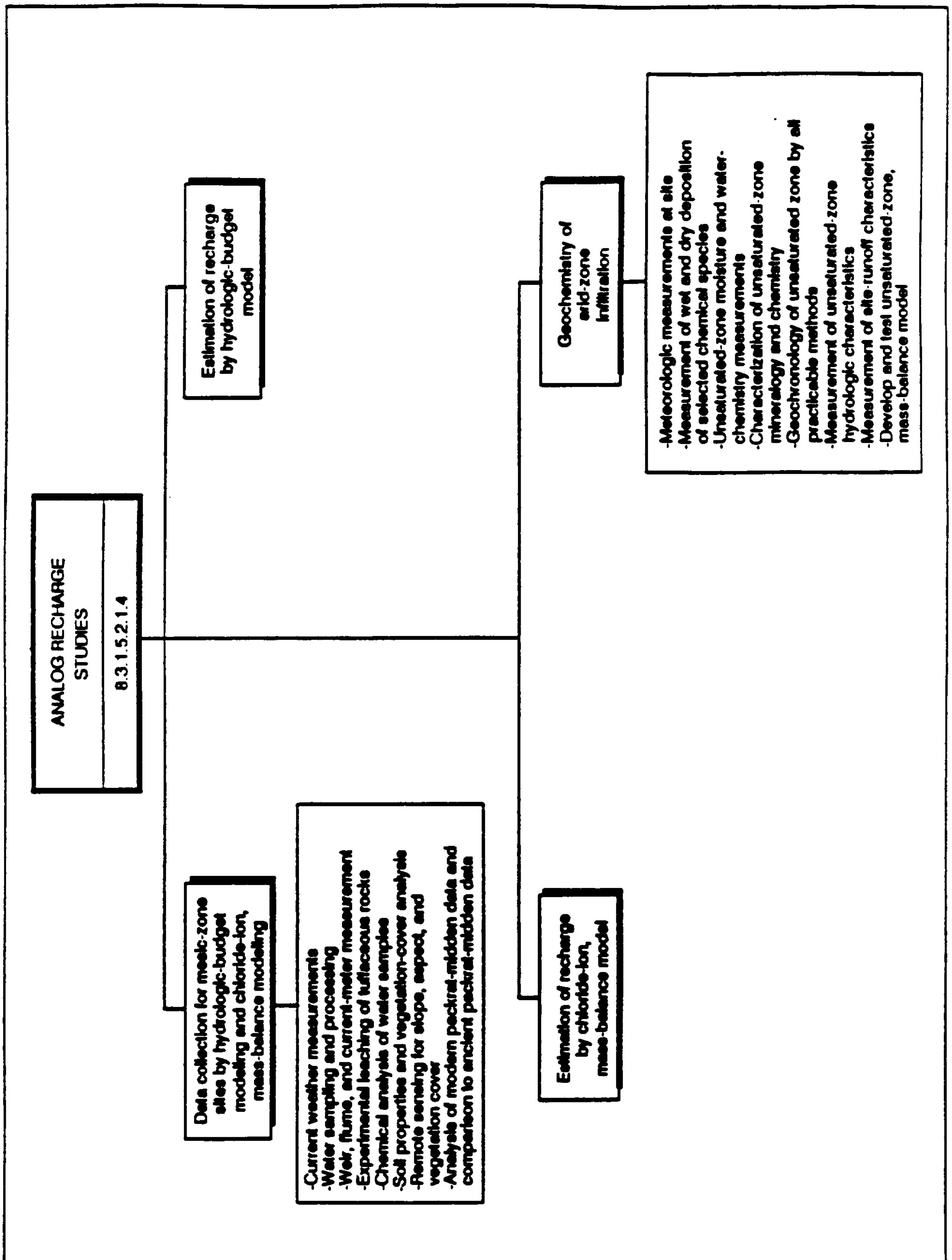

Figure 3.4-1. Logic diagram of analog recharge activity showing tests, analyses, and methods.

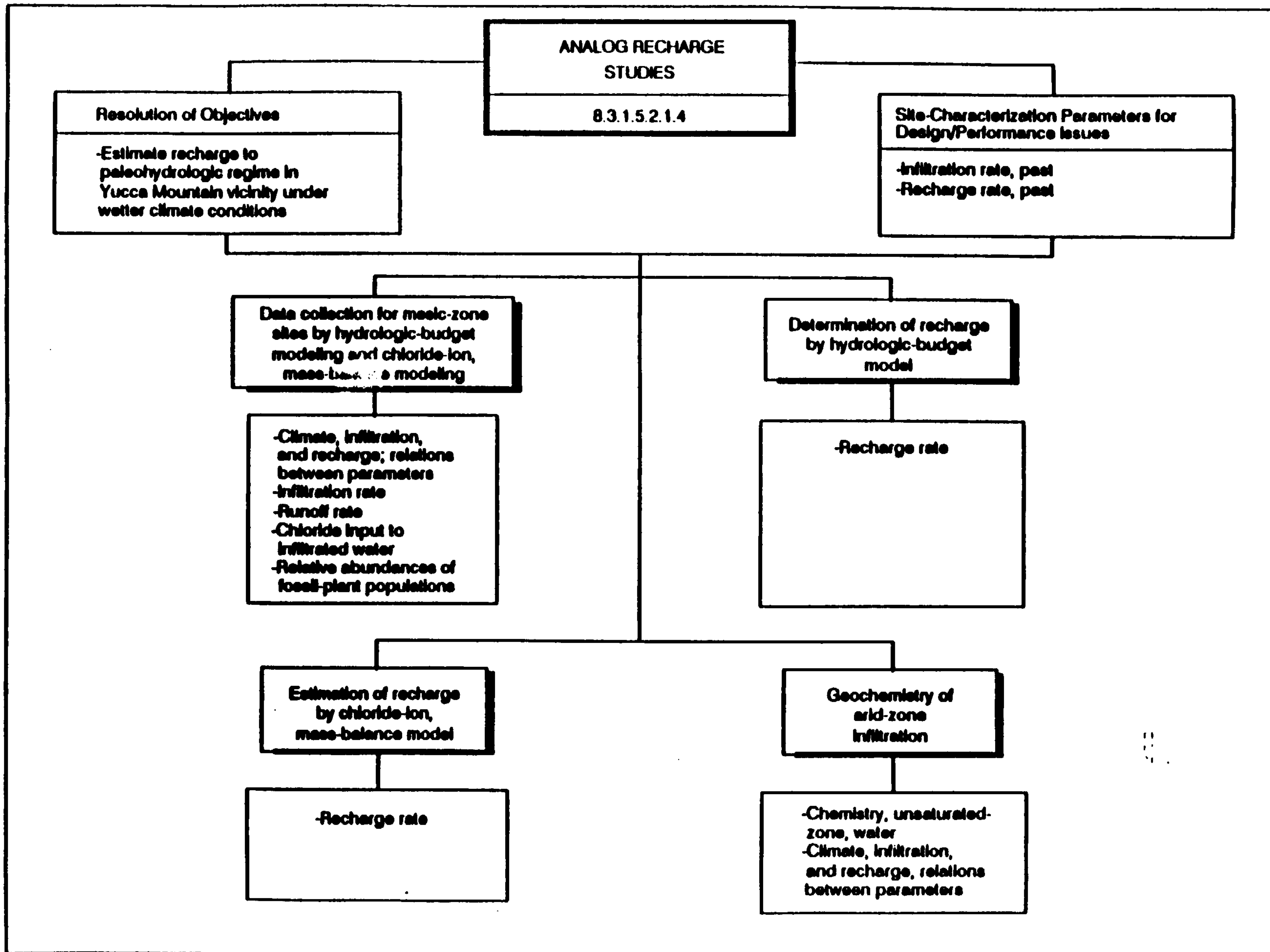

Figure 3.4-2. Logic diagram of analog recharge ...y showing tests, analyses, and activity parameters.

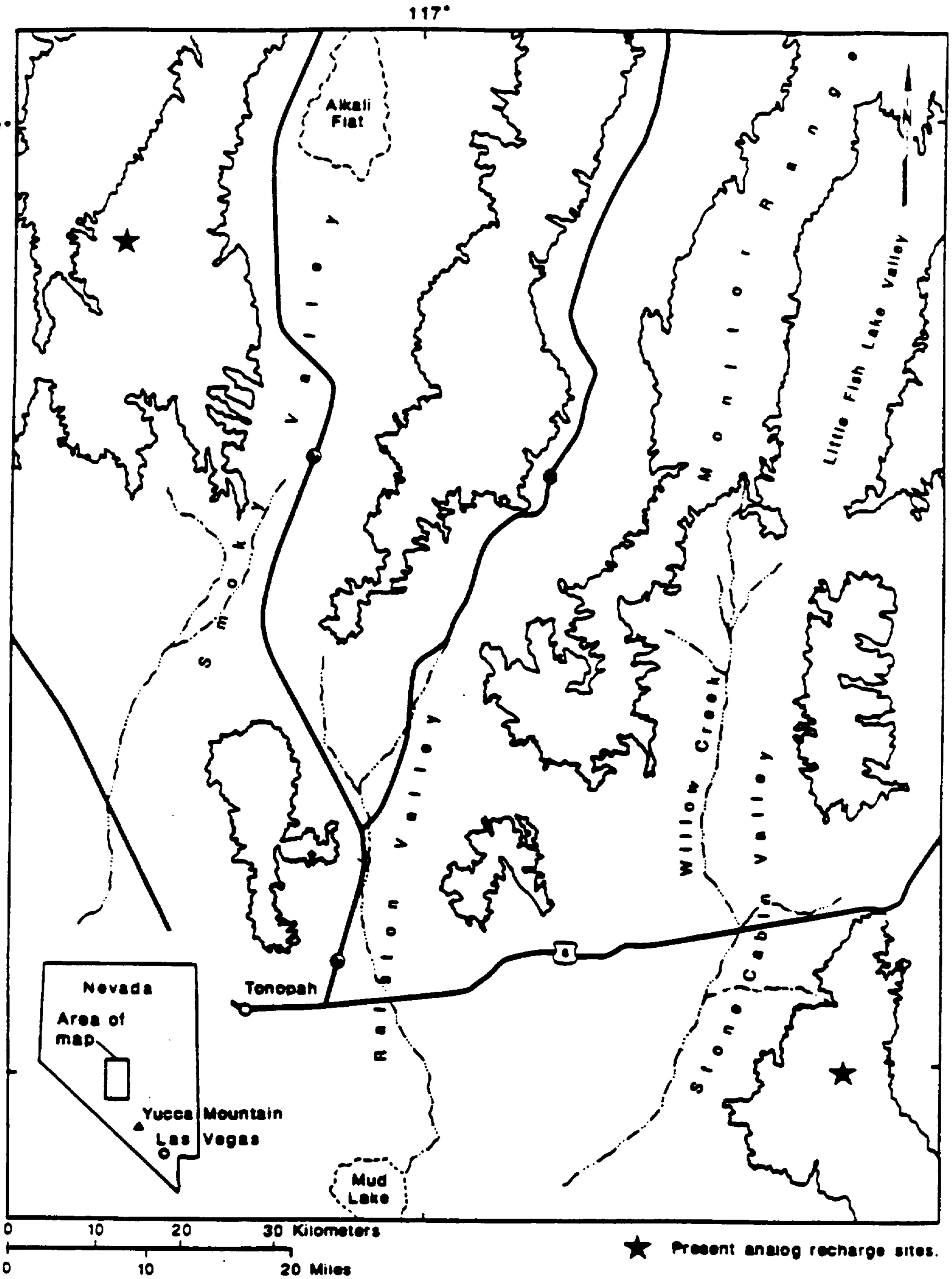

Figure 3.4-3. Locations of existing analog recharge sites in Nevada.

The location of an analog monsoonal site is limited by areas with plant communities that were characteristic of the monsoon-affected paleo-Mojave Desert and by lithologies similar to those existing at Yucca Mountain. The plant communities that Spaulding used to infer a monsoonal climate can be found in Arizona and southeastern California. Within this broad region, appropriate lithologies of silicic ash-flow tuffs are found in southern and western Arizona (Figure 3.4-4). An ideal analog site was found at Organ Pipe Cactus National Monument. The site has an additional benefit in that a good data base already exists for this area, and climate studies by other agencies, which may provide valuable background information, are already planned. Because this site is intended as an analog for the purpose of predicting what would happen at Yucca Mountain under changed climatic conditions, the location in Arizona should not be construed as suggesting that Arizona is an affected state.

The climatic regime responsible for recharge of the present ground water is not known. The analog recharge project will provide recharge rates for various climate scenarios that might effect future regional hydrology. The proposed sites cover only the bare minimum of the climatic possibilities; however, the sites are planned such that the extremes of climate range will be included.

3 4.3.2 Data collection for mesic-zone sites by hydrologic-budget modeling and chloride-ion, mass-balance modeling

At each mesic-zone analog recharge site, measurements will be made of precipitation, air and soil temperatures, solar radiation, and other pertinent microclimatological properties. Chemical analyses will be performed for standard major cations and anions, and isotopic analyses run for delta ^{18}O, delta D, and selective for ^{3}H. The measurement of chemical composition of precipitation is necessary as part of the chloride mass balance. Isotopic composition of precipitation at the analog sites will be compared with that of the ground water sampled at Yucca Mountain. Similar chemical composition may suggest deposition under similar climatic environments.

The composition of the plant communities present, as to the type and density of the component species, will be measured along representative "belt transects." The relationships between the plant communities and transpiration potential and infiltration and/or effective soil moisture will be determined. The slope angle and slope aspect relationships of the topography will be defined using Geographic Information System (GIS) software packages and the digitized topographic data. These data, along with the spatial distribution of the plant communities, as determined by using remote-sensing techniques, are required input to the chloride-ion, mass-balance model and the energy-budget model.

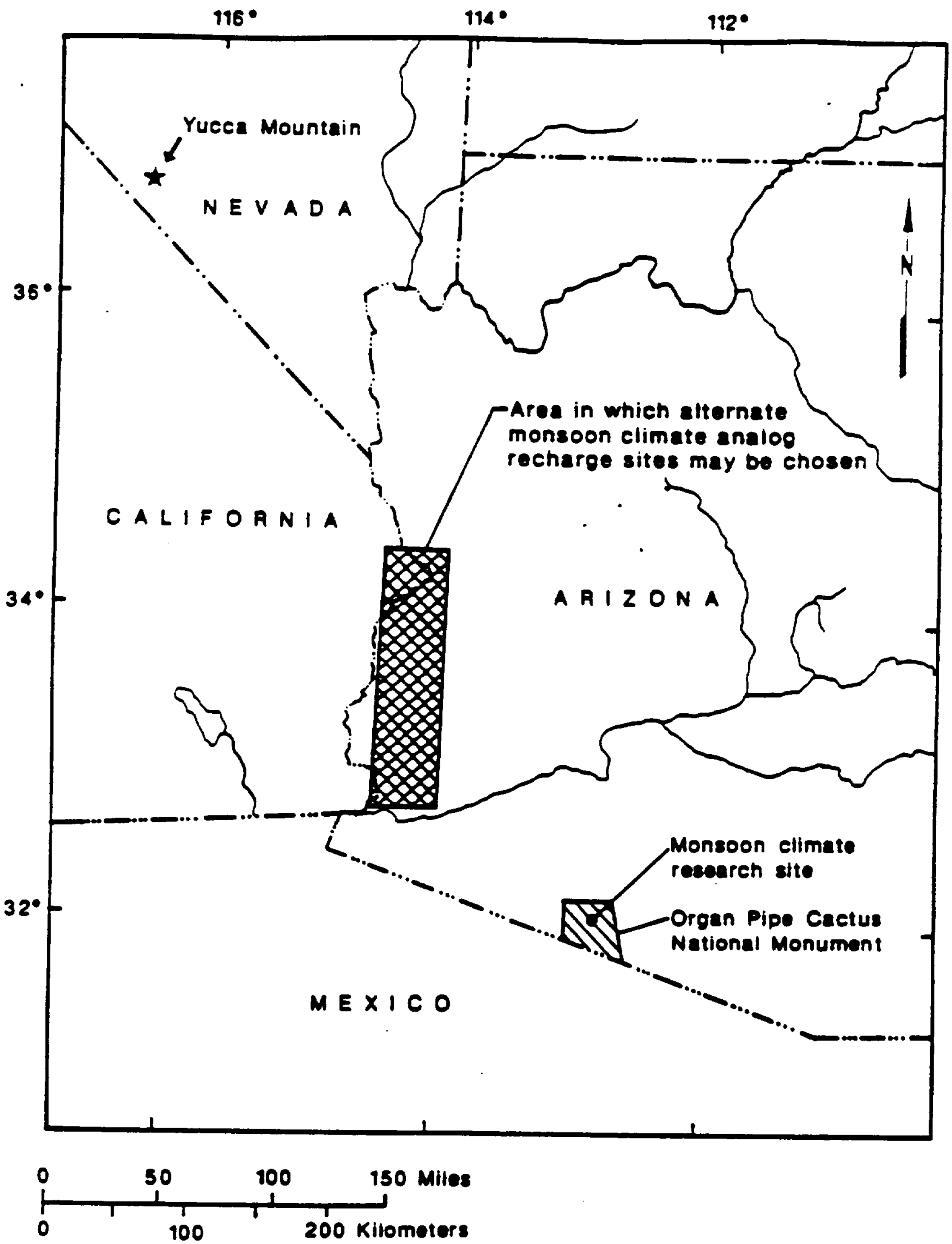

Figure 3.4-4. General locations of future analog-recharge data-collection sites.

The characterization of the vegetative cover, as determined from "belt transects," will be used as ground-truth data for remote-sensing techniques that will determine the spatial distribution of the plant communities and categorize the vegetative cover into classes of equal transpiration capacity. The remote-sensing techniques will use the reflective and thermal spectral characteristics of the plant communities to define the spatial distribution and density of a given community, and to estimate the total acreage of each community. The soil-moisture contents of exposed soils will also be estimated using the reflective and thermal spectral characteristics of the surficial materials. Ground truth for the remote-sensing techniques will come from on-site identification of plant species. The spatial distributions and densities of the plant communities, and the estimated soil-moisture contents, will be used in conjunction with the relationships between the plant communities and the transpiration potentials to categorize the vegetative cover into classes of equal transpiration capacity.

The correlation between the hydrologic properties of surficial materials (as determined by other investigators within the YMP project), the transpiration capacity of the vegetative cover, and the spectral properties of the surficial materials will be evaluated. The correlation will be used to estimate potential infiltration values (and hence, maximum recharge values) within the area of each analog site.

Stream-gauging measurements may be made at each of the selected sites, and continuous stage-recording instruments will be installed when necessary. Crest-stage gauges will be used for redundant-data collection of the peak-runoff measurements made by the continuous recorders. These stream measurements will be used to aid in the development of a water budget for the analog recharge sites.

Packrat middens will be used to compare analog sites with paleoclimatic conditions determined at Yucca Mountain (Study 8.3.1.5.1.3). Field observations will be conducted to locate and collect contemporary packrat middens from each selected site. The contemporary plant communities and packrat-collecting habits also will be investigated in the field and by field observations in order to determine any collecting bias by modern packrats. Information as to collecting bias is needed in order to evaluate samples from paleo-middens for fossil-plant populations. Plant-macrofossil assemblages will be collected in the field and sent to the laboratory for identification. These modern biological indicators will be interpreted and compared with similar macrofossil data that were collected at the Nevada Test Site (NTS).

At each selected site, the infiltration rate will be evaluated. Water samples will be collected from the vadose-water zone to determine the local-infiltration quantity and chemistry. A hydrochemical technique that uses the mobile chloride ion as a tracer through the hydrologic cycle will be used to estimate effective moisture from the samples (Claassen and others, 1986). The plant community and its relation to recharge and soil moisture will be studied to estimate an infiltration rate for the whole basin. Remote-sensing techniques will be used to determine type, spatial distribution, and density of vegetation. Soil temperatures also will be collected on a continuous basis. Evaluation of soil characteristics to determine their hydrologic properties and effect on consumptive water use will be evaluated if needed.

The temporal variability of chloride deposition will be measured at each of the selected sites. To accomplish this task, samples of precipitation, surface water, and moisture content of soils from the vadose-water zone will be collected and analyzed. The integrated precipitation samples will be collected four times per year, using a bulk sampler. The surface-water samples will also be collected from creeks and springs. The soil-moisture samples will be analyzed for major cations and anions and for hydrogen- and oxygen-isotope ratios. A computer program will be developed to make the calculations of water budgets on the basis of chloride-ion concentration data according to the mathematical model proposed by Claassen and others (1986).

One of the assumptions required in the chloride-ion, mass-balance model is that no lithologic source of chloride be present, or that the source be small compared to the input as precipitation. Although there is some evidence that this assumption is appropriate for tuffaceous rocks at NTS (Claassen, 1985), it remains to be demonstrated. Experimental procedures (White and Claassen, 1980) will be used to test the validity of this assumption.

3.4.3.3 Estimation of recharge by the hydrologic-budget model

The hydrologic-budget model developed by Leavesley and others (1983) uses the energy-budget approach to calculate evapotranspiration (ET). ET calculations use meteorological parameters such as daily mean air temperature, solar radiation, absolute humidity, and vegetation data. The snowpack water balance is calculated daily, and an energy balance is computed twice each day for the energy-budget method. Snowmelt in excess of field capacity becomes surface runoff. Recharge is estimated for rainfall as the difference between rainfall and surface runoff plus ET.

Because energy-budget estimates of ET may lack sufficient accuracy, particularly for complex terrain encountered at some of the analog sites, ET also will be estimated using other methods to validate model results. Meteorological methods, such as eddy correlation and variance techniques, will be used, as well as direct methods of transpiration measurement from the vegetation.

3.4.3.4 Estimation of recharge by the chloride-ion, mass-balance model

The chloride-ion, mass-balance model uses the chloride-ion concentration of infiltrating water to determine ET. The maximum quantity of recharge (effective moisture) is then calculated by subtracting the amount of surface runoff plus ET from the amount of precipitation. The use of two models to estimate recharge provides a means of testing the confidence limits placed on estimates of recharge. If results from the two models do not agree well, it may be necessary to obtain a third estimate in order to reduce uncertainty.

Two alternate approaches to estimating recharge by hydrologic-budget modeling and chloride-ion, mass-balance modeling were considered but not selected. These are (1) an approach using soil properties and vegetation analysis only and (2) an approach using estimates of paleotemperature and paleoprecipitation derived from biological evidence in packrat middens. Both methods require making several assumptions and major extrapolation of data; therefore results from these methods are not likely to be as useful to predicting repository performance as the method chosen and described above.

3.4.3.5 Geochemistry of arid-zone infiltration

Experience indicates that a number of techniques can be used to develop highly accurate water budgets for mesic-zone sites. The same techniques (e.g., chloride mass-balance and hydrologic-budget methods in Sections 3.4.3.3 and 3.4.3.4, respectively) applied to arid-zone sites are unlikely to yield accurate results, largely because of uncertainties in the measurement or prediction of the small quantities of water involved. At Yucca Mountain, application of the chloride mass-balance technique is further complicated by the variability of past climates, which are postulated to have ranged from the present-day zonal flow to climates with a pronounced monsoonal component. Therefore, a method of modeling past variance in infiltration can provide a cross-check, serving to integrate estimates of past hydraulic regimes coming from other methodologies, such as midden studies and hydraulic modeling.

In arid climates, authigenic carbonates (caliche) are commonly found at various depths in the soils and bedrock. Although less apparent, clays and soluble salts are also present. Because these deposits are emplaced by infiltrating precipitation, study of their amounts and position in a soil profile can be interpreted in terms of the amount and timing of the infiltration at that site after a valid model to decipher the observations has been developed. The simplest model may focus on chloride because its transport depends only on water movement. Carbonate movement is more complex because of solubility considerations involving CO_2, and so surface vegetation must be included in the model.

Because the total amount of mineral accumulation in these soils depends, simplistically, on atmospheric and (for carbonate) biological input rates multiplied by time, the calibration site selected for development of the model should have the following characteristics: (1) several soils of different ages derived from noncalcareous parent materials should be present, (2) reasonably accurate estimates of atmospheric and biologic inputs must be possible, and (3) existence of an undisturbed environment in order to minimize human impact on model factors. For the model to be maximally useful at Yucca Mountain, additional constraints include, but are not necessarily limited to, the following.

(1) The site should have a climatic regime similar to paleoclimatic regimes at Yucca Mountain, including both monsoonal and zonal flow. This is important because the different temporal distributions of precipitation in these flow regimes cause different infiltration characteristics.

(2) The site should be tied to a regional atmospheric-deposition data-collection network, allowing examination of spatial and temporal variability of these inputs.

(3) The site should have a non-calcareous, chloride-free, tuffaceous lithology similar to that of Yucca Mountain.

These requirements are best met at a site in Organ Pipe Cactus National Monument, Arizona.

The primary advantage to development of a mass-balance model is that *all* paleoclimatic information inferred from other studies, when applied to a valid process model, should be consistent with the observed vadose-zone mineral profiles. Such a model can therefore integrate the results of other studies (such as Activity 8.3.1.5.1.4.1, Modeling of soil properties in the Yucca Mountain region) and test their reasonableness. Because of the number of variables involved, it is possible that several different climatic histories may yield the same profile. It is expected that the use of two materials (carbonate and chloride) which respond differently to climatic inputs will maximize the response of the models to differing climatic histories.

In the first step to development of this method, the flux of pertinent inputs at the calibration site will be measured and recorded. These will include baseline weather measurements as well as precipitation isotopy and wet and dry deposition of carbonate, chloride, and calcium. Measurements of soil-water chemistry will also be attempted. The second step will be to characterize and quantify soil characteristics with depth. These characteristics include mineralogy, PCO_2 profile and time variation, hydrologic characteristics such as permeability and effective porosity, and ages (dating by rock varnish, geomorphic criteria, or other means). The third step will be to develop and calibrate soil mass-balance models for water, chloride, and carbonate. Equations representing conceptual models will be converted to computer algorithms. In the models, behavior patterns will be distinguished between zonal and monsoonal precipitation. The models will be validated using paleoclimatic records to see if mineral concentration profiles in the site soils can be reproduced. The models will be refined until they generate observed profiles. Finally, paleoclimatic histories and hydraulic information from other studies at and near Yucca Mountain (potentially including results from unsaturated-zone infiltration tests) will be input to the models in order to generate calculated depositional profiles. These model-simulated profiles will be compared to observed profiles at Yucca Mountain and vicinity. They might also be used to help determine whether the hydrogenic deposits in Activity 8.3.1.5.2.1.5 are of pedogenic or ground-water origin.

This investigation is similar to SCP activity 8.3.1.5.1.4.1 (Modeling of soil properties in the Yucca Mountain region), and it is anticipated that development of models for formation and movement of infiltration-deposited minerals will support that activity by providing a much more refined model of soil-zone mineral accumulation than is presently available.

3.4.3.6 Methods summary

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

The accuracy and precision of methods are difficult to quantify before actual testing and implementation of the methodology. Generally, for method selection, the accuracy and precision prediction is a relative judgement based on the USGS investigators' familiarity with, and understanding of, the method. For selected methods, if values for accuracy and precision exist, they will be listed within the USGS technical procedures.

Similarly, the duration of a method is difficult to quantify exactly. The duration of some methods may be seconds, whereas the duration of others may be months. The methods, however, have been selected so that the parameters of interest can be evaluated reasonably within the schedule of the study (Section 5.1). Furthermore, the total duration of the method is dependent on the number of times it is implemented, which is dependent on the spatial variability of a parameter within or among geohydrologic units, the accuracy and precision of the method, the number of available samples, and desired level of confidence in reproducibility of the measurement.

Table 3.4-1. Summary of tests and methods for the analog recharge activity (SCP 8.3.1.5.2.1.4)

[Note: Dashes (--) indicate information is not available and to be determined]

Methods (selected and alternate)	Site-characterization parameter	Expected range
Data collection for mesic-zone sites by hydrologic-budget modeling and chloride-ion, mass-balance modeling		
Current weather measurements (selected)	Climate, infiltration and recharge, relationships between parameters	Air/soil temp. -33 °C to +48 °C, solar rad. 0-1,000 watts/m^2, precip. 0-76 cm/yr, humid. 0-100%, wind 0-160 kph (published data, site specific)
Water sampling and processing (selected)	--	--
Weir, plume, and current-meter measurement (selected)	Runoff rate	Flume 0-0.1 m^3/s, V-notch weir 0-0.1 m^3/s, current meter measurement 0-0.3 m^3/s (published data, site specific)
Experimental leaching of tuffaceous rocks (selected)	Chloride input to infiltrated water	--
Chemical analysis of water samples (selected)	Infiltration rate	Chloride 0 to 5 mg/l, sulfate 0 to 10 mg/l, calcium 0 to 100 mg/l (published data, site specific)
Soil properties and vegetation-cover analysis (selected)	"	Unknown
Remote sensing for slope, aspect, and vegetative cover (selected)	"	--
Analysis of modern packrat-midden data and comparison to ancient packrat-midden data (selected)	Relative abundances of fossil-plant populations	Assemblages of various modern plant species

Table 3.4-1. Summary of tests and methods for the analog recharge activity (SCP 8.3.1.5.2.1.4)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Estimation of recharge by hydrologic-budget modeling		
Hydrologic budget model (selected)	Recharge rate	Minimum = 0 cm/yr, maximum = 50 cm/yr (general published literature)
Estimation of recharge by chloride-ion, mass-balance modeling		
Chloride mass-balance model (selected)	Recharge rate	Minimum = 0 cm/yr, maximum = 50 cm/yr (general published literature)
Geochemistry of arid-zone infiltration		
Meteorologic measurements at site (selected)	Climate, infiltration and recharge, relationships between parameters	Temp. -10 to 50 ^{o}C rel hum 0-100% wind vel 0-150 kph wind dir 0-360^{o}, precip 0-10 cm/hr baro P 80 to 100 kPa (general published literature, limits of technique)
Measurement of wet and dry deposition of selected chemical species (selected)	Chemistry, unsaturated-zone water	Wet deposition 0-2 micro-mol cm^{-2}s^{-1} dry deposition 0-10 micro-mol cm^{-2}s^{-1} (general published literature)
Unsaturated-zone moisture and water-chemistry measurements (selected)	"	Soil moisture 0-1,500 kPa water chemistry 0-10 micro-mol/liter (general published literature)

Table 3.4-1. Summary of tests and methods for the analog recharge activity (SCP 8.3.1.5.2.1.4)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
Geochemistry of arid-zone infiltration		
Characterization of unsaturated-zone mineralogy and chemistry (selected)	Chemistry, unsaturated-zone water	Soil mineralogy 0-100 wt% soil chemistry 0-100 wt% (general published literature)
Geochronology of unsaturated zone by all practicable methods (selected)	"	C-14 0-50 ka U-series 0-400 ka desert varnish, not yet known for site TL, not yet known for site (limits of technique)
Measurement of unsaturated-zone hydrologic characteristics (selected)	"	K, 10^{-3} to 10^{-10} cm/sec n_e, 0-60 vol % (general published literature)
Measurement of site runoff characteristics (selected)	"	0-1 m^3/sec (general published literature)
Develop and test unsaturated-zone mass-balance model (selected)	"	--

The methods were also selected by considering their ranges of measurement. It would be senseless to select a method that could not provide accurate data within the expected range of the site-characterization parameter of interest. Again, the expected range of method is difficult to quantify without actual testing or implementation of the technique. The USGS investigators, however, have selected methods which they believe are suitable to provide accurate data within the expected range of the site-characterization parameter. Some of the expected ranges of site-characterization parameters have been bracketed by previous data collection and are shown in Table 3.4-1.

Finally, the interference of a given method with other tests in the site-characterization program was considered in selecting the method. Generally, the selected methods will have little or no interference with other tests and analyses. In cases where methods do interfere, the USGS investigators have planned their testing sequences accordingly, in order to maximize data collection and minimize interference.

3.4.4 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires assignment, justification, and documentation of quality levels to activities that affect quality; and documentation of technical procedures for all technical activities that require quality assurance.

The technical procedures that will be utilized in this activity are standard procedures derived from the scientific literature appropriate to the various techniques. These procedures have been adapted to compensate for site-specific conditions and incorporate the quality-assurance requirements of the Yucca Mountain Project.

Table 3.4-2 provides a tabulation of technical procedures applicable to this activity. The technical procedures are listed according to the tests/analyses of Table 3.4-1. Approved procedures are identified with a USGS number. Procedures that require preparation do not have procedure numbers. Procedures that are identified as "needed" in the table will be completed and available 30 days before the associated testing is started.

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

Table 3.4-2. Technical procedures for the analog recharge activity (SCP Activity 8.3.1.5.2.1.4)
(At the discretion of the PI, approved technical procedures not listed may be used during the activity, should that be appropriate, and revised or replaced with other procedures as needed.)

Technical procedure number (YMP-USGS-)	Technical procedure
Data collection for mesic-zone sites by hydrologic-budget modeling and chloride-ion, mass-balance modeling	
HP-16	Collection and preservation of atmospheric precipitation samples for deuterium and oxygen-18 analyses
HP-54	Water-flow measurements using weirs, flumes, and barrels
HP-97	Measurement of temperature and relative humidity using a Campbell Scientific, Inc 207 temperature and relative humidity probe
HP-57	Method for using graphic and digital water-level recorders
HP-91	Collection and field analysis of surface-water samples
HP-173	Data collection protocol for plant community analysis
HP-166	Stream discharge measurements using a pygmy meter
HP-170	Method for measuring temperature using a Campbell Scientific, Inc. 107 temperature probe
HP-179	Field measurement of precipitation using a tipping-bucket rain gage
HP-167	Precipitation measurement using a Belfort weighing rain gage
HP-168	Measurement of energy flux density by a pyranometer
HP-171	Low-tension vadose moisture sampling
HP-172	Water level measurement using a ten-turn potentiometer
HP-165	Method for measuring snow water content

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Table 3.4-2. Technical procedures for the analog recharge activity (SCP Activity 8.3.1.5.2.1.4)--continued

Technical procedure number (YMP-USGS-)	Technical procedure
HP-184	Collection and preservation of atmospheric precipitation samples for chemical analysis
	Estimation of recharge by chloride-ion, mass-balance modeling
HP-183	Investigation into the chloride ion leaching from fresh rhyolitic surfaces
	Geochemistry of arid-zone infiltration
TBD	Mass-balance modeling
GCP-12	Rb-Sr isotope geochemistry
GCP-21	Sm-Nd isotope geochemistry
GCP-22	Spike calibration for uranium-series and uranium-trend analyses

3.5 Studies of calcite and opaline-silica vein deposits

3.5.1 Objectives

The objective of this activity is to determine the ages, distribution, origin, and paleohydrologic significance of calcite and opaline-silica deposits along faults and fractures in the vicinity of Yucca Mountain.

Geologic investigations at Yucca Mountain have exposed a large, vein-like deposit of calcite and opaline silica in a fault intersected by Trench 14. These deposits are also exposed in trenches north and south of Trench 14 (Figure 3.5-1). Data acquired to date are restricted to Trench 14, and are all consistent with a pedogenic origin for the deposit (Taylor and Huckins, 1986); nonetheless, the possibility of origin by ascending waters cannot be completely ruled out. Origin by ascending waters could indicate conditions at repository depth that were different from those that exist at present. Furthermore, even if the origin is pedogenic, the depth penetrated by descending waters needs to be determined. This datum, in conjunction with geochronology, will be used to test whether or not present conditions at depth are representative of those that existed in the past and those expected to exist in the future.

In addition to the vein-like deposits of calcite and opaline silica, Trench 14 exposes other hydrogenic deposits. These deposits include drusy quartz, chalcedony, and opaline-silica void-fillings in pyroclastic units; in these deposits, calcite is rare or absent. Younger fault breccias with abundant calcite and opal-CT incorporate fragments of the earlier silica-rich deposits. Both of these deposits are thought to be older than the calcite and opaline-silica vein-fillings and may be synvolcanic, but none of the ages or modes of origin is known. Therefore, the significance of these deposits in determining past and future conditions at repository depth cannot be assessed.

Several regulatory considerations (see Section 1.3) require an assessment of geologic materials that relate to past hydrologic conditions at any potential repository site. In addition, members of the Nuclear Regulatory Commission and representatives of the State of Nevada have expressed concern about possible adverse performance of a repository that might be implied by the occurrence of these deposits. Finally, information gained from the study of these deposits will be used in the assessment of volcanic and tectonic suitability of the site; therefore, a thorough understanding of the various hydrologic deposits of silica and carbonate will be needed before a complete assessment of repository performance at Yucca Mountain can be made.

The proposed work will provide a broad spectrum of data for the Nevada Test Site (NTS) and for analog studies that will be used to predict performance of a waste repository. The primary objective will be to determine the origin (including an origin by multiple processes or stages) of the calcite and opaline-silica, vein-like deposits in Trench 14 and similar types of deposits at the NTS and to determine what

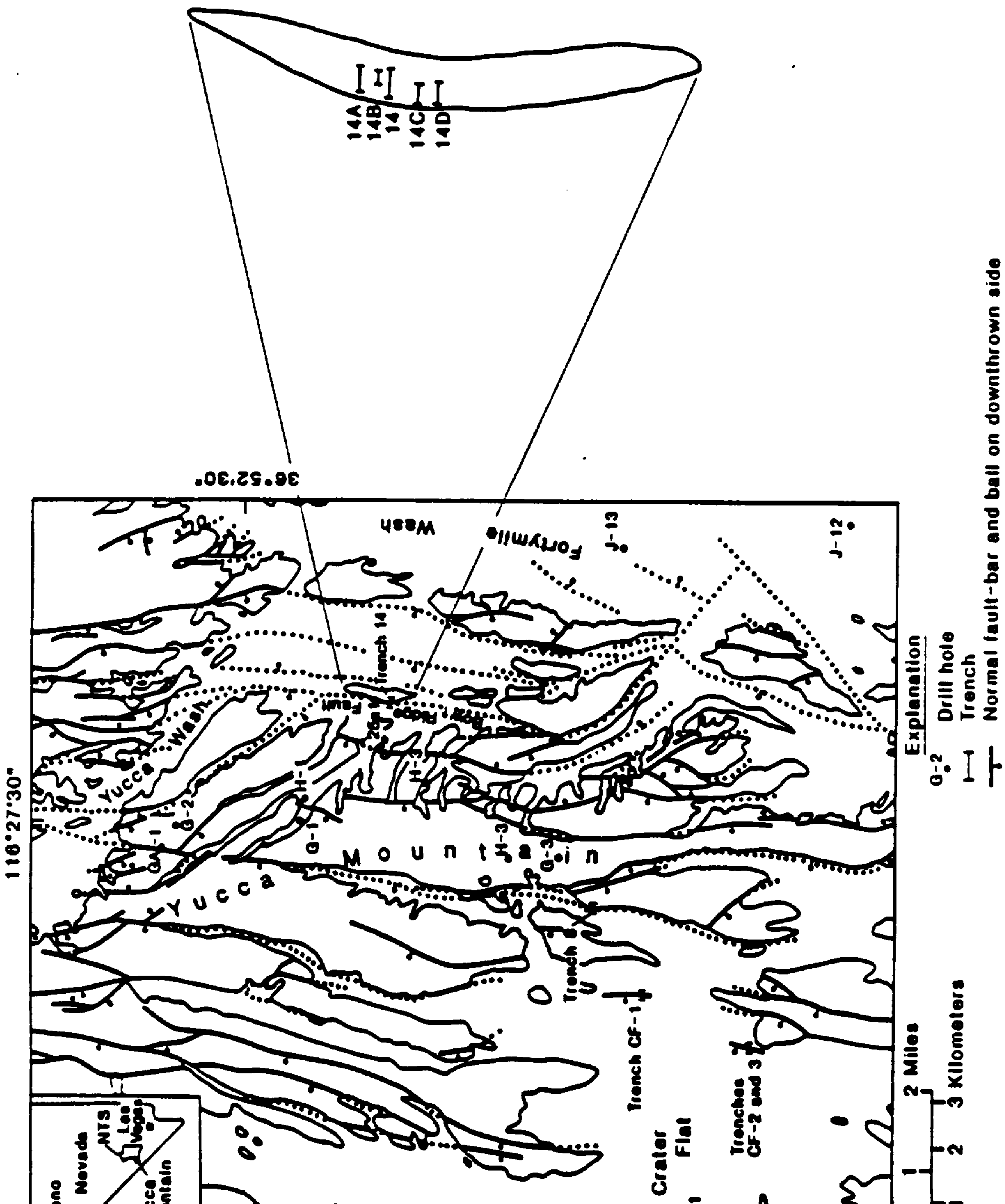

Figure 3.5-1. L[illegible]on of Trench 14.

bearing, if any, that origin would have on future hydrology at repository depth. Also included in this primary objective is the study of similar types of material recovered from depth by coring operations. A second objective will be to examine seemingly older silicified breccias. In both cases, specific questions to be answered include (1) the source of water, (2) the volume of water, (3) the age of the hydrologic system, and (4) the temperature of water. A third objective will be to identify data that have bearing on tectonics, volcanology, or economic geology of the site and to provide those data to the appropriate studies.

3.5.2 Rationale for activity selection

Several possible modes of origin can be proposed for the calcite and opaline-silica deposits such as those in Trench 14. The deposit could have formed from hot or cold waters of deep or shallow circulation, or the water could have been forcibly injected as a result of a hydrotectonic event, such as described at the ACM meeting (1988) or by Kopf (1981). Each possible origin would have a bearing on predictions of repository performance in the future and possible release of radionuclides to the ground water or surface environment.

If the multiple laminae exposed within various fault zones can be shown to be related to individual tectonic events and if these can be dated, this activity will yield a major input to predicting recurrence intervals of future tectonics or, depending on geochronologic results, determining if faulting is active or inactive.

The possible mechanisms of forming the calcite and opaline-silica veins have overlapping physical conditions such that no single test can uniquely define the origin. Consequently, numerous different tests are proposed. No known tests have been omitted that might provide clues as to the origin of these deposits. A partially sequential approach was advocated by a DOE Peer Review Committee (Hanson and others, 1987) that examined a proposal for this activity in May 1987. The committee recommended a primary focus on events younger than 100,000 years; this approach, however, does not take unanticipated events into proper accounting and does not recognize that deposition could have been continuous over a very long time span, such that only part of the deposit might be very old. The strategy adopted in this plan has been to conduct the tests described in parallel as part of an integrated technical characterization of the vein-hosted deposits. If, in the course of the study, other tests (such as in the field of geophysics) are identified as desirable, either on the basis of data obtained or the development of a new type of test, such tests will be proposed immediately in order to keep the project moving forward rapidly.

The number of locations studied will have to be left open to a degree. At least one example of each of the four main possible analogs will be studied in detail: pedogenic, hydrothermal spring, deep-circulating cold spring, and perched water-table spring or seep. Hydrotectonic deposits, if found near the study area, will also be investigated. If reconnaissance activities show that any one of the origins yields a range of properties, that range will have to be characterized by studies of more than one example.

3.5.3 General approach and summary of tests and analyses

3.5.3.1 General approach

A multidisciplinary approach to the origin of the hydrogenic deposits in Trench 14 is advocated. Such an approach allows multiple working hypotheses to be tested independently, and it permits several lines of study to be pursued simultaneously, which consequently may yield a more timely resolution to the questions of origin and probable paleoconditions at repository depth. A group of experts will be assembled who represent various disciplines and methods of study, including field work, mineralogy, geochemistry, fluid-inclusions studies, geochronology, radiogenic tracer-isotope studies, stable-isotope studies, paleontology, and hydrology.

Two workshops on the Trench 14 hydrogenic deposits were held in Las Vegas, Nevada - one on February 28 and the other on April 28, 1986. The first addressed the present state of knowledge of the deposits, and the second concerned proposed methods of investigation. Participants included the USGS, DOE-YMPO, Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), and the State of Nevada. These workshops concluded that analog studies should be conducted simultaneously with investigations of Trench 14. The Peer Review Committee suggested that analog studies be limited in number and scope and that published information be used to a greater extent. Thus, the number of analog studies will be kept to a minimum, and not all analytical techniques will be used for each analog unless the data will also be useful to other activities in this study (e.g., paleontology). Analog studies, however, have a great advantage over literature surveys on other deposits of known origin because of proximity to the Nevada Test Site, acquisition of exactly compatible data sets, and use of identical technical procedures. For these reasons, a few sites of active springs, paleosprings, soils deposits, and seepages will be visited, and representative examples of various types of deposits will be examined in detail. In addition, at least one site containing undisputed pedogenic carbonate and silica will be sampled.

There was a consensus at the April 28 workshop, and the Peer Review Committee concurred, that any sampling be done by a group of experts who will be responsible for subsequent analytical studies. In this way, samples collected would be of sufficient quality and quantity such that the same sampled material could be submitted for all necessary tests. Splits of Critical Samples will be archived at the Sample Management Facility (SMF).

This activity will be conducted jointly between the USGS and Los Alamos National Laboratory (LANL). The USGS will have primary responsibility for overall coordination as well as responsibility for all of the proposed tests except for mineralogy, fluid-inclusion work, geochemistry, and electron spin resonance dating.

Operational and technical interfaces with NTS support contractors will be necessary for trenching and possibly drilling and for core sampling and sample handling.

The proposed work will require logistical support for excavation and drilling. The proposed trenching may require some new methodology for reasons of safety or types of materials to be cut. For example, trenches will have to be wider than those previously dug, and drilling and blasting may be necessary if much bedrock is to be excavated.

Most of the proposed work will not require any major acquisition of new equipment, and none of the proposed tests will preclude use of the facility by others at any time during the study. Testing of isotopic composition of micro-domains will require the addition of a laser to be interfaced to an existing mass spectrometer. The equipment is commercially available, but analytical services are not available. Furthermore, such analyses are interactive, in that a specialist familiar with the problem must decide what parts of a sample are to be tested on the basis of results already obtained. Therefore, the equipment must be purchased, if data acquired by early analytical work indicate a need for these detailed tests. The proposed work would also benefit from the acquisition of a solid-source mass spectrometer (which will be purchased by the USGS) to be used for uranium-series and uranium-trend dating. This would increase the number of samples that could be dated, increase the analytical precision, and decrease the amount of material required for each analysis.

Figure 3.5-2 summarizes the organization of the tests for hydrogenic deposits tests. A descriptive heading for each test and analysis appears in the shadowed boxes of the second and fourth rows. Below each test/analysis are the individual methods that will be utilized during testing. Figure 3.5-3 summarizes the objectives of the activity, site-characterization parameters which are addressed by the activity, and the activity parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the shadowed test/analysis boxes, respectively, in Figure 3.5-3.

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

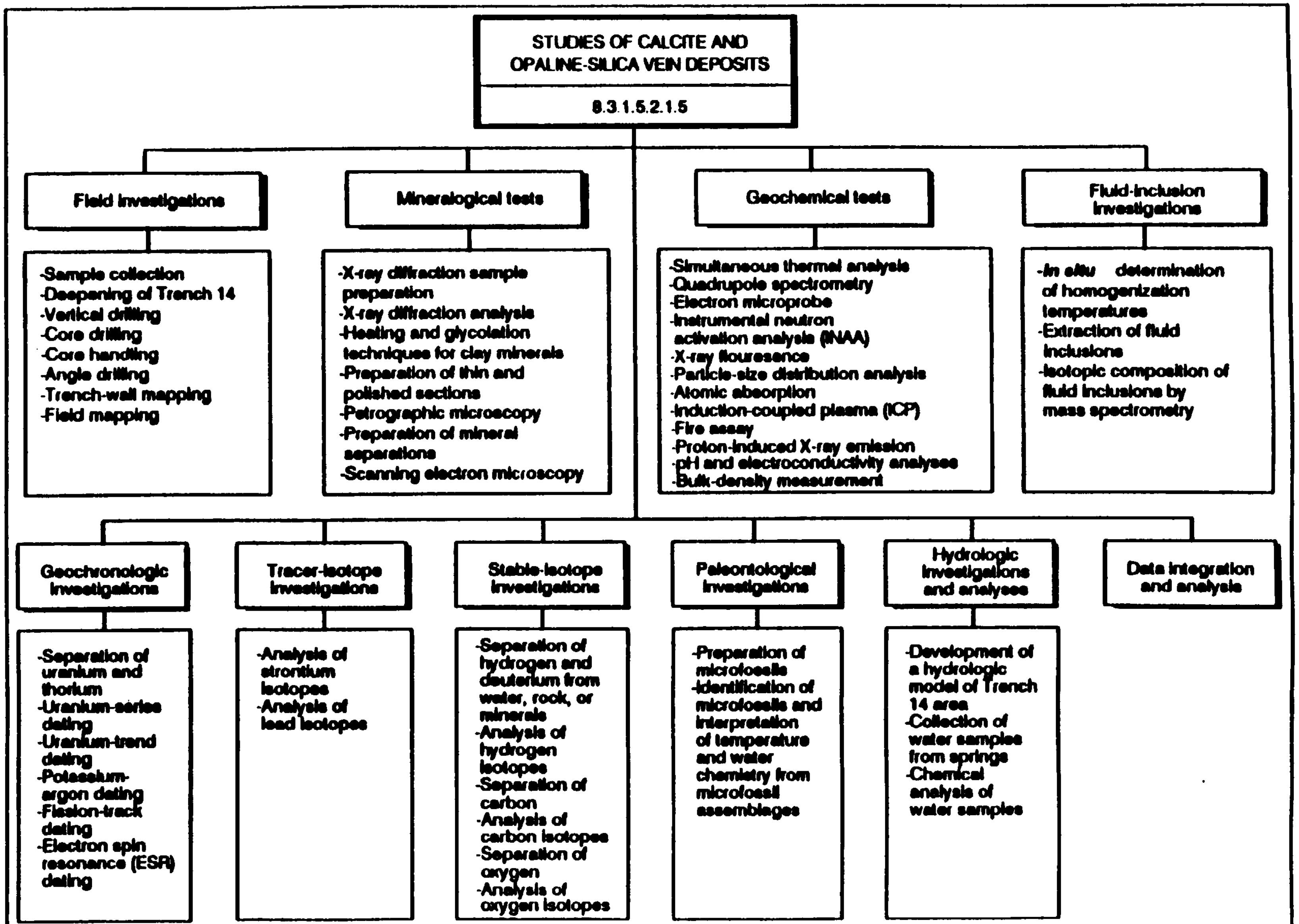

Figure 3.5-2. Logic diagram of calicite and opline-silica vein deposits activity showing tests, analyses, and methods.

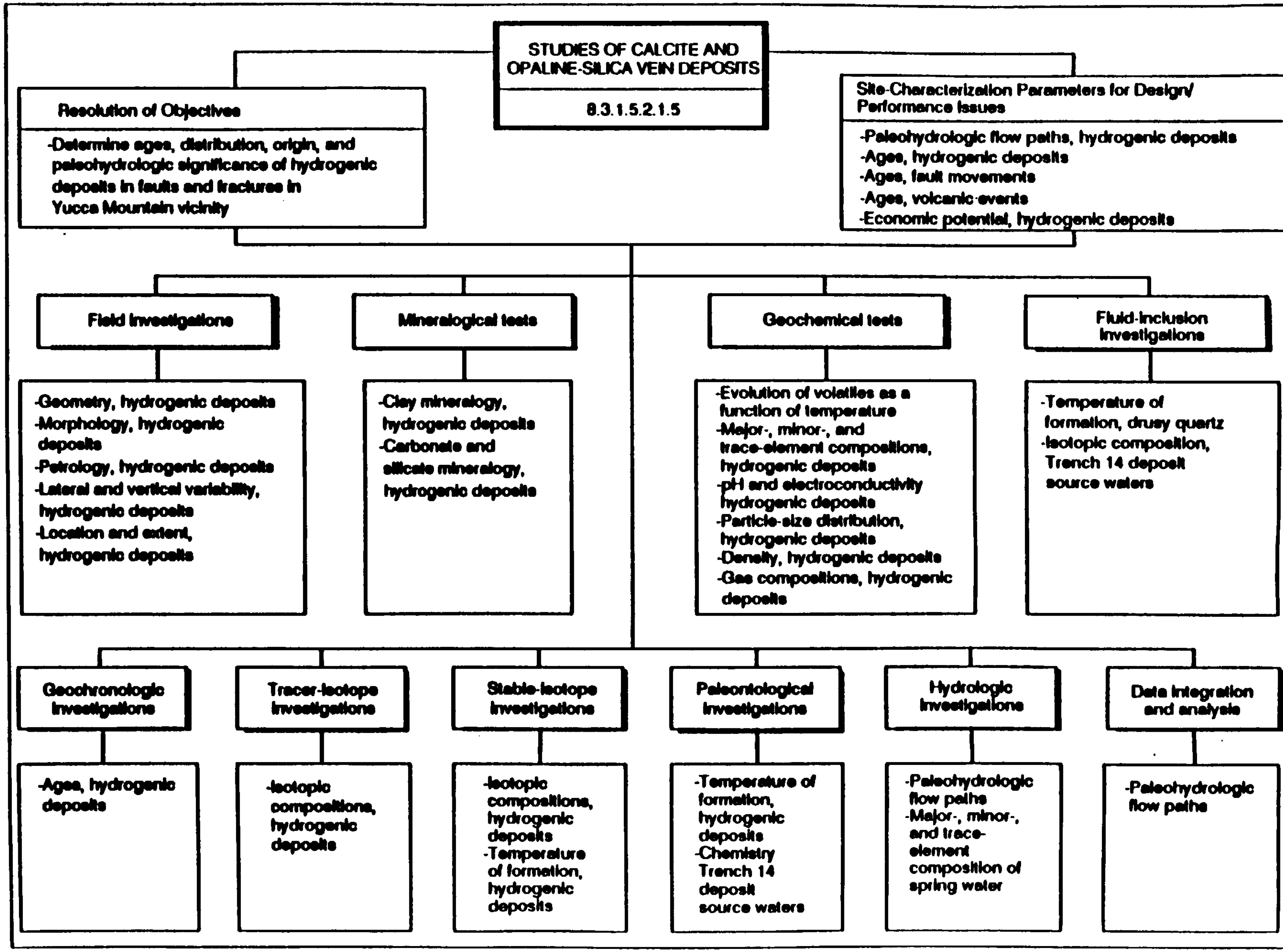

Figure 3.5-3. Logic diagram of calicite and opaline-silica vein deposits activity, showing tests, analyses, and activity parameters.

3.5.3.2 Summary of current knowledge and proposed work

Data pertaining to the origin of the hydrogenic deposit in Trench 14 have been obtained through field, chemical, mineralogical, biological, petrographic, and isotopic studies. Most of the field work and analytical work on rock samples has been done using technical procedures in place at the USGS and Los Alamos National Laboratory prior to March 14, 1986. Most of the sampling and field work has been documented photographically, but some of the results described below will have to be verified by new samples and analyses that follow current procedures. Figure 3.5-4 is a map of the southern wall of Trench 14, and is to be used together with the Trench 14 lithologic descriptions in the appendix of this plan.

All of the work pertaining to the origin of the hydrogenic deposits in Trench 14 that was completed prior to March 14, 1986, will be reassessed in light of new quality-assurance procedures in place when the stop-work orders are lifted. Existing field work probably will not have to be upgraded or redone. Most of the existing analytical data will not be needed to support conclusions of the study, because these data will be duplicated on samples collected for study by multiple techniques. Some of the existing age data will have to be upgraded by re-collection to verify either the type of material analyzed or the absolute age.

The field characteristics of the calcite and opaline-silica deposits observed to date are consistent with a pedogenic origin and would be atypical of either hot- or cold-spring or other deposits formed by ascending waters. The deposits are laterally persistent as opposed to occurring in mounds. Deposited minerals have forced gravel and fragments of bedrock apart rather than having filled existing voids. This feature is thought to be typical of pedogenic processes (Bachman and Machette, 1979; Gile and Grossman, 1979). Studies elsewhere in southern Nevada have shown that infiltration of rain water into alluvium can cause solution of eolian-derived, fine-grained carbonate and reprecipitation of calcite to depths of more than 3 m (10 ft) (Lattman and Simonberg, 1971). Thus, the deposit need not indicate a spring deposit or the large volume of water that would be suggested by such a deposit.

The vein carbonate in Trench 14 is intimately associated with soil carbonate (Figure 3.5-4), and the close spatial relationship suggests a genetic tie as well. Chemical studies indicate that $CaCO_3$ content in soil profiles associated with the vein in Trench 14 increases to a maximum with depth and then decreases (E. M. Taylor, unpublished data, 1985). This pattern is typical of that generated by data for pedogenic carbonate (Bachman and Machette, 1977; Gile and Grossman, 1979), and it contrasts with that of spring-type deposits which typically show uniform concentrations of $CaCO_3$ with depth or no relationship between depth and content of $CaCO_3$. The soil carbonate exposed in Trench 14 is microcrystalline and well stratified on a microscopic scale as opposed to coarsely crystalline

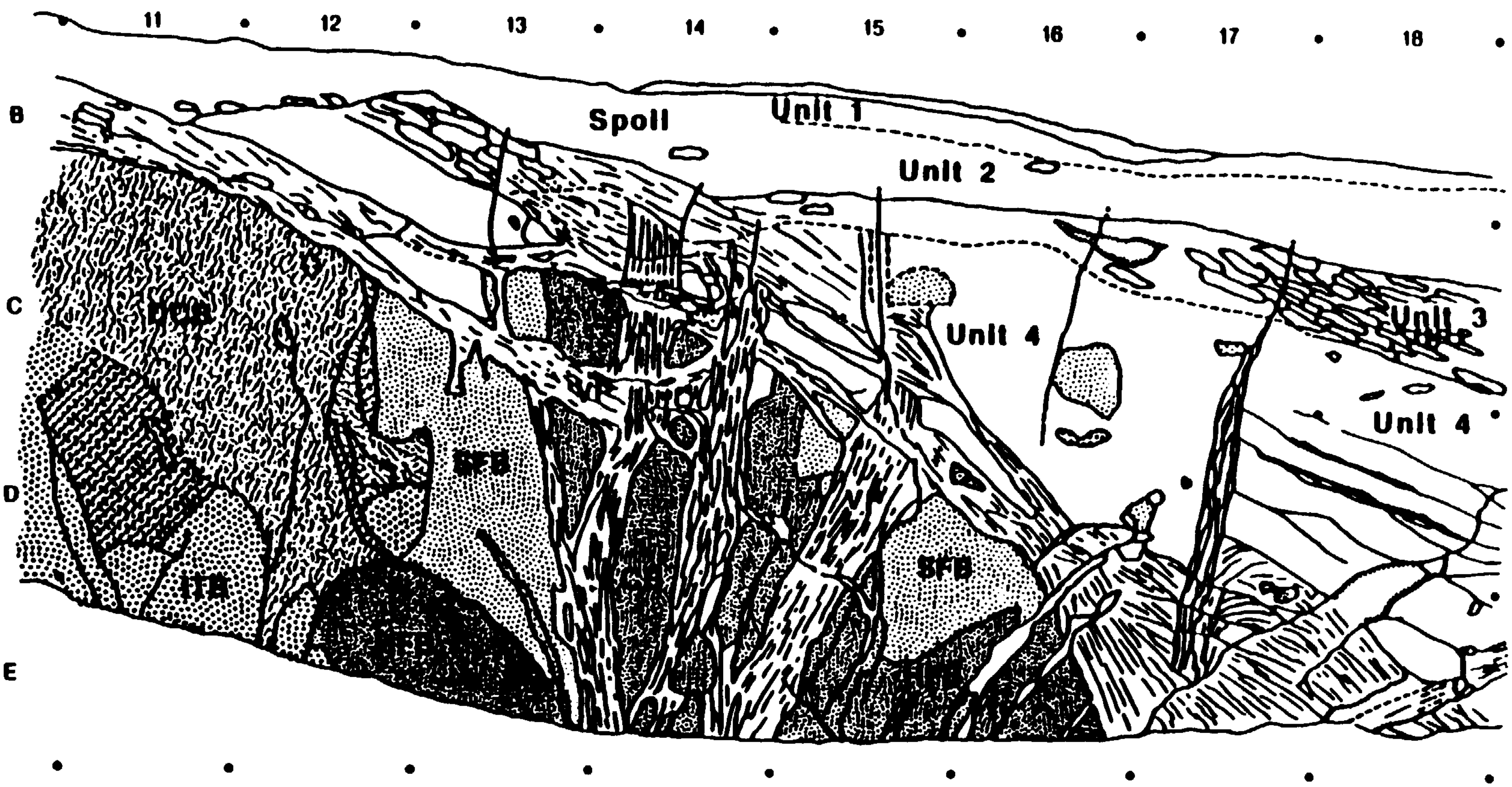

Figure 3.5-4. Map of southern wall of Trench 14 as viewed from the north. Dots around the edge of the map form a 1-meter grid. Bedrock (in various states of induration) is shown by patterns; colluvium is not patterned; calcite- (and minor opaline-silca) filled fractures are shown by light subparallel lines; ash-filled fractures are indicated by heavy, broad, irregular, and subvertical lines. Descriptions of identified units are in the Appendix.

and poorly stratified, which would be typical of spring origin (Birkeland, 1974).

The deposit in Trench 14 does not contain appreciable amounts of authigenic cristobalite and quartz which would be typical of hydrothermal veins, and is not dominated by opal-A, as would be expected in warm-spring deposits, but it does contain opal-CT, which is found in pedogenic deposits elsewhere (Jones and Segnit, 1971). The deposit in Trench 14 also contains sepiolite. This mineral is common in pedogenic deposits (Hay and Wiggins, 1980; Callen, 1984; Hay and others, 1986) but also occurs in low-temperature spring-type and playa deposits of the Amargosa Desert (Khoury and others, 1982; Hay and Stoessell, 1984).

Preliminary $^{18}O/^{16}O$ data for amorphous silica (J. R. O'Neil, 1985, written communication) are similar to values reported for low-temperature quartz. These values are also consistent with precipitation at about 15 °C from water that is isotopically similar to any ground water at the Nevada Test Site today (Claassen, 1985).

Limited fluid-inclusion data also tend to favor a low-temperature origin for the calcite and opaline silica deposit in Trench 14 because the inclusions within the deposit are single-phase as opposed to two- and three-phase inclusions that are typical of high-temperature deposits. These inclusions are extremely small, however, and optical data alone do not provide definitive conclusions (D. Vaniman and others, 1984, written communication).

Paleontological studies of three carbonate samples from Trench 14 resulted in the discovery of charophytes and chrysophyte cysts in two samples, but no ostracodes (R. M. Forester, 1985, written communication; J. P. Bradbury, 1985, oral communication). Ostracodes are indigenous to all modern spring-fed pools near the NTS, and ostracodes are ubiquitous in the fossil record of springs as well as being known from shallow ground water. Charophytes are an advanced form of green algae that calcify the gyrogonite (the structures surrounding the oogonia or female reproductive organ) and may secondarily calcify their stems. Charophytes are an important source of biogenic carbonate in many aquatic environments such as streams, springs, and the littoral zones of lakes. Chrysophyte cysts are the siliceous resting phase of chrysophyte algae. These and perhaps charophytes could be introduced to the deposit as wind-blown debris. Other detritus, such as volcanic ash, has collected in near-vertical cracks in the fracture filling at Trench 14, and biological materials are known to exist in wind-blown materials throughout the region. Conversely, because gyrogonites float and because chrysophytes occur in very large numbers, both could be deposited near the margin of a body of water without other aquatic organisms. The choice between these two alternatives will have to be based on detailed sampling and analysis by specialists in the field of micropaleontology, but at present, existence of a standing body of cold water in the vicinity of Trench 14 seems less likely.

Four ages have been determined for the calcite-silica deposit in Trench 14 by the uranium series method (Szabo and O'Malley, 1985). Three of these yield ages >400 ka, and the fourth is >350 ka. The 350-ka and two of the >400-ka ages were determined on opals, and at present there have been no controlled studies that have documented closed-system behavior for opal with respect to uranium and its daughter products. These ages, however, are consistent with previously reported, relatively old ages for the calcite-silica deposit, but the classification and exact location of some samples dated in earlier studies are not well known (Szabo and others, 1981). Thus, all of the earlier work will have to be upgraded or redone.

Only limited data are available for the predominantly silica (and presumably older) deposits exposed in Trench 14 and elsewhere on Yucca Mountain. These deposits include drusy quartz and chalcedony that line fractures and cavities in Tiva Canyon bedrock, silica cementation of fault breccia in the Tiva Canyon bedrock, and chalcedony and/or opaline silica in the Rainier Mesa and other nonwelded-tuff units. Preliminary stable-isotope and fluid-inclusion studies suggest that the drusy quartz may have formed at somewhat higher temperatures than did the amorphous silica in the calcite and opaline-silica deposits. Restriction of drusy quartz to the Tiva Canyon in Trench 14 suggests that the formation of quartz predates fault juxtaposition of the Tiva Canyon against the nonwelded tuffs exposed in the trench walls.

The fault breccias (SFB in Figure 3.5-4) contain fragments of drusy quartz, and therefore postdate the episode of drusy-quartz formation. Calcite, opal-CT, and sepiolite occur as secondary minerals in the breccias. A firm age relationship between the breccias and the vein-like calcite and opaline-silica deposits has not yet been established, but differences in texture and mineral segregation as well as crosscutting relationships suggest that the breccia and vein deposits arise from at least two different sets of depositional events. Thus the secondary minerals (especially silica minerals) in Trench 14 indicate at least three different episodes of deposition.

Geochemical and isotopic studies have been completed for water from several springs and wells in and around the Nevada Test Site (Bedinger and others, 1984; Waddell and others, 1984; Benson and McKinley, 1985; Claassen, 1985). Earlier analytical work is also available (Malmberg and Eakin, 1962; Walker and Eakin, 1963; Schoff and Moore, 1964; Blankennagel and Weir, 1973; Winograd and Thordarson, 1975; White, 1979). All of these published results are of high quality and can be used to show significant similarities and differences between various springs. Current study efforts can thus be focused rapidly on all appropriate analogs without a prolonged-reconnaissance phase.

The hydrogenic deposit in Trench 14 is laminated on a macroscopic and possibly microscopic scale. Observers at the April 28, 1986, workshop questioned whether or not results from bulk samples provide the same information as would be obtained for micro-samples within single laminations. Work by Winograd and Szabo (1986) has shown that laminations within one fracture filling in the Furnace Creek area developed over a period of more that one million years. In addition, it is possible for fracture fillings to contain exotic crystals that could grossly influence certain trace-element contents of a bulk sample. Thus, as part of the current study, procedures will have to be developed that show the relation between micro- and macro-samples.

Possible approaches to this problem include comparison of results from microprobe and analyses of mineral separations, comparison of microprobe analyses over the area of a thin section, and comparison of these analyses with analysis of essentially pure mineral segregations. Careful sampling within Trench 14 has revealed greater than one-gram quantities of nearly pure opal-CT that have evolved by microsite deposition and a dissolution-reprecipitation mechanism. Other segregates can be looked for in order to ensure chemical uniformity over larger areas.

Another possible approach to test for micro-domains is to check stable-isotope compositions by combined laser and mass-spectrometric techniques. These results should be very sensitive to either small changes in water chemistry or temperature during the period of carbonate and silica deposition, and they can be applied to micron-sized areas across banding on a thick section. A peer review of Activity 8.3.1.5.2.1.5 in May of 1987 has suggested that this analytical technique be used only if other data (such as that obtained by more standard microsampling techniques) demonstrate a need for it.

Published age data are available for carbonate deposits near the Test Site (Winograd and others, 1985; Winograd and Szabo, 1986). These are well documented, of high quality, and will be less critical to conclusions of the study; they can therefore be used without reanalysis.

No other directly applicable investigations are available from non-YMP sources. There are several published reports that contain data on possible analogs to the deposit in Trench 14. These, however, are only generally applicable because of incomplete data sets relative to those that will be collected under this plan. There is a small amount of published tracer-isotope data for the Nevada Test Site (Noble and Hedge, 1969; Doe, 1970); however, exact sample locations are unknown. Furthermore, current analytical techniques allow much greater precision than was possible at the time the older work was done. Therefore, new material will have to be collected and analyzed as part of the current project.

In summary, the proposed work will use a multidisciplinary approach that will include field investigations, mineralogy, geochemistry, fluid-inclusion studies, geochronology, radiogenic tracer-isotope studies, stable-isotope analyses, paleontology, and hydrological studies. Materials to be studied will include samples from Trench 14, pedogenic carbonate and opaline silica from a non-vein-type setting, samples of current and paleospring deposits of both cold and hydrothermal affinity, and water from active springs and wells. Past work will be used to aid selection of other analog sites (Vaniman and others, 1988). Sampling will be done by the group of experts who will be responsible for laboratory analyses in order to ensure that samples are of sufficient quality and quantity such that all work can be done on the same material. The Peer Review Committee has recommended that some oriented samples be taken at Trench 14, and thus some vein samples will be taken in this fashion.

Several localities will be visited by the group of experts, and at least one locality for each type of possible analog will be sampled in detail. Chosen sites will represent a wide range of chemical compositions and thermal characteristics. There are several warm-spring deposits underlain by tuff that would be appropriate analogs to the deposit in Trench 14 if it formed as a result of warm-spring action. These include Bailey Spring in Oasis Valley, Steamboat Springs, Sou Hot Springs, and springs at Brady, McCoy, and Hyder. Cold springs to be visited include Cane Spring, Nevares, Topopah Spring, and springs in Oasis Valley and Amargosa Valley. Figure 3.5-5 shows sampling locations for spring deposits. Paleospring deposits underlain by tuff and having a wide range of chemistries, such as the one at Wahmonie, will also be examined, but in these cases the origin will be less certain and may have to be determined as part of the project. Paleospring deposits have been reported from the Oasis Valley, eastern Death Valley (Winograd and others, 1985), north of Las Vegas (Post, 1978), and at the southern end of Crater Flat (Szabo and others, 1981).

3.5.3.3 Field investigations

The first priorities of field investigations will be to determine the vertical extent of the calcite and opaline silica below the present level of exposure in Trench 14 and to characterize any physical changes that may occur as a function of depth. These objectives will be accomplished by a series of approaches that will be used sequentially. The first approach will be to deepen Trench 14 in the vicinity of the calcite and opaline-silica deposit from a current depth of 4 m (13 ft) to a depth of 8 m (26 ft). If this approach does not intersect the base of the deposit, a series of shallow vertical holes will be drilled to intersect the dipping fracture zone at sequentially greater depths. A maximum of five holes is anticipated such that the deepest hole would be about 20 m (79 ft) in depth. If the shallow vertical drillholes fail to reveal the maximum depth of calcite and opaline-silica deposition, a low-angle hole will be drilled to intersect the fracture zone at a depth of approximately 80 m (315 ft). If it is necessary to drill a low-angle hole, further field studies will probably be necessary.

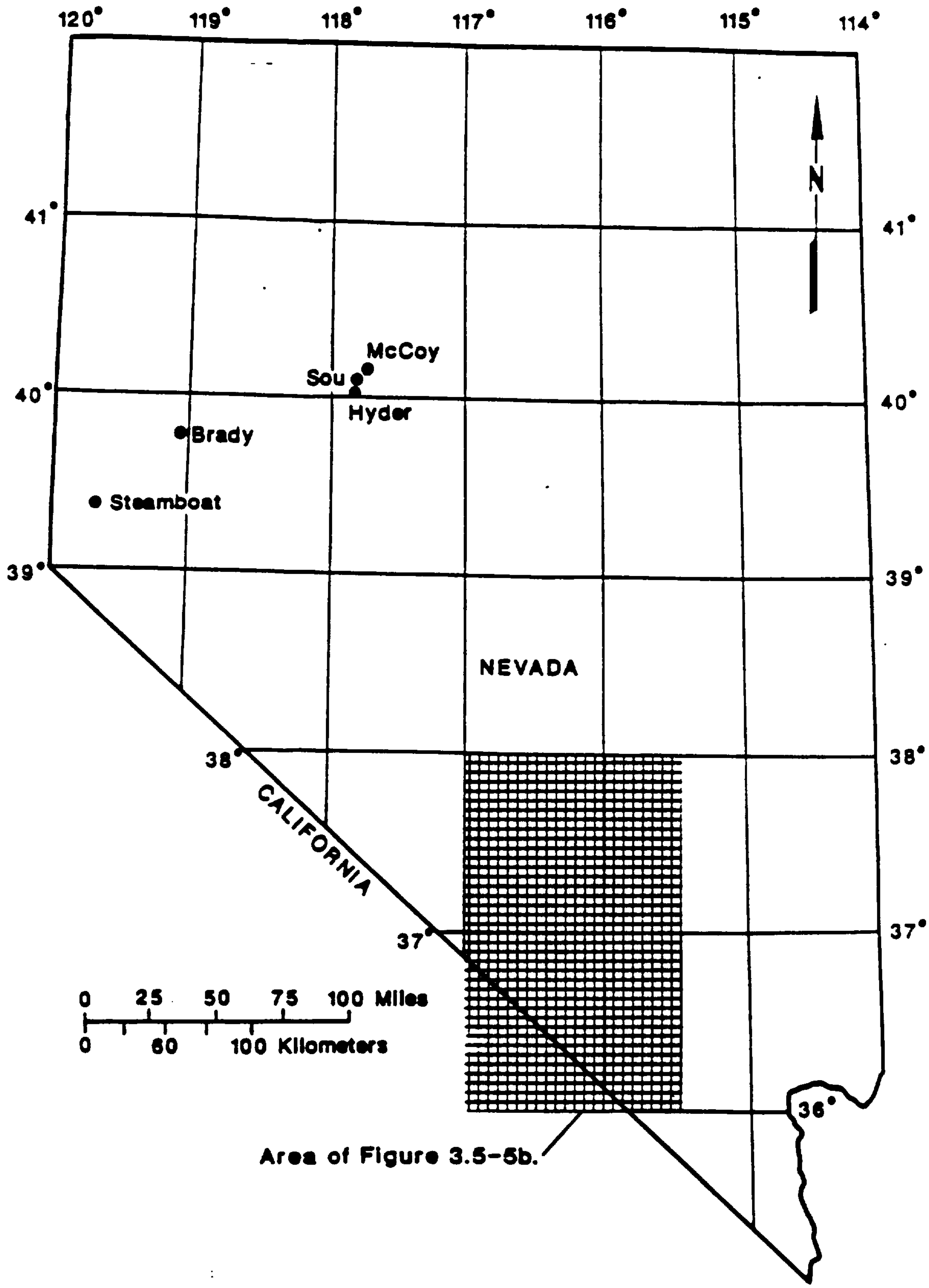

Figure 3.5-5a. Index map for the state of Nevada, showing area of Figure 3.5-5b and location of hot springs to be sampled.

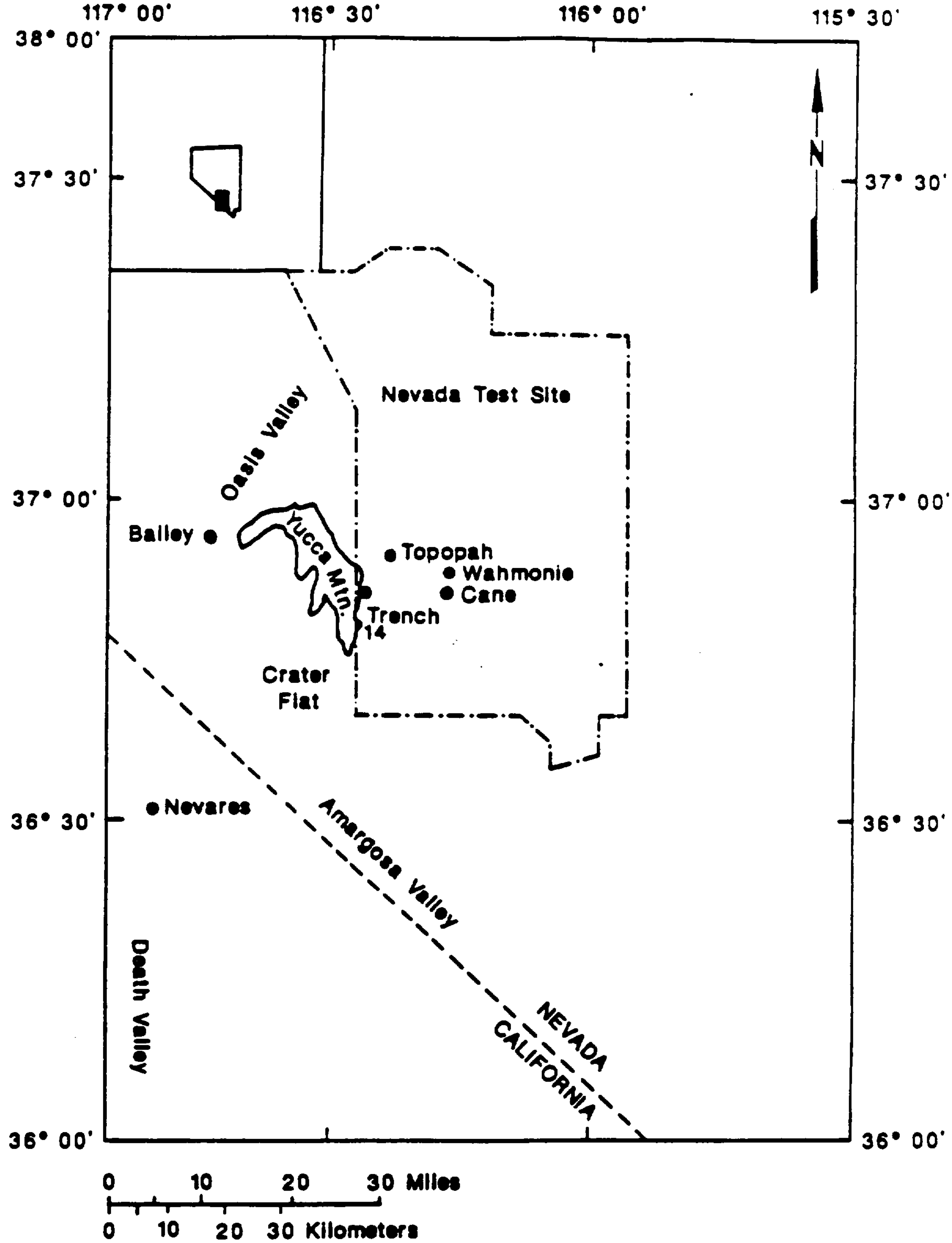

Figure 3.5-5b. Index map for the region around the Nevada Test Site, showing location of springs to be sampled.

The types of studies needed will be determined on the basis of results obtained during the trenching and drilling described above.

The first objectives of the field work will be accomplished using standard drilling and excavation techniques. These techniques will yield cross-sectional exposures that will be mapped in detail. The exposures and drill core will be sampled by the group of experts for analytical work as described below. Veins exposed in trench walls will be mapped in detail. Samples will be collected such that any changes in character as a function of lateral extent or vertical extent will be represented. This phase of the field operations is expected to take four months.

The Peer Review Committee of May 1987 has recommended that the mapping, as part of the field work, be expanded to include "small-scale mapping procedures" as well as micro-mapping techniques (on the scale of millimeters), which use reflected light microscopy and polished slabs, that might establish a fine-scale chronology. These results are also needed by tectonic studies and will therefore be undertaken as part of that study, but the results will be used within this activity as well. The small-scale mapping and micro-mapping will probably continue for one year past completion of the more standard scale mapping.

A second objective of field investigations, which will be accomplished largely as part of allied studies (surficial-deposits mapping activity of Study 8.3.1.5.1.4, Paleoenvironmental history of Yucca Mountain), will be to construct a map of the proposed waste-disposal site, indicating the location and extent of all known spring deposits as well as all Quaternary surficial deposits containing calcite and silica. To the extent possible, the map will show these deposits subdivided by mode of origin. These data will constrain possible origins for the deposits and will be a critical point for modeling of the past and possible future hydrologic flow systems. During this phase of the field activities, the morphology of deposits associated with springs will be examined, and any observable relationship between soils and spring deposits of calcite and silica will be recorded. This phase of the field work will utilize results from remote sensing and results obtained during geologic mapping as part of YMP. If field mapping locates an unfaulted calcite and opaline-silica deposit at a bedrock-colluvium contact, that deposit will be thoroughly investigated as a possible analog to the fracture filling exposed in Trench 14, a trench located near the proposed surface-facility site. This task will require about six months.

The Peer Review Committee has recommended that the task of field studies be expanded to include exposing vein filling at bedrock-colluvial contact in the sand ramps on the west side of Busted Butte and to expose the bedrock-colluvial contact along strike near Trench 14. The former recommendation is not practical due to the amount of overburden that would have to be removed. The latter will be attempted only if spatial relationships remain unclear after deepening of Trench 14.

A third objective of the field investigations will be to characterize pedogenic carbonate deposits that have formed at bedrock-colluvium contacts. It is expected that such deposits will contain larger amounts of calcite and silica than those formed at a distance from this contact or on stable alluvial surfaces, and, therefore, such deposits will be the best analogs for that exposed in Trench 14. Existing trenches may be used for this objective, but it may be necessary to open a new trench away from known faults but in the general vicinity of Trench 14. The exposures will be described, mapped in detail, and subsequently sampled for laboratory studies. Anticipated completion time is eight to nine months. The surficial-deposits mapping activity of Study 8.3.1.5.1.4 (Analysis of the paleoenvironmental history of the Yucca Mountain region), and the exploratory trenching activity of Study 8.3.1.17.4.2 (Location and recency of faulting near prospective surface facilities) may contribute data to the field investigations of this activity.

3.5.3.4 Mineralogical tests

The objectives of the mineralogic studies are (1) to place limits on the conditions of deposition for the calcite, silica, and clay minerals in the vein-like deposits in the vicinity of Yucca Mountain and (2) provide a basis of comparison between calcite-silica deposits of known origin and the deposits of Trench 14. Conditions of deposition may be determined by the mineral assemblage present within the deposit, the chemical composition of certain diagnostic minerals, and any alteration of wallrock or blocks included within the deposit.

The Peer Review Committee has also suggested that this task be used as a principal means of comparing vein-filling material in surface and near-surface deposits with that recovered from drill cores. The latter is an on-going activity at LANL, and results of that activity will be integrated with the mineralogic and geochemical aspects of this activity.

Fracture-filling materials, wall rock of the fractures, and samples of possible analog materials will be subjected to mineralogical study by a variety of techniques, such as petrographic microscopy, X-ray diffraction, scanning electron microscopy, and standard clay-mineral analytical techniques. Precise knowledge of mineral assemblages, degree of crystallinity of diagnostic phases, and mineral paragenesis of the fracture-filling materials may provide constraints on the origin of the deposits. In addition, alteration and reaction textures (or lack thereof) in the wall rock of the fracture may further constrain theories of origin. The micro-mapping of veins will be closely integrated with the mineralogic studies and will include cathode luminescence and ultraviolet fluorescence as recommended by the peer reviewers.

The proposed studies will use standard mineralogic techniques, including X-ray diffraction analysis of bulk samples and mineral separates, petrographic microscopy of thin sections, polished sections and grains in oils, and scanning electron microscopy of fresh surfaces, etched surfaces, and grain mounts. Standard physical-separation techniques will be used to prepare minerals from bulk-chemical analysis; standard clay-mineral analytical techniques, such as heating and glycolation, will be used in conjunction with X-ray diffraction. Several specific features diagnostic of particular modes of origin will be looked for in all of the samples. These include (1) the degree of crystallinity of opal (Jones and Segnit, 1971), (2) chemical purity and crystal size of calcite (Bachman and Machette, 1977), and (3) the identity of clay minerals (Callen, 1984). The Peer Review Committee has recommended that mineralogic studies include detailed chemistry of several mineral phases. This information will be obtained by integrating geochemical and mineralogical aspects of the activity. Data on the mineralogy of wind-blown dust, collected in the soil properties modeling activity of Study 8.3.1.5.1.4 (Analysis of the paleoenvironmental history of the Yucca Mountain region) may also be employed as part of the mineralogical tests.

A preliminary report on the mineralogy of spring, soil, and fault-related carbonate and silica deposits will be prepared approximately five months after sampling has been completed. Completion of all analytical work and the writing of a final report will require 14 months.

Mineralogic studies of the silica deposits, including the drusy quartz, will utilize some or all of the same techniques listed above. Material to be studied will include the various forms of silica, the associated secondary minerals, and, if necessary, the bedrock unit containing the silica deposit, in order to establish stratigraphic position. Results will include a preliminary report that will be written one year after the study commences and a final report that will be completed one year later.

3.5.3.5 Geochemical tests

Geochemical investigations will examine bulk compositions of spring and other water-precipitated deposits in terms of major-, minor-, and trace-element compositions. Analyzed materials will include whole-rock samples and mineral separates (the latter will be done in cooperation with mineralogical investigations). Some hydrous-mineral separates will be studied by simultaneous-thermal analysis and quadrupole spectrometry in order to determine their volatile-element constituents. Other analytical techniques include high-precision X-ray fluorescence for major elements (Taggart and others, 1982), instrumental neutron-activation analysis (INAA) for minor and trace elements (Gordon and others, 1968), and other standard analytical tests, such as particle-size distribution, bulk density, pH, etc., as needed. Analysis of individual mineral grains and zones within grains will be accomplished by use of a Cameca electron microprobe.

In major-element distributions, the exchanges accompanying alteration around tuff clasts and alteration of volcanic glass will be determined from combined chemical and petrographic data. Opal abundances will be used with glass-water silica solubility data to estimate total quantities of water involved in various silica-transport scenarios (Rimstidt and Cole, 1983). Preliminary data suggest that the distribution of uranium in opal is an important aspect of the calcite and opaline-silica deposits. Organic factors (e.g., roots) have effect near the surface; comparison with deeper opaline deposits will help to model uranium transport in this depositional environment. Other trace elements would be expected to vary in abundance if the opaline zone changes to cristobalite and quartz with depth; drill samples can be used to develop geochemical models based on these distributions.

Geochemical investigations will be used in support of, and in conjunction with, mineralogical studies. Major-, minor-, and trace-element compositions of whole-rock samples and of samples from specific phases from fracture filling and analog materials may prove to be diagnostic for certain possible modes of origin. The final choice of analytical methods will depend on sample sizes available, necessary precision, and detection limits, but anticipated methods include X-ray fluorescence, instrumental neutron-activation analysis, and electron microprobe analysis. If any of the geochemical data reveal information of possible economic interest, samples will be referred to those investigating this aspect of the site.

The geochemical studies will be used to help evaluate the possible economic potential of the fault-related deposits around Yucca Mountain (Study 8.3.1.9.2.1). Any indications of economic potential will be communicated to those directly responsible for conducting such studies. A concern with economic impact is highlighted because of the potential consequences to repository integrity should minable deposits be found in or near the repository-controlled zone. The combined methods of atomic absorption, induction-coupled plasma, and fire assay will be used to analyze samples from faults near Yucca Mountain for Ag, As, Au, Bi, Cd, Hg, Mo, Se, Sn, and W. Other potentially valuable elements (Cu, Pb, Zn, U, etc.) will be analyzed by atomic absorption/automated neutron activation.

Geochemical studies of possible analog deposits may be pursued if necessary to aid in the determination of possible origin of deposits such as those that occur in Trench 14. The analytical methods to be used will be relatively rapid and cheap, relying on the combined methods of X-ray fluorescence, automated neutron-activation analysis, and proton-induced X-ray emission. There is scant *a priori* basis for definitively differentiating between a hydrothermal or pedogenic deposit on the basis of geochemistry. In this regard, it is important to note that of the four major types of geothermal waters (alkali chloride, acid sulfate, acid sulfate-chloride, and bicarbonate; Ellis and Mahon, 1977), the only reasonable source for deposits such as those in Trench 14 would be bicarbonate because of the combined evidence of moderate pH and low sulfur and halogen content in the mineralogy (Vaniman and others, in press). Bicarbonate waters are only slightly concentrated variants of compositions such as those found in present cold Yucca Mountain ground waters. Cooled upper zones of a bicarbonate-geothermal system could lead to deposits that would be difficult to distinguish geochemically from evaporation-concentration deposits left by near-surface ground waters.

Geochemical studies will be closely integrated with field and mineralogical studies, and so samples selected for analysis will be based on results of these studies. A preliminary report will be written five months after completion of sampling. Completion of all work and the writing of a final report will require 14 months.

Geochemical studies of the apparently older silica deposits will utilize some or all of the techniques listed above. The secondary minerals associated with the silica will be the principal material studied. Results will include a preliminary report that will be written one year after the study commences and a final report that will be completed one year later.

3.5.3.6 Fluid-inclusion investigations

Fluid inclusions are common in carbonate and silicate minerals that crystallized in a variety of environments. The techniques in use as well as current interpretations are discussed in Roedder (1984). Primary fluid inclusions represent microscopic samples of the fluid from which a crystal grew. They may be a single phase, usually liquid, or they may combine one or more liquids with solids with or without gas. Such inclusions will be looked for in the fracture-filling materials as well as samples from all possible analogs. Fluid inclusions can be studied by *in situ* or extractive techniques. *In situ* study of fluid inclusions will follow the techniques of Roedder (1984). Individual, multiphase inclusions in a mineral can be heated on a heating/cooling stage to the homogenization temperature, at which point a single phase is formed. This temperature represents the minimum temperature of formation of the mineral. The salinity of the included liquid can be estimated from the freezing temperature of the fluid inclusion, as measured on the heating/cooling stage. Extraction of fluid inclusions is accomplished by crushing inclusions under vacuum and collecting the evolved gases at cryogenic temperatures (Norman and others, 1985). Soluble solids within inclusions are collected following thermal decrepitation. Chemical and isotopic compositions of these gases can be determined directly or after chemical separation of individual species. Quadrupole mass spectrometry will be used to determine the chemical compositions of gases. The results obtained can then be compared to results obtained for samples from analogs. Isotopic compositions of individual fluid inclusions can also be obtained by rupturing the inclusions with a laser, if this attachment for the mass spectrometer becomes available.

The drusy quartz from Trench 14 contains two-phase inclusions that may be suitable for temperature determinations with a heating-cooling stage, although most of the inclusions are too small for individual examination. A preliminary extraction of fluid-inclusion liquid from this material indicates a sufficient concentration of inclusions that future study of bulk extracted material should be feasible.

Fluid-inclusion studies of calcite and amorphous or partially crystalline silica may be restricted by uncertainties regarding the integrity of the inclusions over time. Inclusions will be studied isotopically as described in Section 3.5.3.9. Isotopic exchange between inclusions and younger pore fluids could indicate other modifications to the original inclusion composition. A careful exploration study may make it possible to characterize original inclusions and any changes that have occurred. If such studies are successful, the data will be used to place constraints on the composition and temperature of waters that deposited the fracture-filling minerals in Trench 14.

Fluid-inclusion data for silica and calcite and opaline-silica deposits will be included in appropriate reports on the geochemistry of the deposits. For the silica deposits, a preliminary report will be available one year after sampling, and a final report will be ready one year later. For the calcite and opaline-silica deposits, a preliminary report will be available six months after initial sampling, and a final report will be written about ten months later.

3.5.3.7 Geochronologic investigations

Dating of the fracture filling and other secondary material is essential to determine the origin of these deposits and to assess the risk of anticipated and unanticipated events. This phase of the activity was given highest priority by the Peer Review Committee. Timing for the development of the calcite-silica deposit of Trench 14 is particularly important if multiple stages of deposition occurred over long periods of geologic time. For example, the first stage of fracturing and vein-filling could have been penecontemporaneous with siliceous volcanism, and as such, the physical conditions would not have been representative of those existing during most of the depositional history. More significantly, they would not relate to the conditions at repository depth during the past one million years. Such changing conditions during the depositional history could account for the crystallization of two greatly different forms of silica: drusy quartz and opaline silica. Age data will be important in the understanding of sequential changes in the paleohydrology and in the determination of chronology for paleotectonics. The Quaternary data will then be used to predict future hydrology and tectonics.

3.5.3.7.1 Isotopic dating

Several different types of isotopic dating will be used during the project. Uranium-series dating (Schwarcz and Gascoyne, 1984) can be used for materials that have behaved as closed systems and fall within the age range of 5,000 to 400,000 years. Slightly older materials can be dated under highly favorable conditions. Uranium-trend dating can be used for open systems that existed during the time span 5,000 to 800,000 years (Rosholt, 1985). Both of the uranium-dating techniques utilize isotope dilution alpha spectrometry whereby alpha particles are counted within various predetermined energy bands. The counting is done with commercially available silicon-surface-barrier detectors made by Nuclear Diodes Corporation and EG&G ORTEC, coupled with electronic recording equipment made by Nuclear Data Acquisition. Data are interpreted by a computer program, "JB", which was written by USGS personnel to run on a VAX 11/730 computer. If a new solid-source mass spectrometer becomes available, analyses will be done by isotope dilution mass spectrometry. These analyses will require less material and can therefore be used to date thin bands of calcite. Mass spectrometric methods are also more precise and require less time per analysis.

Uranium-series methods will be used for the calcite deposits. Surficial carbonates formed in a continental environment have been shown to yield reliable dates (Szabo and Rosholt, 1982). The suitability of opal for uranium- series dating has not yet been established, and tests of samples of syngenetic opal and carbonate from the Test Site, as well as of opals of known age, will have to be performed prior to reliance on ages of opaline materials collected as part of the proposed work. These experiments will include mapping of uranium in opal and calcite using fission-track radiography. Uranium-trend dating will be used to date unconsolidated Quaternary deposits that have well-developed soil horizons, particularly an argillic B horizon. The calcite and opaline-silica veins in Trench 14 and adjacent trenches are overlain by soils that contain such horizons and can therefore be dated to provide minimum ages for the vein material.

Potassium-bearing substances, such as included volcanic ash from within the fracture zones (Figure 3.5-4), will be dated by the potassium-argon technique (Dalrymple and Lanphere, 1969). This technique is useful for ages greater than 500,000 years, and under especially favorable circumstances, it can be used for ages as young as 10,000 years. Ages obtained by this technique are sensitive to effects of temperature. Thus, if the deposits of predominantly silica are shown to have originated at high temperature (>300 °C), potassium-argon analyses of included materials may provide at least an approximate age of formation.

Fission-track ages will be determined for apatite separated from wallrock and from included blocks of tuff associated with the calcite and opaline-silica deposit in Trench 14. The technique uses spontaneous-fission tracks which are created by the decay of ^{238}U. These are 10-micron paths of damage that can be made visible by chemical etching. The number of tracks is proportional to time and the uranium content of the apatite crystal. Fission tracks in apatite can be partially or completely annealed at very low temperatures relative to other minerals (Wagner and others, 1977). Annealing is a function of time and temperature such that 50 °C for one million years or 140 °C for 20,000 years in a dry environment will completely anneal fission tracks in apatite. Annealing may be more rapid in a wet environment (Burchard and Reimer, 1972). If the deposit in Trench 14 represents a hot-spring environment, at least partial annealing of apatite should be observed. If complete annealing occurred during a heating event, the last cooling will be dated. That age can be compared with the age of the host tuff and the age of the calcite and opaline silica to see which event represents the last major thermal event.

In a similar fashion, minerals such as zircon and apatite from the silica-cemented deposits can be used to date these deposits if they formed at high temperature. If the silica-cemented breccias are found to have formed at temperatures too low to have reset the potassium-argon or fission-track systems, it may be possible to obtain approximate ages by use of the rubidium-strontium system. Previous studies (Zielinski and others, 1981) have shown that this system is reset in, and adjacent to, water-bearing fractures in crystalline rocks and where there is no evidence of elevated temperatures. Unfortunately, the long half-life of rubidium relative to ages expected at the Test Site will lead to very large uncertainties in calculated ages.

A preliminary report will be issued on isotopic ages 6 months after sampling has been completed, and a final summary of ages of carbonate and silica deposits will be written 12 months later.

3.5.3.7.2 Electron spin resonance dating

The primary description of electron spin resonance (ESR) dating is in the study plan for history of mineralogic and geochemical alteration of Yucca Mountain (YMP-LANL-SP 8.3.1.3.2.2, R1). This section contains information on the ESR test relevant to the studies of calcite and silica deposits.

Paramagnetic defects are produced in certain minerals as a result of bombardment by the radioactive decay products of natural radionuclides in rocks (Calas, 1988). ESR dating is based on the principle that the defects are produced at a constant rate, proportional to the rate of decay-product bombardment, over time. By determining the natural defect concentration, the relationship between radiation dose and defect production, and the radionuclide content of the sample environment, one can calculate the rate of defect production and the age of the sample.

Irradiation by the decay products of ^{238}U, ^{232}Th, and ^{40}K produces a variety of paramagnetic defects in minerals (Marfunin, 1979). The ESR work done at LANL by a visiting scientist, Kazuhiro Tanaka of the Central Research Institute of the Japanese electrical power industry, concentrated on measurement of the E' defect centers (electron traps associated with oxygen vacancies [Nambi, 1985]) in calcite and quartz. Mr. Tanaka is dating about ten samples of secondary calcite and quartz from Trench 14 and Busted Butte. After the final results have been obtained and evaluated, we will decide what level of effort will be appropriate for pursuing E' ESR dating.

David Cowan, at the University of Missouri, is in the process of dating drusy quartz from Trench 14 based on ESR measurement of the peroxy center defect. Peroxy centers are produced by alpha recoil associated with the decay of uranium and thorium. Potassium-argon ages for the Tiva Canyon tuff, the source of the drusy quartz, will provide an upper-age limit check on the ESR age of the quartz.

The two ESR techniques have different advantages and limitations. The E' ESR dating technique has been successfully used to date calcite (e.g., Grun, 1985), and the same technique (based on a different defect) has been used to date quartz (Shimokawa and Imai, 1985). Dating of calcite by this technique applies to material up to at least 1 Ma (Skinner, 1985) which is beyond the upper age limit of uranium series dating (except in the case in which the initial $^{234}U/^{238}U$ is known). The upper age limit of the E' technique is the time it takes for all E' defects to be filled with trapped electrons; this time limit is determined by the abundance of defects in the minerals and the radionuclide content of the surrounding material.

Potential advantages of the peroxy center technique over E' measurements include the greater thermal stability of the peroxy center ESR signal (up to about 500 °C [D. Cowan, 1987, personal communication]), the insensitivity of the defect-accumulation rate to the radionuclide content of the material surrounding the quartz, and the possibility of greater success in dating quartz in the 10- to 14-Ma range. For materials of Quaternary age, ESR measurement of E' may be preferable because E' defects accumulate at a faster rate than do peroxy center defects.

Selection of material to be dated will be based on thorough field and petrographic study. The secondary minerals to be dated will be separated from the host rock, if necessary, by hand picking. The presence of minor impurities in a calcite sample need not affect the relevant ESR measurement, but the amount and composition of the impurity would need to be determined (Smith and others, 1985).

Measurements of the E' center will be made with an X-band ESR spectrometer. Measurements will be made on the samples in their natural state and after they have received increasing doses of gamma irradiation, supplied by a ^{60}Co source. *In situ* doses will be measured by thermoluminescence dosimetry after 4-month exposures at sampling sites. Dose rates will be calculated from the dosimetry data.

The measurements for quartz peroxy-center ESR dating will include detection of peroxy center ESR signals from samples subjected to ESR spectrometry, determination of uranium and thorium contents in samples by neutron-activation analysis, and replication of ESR signals in heat-annealed samples by fast neutron bombardment.

The typical precision in ESR ages of Holocene calcite samples is about 1,000 yr (about a 3% to 10% error [Morinaga and others , 1985]). No information is available on typical precision for ages of quartz samples older than Holocene. ESR dating of quartz based on the E' center relies on the same types of measurements as those used for calcite dating.

We estimate that a maximum of 20 calcite and quartz samples will be dated by the ESR technique. A preliminary report is expected at the end of two years.

3.5.3.8 Tracer-isotope investigations

The isotopic compositions of strontium and lead in the calcite-silica deposits and in samples from possible analog materials will be determined to see if these data will provide constraints on the origin of the calcite and opaline-silica deposits. These isotopic compositions should be dependent on the isotopic compositions of the rocks through which the depositing fluid flowed; thus, if the fluids passed through isotopically distinct units, such as those known to exist below Yucca Mountain, the data may identify paleohydrologic-flow paths.

The isotopic composition of lead and strontium varies widely in different geologic materials as a function of differing U/Pb and Rb/Sr values and time of closed-system evolution. Waters in contact with geologic materials eventually acquire the isotopic composition of those materials. These isotopic compositions are then passed to materials that precipitate from the waters, and, therefore, the isotopic composition of water-precipitated deposits records the paleo-path of water movement.

Published studies (Noble and Hedge, 1969; Peterman and others, 1970; Doe, 1970) show that the crystalline basement, carbonate aquifer, and volcanic rocks in the vicinity of the Nevada Test Site all have distinctly different isotopic signatures. The isotopic features are shown diagrammatically on Figures 3.5-6 and 3.5-7. The isotopic composition of the crystalline basement has not been determined in the vicinity of the Nevada Test Site, but by comparison to similar rocks of similar ages, the compositions should occupy a broad field starting in the upper right-hand corner of either diagram and extending off-scale to higher values on both axes. Radiogenic tracer isotopes will not be determined for the analog deposits. Instead, there will be an effort to characterize possible reservoirs for strontium and lead (such as the various types of bedrock, wind-blown carbonate, and pedogenic carbonate) and to compare these compositions with those observed at Trench 14.

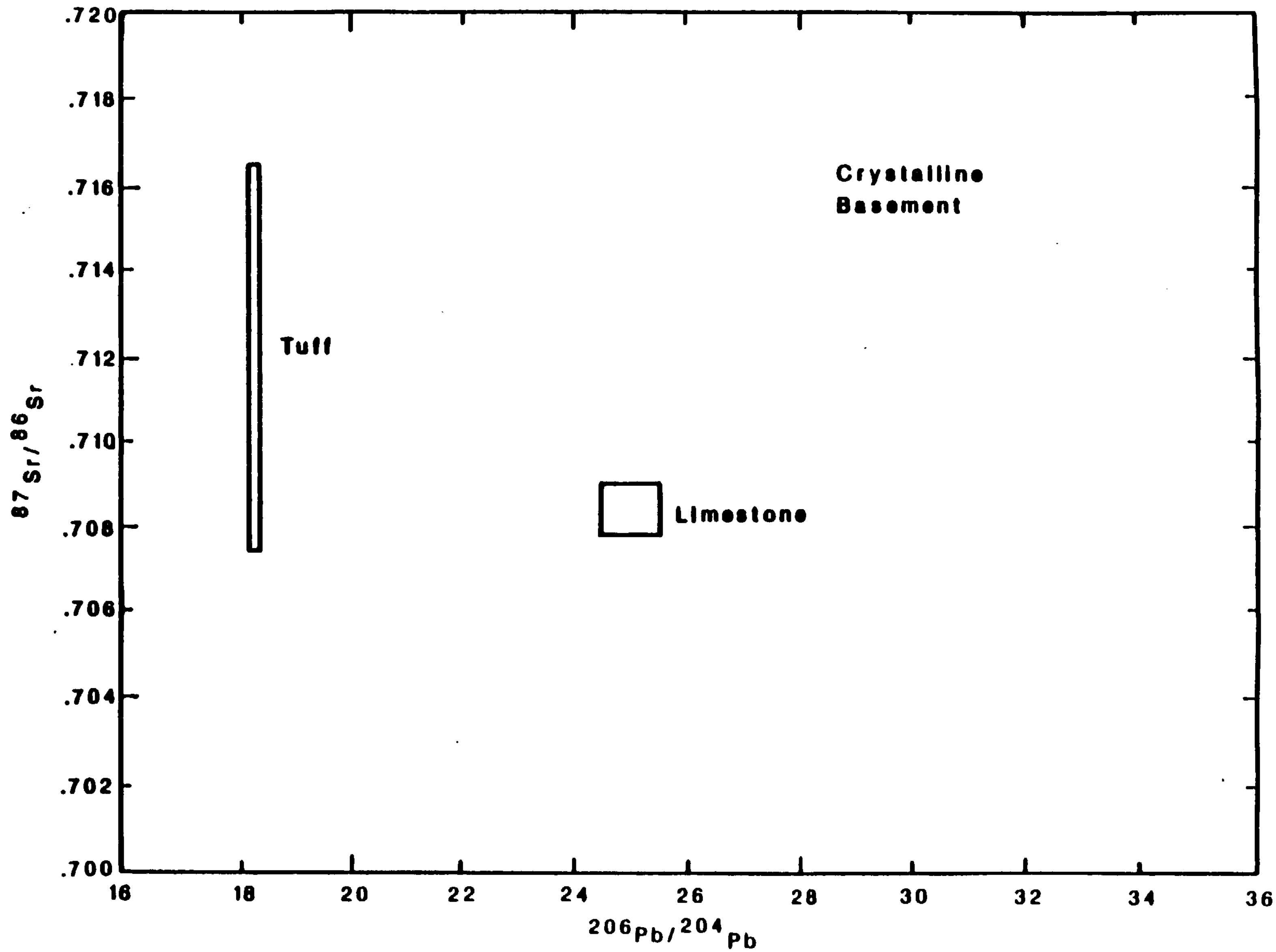

Figure 3.5-6. Strontium and uranogenic-lead isotopic compositions for major types of bedrock in the vicinity of Yucca Mountain, Nevada.

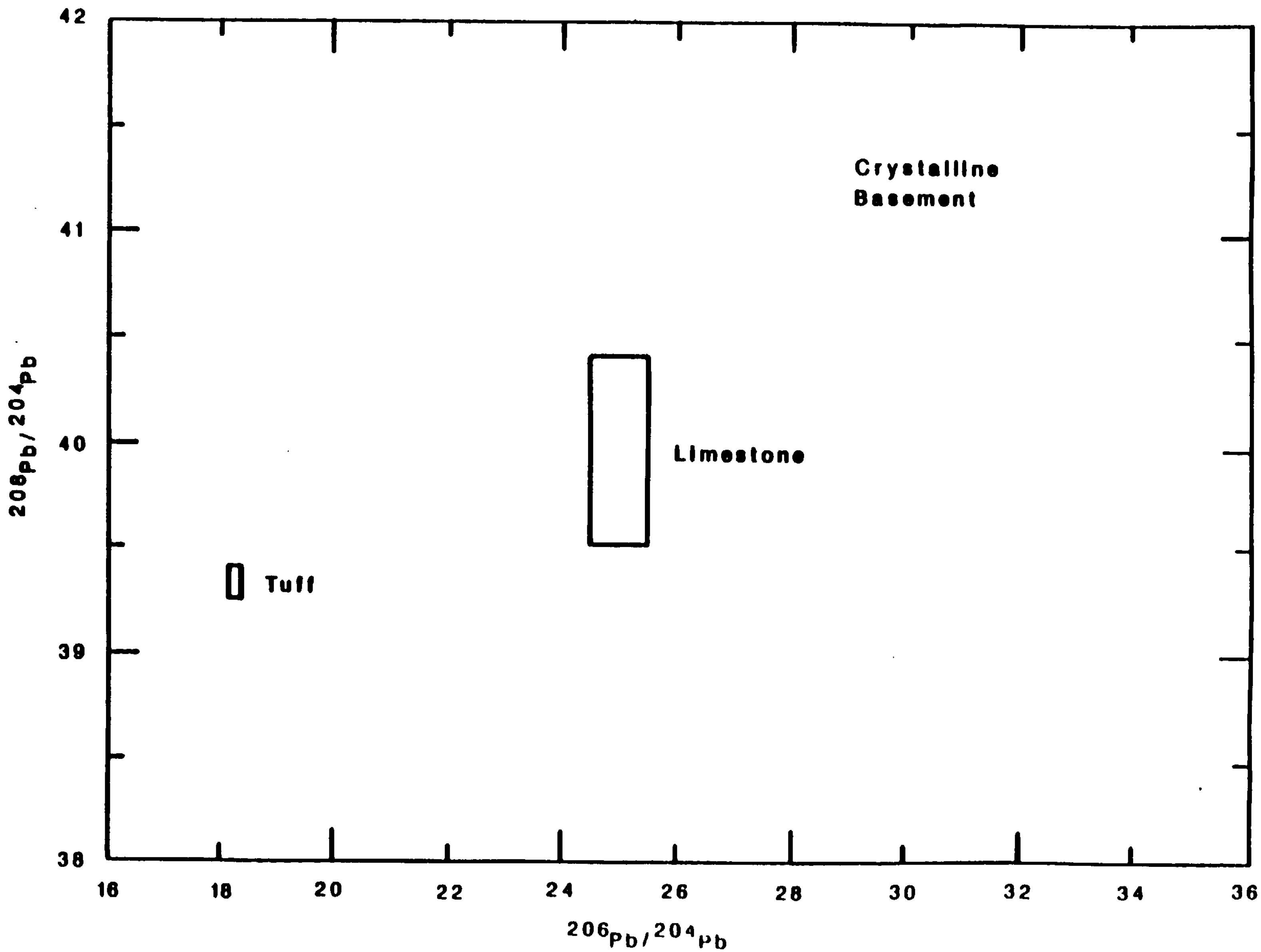

Figure 3.5-7. Uranogenic- and thorogenic-lead isotopic compositions for major types of bedrock in the vicinity of Yucca Mountain, Nevada.

Procedures for strontium analyses will be essentially those described by Peterman and others (1985), and those for lead will be similar to those described by Tatsumoto and others (1972) as modified by Arden and Gale (1974). Isotopic compositions of strontium will be determined by solid-source mass spectrometry using Micromass 54E and a Hewlett-Packard series 200 computer to run the program Analyst (Ludwig, 1985). Lead will be analyzed on a Finnigan MAT 261 mass spectrometer and will utilize a manufacturer-supplied program that has been modified by USGS personnel to run on a Hewlett-Packard 9845 computer.

Preliminary reports on the isotopic compositions of materials collected during the initial sampling will be available six months after the collecting trip. A final report will be available at a later date and will include data for possible sources of the carbonate. The number of potential sources analyzed and the number of analyses per source will be dependent on the preliminary results. There are no known studies that might be used to estimate the variability of compositions within pedogenic carbonates, and there are no preliminary data that show either a homogeneous or inhomogeneous isotopic composition for the vein-like carbonate. Unless great detail is needed to distinguish among possible sources, a final report will be completed 18 months after the sampling trip.

3.5.3.9 Stable-isotope investigations

The isotopic compositions of oxygen, carbon, and hydrogen of minerals are dependent on temperature of precipitation, the water/rock ratio, and the isotopic compositions of the precursor materials and of the fluids from which the mineral formed (Taylor and Epstein, 1962; Magaritz and Amiel, 1980; Hoefs, 1980). Kinetic factors can also be important for carbon- and oxygen- isotopic compositions of travertines formed at low temperatures. Figure 3.5-8 shows typical ranges of delta ^{18}O values for quartz formed in various temperature regimes.

Temperature can be calculated from the isotopic composition of two or more solid phases which were in isotopic equilibrium with one another at the time the system formed and retain their isotopic composition to the present day. Temperature can also be determined if a mineral and the fluid from which it formed can be analyzed. Isotopic composition of fluid inclusions can be very useful in this regard (although the isotope of interest cannot be a major component of the host mineral). If temperature is obtained from two solid phases, the isotopic composition of the fluid can be calculated. Whether measured or calculated, the isotopic composition of the fluid that deposited the calcite-silica, fracture-filling veins can be compared to the compositions of known sources, and the temperature obtained can be used to constrain possible modes of origin.

Isotopic ratios will be measured by gas-source mass spectrometry. Hydrogen-isotope ratios will be measured on a Varian-MAT GD-150; and oxygen- and carbon-isotope ratios will be

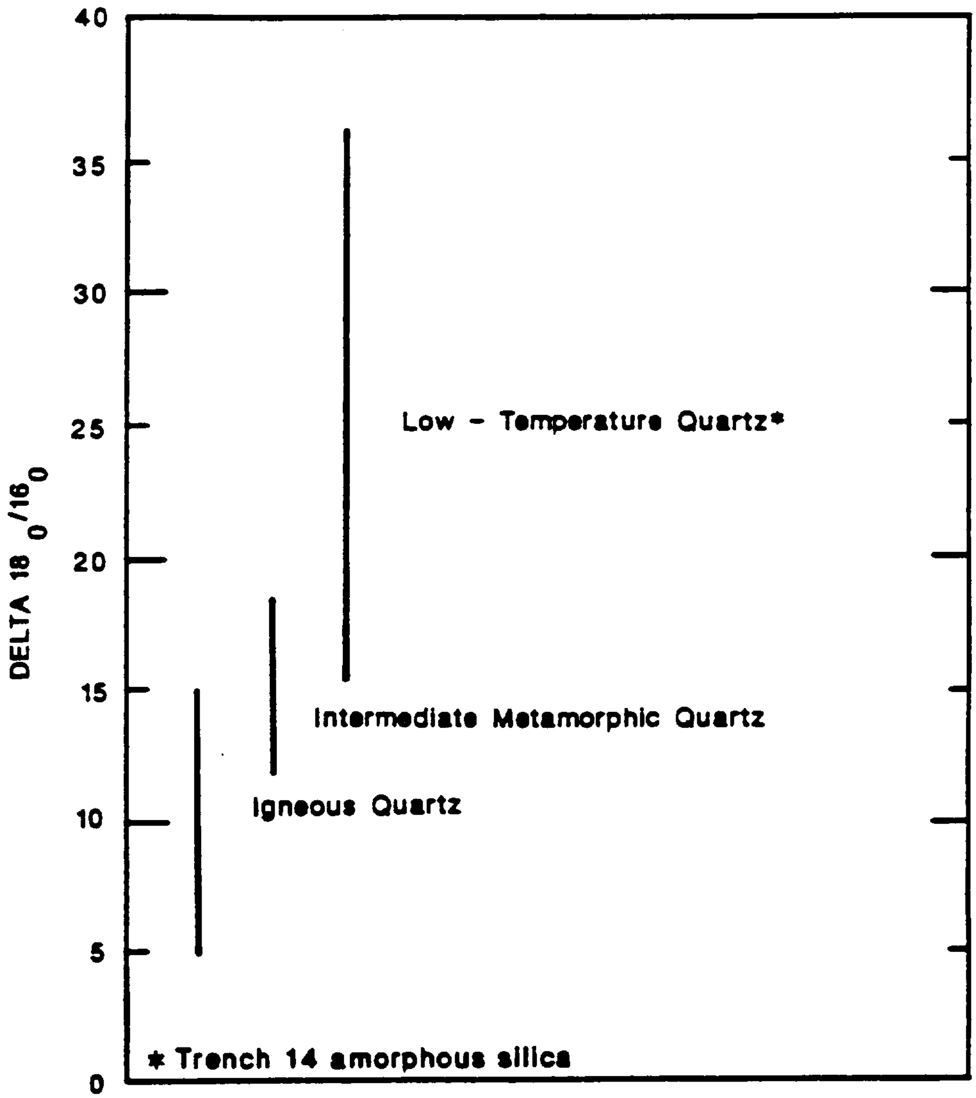

Figure 3.5-8. Typical ranges of delta $^{18}O/^{16}O$ values for quartz formed in various temperature regimes.

measured on a modified Nier double-collecting, 2-cm (0.8-in.), 60-sector mass spectrometer. CO_2 for carbon and oxygen analysis will be prepared from carbonate by the phosphoric-acid technique (McCrea, 1950); oxygen will be liberated from silicates by reaction with ClF_3 as described by Borthwick and Harmon (1982); hydrogen will be liberated from water by reaction with zinc pellets at 420 °C (Coleman and others, 1982). Microsampling and direct analysis of carbon and oxygen within thin zones of the vein-fillings will be possible if a laser system becomes available. The Peer Review Committee felt that acquisition of such a system would be justified only if conventional sampling revealed isotopic inhomogeneity that might be resolvable by micro-sampling.

A preliminary report on the isotopic composition of materials collected by the group of experts will be available six months after the trip. A report containing results for fluid inclusions will be available after necessary study of the inclusions has been completed plus four-months time to do the analytical work (should it be deemed necessary). If laser analyses become available, a preliminary report with these results will be available two to four months after the start of analytical work. Because the total number and types of analyses needed depend upon results obtained in the early stages of the study and acquisition of one new attachment for an existing mass spectrometer, a completion date for the stable-isotope phase of the project can not be forecast accurately. Unless unexpected delays become excessively long or the number of necessary analyses becomes very large, however, a final report should be available 16 to 24 months after start of the project.

3.5.3.10 Paleontological investigations

Data obtained by this technique, especially data obtained from the study of analog deposits, will be necessary for other activities within this study (see Section 3.3.3.2). Only part of the effort described here is therefore directly attributable to the current activity. The overall paleontologic effort was given a high priority by the Peer Review Committee.

Virtually all surface and many subsurface waters contain abundant aquatic organisms, many of which have skeletal material composed of carbonate, opaline silica, or resistant organic matter. The organisms present in a given body of water are determined by a large number of factors, including temperature and chemical composition of the water. If organisms such as ostracodes are preserved within the fracture-filling material, their species and the trace-element composition of their calcareous remains can be compared to hydrologic and biologic data for present-day analogs to tightly constrain possible modes of origin. The mineralized or organic remains of ostracodes, diatoms, mollusks, charophytes, chrysophyte cysts, thecamoebans, and cladocerans, as well as spores and pollen, are among the most common fossils in aquatic paleoenvironments. The occurrence of these fossils in sediments is important in distinguishing certain types of aquatic deposits from other types of sediments, such as eolian or pedogenic deposits.

Fossils recovered from their indigenous environments also provide information about the physical and chemical properties of the water from which the sediments were deposited or precipitated. The occurrence of aquatic taxa in a particular body of water is determined by a number of biotic and abiotic factors. Water temperature and water chemistry, together with general properties such as permanence versus ephemeral, or subterranean water versus surface-water contribution, are especially important because they determine which species are present rather than total abundance. Ostracodes are sensitive to seasonal variability in water temperature and chemistry (Forester, 1983, 1985, 1986), whereas diatoms are sensitive to salinity, nutrients, and availability of light (Bradbury, 1978). Chrysophyte cysts have recently been shown to be sensitive indicators of water chemistry and perhaps to temperature (Adam and Mahood, 1981). Pollen and spores provide insights into the character of the terrestrial-plant community, and hence climate, as well as the aquatic-plant community.

The preservation of aquatic organisms in sediments is usually a function of the chemistry of the pore fluids and/or the water at the sediment-water interface. Generally a fossil assemblage is composed of all taxa that lived in the local environment. In some cases, fossils will be differentially preserved. Skeletal remains composed of calcite (ostracodes, charophytes) will be most commonly preserved in alkaline waters. Conversely, opaline-silica (chrysophyte cysts) remains are readily preserved in acidic or circumneutral waters, but they may dissolve in very alkaline waters. Organic remains are best preserved in anoxic environments. Regardless of the postburial chemistry, therefore, one or more groups of aquatic taxa should be preserved.

Most aquatic taxa are found in their greatest numbers at the sites where they lived, although all microfossils can be transported to other environments by wind or water. Transported assemblages are often composed of taxa that are ecologically incompatible (e.g., saline- with fresh-water taxa) or are incompatible with the enclosing sediment (e.g., lacustrine taxa in a spring deposit). The species composing a transported assemblage are usually present in low abundance and often in subequal abundance, whereas *in situ* assemblages will usually have a few very abundant species but many species with low or intermediate abundances. Very small microfossils (e.g., chrysophyte cysts) may have a greater probability of being transported by wind than do larger microfossils (e.g., ostracodes).

• Unfortunately, most nonmarine organisms that have a fossil record have only recently been studied from a hydrologic perspective. Moreover, the occurrence of taxa that exist only under limited physical and chemical conditions has generally not been documented with the type of detail needed for fine-scale type comparisons. Therefore, modern ostracodes and other environmentally sensitive taxa (diatoms, chrysophyte cysts, charophytes, and pollen) will be collected and analyzed at each of the springs, seeps, or other aquatic environments where deposited material is collected for other types of analytical work. This work is outlined in Section 3.3.3.2. In addition, samples will be collected from nonaquatic environments such as soil profiles, sand ramps, and dunes in order to establish the probability of microfossil transport and preservation in nonaquatic settings. The results of these studies will then be compared to those for the calcite and opaline-silica deposits; if the data argue in favor of an aquatic origin, limits will be proposed for the physical conditions for the waters responsible for the deposits. Techniques to be used will be those described by Kummel and Raup (1965). A preliminary report of the findings will be available six months after the collection trip. A final report with interpretations will be available six months later.

3.5.3.11 Hydrologic investigations and analyses

This task will be accomplished largely by other activities within this study, and therefore, it is described more completely as part of paleodischarge or paleorecharge, depending on the outcome of results of other tasks described in this section.

Records of both surface- and ground-water movement in the past are preserved best by deposits such as the calcite and opaline-silica deposits exposed in Trench 14. Knowledge of the climate and hydrologic regimes that acted on the area of Trench 14 and the Bow Ridge fault in the past is essential to the assessment of repository performance in the future, and that knowledge is directly tied to an understanding of the origin of the deposits exposed within faults exposed around Yucca Mountain.

A three-dimensional numerical model of the hydrologic system in the vicinity of Trench 14 will be attempted in order to test various conceptual models of past water flow in and near the fault. The model will be used to provide constraints on the flux, flow direction, and compositions of the fluids which deposit the vein materials. The scale and detail of the model will depend upon data developed by the subactivities described in the preceding sections. The models will use as constraints information developed by other components of the project, such as isotopic and paleontological data, and may be used to determine what boundary conditions must have existed during vein formation. For example, if tracer isotopes demonstrate derivation from a specific geologic unit, the hydrologic model will be constrained such that water flows from that unit to the deposit.

The hydrologic regime of each spring identified for study will be determined as part of Activity 8.3.1.5.2.1.3 (Section 3.3.3.3), and water samples will be collected at each of the visited springs. Samples will be analyzed for major-, minor-, and trace-elements according to techniques described by Fishman and Friedman (1985), and results will be combined with those obtained for deposits that are currently forming. This modern data base will then be used to infer the chemistry of fluids from which the deposit in Trench 14 was formed. Water from some of the springs to be visited has been analyzed previously, and comparison of the old and new analytical data from the duplicate samples will provide a basis for using previously obtained data for springs that will not be sampled during the current project.

A preliminary report will be available about six to eight months after the sampling trip, and a final report will be available about one year later. Hydrologic data and interpretations from this part of the project form an integral base for data interpretation in other phases of the project, and therefore data will be passed to those phases as they become available.

3.5.3.12 Data integration and analysis

The tests described above may uniquely define the origin of the calcite and opaline silica deposit in Trench 14. For example, the occurrence of a particular ostracode may identify a type of spring by chemistry and temperature, or a particular mineral assemblage may be found that can form only at high temperatures (>100 °C), which would thus indicate a hydrothermal origin. Data acquired thus far, however, suggest that no such solutions are likely and that the origin will be defined by weight of evidence. A conclusion based on weight of evidence will require considerable discussion and evaluation by persons with expertise in all of the above described specialties. Such discussion may well point out the need for further tests or other methods that might help to decide between two or more possible origins. For this reason, data analysis will occur in two stages.

The Principal Investigators and others who are identified as having data that bear on the origin of the deposit in Trench 14 will meet for a workshop six months after the collecting trip. The workshop will be to present preliminary results and to discuss possible interpretations in the light of alternate working hypotheses. The group will assess the needs of further sample collecting and analytical work as well as inclusion of techniques and approaches not currently in use. Similar interim workshops will be held as necessary. A final meeting will be held a year after the last preliminary or interim workshop (or sooner if feasible). At this meeting, the group will draft a final opinion paper on the origin of the calcite and opaline-silica deposits in Trench 14.

3.5.3.13 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.5-1. Also listed are the selected methods for determining the parameters and the current estimate of the parameter-value range. The selected methods in Table 3.5-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The accuracy and precision of methods are difficult to quantify before actual testing and implementation of the methodology.

Table 3.5-1. Summary of tests and methods for the calcite and opaline silica vein deposits activity (SCP 8.3.1.5.2.1.5)
[Note: Dashes (--) indicate information is not available and to be determined]

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Field investigations	
Sample collection (selected)	Not applicable	Not applicable
Deepening of Trench 14 (selected)	Geometry, hydrogenic deposits	"
"	Morphology, hydrogenic deposits	"
Vertical drilling (selected)	Geometry, hydrogenic deposits	"
Core drilling (selected)	"	"
"	Morphology, hydrogenic deposits	"
Core handling (selected)	Not applicable	"
Angle drilling (selected)	Geometry, hydrogenic deposits	"
"	Morphology, hydrogenic deposits	"
Trench-wall mapping (selected)	Lateral and vertical variability, hydrogenic deposits	"
"	Morphology, hydrogenic deposits	"
"	Petrology, hydrogenic deposits	"
Field mapping (selected)	Location and extent, hydrogenic deposits	"

Table 3.5-1. Summary of tests and methods for the calcite and opaline silica vein deposits activity (SCP 8.3.1.5.2.1.5)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Field investigations	
Field mapping (selected)	Morphology, hydrogenic deposits	Not applicable
	Mineralogical tests	
X-ray diffraction sample preparation (selected)	Not applicable	Not applicable
X-ray diffraction analysis (selected)	Carbonate and silicate mineralogy, hydrogenic deposits	"
"	Clay mineralogy, hydrogenic deposits	"
Heating and glycolation techniques for clay minerals (selected)	"	"
Preparation of thin and polished sections (selected)	Not applicable	"
Petrographic microscopy (selected)	Carbonate and silicate mineralogy, hydrogenic deposits	Qualitative and quantitative (0-100%)
Preparation of mineral separations (selected)	Not applicable	Not applicable
Scanning electron microscopy (selected)	Carbonate and silicate mineralogy, hydrogenic deposits	Qualitative and quantitative (0-100%)

Table 3.5-1. Summary of tests and methods for the calcite and opaline silica vein deposits activity (SCP 8.3.1.5.2.1.5)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Geochemical tests	
Simultaneous thermal analysis (selected)	Evolution of volatiles as function of temperature	0 to 15% of sample weight (general published literature)
Quadrupole spectrometry (selected)	Gas compositions, hydrogenic deposits	Not applicable
Electron microprobe (selected)	Major and minor element compositions hydrogenic deposits	Elements present in 0.2% to 70% range (limits of technique)
Instrumental neutron-activation analysis (INAA) (selected)	Major- , minor- , and trace-element compositions, hydrogenic deposits	Variable for 21 elements (general published literature)
X-ray fluorescence (selected)	"	Not applicable
Atomic absorption (selected)	"	Variable for 20 elements (general published literature)
Induction-coupled plasma (ICP) (selected)	Trace-element compositions, hydrogenic deposits	<500 ppm (general published literature)
Fire assay (selected)	Major-, minor-, and trace-element compositions, hydrogenic deposits	Not applicable
Proton-induced X-ray emission (selected)	"	Variable
pH analysis and electroconductivity analyses (selected)	pH, electroconductivity, hydrogenic deposits	pH 5-9 EC 0-100 mho/cm (general published literature)
Particle-size distribution analysis (selected)	Particle-size distribution, hydrogenic deposits	Variable

Table 3.5-1. Summary of tests and methods for the calcite and opaline silica vein deposits activity (SCP 8.3.1.5.2.1.5)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Geochemical tests	
Bulk-density measurement (selected)	Density, hydrogenic deposits	1.0-2.9 g/cm^3 (general published literature)
	Fluid-inclusion investigations	
In situ determination of homogenization temperatures (selected)	Temperature of formation, hydrogenic deposits	100 to 300 °C (unpublished data, general published literature)
Extraction of fluid inclusions (selected)	Not applicable	Not applicable
Isotopic composition of fluid inclusions by mass spectrometry (selected)	Isotopic composition, Trench 14 deposit source waters	delta D = -20 to -120 parts per mil (general published literature)
	Geochronologic investigations	
Separation of uranium and thorium (selected)	Not applicable	Not applicable
Uranium-series dating (selected)	Ages, hydrogenic deposits	0 to 400 ka (limits of technique)
Uranium-trend dating (selected)	"	0 to 700 ka (limits of technique)
Potassium-argon dating (selected)	"	20 ka to 8 Ma (published data, site-specific)
Fission-track dating (selected)	"	<100 ka to 15 Ma (published data, site-specific, limits of technique)

Table 3.5-1. Summary of tests and methods for the calcite and opaline silica vein deposits activity (SCP 8.3.1.5.2.1.5)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Geochronologic investigations	
Electron spin resonance (ESR) dating (selected)	Ages, hydrogenic deposits	<15 Ma (published data, site-specific)
	Tracer-isotope investigations	
Analysis of strontium isotopes (selected)	Isotopic compositions, hydrogenic deposits	$^{87}Sr/^{86}Sr$ = 0.704 to 0.720 (general published literature)
Analysis of lead isotopes (selected)	"	$^{206}Pb/^{204}Pb$ = 16 to 24 (general published literature)
	Stable-isotope investigations	
Separation of hydrogen and deuterium from water, rock, or minerals (selected)	Not applicable	Not applicable
Analysis of hydrogen isotopes (selected)	Isotopic compositions, hydrogenic deposits	delta D = -140 to +100 parts per mil (general published literature)
"	Temperature of formation, hydrogenic deposits	10 to 300 °C (unpublished data, general published literature)
Separation of carbon (selected)	Not applicable	95% to 100% yield (limits of technique)
Analysis of carbon isotopes (selected)	Isotopic compositions, hydrogenic deposits	delta ^{13}C = -20 to +10 per mil (general published literature)

Table 3.5-1. Summary of tests and methods for the calcite and opaline silica vein deposits activity (SCP 8.3.1.5.2.1.5)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Stable-isotope investigations	
Analysis of carbon isotopes (selected)	Temperature of formation, hydrogenic deposits	10 to 300 °C (unpublished data, general published literature)
Separation of oxygen (selected)	Not applicable	95% to 100% yield (limits of technique)
Analysis of oxygen isotopes (selected)	Isotopic composition, hydrogenic deposits	delta ^{18}O = -10 to +40 per mil (limits of technique)
"	Temperature of formation, hydrogenic deposits	10 to 300 °C (general published literature)
	Paleontological investigations	
Preparation of microfossils (selected)	Not applicable	Present or absent
Identification of microfossils and interpretation of temperature and water chemistry from microfossil assemblages (selected)	Chemistry, Trench 14 deposit-source waters	Not applicable
"	Temperature of formation, hydrogenic deposits	10 to 50 °C (limits of technique)
	Hydrologic investigations and analyses	
Development of a hydrologic model of Trench 14 area constrained in accordance with data gathered in above tests (selected)	Paleohydrologic flow paths	Not applicable

Table 3.5-1. Summary of tests and methods for the calcite and opaline silica vein deposits activity (SCP 8.3.1.5.2.1.5)--Continued

Methods (selected and alternate)	Site-characterization parameter	Expected range
	Hydrologic investigations and analyses	
Collection of water samples from springs (selected)	Not applicable	Not applicable
Chemical analysis of water samples (selected)	Major-, minor-, and trace-element compositions, spring waters	"
"	Paleohydrologic flow paths	Shallow to deep circulation
	Data integration and analysis	
To be determined (selected)	Paleohydrologic flow paths	Not applicable

Generally, for method selection, the accuracy and precision prediction is a relative judgement based on the USGS investigators' familiarity with, and understanding of, the method. For selected methods, if values for accuracy and precision exist, they will be listed within the technical procedures.

Similarly, the duration of a method is difficult to quantify exactly. The duration of some methods may be seconds, whereas the duration of others may be months. The methods, however, have been selected so that the parameters of interest can be evaluated reasonably within the schedule of the study (Section 5.1). Furthermore, the total duration of the method is dependent on the number of times it is implemented, which is dependent on the spatial variability of a parameter within or among geohydrologic units, the accuracy and precision of the method, the number of available samples, and desired level of confidence in reproducibility of the measurement.

The methods were also selected by considering their ranges of measurement. It would be senseless to select a method that could not provide accurate data within the expected range of the site-characterization parameter of interest. Again, the expected range of method is difficult to quantify without actual testing or implementation of the technique. The USGS investigators, however, have selected methods which they believe are suitable to provide accurate data within the expected range of the site-characterization parameter. The expected ranges of some of the site-characterization parameters have been bracketed by previous data collection modeling and are shown in Table 3.5-1.

Finally, the interference of a given method with other tests in the site-characterization program was considered in selecting the method. Generally, the selected methods will have little or no interference with other tests and analyses. In cases where methods do interfere, the USGS investigators have planned their testing sequences accordingly, in order to maximize data collection and minimize interference.

3.5.4 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires assignment, justification, and documentation of quality levels to activities that affect quality; and documentation of technical procedures for all technical activities that require quality assurance.

The technical procedures which will be utilized in this activity are standard procedures derived from the scientific literature appropriate to the various techniques. These procedures have been adapted to compensate for site-specific conditions and incorporate the quality-assurance requirements of the Yucca Mountain Project.

Table 3.5-2 provides a tabulation of technical procedures applicable to this activity. The technical procedures are listed according to the tests/analyses of Table 3.5-1. Approved procedures are identified with a USGS number. Procedures that require preparation do not have procedure numbers. Procedures that are identified as "needed" in the table will be completed and available 30 days before the associated testing is started.

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

Table 3.5-2. Technical procedures for the calcite and opaline silica vein deposits activity (SCP Activity 8.3.1.5.2.1.5)
(At the discretion of the PI, approved technical procedures not listed may be used during the activity, should that be appropriate, and revised or replaced with other procedures as needed.)

Technical procedure number (YMP-USGS-)	Technical procedure
	Field investigations
GP-01	Geologic mapping
GP-07	Conventional geologic mapping of trench walls
HP-37	Preliminary procedure for drilling and coring of wet- and dry-lake sediments
GP-27	Trench wall and natural outcrop sampling for coordinated studies
TWS-ESS-DP-101	Sample collection, identification, and control for mineralogy-petrology studies
	Mineralogical tests
TWS-ESS-DP-04	Thin section preparation procedure
TWS-ESS-DP-16	Siemens X-ray diffraction procedure
TWS-ESS-DP-24	Calibration and alignment of the Siemens diffractometers
TWS-ESS-DP-25	Clay mineral separation and preparation for X-ray diffraction analysis
TWS-ESS-DP-50	Operating procedure for gold coating samples using the Technics Hummer II Sputtering System
TWS-ESS-DP-56	Brinkmann automated grinder procedure
GCP-07	Mineral separation for geochemistry and isotopic analysis
TWS-ESS-DP-102	Procedure for determination of volume constituents in thin sections of rock

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Table 3.5-2. Technical procedures for the calcite and opaline silica vein deposits activity (SCP Activity 8.3.1.5.2.1.5)—*continued*

Technical procedure number (YMP-USGS-)	Technical procedure
TWS-ESS-DP-116	Quantitative X-ray diffraction data reduction procedure
TWS-ESS-DP-124	Use of binocular microscope in fracture mineralogy studies
	Geochemical tests
TWS-ESS-DP-06	Carbon coating: operation of the LADD vacuum evaporator for carbon coating samples
TWS-ESS-DP-07	Microprobe operating procedure
TWS-ESS-DP-50	Operating procedure for gold coating samples using the Technics Hummer II Sputtering System
TWS-ESS-DP-51	Mettler AE100 operating procedure
TWS-ESS-DP-52	Sample preparation for X-ray fluorescence analysis: fusing and lapping
TWS-ESS-DP-53	Pulverizing using the Rocklabs 3E shatterbox
TWS-ESS-DP-54	Crushing: operation of 50-ton hydraulic press
TWS-ESS-DP-55	Rock-splitting: operation of 50-ton hydraulic press
TWS-ESS-DP-56	Brinkman automated grinder procedure
TBD	Instrumental neutron activation
GCP-12	Rb-SR isotope geochemistry
TWS-ESS-DP-112	Operating instructions for International Scientific Instrument Model DS-130 scanning electron microscope and TRACOR Northern Series II X-ray Analyzer for evaluation of YMP geologic materials

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Table 3.5-2. Technical procedures for the calcite and opaline silica vein deposits activity (SCP Activity 8.3.1.5.2.1.5)--*continued*

Technical procedure number (YMP-USGS-)	Technical procedure
	Fluid-inclusion investigations
TWS-ESS-DP-101	Handling, storage, and shipping of samples
GCP-14 (in preparation)	Extraction and recovery of water from calcite-hosted inclusion fluids
TWS-ESS-DP-113	Procedure: temperature determinations from fluid inclusion studies
	Geochronologic investigations
GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
GCP-03	Uranium-series dating
GCP-08	Fission-track dating
GCP-09	Preparation of spike solutions
TWS-ESS-DP-101	Sample collection, identification, and control for mineralogy-petrology studies
TWS-MTSQA-QP-14	One-time research and development work
TWS-ESS-DP-50	Operating procedure for gold coating samples using the Technics Hummer II Sputtering System
TWS-ESS-DP-51	Mettler AE100 operating procedure (X-ray fluorescence analysis sample weighing procedure)
TWS-ESS-DP-52	Sample preparation for X-ray fluorescence analysis: fusing and lapping
TWS-ESS-DP-53	Pulverizing using the Rocklabs 3E shatterbox

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Table 3.5-2. Technical procedures for the calcite and opaline silica vein deposits activity (SCP Activity 8.3.1.5.2.1.5)—*continued*

Technical procedure number (YMP-USGS-)	Technical procedure
TWS-ESS-DP-54	Crushing: operation of 50-ton hydraulic press
TWS-ESS-DP-55	Rock splitting: operation of 50-ton hydraulic press
TWS-ESS-DP-56	Brinkman automated grinder procedure
TBD	Instrumental neutron activation
TBD	Electron spin resonance dating
TWS-ESS-DP-113	Procedure: temperature determinations from fluid inclusion studies
GCP-03	Uranium-trend dating
GCP-22	Spike calibration for uranium-series and uranium-trend analyses
	Tracer-isotope investigations
GCP-02	Labeling, identification, and control of samples for geochemistry and isotope geology
GCP-13	U-Th-Pb isotope geochemistry
GCP-12	Rb-Sr isotope geochemistry
	Stable-isotope investigations
TWS-ESS-DP-101	Sample collection, identification, and control for mineralogy-petrology studies
CGP-15	Oxygen isotope analysis of opaline-cilica, chalcedony, and quartz
GCP-16	Carbonate carbon and oxygen isotope analyses

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Table 3.5-2. Technical procedures for the calcite and opaline silica vein deposits activity (SCP Activity 8.3.1.5.2.1.5)—*continued*

Technical procedure number (YMP-USGS-)	Technical procedure
GCP-17	Determination of the isotopic ratio H/D in water
HP-08	Methods for determination of inorganic substances in water
HP-23	Collection and field analysis of saturated-zone ground-water samples
HP-76	Diatom enumeration studies
HP-78	Nonmarine calcareous-microfossil sample preparation and data acquisition procedures
HP-79	Analysis of fossil pollen from Lake sediments
TWS-ESS-DP-101	Sample collection, identification, and control for mineralogy-petrology studies
HP-164	Processing of soil, sediment, and water samples for chrysophyte cysts
	Hydrologic investigations and analyses
HP-23	Collection and field analysis of saturated-zone ground-water samples
HP-91	Collection and field analysis of surface-water samples
TWS-ESS-DP-101	Sample collection, identification, and control for mineralogy-petrology studies
HP-164	Processing of soil, sediment, and water samples for chrysophyte cysts
	Data integration and analysis
	No technical procedures identified

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4 APPLICATION OF STUDY RESULTS

4.1 Application of results to resolution of design and performance issues

Site information resulting from this study will be used indirectly in the resolution of YMP performance and design issues concerned with the effects of future climate changes on the future geohydrologic regime at Yucca Mountain and environs, and also in issues concerned with future tectonic movement, future volcanism, and human interference. Principal applications will be in overall system performance (Issue 1.1) and higher-level findings (Issue 1.9). Secondary applications will be in NRC siting criteria (Issue 1.8); repository compliance with preclosure design criteria and providing information for resolution of performance issues (Issue 2.7); adequacy of repository construction, operation, closure, and decommissioning for resolution of performance issues (Issue 4.4); and operation of the repository such that credible accidents do not result in excessive radiation exposures (Issue 2.3). Peripheral applications will be in ground-water travel time (Issue 1.6), waste-package characteristics (Issue 1.10), characteristics and configurations of the repository and repository engineered barriers (Issue 1.11), and characteristics and configurations of shaft and borehole seals (Issue 1.12).

The application of site information from this study to design and performance parameter needs required for the resolution of design and performance issues is addressed in Section 1.3. Sections 2 and 3 use logic diagrams and tables to summarize specific relationships between performance and design parameter needs and activity and site-characterization parameters.

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

Data collected in this study will be employed principally in Study 8.3.1.5.2.2 (Characterization of the future regional hydrology due to climate changes) in Investigation 8.3.1.5.2 (Studies to provide the information required on potential effects of future climatic conditions on hydrologic characteristics). The relation of the present study to Study 8.3.1.5.2.2 has been presented in Sections 1 and 2. In addition, other site-characterization studies and investigations to which this study contributes are:

- 8.3.1.2.1 Studies to provide a description of the regional hydrologic system
- 8.3.1.2.2 Studies to provide a description of the unsaturated-zone hydrologic system at the site
- 8.3.1.2.3 Studies to provide a description of the saturated-zone hydrologic system at the site.

In the above three investigations, paleoflooding and debris-transport data gathered in Activity 8.3.1.5.2.1.1 may be applied to interpretation of modern surface-water hydrology at Yucca Mountain. Data on the geohydrologic units, hydraulic characteristics, and potentiometric levels generated in Activity 8.3.1.5.2.1.3 may be applied to the investigations of both the saturated and unsaturated zones. Infiltration and recharge values calculated in Activity 8.3.1.5.2.1.4 may contribute to the understanding of present-day infiltration in the unsaturated zone. If Activity 8.3.1.5.2.1.5 should indicate a hydrothermal or deep-seated spring origin for the Yucca Mountain hydrogenic deposits and that the deposits are not of great age, that information would bear upon the saturated-zone regime description, whereas a recent pedogenic origin would apply to the unsaturated-zone description.

* * *

The following is a citation of the paleoclimate program investigation receiving data from this study, and a discussion of this study's contributions to that investigation.

- 8.3.1.5.1 Studies to provide information required on nature and rates of change in climatic conditions to predict future climates

The Quaternary regional hydrology study will provide, during the course of field investigations, data that can be employed in the reconstruction of paleoclimate scenarios in the paleoclimate program. Timing and characteristics of paleoflooding events from Activity 8.3.1.5.2.1.1 may contribute to assembling a time series of paleoclimate episodes, and these may serve as a cross-check on paleoclimatic history from other lines of evidence. Lithologic, geochemical, and paleontological evidence from Activity 8.3.1.5.2.1.3 may supplement data for the lake, marsh, and playa activity in the paleoclimate program. Fossil evidence gathered in Activity

8.3.1.5.2.1.5 from Trench 14 and other hydrogenic deposits may be applied to terrestrial paleoecology studies. From the analog recharge work in Activity 8.3.1.5.2.1.4, the contemporary packrat-midden data may be useful in the terrestrial paleoecology activity. The development and validation of the chloride-ion mass-balance model, also from this activity, may be used to advantage in the modeling of soil-properties activity in the paleoclimate program. It is also possible that there will be a two-way exchange of information between Activity 8.3.1.5.2.1.4 and the soil-moisture analog activity of the paleoclimate program.

* * *

The following is a list of the geochemistry program investigations receiving data from this study, and a discussion of this study's contributions to those investigations.

- 8.3.1.3.1 Studies to provide information on water chemistry within the potential emplacement horizon and along potential flow paths
- 8.3.1.3.2 Studies to provide information on mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths
- 8.3.1.3.3 Studies to provide information on stability of minerals and glasses
- 8.3.1.3.4 Studies to provide information required on radionuclide retardation by sorption processes along flow paths to the accessible environment
- 8.3.1.3.5 Studies to provide information required on radionuclide retardation by precipitation processes along flow paths to the accessible environment
- 8.3.1.3.6 Studies to provide information required on radionuclide retardation by dispersive/diffusive/ advective transport processes along flow paths to the accessible environment
- 8.3.1.3.7 Studies to provide information required on radionuclide retardation by all processes along flow paths to the accessible environment

The hydrogenic-deposits studies of Activity 8.3.1.5.2.1.5 may bear upon the geochemistry program, depending upon which of the possible modes of origin (e.g., deep-seated hydrothermal, shallow pedogenic, etc.) is supported by the weight of the evidence collected. The above geochemical investigations would be supported by the activity if an origin by deep-seated hydrothermal processes in the Quaternary is decided upon. Such an origin would require that the chemistry of the hot carbonate-rich hydrothermal fluids responsible for the deposits be factored into the evaluation of future rock geochemistry at repository depth. Among the possible geochemical effects of a future hydrothermal event at Yucca

Mountain are devitrification of glass and formation of zeolite and clay minerals.

* * *

The following is a citation of the thermal and mechanical rock-properties program investigation receiving data from this study, and a discussion of this study's contributions to that investigation.

- 8.3.1.15.1 Spatial distribution of thermal and mechanical properties.

Activity 8.3.1.5.2.1.5 bears upon the thermal regime if a deep-seated hydrothermal origin should be decided upon for the Yucca Mountain hydrogenic deposits. The future occurrence of a hydrothermal event at Yucca Mountain would impose new heat flux upon the repository horizon, changing the thermal regime and potentially altering rock thermomechanical properties.

* * *

The following are citations of erosion program and preclosure hydrology program investigations receiving data from this study, and a discussion of this study's contributions to those investigations.

- 8.3.1.6.2 Potential effects of future climatic conditions on locations and rates of erosion.

- 8.3.1.16.1 Flood-recurrence intervals and levels at potential location of surface facilities.

Paleoflood data and interpretive results from Activity 8.3.1.5.2.1.1 will be very valuable for the prediction of runoff and flooding under current climatic conditions, in the evaluation of flood potential and debris hazards (Study 8.3.1.16.1.1).

Also in Activity 8.3.1.5.2.1.5, a pedogenic origin for the Yucca Mountain hydrogenic deposits, if decided upon, would bear upon evaluating future erosion. Such an origin might imply that a large amount of surface water had been concentrated at the Trench 14 fault zone and other hydrogenic deposits, either by channeling of surface runoff or by local meteorological conditions. The possible future occurrence of such a concentration would have to be factored into future erosion, as well as flood potential at surface facilities.

* * *

The following are citations of postclosure tectonics program investigations receiving data from this study, and a discussion of this study's contributions to those investigations.

- 8.3.1.8.2 Studies to provide information required on rupture of waste packages by tectonic events.

- o 8.3.1.8.3 Studies to provide information required on changes in unsaturated- and saturated-zone hydrology due to tectonic events.

Radiometric age dates on volcanic ash present in the Trench 14 hydrogenic deposits may be applied to evaluation of the timing of Quaternary volcanic events and to estimating the probability of their future occurrence.

Radiometric ages of Trench 14 mineralization associated with fault movement may be applied to the analysis of the past frequency and rate of faulting in the Yucca Mountain area, and to estimating the probability and rates of future faulting.

* * *

The following is a citation of the human interference program investigations receiving data from this study, and a discussion of this study's contributions to that investigation.

- o 8.3.1.9.2 Studies to provide information required on present and future value of energy, mineral, land, and ground-water resources.

Major-, minor-, and trace-element geochemistry of the Trench 14 calcite and opaline-silica deposits, along with the overall evaluation of the origin of the mineralization, may bear upon assessing the potential of Yucca Mountain for the presence of economic-mineral deposits.

5 SCHEDULES AND MILESTONES

5.1 Schedules

The proposed schedule presented in Figure 5.1-1 summarizes the logic network and reports for the four activities of the Quaternary regional hydrology study. This figure represents a summary of the schedule information which includes the sequencing, interelations, and durations of the activities described in this study (as of the date of this study plan). It includes the SCP major events from SCP Table 8.3.1.5-6. 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 study will contribute or may interfere with other studies.

The syntheses of the results of this study (Quaternary regional hydrology) with the results of Study 8.3.1.5.1.6 (Characterization of future climate conditions) will be used in the evaluations of future climate effects on hydrology in Study 8.3.1.5.2.2 (Characterization of future regional hydrology due to climate changes). The results of the future hydrology study will be used to supply input data to the resolution of Issues 1.1 (Total system performance).

The results of Activity 8.3.1.5.2.1.5 (calcite-silica deposits) will also be used as input to a conceptual model of calcite-silica deposits for Issue 1.1 scenario screening (due early in the testing), and an issues resolution report (IR-35) on the mode of origin of calcite-silica deposits and potential effects upon repository performance (due later in the testing). Input to the conceptual model will occur after either the first (milestone P915) or second (milestone T168) workshop. At these times, exchange of preliminary results and discussion of direction for future work will take place. Input to the issues resolution report will occur after the third workshop (milestone T169) and the final report (hydrogenic deposits with emphasis on opaline-silica deposits) is completed. Sample collection and initiation of testing for the calcite-silica activity requires early trenching and drilling (DOE/REECo interface). Milestones Q095 and Q096 indicate this requirement.

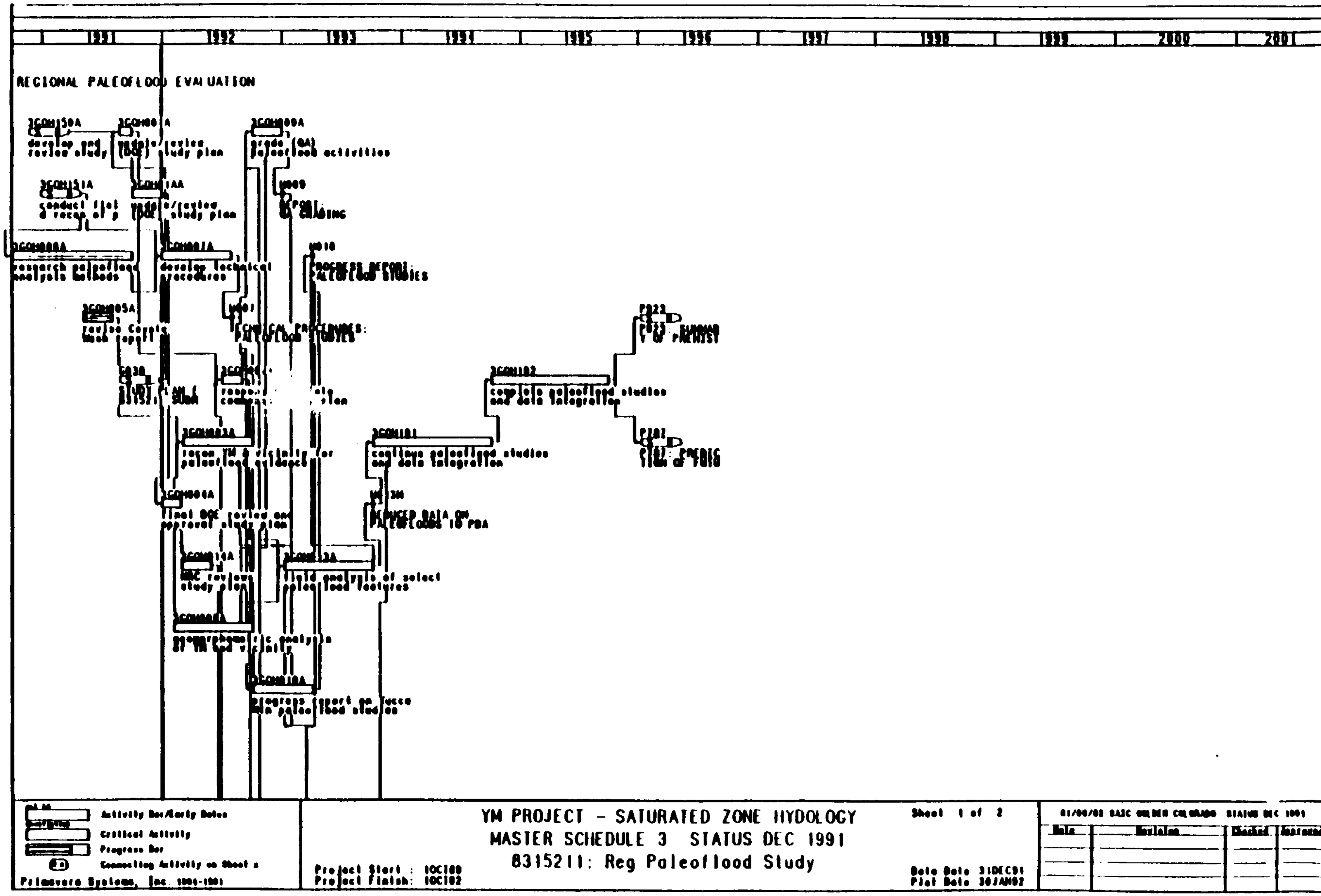

Figure 5.1-1a. Summary network for Quaternary regional hydrology study.

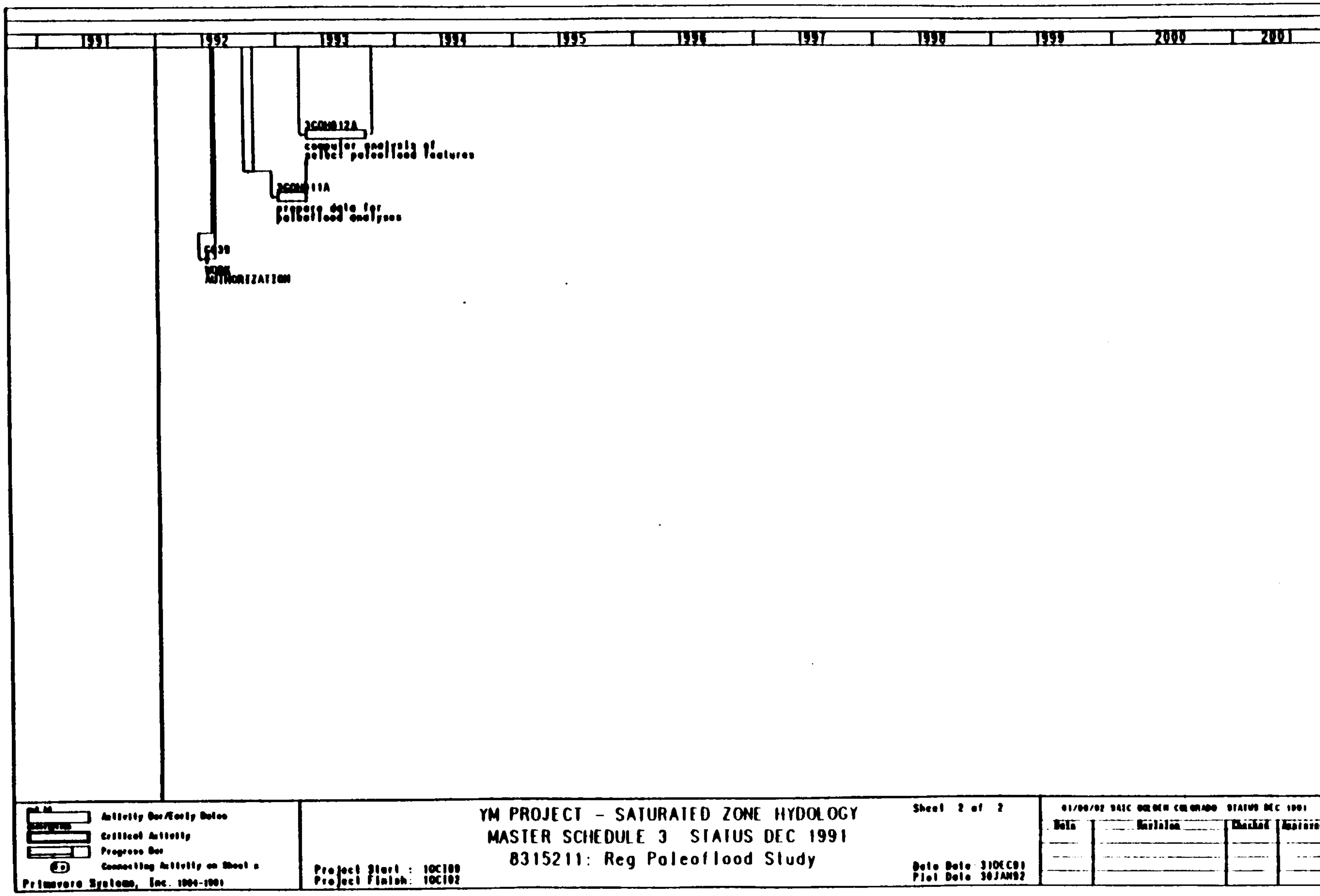

Figure 5.1-1b. Summary network for Quaternary regional hydrology study (continued)

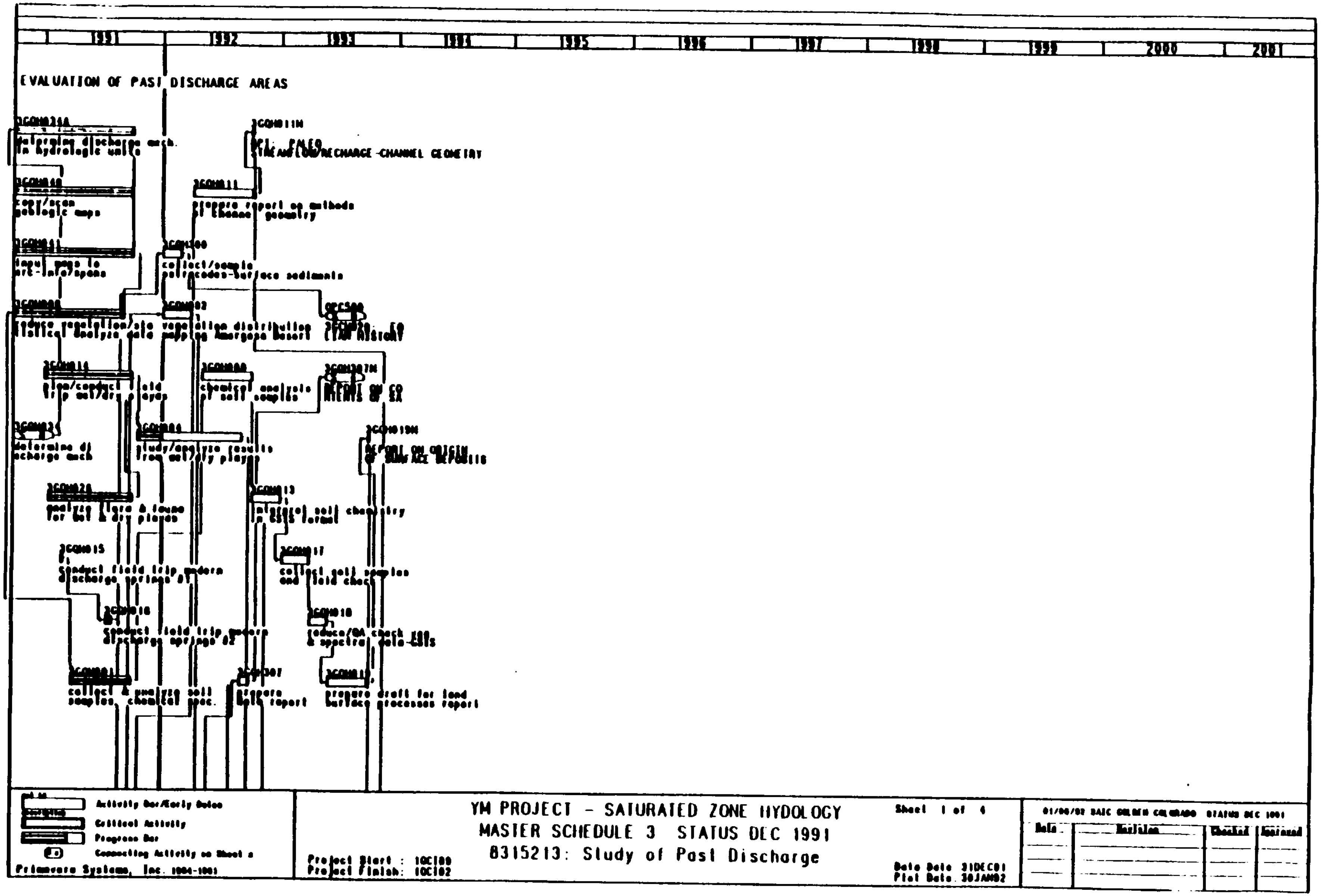

Figure 5.1-1c. Summary network for Quaternary regional hydrology study (continued).

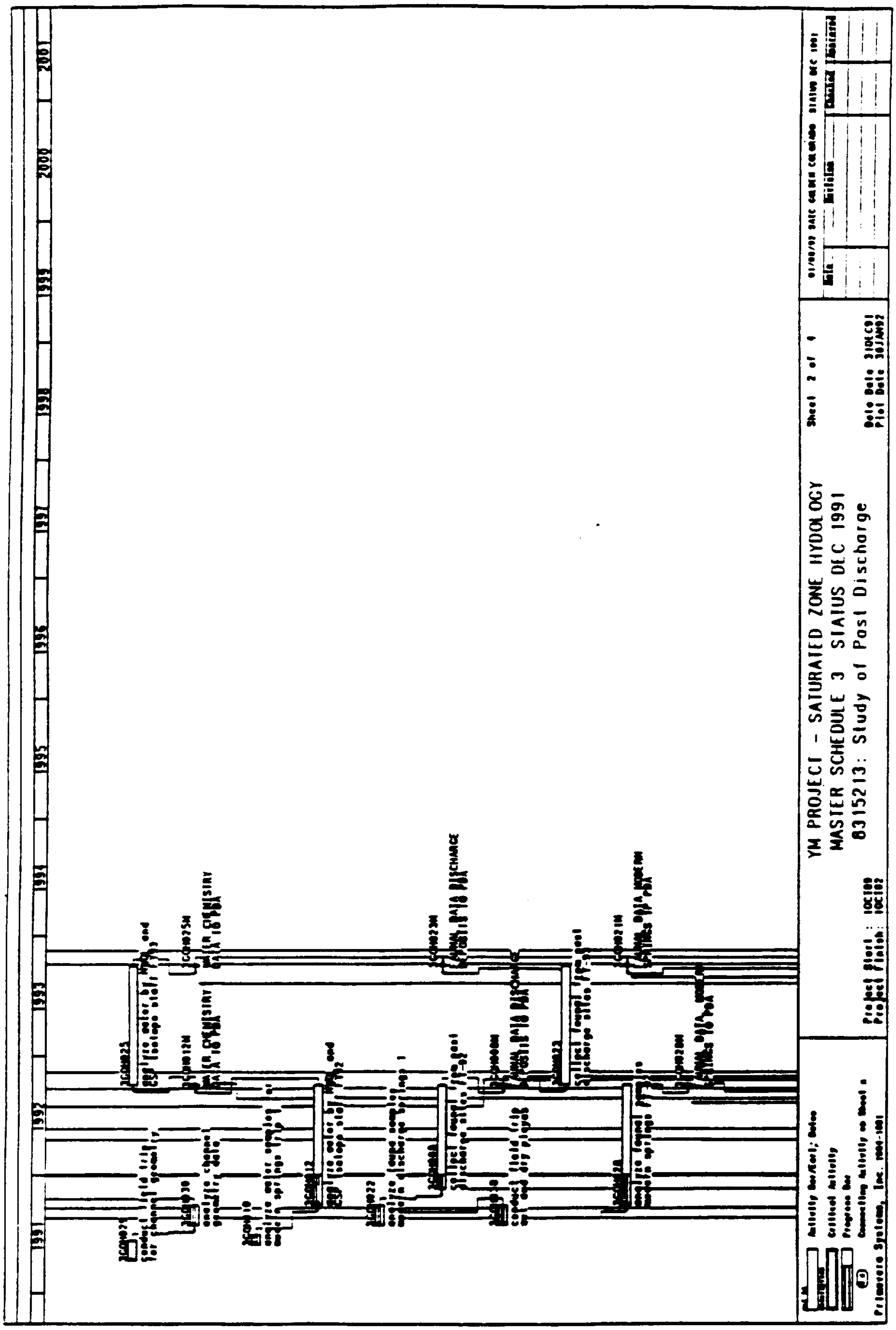

Figure 5.1-1d. Summary network for Quaternary regional hydrology study (continued)

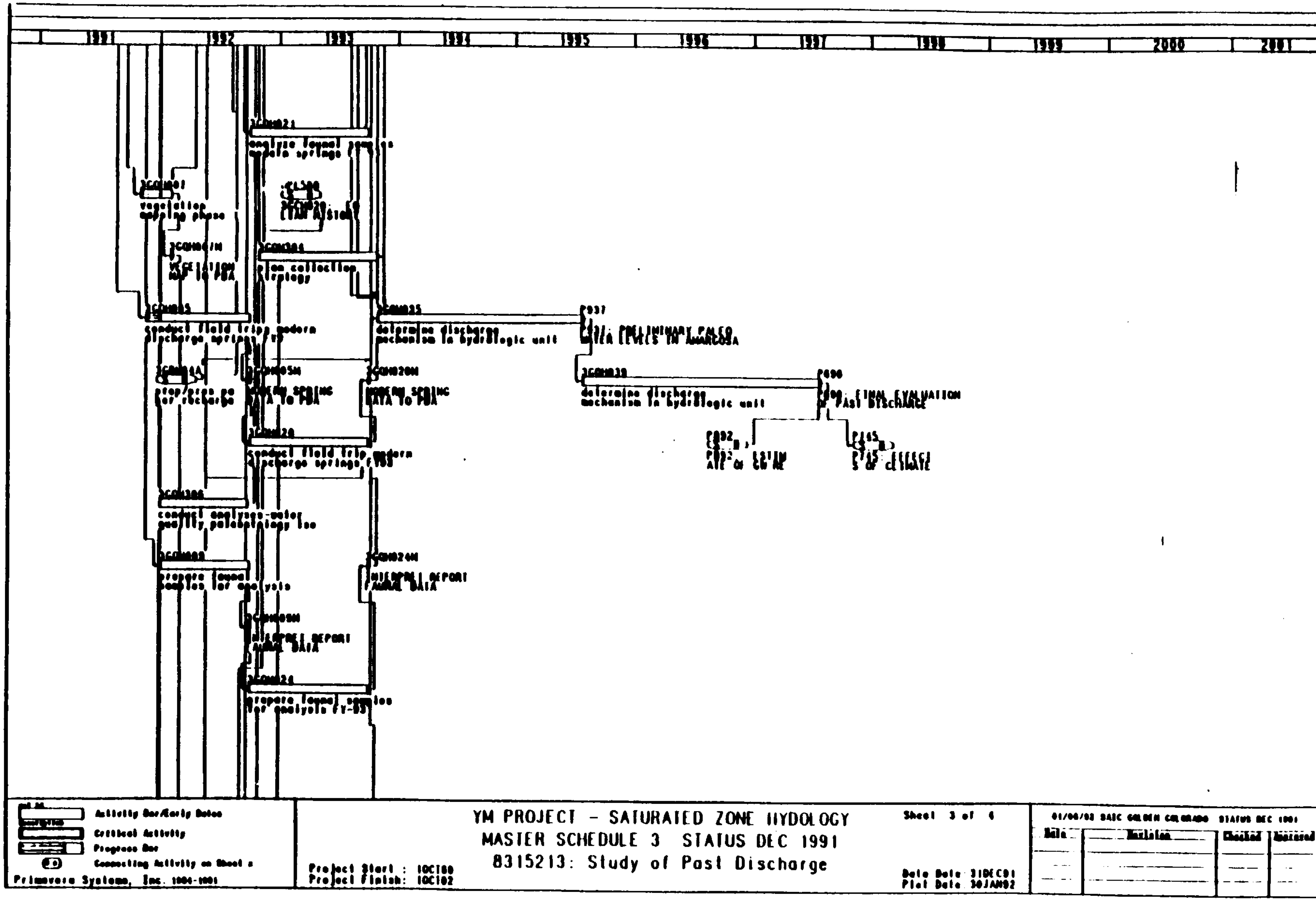

Figure 5.1-1e. Summary network for Quaternary regional hydrology study (continued).

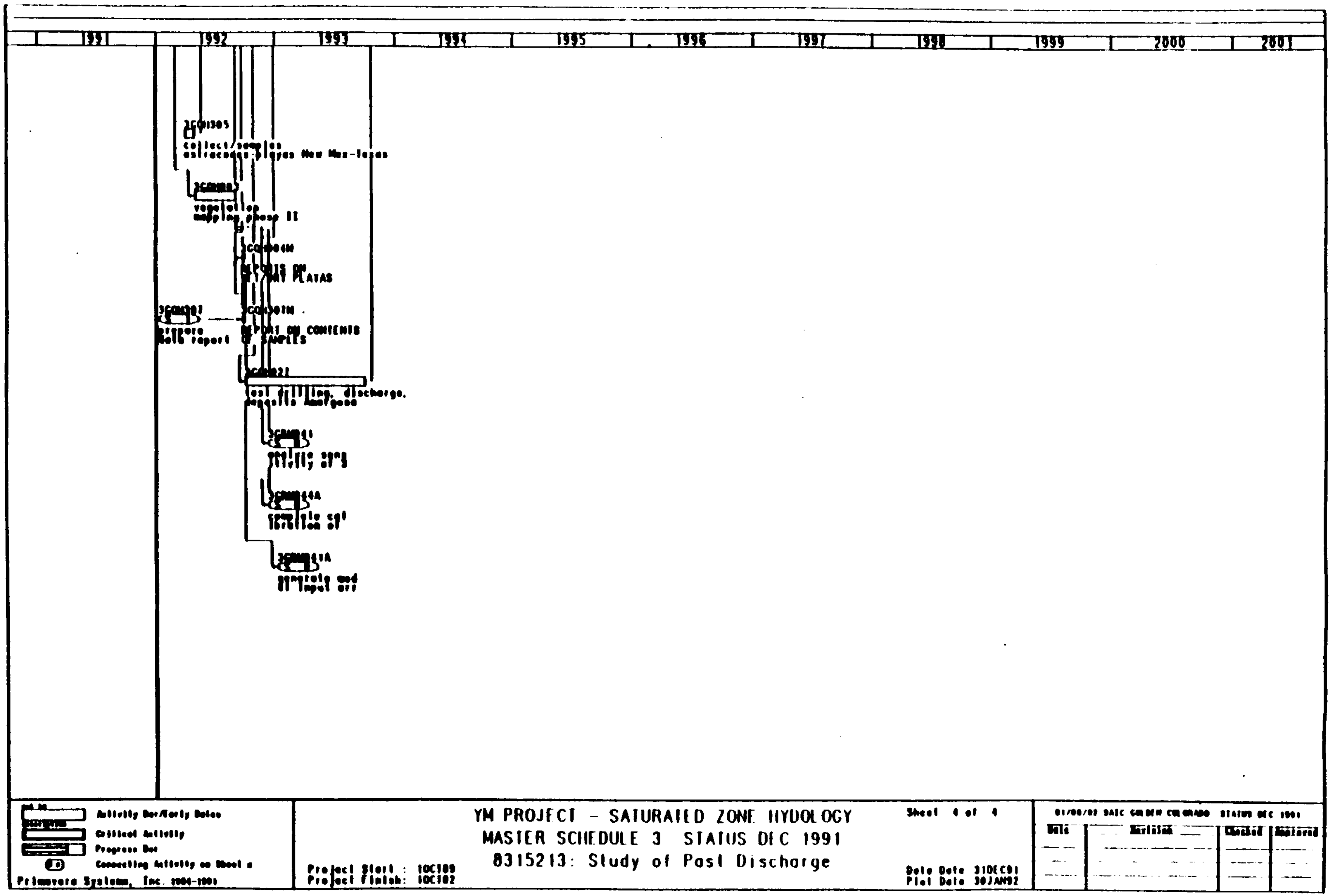

Figure 5.1-1f. Summary network for Quaternary regional hydrology study (continued)

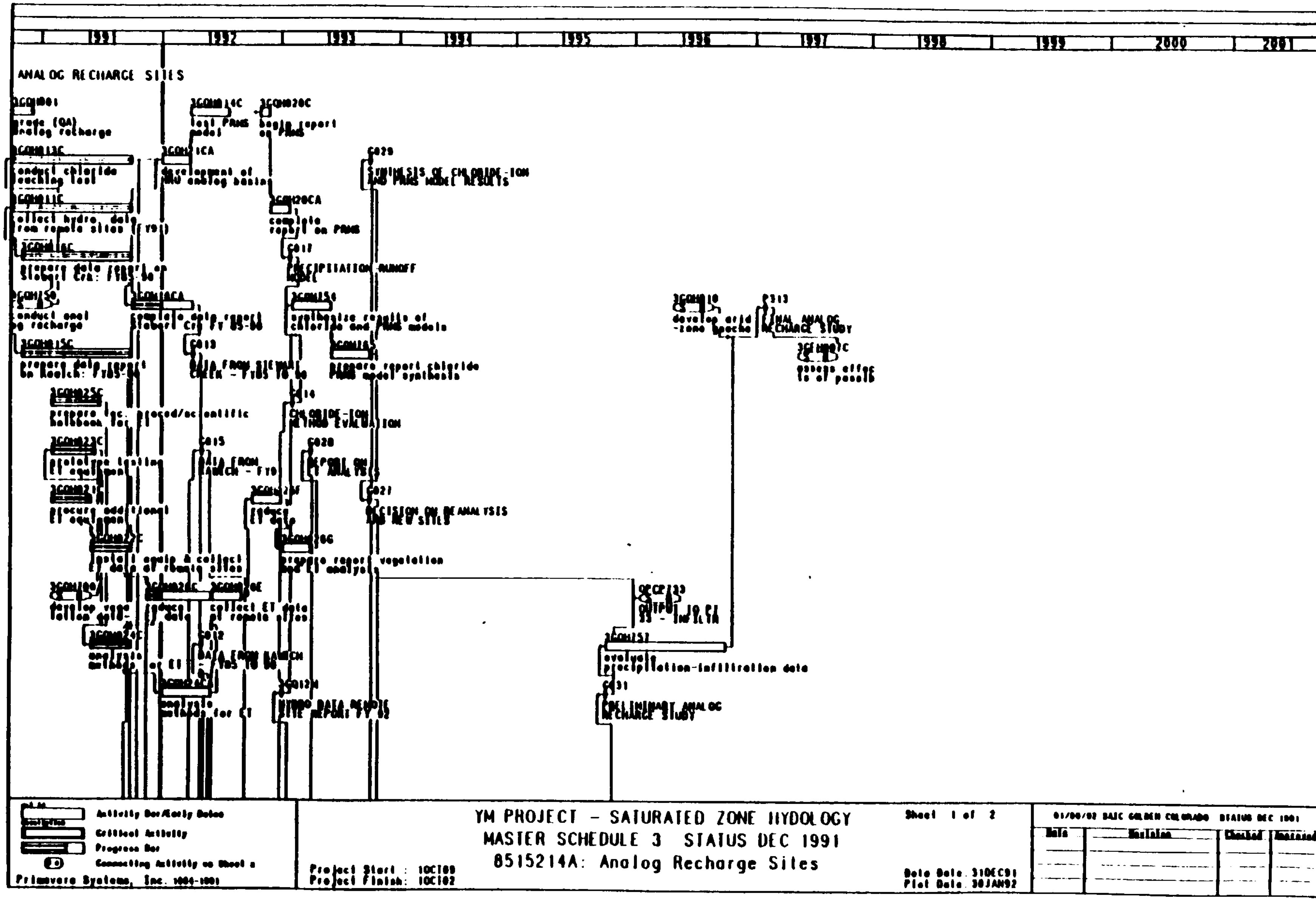

Figure 5.1-1g. Summary network for Quaternary regional hydrology study (continued).

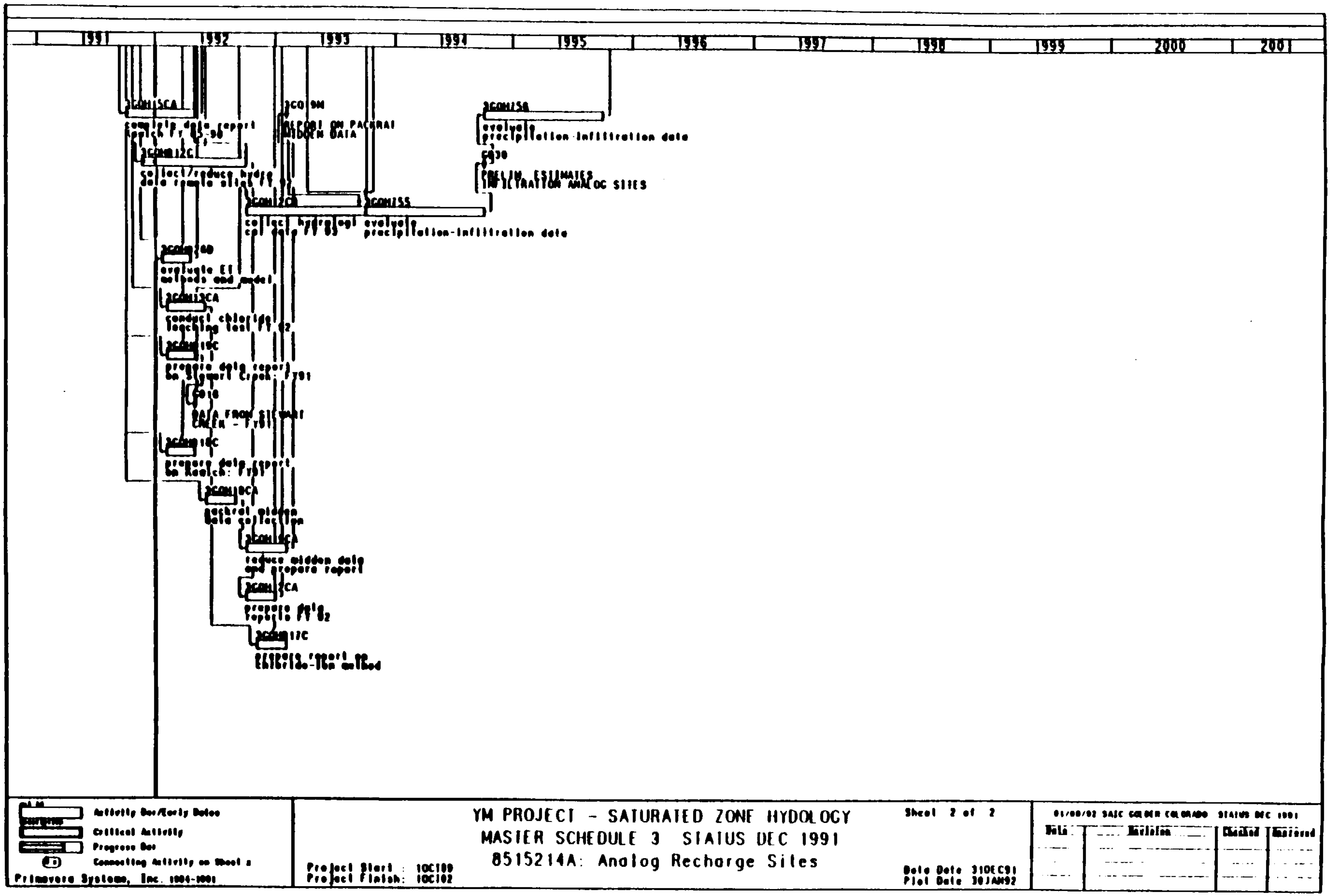

Figure 5.1-1h. Summary network for Quaternary regional hydrology study (continued).

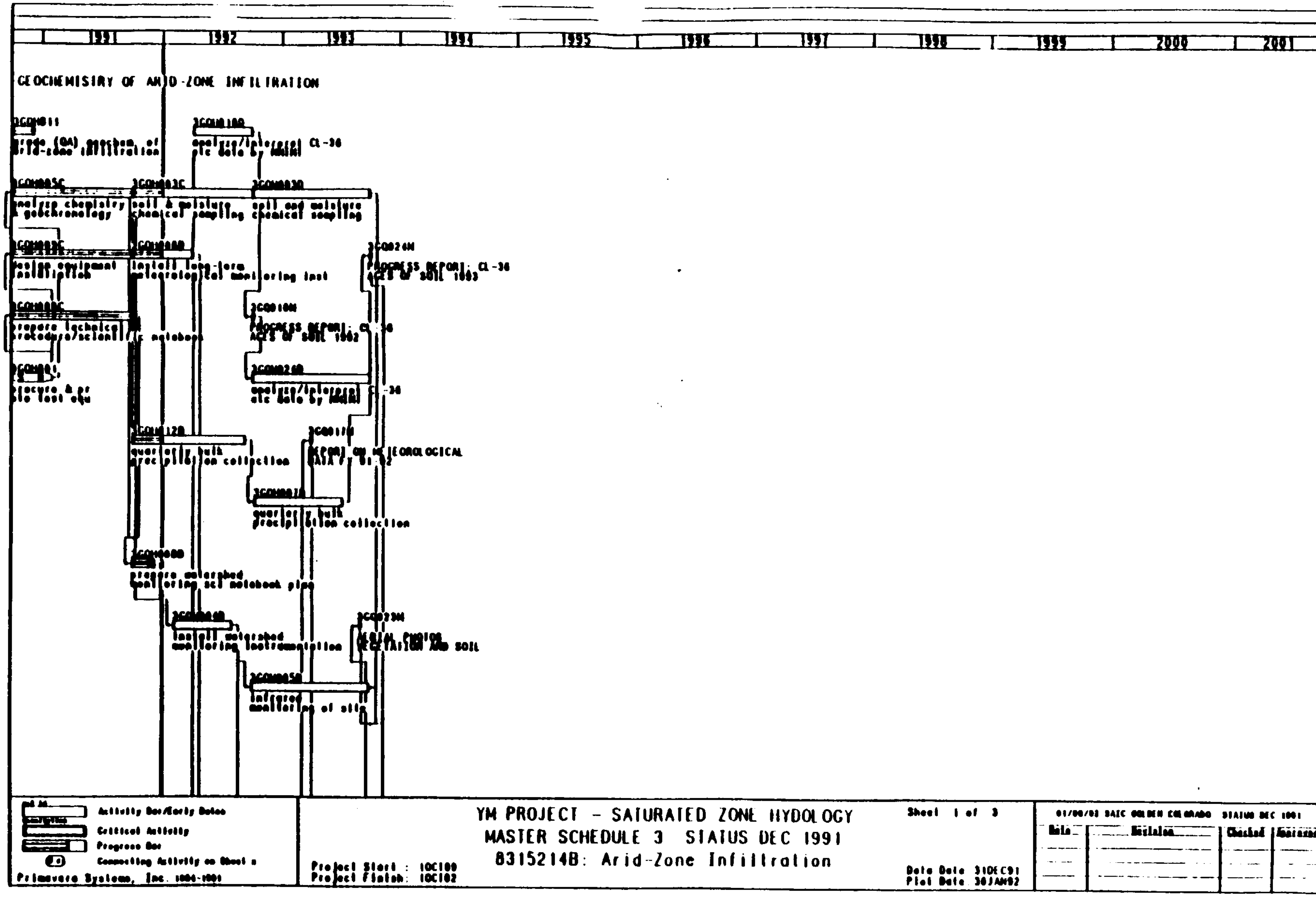

Figure 5.1-11. Summary network for Quaternary regional hydrology study (continued)

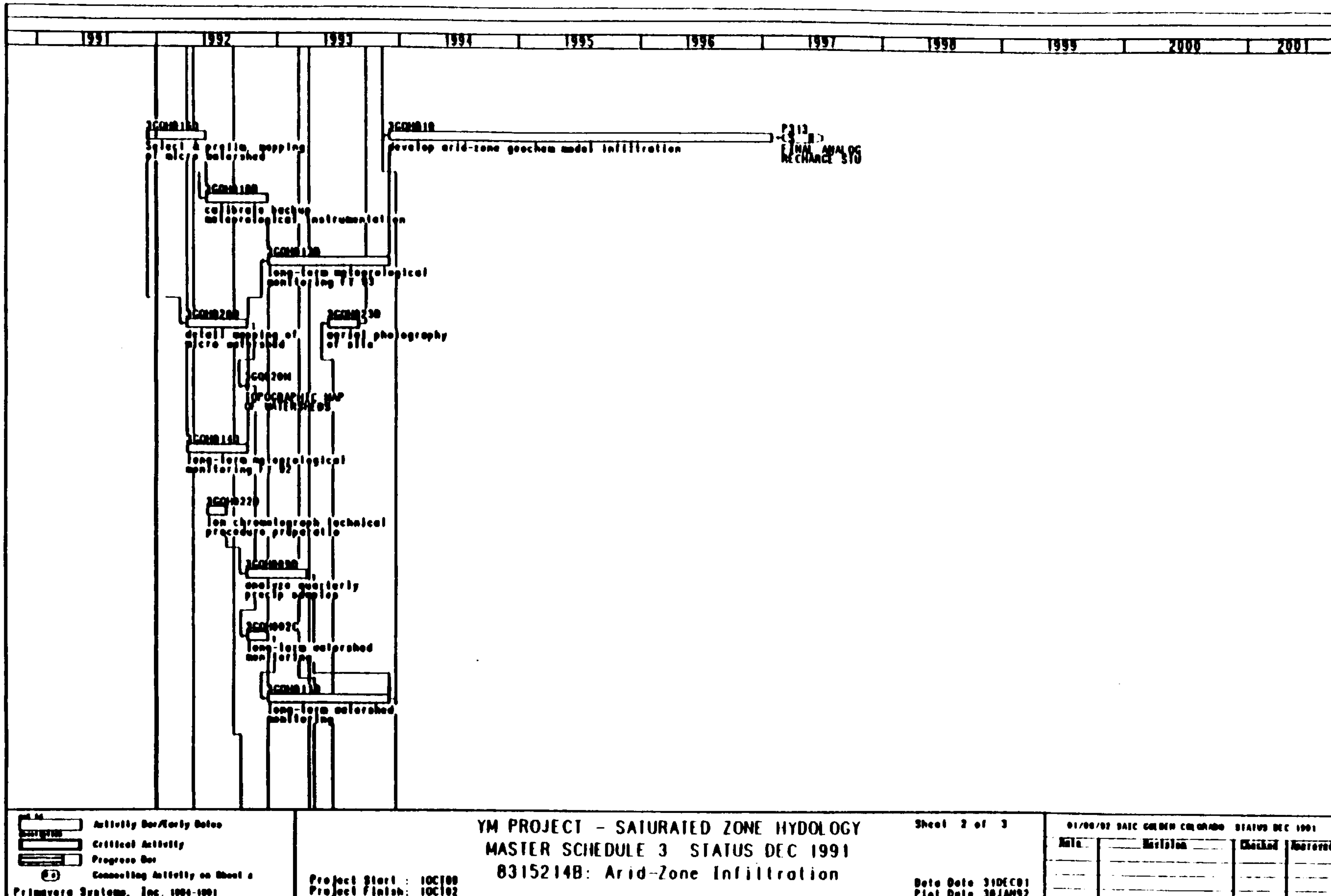

Figure 5.1-1j. Summary network for Quaternary regional hydrology study (continued).

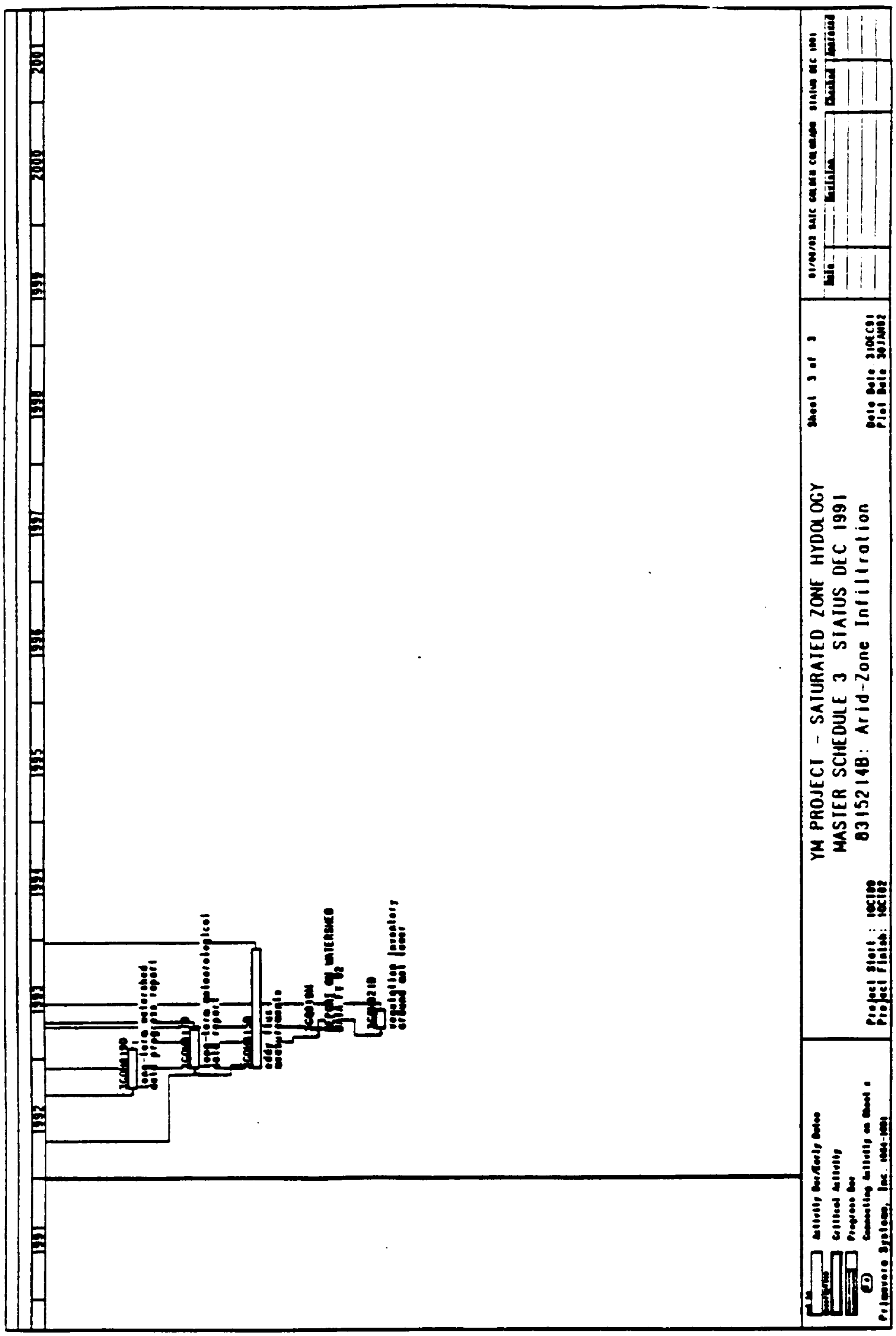

Figure 5.1-1k. Summary network for Quaternary regional hydrology study (continued).

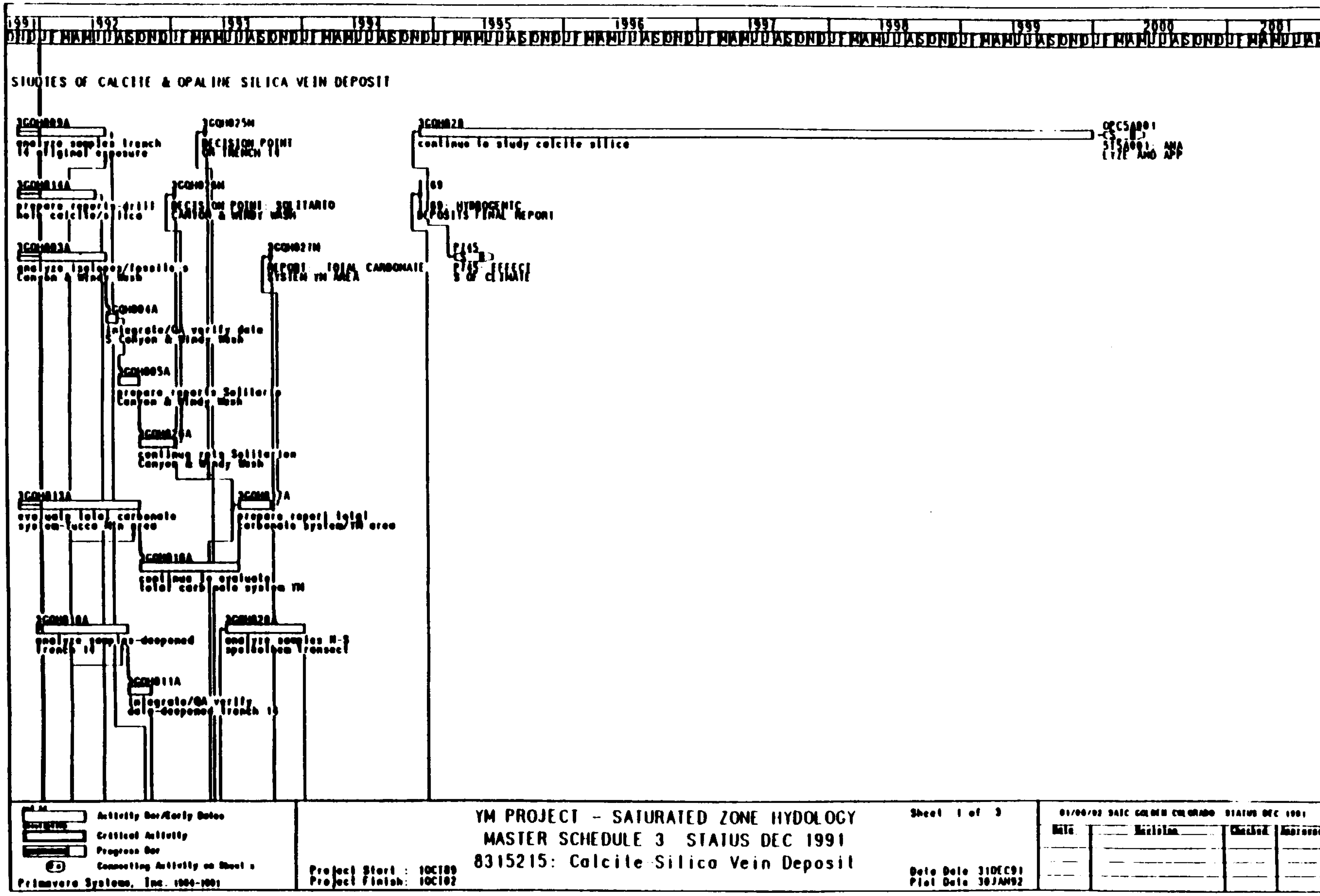

Figure 5.1-11. Summary network for Quaternary regional hydrology study (continued)

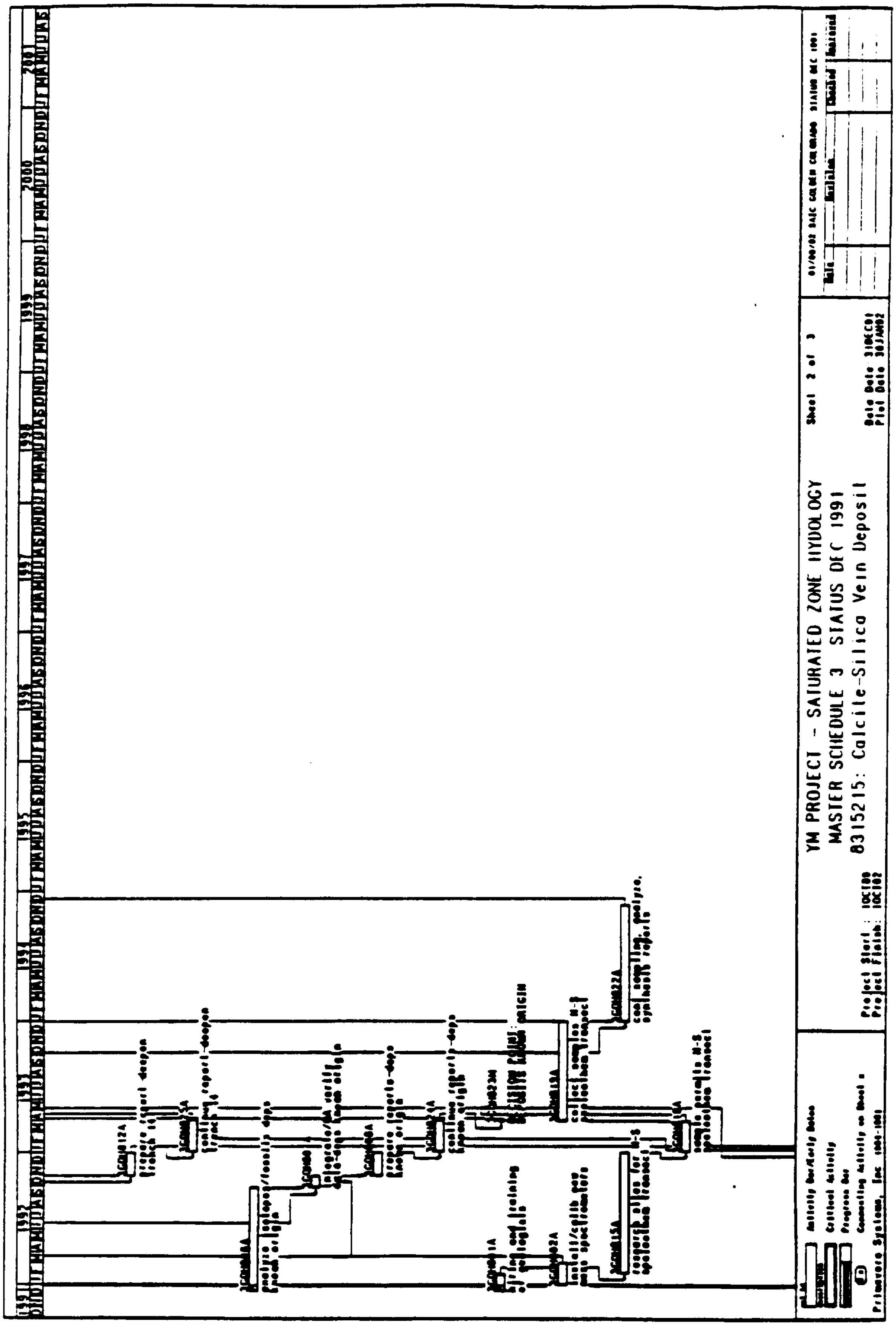

Figure 5.1-1m. Summary network for Quaternary regional hydrology study (continued)

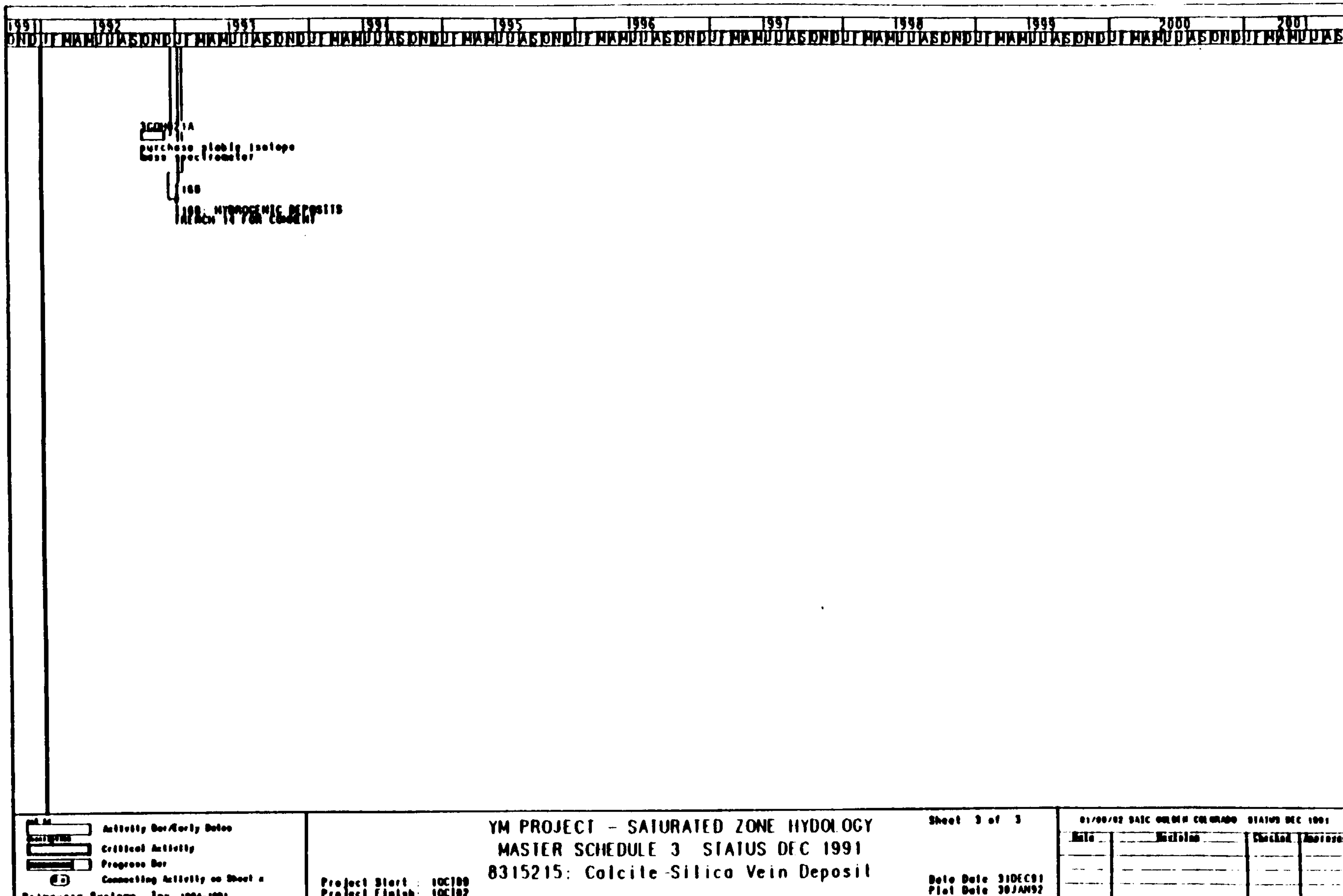

Figure 5.1-1n. Summary network for Quaternary regional hydrology study (continued).

5.2 Milestones

The milestone number, title, level, and corresponding work breakdown structure number associated with the four activities of the Quaternary regional hydrology study testing are summarized in Table 5.2-1.

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

It should be emphasized that the reliability of the scientific interpretations and conclusions in this study will increase, and the degree of uncertainty correspondingly will decrease, with increased durations of data collection and testing in the various activities.

Table 5.2-1. Milestone list for work-breakdown structure number - 1.2.3.6.2.2.1 (SCP 8.3.1.5.2.1)

Milestone Number	Milestone	Milestone Level
Regional paleoflood evaluation: 8.3.1.5.2.1.1		
G038	Study Plan (8.3.1.5.2.1) submitted to YMP	3
G039	Work authorization	3
H010	Progress report: Paleoflood studies	3
H007	Technical procedures: Paleoflood studies	4
H009	Report: QA grading	4
H013M	Reduced data on paleofloods to PDA	4
Evaluation of past-discharge areas: 8.3.1.5.2.1.3		
P937	P937: Preliminary paleo water levels in Amargosa	2
3GQH009M	Interpretive report: Faunal data	3
3GQH011M	Report: Paleo streamflow/recharge-channel geometry	3
3GQH019M	Report on origin of surface deposits	3
3GQH02AM	Interpretive report: Faunal data	
P690	P690: Final evaluation of past discharge	3
3GQH004M	Reports on wet/dry playas	4
3GQH005M	Modern spring data to PDA	4
3GQH007M	Vegetation map to PDA	4
3GQH008M	Faunal data discharge deposits to PDA	4
3GQH012M	Water chemistry data to PDA	4

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Table 5.2-1. Milestone list for study (SCP 8.3.1.5.2.1)—*Continued*

Milestone Number	Milestone	Milestone Level
3GQH020M	Modern spring data to PDA	4
3GQH021M	Faunal data modern springs to PDA	4
3GQH023M	Faunal data discharge deposits to PDA	4
3GQH025M	Water chemistry data to PDA	4
3GQH028M	Faunal data, modern springs to PDA	4
3GQH307M	Report on contents of samples	4
Analog recharge studies: 8.3.1.5.2.1.4		
Analog Recharge		
3GQ19M	Report on packrat midden data	[illegible]
G012	Data from Kawich - FY 85 to 90	3
G013	Data from Stewart Creek - FY 85 to 90	3
G014	Chloride-ion method evaluation	3
G015	Data from Kawich - FY 91	3
G016	Data from Stewart Creek - FY 91	3
G017	Precipitation-runoff model	3
G028	Report on ET analysis	3
G029	Synthesis of chloride-ion and PRMS model results	3
G030	Preliminary estimates infiltration analog sites	3
G031	Preliminary analog recharge study	3

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Table 5.2-1. Milestone list for study (SCP 8.3.1.5.2.1)--*Continued*

Milestone Number	Milestone	Milestone Level
P313	Final analog recharge study	3
3GQ12M	Hydro data remote site report FY 92	4
G027	Decision on reanalysis and new sites	4
H002	Work authorization (8.3.1.5.2.1.4)	4
Arid-zone infiltration		
3GQ010M	Progress report: Cl-36 ages of soil 1992	4
3GQ017M	Report on meteorological data FY 91-92	4
3GQ019M	Report on watershed data FY 92	4
3GQ020M	Topographic map of watersheds	4
3GQ023M	Aerial photos vegetation and soil	4
3GQ024M	Progress report: Cl-36 ages of soil 1993	4
Studies of calcite and opaline-silica vein deposits: 8.3.1.5.2.1.5		
T168	T168: Hydrogenic deposits Trench 14 for comment	2
T169	T169: Hydrogenic deposits final report	2
3GQH823M	Decision point: Deposits known origin	4
3GQH825M	Decision point on Trench 14	4
3GQH826M	Decision point: Solitario Canyon and Windy Wash	4
3GQH827M	Report: Total carbonate system YM area	4

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7 APPENDICES

7.1 Description of lithologic units exposed in Trench 14 (Activity 8.3.1.5.2.1.5)

The east end of Trench 14 is almost entirely in bedrock. The west end is almost entirely locally derived colluvium with eolian additions. Between the bedrock and the colluvium, there is a wide zone containing various breccias separated by vein fillings. Bedrock units are distinguished from breccia units because we believe that they are in place, although in some cases they are highly fractured. We have therefore separated the units into (1) bedrock, (2) fault zone, and (3) colluvium.

Color names for bedrock and breccia are from the Geological Society of America rock color chart, and color names for the colluvial units, the vein fillings, and the fracture fillings in bedrock are from the Munsell soil color chart.

There are two, and possibly three, lithologic units in the colluvium, but the colluvium has been divided into six units based on the morphology of secondary $CaCO_3$ and opaline silica and the amount of secondary clay. Lithologic units are separated on the log by a solid line; the individual units, by a dashed line.

Unless otherwise stated, colors refer to the <2 mm (<0.1 in) fraction. Textures refer to the <2 mm (<0.1 in) fraction with secondary $CaCO_3$ and organics removed.

BEDROCK UNITS

BEDROCK INTACT TIVA BEDROCK (ITB) - Tiva upper lithophysal, ~12 Ma, tuff, ash flow, pale red (5R6/2), moderately to densely welded, devitrified; pumice: sparse, very light gray (N8) to light gray (N7), flattened approximately 4:1 to 6:1; phenocrysts: 1%-2%, sanidine, plagioclase, rare biotite; lithic fragments, rare to none; abundant lithophysal cavities lined with vapor-phase minerals, botryoidal chalcedony, and drusy quartz. Lithophysae up to 10 cm (3.9 in). Small MnO_2 dendrites throughout groundmass. Intact bedrock may be fractured by cooling joints, some of which appear to have been reactivated during faulting and brecciated.

HIGHLY FRACTURED TIVA BEDROCK (HFB) - Highly fractured Tiva bedrock (described above) which does not appear to be sheared. Lithophysae are not offset, and pumice orientations are preserved across fractures. Unit contains drusy and botryoidal quartz (C9-C10). Drusy quartz is usually located in lithophysal cavities but may also be found in fractures. May contain small amounts of secondary $CaCO_3$ and opaline silica in fractures. Fracture spacing is approximately 1-10 cm (0.4 - 3.9 in), and fractures are mostly vertical, breaking the bedrock into long angular fragments. Unit grades laterally to ITB, and the upper contact may be gradational with DCB.

DENSELY CARBONATE-CEMENTED FRACTURED TIVA BEDROCK (DCB) - Tiva bedrock (described above) which has been fractured and weathered. Carbonate in fractures appears to have infiltrated with fines from surface as the bedrock weathered in place. Matrix supported with a nearly continuous $CaCO_3$ white (10YR 8/0 [dry], 10YR 8/3 [moist]) and fine-grained cement infiltrating all fractures. Matrix $CaCO_3$ is powdery with denser, smoother $CaCO_3$ coating clasts (stages II and III). Some opaline silica between rock fragments may be replacing the secondary $CaCO_3$. Fracture spacing is approximately 7-20 cm (2.8 - 7.9 in), breaking the rocks into angular to subrounded fragments. DCB tends to be above and gradational to HFB.

FAULT ZONE--BRECCIA AND VEIN FILLING

SILICA-CEMENTED FAULT BRECCIA (SFB) - Breccia has clasts of lithophysal unit described as Intact Tiva Bedrock (ITB) above, and also clasts from the lower part of the densely welded Tiva Canyon cap rock (D15). The cap rock has fewer and much more flattened lithophysae, common white and medium light gray (N6) pumice, flattened approximately 5:1; phenocrysts, approximately 20%. Clasts within breccia are angular to subrounded and matrix supported. Most clasts under 10 cm (3.9 in) seem pervasively silicified. Matrix is grayish orange (10YR 7/4) to pale yellowish brown (10YR 6/2), which is nearly the same color as the opaline SiO_2 in Unit 3 and the vein fillings.

Botryoidal quartz may occur as a coating on this breccia (D13, D16, and C10). SFB is extremely hard and breaks through clasts. Grades laterally to CB. Some areas of softer $CaCO_3$-cemented breccia may be included with SFB (B7N, D7N, A2).

CATACLASTIC BRECCIA (CB) - Color is between grayish red (10R 4/2) and grayish red-purple (5RP 4/2), also medium gray (N5) to medium dark gray (N4) on outsides of some areas which grade to light gray inside (E14, D14). Densely silicified and hard, although opaline SiO_2 is not distinguishable as a visible matrix. Few pumice or lithophysae found (center light gray portion in one area has small flattened lithophysae preserved and abundant phenocrysts [sanidine, bronze biotite], is similar to cap rock described in SFB, and has medium dark gray pumice). We think CB is a totally powdered and recemented breccia. Contains a few clasts of apparently normal Tiva Canyon. Often silicification grades from good at the edges, where it is in contact with the vein fillings, to less cemented in the center (E14, D14). CB grades laterally to and may include some SFB.

VEIN FILLING (VF) - The vein fillings consist of alternating laminae of hard white (10YR 8/0 [dry] and [moist]) $CaCO_3$, light gray to very pale brown opaline silica (10YR 7/2 [dry], 10YR 7/3 [moist]), chalky $CaCO_3$, and less-cemented, white to light gray sand (10YR 8/2 [dry], 10YR 7/2 [moist]). Unit contains <5% gravel. Dry consistency varies from extremely hard to loose. Individual laminae do not match or correspond with laminae on other side of center fracture and vary in thickness from a 0.2-10.0 cm (0.1 - 3.9 in). Contacts between $CaCO_3$ and opaline-silica stringers are abrupt. Vein fillings are also in abrupt contact with breccias except where laminae adjacent to breccia are opaline silica, and where breccia is softer. Dense opaline-silica stringers tend to be both near the center of veins and near their contacts with breccia. Unit

3 may bend downslope to merge with vein filling (bottom right B13, top right C14, upper right B7-N).

Magnetic black ash (Sarna-Wojcicki, U.S. Geological Survey, oral communication, 1984) loosely fills some fractures. Ash-lined fractures tend to be in the center of vertically oriented veins. Fractures containing ash crosscut all other laminae in the vein filling and Unit 3. Although the ash is usually contained in discrete fractures, in the upper right section of C15, the black ash is disseminated throughout a pod of ooidic $CaCO_3$ which is connected to the top of Unit 3 by a fracture surrounded by disseminated ash. The shape of the ash pod suggests that it may be a paleoanimal burrow.

COLLUVIUM

UNIT 1 (SURFICIAL A AND Bk) - Pale brown (10YR 6/3 [dry]) to dark brown (10YR 4/3 [moist]), soft, moderately sorted, sandy to very sandy silt (soil texture: loamy sand to sandy loam) with 15%-30% pebble, cobble gravel. Gravel is angular to subrounded and up to 20 cm (7.9 in). Contains a large eolian component. Vesicular (Av) at the surface grades into clay-enriched (Btk) zone with scarce secondary $CaCO_3$. The $CaCO_3$ forms thin coats on the underside of pebbles (stage I). Basal contact is abrupt and wavy. Generally nonbedded but may contain a few stone lines near base. Unit thickness is from 10 to 60 cm (3.9 in to 23.6 in).

UNIT 2 (PRISMATIC B) - Yellowish brown (10YR 5/4 [dry]) to dark yellowish brown (10YR 3/4 [moist]), slightly hard to hard sandy silt (soil texture: sandy loam), moderately sorted, <5%-10% angular to subangular pebble cobble gravel with cobbles up to 15 cm (5.9 in). Top of unit has a well-developed prismatic structure, with virtually no secondary $CaCO_3$. Basal section may contain $CaCO_3$ and opaline-silica-cemented plates that have been moved up from, and/or down slope from, Unit 3. Basal contact is abrupt and wavy. Unit thickness is from <1 to 50 cm (<0.4 to 19.7 in). Dies out at column 42. Unit 2 has been dated by the uranium-trend method as 90 + 50 ka and 38 + 10 ka (Swadley and others, 1984).

UNIT 3 (PLATY) - White (10YR 8/0-2 [dry]) to very pale brown (10YR 8/2-3 [moist]), extremely hard, silty sand to sandy silt (soil texture: loamy sand to sandy loam) with <5% gravel, gravel clasts up to 10 X 20 cm (3.9 X 7.9 in). Unit is characterized by well-developed $CaCO_3$, and opaline-silica-cemented plates (stage IV). Discrete opaline-silica stringers that form "sandwich"-like zones with the $CaCO_3$ compose up to 10% of Unit 3. Opaline silica is lighter in color here than in vein fillings--white to very pale brown (10YR 8/2). Plates vary in length from 5 to 40 cm (2.0 to 15.8 in), and in width from 3 to 10 cm (1.2 to 3.9 in). Unit 3 is also found over the main fault zone and with the fault filling (B11). Unit 3 thins, and plates decrease in size downslope with distance from the main fault (C21). Plates downslope also have an increased percentage of infiltrated fines (F45) until in some cases Unit 3 appears to be floating in the fine-grained matrix (E27). There is no evidence for animal burrowing. Opaline silica forms discrete stringers in places (C27). May contain lenses containing up to

80% white (10YR 8/0 [dry], 10/3 [moist]) ooidic $CaCO_3$ (top A4). Basal contact is abrupt and wavy. Unit thickness is from <1 to 50 cm (<0.4 to 19.7 in). Unit 3 has been dated by the uranium-trend method as 270 + 90 ka; however, dense opaline-silica stringers above the main fault have infinite uranium-series ages of >400, >350, and >550 ka (Swadley and others, 1984).

UNIT 4 (STAGE III) - white (10YR 8/0 [dry], 10YR 8/2 [moist]), extremely hard, (stage III) pebbly, silty sand to pebbly, sandy silt, <5% gravel up to 4.5 cm (1.8 in). Texture is silty sand (soil texture: loamy sand to sandy loam). Cemented by disseminated $CaCO_3$ and <5% thin stringers of opaline silica. Up to 50% of Unit 4 in places is 50% ooidic $CaCO_3$. Contains filled paleoanimal burrows (E31-E32). Basal contact is abrupt and smooth. Unit thickness is from <1 to cm (avg 40 cm). Unit 4 has been dated by the uranium-trend method as 420 + 50 and 480 + 90 ka (Swadley and others, 1984).

7.2 Quality-assurance requirements

7.2.1 Quality-assurance requirements matrix

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

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

Applicable NQA-1 criteria for Study 8.3.1.5.2.1 and how they will be satisfied

NQA-1 Criteria #	Documents addressing these requirements
1. Organization and interfaces	The organization of the OCRWM program is described in the Mission Plan (DOE/RW-005, June 1985) and further described in Section 8.6 of the SCP. Organization of the USGS-YMP is described in the following: QMP-1.01 (Organization Procedure)
2. Quality-assurance program	The Quality-Assurance Programs for the OCRWM are described in YMP-QA Plan-88-9, and OGR/83, for the Project Office and HQ, respectively. The USGS QA Program is described in the following: QMP-2.01 (Management Assessment of the YMP-USGS Quality-Assurance Program) QMP-2.02 (Personnel Qualification and Training Program) QMP-2.05 (Qualification of Audit and Surveillance Personnel) QMP-2.06 (Control of Readiness Review)

	QMP-2.07 (Development and Conduct of Training)
	Each of these QA programs contains Quality Implementing Procedures further defining the program requirements. An overall description of the QA Program for site characterization activities is described in Section 8.6 of the SCP.
3. Scientific investigation control and design	This study is a scientific investigation. The following QA implementing procedures apply:
	QMP-3.02 (USGS QA Levels Assignment [QALA])
	QMP-3.03 (Scientific and Engineering Software)
	QMP-3.04 (Technical Review of YMP-USGS Publications)
	QMP-3.05 (Work Request for NTS Contractor Services [Criteria Letter])
	QMP-3.06 (Scientific Investigation Plan)
	QMP-3.07 (Technical Review Procedure)
	QMP-3.09 (Preparation of Draft Study Plans)
	QMP-3.10 (Close-out Verification for Scientific Investigations)
	QMP-3.11 (Peer Review)
4. Administrative operations and procurement	QMP-4.01 (Procurement Document Control)
	QMP-4.02 (Acquisition of Internal Services)
5. Instructions, procedures, plans, and drawings	The activities in this study are performed according to the technical procedures listed in Section 3 of this study plan, and the QA administrative procedures referenced in this table for criterion 3.
	QMP-5.01 (Preparation of Technical Procedures)

	QMP-5.02 (Preparation and Control of Drawings and Sketches)
	QMP-5.03 (Development and Maintenance of Management Procedures)
	QMP-5.04 (Preparation and Control of the USGS QA Program Plan)
6. Document control	QMP-6.01 (Document Control);
7. Control of purchased items and services	QMP-7.01 (Supplier Evaluation, Selection and Control)
8. Identification and control of items, samples, and data	QMP-8.01 (Identification and Control of Samples) QMP-8.03 (Control of Data)
9. Control of processes	Not applicable
10. Inspection	Not applicable
11. Test control	Not applicable
12. Control of measuring and test equipment	QMP-12.01 (Instrument Calibration)
13. Handling, shipping, and storage	QMP-13.01 (Handling, Storage, and Shipping of Instruments)
14. Inspection, test, and operating status	Not applicable
15. Control of nonconforming items	QMP-15.01 (Control of Nonconforming Items)
16. Corrective action	QMP-16.01 (Control of Corrective Action Reports) QMP-16.02 (Control of Stop-Work Orders) QMP-16-03 (Trend Analysis)
17. Records management	QMP-17.01 (YMP-USGS Records Management)

		QMP-17.02 (Acceptance of Data Not Developed Under the YMP QA Plan)
18.	Audits	QMP-18.01 (Audits)
		QMP-18.02 (Surveillance)

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