YUCCA MOUNTAIN PROJECT
STUDY PLAN APPROVAL FORM

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Study Plan Number 8.3.1.2.1.3

Study Plan Title Characterization of the Yucca Mountain Regional Ground-Water Flow System

Revision Number 0

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Director, Regulatory and Site Evaluation Division / Date

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ABSTRACT

This study plan describes four activities to be performed in the Yucca Mountain region as part of the Geohydrology Program. The objectives of these activities are to further refine key hydrologic variables of the regional ground-water flow system, and to obtain hydrologic, hydrochemical, and geophysical data to support models of saturated-zone ground-water flow. These models will be used to evaluate the magnitude and direction of regional saturated-zone flow. The activities include:

- Assessment of the regional hydrogeologic data needs in the saturated zone;
- Regional potentiometric-level distribution and hydrogeologic framework studies;
- Fortymile Wash recharge study; and
- Evapotranspiration studies.

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

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, this study is designed to collect and evaluate the data required to assess the performance of the Yucca Mountain Site with respect to 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 regional ground-water flow system surrounding and including Yucca Mountain. The study is organized into four activities:

- 8.3.1.2.1.3.1 - Assessment of the regional hydrogeologic data needs in the saturated zone,
- 8.3.1.2.1.3.2 - Regional potentiometric-level studies
- 8.3.1.2.1.3.3 - Fortymile Wash recharge study, and
- 8.3.1.2.1.3.4 - Evapotranspiration studies.

Note that the numbers (e.g., 8.3.1.2.1.3.1) used throughout this plan serve as references to specific sections of the YMP Site Characterization Plan (SCP). The SCP (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 relation of this study to the SCP geohydrology program. This study is one of four planned to characterize the regional hydrology. 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 plans for each activity are presented in Section 3. The descriptions include (a) objectives and parameters, (b) technical rationale, and (c) tests and analyses. Alternate test and analysis methods are summarized, and cross references are provided for 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, and a study-plan reference list is presented in Section 6.

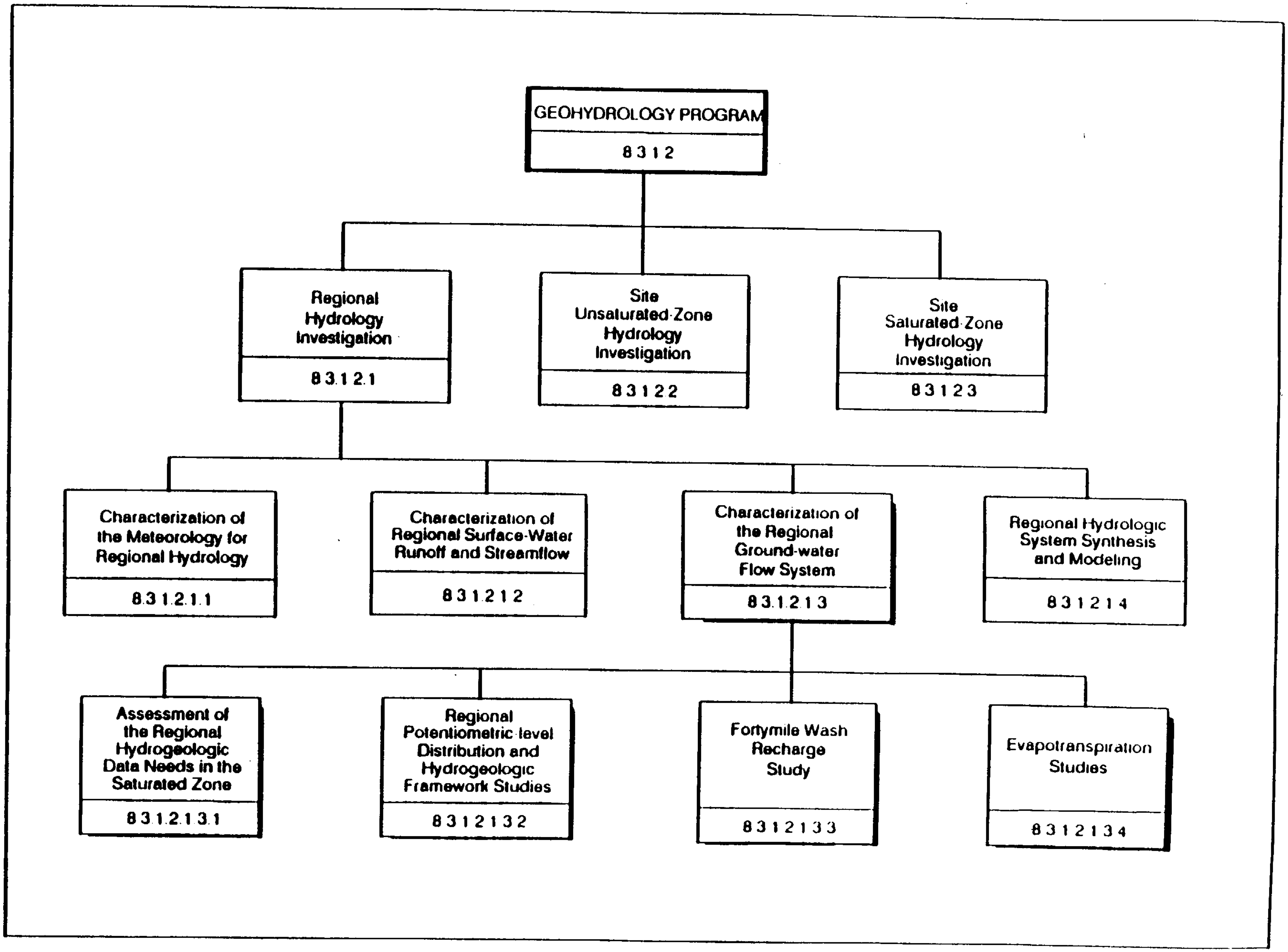


Figure 1.1-1. Diagram showing the location of study within the regional hydrology investigation and ganization of the geohydrologic characterizatior ogram.

1.2 Objectives of study

The objectives of this study are: (1) to further refine key hydrologic variables of the regional ground-water flow system which will allow for differentiation between current representations of the ground-water flow system and alternative conceptual models; and (2) to obtain hydrologic, hydrochemical, and geophysical data to support models of ground-water flow to determine the magnitude and direction of ground-water flow.

Aquifer properties have been measured in many deep drillholes on the Nevada Test Site (Winograd and Thordarson, 1975). Many uncertainties remain, limiting the accuracy available for site-specific applications. The hydraulic properties of the hydrogeologic units vary greatly within the groundwater basin. These units include tuffaceous, carbonate, and alluvial aquifers as well as clastic and crystalline aquitards. The aquitards act as major barriers to groundwater flow and have a major impact on regional groundwater flow direction and magnitude. In addition, faults within the groundwater basin may act either as barriers or conduits to groundwater flow and may explain anomalously large gradients found in certain locations. Figure 1.2-1 is a map showing the locations of the regional, subregional, and site ground-water flow systems. Figure 1.2-2 is a location map of the ground-water subbasin that is the focus of this study, and shows the lines of section for Figures 1.2-3 and 1.2-4, hydrogeologic cross sections through the subbasin (Czarnecki, 1989). Figure 1.2-5 is an isopach map of alluvium thickness in the Amargosa Desert, Fortymile Wash, and Ash Meadows (Oatfield and Czarnecki, 1988).

A major assumption in the conceptual model of the regional and subregional ground-water flow systems (Figure 1.2-1) is that ground-water flow from the valley-fill aquifer beneath the Amargosa Desert splits to two principal discharge areas, with some ground water flowing west beneath the Funeral Mountains toward the spring discharge area near Furnace Creek Ranch in Death Valley. The remaining water flows south toward the discharge area at Franklin Lake playa. Figure 1.2-6 is a map of the subregional potentiometric surface, from which ground-water flow directions can be inferred. An alternate explanation may be that ground water flows south toward Franklin Lake playa through an upper, valley-fill, flow system, and west through a separate, lower flow system. If this is the case, one might expect the potentiometric and hydrochemical data to differ between the two systems, reflecting different sources of recharge. Resolution of this uncertainty has been limited, in part, by the lack of deep potentiometric data (greater than 600 meters) and is significant for adequately estimating groundwater mass balances in models of regional and subregional ground-water flow. Additional resolution may be provided by analyzing hydrochemistry of samples from the deep and shallow flow systems.

To characterize the regional ground-water flow system (Figure 1.2-1), sufficient data are required to adequately describe: (1) the regional potentiometric surface; (2) the regional distribution of hydraulic head with depth; (3) the regional distribution (both areally and vertically) of hydraulic properties (transmissivity, hydraulic conductivity, degree of anisotropy, and storage coefficient) of hydrologic units; (4) the distribution and rates of ground-water recharge and discharge; and (5) the distribution of

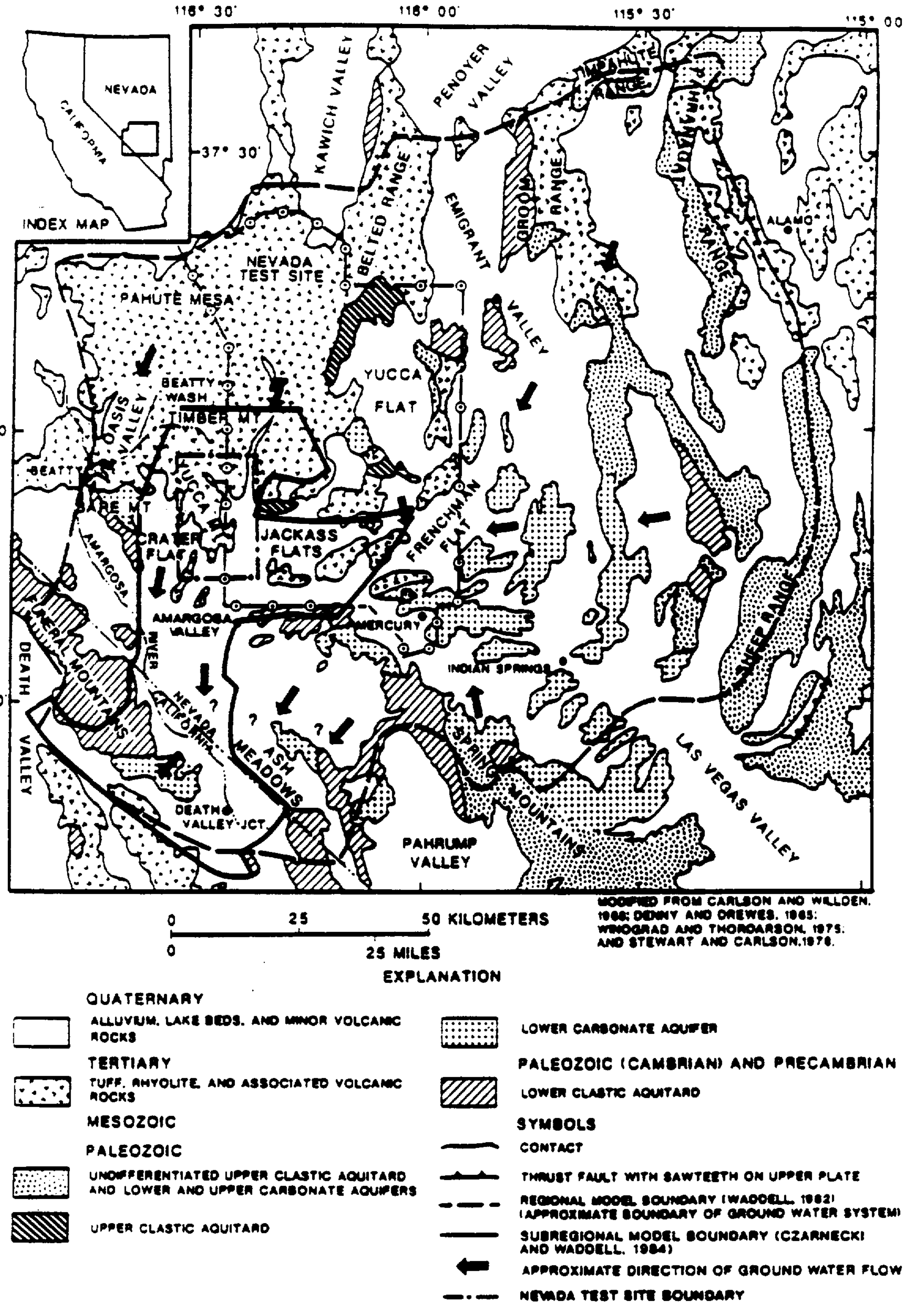


Figure 1.2-1. Location of the regional, subregional, and site ground-water flow systems.

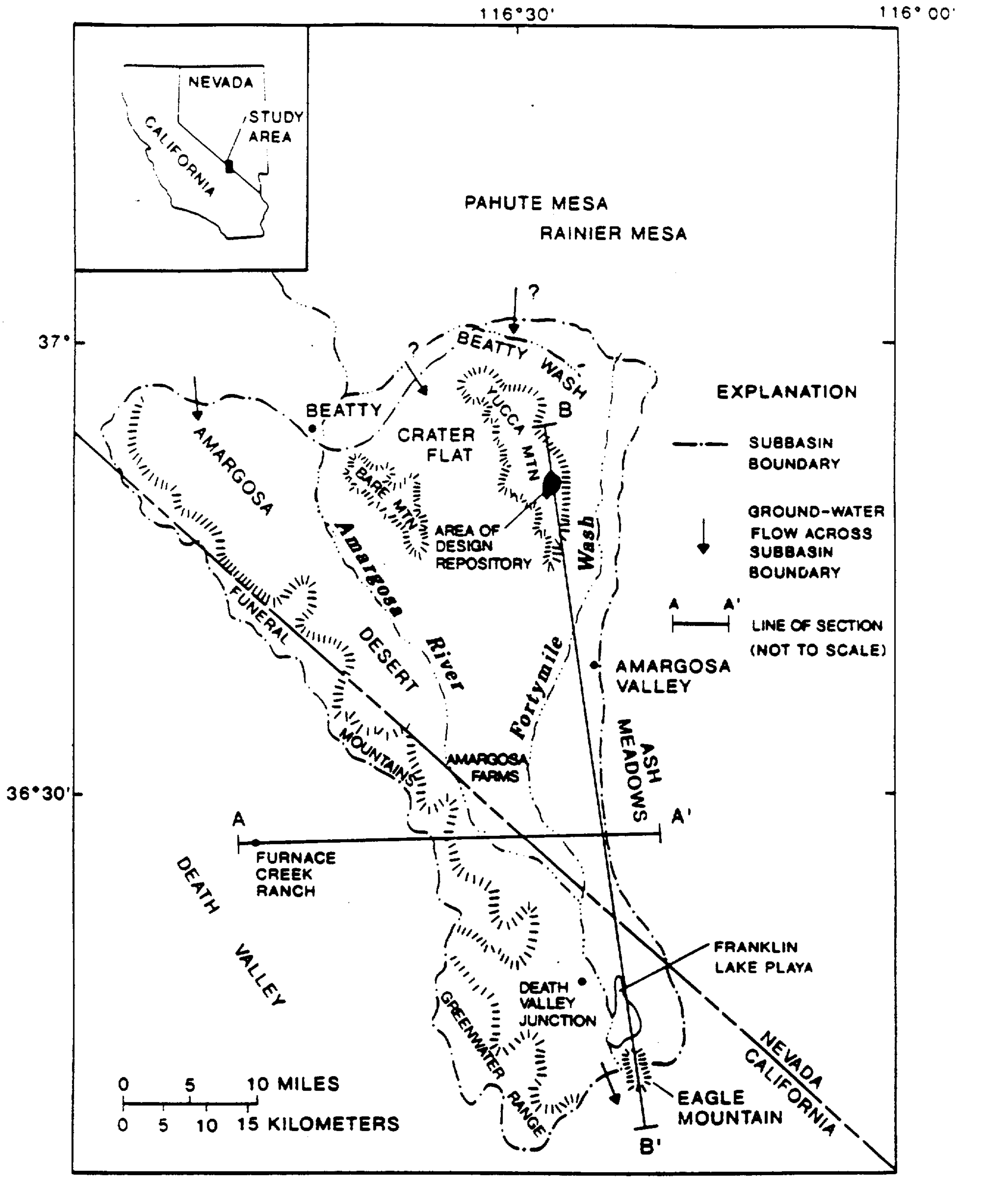


Figure 1.2-2. Location map of ground-water subbasin.

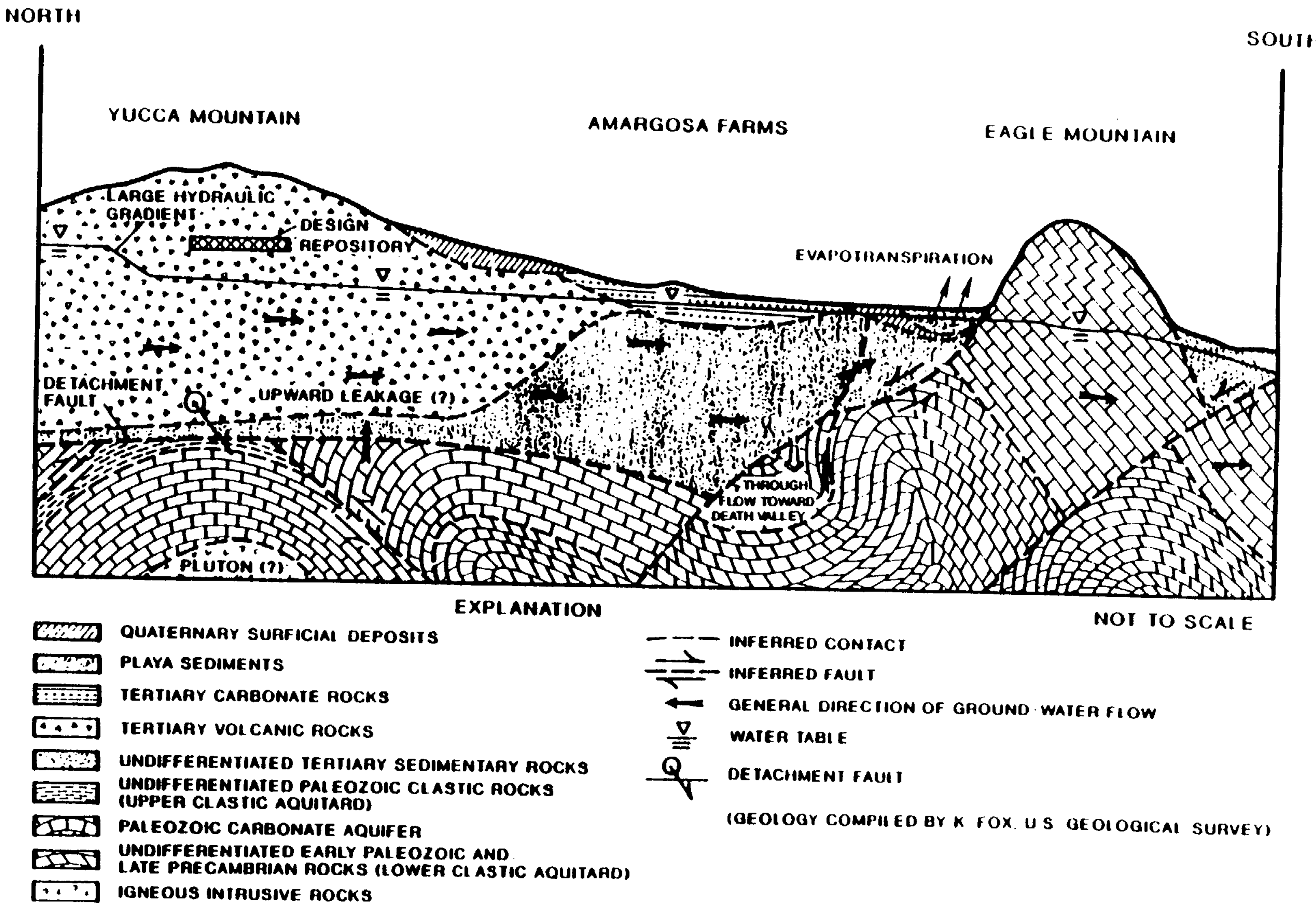


Figure 1.2-3. North-south diagramatic cross section through subregional flow system.

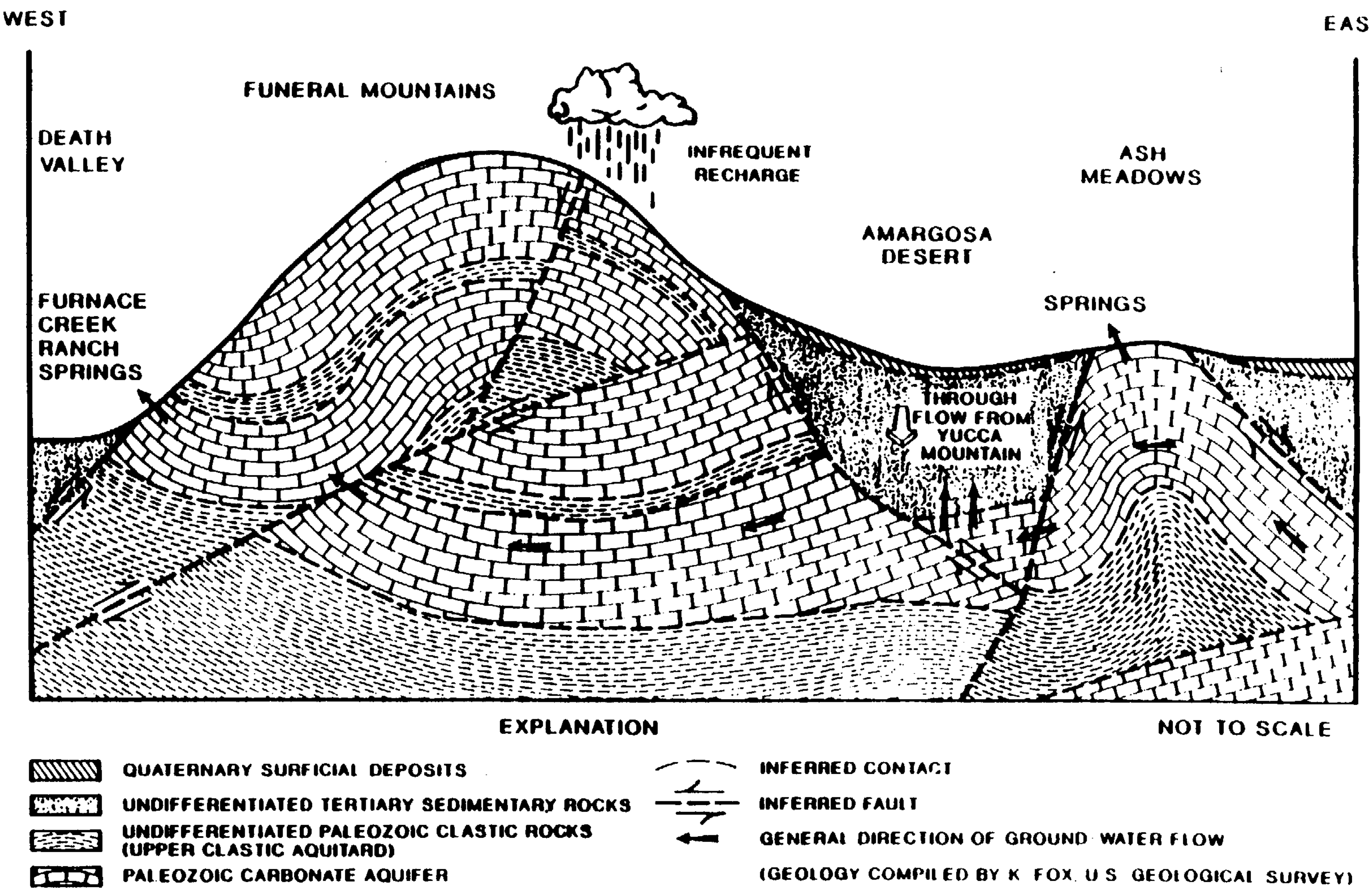


Figure 1.2-4. West-east diagrammatic cross section through subregional flow system

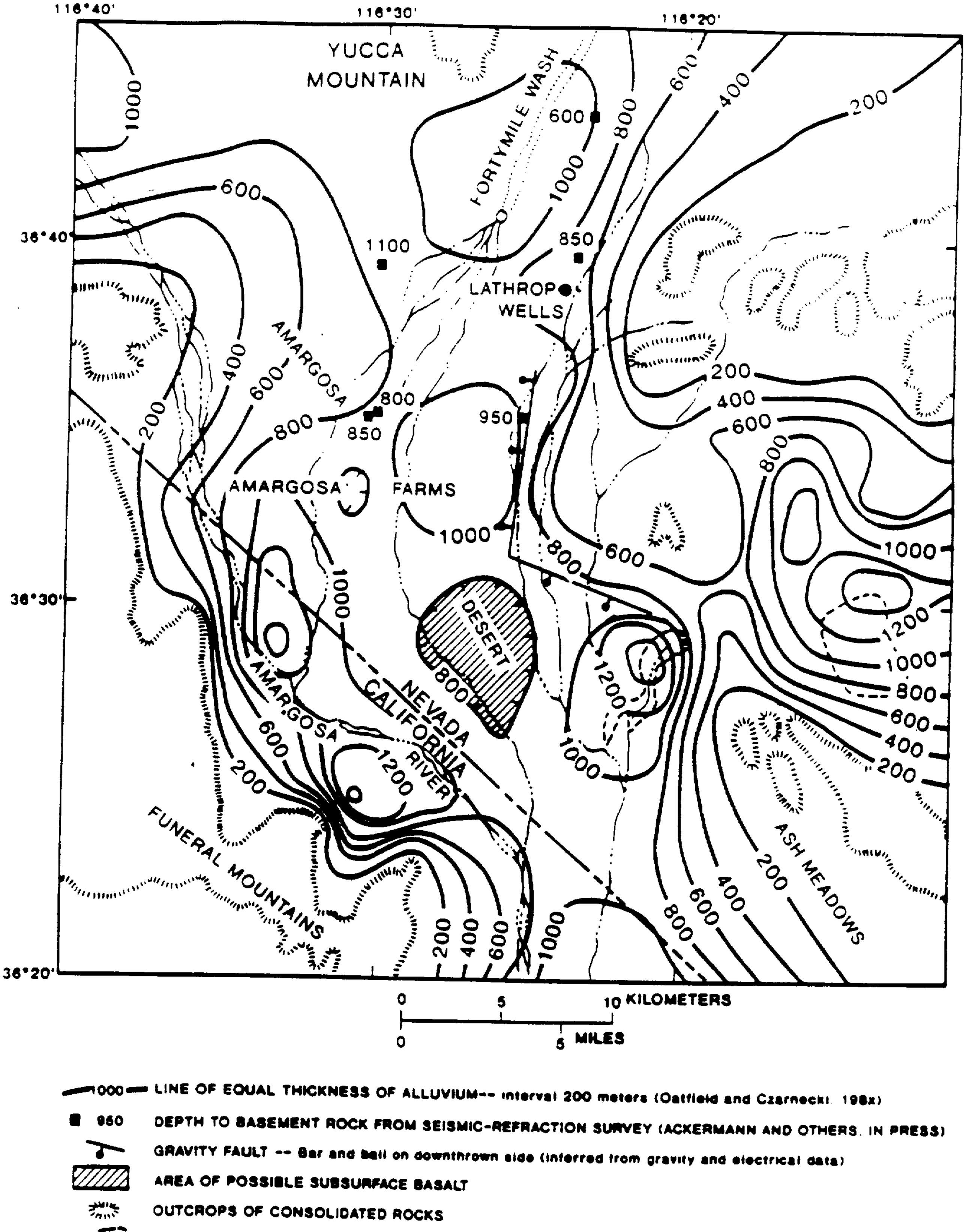


Figure 1.2-5. Alluvial thickness from vertical electric sounding resistivity surveying. (after Oatfield and Czarnecki, 1988)

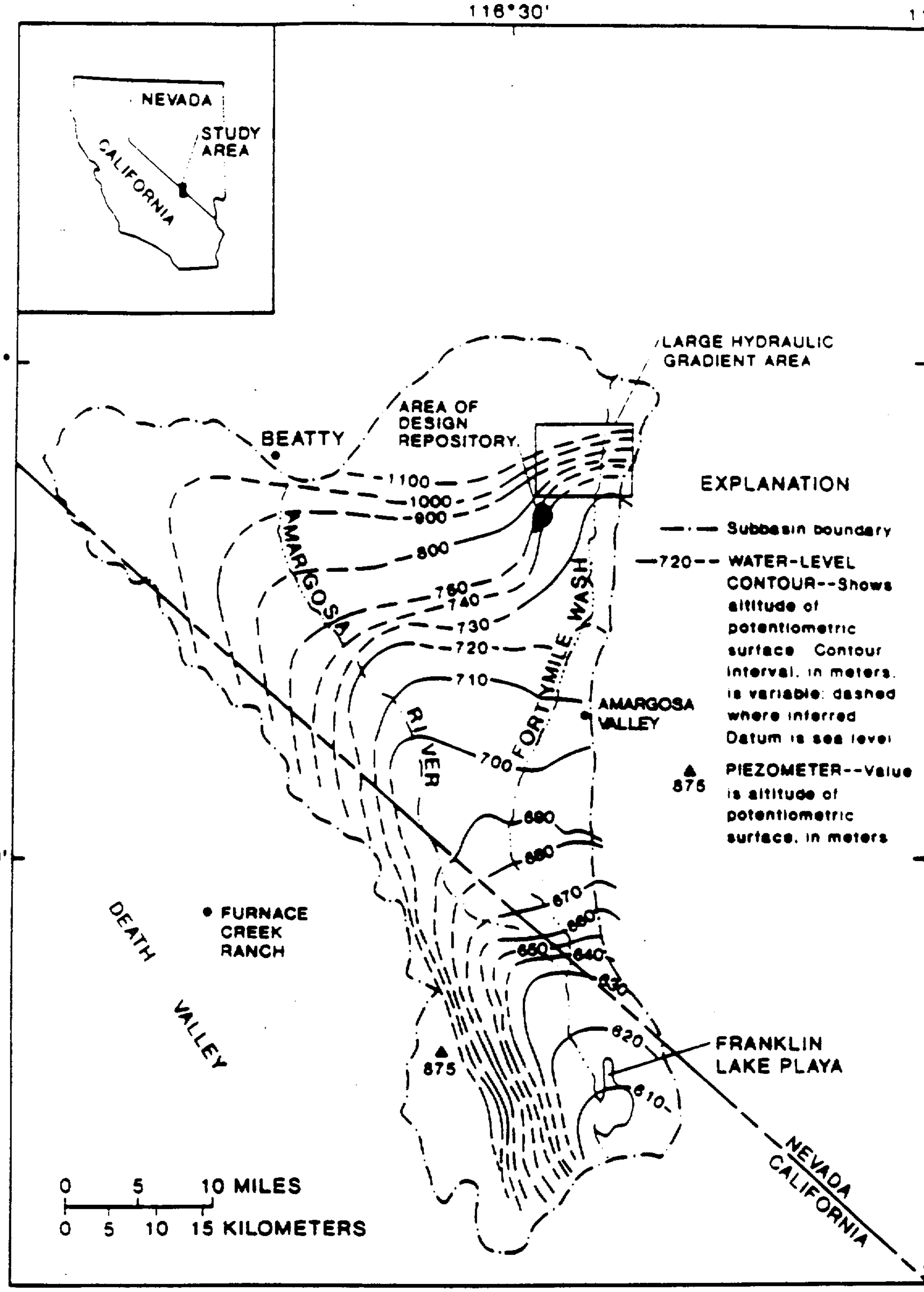


Figure 1.2-6. Subregional potentiometric surface (Czarnecki, 1989).

ground-water flow rates and velocities. Ground-water flow models of this area have, in the past, used data items 1 and 2 to estimate items 3 through 5. Improvements in any one of these variables will improve the overall characterization of the regional hydrogeology. However, only the potentiometric surface and the distribution of hydraulic head with depth can be directly measured at points with relative ease.

The description of the regional hydrologic system is based on constructing a consistent regional model (Figure 1.2-1) of groundwater flow, so that reliable boundary conditions can be assigned to the more critical site area embedded within the regional flow system. To do so, fluxes and hydraulic heads at boundaries of the regional system are required, as well as regional transmissivities.

Regional groundwater modeling to date has included regional heterogeneities of various hydrogeologic units, and, according to a USGS report (Czarnecki and Waddell, 1984), has acceptably represented the groundwater flow system under specified assumptions. Major assumptions inherent in regional models pertain to the location and magnitude of recharge and discharge boundary conditions and regional transmissivities. Recharge estimates across model boundaries are often crude resulting from lack of sufficient hydraulic gradient and transmissivity data. Regional ground-water modeling is described in detail in YMP-USGS SP 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling).

1.3 Regulatory rationale and justification

The information collected in the regional ground-water flow study, both saturated- and unsaturated-zone data, will apply primarily to two performance issues: Issue 1.6 (Ground-water travel time) and Issue 1.1 (Total system performance). Surface-water and unsaturated-zone data collected in the support of evaluating the regional saturated-zone ground-water flow system have secondary applications to several design issues: Issue 1.11 (Configuration of underground facilities), Issue 4.4 (Adequacy of repository construction, operation, closure, and decommissioning), Issue 1.12 (Characteristics and configurations of shaft and borehole seals), Issue 2.1 (Radiation dose allowable to public), Issue 2.2 (Radiological safety of workers), Issue 2.3 (Radiological exposures from credible accidents), and Issue 2.7 (Adequacy of repository characteristics and configurations for regulatory requirements). This discussion will emphasize the contributions of the present study to the ground-water travel-time and total system performance issues.

The overall regulatory-technical relations between the SCP design and performance-assessment issues and the data collected in this study are presented in the geohydrology testing strategy presented in SCP Section 8.3.1.2 (Table 8.3.1.2-1) and the issue-resolution strategies presented in SCP Sections 8.3.2 through 8.3.5. The description presented below provides a more specific identification of these relations as they apply to this study. A detailed tabulation of parameter relations is presented in Appendix 7.2 (Table 7.2-1).

In this and other study plans, it has been useful to group the measured parameters of the various activities (activity parameters) into a limited set of site-characterization parameters, broader categories of information that encompass activity parameter data collected in the field and laboratory, or generated by modeling. By introducing this category, it becomes easier to demonstrate how the study relates to satisfying the information requirements of parameters in the design and performance issues. This demonstration is made in Table 7.2-1 in Appendix 7.2. In the case of the regional ground-water flow system study, the activity parameters (presented in the figures and tables of Sections 3.2, 3.3, and 3.4) can be grouped under a set of site-characterization parameters as shown below:

Activity 8.3.1.2.1.3.2 -Regional potentiometric-level distribution and hydrogeologic framework studies	Hydraulic head Hydraulic conductivity Storage coefficient Hydraulic gradient, regional Ground-water flow directions Hydrogeologic unit contacts Hydraulic conductivity of barriers and structures Flow-system geometry
Activity 8.3.1.2.1.3.3 - Fortymile Wash recharge study	Recharge, distribution and magnitude

Activity 8.3.1.2.1.3.4 - Evapotranspiration studies	Evapotranspiration, distribution and magnitude

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

Project-organization interfaces between the regional ground-water flow system study (8.3.1.2.1.3) and the YMP design and performance issues are illustrated in Figure 1.3-1. The figure also indicates project interfaces with other site studies; the latter relations are described further in Section 4.2. The relations between the design and performance issues noted below and the regulatory requirements of 10 CFR 60 and 10 CFR 960 are described in Section 8.2.1 of the SCP.

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

One of the requirements for resolving Issue 1.6 is the confirmation and refinement of conceptual models of flow through the saturated zone at the Yucca Mountain site.

The present study is an indispensable data collection and analysis exercise that will serve as the groundwork for the modeling of saturated-zone flow described in YMP-USGS SP 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling study). The hydrogeologic data gathered in the regional ground-water flow system study will be employed in the regional modeling study, and the results of the modeling study will be coordinated with the saturated-zone flow analysis in Issue 1.6, one of whose objectives is to determine which sets of hydrologic flow paths in the saturated zone will be used in ground-water travel-time calculations.

The data collected in the present study are not intended for direct use in the estimation of ground-water travel time. The data will be used in the development of regional saturated-zone models in Study 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling), models which will be used in specifying boundary conditions for site saturated-zone modeling of Study 8.3.1.2.3.3 (Site saturated-zone synthesis and modeling). The site saturated-zone modeling, supported by hydrologic data collected under the scope of Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system) and modeling results from Study 8.3.1.2.1.4, will be the main Geohydrology Program contributor to the performance assessment modeling for the calculation of ground-water travel-times.

In SCP Table 8.3.5.12-2, a required ground-water travel-time has been established at 1,000 years, and values for goals for the performance parameters of hydraulic gradient (dh/dl), saturated hydraulic conductivity (K_s), and flow-path distance (d) have been calculated. If these goal values are realized, the goals would establish a bounding basis for concluding with reasonable confidence that travel time in the saturated zone will exceed 1,000 years.

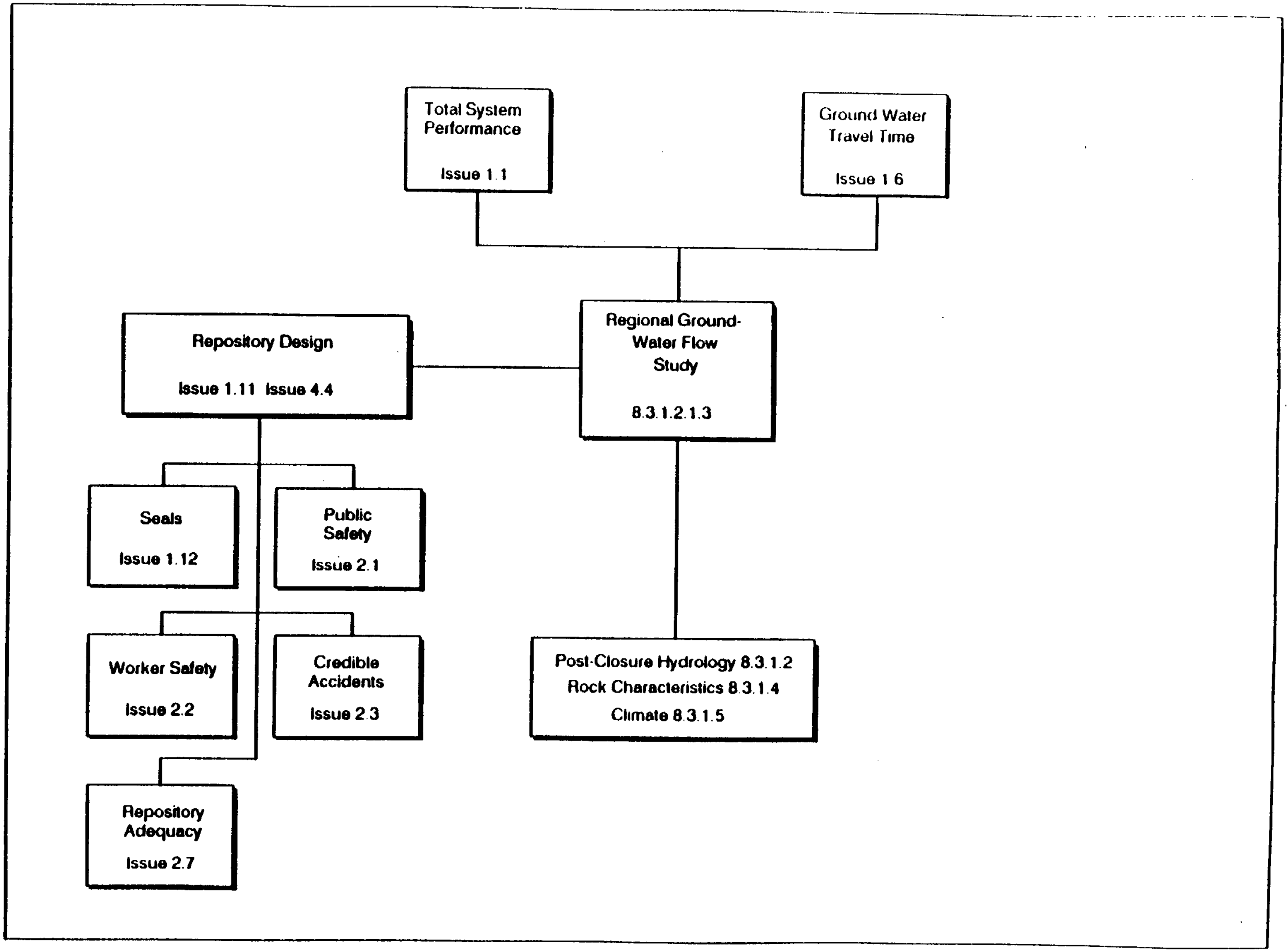


Figure 1.3-1. Diagram showing interfaces of regional ground-water flow study with YMP performance and design issues and other site-characterization programs.

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

Issue 1.6 thus contains two categories of parameters: (1) the performance parameters identified for establishing bounds on the travel time for comparison to goals and (2) the supporting performance parameters identified for developing a probabilistic performance measure expressed as a cumulative distribution function of travel time. The relations of site-characterization parameters from the study to Issue 1.6 performance and supporting performance parameters are shown in Table 7.2-1. Some of the values for the supporting parameters (e.g. hydraulic head) will be provided by direct measurement in the field as part of the present study. Other values will result from the calibration exercises for regional and subregional models in Study 8.3.1.2.1.4.

In Information Need 1.6.1 (Site information and design concepts needed to identify the fastest path of likely radionuclide travel and to calculate the ground-water travel time along that path), the present study contributes pre-waste-emplacement site data in the categories of system geometry, material property values, and initial and boundary conditions.

The regional saturated-zone modeling activities in Study 8.3.1.2.1.4 will use data collected in the present study, and use it in ground-water flow direction and magnitude calculations that are part of the resolution of Issue 1.6. (The process of data reduction through modeling is described in Section 3 of YMP-USGS SP 8.3.1.2.1.4, Regional hydrologic system synthesis and modeling.) The site data collected in the present study include some of the supporting parameters listed in Table 7.2-1 and SCP Table 8.3.5.12-3, thus providing specific input for the solution of the general equations of ground-water travel time in Issue 1.6.

In Information Need 1.6.3 (Identification of the paths of likely radionuclide travel from the disturbed zone to the accessible environment and identification of the fastest path), the present study contributes to the information need by its support of the regional hydrologic model, which provides boundary conditions for the site hydrologic model (described in YMP-USGS SP 8.3.1.2.3.3) that will be employed to identify possible ground-water flow paths.

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

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

Scenario Class E, also called the nominal case, describes the undisturbed performance of the repository; it takes into account the legitimate, distinguishable alternative conceptual models (including those for site saturated-zone flow) that are supported by the available information. This class is associated with anticipated or expected conditions, and it describes the predicted behavior of the repository and the uncertainties in predicted behavior, considering only likely natural events. Disruptive scenario classes (disturbed cases) are also developed in Issue 1.1. These classes are considered sufficiently credible to warrant consideration, but are outside the range of probability considered for the nominal case.

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

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

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

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

In Information Need 1.1.3 (Analytical models for predicting releases to the accessible environment attending realizations of the potentially significant release-scenario classes), the same rock-hydrologic properties are needed from the study as are required to resolve Issue 1.6 (see Table 7.2-1).

Performance Issue 2.1
(Public radiological exposures - normal conditions)

The present study may have a peripheral contribution to the resolution of Issue 2.1, insomuch as original atmospheric and precipitation data are collected as part of the Fortymile Wash recharge study (Activity 8.3.1.2.1.3.3) or the evapotranspiration studies (Activity 8.3.1.2.1.3.4). These meteorological data could be used to help satisfy performance parameter requirements for estimating radionuclides concentrations in environmental media and individual doses at the land surface resulting from repository operation.

Performance Issue 2.2
(Worker radiological safety - normal conditions)

The present study may have a peripheral contribution to the resolution of Issue 2.2, also from meteorological data collected in the Fortymile Wash recharge study and the evapotranspiration studies. These data could be used to help satisfy performance parameter requirements for evaluating the transport characteristics of the atmosphere within the site boundaries, and estimating doses resulting from airborne radionuclide concentrations around the repository facilities.

Performance Issue 2.3
(Accidental radiological releases)

The present study may have a peripheral contribution to the resolution of Issue 2.3, also from the meteorological data collected in the Fortymile Wash recharge study and the evapotranspiration studies. These data could be used to help satisfy performance parameter requirements for evaluating the quick-acting dispersion and transport characteristics of the site, and the consequences of credible off-site accidents that could effect the repository and essential workers.

Design Issue 1.11
(Configuration of underground facilities - postclosure)

The present study will contribute to the resolution of Issue 1.11 by providing geologic and hydrogeologic data to support the design parameters of hydrogeologic unit contacts and water table elevations. These parameters will be used to evaluate the available useable area of the repository.

Design Issue 2.7
(Repository design criteria for radiological safety)

The present study may have a peripheral contribution to the resolution of Issue 2.7, also from the meteorological data collected in the Fortymile Wash recharge study and the evapotranspiration studies. These data could be used to help satisfy design parameter requirements for evaluating the ability to control radioactive materials in repository effluent streams.

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

The present study will contribute to the resolution of Issue 4.4 by supporting design parameters in several areas. Insomuch as original atmospheric and precipitation data are collected in the Fortymile Wash recharge study and evapotranspiration studies, these data can support the evaluation of the adequacy of facilities to withstand natural weather phenomena without damage to functional capability. Surface-water data collected as part of the Fortymile Wash recharge study can support the evaluation of surface facilities relative to floodplain location, and the evaluation for suitable soil conditions and erosion potential. Hydrogeologic unit contacts delineated in the potentiometric-levels activity (8.3.1.2.1.3.2) can support the evaluation of adequacy of host-rock thickness for drift construction and waste emplacement, adequacy of drift sizes and slopes, and compatibility of drifts with repository sealing. Water-table elevation data collected in the same activity can support the evaluation of shaft and ramp compatibility with repository sealing.

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

The present study will contribute to the resolution of Issue 1.12 in the evaluation of the various functions of the shaft and borehole seals. The study will provide data on alluvium thickness to support the design parameters of thickness of alluvium and morphology of the bedrock surface, surface-water hydrologic data to support the design parameter of quantity of water due to surface flooding events, meteorological data to support the design parameter of temperature variations at the ground surface, and hydrogeologic unit contact data to support the design parameter of unit contacts in exploratory boreholes.

2 RATIONALE FOR STUDY

2.1 Technical rationale and justification

2.1.1 Statement of problem and test justification

The problem to be addressed in the geohydrology program is the assembling of a complete and accurate representation of the hydrologic system at Yucca Mountain and vicinity. This representation must reflect an understanding of hydrologic processes, initial and boundary conditions, and their interrelations. The characterization of Yucca Mountain hydrology will then be combined with the results of other site programs to produce a complete description of the site.

Data collection and interpretation in the geohydrology program consists of work in two distinct hydrologic regimes: the unsaturated zone and the saturated zone. The culmination of the investigations in each of these regimes will be hydrologic models that describe their behavior. Because the surface-water flow regime impacts each of these zones, a surface-water model will be developed that will contribute to each of the saturated- and unsaturated-zone models. Figure 2.1-1 is a logic diagram of the saturated-zone hydrologic model resulting for the geohydrology program.

Because the saturated zone beneath the repository site is the final flow path for ground-water flow and radionuclide transport to the accessible environment, the evaluation of the regional saturated-zone flow system is of great importance to the geohydrology program and to the Yucca Mountain Project. The present study is the main contributor of measured hydrologic data to this evaluation. An accurate representation of the regional hydrology is indispensable to the understanding of present and past conditions, and will serve as the basis for assessing the effects of possible future climatic and tectonic changes on saturated-zone flow.

Site characterization of the ground-water system within the saturated zone focuses on determining the boundary conditions imposed by geologic structure, recharge, and discharge; hydraulic gradients in three dimensions; and aquifer properties of hydrostratigraphic units. In Investigation 8.3.1.2.1, studies have been developed to characterize the regional meteorology, surface-water runoff, and regional ground-water flow system (present study). The resulting description of the boundary conditions, hydraulic gradients, and aquifer properties will form the basis for synthesis and modeling activities that will conclude with calculations (in Study 8.3.1.2.1.4) of flow paths, fluxes, and velocities within the saturated zone, and will become a component of the evaluation of future climate effects on hydrology.

The four activities of this study are necessary because they provide the basic hydrologic data needed for the construction and refinement of a regional saturated-zone model (described in YMP-USGS SP 8.3.1.2.1.4). The assessment of regional hydrogeologic data needs (Activity 8.3.1.2.1.3.1) is necessary to define what additional hydrologic data is required to reduce uncertainties in model results to levels compatible with the goals

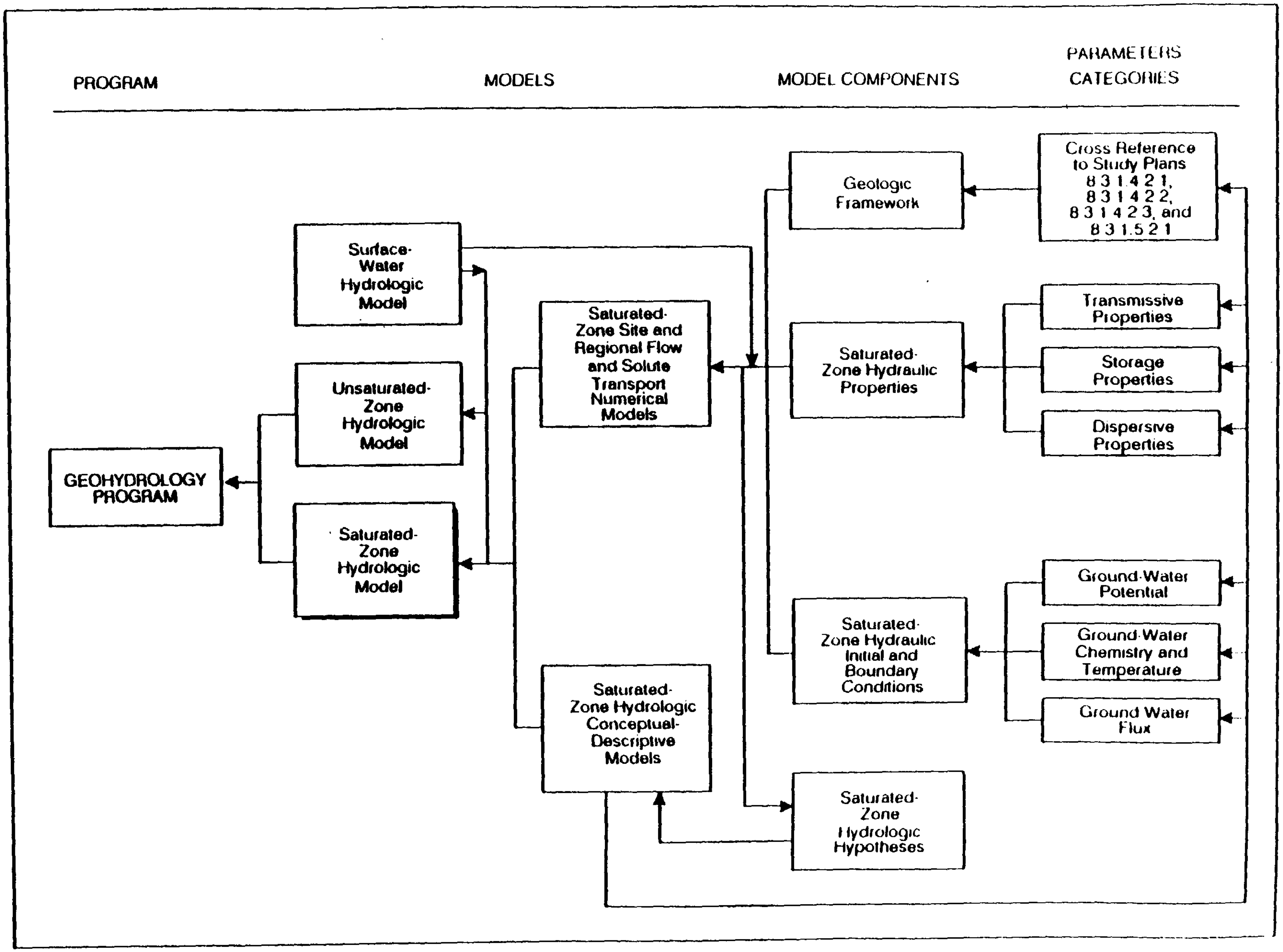


Figure 2.1-1. Logic diagram of the saturated-zone hydrology component of the geohydrology program

of the YMP. The regional potentiometric-level distribution and hydrogeologic framework studies (Activity 8.3.1.2.1.3.2) are necessary to improve the representation of spatial and temporal distribution of potentiometric levels, hydraulic properties, and boundaries in order to refine the conceptual model of the regional ground-water flow system. The Fortymile Wash recharge study (Activity 8.3.1.2.1.3.3) is necessary to evaluate the hypothesis that Fortymile Wash is now or has been a source of recharge to the regional ground-water system, and its importance as a component of the conceptual model. Results from this activity will be supplemented by investigations of recharge rates at Yucca Mountain in Studies 8.3.1.2.2.1 (Unsaturated-zone infiltration) and 8.3.1.2.2.3 (Unsaturated-zone percolation - surface-based study), and at other recharge areas in Study 8.3.1.5.2.1 (Quaternary regional hydrology). The evapotranspiration studies (Activity 8.3.1.2.1.3.4) are necessary in order to evaluate the distribution and rate of ground-water discharge in the subregional flow system.

2.1.2 Parameters and testing strategies

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

In SCP Table 8.3.1.2-1, activity parameters for the geohydrology program are grouped according to parameter categories, which also appear in Table 2.1-1. The parameters associated with each activity in that table also appear in Tables 3.2-1, 3.3-1, and 3.4-1 of Section 3. Parameter categories serve to group similar types of performance and design parameters supporting design and performance-assessment issues resolutions (SCP Sections 8.3.2-8.3.5) and match them with groups of similar types of activity parameters to be obtained during site characterization. Parameter categories in the SCP were introduced as a classification scheme to aid in assessing the appropriateness and completeness of the data collection program. In Figure 2.1-1, the categories are shown supporting specific model components that make up the saturated-zone model. This figure corresponds to SCP Figure 8.3.1.2-4, and in that document is accompanied by parallel logic diagrams for the surface-water and unsaturated-zone components of the geohydrology program.

Table 2.1-1 groups the activity parameters of the study according to characterization parameters. In SCP usage, a characterization parameter is a parameter obtained by a characterization program that has a logical, direct tie to a performance or design parameter, and for which a testing basis can be defined. Most characterization parameters will be developed from some combination of activity parameters, and will be the products of data reduction, test analyses, and modeling. Some of the activity parameters listed in Table 2.1-1, although not required directly for

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
Regional potentiometric-level distribution and hydrogeologic framework studies (8.3.1.2.1.3.2)	Hydraulic head	Hydraulic head
	Hydraulic conductivity	Effective saturated thickness
		Permeability
		Transmissivity
		Hydraulic conductivity
	Storage coefficient	Storage coefficient
		Porosity
	Hydraulic gradient, regional	Temperature, hydrogeologic units
		Thermal conductivity
		Heat flow
	Ground-water flow directions	Chemistry, ground water
	Hydrogeologic unit contacts	Stratigraphic contacts, hydrogeologic units
		Lithologies, hydrogeologic units
		Density
	Hydraulic conductivity of barriers and structures	Hydraulic conductivity

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
	Flow-system geometry	Stratigraphic content, hydrogeologic units
Fortymile Wash Recharge Studies (8.3.1.2.1.3.3)	Recharge, distribution and magnitude	Streamflow parameters measured in Activity 8.3.1.2.1.2.1
		Water chemistry, Fortymile Wash runoff
		Recurrence intervals, runoff events
		Recurrence intervals, potential recharge events
		Meteorological parameters from Study 8.3.1.2.1.1 and Activity 8.3.1.2.1.2.1
		Water chemistry, precipitation
		Evapotranspiration values, Yucca Mountain, from Studies 8.3.1.2.2.1 and 8.3.1.2.1.1
		Drainage area, basin
		Elevation, basin
		Slope, basin
		Aspect, basin
		Channel morphology

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
		Surficial and vegetative cover, basin
		Soil moisture
		Matric potential
		Porosity
		Mineralogy
		Grain-size distribution
		Surficial deposits, distribution and characteristics
		Depositional environment
		Temperature, hydrogeologic units
		Hydraulic conductivity, unsaturated zone
		Air permeability, unsaturated zone
		Chemistry, pore water, unsaturated zone
		Isotope chemistry, channel fill and bedrock
		Radiometric ages, groundwater beneath Fortymile Wash

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
		Recharge rate, Fortymile Wash
		Chemistry, unsaturated-zone gases
		Hydraulic head
		Water chemistry, saturated zone
		Recharge, magnitude, Fortymile Wash
		Recharge, distribution, Fortymile Wash
		Precipitation/runoff relations, from Activity 8.3.1.2.1.2.1
		Runoff, duration
		Runoff quantities
Evapotranspiration studies (8.3.1.2.1.3.4)	Evapotranspiration, distribution and magnitude	Net radiation
		Soil-heat flux
		Soil temperature
		Soil composition
		Vapor pressure
		Air temperature

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

Activity	Site-Characterization Parameter	Activity Parameters Associated with Site-Characterization Parameter
		Windspeed
		Soil density
		Resistance to heat flow
		Vertical Windspeed
		Vapor density
		Evaporation
		Stomatal resistance
		Hydraulic head, spatial distribution
		Depth to saturation

(Note: The parameter "fracture and matrix porosity" appears in the SCP parameters list for Activity 8.3.1.2.1.3.1, and the parameters "lineaments" and "fractures" appear in the SCP parameters list for Activity 8.3.1.2.1.3.2; these have not been included in this table. The role of fracture networks in site saturated-zone hydrology will be addressed in Study 8.3.1.2.3.1.)

resolving performance and design issues, are required to accomplish satisfactory hydrologic modeling, which in turn increases confidence in the accuracy of the characterization parameters that are required for performance and design analyses. Hydrologic data collected in this study can be traced from activity parameters through characterization parameters and to its intended use in satisfying performance and design-parameter requirements for issues resolutions. This last step is addressed by Table 7.2-1.

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

In addition to supporting design and performance parameters, the activity parameters listed in Table 2.1-1 and Section 3 are needed to test hypotheses that support conceptual models, and also as input to numerical models (especially those of Study 8.3.1.2.1.4). A sufficient level of confidence in parameter values must exist for the data to be employed for either of these purposes. The approaches to data collection selected for the present study have been chosen to minimize uncertainty in parameter values and in the understanding of parameter interrelations, within the constraints of available resources. Where possible, multiple approaches within an activity are directed toward evaluating the value of a parameter by different means. The combined effect of using multiple approaches (or tests) will be to increase the level of confidence in the parameter, because reliance will not be placed exclusively in one approach. Within a particular activity, some approaches may provide only partial information, while others will provide extensive information necessary for determination of a hydrologic parameter. By combining the test results and studying their relations, a greater understanding and confidence of any particular parameter can be achieved.

Because of the nonstandard nature of some of the tests, the possibility that one or more tests may fail in achieving the desired objectives is recognized. The use of multiple approaches for determining parameters increases confidence that the failure or the partial failure of one or more tests will not severely inhibit the ability of the characterization activities in providing the required information. The investigators will retain the option to exercise scientific judgement in the development of the testing program as the study evolves, remaining flexible in the selection of alternate tests and methods.

2.1.3 Hydrologic hypotheses

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

Figure 2.1-1, the logic diagram of the saturated-zone component of the geohydrology program, shows the relation of saturated-zone hydrologic hypotheses to model components. Hydrologic hypotheses for the saturated zone are discussed at the beginning of SCP Section 8.3.1.2. The current representation and alternate hypotheses for the saturated-zone hydrologic system conceptual models appear in SCP Table 8.3.1.2-2b.

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

2.1.4 Hydrologic modeling

Assuming that the overall hydrologic system within the saturated and unsaturated zones at Yucca Mountain can be described by conventional theories of fluid storage and movement in porous and fractured media, present and future spatial distribution and magnitude of hydrologic parameters can be estimated from hydrologic models that are appropriately constructed from reliable measured data.

Hydrologic modeling provides estimates of ground-water flow direction and magnitude for defining flow paths and computing ground-water travel time. Such modeling requires sufficiently detailed knowledge of the geohydrologic framework and the three-dimensional distribution of hydrologic parameters. The regional ground-water flow system study is important in determining the required hydrologic parameters for developing an accurate description of the flow system that includes Yucca Mountain.

2.2 Constraints on the study

2.2.1 Representativeness of repository scale and correlation to repository conditions

The regional ground-water flow system study is designed to characterize the ground-water hydrology surrounding and including Yucca Mountain, and will be done at a scale considerably larger than that of the repository itself. Despite this larger scale, results from the study will have direct transferability in the development of regional ground-water flow models, which in turn will provide flow and head boundary conditions for models at the repository scale.

2.2.2 Accuracy and precision of methods

Selected methods for testing in each activity are summarized in tables at the end of each activity description (Section 3). These methods were selected on a basis of their precision and accuracy, duration, and interference with other tests and analyses. The accuracy and precision of the regional hydrologic tests is difficult to quantify prior to any implementation of the testing methods because many of them represent state-of-the-art science. The degree of accuracy and/or precision of each method within activities is a qualitative, relative judgement based on the USGS investigators' familiarity and understanding of the method.

2.2.3 Potential impacts of activities on the site

Planned infiltration studies at Fortymile Wash will involve the introduction of water with LiBr or other suitable tracer into the unsaturated zone. Although the quantity of water to be used will be relatively small, the potential exists for contamination of water within the unsaturated zone and saturated zone in the near vicinity of these tests. Other studies involved with obtaining hydrochemical or hydrologic data in the near vicinity of these tests should be so advised of the potential impact, but at present it is the opinion of the Principal Investigator that the Fortymile Wash infiltration tests will not conflict with other site-characterization efforts in the area.

2.2.4 Time required versus time available

The times defined in Section 5.1 for conducting the various activities presented in Section 3 are based on time constraints. Because of the uncertainty of actual times required to achieve acceptable scientific conclusions, these times are subject to revision during the conduct of investigations.

2.2.5 Limits of analytical methods

Although numerical modeling of tests planned in this study will be performed, the problem remains of identifying parameters in a distributed system with many degrees of freedom available. Measurements in the tests will be made at a few locations in a system in which the numerical mesh of the model may have thousands of unknowns. The use of all available data can reduce uncertainty, but some uncertainty will remain. Uncertainty analyses may be considered as an alternative to the solution of those problems that incorporate the unknown features of the system.

2.2.6 Potential for interference among activities

Generally, the selected tests of this study will have little or no interference with other planned tests (see Section 2.2.3). Potential interferences will be addressed in the development of schedules by the investigators and NHP/USGS-YMP management, and at a finer level of detail by the ongoing cooperation among investigators (both within NHP, and between NHP and other USGS branches and other project participants).

3 DESCRIPTION OF ACTIVITIES

The study is organized into four activities:

- o 8.3.1.2.1.3.1 - Assessment of the regional hydrogeologic data needs in the saturated zone,
- o 8.3.1.2.1.3.2 - Regional potentiometric-level and hydrogeologic framework studies,
- o 8.3.1.2.1.3.3 - Fortymile Wash recharge study, and
- o 8.3.1.2.3.3.4 - Evapotranspiration studies.

The plans for these activities are described in Sections 3.1 through 3.4.

3.1 Assessment of the regional hydrogeologic data needs in the saturated zone

3.1.1 Objectives

The objective of this activity is to prioritize data needs for use in the regional ground-water flow description. Included in these data needs are:

- o Distribution of hydraulic head, hydraulic conductivity, transmissivity, and storage coefficient.

- o Location and rate of recharge and discharge.

3.1.2 Rationale for activity selection

The assessment of regional hydrogeologic data needs is necessary, because while enough data currently exist to construct models of regional ground-water flow, sufficient uncertainty in initial and boundary conditions exists to reduce the certainty of model results. By prioritizing model variables as to their effects on key model-calculated results (such as ground-water flow-path directions and magnitudes), data collection may be focused to minimize uncertainties in these key variables. The assessment of the completeness and condition of the hydrogeological data base is an exercise that will be conducted in parallel with data collection throughout the span of this study.

3.1.3 General approach and summary of tests and analyses

There are some obvious ways to determine data collection needs when doing a study of this sort. One of the first things is to identify what variables are necessary to build a model of ground-water flow. These variables represent (quite simply) the spatial distribution of the following: (1) hydraulic head, (2) transmissivity, (3) storage coefficient and porosity (needed for transient simulations), (4) recharge, and (5) discharge. If these variables (as they are currently understood for the regional ground-water flow system of Yucca Mountain and vicinity) were ordered according to their uncertainty (from largest to smallest) they would be: (1) recharge, (2) storage coefficient, (3) transmissivity, (4) discharge, and (5) hydraulic head.

The status of this data-needs assessment is largely complete due in large part to prior characterization studies (Waddell, 1982; Czarnecki and Waddell, 1984; Czarnecki, 1985; Sinton and Downey, in review). Each of these studies contained sets of sensitivity analyses that showed the effect of uncertainty in key variables with regard to flow-system modeling and response. The results of these studies play a substantial role in deciding which activities should be done.

No matter how well one knows or can describe a hydrologic system such as the one of Yucca Mountain and vicinity, uncertainty will always remain. This activity, although largely completed, will continue throughout the life of this study as new data and concepts are obtained and developed.

Figure 3.1-1 summarizes the organization of the data assessment activity. A descriptive heading for each test and analysis appears in the boxes of the second and third rows. The figure summarizes the overall structure of the planned activity in terms of methods to be employed and measurements to be made.

3.1.3.1 Recharge

In the current models of the regional flow system (Waddell, 1982; Czarnecki and Waddell, 1984; Sinton and Downey, in preparation), a basic assumption was made that recharge to the flow system was in equilibrium with discharge (i.e. the system is at steady state). Recharge in arid environments such as Yucca Mountain and vicinity is perhaps the most difficult variable to "measure" or estimate from direct measurements. Reasons for this difficulty are: (1) the uncertainty in the relation between precipitation and resultant recharge, (2) the sporadic and infrequent nature of major precipitation events, (3) the uncertainty in the location and distribution of subsurface barriers and conduits (such as fractures and faults) that could retard or enhance recharge, and (4) the problem of looking at a "vertical" process in a variably saturated "porous media" (media may also be fractured), using essentially point-estimate methods (vertical boreholes). (In the area of location and distribution of subsurface barriers to recharge, data contributed from the past-discharge activity of YMP-USGS SP 8.3.1.5.2.1 may be applicable; included are caliche studies, remote sensing and geobotanical methods of locating recharge, and regional mapping of fracture zones and lineaments.)

Despite these difficulties and uncertainties, recharge has been specified in the above-mentioned models based in large part on where recharge is likely to occur (based on climatic considerations) and where the model indicated that it should occur. A case in point for the latter is recharge along Fortymile Wash. In the models of Czarnecki and Waddell (1984) and Sinton and Downey (in preparation), recharge was specified along Fortymile Wash (Figure 1.2-2) in order for the models to match observed values of hydraulic head in the vicinity of Yucca Mountain. This work (as well as the analysis in Czarnecki [1985]) indicated the importance of better quantifying recharge along Fortymile Wash based on actual field study.

In contrast, the northernmost flux boundary in the Czarnecki and Waddell (1984) model consisted of a series of constant head nodes that supply the appropriate amount of recharge across that boundary to satisfy the mass-balance requirements of the model (i.e. total recharge equals total discharge). This recharge line source corresponds to the throughflow resulting from expected recharge at Pahute Mesa and Rainier Mesa, areas that are topographically higher and climatically wetter than Yucca Mountain. This boundary was arbitrarily chosen far enough away from Yucca Mountain so that the

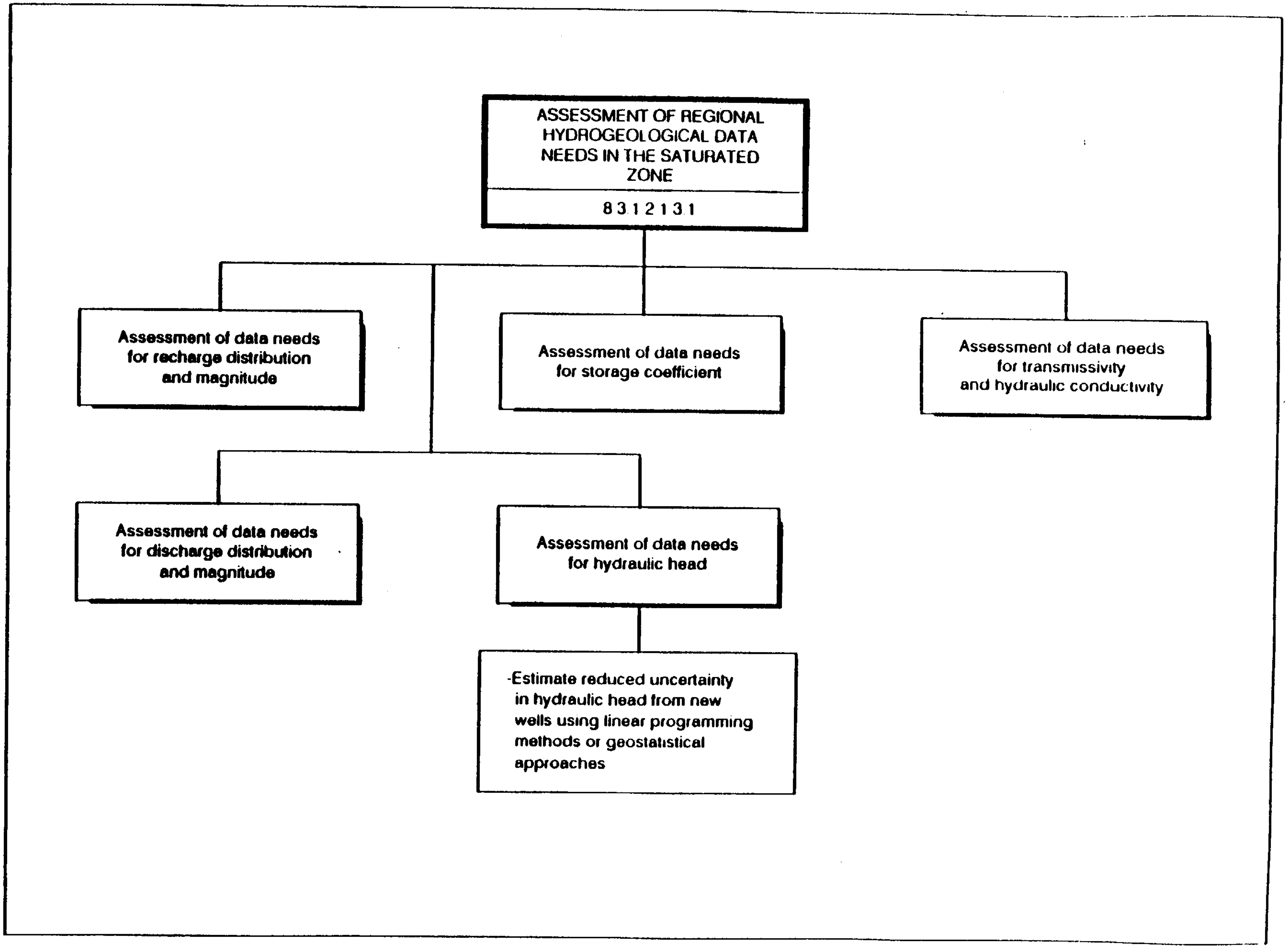


Figure 3.1-1. Logic diagram of regional hydrogeological data assessment.

near-field effects of the boundary condition (which could be considered as essentially a string of recharge wells) would not influence ground-water flow direction and magnitude in the area of interest (i.e. Yucca Mountain). This is not to say that recharge (or in this case throughflow) occurs everywhere across this arbitrary boundary line. In fact, more recent work (Czarnecki, 1987, 1989) indicates that ground-water divides may exist in relatively low-lying areas (such as the Greenwater and Funeral Ranges, Figure 1.2-2), implying that a potential ground-water divide may exist between the Beatty Wash drainage and the Crater Flat drainage (Figure 1.2-2). If this is the case, then the recharge boundary condition specified in the model should be modified to reflect a recharge mound along the topographic divide between Crater Flat and Beatty Wash. This is a condition where additional hydraulic-head data are needed in an area where data are currently sparse. The purpose of this data is not only to better define the potentiometric surface, but also to define the boundary of the flow system that includes Yucca Mountain. Additional drillholes are planned (see Section 3.2.3.1) to supply the requisite hydraulic-head data to help resolve this boundary condition.

The draft geophysics white paper (Oliver and others, 1990) proposes that borehole geophysical data generated in Activity 8.3.1.4.2.1.3 (Borehole geophysical surveys) will be used in this activity to identify low-permeability near-surface units (presumably in recharge areas and in the Amargosa Desert).

3.1.3.2 Storage coefficient

As indicated above, storage coefficient (or porosity) is not a required variable in steady-state simulations of ground-water flow. The potential range of values for storage coefficient for water table conditions (unconfined flow) may be large because of the potentially large range of effective porosity values (as small as 0.0001 for fractured tuff and as large as 0.2 for alluvium or nonwelded tuff; Czarnecki and Waddell [1984]). This uncertainty will be reflected in the uncertainty associated with estimates of ground-water travel time.

3.1.3.3 Transmissivity

Transmissivity estimates based on hydraulic testing in wells are available from a variety of sources and methods for the study area. The reliability of slug tests for yielding usable values of transmissivity in fractured tuff at Yucca Mountain is suspect in many cases, because the testing is suspected of having caused hydrofracturing of the rock mass. Additionally, the results from these tests could not be analyzed reliably because they did not lend themselves to a porous-media-type analysis. In the few cases where reliable transmissivity estimates exist (Moench, 1984; Thordarson, 1983), the agreement with these values and those obtained from the parameter-estimation-model results of Czarnecki and Waddell (1984) was satisfactory to the investigators. Hydraulic testing of boreholes in the Amargosa Desert has also yielded values of transmissivity that are similar to those estimated by the parameter-estimation model.

Additional transmissivity estimates are available via analysis of specific capacity data from water wells using the method developed by Theis (1963) and modified in Czarnecki and Craig (1985) and analysis of borehole geophysical data. Finally, one may infer relative changes in transmissivity by observing increases or decreases in hydraulic gradient. Small gradients might be associated with large transmissivity (or alternately small flux); large gradients might be associated with small transmissivity (or alternately large flux).

3.1.3.4 Discharge

Discharge within the flow system of Yucca Mountain and vicinity has previously been considered to occur at two principal locations: Franklin Lake playa (also known as Alkali Flat), and along a line of springs near Furnace Creek Ranch in Death Valley, California. Czarnecki (1987, 1989) and Czarnecki and Wilson (1990) offer alternate conceptual models that discuss possible pathways by which water could flow toward these two discharge areas. Potentiometric data suggest that a ground-water divide may exist in the Greenwater Range between the southern Amargosa Desert and Greenwater Valley. By extending the rationale that upland areas may be the locations for additional ground-water divides (even in arid regions), one might assume that divides exist beneath the Funeral Mountains, the Grapevine Mountains, and the topographic divide between Beatty Wash and Crater Flat. Additional confirmatory potentiometric data are needed to confirm these assumptions.

Because discharge at Furnace Creek Ranch and Franklin Lake playa had been quantified by previous investigators (Walker and Eakin, 1963; Pistrang and Kunkel, 1964; Winograd and Thordarson, 1975; Czarnecki and Waddell 1984; Czarnecki and Stannard, 1986), the uncertainty in estimates of discharge is less than other variables required in models that simulate ground-water flow in the vicinity of Yucca Mountain. The uncertainty is large enough to warrant further refinement, particularly in determining the area over which discharge via evapotranspiration occurs in the vicinity of Franklin Lake playa (see Activity 8.3.1.2.1.3.3).

In the geophysics white paper (Oliver and others, 1990), feasibility testing is discussed to evaluate the use of LANDSAT and other radar to detect and delineate major zones of discharge or recharge that may be associated with lineaments, to be applied to the remote sensing for regional hydrology efforts.

3.1.3.5 Hydraulic head

Measurements of hydraulic head are the easiest of all flow system variables to obtain. Numerous wells are located throughout the flow system, although most are clustered in the near vicinity of Yucca Mountain and the Amargosa Farms area (Figure 1.2-6). The uncertainty in measured values of hydraulic head is offset by the manner in which these data are used. For example, hydraulic head data are used as a check or calibration standard for numerical models of ground-water flow. Although a value of hydraulic head obtained from field measurements is accurate to within ±3 meters (included in this uncertainty is the error associated with the measuring point altitude; see Czarnecki and Waddell [1984, p. 11]), the error associated with attributing a field value to the nearest model estimate of hydraulic head at a finite-element node (or finite-difference cell) can be larger because of the spatial distance between the field and model points. The accuracy attributable to measured depths to water for monitoring wells at Yucca Mountain is better than 0.1 m for depths to water greater than 750 m (Gemmell, 1990, p. 10). Where numerous wells are clustered in an area, an average value of hydraulic head can be calculated and used to compare against model results, further increasing the potential for "error". The error in hydraulic head measuring or matching (comparing calculated to observed values) must also be considered within the context of the range in values of hydraulic head within the flow system being studied. For Yucca Mountain and vicinity, the range in heads is from about 1,400 m at Pahute Mesa to 600 m at Franklin Lake playa, to about sea level in Death Valley, much larger than the error associated with measurement or even matching. Measurement error is within the range of calibration error used in the models.

Nonetheless, the uncertainty in hydraulic head is large in areas where data are sparse. These areas include: (1) the large hydraulic gradient area north of Yucca Mountain, particularly upper Yucca Wash; (2) the potential ground-water divide areas in the Funeral Mountains, the Grapevine Mountains, and the topographic divide between Beatty Wash and Crater Flat; and (3) Timber Mountain. An attempt will be made to determine the reduced uncertainty to be derived from drilling additional wells in these areas using linear programming methods, geostatistical approaches (kriging), and information derived from previous boreholes. Four additional drill holes have been proposed specifically to better define the potentiometric surface in the large hydraulic gradient area. These are treated in more detail in Section 3.2.

Little is known about the distribution of hydraulic head with depth within the flow system. Hydraulic-head data in the vertical dimension are critical for calibrating three-dimensional models of ground-water flow. At present, only a handful of points exist where hydraulic head has been determined at various depths. Composite heads from pre-existing wells can generally be used because differences in components of vertical heads are small compared to the horizontal scale of regional modeling. In special cases the investigator will attempt to distinguish among components of composite head. Additional locations where vertical head distribution was measured led to the formulation of an alternate conceptual model of the flow system (Czarnecki, 1987), suggesting that the cause of increased head with depth was because of the presence of a deeper, separate aquifer. The results in these papers were based, in part, on hydraulic-head measurements that were corrected for possible temperature effects, but could affect the vertical head relation reported. Results of additional hydrochemical sampling and analyses of ground water from these and future boreholes are expected to indicate the age, origin and evolution of this deep ground water.

3.1.3.6 Methods summary

Because this activity is one of assessment of data needs in the saturated zone, the activity does not generate new original hydrologic data. Therefore there is no table of tests and methods versus activity parameters included in this section. Investigators in this activity are sufficiently familiar with the existing Yucca Mountain hydrologic data base and the requirements of the project to do the data assessment in a thorough and satisfactory manner. All prior data collected outside the project will be evaluated for its suitability to regional ground-water flow system characterization.

A few examples of models that are being examined include: (1) Czarnecki (1985) whose sensitivity analyses led to the establishment of the Fortymile Wash activity; (2) Czarnecki (1989) which questions the presence of throughflow from the Timber Mountain area north of Yucca Mountain into Crater Flat, and also the presence of a ground-water divide beneath the Funeral Mountains; and (3) Sinton (1989) which looks at alternate conceptual models to explain the cause of the large hydraulic gradient north of Yucca Mountain. Examples of data that may be collected and/or analyzed to resolve these issues include: (1) recharge rates in Fortymile Wash; (2) potentiometric data (a) in northern Crater Flat, (b) north of Yucca Mountain, and (c) on the east flank of the Funeral Mountains; and (3) geophysical, drillhole, and potentiometric data in the vicinity of the large hydraulic gradient.

3.1.4 Quality-assurance requirements

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires documentation of technical procedures for all technical activities that require quality assurance. No technical procedures apply to this activity because it is not a data collection exercise, but rather a prioritization of data needs for use in the regional ground-water flow system description.

3.2 Regional potentiometric-level distribution and hydrogeologic framework studies

3.2.1 Objectives

The objectives of this activity are (1) to determine the potentiometric distribution within the regional ground-water flow system, and (2) to characterize the hydrogeologic framework of the regional ground-water flow system to support reliable estimates of ground-water flow direction and magnitude within the saturated zone.

3.2.2 Rationale for activity selection

Refinement of the understanding of the regional ground-water flow system is contingent on improvements in the spatial and temporal distribution of potentiometric levels, hydraulic properties (transmissivity and storage coefficient), and boundaries (ground-water divides). Coupled with this refinement is the need to better describe the hydrogeologic framework of the flow system (for example, the three-dimensional distribution of hydrogeologic units and their hydraulic properties within the flow system). The rationale behind this activity is to reduce the uncertainty in key flow system variables (determined in Activity 8.3.1.2.1.3.1) so as to improve the reliability and utility of ground-water flow models of the regional and site ground-water flow systems.

3.2.3 General approach and summary of tests and analyses

Tests and measurements will be done to improve the current understanding of the spatial distribution of the following variables: (1) potentiometric levels, (2) transmissivity, (3) storage coefficient, and (4) hydrogeologic units. Where possible (and appropriate), temporal variations in the above variables will be determined.

Figure 3.2-1 summarizes the organization of the regional potentiometric level and hydrogeologic framework 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 3.2-2 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 3.2-2.

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.

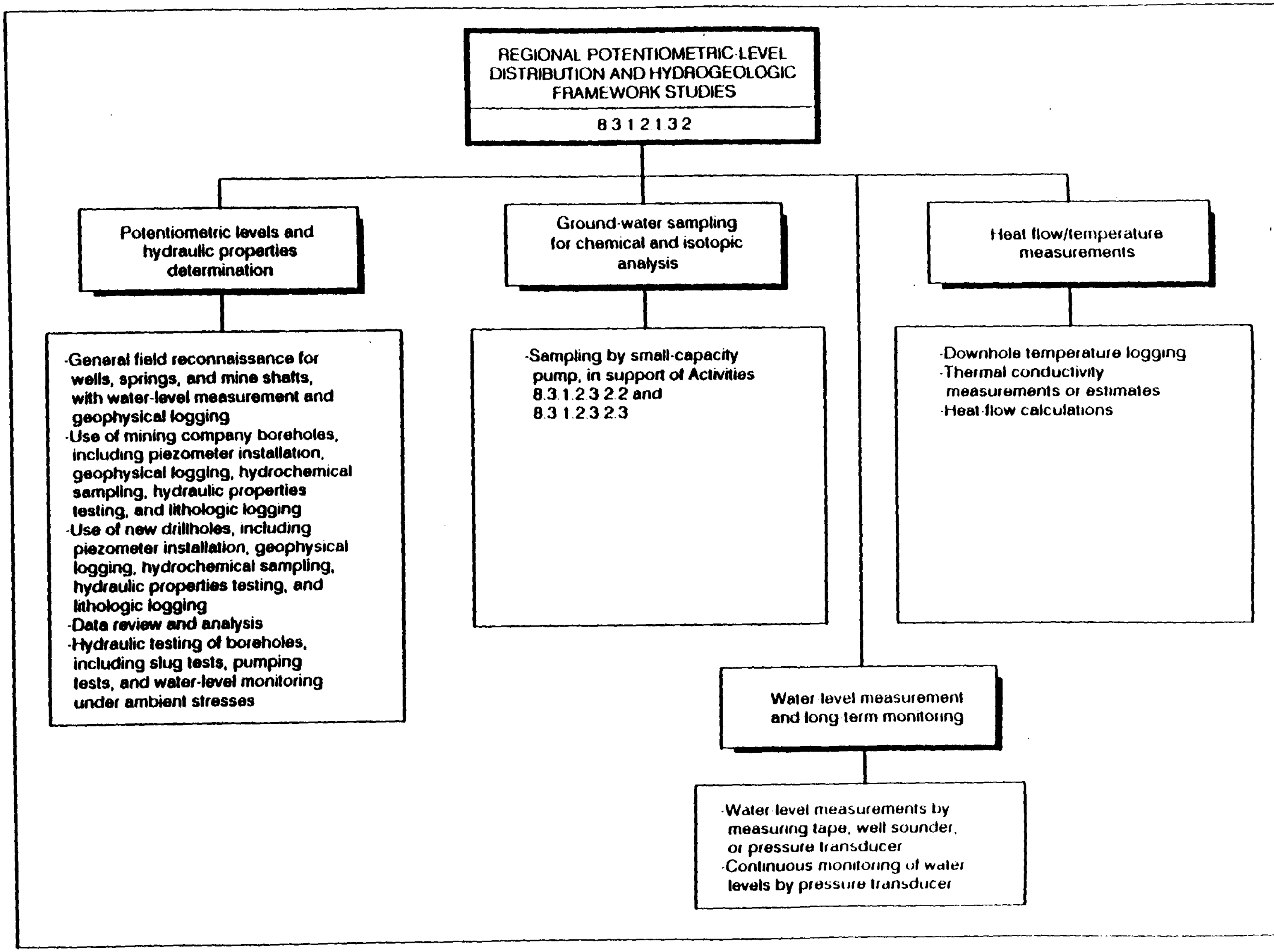


Figure 3.2-1. Logic diagram of regional potentiometric level and hydrogeologic framework activity, showin[g] t[es]ts, analyses, and methods.

3.2.3.2 Ground-water sampling for chemical and isotopic analysis

In conjunction with the regional and site hydrochemical modeling study, a small-capacity pump will be used in piezometers, wells, and open boreholes as access to them becomes available, to obtain water samples for chemical and isotopic analyses. This sampling is to be done in support of Activity 8.3.1.2.3.2.3 (Regional hydrochemical characterization).

An alternative to using a small-capacity pump may be to use a multilevel dialysis cell sampler (Ronen and others, 1987) for determining small scale, vertical changes in hydrochemistry in the saturated and unsaturated zones. This method will be used in boreholes constructed in recharge and discharge areas (Fortymile Wash and Franklin Lake playa). This method might be usable elsewhere, depending on the condition of the sampling environment.

3.2.3.3 Heat flow/temperature measurements

Although it is recognized that these boreholes will not be ideally constructed for heat-flow calculations, some useful heat-flow information can be obtained from them. Therefore, where feasible, temperature logs and thermal-conductivity measurements or estimates will be made in newly drilled holes and newly located existing holes, and heat flow will be calculated. The results will be integrated with ongoing heat-flow analyses (Study 8.3.1.8.5.2, Characterization of igneous intrusive features) to support potentiometric data in interpreting regional ground-water flow directions and hydraulic gradients.

3.2.3.4 Water-level measurement and long-term monitoring

Depth-to-water measurements will be obtained by means of a measuring tape, well sounder, or pressure transducer. The water-level depth will be converted to altitude when combined with the surveyed or estimated altitude of land surface. For newly drilled water-table holes, water levels may also be monitored continuously by means of a downhole pressure transducer that is connected to recording equipment at the surface. These holes will be added to the existing water-level monitoring network of about 25 holes located in the vicinity of Yucca Mountain. If determined applicable, corrections will be made to account for factors that could affect hydraulic head, such as relative density differences. An account of noninstrumental factors affecting measurement of static water levels is given in Winograd (1970). Corrections and adjustments needed to obtain accurate depths to water are shown in Gemmel (1990, p. 12-13).

Long term monitoring of water levels will be made in selected water wells and boreholes within the regional ground-water flow system as part of ongoing water-level monitoring program for the site saturated-zone studies and as part of the regional monitoring of the Environmental Field Activities Program (EFAP) being done by the USGS

Carson City office. Repeated measurements will be done at intervals as large as every six months. These data will also be used in conjunction with data contained in the USGS Ground-Water Site Inventory (GWSI) database.

3.2.3.5 Hydraulic properties

The plan to improve estimates of hydraulic properties (transmissivity, hydraulic conductivity, and storage coefficient) within the regional ground-water flow system will be broken into the following tests: (1) Review existing data sources for estimates of hydraulic properties and data that can be used to estimate hydraulic properties; and (2) hydraulic testing. Accurate values are needed to substantiate model estimates of these properties.

3.2.3.5.1 Data review and analysis

Various approaches are available for estimating hydraulic properties (Lohman, 1972; Driscoll, 1986). One of the simplest methods for determining an estimate of transmissivity is based on knowing the specific capacity (well pumping rate/drawdown), well diameter, and the duration of pumping, and using a modified version of the Theis equation to back out transmissivity. This method is described in detail in a paper by Theis (1963) and subsequently automated for handheld calculators in a paper by Czarnecki and Craig (1983). Data for this method are available from existing data sources (USGS GWSI database; state engineer's office data) which will be searched for pertinent data. A compilation of hydraulic properties will be assembled based on this data search, and on values derived from analysis of these data. Because the bulk of the existing data for wells located off the Nevada Test Site is likely to only include variables such as pumping rate, duration of pumping, well radius, and drawdown at a specified time, few other methods are considered applicable.

It is acknowledged that ground-water flow in the vicinity of Yucca Mountain that occurs in tuffaceous rock is likely to be dominated by the effects of fracture flow. Analyses of hydraulic-testing results in fractured media do not lend themselves to classic porous-media type analyses mentioned above. Therefore, the best currently available analyses pertaining to analyses of fracture flow will be incorporated. For additional reference see YMP-USGS SP 8.3.1.2.3.1 (Site saturated-zone ground-water flow system). The incorporation of fracture characteristics in the hydrologic modeling of the saturated zone is part of the scope of work for Study 8.3.1.2.3.3 (Site saturated-zone modeling and synthesis).

3.2.3.5.2 Hydraulic testing

Hydraulic testing of boreholes will be done to further extend the hydraulic properties database compiled in Activity 8.3.1.2.1.3.1. Wherever and whenever possible, testing of wells, piezometers, and open boreholes will be performed to determine transmissivity and storage coefficient. Examples of the types of tests that could be used (depending on well access, condition, and design) are: (1) "slug" or injection testing, (2) aquifer tests, and (3) continuous monitoring of water levels under ambient stresses. These methods are discussed in the following paragraphs.

"Slug" or injection tests consist of the instantaneous stressing of a well by rapidly pouring water downhole (or rapidly removing a water-displacing device that has been placed below the water-level in a well sufficiently long so as to allow the water-level to equilibrate). This initial stressing is preceded and followed by monitoring of the water level in the well. Analysis of test results involves the method described by (Cooper and others, 1967; Lohman, 1978). Advantages to this type of testing are its simplicity and relative ease of implementation. A hydrologic procedure (USGS-HP-89, Method of performing injection (slug) tests of cased boreholes in remote areas) details the steps, problems and assumptions involved in this type of test.

Aquifer tests will be performed in conjunction with hydrochemical sampling (Activity 8.3.1.2.3.2.2). An example of how an aquifer test would be done is described in Lohman (1978) and Driscoll (1986). In the case of this test, the water level in the pumped well would be monitored using the appropriate water-level monitoring device, such as a pressure transducer, before, during, and after the well has been pumped. If other wells in the near vicinity of the pumped well are available, they will also be monitored.

Decisions to monitor water-level changes during hydrochemical sampling will be determined on a case by case basis (in some instances downhole access will be impossible because of restricted access caused by the presence of the pump). Analysis of pumping test results will yield local estimates of transmissivity, hydraulic conductivity, and storage coefficient.

3.2.3.5.3 Geophysical and lithologic logs

Geophysical logs (resistivity, caliper, gamma-gamma, and neutron-density) will be run in some mining company boreholes (see Section 3.2.3.1) to provide data on stratigraphy, lithology, porosity, and permeability of the host rock. Borehole cuttings, collected by the mining company at 10-ft intervals from these holes, will be provided for analysis of (1) lithology, (2) grain size, (3) bulk density, (4) permeability and hydraulic conductivity, (5) environment of deposition, and (6) effective saturated thickness.

3.2.3.6 **Methods summary**

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.2-1. Also listed are the selected methods for determining the parameters. 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 several approaches to conducting the test. In those cases, only the most common methods are included in the tables. The selected methods in Table 3.2-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

3.2.4 **Quality-assurance requirements**

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

Table 3.2-2 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a USGS number. Procedures that require preparation do not have procedure numbers.

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 3.2-1. Summary of tests and methods for the regional potentiometric level activity (SCP 8.3.1.2.1.3.2)

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

Methods (selected and alternate)	Site-characterization parameter
Potentiometric-levels and hydrologic framework determination	
General field reconnaissance (selected)	Bulk density
"	Effective saturated thickness
"	Hydraulic conductivity
"	Hydraulic head
"	Lithologies, lithologic units
"	Permeability
"	Porosity
"	Storage coefficient
"	Stratigraphic contacts, lithologic units
"	Transmissivity
Use of mining-company boreholes (selected)	Bulk density
"	Effective saturated thickness
"	Hydraulic conductivity
"	Hydraulic head
"	Lithologies, lithologic units
"	Permeability
"	Porosity
"	Storage coefficient

Table 3.2-1. Summary of tests and methods for the regional potentiometric level activity (SCP 8.3.1.2.1.3.2)--Continued

Methods (selected and alternate)	Site-characterization parameter
Potentiometric-levels and hydrologic framework determination--Continued	
Use of mining-company boreholes (selected)	Stratigraphic contacts, lithologic units
"	Transmissivity
Use of new drillholes (selected)	Bulk density
"	Effective saturated thickness
"	Hydraulic conductivity
"	Hydraulic head
"	Lithologies, lithologic units
"	Permeability
"	Porosity
"	Storage coefficient
"	Stratigraphic contacts, lithologic units
"	Transmissivity
Ground-water sampling for chemical and isotopic analysis	
Sampling by small-capacity pump, in support of Activities 8.3.1.2.3.2.2 and 8.3.1.2.3.2.3 (selected)	Chemistry, ground water
Heat flow/temperature measurements	
Downhole temperature logging (selected)	Temperature, hydrogeologic units

Table 3.2-1. Summary of tests and methods for the regional potentiometric level activity (SCP 8.3.1.2.1.3.2)--Continued

Methods (selected and alternate)	Site-characterization parameter
Heat flow/temperature measurements--Continued	
Thermal conductivity measurements or estimates (selected)	Thermal conductivity
Heat flow calculations (selected)	Heat flow
Water-level measurement and long-term monitoring	
Water-level measurements by measuring tape, well sounder, or pressure transducer (selected)	Hydraulic head
Continuous monitoring of water levels by pressure transducer (selected)	"
Hydraulic properties	
Data review and analysis (selected)	(Does not directly generate parameters)
Hydraulic testing of boreholes (selected)	Hydraulic conductivity
"	Storage coefficient
"	Transmissivity

Table 3.2-2. Technical procedures for the regional potentiometric levels activity (SCP Activity 8.3.1.2.1.3.2)

	Technical procedure
	Potentiometric-levels determination
HP-09	Construction of piezometers in unconsolidated sediments
HP-25	Method for measuring water levels using a portable multiconductor
HP-26	Method for calibrating water-level measurement equipment using the reference steel tape
HP-61	Use of hand-held steel tapes
HP-99	Instruction for operation of a well sounder for measuring water levels
TBD	Scientific notebook: General field reconnaissance for wells, springs, and mine shafts for water-level measurements
	Ground-water sampling for chemical and isotopic analysis
HP-08	Methods for determination of inorganic substances in water
HP-23	Collection and field analysis of saturated-zone ground-water samples
HP-11	Methods for determination of radioactive substances in water
HP-200	Collection of ground-water samples from wells
	Heat flow/temperature measurements
GPP-02	Heat-flow studies related to nuclear waste storage investigations

Table 3.2-2. Technical procedures for the regional regional potentiometric levels activity (SCP Activity 8.3.1.2.1.3.2)--Continued

	Technical procedure
	Heat flow/temperature measurements--Continued
GPP-05	Heat-flow studies calibration procedures
	Water-level measurement and long-term monitoring
HP-01	Methods for determining water level
	Hydraulic properties
GPP-14	Induced-polarization borehole logging operations
GPP-17	Magnetometer borehole logging operations
HP-02	Acoustic televiewer investigations
HP-06	Hydrologic pumping test
HP-34	Preliminary method for measuring discharge for an aquifer test using a staff gage and a calibrated container
HP-50	Method for neutron scatter and gamma-ray attenuation logging using the USGS Logging Van (I-139055)
HP-60	Method for monitoring water-level changes using pressure transducers
HP-71	Method for monitoring water-level changes using a Campbell Scientific 21X Micrologger
TBD	Borehole video and logging survey procedure: Horizontal and vertical holes

Table 3.2-2. Technical procedures for the regional regional potentiometric levels activity (SCP Activity 8.3.1.2.1.3.2)--Continued

	Technical procedure
	Hydraulic properties--Continued
TBD	Borehole drill-cutting and core sampling
HP-89	Method of performing injection (slug) tests of cased boreholes in remote areas

3.3 Fortymile Wash recharge study

3.3.1 Objectives

The objectives of this activity are:

1. to qualitatively determine to what extent Fortymile Wash has been a source of recharge to the saturated zone in the vicinity of Yucca Mountain under modern and paleoclimatic geohydrologic conditions; and

2. to determine the magnitude and distribution of modern and paleo recharge along Fortymile Wash.

3.3.2 Rationale for activity selection

The hypothesis that Fortymile Wash may currently be or has been a source of recharge to the ground-water flow system in the vicinity of Yucca Mountain was proposed by Naff (1973) and later supported by Claassen (1985). The hypothesis is based on hydrochemical analyses of ground water along Fortymile Wash and beneath the Amargosa Desert (south of Yucca Mountain) (Figure 1.2-2). Concentrations of major cations and anions in ground water beneath the Amargosa Desert are larger to the east, west, and south relative to the central part of the desert. Concentrations of major species increase progressively to the south along Fortymile Wash, indicating that younger, fresher ground water may flow from Fortymile Wash into the Amargosa Desert. Uncorrected carbon-14 dates of ground water along Fortymile Wash indicate older ground water southward along Fortymile Wash (Claassen, 1985). Ground-water quality in the Fortymile Wash-Amargosa Desert area is exemplified by the distribution of dissolved sodium in ground water (Figure 3.3-1).

Numerical models of ground-water flow in the vicinity of Yucca Mountain (Czarnecki and Waddell, 1984; Sinton and Downey, in preparation) were used to evaluate recharge along Fortymile Wash with respect to other model components. Results of these studies indicated that recharge along Fortymile Wash may be a substantial percentage of the total recharge to the ground-water flow system, and that water levels beneath Yucca Mountain may be strongly influenced by increased recharge along the wash under wetter climatic conditions (Czarnecki, 1985). Czarnecki's modeling showed that the resultant rise in water-table altitude beneath the design repository area was 100 m if only the flux beneath Fortymile Wash were increased fifteen-fold to correspond to a doubling of precipitation: when all recharge fluxes were increased fifteen-fold, the water-table altitude rose 130 m indicating that recharge at Fortymile Wash had the dominant effect. Increases in recharge could result from climatic changes in the Yucca Mountain region. Smaller washes in the Yucca Mountain area are also being evaluated for their recharge potential (YMP-USGS SP 8.3.1.2.2.1, Unsaturated-zone infiltration, Activity 8.3.1.2.2.1.2).

Estimates of recharge rates and distribution will be incorporated into numerical models of ground-water flow. Quantitative estimates of recharge rates along Fortymile Wash will significantly reduce the amount of

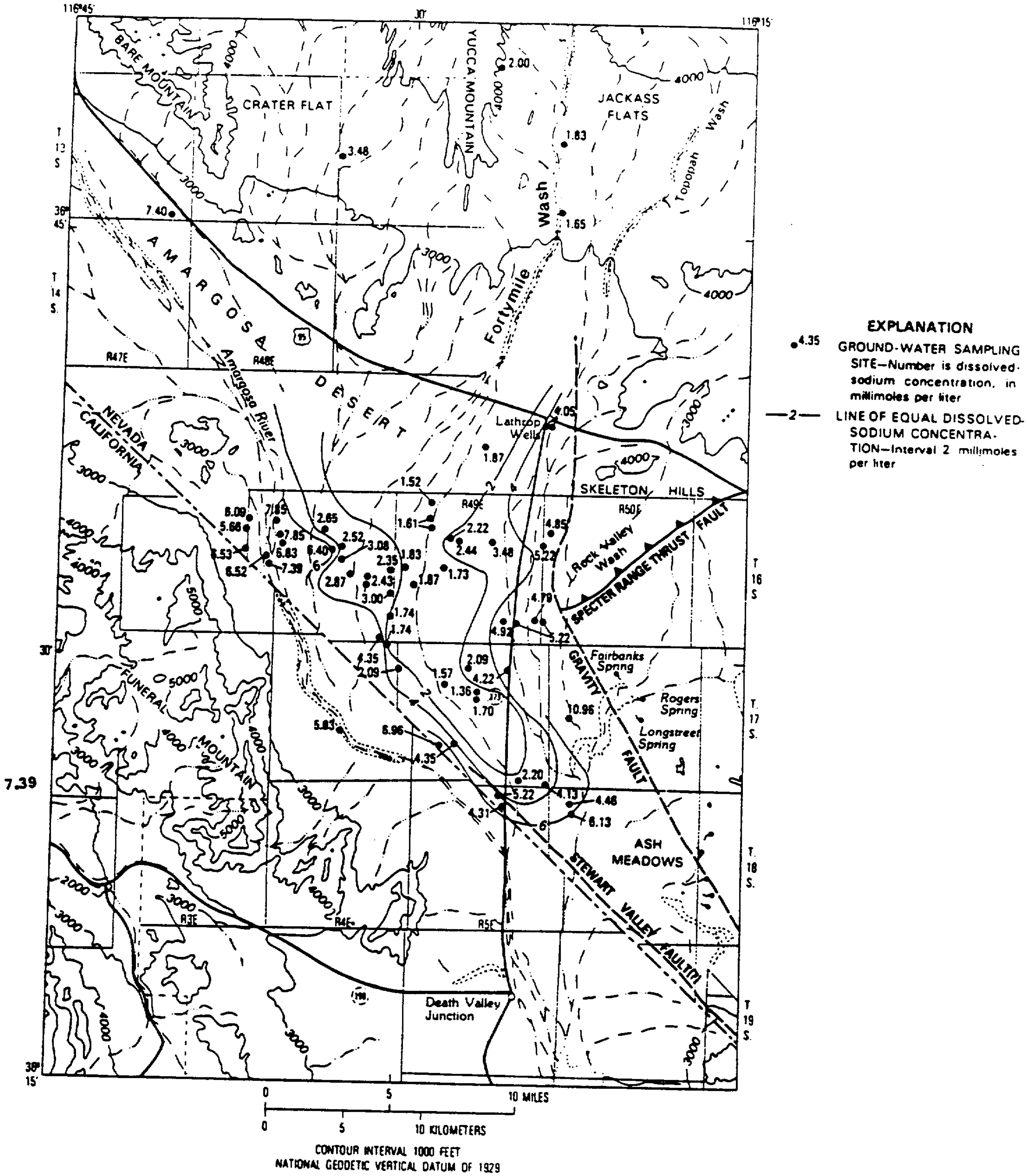


Figure 3.3-1. Dissolved sodium (Na+) in ground water.

uncertainty associated with the modeling process and model variables. Numerical modeling activities are discussed in detail in YMP-USGS SP 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling).

3.3.3 General approach and summary of tests and analyses

Surface water and meteorological measurements will be combined with unsaturated-zone, saturated-zone, and geomorphic measurements to obtain estimates of the recharge rates along Fortymile Wash (Figure 1.2-2). The potential for Fortymile Wash to be a source of ground-water recharge will be assessed by several methods. Monitoring of unsaturated-zone and saturated-zone responses during natural runoff events and artificial infiltration experiments in Fortymile Wash will provide data necessary to characterize recharge. Infiltration rates will be combined with precipitation-runoff data to derive estimates of long-term recharge rates along Fortymile Wash. Hydrochemical analyses of unsaturated-zone and saturated-zone water and core will also provide data on modern and paleo recharge rates. Tritium and chlorine-36 isotopes will be used to assess the depth to which modern water has infiltrated beneath Fortymile Wash. Deuterium and oxygen-18 isotopes will be used to assess past climatic conditions under which recharge may have occurred. Carbon-14, carbon-13, tritium, beryllium-10, and chlorine-36 will be used to characterize ground-water ages and infiltration rates.

The relation between the magnitude and duration of streamflow during runoff events, and the magnitude, distribution, and duration of precipitation events must be evaluated to assess the recharge potential of Fortymile Wash. Characterizing relations between streamflow and precipitation will give a better understanding of runoff processes, and, thus, the processes that affect infiltration rates.

Modern (and perhaps paleo) recharge rates possibly may be estimated through an analysis of channel geometry, and the application of the equation of continuity (Section 3.3.3.6). The geomorphic configuration of the channel is a product of modern and paleo streamflows. Geometric analysis of the channel along appropriate channel reaches may indicate the distribution and magnitude of channel losses (infiltration).

Results of the unsaturated- and saturated-zone tests and monitoring will be analyzed with surface-based measurements and estimates to derive long-term estimates of recharge along Fortymile Wash. These analyses may involve precipitation-runoff and unsaturated-zone modeling efforts. Detailed descriptions of the methods to be used in this study are contained in the following sections.

Fortymile Wash recharge studies will be supported by the neutron-moisture logging methodology of Activity 8.3.1.2.2.1.2 (natural infiltration studies), borehole geophysical logging under Activity 8.3.1.4.2.1.3, geophysical data from the borehole evaluation of faults and fractures in Activity 8.3.1.4.2.2.3, and geophysical applications from the site vertical boreholes study in Activity 8.3.1.2.2.3.2.

Figure 3.3-2 summarizes the organization of the Fortymile Wash 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. Cross references to other study plans that provide input to the Fortymile Wash recharge tests also appear in Figure 3.3-2. Figure 3.3-3 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 in Figure 3.3-3.

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.

3.3.3.1 Surface-water measurements

Surface-water measurements and analyses will include: (1) streamflow measurements (continuous recording of stream-stage and crest stream-stage during precipitation-runoff events); (2) collection of water samples of runoff for hydrochemical analyses; (3) estimates of the distribution, magnitude, and duration of discharge along Fortymile Wash; and (4) statistical analysis of precipitation-runoff events to determine recurrence intervals for various magnitudes of runoff events. These data and analyses are part of activities in YMP-USGS SP 8.3.1.2.1.2 (Regional surface-water runoff and streamflow).

The infrequent occurrences of runoff, and variability of flow magnitude among different runoff events, make long-term data collection necessary in order to provide a bare minimum amount of needed data. Thus the collection of streamflow data must, out of necessity, be a long-term venture, with an initially planned duration of about six years. It cannot be determined at this time what degree of confidence can be obtained from the analyses of the six-year record planned. The reliability of the streamflow data input for the Fortymile Wash recharge studies will improve with increased duration of data collection. For this reason it is important that the collection of streamflow data for this activity proceed in as timely a manner as possible.

3.3.3.1.1 Streamflow measurements

Measurement of the magnitude and duration of discharge along Fortymile Wash during runoff events is necessary to adequately characterize recharge rates along Fortymile Wash. This is because of infiltration of runoff into the unsaturated zone beneath the wash.

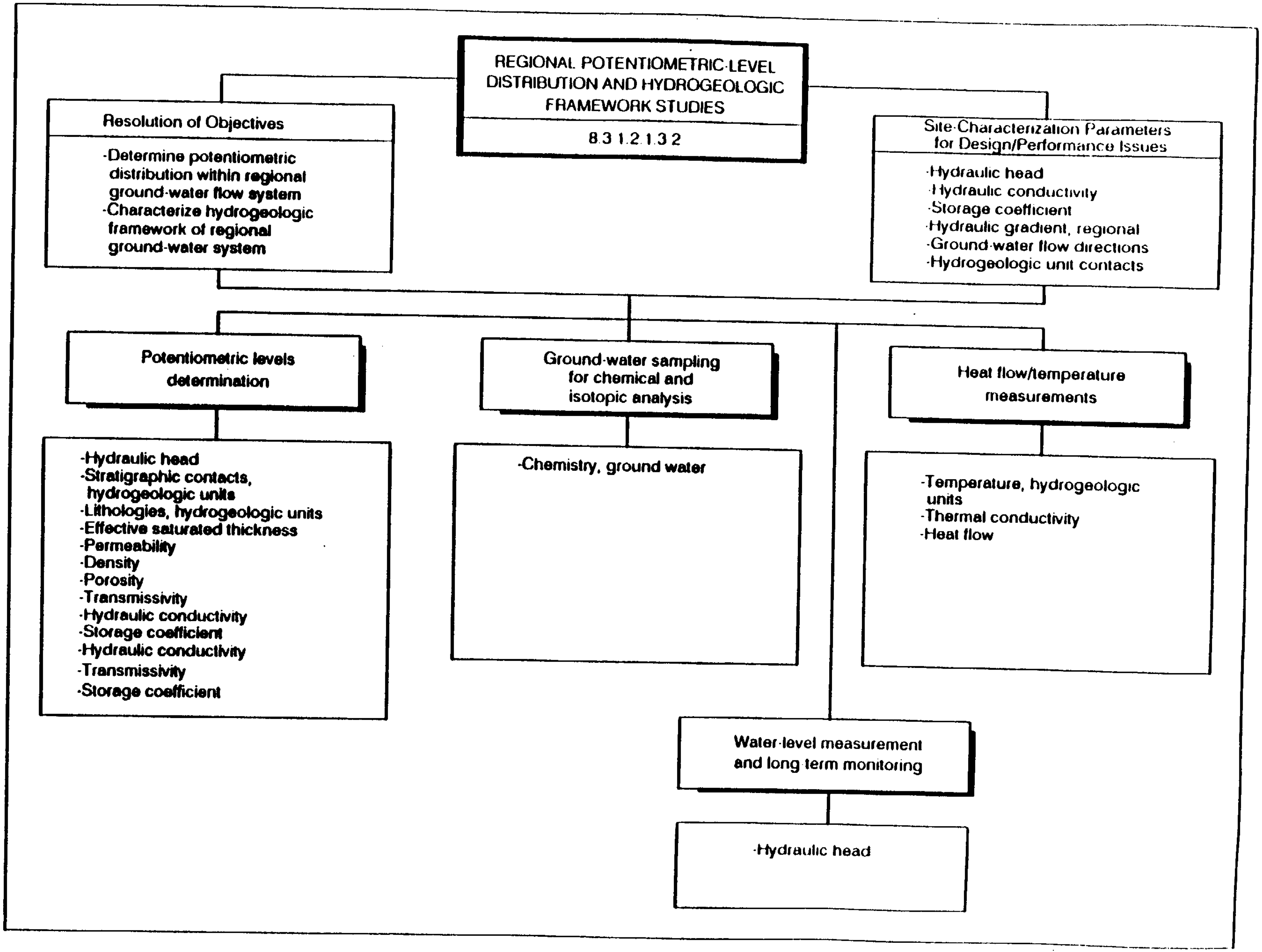


Figure 3.2-2. Logic diagram of regional potentiometric-level distribution and hydrogeologic framework activity, showing tests, analyses, and activity parameters.

3.2.3.1 Potentiometric levels determination

A field reconnaissance will locate previously unknown or unobserved wells, springs, and mine shafts that may yield information about regional ground-water levels. In addition, searches will be made for agencies, local residents, and well drillers that are likely to have well records or water-level information. Where possible, depth-to-water measurements will be obtained in these previously unknown or unobserved wells. Depth to water and total well depth will be determined by means of a measuring tape, or a sensor. Where possible, geophysical logs will be run at these sites. The altitude of the land surface also will be determined at these sites.

Various mining companies are drilling boreholes in the vicinity of Yucca Mountain as a part of their exploration programs. These companies have agreed to allow all or part of the following: (1) installation of piezometers in their holes for YMP data collection, (2) borehole geophysical logging of these holes, (3) hydrochemical sampling of water in these holes; and (4) performing pumping tests and/or slug tests to determine hydraulic properties (transmissivity, hydraulic conductivity, and storage coefficient). Some piezometers and piezometer nests have been installed to measure water levels in areas adjacent to the Yucca Mountain site to provide data for regional hydrologic studies. Additional piezometers will be installed if additional holes are made available to the Project. General areas where these boreholes will be located are shown in Figure 3.2-3. Instrumentation of each of these holes with two piezometers will provide deep and near-surface potentiometric data for determining vertical hydraulic head distribution. Water samples will be obtained from these piezometers for hydrochemical analyses. Water-level recovery will be monitored after sampling to determine estimates of transmissivity. Downhole temperature will be measured at selected intervals to estimate the vertical component of groundwater flow. Regional groundwater flow rates and velocities may then be estimated from transmissivity, hydraulic conductivity, effective saturated thickness, and hydraulic gradient.

Data collection from previously unknown sources will be considered as a cost-effective supplement to the activity. Although surface geophysical surveys will not be used independently as part of this activity, the investigators will employ applicable data that may be generated in regionally oriented geophysical surveys in Studies 8.3.1.4.2.1 (Vertical and lateral distribution of stratigraphic units within the site area) and 8.3.1.17.4.3 (Quaternary faulting within 100 km of Yucca Mountain, including the Walker Lane).

Construction of new drillholes as part of the USGS-YMP will provide additional opportunities for potentiometric-levels, hydraulic properties, and hydrochemical data collection at the following locations: (1) Fortymile Wash (at least eight boreholes into the saturated zone are planned; see Activity 8.3.1.2.1.3.3); (2) Franklin Lake playa (at least 10 piezometer nests containing three piezometers

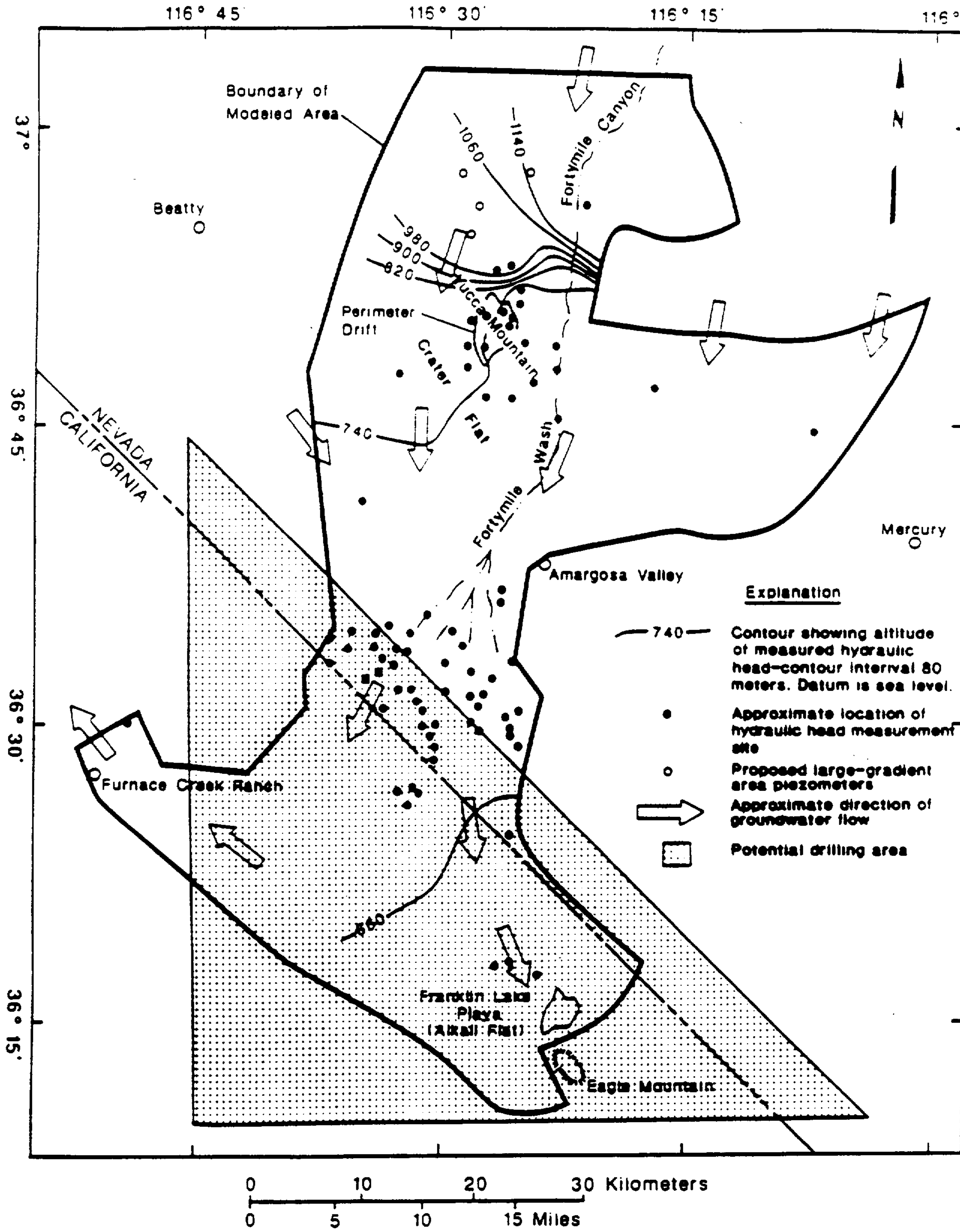


Figure 3.2-3. Location of hydraulic-head measurement sites and of potential drilling areas in the Amargosa Desert by a commercial mining company for installation of piezometers. (Czarnecki and Wadell, 1984, Fig.3)

each are planned to delimit the areal extent of vertically upward flow caused by evapotranspiration (see Activity 8.3.1.2.1.3.4); (3) Crater Flat (drillholes USW WT-21 and WT-22 are planned as part of this activity; see Figure 3.2-4 for approximate locations); (4) eastern edge of the Funeral Mountains, west of the Amargosa Farms area (at least one piezometer nest is planned as part of this activity; see Figure 3.2-5 for approximate location); (5) south and west of the town of Amargosa Valley, also known as Lathrop Wells (a deep [6,000-ft] drillhole is being considered to determine the presence and characteristics of pre-Tertiary hydrogeologic units as part of this activity; see Figure 3.2-4 for approximate location); and (6) at the site as part of the site potentiometric levels activity (Activity 8.3.1.2.3.1.2). The drilling of these holes will be integrated and coordinated with the overall drilling program as outlined in SCP Section 8.3.1.4.1. Drillholes in points 1, 2, and 6 are discussed in their appropriate activity sections; a discussion of points 3, 4, and 5 follows.

Because Crater Flat lacks potentiometric-level data needed for modeling of that area, two new water table holes will be drilled. USW WT-21 will be located about 2 km southwest of USW H-6 and drilled to a probable depth of about 550 m. USW WT-22 will be located in northern Crater Flat and drilled to a probable depth of about 400 m. By utilizing existing and anticipated mining company and livestock wells in the vicinity of USW WT-22, it may be possible to determine whether a ground-water divide exists beneath the topographic divide that separates the Beatty Wash drainage from the Crater Flat drainages. This is an important boundary to resolve with regard to ground-water flow toward Yucca Mountain.

Because these borehole locations are off the Nevada Test Site, construction will be open to competitive bidding. This is an important consideration because the number of drillholes that is currently scheduled for construction is largely restricted by available funding, coupled with the high cost of drilling on the Nevada Test Site. By opening this drilling up to competive bid, a substantial cost savings could be realized (on the order of at least 4 to 6 times less). Otherwise the chances are great that these holes will not be scheduled because of cost considerations.

Does ground water flow from within the basin-fill sediments below the Amargosa Desert, southwest toward the Furnace Creek Ranch spring line (see Figure 1.2-6)? This question is raised by Czarnecki (1989) and Czarnecki and Wilson (1990), and may be resolved by drilling a piezometer nest on the eastern edge of the Funeral Mountains, west of the Amargosa Farms area. This nest would consist of two to three piezometers installed either in one hole or separate holes such that the deepest piezometer penetrates the saturated Paleozoic carbonate rocks, in order that its potentiometric level can be compared with levels from within the overlying Tertiary alluvial fan and basin-fill sediments. (Because the borehole location is off the Nevada Test Site, construction may be open to competitive bidding.) A higher potentiometric level at depth would be consistent with other

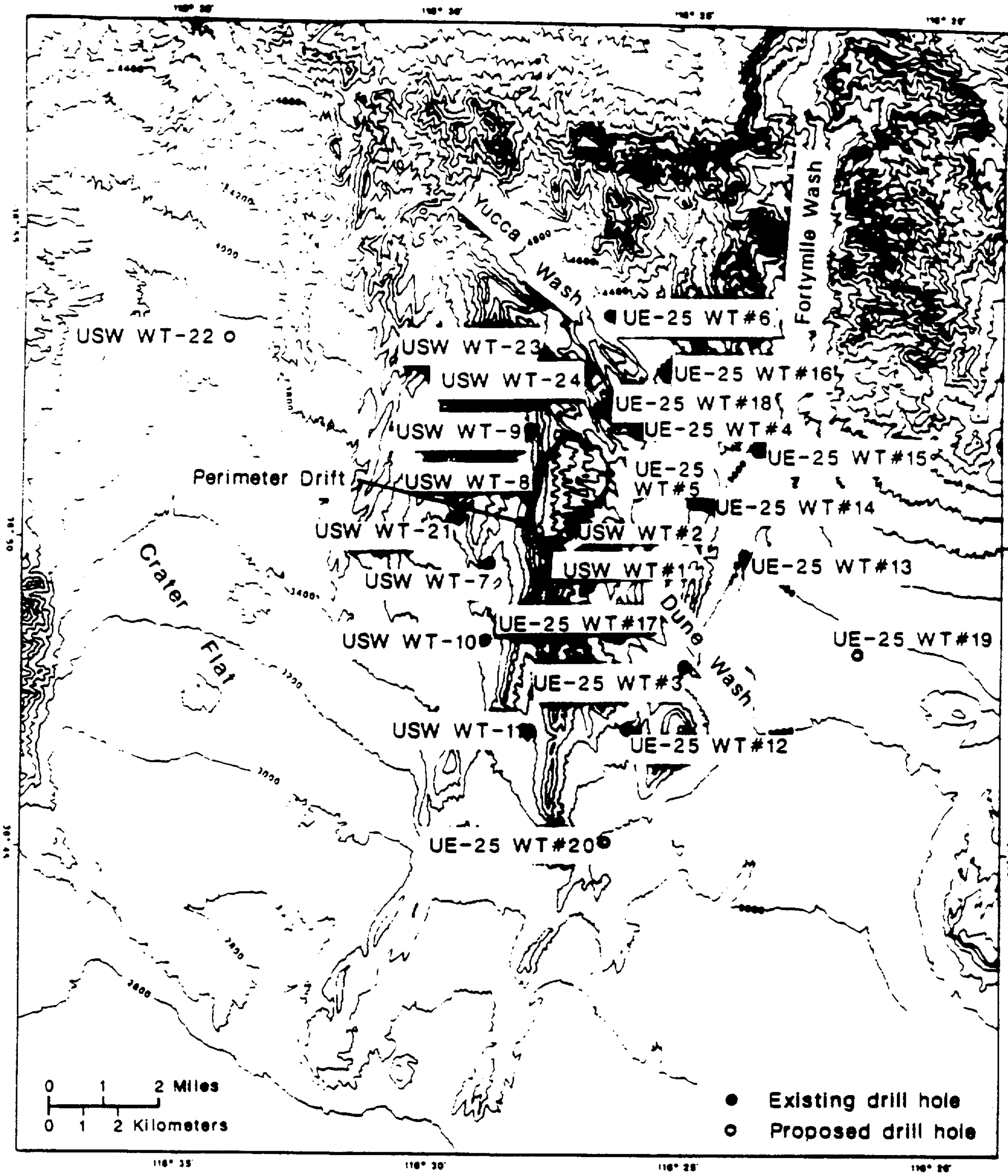


Figure 3.2-4. Location of existing and proposed water-table holes in near vicinity of Yucca Mountain.

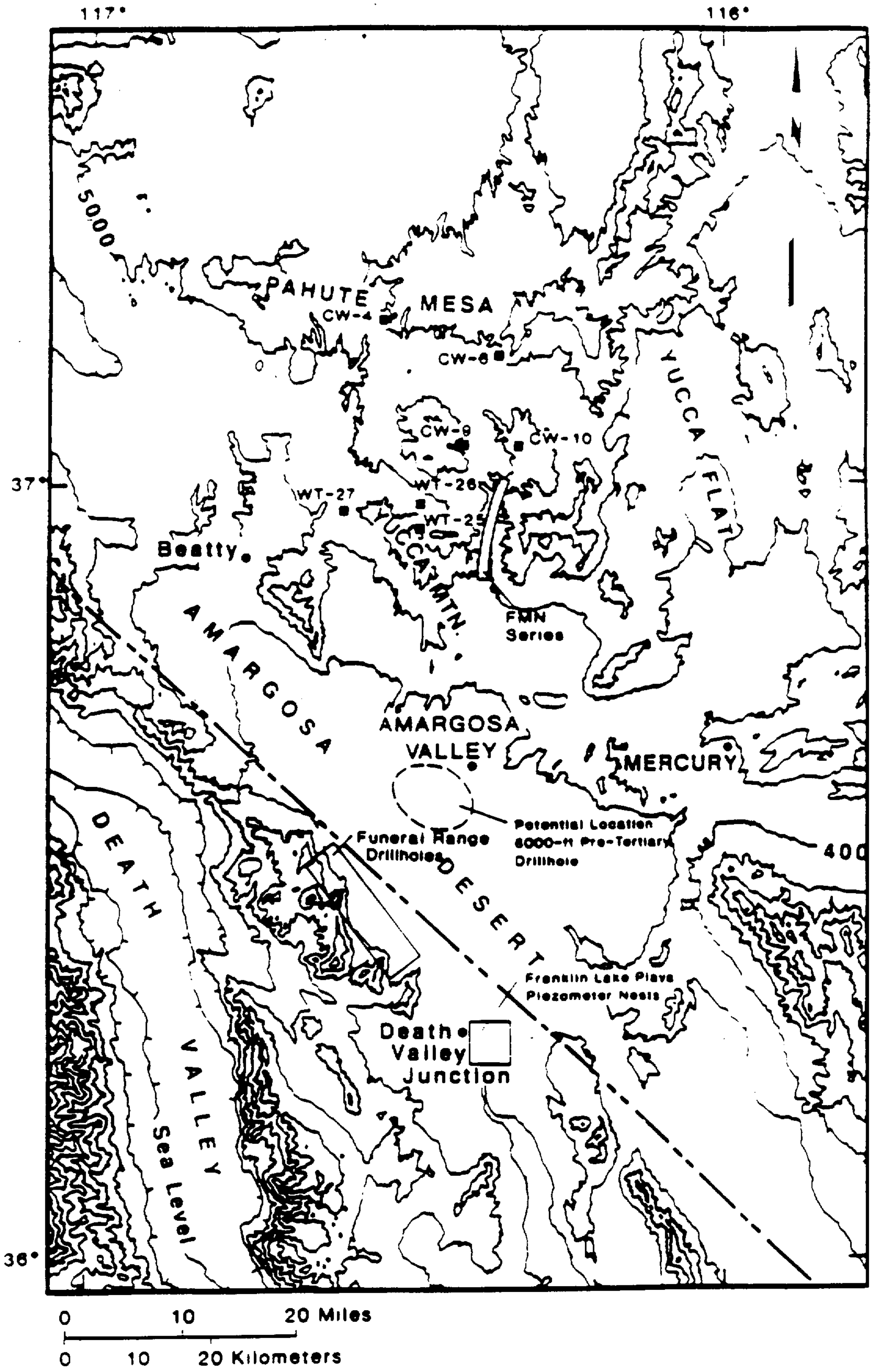


Figure 3.2-5. Locations of proposed regional drill holes.

potentiometric levels from deep piezometer nests and would support the presence of a ground-water divide beneath the Funeral Mountains, which separates the local Amargosa Valley ground-water flow system from the Death Valley ground-water flow system. A lower potentiometric level at depth would support the concept of Paleozoic carbonate rocks draining water from the Amargosa Valley toward Death Valley. The ramifications for either of these two cases, as related to the modeling of ground-water flow, are substantial and need to be resolved so that a reliable assessment of ground-water flow direction and magnitude (and hence travel time) at the site can be made. Current representations of the flow system (Czarnecki and Waddell, 1984; Czarnecki, 1985) assume that about one-third of the water flowing beneath Yucca Mountain discharges as springs and distributed evapotranspiration at Furnace Creek Ranch in Death Valley, and the remaining two-thirds discharges at Franklin Lake playa as evapotranspiration. If, as suggested, a ground-water divide blocks flow from the Amargosa Desert to Death Valley, then models reflecting this revised concept would likely show about one-third less flow beneath Yucca Mountain (all other conditions being equal). The net result would be an increase in calculated ground-water travel time from the repository to the accessible environment.

Extant models of ground-water flow of Yucca Mountain and vicinity (Czarnecki and Waddell, 1984; Czarnecki, 1985) treat the area beneath the Funeral Mountains as a no-flow boundary. It is assumed that modification of this boundary condition to one allowing flow will result in larger magnitude flow (because more flow will need to occur from recharge areas) and possibly altered direction beneath the design repository area. If no flow occurs from the Amargosa Desert sediments (Yucca Mountain flow system) to Death Valley, then one-third of the specified discharge in these models will need to be removed, resulting in decreased flow magnitude beneath Yucca Mountain.

Because little specific data is available about the depth, thickness, and areal distribution of pre-Tertiary rocks at the Yucca Mountain site (the pre-Tertiary is penetrated by only one borehole, UE25 p#1), surface geophysical surveys are being considered for characterizing the Paleozoic-Tertiary contact and the nature of the underlying Paleozoic section (geophysics white paper [DOE, 1989]).

Previous seismic refraction, magnetic, and gravity surveys have provided some basis for constructing conceptual models of ground-water flow in the Paleozoic rocks, these methods have not been decisive in determining either geometry or lithology. Additional surface geophysical surveys, particularly seismic refraction, will provide useful data for refining existing conceptual models. Design objectives for employing upper-crustal seismic refraction lines for saturated-zone hydrologic data collection will be considered by the geophysics integration activity (SCP Section 8.3.1.4.1.2).

Substantial uncertainty exists regarding the pre-Tertiary hydrogeologic units underlying the Amargosa Desert about 25 km south of the site area. A preliminary analysis of existing data (Oatfield and Czarnecki, 1988) shows the presence of basement rocks of unknown age at depths ranging from 800 to 1000 m, based on Schlumberger-resistivity and seismic-refraction surveys done in the area. It is postulated that these hydrogeologic units may be Paleozoic carbonate rocks; if so, they might provide a preferential pathway for ground-water flow from the overlying Tertiary volcanic and basin-fill units, provided the potentiometric level in the Paleozoic units is less than in the overlying units. Otherwise, if heads are higher in the deeper units, then the conceptual model proposed in Czarnecki and Wilson (1989) and illustrated in the north-south cross section in Figure 1.2-3 would be further supported. A deep drillhole (about 1,200 to 2,000 m in depth) may be needed for characterizing these deeper units and to determine the hydraulic relation between the pre-Tertiary and Tertiary units. This drillhole would likely be drilled using the reverse-circulation method, with foam or air as the drilling fluid to preserve hydraulic properties within the borehole. At a minimum three piezometers or packed off intervals will be used to determine vertical head relations within the borehole. (Because the borehole location is off the Nevada Test Site, construction will be open to competitive bidding.) A review of the number and spacing of water-table drill holes in the Yucca Mountain area has revealed that existing plans for new drill holes are inadequate to provide potentiometric, hydrologic, and hydrochemical data to answer the following questions: (1) From where and by what flow paths does water beneath Yucca Mountain originate? and (2) What is an accurate representation of the upgradient ground-water-flux boundary condition required for modeling ground-water flow at the scale of the site? Without answers to these fundamental questions it will be impossible to accurately model saturated ground-water flow direction and magnitude from the site to the accessible environment. In addition to the discussion of proposed new wells (in the following paragraphs), the plans for additional saturated-zone wells at Yucca Mountain and vicinity appear in SCP Investigation 8.3.1.4.1 (Integrated drilling program and integration of geophysical activities) and YMP-USGS SP 8.3.1.2.3.1 (Site saturated-zone ground-water flow system); some of these planned wells are shown on Figure 3.2-4.

It is proposed that three new water-table drill holes (WT-25, WT-26, and WT-27) be added in the area of large hydraulic gradient, and that the proposed location of FMN 1-10 be moved so as to take advantage of the data to be derived from the four new holes. The proposed new drill holes and relocations are shown in Figure 3.2-5. Also, the potential exists for deepening planned drillholes scheduled as part of the characterization of volcanic features (YMP-LANL-SP 8.3.1.8.5.1.5). In addition, the DOE NTS Environmental Restoration Program plans to drill monitoring wells CW-6, CW-9, and CW-10 in the vicinity of Timber Mountain that will provide valuable potentiometric and hydrochemical data from this upgradient area.

The three proposed boreholes (WT-25, -26, and -27) are needed to provide critically needed data from north of Yucca Mountain to adequately characterize: (1) the large hydraulic gradient; and (2) the upgradient ground-water flux boundary condition necessary for constructing site-scale ground-water flow models.

The three additional boreholes are discussed in the order of priority, and in the order in which they should be drilled. Figure 3.2-5 shows the locations for the three proposed wells, other proposed wells, and existing wells.

The highest priority is proposed well USW WT-25. This well should be drilled near the topographic divide between Yucca Wash and Beatty Wash. Topography permitting, the ideal site would be at Pinyon Pass just west of Pinnacles Ridge. This well will contribute to an understanding of the large hydraulic gradient as well as general potentiometric-surface conditions north of Yucca Mountain. Second priority is proposed well USW WT-26. This well should be drilled about one mile south of Beatty Wash at an approximate altitude of 1475 meters. This well, along with WT-25, will determine if a ground-water divide exists between Beatty Wash and Yucca Wash. It should be placed in the drilling schedule after USW WT-24. Third priority is proposed well WT-27. This well should be drilled on the topographic divide between Crater Flat and Beatty Wash. The exact location would depend on a reconnaissance of the topography of the area.

(The following discussion of proposed contributions of surface geophysics from other activities to this activity has been extracted from the draft geophysics white paper [Oliver and others, 1990].) The refined numerical model for ground-water flow at Yucca Mountain (Czarnecki and Waddell, 1984) employed the extensive geophysical investigations at the NTS in the development of a conceptual model of the hydrologic system. These included geophysical anomalies in the large hydraulic gradient area.

Because the water table does not appear to be a dependable target for sounding by electrical, gravity, or seismic methods, geophysical work in the large-gradient area will emphasize detection of geologic features giving rise to the gradient.

In a scoping study for using detailed gravity data for the investigation of the large hydraulic gradient, a density model was adjusted so that calculated gravity would agree with observed gravity, with the result that the existing gravity data appear to correlate to deep structure and are probably not significantly affected by the potentiometric surface. A feasibility study for the use of more detailed gravity data will consist of northwest profiles along the large-gradient area; the profiles will coincide with past magnetelluric profiles.

High-resolution temporal monitoring by means of a cryogenic-type gravimeter will also be considered, and possibly tested in the field. This method would be applied to the correlation of water-well level observations with atmospheric fluctuations, tidal acceleration, earth tides, and other geophysical phenomena at the site; and also to comparison of continuous gravity recordings with theoretical models that might result from active processes such as rising magma or active fault slip.

A program of closely spaced magnetelluric and audio-magnetelluric soundings is planned, oriented along northwest profiles across the large hydraulic gradient. Its purpose is to detect large-scale structures and lithologic variations that may be associated with the cause of the large hydraulic gradient.

Other geophysical surveys will also be employed in characterizing the large-gradient area, to identify anomalies that may cause the gradient and also possible targets for drilling or intensified geophysical exploration. They are planned mostly in conjunction with geology and tectonic studies, and are listed below:

(1) Detailed gravity study of the site area (Activity 8.3.1.17.4.7.2),

(2) Mini-Sosie seismic reflection surveys (Activity 8.3.1.4.2.1.2),

(3) Analysis of in-situ stress information obtained from fracture indications recorded by the borehole acoustic televiewer (Activity 8.3.1.4.2.2.3),

(4) Ground and airborne magnetic surveys (Activities 8.3.1.17.4.7.3 and 8.3.1.17.4.7.4), and

(5) Upper-crustal high-resolution seismic refraction (Activity 8.3.1.4.2.1.2).

Application of methods such as seismic reflection will depend in large part on testing and evaluation conducted elsewhere. In general geophysical studies of the large hydraulic gradient area involve significant feasibility testing, and integration with other planned geophysical testing and exploration activities.

The lithostratigraphic data collected in the exploratory shaft will assist (through Study 8.3.1.4.2.3, Geologic model) in defining the hydrogeologic units and the geometric relations among them for the description of the regional saturated-zone hydrologic system. The geometry and physical properties of fractures and faults will contribute to understanding the discontinuities in the hydrogeologic units of the system.

One of the products of Study 8.3.1.17.4.6 (Quaternary faulting within the site area) will be a map of all Quaternary faults identified within the site area. The northern boundary of the proposed coverage of the map impinges upon the large-gradient area that will be studied as part of this activity. Data on the geometry and offset of Quaternary faults near or within the large-gradient area can be used in the evaluation of the possible role of faulting as the cause of the gradient.

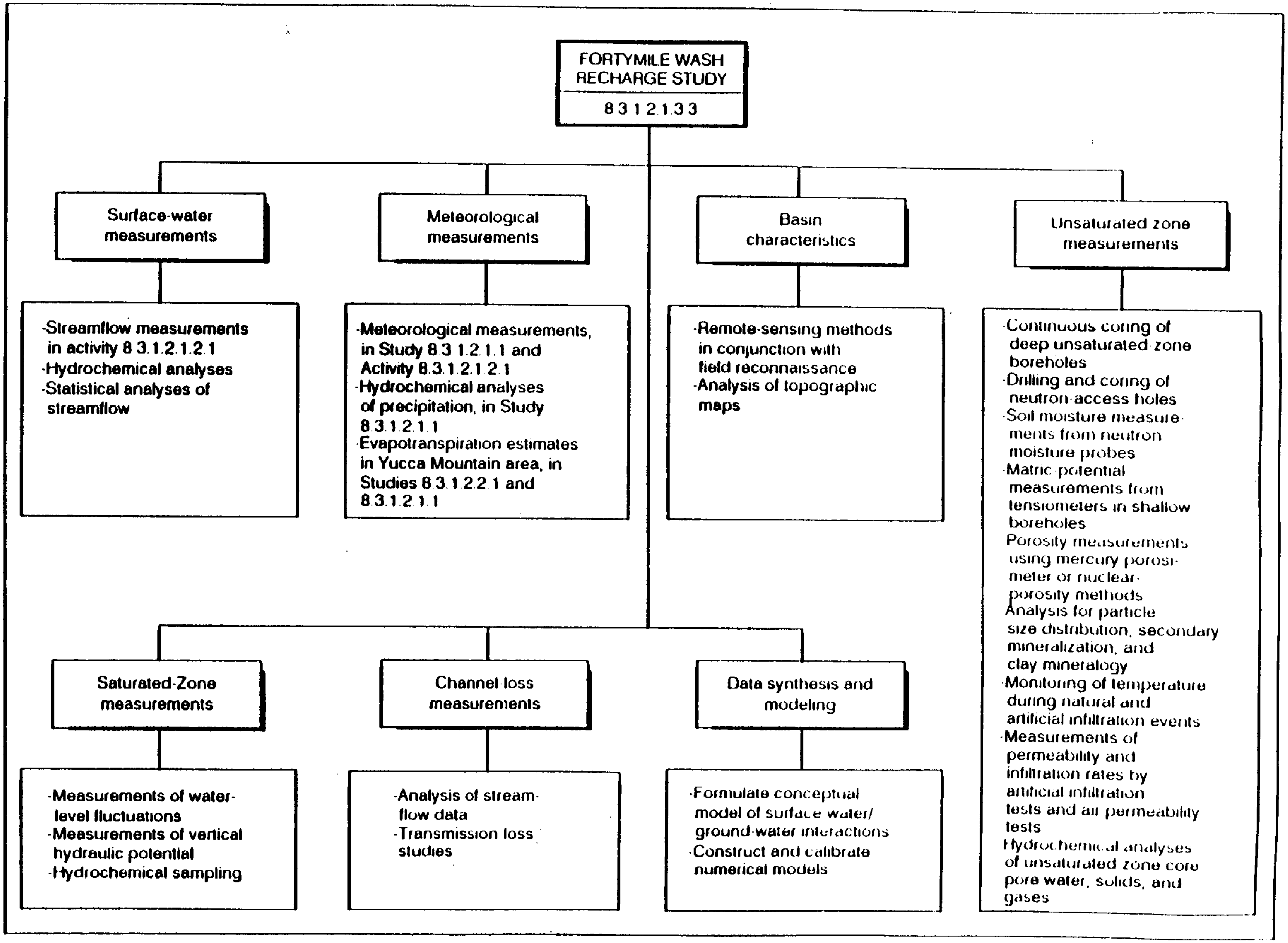
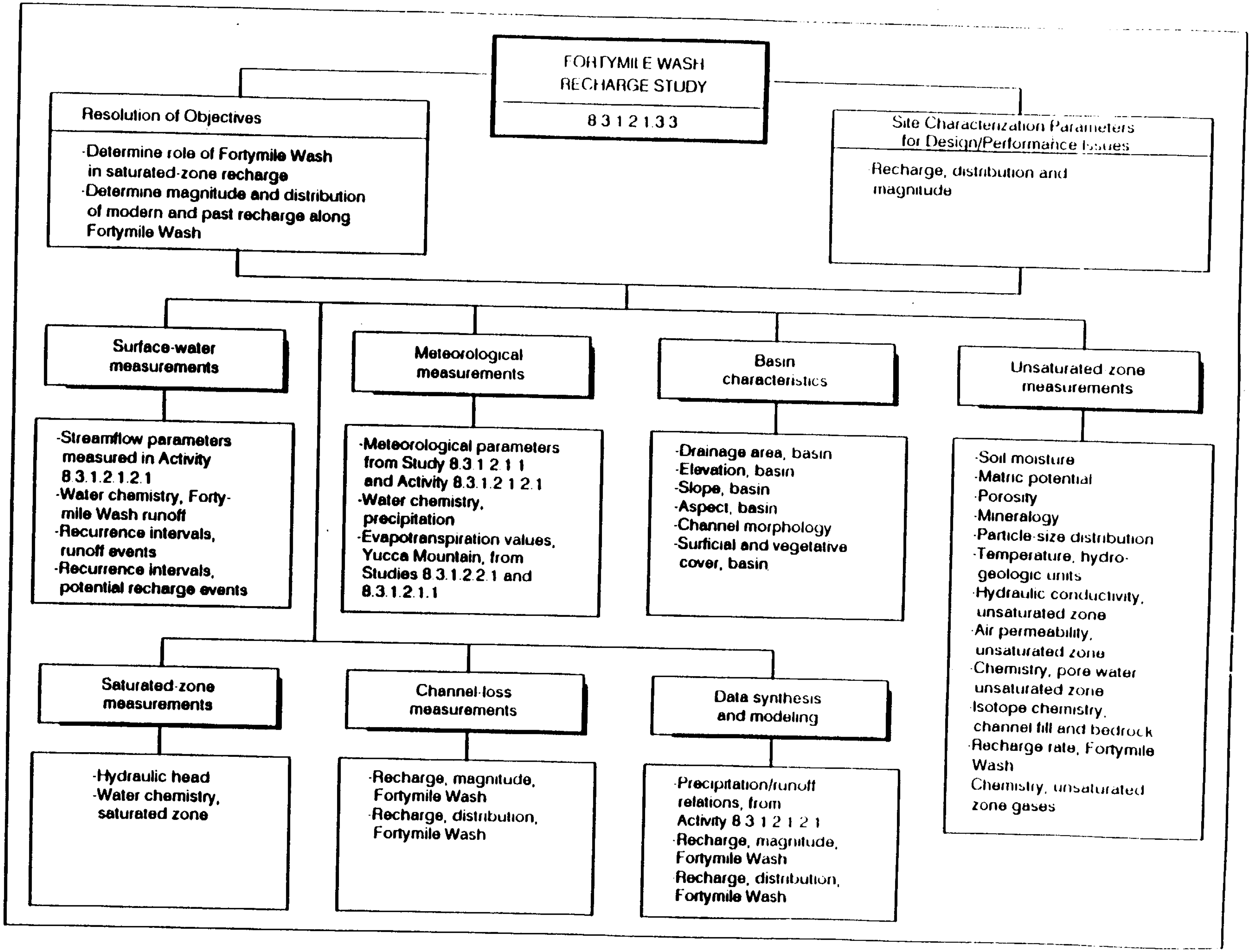


Figure 3.3-2. Logic diagram of Fortymile Wash recharge activity, showing tests, analyses, and methods



F[illegible]re 3.3-3. Logic diagram of Fortymile Wash activi[illegible] howing tests, analyses, and activity parameters

The height, distribution, and duration of stream stage along Fortymile Wash will be continuously measured at selected sites in the Fortymile Wash basin (Figure 3.3-4). Estimates of discharge at each of the sites will be made by indirect methods (such as the slope-area method) after the runoff event has occurred, YMP-USGS SP 8.3.1.2.1.2 (Regional surface-water runoff and streamflow). Continuously recorded stream-stage data will be converted into a continuous record of the rate and volume of discharge. Direct measurement of stream discharge would be difficult due to the rare, intense, localized nature of precipitation-runoff events in the Yucca Mountain area (YMP-USGS SP 8.3.1.2.1.2). Estimates of total discharge during precipitation-runoff events will be used to estimate channel losses between gaging stations. Channel losses, when corrected for evapotranspiration and tributary-stream inflow, will provide an estimate of the total amount of water available for ground-water recharge.

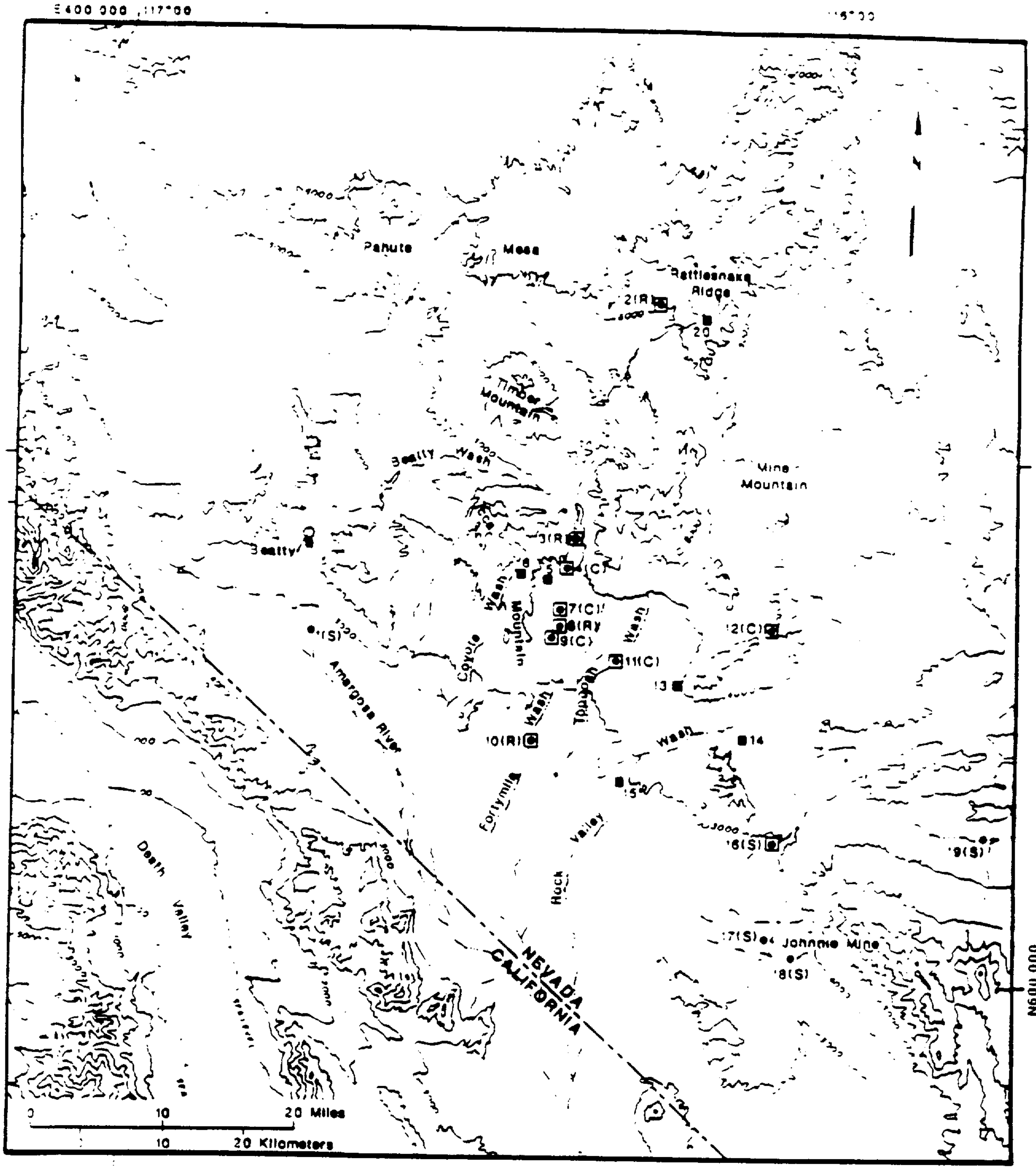
Streamflow measurements will be made at three types of gaging stations (sites): (1) continuous recording stations (primary sites), (2) crest-stage gaging stations (secondary sites), and (3) spot estimates of stream discharge by observers at select sites (tertiary sites). Four permanent primary sites exist along Fortymile Wash (see YMP-USGS SP 8.3.1.2.1.2 for locations and a description of the sites, and procedures to be used). The locations of the secondary crest stage sites have been determined, and are indicated in YMP-USGS SP 8.3.1.2.1.2. Stream discharge at tertiary sites will be monitored by observation of flow through appropriate hydraulic structures (culverts, open channels, etc.).

3.3.3.1.2 Hydrochemical analyses

Water samples of runoff in Fortymile Wash will be collected and analyzed for major cations, anions, pH, specific conductance, and stable isotopes. Hydrochemical data will provide necessary data on modern water chemistry, such as background levels on stable isotope activities, the relation between precipitation-runoff events, and the distribution of chemical species in surface waters.

3.3.3.1.3 Statistical analyses of streamflow

Statistical analyses of the magnitude, duration, and recurrence of runoff events will be done to determine recurrence intervals for various types of events. This type of analysis is necessary to characterize the duration, timing, and magnitude of potential recharge events along Fortymile Wash. Further discussion of statistical analyses is contained in YMP-USGS SP 8.3.1.2.1.2.



Key

- Rain gage
- Stream gage
- Rain gage and stream gage
- (R) Recording stream gages
- (C) Crest-stage gages
- (S) Crest-stage gage, part of statewide net

Figure 3.3-4. Existing regional precipitation and streamflow stations.

3.3.3.2 Meteorological measurements

Meteorologic measurements of barometric pressure, temperature, wind speed, net solar radiation, and the magnitude and distribution of precipitation will be utilized in the estimates of the amount of water available for areal infiltration throughout the Fortymile Wash drainage basin. Meteorologic data will be measured by the regional meteorologic network (YMP-USGS SP 8.3.1.2.1.1.) and the supplementary network at the streamflow data sites (Figure 3.3-4).

Rain gages (recording and storage gages) will be used to measure the duration, magnitude, and distribution of rainfall throughout the Fortymile Wash drainage basin. Recording gages will be of the tipping bucket or weighing bucket type; data from these devices will be recorded by analog or digital devices. Storage gages will be either standard aluminum cans or plastic containers with graduated markings; these devices will be monitored by observers. Snow accumulation, storage, and dissipation will be monitored by using observers and snow pillows (a snow pillow consists of an inflated elastomeric bladder connected to a pressure transducer in such a way that the weight of snow falling on the bladder may be determined by pressure changes in the bladder). Continuous-recording thermometers or thermographs will be used to measure temperature variations at selected stream-gage sites. Meteorologic measurements will be used to characterize the relation between precipitation events and resulting runoff in the Fortymile Wash basin. Further discussions of the methods and devices to be used and analyses to be done during the meteorological study are contained in YMP-USGS SP 8.3.1.2.1.1 (Regional meteorology).

Hydrochemical analyses will be done on water samples collected during precipitation events. Hydrochemical data will provide necessary data on modern water chemistry, such as background levels on stable isotope activities, and the relation between precipitation-runoff events and the distribution of chemical species in surface waters (see YMP-USGS SP 8.3.1.2.1.1 for a detailed discussion of hydrochemical analyses).

Estimates of recharge along Fortymile Wash must account for evapotranspiration losses. The depth to which evapotranspiration occurs in the Yucca Mountain area is not likely to exceed 15 m (Rush, 1970), and probably will not exceed 3 m because of the lack of vegetation in the active stream channel. Water that infiltrates past the zone of evapotranspiration is net infiltration; it is the amount of water that may eventually percolate down to the saturated zone (ground-water recharge). Estimates of evapotranspiration in the Yucca Mountain area will be made as part of YMP-USGS SP 8.3.1.2.2.1 (Unsaturated-zone infiltration), YMP-USGS SP 8.3.1.2.1.1, and YMP-USGS SP 8.3.1.5.2.1 (Quaternary regional hydrology); a detailed discussion of the measurement of evapotranspiration is contained in the first of the above study plans. Evapotranspiration probably will not vary significantly in the Yucca Mountain area; therefore, this activity will be using data collected and analyzed as part of the above-mentioned study plans.

3.3.3.3 **Basin characteristics**

Drainage basin characteristics are needed for precipitation-runoff modeling and channel loss estimates, and include: drainage area, elevation, slope, aspect, channel morphology, and surficial and vegetative cover. Topographic maps, digital terrain data, and remote sensing data will be used to determine basin characteristics.

Remote sensing methods will be used in conjunction with field-reconnaissance mapping to characterize surficial and bedrock deposits, and vegetative cover distribution and types. Data to be used in remote sensing studies (Activities 8.3.1.5.2.1.3 and 8.3.1.2.2.1.1) will include satellite-based data (thematic mapper and multispectral scanner imagery), low-altitude areal photography, and digital elevation data. Basin characteristics that cannot be determined using remote-sensing methods will be determined by map analysis. A detailed description of remote sensing activities can be found in YMP-USGS SP 8.3.1.5.2.1, RO.

3.3.3.4 **Unsaturated-zone measurements**

Unsaturated zone measurements will be made in two types of boreholes: (1) deep boreholes designed to penetrate into the saturated zone about 100 m, and (2) shallow boreholes for soil-moisture content measurements (hereafter referred to as neutron-access holes). Soil-moisture content will be determined by nuclear geophysical logging methods. Deep boreholes and neutron-access holes will be used to monitor unsaturated-zone and saturated-zone response during artificial infiltration tests and during natural runoff events. Holes that penetrate the saturated zone will also be used to obtain unsaturated-zone and saturated-zone water and core samples to determine modern and paleo infiltration rates based on hydrochemical and geohydrologic properties.

Boreholes UE-25 FM#1 (approximately 427 m deep), UE-25 FM#2 (approximately 381 m deep), and UE-25 FM#3 (approximately 290 m deep) will be located in Fortymile Wash (Figure 3.3-5), all of which are designed to penetrate the saturated zone. The approximate depths shown reflect the best estimates of the depths necessary to penetrate the saturated zone sufficiently (approxmiately 50 m) to permit hydraulic and hydrochemical testing. The locations were selected to augment the data to be obtained from the FMN-series holes and to examine deep-recharge conditions for different depth regimes along Fortymile Wash. Further, it is thought that the Calico Hills formation at FM#2 will be unsaturated, which could have a large effect on recharge mechanisms and potential flow paths to the saturated zone. All three boreholes will be continuously cored to obtain a complete lithologic record. Continuous core is particularly important in locating and characterizing layers with small values of permeability, such as caliche.

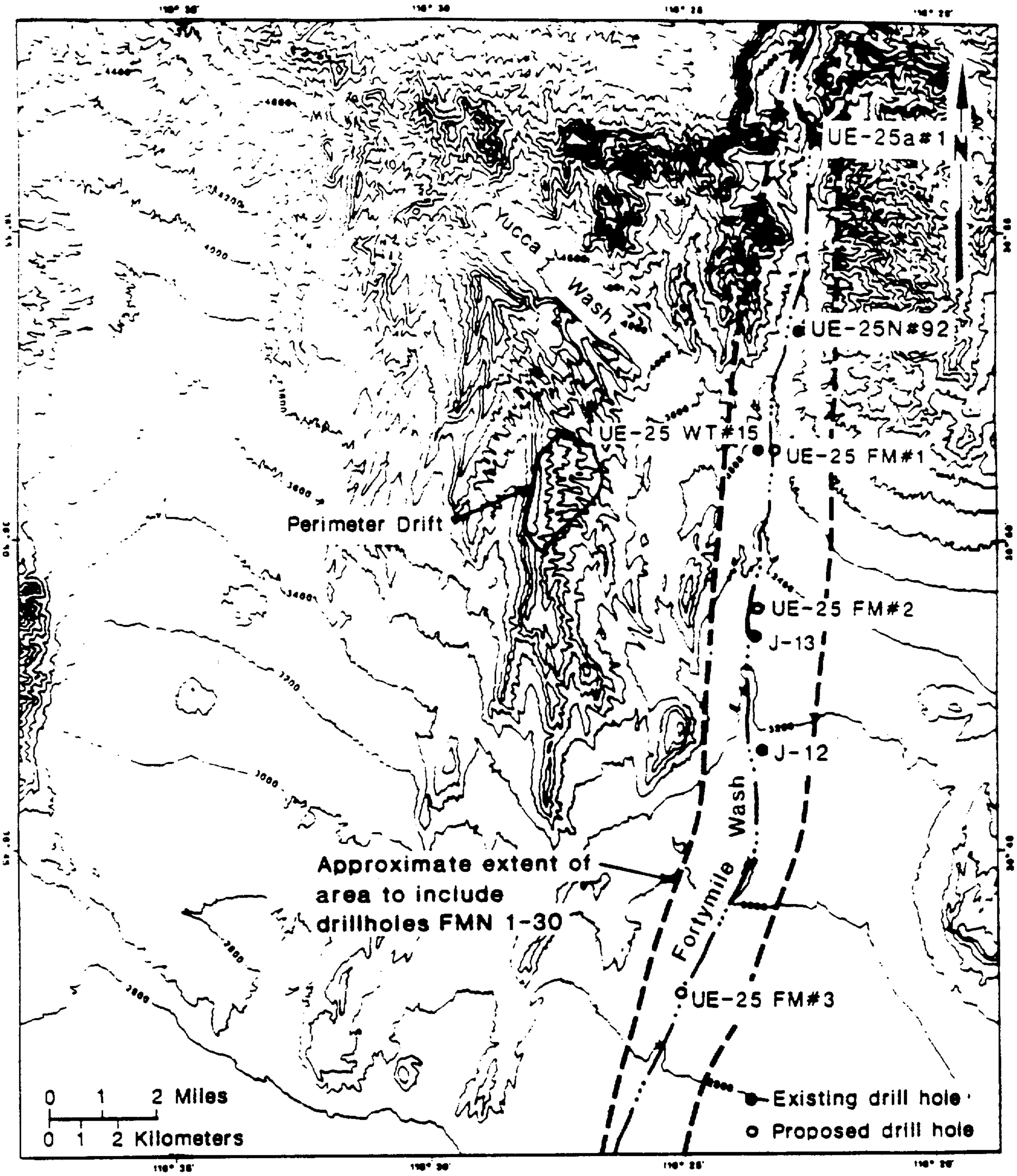


Figure 3.3-5. Location of existing and proposed drillholes for the Fortymile Wash recharge study.

Approximately 20 to 30 neutron-access holes will be located in or across Fortymile Wash to give sufficient areal and linear coverage to represent recharge conditions in active and non-active portions for different sediment regimes of the channel; the locations of these holes has not yet been determined. The final number of drill holes will depend upon the number and length of cross-sectional lines ("fences") specified by the investigator. These holes will be located to define the upper limit of the saturated zone, and to monitor moisture content under natural conditions, during precipitation-runoff events, and possibly during artificial recharge experiments. Continuous or discontinuous core will be obtained in some of the neutron-access holes to help define the lateral distribution of units with small vallues of permeability. All of the neutron-access holes will be drilled to a depth of at least 50 m, and some will be drilled into the saturated zone. Holes will likely be drilled using the ODEX method, which provides a skin-tight fit of the driven casing within the borehole.

Measurements to be made in the unsaturated zone will provide data on the distribution of soil moisture, porosity, permeability, and the hydrochemical composition of pore waters and channel-fill materials. The deep boreholes and neutron-access holes will be used for monitoring moisture content under natural conditions, during natural runoff events, and during artificial recharge experiments. Soil moisture measurements will be done on core obtained from deep boreholes and from neutron-access holes. Measurements made on core will be used in conjunction with moisture content profiling in the boreholes to determine moisture-flux in the unsaturated zone during artificial infiltration tests and during natural runoff events in Fortymile Wash. Data generated here may have application to the analog-recharge activity (8.3.1.5.2.1.4) of YMP-USGS SP 8.3.1.5.2.1.

3.3.3.4.1 Soil moisture

Soil moisture will be measured using core obtained from the deep boreholes and from the neutron-access holes. Soil moisture will be determined by the gravimetric method (wet weight versus dry weight) (see YMP-USGS SP 8.3.1.2.2.1, Activity 8.3.1.2.2.1.1, Hydrologic properties of surficial materials). Neutron moisture probes (compensated-epithermal neutron) will be used to determine relative and absolute moisture contents with depth in the neutron-access holes and the deep boreholes.

Neutron moisture probes will be calibrated using both laboratory and field data. Laboratory calibrations require the construction of models that simulate borehole conditions; such models are difficult to construct and may not provide adequate calibration data. Field calibration of neutron moisture probes involves the correlation of moisture content obtained from core samples and probe response. Neutron moisture probe calibration is discussed in detail in YMP-USGS SP 8.3.1.2.2.1.

3.3.3.4.2 Matric-potential measurements

To adequately characterize infiltration in the unsaturated zone, measurements of hydraulic head (or matric potential) will be done. Matric potential will be measured using tensiometers that will be installed in small-diameter boreholes. Several tensiometers may be installed in a single hole to determine the vertical variation of matric potential. Intervals for monitoring will be selected based on the character of the strata beneath Fortymile Wash. The holes for measurement of matric potential will not be greater than 10 m deep, and will be located along the channel of Fortymile Wash next to neutron-access holes. Tensiometer nests will also be installed in infiltrometer sites to characterize the flux of water in situ.

3.3.3.4.3 Porosity

Porosity will be determined from laboratory measurements on core using a mercury porosimeter, or by using nuclear-porosity methods. In situ porosity measurements will be made in the deep boreholes and the neutron-access holes using neutron-porosity probes. A detailed discussion of laboratory and field porosity determination, and calibration of the neutron porosity probe is contained in YMP-USGS SP 8.3.1.2.2.1.

3.3.3.4.4 Mineralogy and particle-size distribution

Samples of core from each well will be analyzed for particle-size distribution, secondary mineralization (such as caliche), and clay mineralogy. Particle-size distribution can be used to estimate permeability and porosity, and to infer depositional environments. The clay mineralogy of core samples will be analyzed to determine clay mineralogy and distribution; detailed discussion of clay mineralogy studies can be found in SCP Section 8.3.1.3.2.2. Clay mineralogy may indicate depositional environments and indicate qualitatively the intensity and duration of recharge that has occurred through the channel fill. The presence of authigenic clay coating on sand and gravel grains also may indicate localized recharge.

The distribution and degree of cementation by secondary minerals may provide paleoclimatic information. Studies of caliches will potentially lead to correlation with wetter or cooler periods of deposition than the present, as determined by other methods, such as the study of packrat middens in YMP-USGS 8.3.1.5.1.4 (Paleoenvironmental history), and paleohydrologic studies in YMP-USGS SP 8.3.1.5.2.1.

3.3.3.4.5 Temperature profiling

Temperature will be periodically monitored in the unsaturated zone and saturated zone during natural and artificial infiltration events (Study 8.3.1.8.5.2, Characterization of igneous intrusive features). Temperature profiles can be used to estimate moisture flux through the unsaturated zone (Sass and others, 1987).

3.3.3.4.6 Permeability and infiltration rates

Numerous workers have investigated unsaturated-zone infiltration and permeability. Early work was done by Schiff (1953), Aronovici (1954), Burgy and Luthin (1956), Franzini (1956), and Bower (1962). Recent work by Gillespie and Hargadine (1976), Gillespie, Hargadine, and Stough (1977), Libardi and others (1980), Lichtler, Stannard, and Kouma (1980), Sophocleous and Perry (1987), and Gillespie and Perry (1988) provide the basis for investigating infiltration and permeability along Fortymile Wash. Weeks (1978) gives a detailed description of air permeability testing and interpretation of test results. The following discussions of plans to measure infiltration rates and permeabilities along Fortymile Wash draw heavily from the above-mentioned works.

3.3.3.4.6.1 Artificial infiltration tests

Infiltrometers will be used for infiltration and ponding tests based in part on the methodology and equipment used in Gillespie and Hargadine (1976), Gillespie, Hargadine, and Stough (1977), Libardi and others (1980), Lichtler, Stannard, and Kouma (1980), Sophocleous and Perry (1987), and Gillespie and Perry (1988). An infiltrometer will consist of a galvanized steel ring (stock tank) approximately 3 to 10 m in diameter and 1 m deep. Infiltrometers will be installed so that the bottom of the ring is beneath the ground surface about 0.3 m. Infiltrometers will be placed around each of the deep boreholes, and around neutron-access holes. There will be a minimum of four infiltrometer sites: (1) one around each deep borehole (UE-25 FM#1, UE-25 FM#2, UE-25 FM#3), and (2) one located upstream of UE-25 FM#1, possibly near UE-29 a#1 (Figure 3.3-5). This northernmost site will be constructed around one or more neutron-access holes, at least one of which will be continuously cored. The purpose of this site will be to characterize recharge rates, volumes, and history at a site where fractured bedrock and the saturated zone occur at shallow depth beneath the channel of Fortymile Wash.

Two types of infiltration tests will be done: steady-state and dynamic. Volumetric flux into the infiltrometers and water levels in the infiltrometers will be monitored during all infiltration tests and natural runoff events. Water levels in the deep boreholes and neutron holes that penetrate the saturated zone will be monitored also. Steady-state tests involve filling an infiltrometer to a desired depth, and maintaining that water level in the infiltrometer during the first part of the test. Moisture content in the unsaturated zone will be monitored during such tests. As moisture content approaches a constant value, steady-state flux conditions will prevail. After steady-state conditions have been achieved, the water supply will be discontinued. Determination of moisture content using neutron moisture probes as the soil column drains will be used to derive estimates of unsaturated-zone hydraulic conductivities (Libardi and others, 1980).

Dynamic tests will be used to simulate streamflow hydrographs. Hydrographs will be determined from monitoring natural runoff events and from numerical simulation of surface-water flow (precipitation-runoff modeling). Infiltrometers will be filled according to a representative streamflow hydrograph. Volumetric flow into the infiltrometer, water levels in the infiltrometer, and soil moisture in the unsaturated zone will be monitored during these tests. Water-level fluctuations during these tests will be monitored also. The dynamic tests will provide information on unsaturated zone response during natural runoff events (Gillespie and Perry, 1988).

3.3.3.4.6.1.1 Prototype artificial infiltration tests

A prototype artificial infiltration test will be done at UE-25 N#92 located in Fortymile Wash (Figure 3.3-5). This test will be done to evaluate methods of monitoring water movement through the unsaturated zone and to determine the feasibility of testing at what may be considered to be fairly representative of other additional sites. A small-diameter (approximately 3 m) infiltrometer will be emplaced around UE-25 N#92 and a steady-state type infiltration test will be done. The test will be done to determine if a single moisture probe can be used to track moisture fronts as they move downward through the unsaturated zone. (Infiltration water can be tagged with Be to verify transport proceses.) If a single probe is inadequate then a multi-level probe technique will have to be developed. Another uncertainty is whether a single neutron-access hole will be adequate to quantify the amount of water moving in the unsaturated zone; three or more such holes may be necessary to better define cross-sectional areas through which infiltration may occur.

3.3.3.4.6.2 Air permeability tests

Water-level fluctuations due to barometric fluctuations will be recorded in the deep boreholes (UE25 FM#1-3) and, possibly in some of the neutron-access holes that intersect the top of the saturated zone. Analysis of these fluctuations can be used to determine air permeability and estimate bulk hydraulic conductivity for the unsaturated zone (Weeks, 1978).

The method of Weeks (1978) for determining air permeability can also be used to characterize layers in the unsaturated zone that may impede infiltration (such as caliche or clay layers). If such layers are encountered during drilling of the deep boreholes or neutron-access holes, one or more additional small-diameter, shallow (< 100 m) boreholes will be drilled for the purpose of measuring the air permeability of such layers. These holes will be instrumented with small-diameter piezometers, backfilled, and sealed at land surface. The piezometers will be placed so that they bracket suspected zones of small permeability; bracketing such zones will allow the determination of their permeability. This technique provides a simple way to characterize the permeability of large volumes of material and will be used if time and personnel permit.

3.3.3.4.7 Hydrochemical analyses of unsaturated-zone core

Hydrochemical analyses of unsaturated zone core will be done to determine the chemical composition and the absolute and relative ages of pore waters and channel fill materials. Oxygen-18 and deuterium can be used to infer paleoclimatic conditions under which recharge occurred (Freeze and Cherry, 1979). Isotopic fractionation occurs when water is evaporated or precipitated, because water that contains oxygen-18 and deuterium has slightly different vapor pressures and freezing points compared to water composed of oxygen-16 and hydrogen. Thus, evaporation produces "light" water (depleted in oxygen-18 and deuterium), and condensation produces "heavy" water (enriched in oxygen-18 and deuterium) (Freeze and Cherry, 1979). Fractionation processes result in progressively lighter precipitation at higher elevations, nearer to the poles and farther inland. Therefore, recharge that occurred under a different climatic regime compared to the modern climate will have different isotopic composition.

Atmospheric testing of thermonuclear devices during the 1950s and 1960s resulted in precipitation enriched in tritium and chlorine-36, both of which are non-reactively transported in solution in the unsaturated and saturated zones. Tritium has a half life of 12.3 years, and chlorine-36 has a half life of about 300,000 years. High concentrations of tritium and chlorine-36 in pore waters, sediments, and ground-water have been used to infer infiltration rates and recent recharge (Norris and others, 1987; Freeze and Cherry, 1979). Carbon-14 is a naturally occurring isotope of carbon with a half life of 5,730 years, and has been used extensively to date ground water (Freeze and Cherry, 1979; Mook, 1980). Carbon-13, a stable isotope of carbon, can be used to correct carbon-14 ages, because carbon-14 and carbon-13 undergo similar fractionation processes (Mook, 1980).

The presence of elevated beryllium-10 (Be-10) concentrations in the unsaturated zone may indicate: (1) buried soil horizons, (2) slow movement in solution with infiltrating water in the unsaturated zone, or (3) transport on sediment moving downward with water through the unsaturated zone (Osterkamp, 1989). Be-10 is a naturally occurring cosmogenic radioisotope (half-life approximately 1.5 million years) of known accumulation rate with precipitation (Brown, 1987). Because Be-10 becomes tightly bound and concentrated on soil sediment, its movement and storage are related to those of water and sediment. Information about the distribution of Be-10 will provide corroborative evidence of modern and paleo infiltration rates.

It appears probable that during late-Quaternary time, all discharge events that resulted in transmission losses and ground-water recharge along Fortymile Wash and other Nevada Test Site channels added Be-10 to the unsaturated zone. Successive recharge events resulted in progressive transport of the Be-10 to deeper horizons of the unsaturated zone. Profiles of Be-10 concentrations with depth will be used with a one-dimensional solute-transport model to estimate (1) where recharge has been most pronounced during the last 50,000 years or more and (2) variations in recharge rates during the same time period. Because the subsurface concentrations will be related to modern deposition rates and inventories of Be-10, losses by eolian and biologic processes will not be of consequence.

Be-10 will be bound up with both primary and authigenic clays, as well as with quartzitic silts and sands. It is this characteristic that makes Be-10 a superior tracer in sediments. Its partition coefficient of 1×10^{-5} allows it to move wherever sediment is carried.

Goel and others (1957) and Amin and others (1966) were the first to use Be-10 to determine sedimentation rates in the ocean. Determined values agreed fairly well with sedimentation rates determined from the same cores by the ionium method of dating and by magnetic-reversal stratigraphy.

Be-10 content is determined with the mass-spectrometer technique of isotope dilution, Be-7 with low-level counting, and Be-9 is added to the samples to serve as a spike for the former and as a carrier for the latter. After spiking with Be-9 and acidification with HCl, the samples are analyzed from Be-10 in a tandem Van de Graaff acceleration.

The Be-10 concentrations of soil and modern lacustrine sediments are not yet well known. Braun and others (1981) showed that sediment from the Atchafalaya River in Louisiana, has an average Be-10 concentration of about 4.4×10^{8} atoms per gram. In comparison, Osterkamp (1989) reported samples from lacustrine beds of playas on the Southern High Plains with Be-10 concentrations up to 30×10^{8} atoms per gram. Samples from near-surface channel deposits at the NTS are expected to have Be-10 concentrations between these two values.

3.3.3.4.7.1 Pore water

Pore water from core obtained from the deep boreholes and neutron-access holes will be analyzed for oxygen-18, deuterium, carbon-13, carbon-14, tritium, and chlorine-36. As discussed above, these isotopes will be used to determine ground-water age, and to infer paleoclimatic conditions and natural infiltration rates. (Refer to YMP-USGS SP 8.3.1.2.2.7, Unsaturated-zone hydrochemistry, Section 3.2, for detailed discussion of aqueous-phase sampling and analyses.)

3.3.3.4.7.2 Solids

Channel-fill material from core and cuttings obtained from the deep boreholes and neutron-access holes will be analyzed for oxygen-18, deuterium, chlorine-36, and beryllium-10 content, all of which may be useful in determining recharge. Chlorine-36 is a natural tracer that has been used to characterize natural infiltration rates (Norris and others, 1987).

Surface sediments and core samples will be analyzed for beryllium-10 content. By measuring inventories, accountings of beryllium-10 per unit area at channel and interchannel sites, comparisons will be made with the known accumulation rate. Numerical modeling of beryllium-10 transport through the unsaturated zone can provide estimates on rates of recharge at channel versus interchannel sites, and give an indication of the total time during which recharge has occurred.

3.3.3.4.7.3 Gases

Gas samples will be collected from the unsaturated zone near the top of the saturated zone (as described in YMP-USGS SP 8.3.1.2.3.2 and YMP-USGS SP 8.3.1.2.2.7). Gas samples will be analyzed for deuterium, oxygen-18, carbon-13, carbon-14, and tritium, and for major components (carbon dioxide, nitrogen dioxide, etc.). This data will be used in the determination of paleoclimatic conditions, the state of equilibrium of the system, and relative and absolute ages for unsaturated-zone gases.

3.3.3.5 Saturated-zone measurements

3.3.3.5.1 Depth to water and bedrock

Depth to water will be obtained from the deep boreholes and from neutron holes that penetrate the saturated zone. Fluctuations in the water table will be monitored during natural and artificial infiltration events; a rise in the water table during these events is direct evidence that recharge is occurring (excluding barometric effects). Water table fluctuations associated with barometric changes and the position of the moon (earth tides) will also be monitored and analyzed. Barometric-fluctuation effects are discussed under Section 3.3.3.4.3.2 (Air-permeability tests). Earth tide fluctuations, commonly observed in confined aquifers, can be used to infer aquifer permeability and compressibility.

Well hydrographs may provide evidence of recharge events during periods of elevated precipitation. Hydrographs recording water level changes in the vicinity of Yucca Mountain will be analyzed for the presence of rapid or sustained rises in water levels corresponding to wet years (such as the period of 1984-85).

Evidence of water-table rise beneath ephemeral streams following runoff events in Walnut Gulch, Arizona, is given in Renard and others (1964).

The draft geophysics white paper (DOE, 1989) proposes the use of geophysical methods to (to the extent feasible) to detail the depth to bedrock in the vicinity of Fortymile Wash borings, and also for reconnaissance. Available methods include:

(1) Seismic refraction for shallow and intermediate-depth contacts,

(2) High-resolution gravity profiling across features such as Fortymile Wash, and

(3) Seismic reflection surveys for deeper targets.

Planned reviews of seismic and electrical methods (Studies 8.3.17.4.7.1 and 8.3.1.17.4.7.5) will address the objective of sounding depth to bedrock.

An alluvial thickness model for Amargosa Desert has been assembled from the analyses of electrical resistivity, gravity, and seismic refraction surveys, and from lithologic data from test borings and irrigation wells. This model will be used in ongoing numerical models of the ground-water flow system. The mapping of alluvial thickness from analysis of geophysical data could probably also be applied north of the Amargosa Desert in areas such as Fortymile Wash and Jackass Flats. The detection of low-permeability units in the alluvium may be best accomplished by coring, but in place of coring downhole geophysical logging will be used. The use of the neutron moisture meter tool in steel-cased borings has been applied at Yucca Mountain to detect infiltration to depths as great as 10m. The same method would be used in major recharge areas such as Fortymile Wash, but extended to depths of hundreds of meters.

3.3.3.5.2 Vertical hydraulic potential

If possible, vertical hydraulic potential will be measured in the deep boreholes at a minimum of two positions (using inflatable packer assemblies): near the top of the saturated zone, and near the bottom of each borehole. Downward vertical hydraulic potentials often exist in areas of recharge (Freeze and Cherry, 1979). Periodic measurements will be made. Flow meters will also be used (as appropriate) for the measurement of vertical hydraulic potential.

3.3.3.5.3 Hydrochemical samples

Hydrochemical samples will be obtained from the deep boreholes (UE-25 FM#1, UE-25 FM#2, UE-25 FM#3) and from neutron-access holes that penetrate the saturated zone. Analyses will include determination of major cation and anion species, pH, specific conductance, temperature profiles, dissolved carbon dioxide, dissolved oxygen, oxygen-18, deuterium, carbon-14, carbon-13, chlorine-36, tritium, and dissolved organic species. Sampling may be done by pumping, use of borehole samplers (such as as thief samplers or bailers), or use of a multi-level *in situ* sampler (Ronen and others, 1985). Hydrochemistry beneath Fortymile Wash may be useful to determine ground-water ages (relative and absolute) and infiltration rates and history.

Pumping methodology may involve use of one of the following: 1) an electrical submersible pump, 2) a bladder-air-driver pump, or 3) a positive-displacement piston pump. If a thief sampler is used, the principle of operation is to lower an open sample vessel downhole using a cable, and to seal it by sending a "messenger" down the cable to activate the sealing mechanism; by this method ambient gas concentrations may be preserved.

The multilevel *in situ* hydrochemical sampler is a modular tool consisting of a series of sample vessels (typically 20-ml polyethylene bottles), the ends of which are replaced with dialysis membranes. The sample vessels (or "cells") are initially filled with water of a known chemistry (typically distilled water). The cells are held in place using a rigid inert rod, and are separated from each other through the use of flexible disks.

The entire assembly is lowered downhole such that flexible disks fit snugly against the borehole or well screen, and remain sufficiently long downhole so that the initial (distilled) water in the cells comes into equilibrium with the water in the borehole and formation (approximately 48 to 100 hours depending on ambient hydraulic conductivity). Ionic and neutral species move across the membrane because of the chemical gradient across the membrane.

The sampler is then removed from the borehole and the water samples analyzed. Vertically stratified hydrochemical samples can be obtained using this type of sampler; ambient, undisturbed profiles of the chemistry in the saturated zone can be obtained at resolutions as small as 3 cm.

Water samples will be collected if perched ground water is encountered during drilling. Drilling into perched-water zones will be accomplished by the procedures discussed in YMP-USGS SP 8.3.1.2.2.4 (Unsaturated-zone percolation - ESF) in the section on the perched-water test (Activity 8.3.1.2.2.4.7).

3.3.3.6 Channel-loss measurements

Channel loss estimates will be made by: (1) analyzing streamflow data along Fortymile Wash, and (2) by analysis of the geomorphic features of Fortymile Wash and its tributaries (transmission-loss studies).

3.3.3.6.1 Analysis of streamflow data

A direct method of estimating recharge along Fortymile Wash is the analysis of streamflow measurements. Data from gages on Fortymile Wash will be examined to determine flow reductions, adjusted for evapotranspiration and tributary inflow, in the downstream direction during individual flow events. These data and results will be compared to much more extensive data sets from other areas of similar climate (similar climate does not necessarily imply similar precipitation-runoff relations, because of differing geomorphology). Among these areas are southern Arizona (Walnut Gulch), western Kansas, and southern Israel.

3.3.3.6.2 Transmission-loss studies

Transmission-loss studies entail the collection of data, through field work and existing sources, to obtain estimates of modern and paleo-transmission losses along channels in the Yucca Mountain area. Two methods will be used to indirectly estimate long-term recharge along Fortymile Wash; these will be compared and analyzed with respect to direct measurement techniques. The two methods are: (1) the channel-geometry method, and (2) the distributed simulation model technique. Additionally, all runoff events will be monitored for channel losses to the extent practicable.

Through the channel-geometry method, discharge characteristics at several sites within a channel will be estimated through measurement of channel properties. Differences in these estimates, after accounting for tributary inflow, will indicate changes in discharge in the downstream direction. These changes in discharge, therefore, may be indicative of transmission losses. The channel-geometry method is a modification of the hydraulic-geometry concept (Leopold and Maddock, 1953), but differs from it in that it has the advantage of being easily applied, and yields estimates based on channel characteristics formed by the water and sediment discharge of a stream. Thus, the size of an alluvial channel is assumed to be a function of the water-sediment mixture conveyed through that channel, and the shape of the channel is largely a result of the sediment sizes transported during flow events. The basis of the channel-geometry method is the continuity equation for discharge (water) of a stream (Hedman and Osterkamp, 1982):

$$Q_i = WDV, \qquad \text{(Eq. 3.3-1)}$$

where Q_i is instantaneous discharge, W is water-surface width, D is mean depth of water, and V is mean velocity of water. Considering numerous stream sites of various flow characteristics, the simplifying assumption is made that the rates of change of W, D, and V with Q_i are constant, and, therefore, can be expressed by a multiple-regression equation. This assumption requires that Qi represents the same flow frequency (flow duration or recurrence interval) at all sites considered. The equation is

$$Q_i = kW^b D^f V^m, \qquad \text{(Eq. 3.3-2)}$$

where k is a coefficient and b, f, and m are exponents. This form of the continuity equation can be expressed as three simple proportionalities:

$$Q_i \sim W^b \qquad \text{(Eq. 3.3-3)}$$
$$Q_i \sim D^f$$
$$Q_i \sim V^m,$$

the practical use of which requires that water-surface width, mean water depth, and mean water velocity be measured for the same flow frequency at all sites considered. This requirement cannot be met because stream stage cannot be related to a flow-frequency if the site is ungaged, and because the three parameters cannot be measured at many or most flow frequencies for intermittent and ephemeral streams (such as those in the vicinity of Yucca Mountain).

To avoid the necessity of surface-water measurements, therefore, the channel-geometry method relies on measurements obtained from a geomorphic reference feature recognizable at channel sites. When using a geomorphic level as a basis of evaluating flow characteristics, velocity, of course, cannot be measured. Mean channel depth generally is measured and related to discharge, but variability of channel profiles and the capacity for measurement error may lead to unreliable results. Thus, the channel-geometry relations will be largely limited to channel-width measurements as an independent variable and will yield a specified measure of discharge as the dependent variable:

$$Q_v = aW^b, \qquad \text{(Eq. 3.3-4)}$$

where "a" is a coefficient, and Q_v is a measure of streamflow, such as mean discharge or a flood discharge of specified recurrence interval. Coefficients and exponents for flow frequencies of the above equation will be determined by relating widths to discharges at many gaged stream-channel sites of the western United States; many of these measurements are already available. The resulting equations will be compared to data from gage sites in the Yucca Mountain region, and then adjusted equations will be applied to ungaged channel sites in the area of Yucca Mountain. Thus, estimates of discharge characteristics and transmission losses will be obtained. More detailed discussions of the channel-geometry technique and available data bases can be found in Moore (1968), Hedman (1970), Hedman and others (1972), Hedman and Osterkamp (1982), Osterkamp and Hedman (1982), and Osterkamp and others (1983).

The second method employed to estimate transmission losses will be based on equations for the channel component of a distributed simulation model developed by the Department of Agriculture (ARS and SCS). Runoff from upland areas will be: (1) estimated by indirect methods, such as channel-geometry techniques, and (2) computed using the SCS runoff equation. These runoff values (V) permit calculation of a peak discharge (Q) when a mean duration of flow (D), obtained from gage-site data in the Yucca Mountain area, is known (c is a coefficient):

$$Q = cV/D. \qquad \text{(Eq. 3.3-5)}$$

Runoff-hydrograph data from gage sites in the Yucca Mountain area and similar data from instrumented watersheds of Arizona will be analyzed to develop a relation between mean flow duration (D_m) and watershed area, A:

$$D_m = dA^y, \qquad \text{(Eq. 3.3-6)}$$

where d is a coefficient and y is an exponent. From the USDA National Engineering Handbook (Lane, 1982), a relation was developed for transmission-loss parameters, which are necessary input for the distributed model:

$$\frac{dV}{dx} = -wf - wkV(x,w) + \frac{V_l}{x}, \qquad \text{(Eq. 3.3-7)}$$

where V(x,w) is the outflow volume from a reach of length x and mean width w; V_l is the volume of lateral inflow, and f and k are parameters. The solution to the above equation (Lane, 1985) is:

$$V(x,w) = a(x,w) + b(x,w)V_u + F(x,w)V_l/x, \qquad \text{(Eq. 3.3-8)}$$

where V(x,w) (greater than or equal to zero) is the outflow volume and V_u is the upstream inflow. Thus the model is a cascading flow description of runoff volumes at ends of various stream-channel lengths x and mean widths w. Each channel reach receives upstream input from an upland area, or from one or more upstream tributary channels. Lateral inflow to a channel reach is from one or two lateral contributing areas, and is assumed uniform along the channel reach. Thus, in a different manner as for the channel-geometry approach, the differences in inflow and outflow are determined for each reach, and most of these differences (adjusted for evapotranspiration) are assumed to be transmission losses and therefore recharge to the ground-water reservoir.

3.3.3.7 Data synthesis and modeling

The relationship between precipitation and runoff will be determined by analysis of meteorologic and streamflow data, and numerical simulation of precipitation-runoff events (based on field data). These data will also provide information about the frequency of events. Numerical models of precipitation-runoff may require more data than will be collected as part of the Yucca Mountain Project, in order to be adequately calibrated. The accuracy of the analyses will depend on the quality and quantity of the surface-water and meteorological data. The ability to measure accurately the naturally occurring precipitation and runoff events during the period of study will depend on the number of measurement sites, and the duration of the monitoring activities (see YMP-USGS SP 8.3.1.2.1.2 for a detailed discussion of precipitation-runoff characterization).

Data from the above activities will be synthesized into a conceptual model of surface-water/ground-water interactions along Fortymile Wash. The conceptual model (and the data) will be used as a basis for numerical models of: (1) precipitation-runoff, and (2) unsaturated-zone ground-water movement (cross-sectional model). Numerical models can be used to: (1) test hypotheses (alternate conceptual models), (2) estimate variables that are not easily measured in the field or are costly to determine, and (3) evaluate the relative importance of the various model components (sensitivity analyses). Calibration of the numerical models will be based on field-observed data. Once the numerical models have been calibrated to present-day conditions, they may be used to predict future conditions along Fortymile Wash. Detailed discussion of numerical modeling can be found in YMP-USGS SP 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling).

The amount of water available for infiltration will be determined from: (1) analysis of streamflow measurements, (2) transmission-loss analyses, (3) statistical analysis of streamflow (recurrence interval analysis), and (4) numerical precipitation-runoff model results. Net infiltration rates will be determined from artificial infiltration testing and radioisotope dating techniques, as discussed under section 3.3.3.4 (unsaturated-zone measurements). Results from these two major parts of this activity, the determination of the amount of available water for infiltration (surface-water measurements) and the determination of natural net infiltration rate (unsaturated zone/saturated zone measurements), will be combined to derive estimates of the distribution and magnitude of long-term recharge rates along Fortymile Wash, for modern and paleo-climatic conditions.

3.3.3.8 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.3-1. Also listed are the selected methods for determining the parameters. 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 several approaches to conducting the test. In those cases, only the most common methods are included in the tables. The selected methods in Table 3.3-1 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site parameter. Models and analytical techniques have been or will be developed to be consistent with test results.

3.3.4 Quality-assurance requirements

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

Table 3.3-2 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a USGS number. Procedures that require preparation do not have procedure numbers.

QMP 5.05 applies to experimental or research activities that produce data, recommendations, or other basis for site characterization. Criteria for supporting the use of the scientific notebook approach are that the investigation 1) largely requires professional judgement, 2) requires the use of trial and error methods, and 3) is beyond the state of the art, requiring development and experimentation. The scientific notebook approach is not for activities conducted under established and (or) standard practices; these require technical procedures.

In this activity, use of the scientific notebook method is proposed for the following methods: matric-potential measurements (Section 3.3.3.4.2), artificial infiltration tests (Section 3.3.3.4.6.1), air permeability tests (Section 3.3.3.4.6.2), analysis of streamflow data for channel-loss measurements (Section 3.3.3.6.1), and transmission-loss studies for channel-loss measurements (Section 3.3.3.6.2).

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

Table 3.3-1. Summary of tests and methods for the Fortymile Wash recharge activity (SCP 8.3.1.2.1.3.3)

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

Methods (selected and alternate)	Site-characterization parameter
Surface-water measurements	
Streamflow measurements in Activity 8.3.1.2.1.2.1 (selected)	Streamflow parameters measured in Activity 8.3.1.2.1.2.1
Hydrochemical analyses (selected)	Water chemistry, Fortymile Wash runoff
Statistical analyses of streamflow (selected)	Recurrence intervals potential recharge events
"	Recurrence intervals, runoff events
Meteorological measurements	
Meteorological measurements in Study 8.3.1.2.1.1 and Activity 8.3.1.2.1.2.1 (selected)	Meteorological parameters from Study 8.3.1.2.1.1 and Activity 8.3.1.2.1.2.1
Hydrochemical analyses of precipitation, in Study 8.3.1.2.1.1 (selected)	Water chemistry, precipitation
Evapotranspiration estimates in Yucca Mountain area, in Studies 8.3.1.2.2.1 and 8.3.1.2.1.1 (selected)	Evapotranspiration values, Yucca Mountain, from Studies 8.3.1.2.2.1 and 8.3.1.2.1.1
Basin characteristics	
Remote-sensing methods in conjunction with field reconnaissance (selected)	Channel morphology
"	Surficial and vegetative cover, basin
Analysis of topographic maps (selected)	Aspect, basin

Table 3.3-1. Summary of tests and methods for the Fortymile Wash recharge activity (SCP 8.3.1.2.1.3.3)--Continued

Methods (selected and alternate)	Site-characterization parameter
Basin characteristics--Continued	
Analysis of topographic maps (selected)	Channel morphology
"	Drainage area, basin
Analysis of topograhic maps (selected)	Elevation, basin
Analysis of topographic maps (selected)	Slope, basin
Unsaturated-zone measurements	
Continuous coring of deep unsaturated-zone boreholes (selected)	(Does not directly measure parameters)
Drilling and coring of neutron-access holes (selected)	"
Soil-moisture measurements from neutron moisture probes (selected)	Soil moisture
Matric-potential measurements from tensiometers in shallow boreholes (selected)	Matric potential
Porosity measurements using mercury porosimeter or neuclear-porosity methods (selected)	Porosity
Analysis for particle-size distribution, secondary mineralization, and clay mineralogy (selected)	Mineralogy
"	Particle-size distribution
Monitoring of temperature during natural and artificial infiltration events (selected)	Temperature, hydrogeoloigic units

Table 3.3-1. Summary of tests and methods for the Fortymile Wash recharge activity (SCP 8.3.1.2.1.3.3)--Continued

Methods (selected and alternate)	Site-characterization parameter
Unsaturated-zone measurements--Continued	
Measurements of permeability and infiltration rates by artificial infiltration tests and air-permeability tests (selected)	Air permeability, unsaturated zone
"	Hydraulic conductivity, unsaturated zone
Hydrochemical analyses of unsaturated-zone core: pore water, solids, and gases (selected)	Chemistry, pore water, unsaturated zone
"	Chemistry, unsaturated-zone gases
"	Isotope chemistry, channel fill and bedrock
"	Recharge rate, Fortymile Wash
Saturated-zone measurements	
Measurements of water-level fluctuations (selected)	Hydraulic head
Measurements of vertical hydraulic potential (selected)	"
Hydrochemical sampling by various methods (selected)	Water chemistry, saturated zone
Channel-loss measurements	
Analysis of streamflow data (selected)	Recharge, distribution, Fortymile Wash
"	Recharge, magnitude, Fortymile Wash
Transmission-loss studies (selected)	Recharge, distribution, Fortymile Wash

Table 3.3-1. Summary of tests and methods for the Fortymile Wash recharge activity (SCP 8.3.1.2.1.3.3)--Continued

Methods (selected and alternate)	Site-characterization parameter
Channel-loss measurements--Continued	
Transmission-loss studies (selected)	Recharge, magnitude, Fortymile Wash
Data synthesis and modeling	
Formulate conceptual model of surface-water/ground-water interactions (selected)	Recharge, distribution, Firtymile Wash
"	Recharge, magnitude, Fortymile Wash
Construct and calibrate numerical models (selected)	Recharge, distribution, Fortymile Wash
"	Recharge, magnitude, Fortymile Wash

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Table 3.3-2. Technical procedures for the Fortymile Wash recharge activity (SCP Activity 8.3.1.2.1.3.3)

	Technical procedure
	Surface-water measurements
HP-44	Installation, operation, and inspection of crest-stage streamflow gages
HP-45	Method of installation, operation, and inspection of recording streamflow gage using the bubble-gage STACOM manometer system
	Basin characteristics
TBD	Scientific notebook: Remote sensing methods
	Unsaturated-zone measurements
GP-16	Procedure for the handling and storage of drill core at the core library
GP-19	Procedure for the identification, handling, and disposition of drill-hole core and cutting samples from the drill site to the core library
HP-28	Laboratory procedures for the determination of moisture-retention curves on rock core
HP-32	Method for monitoring moisture content of drill-bit cuttings from the unsaturated zone
HP-69	Construction and operation of simple tensiometers
HP-62	Method for measuring sub-surface moisture content using a neutron moisture meter

Table 3.3-2. Technical procedures for the Fortymile Wash recharge activity (SCP Activity 8.3.1.2.1.3.3)--Continued

	Technical procedure
	Unsaturated-zone measurements
GP-28	Transfer of NNWSI Project drill-hole samples and related records from the core library and data center to the sample-management facility
TBD	Scientific notebook: Porosity measurements using mercury porosimeter or nuclear porosity methods
TBD	Scientific notebook: Analysis for particle-size distribution, secondary mineralization, and clay minerology
TBD	Scientific notebook: Monitoring of temperature during natural and artificial infiltration events
TBD	Scientific notebook: Measurements of permeability and infiltration rates by artificial tests and air permeability tests
TBD	Scientific notebook: Hydrochemical analysis of unsaturated-zone core - pore water, solids, and gases
TBD	Scientific notebook: Ponding and infiltration testing
	Saturated-zone measurements
HP-01	Methods for determining water level
HP-08	Methods for determination of inorganic substances in water
HP-23	Collection and field analysis of saturated-zone ground-water samples
HP-11	Methods for determination of radioactive substances in water

Table 3.3-2. Technical procedures for the Fortymile Wash recharge activity (SCP Activity 8.3.1.2.1.3.3)--Continued

	Technical procedure
	Saturated-zone measurements
HP-200	Collection of ground-water samples from wells

results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

3.4 Evapotranspiration studies

3.4.1 Objectives

The objective of this activity is to estimate ground-water discharge by evapotranspiration in the Amargosa Desert, in order to provide boundary-condition data (discharge data) for the regional and subregional ground-water flow models.

3.4.2 Rationale for activity selection

A data requirement of the models of regional ground-water flow is the distribution and rate of ground-water discharge. Ground-water discharge occurs primarily as evapotranspiration, evaporation, and spring discharge within the regional ground-water flow system. The two principal discharge areas in the flow system are Franklin Lake Playa and the Furnace Creek Ranch area (Figure 1.2-2). Estimates of spring discharge and evapotranspiration have been made for these areas (Walker and Eakin, 1963; Hunt et al., 1966; Winograd and Thordarson, 1975; Miller, 1977). The spring discharge measurements are considered reliable, but estimates of evapotranspiration at Franklin Lake Playa do not conclusively yield annual average volumetric discharge fluxes because the area over which evapotranspiration occurs is not adequately defined. The need for these estimates stems, in part, from the sensitivity analyses performed by Czarnecki and Waddell (1984). These analyses showed that the specified flux at Franklin Lake Playa had the largest effect of all the specified fluxes within the model on the estimate of transmissivity (and therefore flux) in the near vicinity of the design repository area.

3.4.3 General approach and summary of tests and analyses

In the area of ground-water discharge by evapotranspiration, an upward hydraulic gradient is expected to occur in the saturated zone; elsewhere, the gradient is expected to be downward or lateral. To determine whether an upward gradient exists, a nest of piezometers will be installed at each of several sites with various depths to the water table. Variations in head with depth will be measured at each site. One of the sites will be where the water table is at least 30 m below land surface, where it can confidently be assumed that no significant ground-water discharge by evapotranspiration occurs (based on professional judgment). From the gradient information and water level fluctuations obtained from the piezometers, approximate values of the critical depth to water for ground-water discharge to occur will be evaluated.

At each piezometer location, evapotranspiration will be estimated using energy-balance techniques (Weeks and others, 1987; Stannard, 1985). A background estimate will be made concurrently, further upgradient where depths to groundwater exceed 30 meters, a depth to water greater than that which would allow discharge from the saturated zone by phreatophytes or bare soil evaporation. Equipment will be located in areas with similar vegetation type and density.

It is recognized that the value for the critical depth to the water table probably is not a constant but depends on various factors (besides depth to water) that influence evapotranspiration rates, such as soil texture and plant type and density (which might be determined, in part, through ground surveys coupled with remote sensing). These factors will be considered in locating the piezometer and evapotranspiration-measurement sites and in evaluating the test results.

Figure 3.4-1 summarizes the organization of the evapotranspiration tests. A descriptive heading for each test and analysis appears in the shadowed boxes of the second row. 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 Identification and evaluation of potential evapotranspiration areas

The area over which evapotranspiration occurs at Franklin Lake playa has not been adequately defined. For this reason phreatophyte mapping will be performed there; the different phreatophyte species will be identified and their relative and absolute distributions evaluated. (This effort may be aided by specific work in the past-discharge activity of YMP-USGS SP 8.3.1.5.2.1 on salt-tolerant plant species as related to diffuse discharge.) An initial series of nested piezometer sites will be installed at locations selected by phreatophyte mapping, in order to measure the increasing depths to ground water and define vertical flow. At each piezometer location evapotranspiration will then be estimated by various energy-balance methods. Ground-water samples will also be collected at various depths in the nested piezometers, for chemical and isotopic analyses to evaluate vertical ground-water flow in evapotranspiration areas.

Once the relation between depth to the zone of saturation and evapotranspiration rate has been established, additional piezometers will be constructed to further delineate depths to ground water exceeding the depth at which evapotranspiration is likely to occur. Approximate depths to ground-water may also be determined to resolution of 1 m using either electrical resistivity or seismic refraction surveys, and these methods will be used in siting the piezometers.

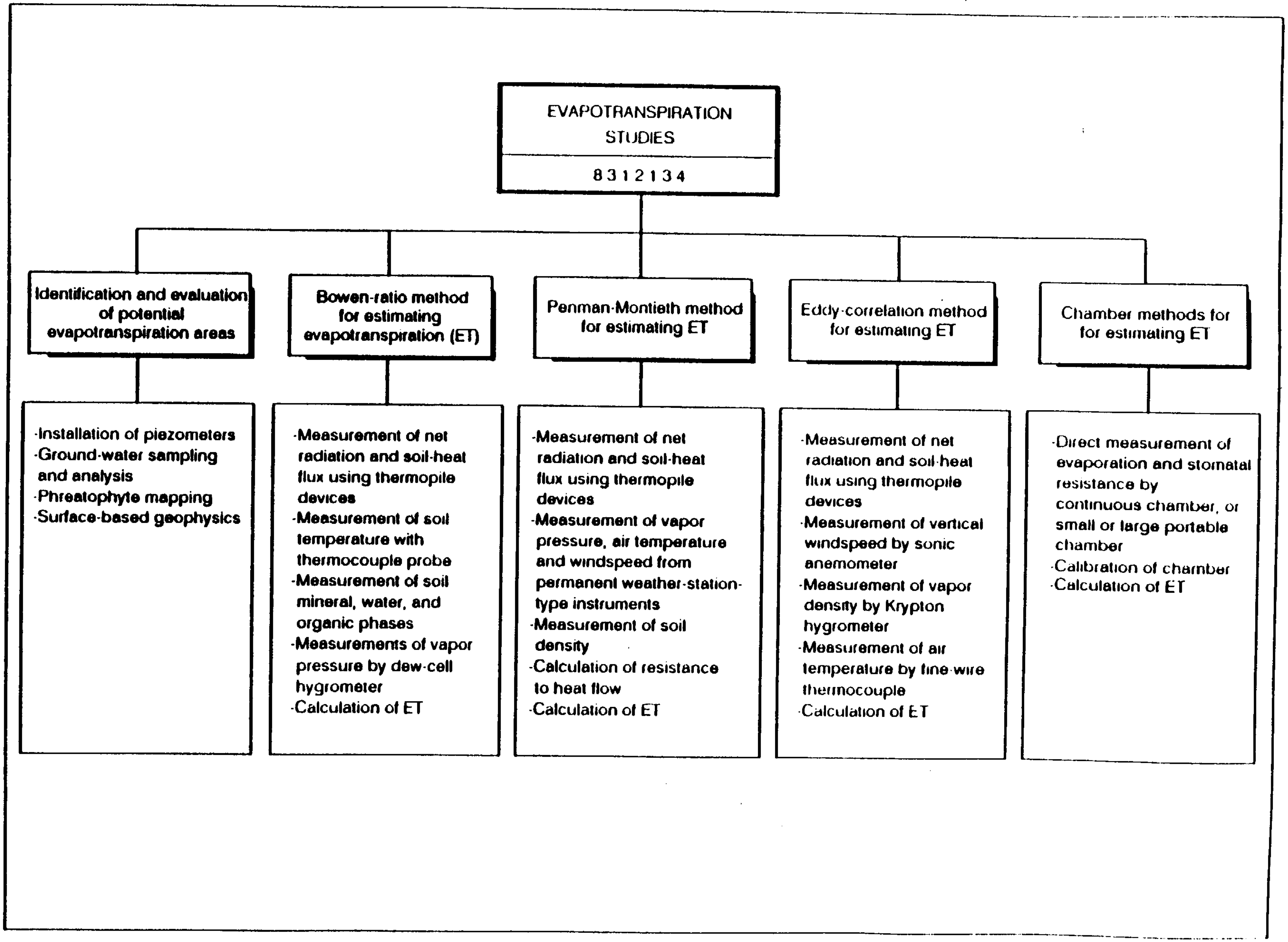


Figure 3.4-1. Logic diagram of evapotranspiration activity, showing tests, analysis, and methods

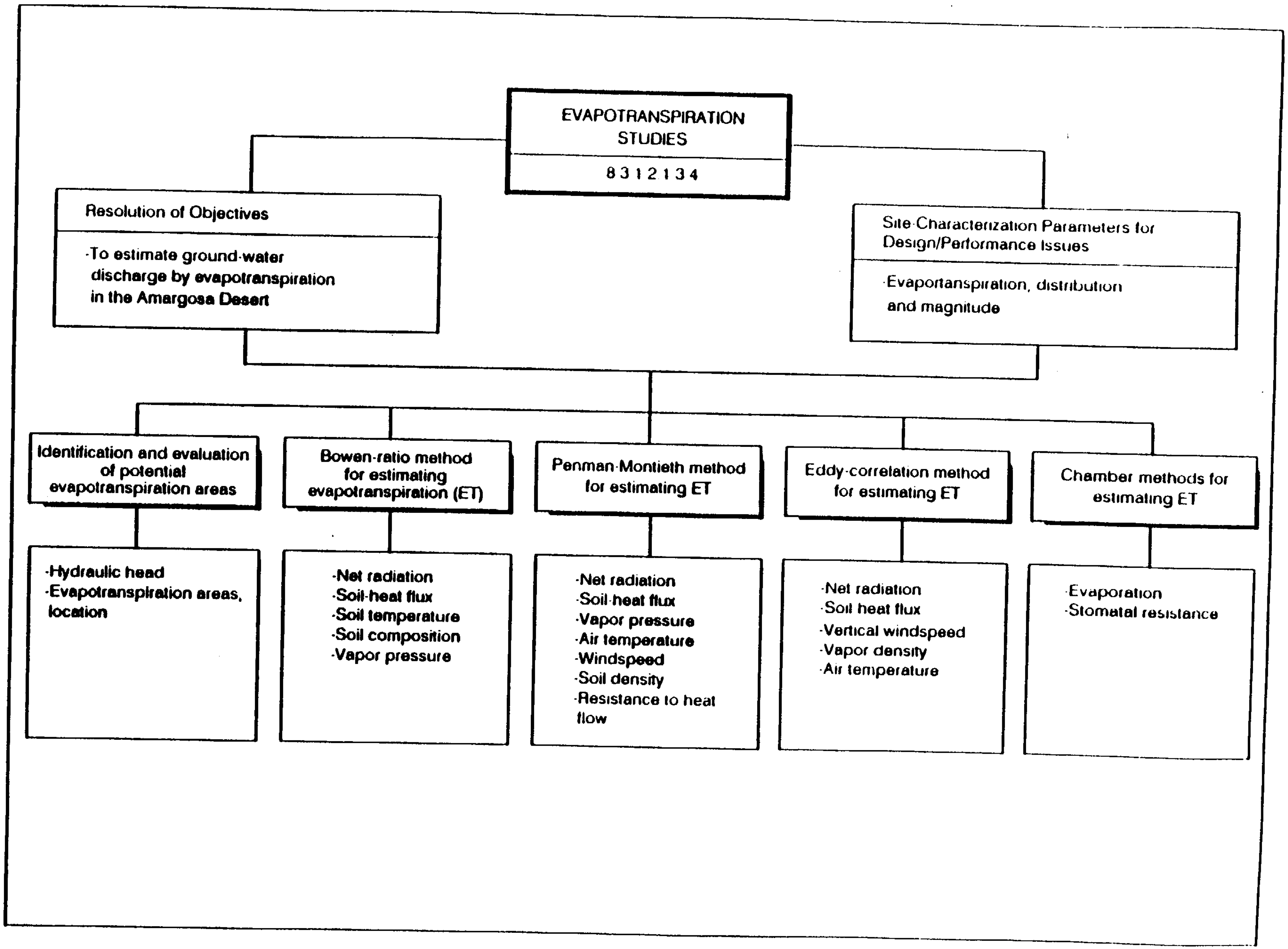


Figure 3.4-2. Logic diagram of evapotranspiration activity, showing tests, analyses, and activity parameters

3.4.3.2 Energy-balance methods for estimating evapotranspiration

At various locations throughout the discharge area associated with Franklin Lake playa, measurements will be made so that evapotranspiration may be estimated using energy-balance methods. Because each method has certain advantages and disadvantages associated with its implementation, actual use will be decided on a case by case (or site by site) basis. A discussion of each of the potentially usable energy-balance methods (provided by D. I. Stannard, USGS Denver) follows.

Energy-balance methods, which became popular in the late 1950s (Tanner, 1960), establish a horizontal layer that has a lower boundary at land surface and an upper boundary just above the plant canopy. The four major energy-flux terms crossing the boundaries of this layer are accounted for on site. Evaporation of water requires energy; thus evaporation can be expressed as an energy flux, known as latent-heat flux. The term "energy flux" actually means energy-flux density, or energy per unit time per unit area, typically expressed in watts per m^2 (a watt is a joule per sec). The energy-balance equation is illustrated schematically in Figure 3.4-3, and can be written as:

$$RN - G = H + \lambda E \qquad \text{(Eq. 3.4-1)}$$

where RN, G, and H are in watts per m^2;

RN is net radiation, or the algebraic sum of all short- and long-wave radiation crossing the upper boundary of the layer;

G is soil-heat flux, or the heat that moves by conduction across the lower boundary of the layer through the soil;

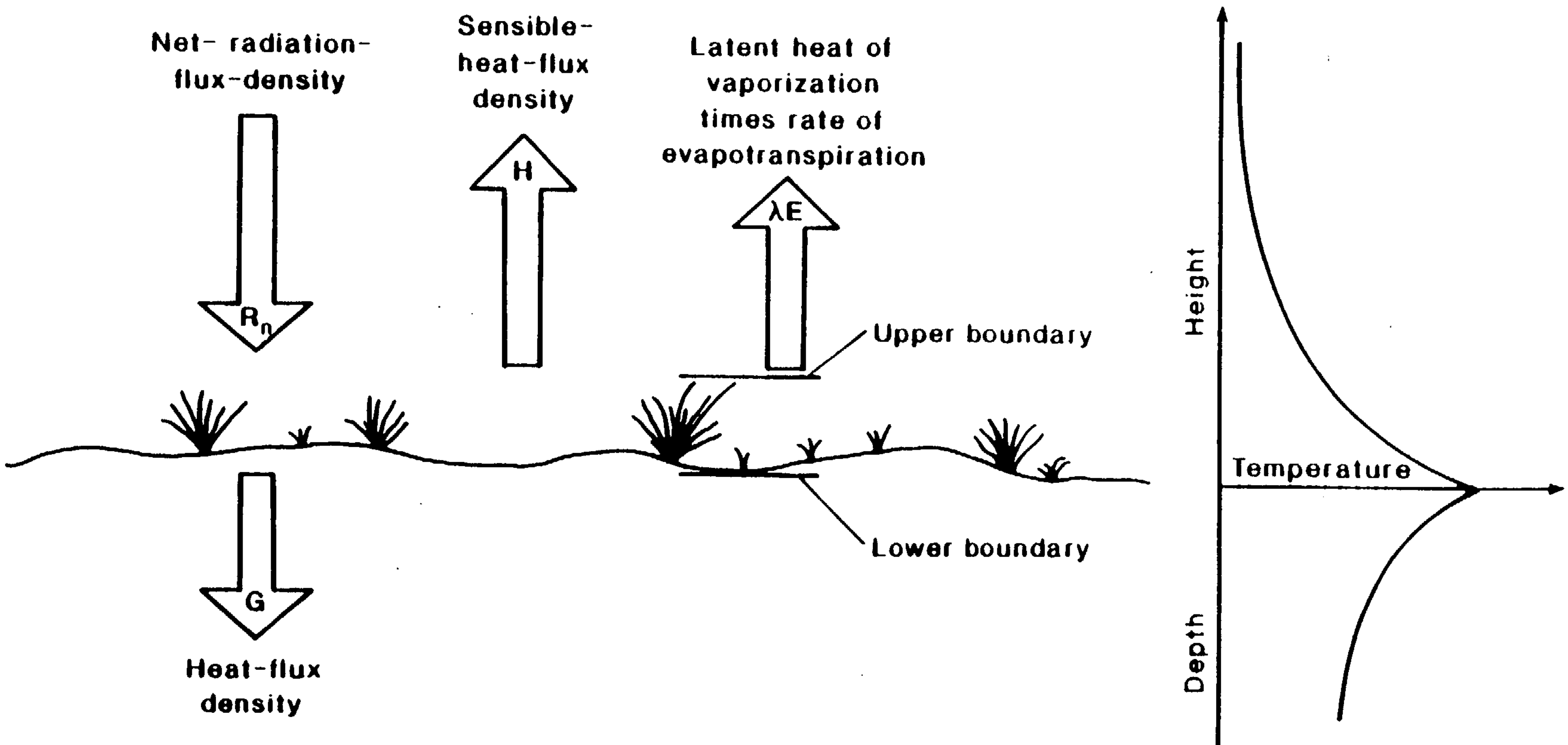
H is sensible-heat flux, or the heat that moves by turbulent transport through the air across the upper boundary of the layer;

λ is the latent heat of vaporization of water, in joules per gram; and

E is evaporation in grams per m^2 per sec.

The latent heat of vaporization is a function of temperature, and may be expressed as:

$$\lambda = 2500.25 - 2.365\ T \qquad \text{(Eq. 3.4-2)}$$



$$R_n - G - H - \lambda E = 0$$

Figure 3.4-3. The energy-balance method.

where λ is in joules per gram; and T is average temperature of the evaporating surface in degrees Celsius. In practice, air temperature is used for T. The sign convention used in this outline is shown in Figure 3.4-3; the typical midday directions of all four fluxes are taken as positive. Other conventions are used in the literature.

A 24-hr time series of the four fluxes is shown in Figure 3.4-4. RN is the energy source "driving" the other fluxes. During the day, the land surface warmed by RN conducts heat to the overlying air (H) and to the subsurface materials (G). λE also removes heat from the surface.

At night, long-wave radiation emitted by the soil causes net radiation to change direction. Radiative cooling of the soil surface usually lowers its temperature below the subsurface and air temperatures, causing G and H to change direction. If air temperature drops below the dew-point, dew forms and the heat of condensation is released, causing λE to change direction.

In the following sections, various methods will be described that are designed to estimate evapotranspiration based on the energy budget. These include: (1) the Bowen ratio method; (2) the Penman-Montieth method; (3) the eddy-covariance method; and (4) chamber methods. Details of each method follow.

3.4.3.2.1 Bowen-ratio method

This method involves measuring RN and G onsite using thermopile devices, and partitioning H and λE according to the ratio of vertical temperature and humidity gradients just above the plant canopy. Assumptions associated with the use of this method are: (1) that vapor flux occurs only in the vertical direction; (2) that the eddy diffusivity (or permeability) of the boundary layer to all transported quantities is the same; (3) that vapor flux is constant with height within the boundary layer; and (4) that energy stored in the plant canopy is constant from the beginning to the end of the measurement period.

Using the ideal gas law, and expressing evaporation as an energy flux, the equation used to estimate evapotranspiration can be written as:

$$E = - \frac{K}{\phi_v} \frac{\rho\lambda\epsilon}{P} \frac{de}{dz} \qquad \text{(Eq. 3.4-3)}$$

where ϵ is the ratio of molecular weight of water to dry air, equal to 0.622;

P is ambient barometric pressure in kiloPascals (kPa);

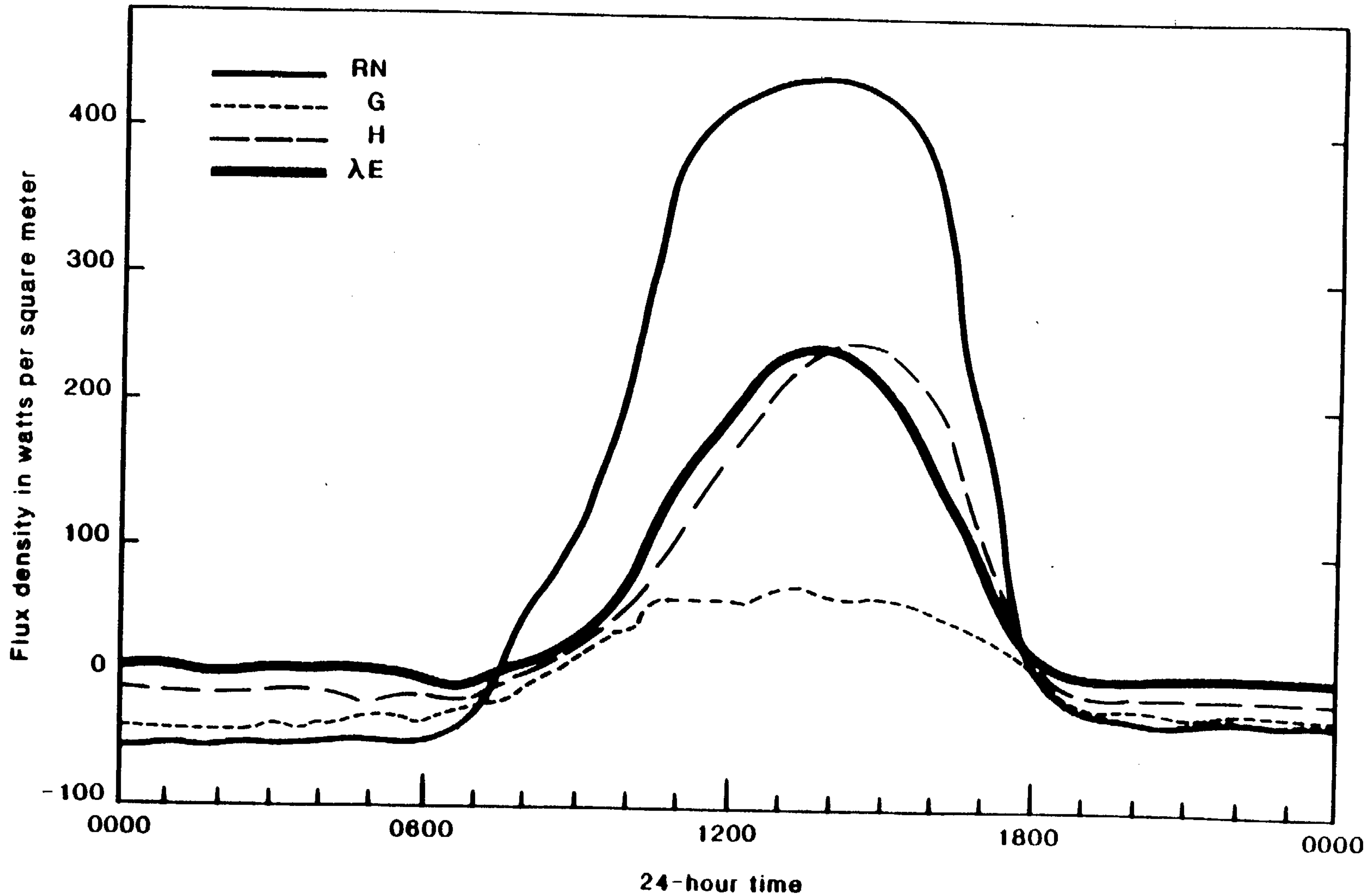


Figure 3.4-4. Typical fluxes during one day

e is vapor pressure in kPa; and

other terms are as defined above.

The Bowen ratio is defined as the ratio of sensible- to latent-heat flux. Using the equation for sensible heat flux for H and Equation 3.4-3 for λE, the Bowen ratio can be written as:

$$\beta = \frac{H}{\lambda E} = \frac{PC_p}{\lambda \epsilon} \frac{dT}{de} \qquad \text{(Eq. 3.4-4)}$$

The ratio $\frac{PC_p}{\lambda E}$ is approximately constant for a given elevation. Known as the psychrometer constant, λ, it can be written as (Fritschen and Gay, 1979):

$$\lambda = 0.000646 \text{ P } (1 + 0.000946 \text{ T}). \qquad \text{(Eq. 3.4-5)}$$

The units of γ are kPa per degree C.

The derivative $\frac{dT}{de}$ can be replaced with finite differences, and

Equation 3.4-4 becomes:

$$\beta = \gamma \frac{\Delta T}{\Delta e} \qquad \text{(Eq. 3.4-6)}$$

Using the fact that $\beta = H/\lambda E$, the energy-balance equation can be written to solve for λE as:

$$\lambda E = \frac{RN - G}{1 + \beta} \qquad \text{(Eq. 3.4-7)}$$

Thus, by measuring RN, G, ΔT, and Δe on site, λE can be calculated. At times when H is changing direction (such as sunrise and sunset), for some short period, it will often be equal and opposite to λE. β approaches -1, and Equation 3.4-7 yields wild values of λE. In theory, $\beta = -1$ only when (RN - G) = 0, but small measurement errors in RN, G, ΔT, or Δe can produce a β very close to -1 when (RN - G) is significantly nonzero. In practice, when $|\beta + 1| < \delta$ (where δ is some number less than 1, such as .2 or .3), λE needs to be calculated by an alternate procedure. If windspeed-gradient measurements are available, H can be calculated from the equations for diabatic conditions and λE can be calculated from Equation 3.4-1. If windspeeds measurements are lacking in arid climates, λE can simply be set to zero. In humid climates, β can be set to some value that yields reasonable (small) values of λE from Equation 3.4-7.

Measurements are made every few seconds for 10 or 15-minute intervals, and fluxes averaged and reported for 30 or 60-minute intervals. A commercially available apparatus costs about $3500, not including a data logger.

RN is most easily measured with thermopile devices (Figure 3.4-5), which integrate the short- and long-wave, upward and downward radiation fluxes into a single measurement. An important attribute for a net radiometer is that its sensitivities to short- and long-wave radiation be equal. Several net-radiometers are available from meteorological supply houses; generally accuracy is proportional to cost.

The net radiometer is deployed just above the top of the plant canopy, well away from its support pieces, using a horizontal arm. The net radiometer "sees" a cosine-weighted average of the upward and downward views. In scattered vegetation, the net radiometer must be carefully placed to see a representative view.

G at land surface is measured by burying a soil-heat-flux plate (Figure 3.4-6) 5 to 10 cm below the surface to measure G at depth, and then adding the change in heat stored in the soil profile above the plate. The storage term is calculated from the change in average temperature of the profile and an estimate of the specific heat capacity of the soil. The flux equation is:

$$G = G_d + \Delta S \qquad \text{(Eq. 3.4-8)}$$

where G is soil-heat flux at land surface in watts per m^2;

G_d is the soil-heat flux at depth as measured using the soil-heat-flux plate, in watts per m^2; and

ΔS is the change in energy stored in soil above the plate, divided by measurement interval, in watts per m^2.

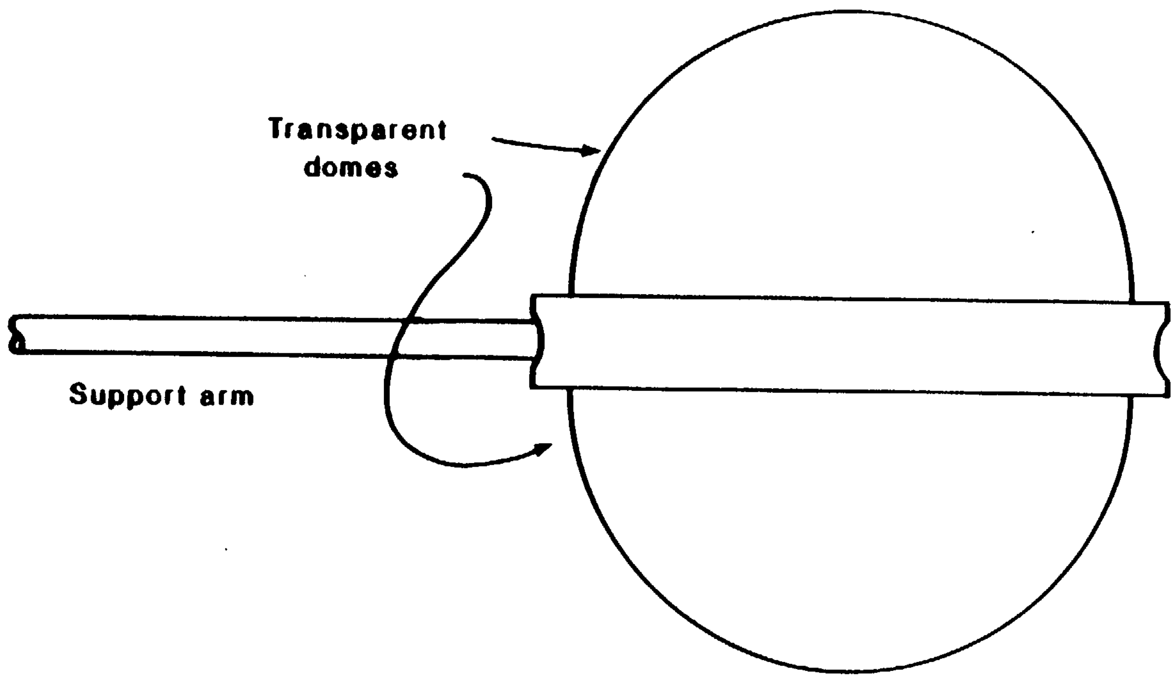


Figure 3.4-5. Net radiometer.

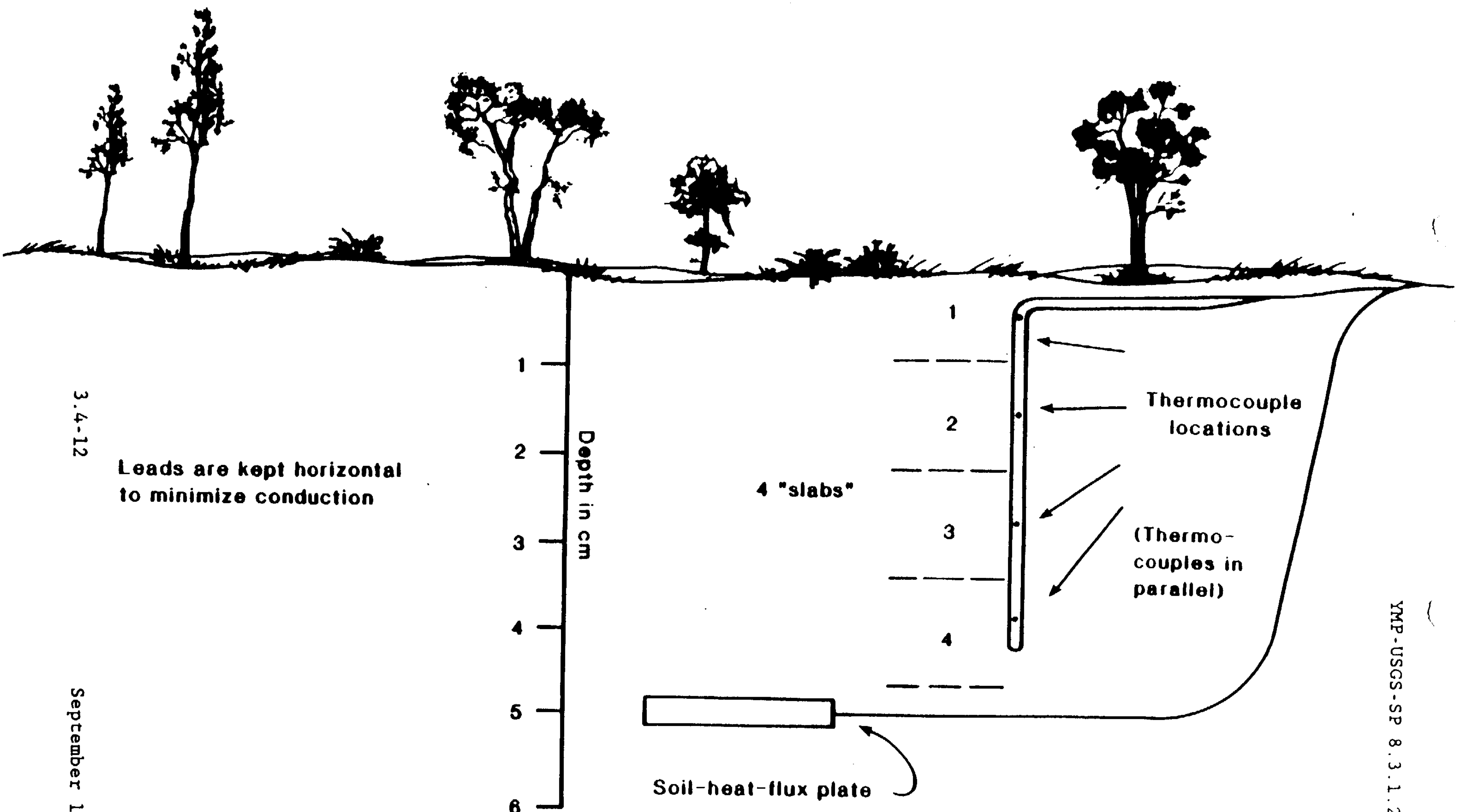


Figure 3.4-6. Soil-heat-flux plate a' ' thermocouple probe installation.

The storage term is

$$\Delta S = \frac{10{,}000\ (T_f - T_i)\ c\ d}{\Delta t} \qquad \text{(Eq. 3.4-9)}$$

where 10,000 is a factor to convert cm^{-2} to m^{-2};

T_f is the average temperature of the soil above the plate at the end of the measurement interval, in degrees C;

T_i is the average temperature of the soil above the plate at the beginning of the measurement interval, in degrees C;

c is volumetric heat capacity of soil above the plate, in joules per degree C per cm^3;

d is the depth of the plate in cm; and

Δt is length of measurement interval, in sec.

The volumetric heat capacity of a soil containing mineral, organic, and water phases can be estimated using the DeVries equation:

$$c = \rho_{bd}\ (0.73\ f_m + 1.93\ f_o + 4.19\ f_w) \qquad \text{(Eq. 3.4-10)}$$

where ρ_{bd} is dry bulk density of soil in g per cm^3;

f is weight fraction of a phase on a dry-weight basis (i.e. weight of a phase divided by the weight of mineral plus organic phases, unitless;

subscripts m, o, and w refer to mineral, organic, and water phases; and

the numbers 0.73, 1.93, and 4.19 are approximate gravimetric heat capacities for mineral, organic, and water phases, in joules per gram per degree C.

The parameters in Equation 3.4-10 are determined by taking volumetric soil samples on site (usually daily). The sample is first weighed wet, then dried at 105 degrees C for 24 hrs, weighed dry, then "burned" to oxidize the organic matter, and weighed again. For a soil with no organic matter, the f term becomes equal to 1.

The average temperature of the soil profile above the heat-flux plate is measured with a thermocouple probe (Figure 3.4-6), consisting of several thermocouples in parallel, spaced evenly from land surface to the depth of the plate.

Usually three plate-probe pairs are deployed, and the average of the three is used for G. The locations of the plates should typify average soil heating conditions at the site.

The gradients ΔT and Δe are measured just above the plant canopy. Gradients are small, (usually less than 1 degree C per meter for ΔT and 0.1 kPa per meter for Δe) so that some method for removing bias between sensors needs to be used. Sometimes matched wet- and dry-bulb thermistors are used, or the thermistors are periodically subjected to the same temperature to track the bias. Another method is to use thermocouples in series. Alternatively, a mechanism for interchanging sensors can been used: by averaging data over one full interchange cycle, bias is automatically removed. Still another method is to pump air from upper and lower locations past a single sensor. The only commercially available apparatus at present that uses this method is made by Campbell Scientific, Inc., in Logan, Utah.

T is measured directly, but measurement of e requires measuring any two independent psychometric parameters (Fritschen and Gay, 1979). Usually, dry- and wet-bulb temperatures are measured, but recently, measurement of dewpoint has become very accurate, and is used instead of wet-bulb. This can be accomplished using a dew-cell hygrometer, which, in the case of the Comstock Instruments model, has the added advantages of being very durable and having a built-in thermocouple. The Comstock dew-point hygrometer uses the salt-solution, phase-transition point of lithium chloride to measure ambient dew-point temperatures. Sensor temperature is a direct measure of atmospheric water content. The sensor is heated electronically, rather than by conduction through salt. This results in high sensitivity to humidity changes and reduced power requirements. Unlike conventional, cooled dew-point sensors, psychrometers, or relative humidity sensors, the heated sensor minimizes the possibility of sensor contamination from salts, particulates, or condensation. These features make it ideal for battery-powered applications where low power consumption, accuracy, and long-term reliability are primary considerations.

Temperature sensors need to be adequately shielded from the sun (Fuchs and Tanner, 1965). Wet-bulb sensors usually are aspirated to obtain the 3 m per sec windspeed needed for full wet-bulb depression. If sensors are interchanged, they need to equilibrate to the new temperature and humidity each time before recording data. A typical sampling scheme would be to scan the sensors every 2 to 10 seconds for 4 minutes, average the readings, interchange, and allow 1 minute to equilibrate. A 10-minute Bowen ratio would then be calculated from Equation 3.4-7.

3.4.3.2.2 **Penman-Montieth method**

Eddy diffusivity has been used in this activity description to characterize the effectiveness with which quantities are transported by turbulence. Another approach is to integrate $\frac{1}{K}$ from the surface to some measurement height, producing a resistance, r, exactly analogous to an electrical resistor. Vapor flux is then proportional to the difference between the concentration of the transported quantity at the surface and at the measurement height, divided by the resistance.

PET (potential evapotranspiration) is defined as the vapor flux which occurs from a given vegetation under a given set of meteorologic conditions when water is supplied freely to the evaporating surfaces. The Penman equation, written to describe this process for short grass, is based on the energy balance of a wet-bulb surface.

In addition to the assumptions made when using the Bowen ratio, the following assumptions are made when using the Penman-Montieth method: (1) advection of sensible heat (oasis effect) is assumed to be negligible, and (2) local sources of heat and vapor are identical.

A more general form of the Penman equation includes a soil-heat flux term, and replaces the wind function with a reciprocal resistance:

$$\lambda E_p = \frac{s(RN-G) + \dfrac{\rho C_p(e_s - e_a)}{r_h}}{s + \gamma} \qquad \text{(Eq. 3.4-11)}$$

where E_p is PET in grams per m^2 per sec;

s is the slope of saturation vapor pressure curve in kPa per degree K;

e_s is the saturation vapor pressure at air temperature at height z, in kPa;

e is the vapor pressure of air at height z, in kPa;

r_h is the resistance to heat flow, or aerodynamic resistance from land surface to height z, in sec per meter.

Other parameters are as defined above. Lowe (1976) presents an accurate polynomial for s.

The resistance r_h is a function of surface roughness and windspeed:

$$r_h = \frac{\ln \frac{z-d+z_h}{z_h} \ln \frac{z-d+z_m}{z_m}}{k^2 u} \qquad \text{(Eq. 3.4-12)}$$

where z_h = .2 z_m = roughness length for heat, and c = profile corrector for sensible heat, and like the flux correctors, is a function of z (Brutsaert, 1982).

Irrigated crops often approximate PET conditions, but wildland vegetation seldom does except in areas of very shallow water tables and heavy vegetation. As a vegetated surface becomes unsaturated, the water must overcome an additional resistance due to stomatal closure and partially dry soil.

In this case the total resistance to vapor flow, r_v, is greater than r_h. The formulation of this concept leads to the Penman-Montieth equation:

$$\lambda E = \frac{s(RN-G) + \frac{\rho C_p(e_s - e_a)}{r_n}}{s + \gamma \frac{r_v}{r_h}} \qquad \text{(Eq. 3.4-13)}$$

Knowing d, z_h, and z_m, all the parameters in Equation 3.4-13 except r_v can be determined from permanent weather-station-type instruments. Thus the problem is to determine r_v.

The value of r_v/r_h increases as a surface becomes drier, and often can be expressed as a function of total leaf area, vapor pressure deficit, temperature, solar radiation, and soil moisture (e.g. Stewart, 1988). This function can be calibrated by making independent measurements of λE for short periods of time, and solving Equation 3.4-13.

Ideally, RN and G are measured with thermopile devices. Lacking these, the quantity (RN-G) can be regressed onto solar radiation (incoming shortwave), which sometimes is measured at standard weather stations. Air temperature, humidity, and windspeed are all measured above the canopy; great accuracy is not required.

3.4.3.2.3 Eddy correlation method

This method provides the most direct measure of evapotranspiration. If humidity and vertical windspeed are measured "very often" (e.g. 10 hz), the "degree to which they vary together" is a measure of vapor-flux density. Wetter eddies tend to move upward; drier eddies tend to move downward. Similar reasoning is used for H. The only assumption associated with using this method is that vapor flux occurs in the vertical direction only.

Equations giving vertical fluxes of water vapor and heat are

$$E = \overline{w'q'} \qquad \text{(Eq. 3.4-14)}$$

$$H = \rho \ C_p \ \overline{w'T'} \qquad \text{(Eq. 3.4-15)}$$

where $w' = w - \bar{w}$;

$q' = q - \bar{q}$;

$T' = T - \bar{T}$;

w = vertical windspeed in m per sec;

(overbars indicate averages over the measurement interval);

$\overline{w'q'}$ is the covariance of vertical wind and vapor density, in g per m^2 per sec;

$\overline{w'T'}$ is the covariance of vertical wind and temperature, in m degrees C per sec; and other parameters are as defined above.

In humid environments, a correction term (Webb and others, 1980), equal to $\lambda q \ w'T'/T$ (where T_k is in degrees Kelvin), is added to E, which accounts for thermal expansion and contraction of air.

Fast-response sensors and data loggers capabde of online statistical calculations have recently made eddy covariance popular. Measurements are made at about 10 hz (times per sec) and covariances are calculated about every 15 minutes.

Mechanical anemometers are not responsive enough for vertical wind measurement. The sonic anemometer (Figure 3.4-7) uses phase shift of emitted sound to measure w. Transducers used to emit and receive sound can be ruined by rain, making prolonged unsupervised use of this equipment difficult.

The Krypton hygrometer (Figure 3.4-7) uses absorption of radiation by water vapor to measure q; however, it needs to be within about 10 cm of sonic to be "seeing" the same eddies. Water droplets on Krypton tubes invalidate measurements, but will not ruin the sensor.

A fine-wire thermocouple (.0005-in diameter) eliminates the need for a radiation shield, and has a fast response. The thermocouple is usually included as part of a sonic anemometer. However, windblown particles, insects, snow, sleet, and hail can break this extremely delicate thermocouple.

Usually RN and G are measured using equipment mentioned previously to provide a check on H and λE using Equation 3.4-1. The Krypton hygrometer and sonic anemometer cost about $6,000 together, and RN and G sensors add about $1,000.

3.4.3.2.4 Chamber methods

Chambers that surround all or part of a plant, or several plants, have been used to measure ET directly, and to measure stomatal resistance. Stomatal resistances are used in ET models to predict transpiration. Direct measurements can be continuous or instantaneous. Continuous chambers remain in place for hours or days; instantaneous ones are used to measure the rise in vapor density for a period of about a minute. All are point measurements and need to be extrapolated to obtain areal estimates of ET.

Continuous chambers are used primarily in agriculture. Their operation is based on air conditioners that condense water vapor, and condensate is collected (in a closed system). Vapor density of incoming and outgoing airstreams is measured (in an open system). Radiation, temperature, and wind are altered, so they are used mostly for comparative ET (Decker and others, 1962; Puckridge, 1978; Greenwood and Beresford, 1979).

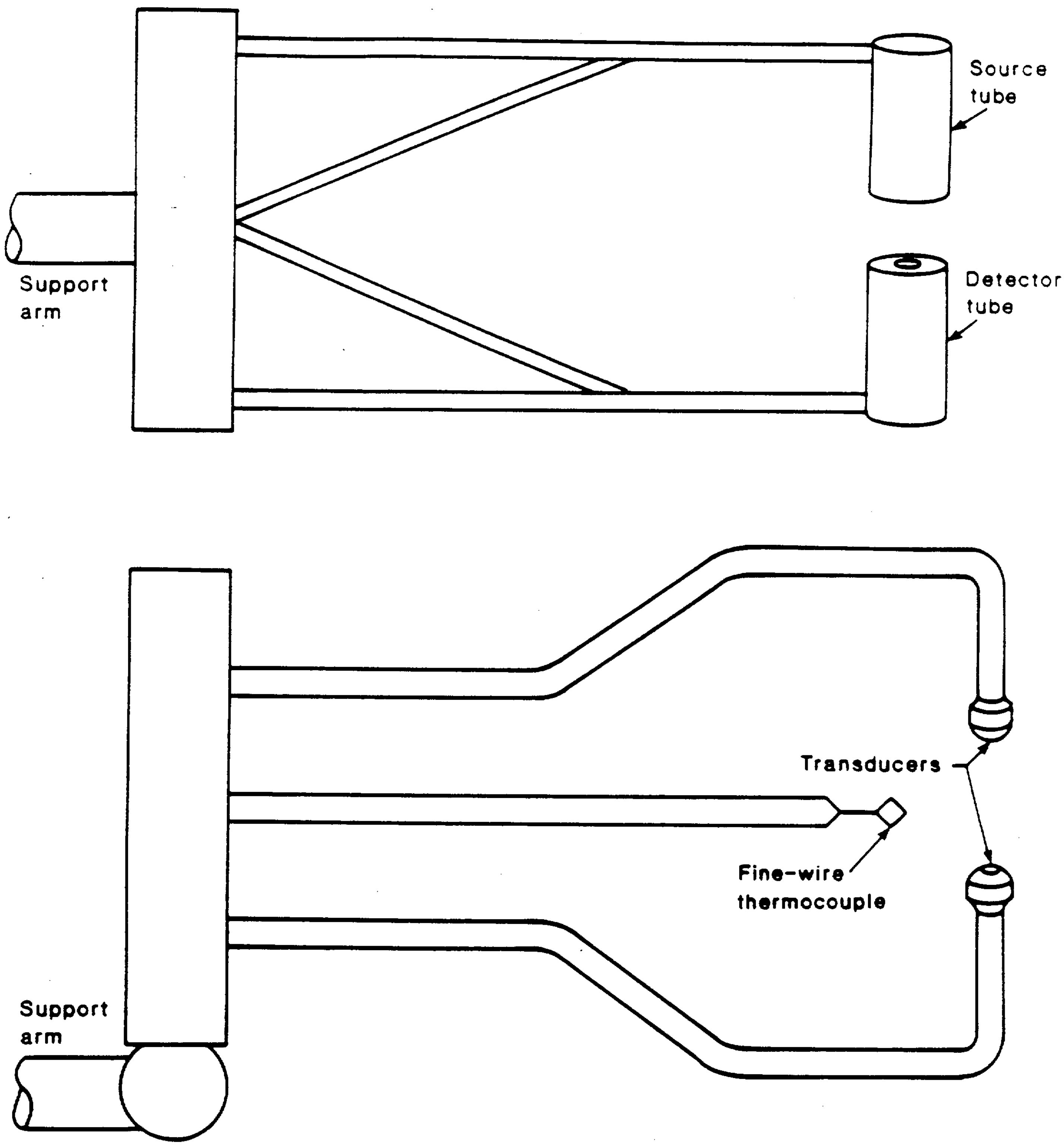


Figure 3.4-7. Krypton hygrometer and sonic anemometer.

Small portable chambers are usually about a liter in volume and enclose a single leaf. A porometer measures stomatal resistance by passing a flow of fairly dry air past the leaf, and recording the moisture increase (Beardsell and others, 1972; Groeneveld and others, 1986). Other small chambers record the rise in vapor density (closed system) to calculate the transpiration rate of the leaf. Both measurements need LAI (leaf area index) to convert measurements to areal transpiration rates. LAI is the ratio of total leaf area to total land surface area. These methods do not measure bare-soil evaporation.

Large portable chambers range in size from 0.3 to 5 m^3. Larger chambers are designed for agriculture and are able to be moved with a tractor (Reicosky and Peters, 1977). Smaller chambers can be moved by one or two people and are ideal for wildland vegetation or urban applications (Morgan and Willis, 1983; Stannard, 1988).

Assumptions that are associated with the use of chambers are:

(1) the measurement period is short enough so that plant and soil do not react to alter RN, u, and T;

(2) air, and therefore vapor density, in the chamber are well mixed, so that a single measurement of q suffices;

(3) there is linear interpolation between measurement times; and

(4) the geometric model is used in sparse vegetation.

Chambers are made from mylar on metal frames, Lexan, acrylic, and other transparent plastics. Fans are placed strategically to mix air. The vapor density sensor is placed in a "well mixed" location.

Calibration is done by evaporating water at a known rate (using a toploading balance) and then comparing the known rate to the rate measured by the chamber. This accounts for water adsorption and sensor inaccuracy.

The field procedure involves placing the chamber over the desired measurement site and monitoring the rise in vapor density. The slope of vapor density vs. time is proportional to ET from that particular location.

Figure 3.4-8 shows a time series of q inside a chamber. Evaporation is calculated as:

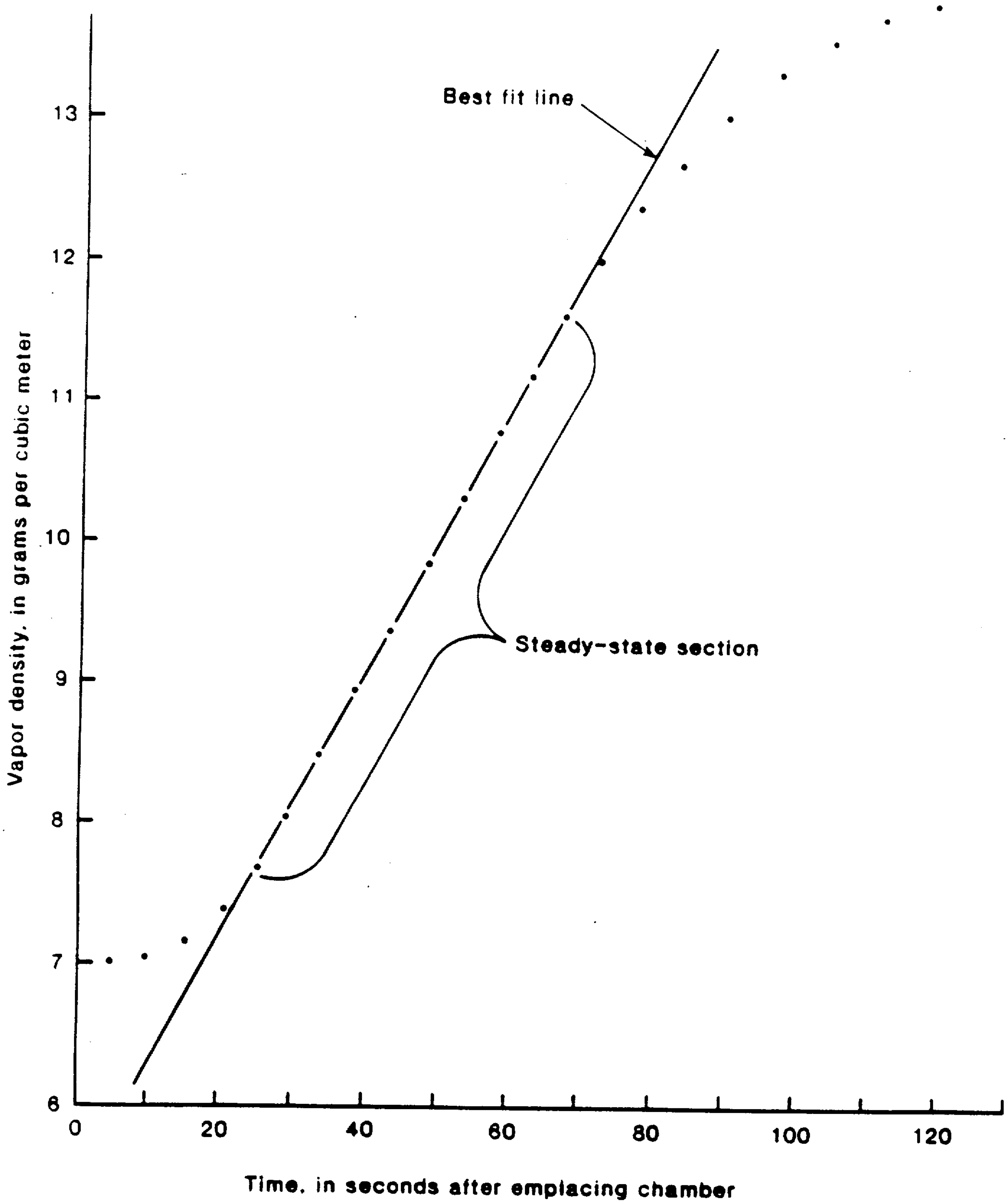


Figure 3.4-8. Time series of vapor density inside chamber.

$$E = \frac{MVC}{A} \qquad \text{(Eq. 3.4-16)}$$

where E is evaporation in g per m^2 per sec;

M is the slope of the constant-slope section of the vapor density time series, in g per m^3 per sec;

V is the volume of chamber in m^3;

C is the calibration factor of the chamber, unitless; and

A is the area covered by chamber, in m^2.

For dense, uniform vegetation, (e.g. a lawn) the measured rate may be extrapolated directly to an areal average ET. In scattered or diverse vegetation, the geometric model needs to be used to account for the relative density of each species and the size of each species measured by the chamber. Measurements are integrated over time using linear interpolation.

3.4.3.3 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 methods for determining the parameters. 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 several 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 USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site parameter. Models and analytical techniques have been or will be developed to be consistent with test results.

3.4.4 Quality-assurance requirements

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

Table 3.4-2 provides a tabulation of technical procedures applicable to this activity. Approved procedures are identified with a USGS number. Procedures that require preparation do not have procedure numbers.

Page 1

Table 3.4-1. Summary of tests and methods for the evapotranspiration activity (SCP 8.3.1.2.1.3.4)

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

Methods (selected and alternate)	Site-characterization parameter
Identification and evaluation of potential evapotranspiration areas	
Installation of piezometers (selected)	Hydraulic head
Ground-water sampling and analysis (selected)	Evapotranspiration areas, location
Phreatophyte mapping (selected)	"
Surface-based geophysics (selected)	Hydraulic head
Energy-balance methods: Bowen-ratio method for estimating evapotranspiration (ET)	
Measurement of net radiation and soil-heat flux using thermopile devices (selected)	Net radiation
"	Soil-heat flux
Measurement of soil temperature with thermocouple probe (selected)	Soil temperature
Measurement of soil, mineral, water, and organic phases (selected)	Soil composition
Measurement of vapor pressure by dew-cell hygrometer (selected)	Vapor pressure
Calculation of ET (selected)	Evapotranspiration
Energy-balance methods: Penman-Montieth method for estimating ET	
Measurement of net radiation and soil-heat flux using thermopile devices (selected)	Net radiation

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Table 3.4-1. Summary of tests and methods for the evapotranspiration activity (SCP 8.3.1.2.1.3.4)--Continued

Methods (selected and alternate)	Site-characterization parameter
Energy-balance methods: Penman-Montieth method for estimating ET--Continued	
Measurement of net radiation and soil-heat flux using thermopile devvices (selected)	Soil-heat flux
Measurement of vapor pressure, air temperature, and windspeed from permanent weather-station-type instruments (selected)	Air temperature
"	Vapor pressure
"	Windspeed
Measurement of soil density (selected)	Soil density
Calculation of resistance to heat flow (selected)	Resistance to heat flow
Calculation of ET (selected)	Evapotranspiration
Energy-balance methods: Eddy-correlation method for estimating ET	
Measurement of net radiation and soil-heat flux using thermopile devices (selected)	Net radiation
"	Soil-heat flux
Measurement of vertical windspeed by sonic anemometer (selected)	Vertical windspeed
Measurement of vapor density by Krypton hygrometer (selected)	Vapor density
Measurement of air temperature by fine-wire thermocouple (selected)	Air temperature

Page 3

Table 3.4-1. Summary of tests and methods for the evapotranspiration activity (SCP 8.3.1.2.1.3.4)--Continued

Methods (selected and alternate)	Site-characterization parameter
Energy-balance methods: Eddy-correlation method for estimating ET--Continued	
Calculation of ET (selected)	Evapotranspiration
Energy-balance methods: Chamber methods for estimating ET	
Direct measurement of evaporation and stomatal resistance by continuous chamber, or small or large portable chamber (selected)	Evaporation
"	Stomatal resistance
Calibration of chamber (selected)	(Does not directly measure parameters)
Calculation of ET (selected)	Evapotranspiration

Table 3.4-2. Technical procedures for the evapotranspiration activity (SCP Activity 8.3.1.2.1.3.4)

	Technical procedure
	Identification and evaluation of potential evapotranspiration areas
GPP-19	Surface geophysics: Electrical methods, direct-current investigations
HP-09	Construction of piezometers in unconsolidated sediments
HP-23	Collection and field analysis of saturated-zone ground-water samples
HP-61	Calibration and use of hand-held steel tapes
HP-99	Instruction for operation of a well sounder for measuring water levels
TBD	Shallow seismic reflection and refraction surveys
HP-200	Collection of ground-water samples from wells
	Energy-balance methods for evaluating evapotranspiration
TBD	Scientific notebook: Phreatophyte mapping
TBD	Scientific notebook: Bowen ratio method for estimating evapotranspiration
TBD	Scientific notebook: Penman-Montieth method for estimating evapotranspiration
TBD	Scientific notebook: Eddy correlation method for estimating evapotranspiration
TBD	Scientific notebook: Chamber methods for estimating evapotranspiration

QMP 5.05 applies to experimental or research activities that produce data, recommendations, or other basis for site characterization. Criteria for supporting the use of the scientific notebook approach are that the investigation 1) largely requires professional judgement, 2) requires the use of trial and error methods, and 3) is beyond the state of the art, requiring development and experimentation. The scientific notebook approach is not for activities conducted under established and (or) standard practices; these require technical procedures.

In this activity, use of the scientific notebook method is proposed for all of the energy-balance methods for estimating evapotranspiration: Bowen-ratio method, Penman-Montieth method, Eddy correlation method, and chamber methods.

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.

4 APPLICATION OF STUDY RESULTS

4.1 Application of results to resolution of design and performance issues

The data collected in this study will principally be used in the resolution of Performance Issues 1.6 (Ground-water travel time) and 1.1 (Total system performance). It will have secondary applications in Performance Issues 2.1 (Public radiological exposures - normal conditions), 2.2 (Worker radiological safety - normal conditions), and 2.3 (Accidental radiological releases); and in Design Issues 1.11 (Configuration of underground facilities - postclosure), 2.7 (Repository design criteria for radiological safety), 4.4 (Technologies of repository construction, operation, closure, and decommissioning), and 1.12 (Characteristics and configurations of shaft and borehole seals).

The application of site information from this study to design- and performance-parameter needs required for the resolution of design- and performance-parameter issues is addressed in Section 1.3 and Table 7.2-1. Sections 2 and 3 use logic diagrams to summarize specific relations between performance-and design-parameter needs and site-characterization parameters determined from this study.

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

Site-characterization data from this study will principally be used in Study 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling). The regional potentiometric-level activity from the present study will provide key data pertaining to ground-water levels, hydraulic characteristics, and hydrogeologic unit contacts for the conceptualization of flow models, and for the subregional and regional hydrologic modeling. The Fortymile Wash recharge activity will provide data on recharge rates for conceptualization of hydrologic flow models. The evapotranspiration studies will provide boundary condition data for regional hydrologic modeling.

The present study will contribute to Study 8.3.1.2.1.2 (Characterization of runoff and streamflow) in that the drainage-basin data and recurrence intervals of runoff events for Fortymile Wash (Activity 8.3.1.2.1.3.3) can be used to support the surface-water runoff monitoring activity of that study.

The present study will support Study 8.3.1.2.2.1, Characterization of unsaturated-zone infiltration, in that data on natural infiltration locations and rates, as well as surficial deposit hydrologic data gathered in the Fortymile Wash recharge activity, can be used to support the evaluation of the natural recharge activity and the surficial materials hydrologic properties activity of that study.

The present study will support Study 8.3.1.2.2.3 (Characterization of percolation in the unsaturated zone - surface-based study), in that the unsaturated-zone physical and hydraulic-properties data gathered in the Fortymile Wash recharge activity can be used to support the matrix hydrologic properties testing activity and the site vertical-boreholes activity of that study.

The present study will support Study 8.3.1.2.3.1 (Characterization of the site saturated-zone ground-water flow system) by augmenting the potentiometric-level, hydraulic-properties, and hydrogeologic-unit contact data collected during that study.

The present study will support Study 8.3.1.2.3.2 (Characterization of the site saturated-zone hydrochemistry) in that hydrochemistry data collected in the Fortymile Wash recharge activity can be used in the hydrochemical characterization of upper saturated-zone water activity of that study.

The present study will support Study 8.3.1.4.2.1 (Characterization of vertical and lateral distribution of stratigraphic units within the site area) in that stratigraphic data collected in the regional potentiometric levels activity can be used in the surface and subsurface stratigraphic activity of that study.

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 regional ground-water flow system study. This figure represents a summary of the schedule information which includes the sequencing, interrelations, 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 8.3.1.2-11. The drilling of the proposed wells WT-25, -26, and -27 has not yet been incorporated in the schedule for the potentiometric-levels activity. The development of the schedule for the present study has taken into account how the study will be affected by contributions of data or interferences from other studies, and also how the present study will contribute or may interfere with other studies.

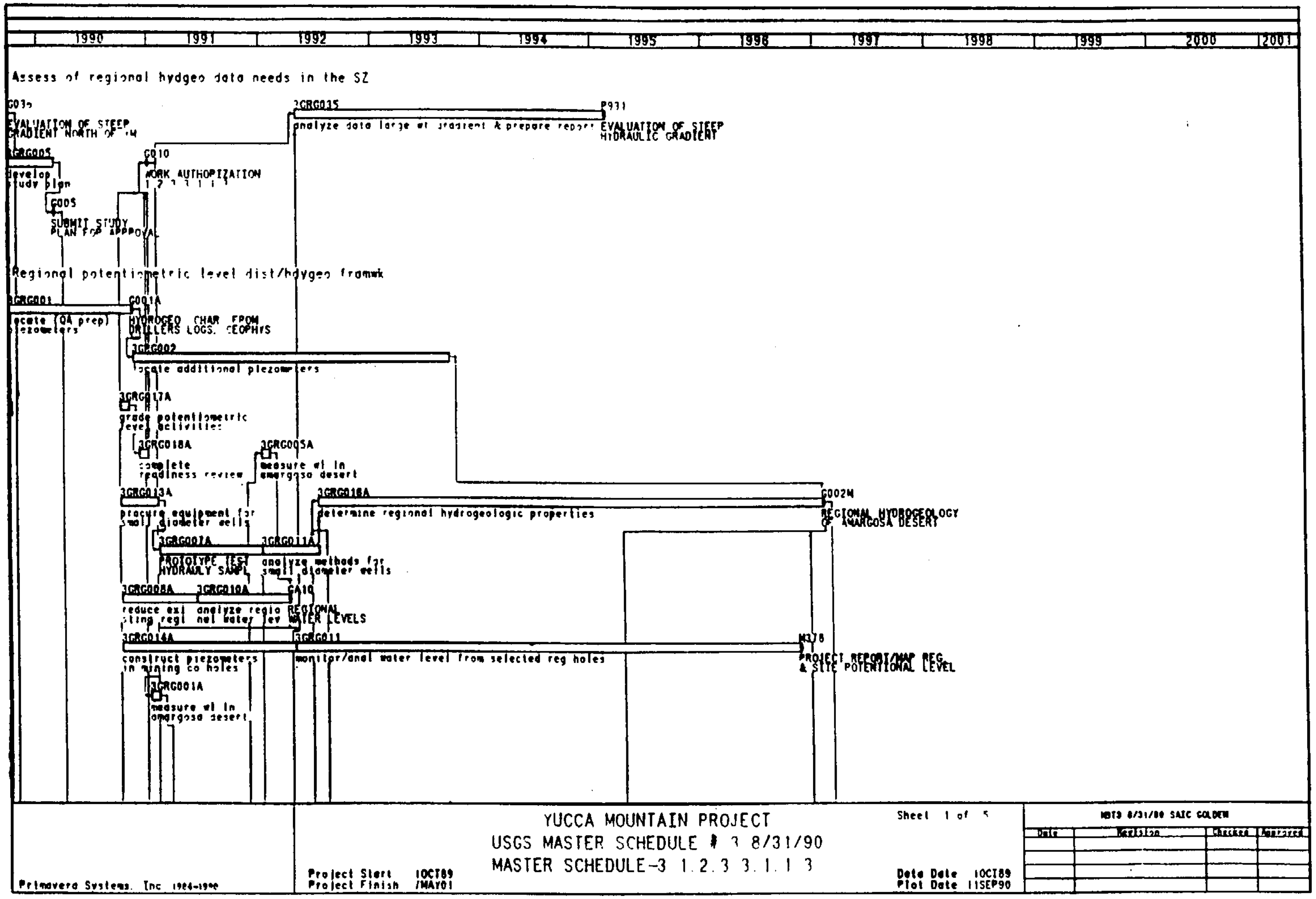

Figure 5.1-1a. Summary network of regional ground-water flow system study.

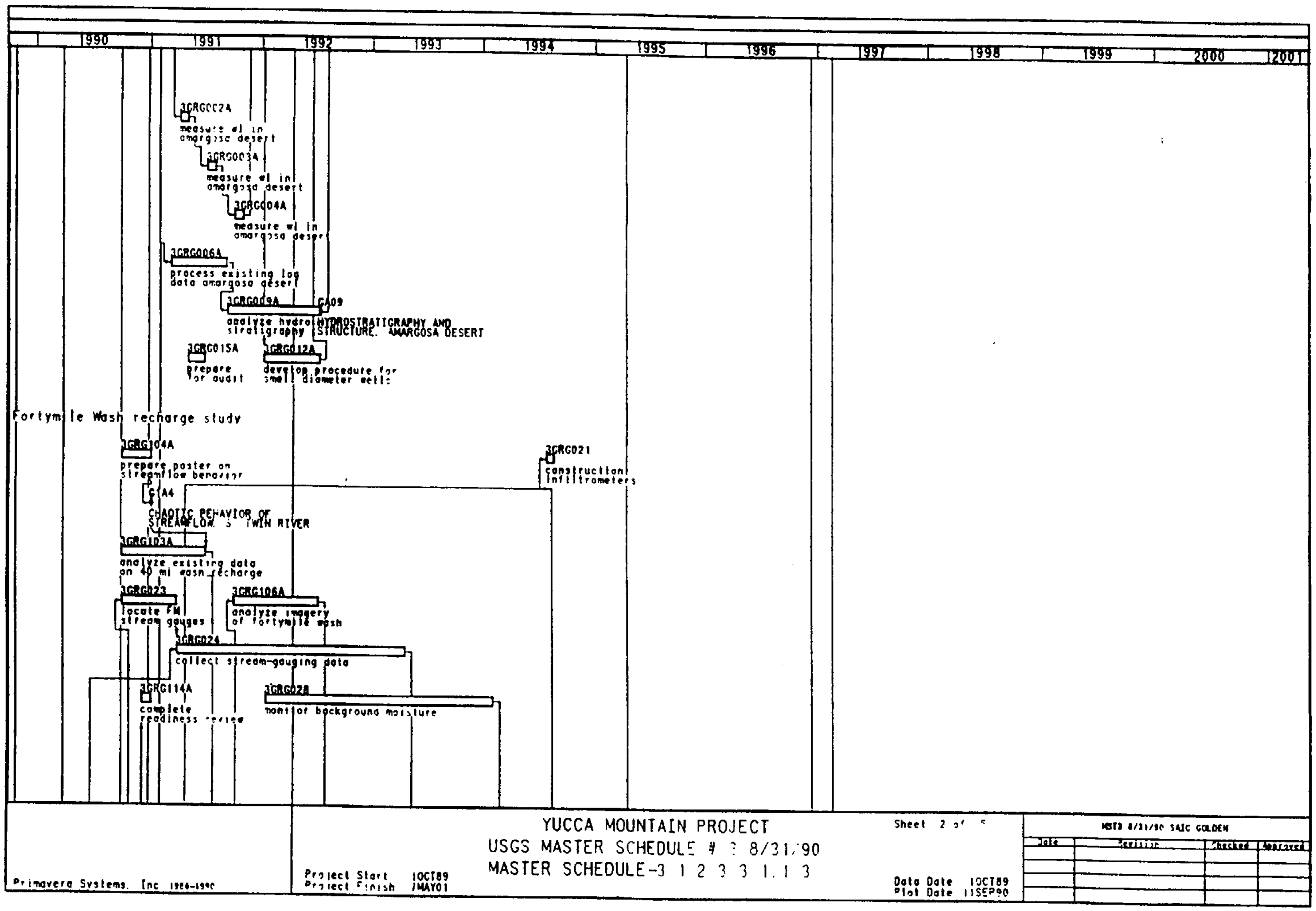

Figure 5.1-1b. Summary network of regional ground-water flow system study. (continued)

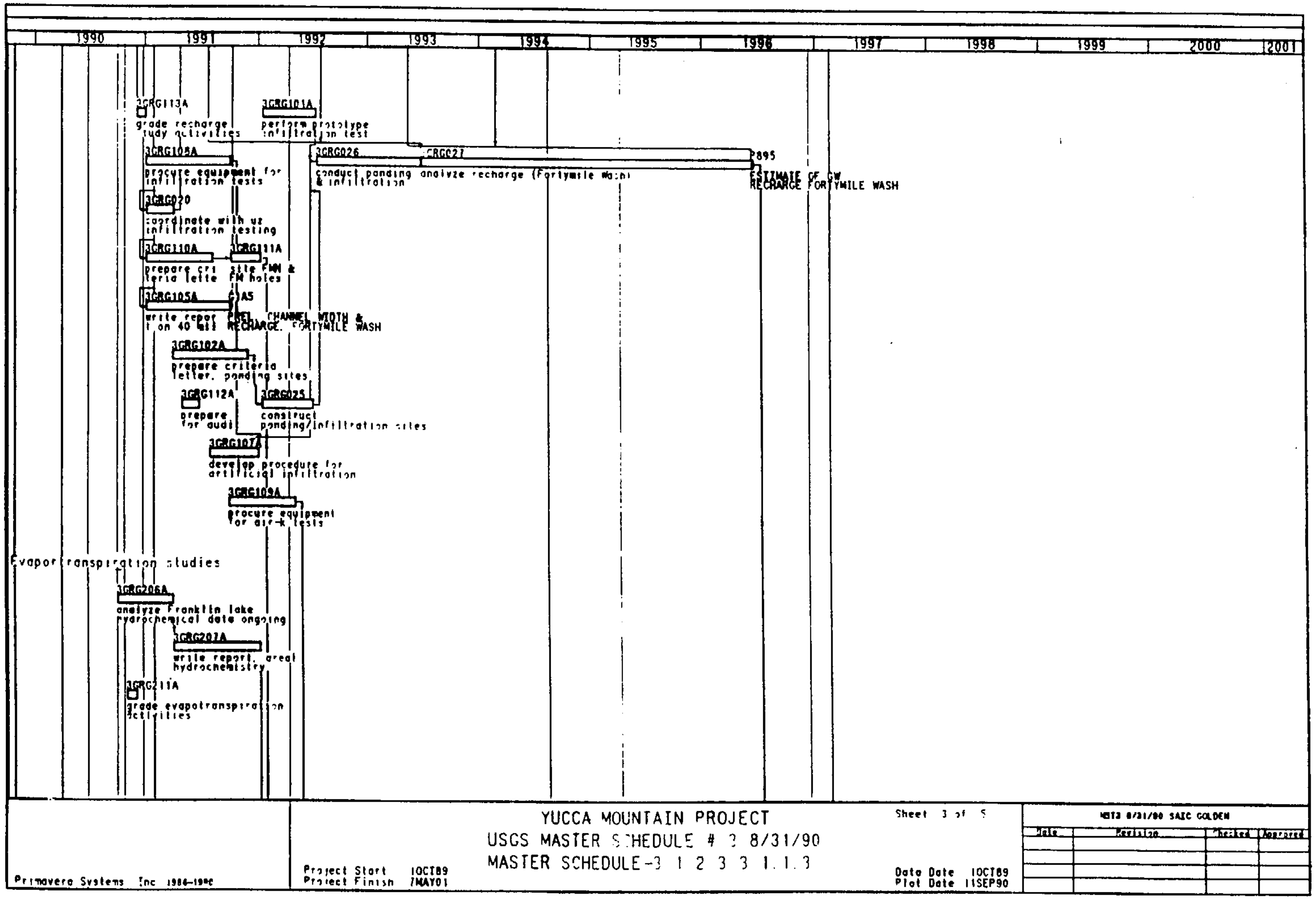

Figure 5.1-1c. Summary network of regional ground-water flow system study. (continued)

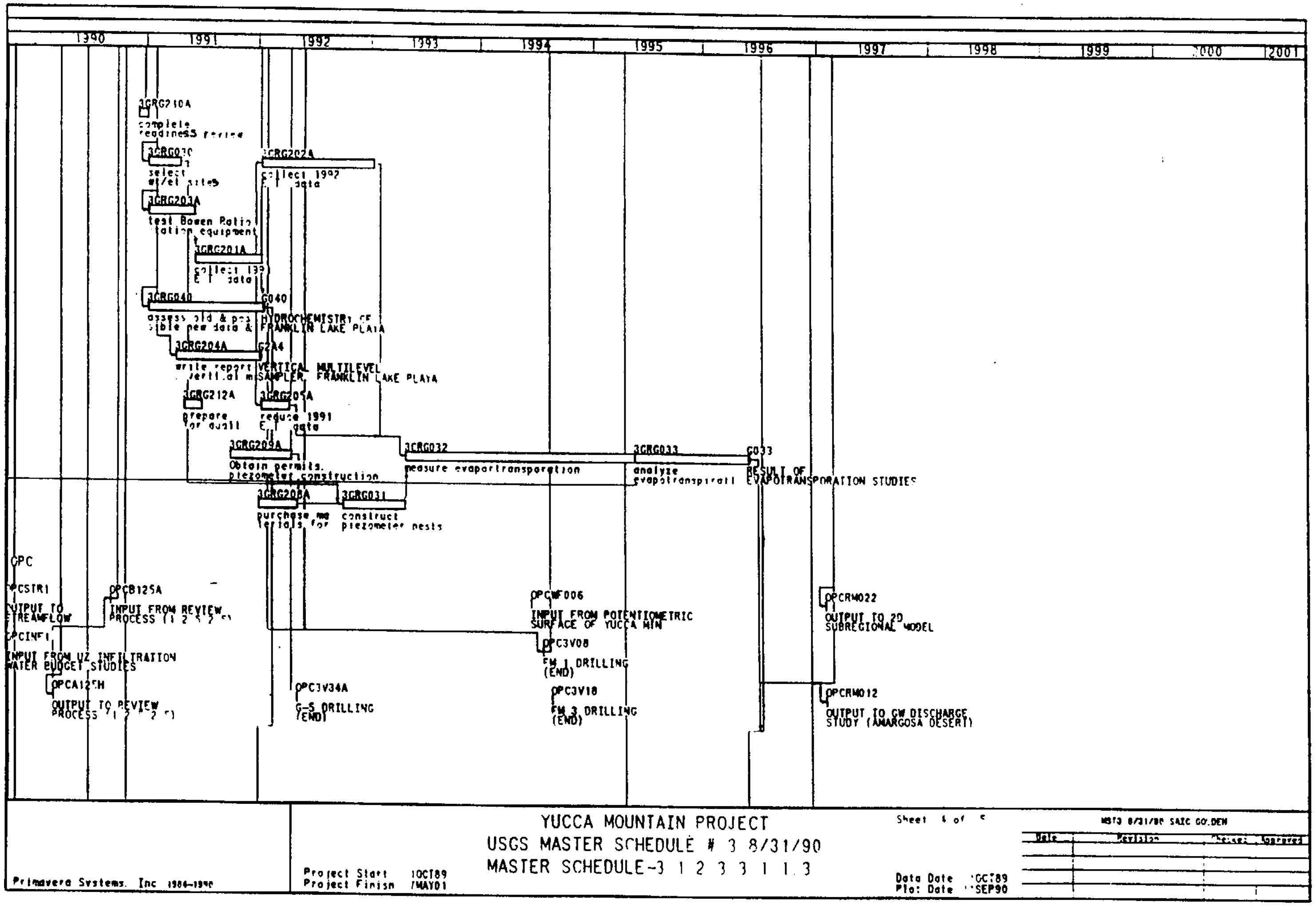

Figure 5.1-1d. Summary network of regional ground-water flow system study. (continued)

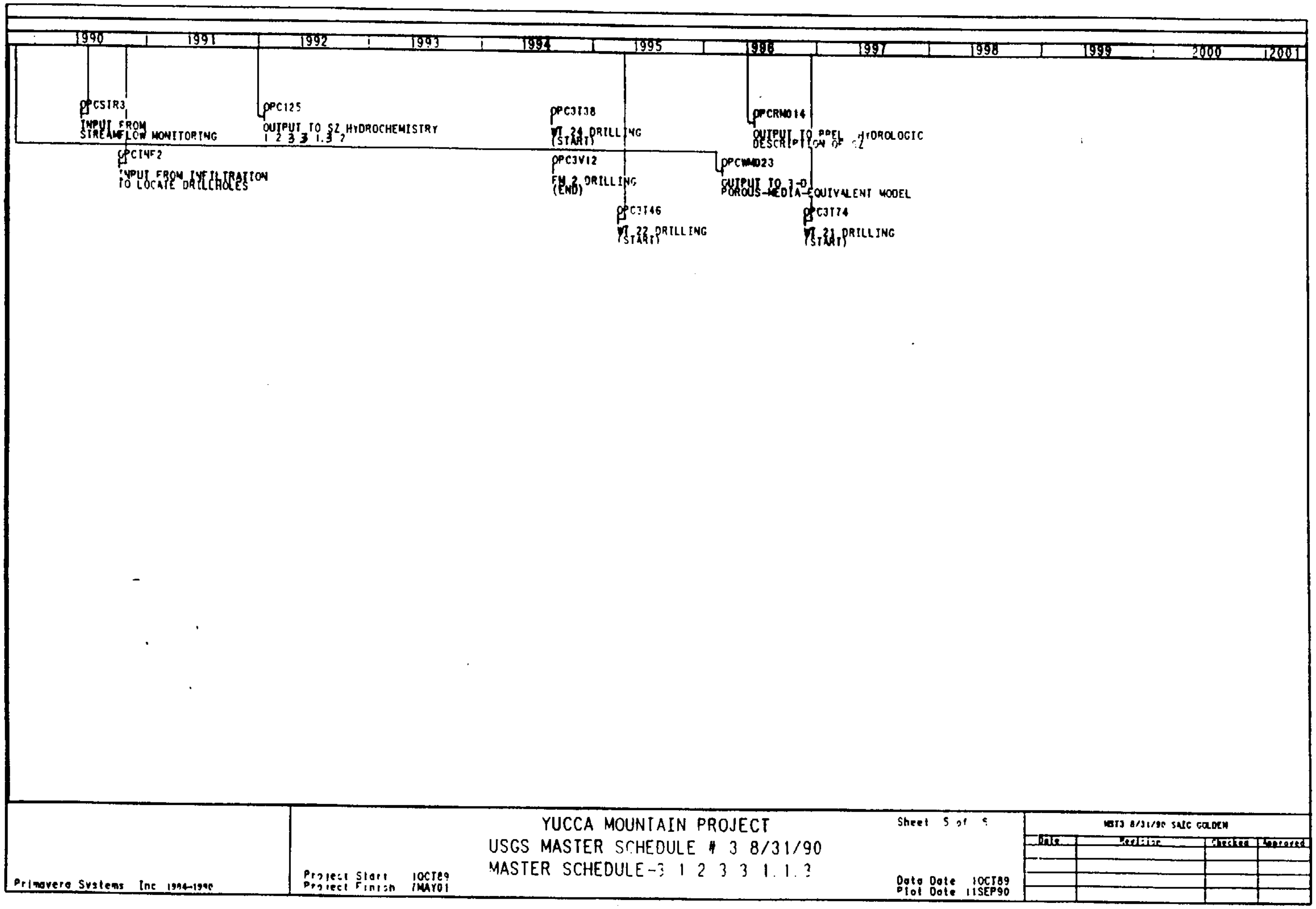

Figure 5.1-1e. Summary network of regional ground-water flow system study. (concluded)

5.2 Milestones

The milestone number, title, and corresponding work breakdown structure number associated with the four activities of the regional ground-water flow system 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.

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Table 5.2-1. Milestone list for work-breakdown structure number-1.2.3.3.1.1.3 (SCP 8.3.1.2.1.3)

[Milestone dates are unavailable at this time]

Milestone number	Milestone	Milestone level
Characterization of the regional ground-water flow system: 8.3.1.2.1.3		
3003	Characterization of Regional Hydrogeology of Amargosa Desert	3
8C02	Submit Study Plan 8.3.1.2.1.3 for DOE Audit review	3
8C03	Submit Study Plan 8.3.1.2.1.3 to NRC	3
Assessment of regional hydrogeologic data needs in the saturated zone: 8.3.1.2.1.3.1		
3204	Work Authorization (Assessment of Regional Hydrological Data Needs)	3
8C04	[Complete Flow-Model Sensitivity Work with ORNL, Penn State, USGS]	4
8C10	Propose Number and Locations for New Water-Table Holes in Large-Gradient Area	4
Regional potentiometric-level distribution and hydrogeologic framework studies: 8.3.1.2.1.3.2		
M378	Project Issues Report/Map: Regional Potentiometric Level Measurements	1
P931	Report: Evaluation of Steep Hydraulic Gradient Near Yucca Mountain	2
S238	Report: Hydrogeo. Char. from Drillers Logs & Geophysical Surveys in the Amargosa	3
Z311	Issue Map: Updated Water Table	3
8C05	Work Authorization (Regional Potentiometric Levels and Hydrogeologic Framework)	3
8C08	Complete Amargosa Desert Boreholes OFR	4
8C09	Final Draft: Amargosa Deep Borehole Data	4

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Table 5.2-1. Milestone list for the study (SCP 8.3.1.2.1.3)--Continued

Milestone number	Milestone	Milestone level
Fortymile Wash recharge study: 8.3.1.2.1.3.3		
P892	Issue Report: Estimate of G-W Recharge Fortymile Wash	2
8C12	Work Authorization (Fortymile Wash Recharge Study)	3
8C15	Criterial Development for Final Neutron and Fortymile Wash (FM) Hole Sites	4
8C11	Submit Land-Access Request Letter and Obtain Environmental Permits	4
Evapotranspiration studies: 8.3.1.2.1.3.4		
8C16	Work Authorization (Evapotranspiration Studies)	3
3004	Report: Results of Evapotranspiration Studies	3
8C19	Submit to DOE: Report on Hydrochemical Evidence for Evapotranspiration at Franklin Lake Playa	3
2H17	Hydrochemistry of Franklin Lake Playa	3

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7 APPENDICES

7.1 Quality-assurance requirements

7.1.1 Quality-assurance requirements matrix

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

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

Applicable NQA-1 criteria for Study 8.3.1.2.1.3 and how they will be satisfied

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

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

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

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

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

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

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

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

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

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance				(SCP 8.3.5.13)
Performance Measures: EPPM[a], nominal case, release scenario class E, water pathway release (Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.)					
Parameter Category: Rock-unit contact location and configuration					
$-/d_u$: average thickness of repository area unsaturated zone between repository and water table (scenario class E, nominal case)[b]	Repository area; Unsaturated zone	Goal: >100 m Current: Medium Needed: High	Hydrogeologic unit contacts	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
Altitudes of geohydrologic-unit contacts; as a function of lateral-spatial location	Controlled area; Unsaturated-zone units, overburden	Goal: Mean, Variance Current: Medium, Medium Needed: High, Medium			
Parameter Category: Saturated-zone transmissive properties					
n_e: average effective matrix porosity, controlled area, saturated zone (scenario class E, nominal case)[b(1)]	Controlled area; Saturated zone	Goal: >0.1 Current: Low Needed: Medium	Hydraulic conductivity	Ground-water subbasin, Yucca Mountain region; Saturated zone hydrogeologic units	8.3.1.2.1.3.2

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance				(SCP 8.3.5.13)
Performance Measures: (Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.) EPPM[a], nominal case, release scenario class E, water pathway release					
Parameter Category: Saturated-zone transmissive properties					
Hydraulic conductivity (Rock matrix)	Controlled area; Saturated-zone units	Goal: Mean, Variance, Autocorrelation length Current: Medium Needed: High, Low, Low			
Hydraulic conductivity (Fracture networks)	"	Goal: Mean, Variance, Autocorrelation length Current: Low Needed: High, Low, Low			
Effective porosity (Rock matrix)	"	Goal: Mean, Variance, Autocorrelation length Current: Low, Low, Low Needed: Medium, Medium, Low			
Effective porosity (Fracture networks)	"	"			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance				(SCP 8.3.5.13)
Performance Measures: EPPM[a], nominal case, release scenario class E, water pathway release (Supporting parameters needed to evaluate the nominal case and as baseline data for the disturbed cases.)					
		Parameter Category: Saturated-zone water potential			
d_s: average length of flow paths, through saturated zone from controlled area to accessible environment boundary (scenario class E, nominal case)[b(1)]	Controlled area; Saturated zone	Goal: >5000 m Current: Low Needed: Medium	Hydraulic gradient, regional	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
Altitude of water table, ambient, as a function of lateral spatial location	Controlled area; Saturated-zone units	Goal: Mean, Variance Current: Medium, Medium Needed: High, Medium	Hydraulic head	"	"
Effective thickness of saturated zone; as a function of lateral-spatial location	"	Goal: Mean Current: Low Needed: Low			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance				(SCP 8.3.5.13)
Performance Measures: EPPM[a], nominal case, release scenario class E, water pathway release					
		Parameter Category: Saturated-zone ground-water flux			
q_s: average discharge in saturated zone under controlled area (scenario class E, nominal case)[b(1)]	Controlled area; Saturated zone	Goal: <32 mm/yr Current: Low Needed: Medium	Ground-water flow directions	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
			Recharge distribution and magnitude	Yucca Mountain and vicinity; Unsaturated-zone units	8.3.1.2.1.3.3
			Evapotranspiration, distribution and magnitude	Amarosa Desert; Unsaturated-zone units	8.3.1.2.1.3.4

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement, ground-water travel time				(SCP 8.3.5.12)
Performance Measures:	(Supporting parameters used in calculating performance parameters for ground-water travel time.) Boundary of repository-induced changes in effective fracture porosity Ground-water travel time*, Saturated zone (secondary reliance)				
		Parameter Category: Rock-unit contact location and configuration			
Contact altitude, hydrologic units (Rock mass)	Repository area; Unsaturated zone, each geohydrologic unit below repository	Goal: Mean, SCor, SDev Current: Medium, NA, NA Needed: High, Low, Medium	Hydrogeologic unit contacts	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
Aquifer geometry (Rock mass)	Controlled area; Saturated zone, upper 100 m	Goal: Mean Current: Low Needed: Medium			
Contact altitude, lithologic units (Rock mass)	Controlled area; Saturated zone, each litho unit in upper 100 m	"			
Altitude of the hydrogeologic unit contacts	Repository area; Subsurface	Goal: -- Current: -- Needed: --			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement, ground-water travel time				(SCP 8.3.5.12)
Performance Measures: Ground-water travel time[e], Saturated zone (secondary reliance) (Supporting parameters used in calculating performance parameters for ground-water travel time.)					
Parameter Category: Saturated-zone transmissive properties					
Effective porosity[1]	Controlled area; Saturated zone	Goal: >0.01 Current: Low Needed: Low	Hydraulic conductivity	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
Permeability, saturated (Fault zones)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low			
Permeability, saturated (Fractures)	"	Goal: Mean, SCor, SDev Current: Low, NA, NA Needed: Medium, Low, Medium			
Permeability, saturated (Rock mass)	"	"			
Permeability, saturated (Rock matrix)	"	Goal: Mean, SDev Current: Medium, NA Needed: Medium, Low			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement, ground-water travel time			(SCP 8.3.5.12)	
Performance Measures: (Supporting parameters used in calculating performance parameters for ground-water travel time.) Ground-water travel time[a], Saturated zone (secondary reliance)					
Parameter Category: Saturated-zone transmissive properties					
Porosity, effective (Fault zones)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low			
Porosity, effective (Fractures)	"	Goal: Mean, SCor;SDev Current: Low, NA, NA Needed: Medium, Low, Medium			
Porosity, effective (Rock Mass)	"	"			
Porosity, effective (Rock Matrix)	"	Goal: Mean, SDev Current: Low, NA Needed: Low, Low			
Porosity, total (Fault zones)	"	Goal: Mean, SDev Current: NA, NA Needed: Medium, Low			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement, ground-water travel time				(SCP 8.3.5.12)
Performance Measures: (Supporting parameters used in calculating performance parameters for ground-water travel time.) Ground-water travel time[e], Saturated zone (secondary reliance)					
Parameter Category: Saturated-zone transmissive properties					
Porosity, total (Fractures)	Controlled area; Saturated zone, each litho unit in upper 100 m	Goal: Mean, SCor, SDev Current: NA, NA, NA Needed: Medium, Low, Medium			
Porosity, total (Rock mass)	"	Goal: Mean, SCor, SDev Current: Low, NA, NA Needed: Medium, Low, Medium			
Porosity, total (Rock matrix)	"	Goal: Mean, Scor, SCor Current: Medium, NA, Medium Needed: Medium, Medium, Medium			
Parameter Category: Saturated-zone water potential					
dh/dl (gradient)[(1)]	Controlled area; Saturated zone	Goal: <0.001 Current: Low Needed: Low	Hydraulic gradient, regional	Ground-water subbasin, Yucca Mountain region; Saturated zone hydrogeologic units	8.3.1.2.1.3.2

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement, ground-water travel time				(SCP 8.3.5.12)
Performance Measures: Ground-water travel time[e], Saturated zone (secondary reliance) (Supporting parameters used in calculating performance parameters for ground-water travel time.)					
Parameter Category: Saturated-zone water potential					
Distance along flow paths[(1)]	Controlled area; Saturated zone	Goal: 1000 m Current: Low Needed: Medium	Hydraulic head	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
Pressure head, function of depth (Ground water)	Controlled area; Saturated zone, upper 100 m	Goal: Mean Current: Low Needed: Medium			
Water-table altitude (Ground water)	Controlled area; Saturated zone, water table level	Goal: Mean, SDev Current: Medium;NA Needed: High, Low			
Parameter Category: Saturated-zone ground-water flux					
q/K_s where K_s is hydraulic conductivity of saturated-matrix zones[(1)]	Controlled area; Saturated zone	Goal: <10 m/yr Current: Low Needed: Low	Ground-water flow directions	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement, ground-water travel time				(SCP 8.3.5.12)
Performance Measures: (Supporting parameters used in calculating performance parameters for ground-water travel time.)					
Parameter Category: Saturated-zone ground-water flux					
Flux, flow rate (Rock mass)	Controlled area; Saturated zone, upper 100 m	Goal: Mean Current: Low Needed: Medium	Recharge distribution and magnitude	Yucca Mountain and vicinity; Unsaturated-zone units	8.3.1.2.1.3.3
			Evapotranspiration, distribution and magnitude	Amarosa Desert; Unsaturated-zone units	8.3.1.2.1.3.4

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.11	Characteristics and configurations of repository and engineered barriers (postclosure)				(SCP 8.3.2.2)
Performance Measures:	Usable area: Is usable area adequate for 70,000 metric tons of uranium (MTU) waste? Temperature Temperature Temperature				
		Parameter Category: Rock-unit contact location and configuration			
Elevation of unit contacts for positioning underground facility[f] (Structure contour maps on upper and lower contacts of TSw2 in primary area and extensions)	Primary area and extensions; TSw2	Goal: Contours accurate to 30 m +/- Current: Low Needed: Medium	Hydrogeologic unit contacts	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
Elevation of unit contacts for positioning underground facility (Structure contour map on lower contact of TSw2, minimum overburden)	"	Goal: Contours accurate to 10 m +/- Current: Low Needed: High			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.11	Characteristics and configurations of repository and engineered barriers (postclosure)				(SCP 8.3.2.2)
Performance Measures: Usable area: Is usable area adequate for 70,000 metric tons of uranium (MTU) waste? Temperature Temperature Temperature					
Parameter Category: Rock-unit contact location and configuration					
Elevation of unit contacts for positioning underground facility (Structure contour map on upper contact of TSw2, minimum overburden)	Primary area and extensions; TSw2	Goal: Contours accurate to 10 m +/- Current: Low Needed: Medium			
Geologic stratigraphy to water table (location of unit contacts for thermal modeling) (Structure contour maps on upper and lower contacts of TSw2 in primary area and extensions)	"	Goal: Contours accurate to 30 m +/- Current: Low Needed: Medium			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.11	Characteristics and configurations of repository and engineered barriers (postclosure)			(SCP 8.3.2.2)	
Performance Measures: Temperature Temperature Temperature Usable area: Is usable area adequate for 70,000 metric tons of uranium (MTU) waste?					
	Parameter Category: Rock-unit contact location and configuration				
Geologic stratigraphy to water table (location of unit contacts for thermal modeling) (Structure contour map on lower contact of TSw2 in areas with minimum overburden)	Primary area and extensions; Unsaturated zone	Goal: Contours accurate to 10 m +/- Current: Low Needed: Medium			
Geologic stratigraphy to water table (location of unit contacts for thermal modeling) (Structure contour map on upper contact of TSw2 in areas with minimum overburden)	"	"			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.11	Characteristics and configurations of repository and engineered barriers (postclosure)				(SCP 8.3.2.2)
Performance Measures: Temperature Usable area: Is usable area adequate for 70,000 metric tons of uranium (MTU) waste?					
Parameter Category: Rock-unit contact location and configuration					
Geologic stratigraphy to water table (Structure contour map on upper and lower contacts of other units in primary area and extensions)	Primary area and extensions; TCw, PTn, TSw, Chn	Goal: Contours accurate to 60 m +/- Current: Low Needed: Medium			
Parameter Category: Saturated-zone water potential					
Water-table elevation (Contour map of water table in primary area and extensions)	Primary area and extensions; Water table	Goal: Contours accurate to +/- 7.5 m Current: Medium Needed: Medium	Hydraulic gradient, regional	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
Water-table elevation (Contour map of water table in areas with minimum ground-water travel time)	"	Goal: Contours accurate to 10 m +/- Current: Medium Needed: High	Hydraulic head	"	"

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.12	Seal characteristics				(SCP 8.3.3.2)
Performance Measures:	Quantity of water Quantity of water Drainage capacity				
		Parameter Category: Rock-unit contact location and configuration			
Morphology of bedrock surface; in order of priority - downgradient, ingradient, and about 160m from shaft locations	Vicinity of shaft locations; Near surface	Goal: Determine contours to within +/- 3 m Current: Low Needed: Medium	Hydrogeologic unit contacts	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
Thickness of alluvium	Within 75m of shaft and borehole locations; Near surface	Goal: Determine thickness to within +/- 10% Current: Low Needed: Medium			
Unit contacts in exploratory boreholes; all boreholes (see SCP Table 8.3.3.2-4)	All boreholes in categories A and B[d];	Goal: Contact location +/- 5 m Current: Low Needed: High			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.12	Seal characteristics				(SCP 8.3.3.2)
Performance Measures: Drainage capacity					
		Parameter Category: Saturated-zone transmissive properties			
Saturated, bulk-rock hydraulic conductivity	At base of ES-1 and in boreholes; CHn1	Goal: Saturated, bulk-rock hydraulic conductivity $k_{SAT} > 1 \times 10^{-5}$ cm/s Current: Low Needed: Low	Hydraulic conductivity	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 4.4	Repository construction, operation, closure, and decommissioning technologies			(SCP 8.3.2.5)	
Performance Measures: Thickness for drift construction and waste emplacement Shafts and ramps compatible with requirements for repository sealing Drift sizes and slopes compatible with requirements for personnel and material transport and utility routing Drifts (underground layout) compatible with repository sealing Shafts and ramps compatible with requirements for repository sealing					
Parameter Category: Rock-unit contact location and configuration					
Stratigraphic contacts for top and bottom of the TSw2 formation within candidate areas for repository	Primary area and extensions; TSw2	Goal: Determine elevation of stratigraphic contacts at selected points within candidate repository area to accuracy of +/- 10 m Current: Low Needed: High	Hydrogeologic unit contacts	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
Elevation of upper Calico Hills	Exploratory shafts; CHn	Goal: Elevation within 5 m Current: High Needed: High			
Upper- and lower-contact elevations for TSw2 formation over the entire repository area	Primary area; TSw2	Goal: Upper- and lower-contact elevations for the TSw2 within 20 m Current: -- Needed: Medium			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 4.4	Repository construction, operation, closure, and decommissioning technologies				(SCP 8.3.2.5)
Performance Measures: Drifts (underground layout) compatible with repository sealing Shafts and ramps compatible with requirements for repository sealing					
Parameter Category: Rock-unit contact location and configuration					
Upper- and lower-contact elevations for the TSw2 unit within the potential repository area	Primary area and extensions; TSw2	Goal: Upper- and lower-contact elevations for the TSw2 within 20 m Current: Medium Needed: Medium			
Parameter Category: Saturated-zone water potential					
Ground-water table 2,400 ft elevation at ES-1	Exploratory shafts; Water table	Goal: -- Current: High Needed: High	Hydraulic gradient, regional	Ground-water subbasin, Yucca Mountain region; Saturated-zone hydrogeologic units	8.3.1.2.1.3.2
			Hydraulic head	"	"

SP 8.3.1.2.1.3, R0

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