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Study Plan for
Study 8.3.1.2.3.2

Characterization of the Yucca Mountain Saturated-Zone Hydrochemistry

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Revision 0

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

Prepared by
U.S. Geological Survey

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YUCCA MOUNTAIN PROJECT
STUDY PLAN APPROVAL FORM

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Study Plan Number 8.3.1.2.3.2

Study Plan Title Characterization of the Yucca Mountain Saturated-Zone Hydrochemistry

Revision Number Rev 0

Prepared by: S. Hans

Date: April 15, 1992

Approved:

4/16/92
Director, Regulatory and Site Evaluation Division / Date

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RECORD OF REVISIONS

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R0	Study rationale and plans for four activities: Assessment of saturated-zone hydrochemical data availability and needs (Section 3.1) Hydrochemical characterization of water in the upper part of the saturated zone (Section 3.2) Regional hydrochemical tests and analyses (Section 3.3) Synthesis of saturated-zone hydrochemistry (Section 3.4)	11-27-91

ABSTRACT

This study plan describes four site-characterization activities for the saturated-zone hydrochemistry of Yucca Mountain. These activities will contribute to an understanding of the chemical characteristics of hydrostratigraphic units, provide an understanding of their relation to ground-water flow paths, transport, and travel times, and provide hydrologic-parameter input for the resolution of design and performance parameters. The activities include the following.

- Assessment of saturated-zone hydrochemical data availability and needs,
- Hydrochemical characterization of water in the upper part of the saturated zone,
- Regional hydrochemical characterization, and
- Synthesis of saturated-zone hydrochemistry.

The rationale of the site saturated-zone hydrochemistry 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 the study results, Section 5 presents the schedules and associated milestones, study-plan references are listed in Section 6, and quality assurance requirements are discussed in Section 7.

CHARACTERIZATION OF THE YUCCA MOUNTAIN SATURATED-ZONE HYDROCHEMISTRY

YMP-USGS SP 8.3.1.2.3.2, R0

STUDY PLAN

NOVEMBER 1991

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1 PURPOSE AND OBJECTIVES OF STUDY

1.1 Purpose

The U.S. Geological Survey (USGS) is conducting studies at Yucca Mountain, Nevada, and within the surrounding region as part of the Yucca Mountain Project (YMP). The purposes of the USGS studies are to provide hydrologic and geologic information essential to an evaluation of: (1) the suitability of Yucca Mountain as a site for construction of a high-level nuclear-waste repository, and (2) the ability of the mined geologic-disposal system (MGDS) to isolate the waste in compliance with regulatory requirements.

The purpose of this study plan is to describe the individual activities (next level below study in project organization) comprising this study, which will provide the hydrochemical information needed in geohydrological and geochemical site characterization efforts. This study is one of five planned to investigate and describe the geohydrological characteristics of the saturated zone at site and/or regional scales. In addition to the three studies shown in Figure 1.1-1, the other two are Study 8.3.1.2.1.3 (Regional saturated-zone ground-water flow system) and Study 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling). It is designed primarily to describe the water chemistry in the saturated, and immediately adjacent unsaturated, rocks beneath and adjacent to Yucca Mountain, and in the saturated rocks within the surrounding region. The study comprises four activities:

- 8.3.1.2.3.2.1 - Assessment of saturated-zone hydrochemical data availability and needs,
- 8.3.1.2.3.2.2 - Hydrochemical characterization of water in the upper part of the saturated zone,
- 8.3.1.2.3.2.3 - Regional hydrochemical characterization, and
- 8.3.1.2.3.2.4 - Synthesis of saturated-zone hydrochemistry.

The numbers (e.g., 8.3.1.2.3.2.1) used throughout this plan refer to specific sections of the YMP Site Characterization Plan (SCP). The SCP (U.S. Department of Energy, 1988a) 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.

Gas-phase samples, hydrochemical data, and liquid-phase samples will be collected at wells and springs throughout the site and region. The resultant data base will include intensive properties, such as water temperature and specific electrical conductance; concentrations of selected dissolved inorganic and organic constituents; selected dissolved radioisotope activities and stable isotope ratios; and concentrations, radioisotope activities, and stable isotope ratios of selected gaseous elements and compounds. The specific analytical suites to be applied are discussed in the descriptions of the individual activities. The incidence

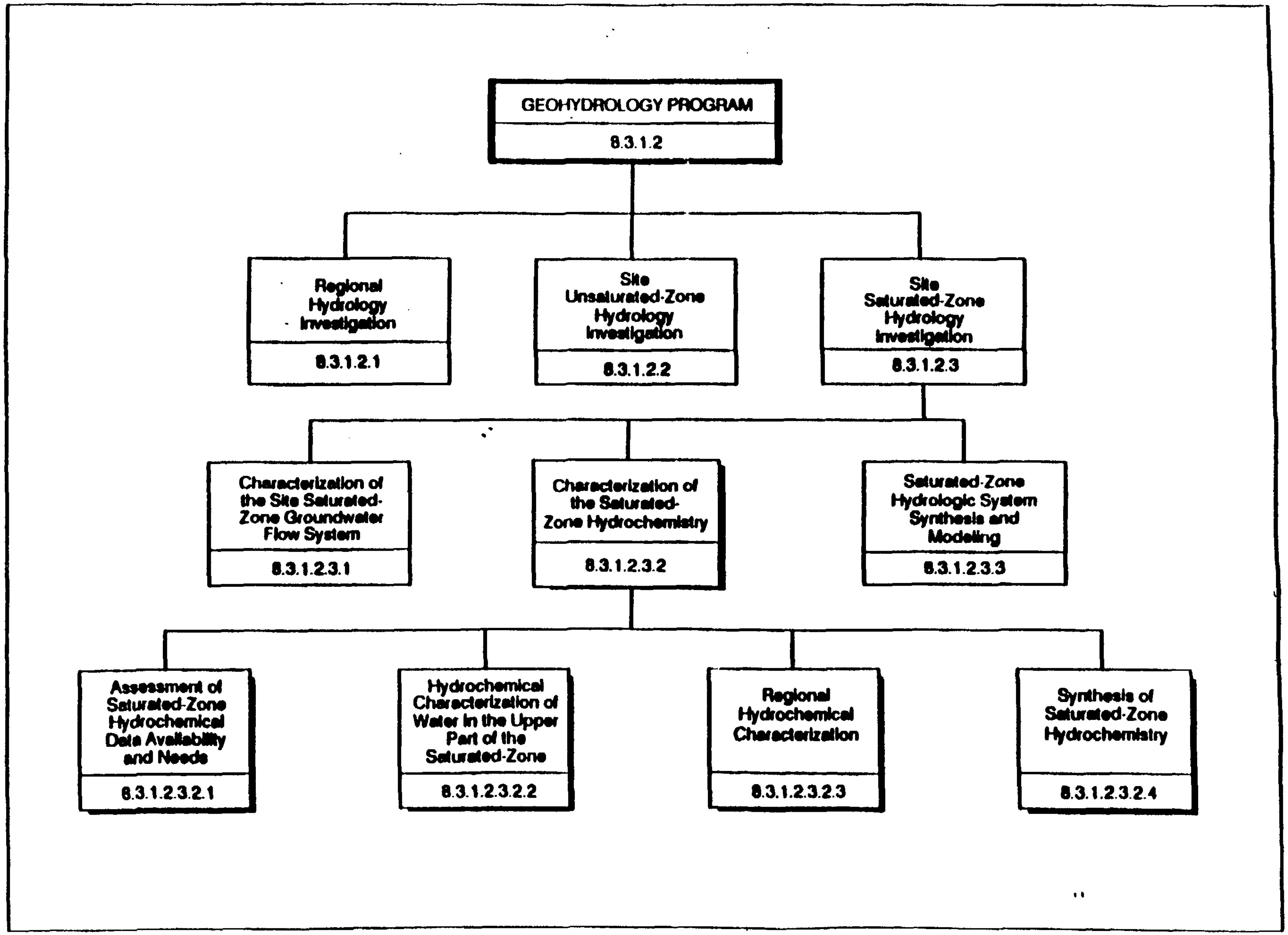


Figure 1.1-1. Diagram showing the location of study within the saturated-zone investigation and organization of the Geohydrology Program.

of new data will be highest at and in the vicinity of Yucca Mountain. New regional information will be collected within an area approximately from Gold Flat south to Silurian Valley, and from Death Valley east to the Spring Mountains (Figure 1.1-2).

The data generated by this study will serve numerous purposes. They will enable identification of plausible solid phases and chemical processes that contribute to spatial compositional variations in saturated-zone waters. Delineation of the processes will focus on the interrelationships between saturated- and unsaturated-zone hydrochemistry and the lithology and mineralogy of the encompassing rocks. Data generated will provide insight to the physical nature of the geohydrologic system, as they will contribute to the identification and quantification of fluxes to, from and within the saturated zone. They also will be used to examine various aspects of the conceptual model of the geohydrologic system, including hydrologic boundaries, directions and magnitudes of flow, and residence times within the saturated and unsaturated zones. The data are also requisite to investigations of the movement and fate of radionuclides within the near and far fields, and predictions of radionuclide release rates to the accessible environment.

The specific investigations and studies that will employ data generated in the present study are discussed in Section 4.2.

Figure 1.1-2. Map showing the general region of interest.

1.2 Regulatory rationale and justification

The relations between design and performance information needs and data collected in this study are addressed in the geohydrology-testing strategy in SCP Section 8.3.1.2 and the issue-resolution strategies (ground-water travel time and performance assessment) in SCP Sections 8.3.5.12 and 8.3.5.13. The description presented below provides a more specific identification of these relations as they apply to this study. Project-organization interfaces between this study, YMP performance issues and other site studies are illustrated in Figure 1.2-1.

Information derived from the study will principally support the performance determinations of pre-waste-emplacement ground-water travel time (Issue 1.6) and the predictions of radionuclide releases to the accessible environment (Issue 1.1). Study results will also provide hydrochemical information to be used in the analyses of repository preclosure design and technical feasibility (Issue 4.4). Unsaturated-zone water-chemistry data from immediately above the water table (Activity 8.3.1.2.3.2.2) may be used to indirectly support analyses of waste-package performance (Issue 1.10).

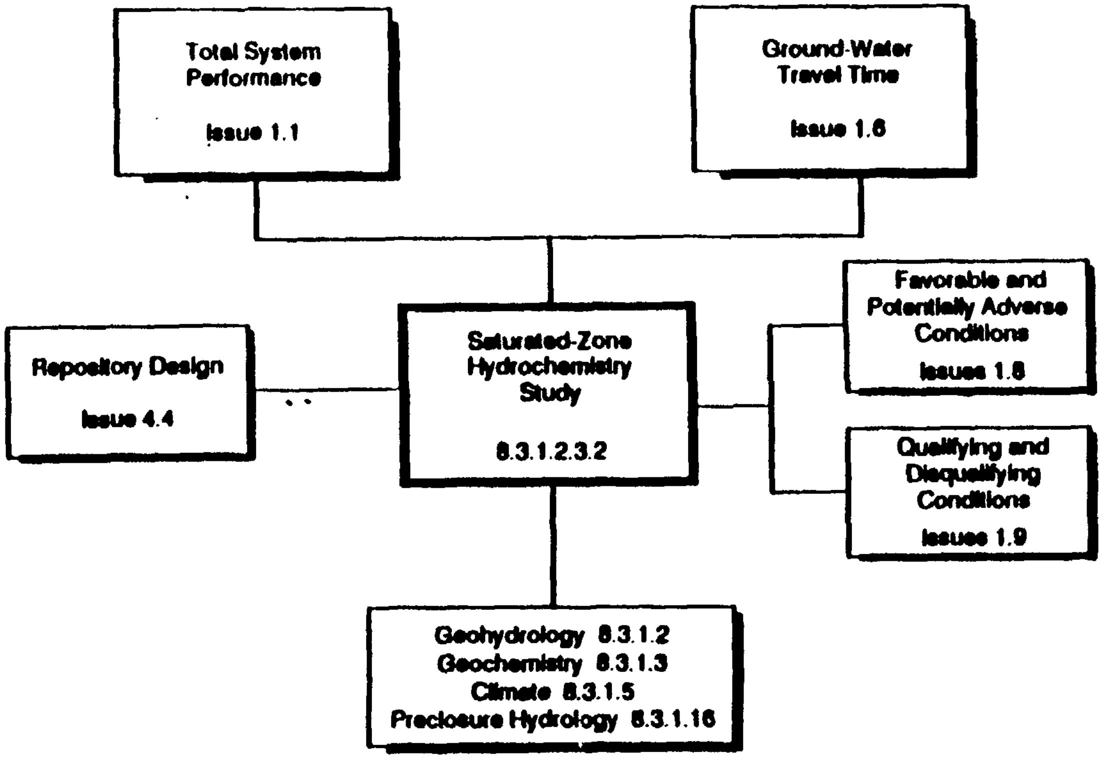
Performance Issue 1.1
(Total-system radionuclide release to the accessible environment)

This issue is concerned with the containment requirements specified by 10 CFR 60.112, and also 40 CFR 191.13 (a):

> Disposal systems for spent nuclear fuel or high-level or transuranic wastes shall be designed to provide a reasonable expectation, based upon performance assessments, that the cumulative releases of radionuclides to the accessible environment for 10,000 years after disposal from all significant processes and events that may affect the disposal system shall:
>
> (1) Have a likelihood of less than one chance in 10 of exceeding the quantities calculated according to Table 1 (Appendix A);
>
> (2) Have a likelihood of less than one chance in 1,000 of exceeding ten times the quantities calculated according to Table 1 (Appendix A).

Appendix A of 40 CFR part 191 contains a table of the radioactive release limits for each radionuclide to be considered in calculating normalized release to the accessible environment.

Eight classes of scenarios "...involving definite types of events or processes, but with intensities, epochs of occurrence or durations, and orders of occurrence allowed to range freely over the physically possible numerical values..." have been developed to identify the significant processes and events to be considered in the course of performance



Figur[illegible] 1.2-1. Diagram showing the organizational inte[illegible]s of the saturated-zone hydrochemistry stud[illegible] YM[illegible] formance and design issues and other site-ch[illegible]terization programs.

assessments. Descriptions of the scenarios are given in SCP Section 8.3.5.13 (see SCP Table 8.3.5.13-3). The results of this study will be used to support performance parameters, which will be used to calculate or assess performance measures for each scenario class. The study results will also provide baseline data for disturbed-case scenario classes.

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

This issue addresses one of the NRC performance objectives for high-level waste repositories, as stated in 10 CFR 60.113 (a) (2):

> The geologic repository shall be located so that pre-waste-emplacement ground-water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other time as may be approved or specified by the Commission.

The general strategy for resolving this issue entails the definition, characterization, and assessment of multiple barriers to ground-water flow by dividing flow paths and flow processes into discrete categories. In the unsaturated zone, multiple natural barriers have been identified as seven distinct geohydrologic units for which different types of general flow processes may be distinguished, including dispersive and advective flow in rock pores and fractures and diffusion between and within the pores and fractures. The entire saturated zone is considered an additional geohydrologic unit (SCP, p. 8.3.5.12-11). The frequency distribution of calculated ground-water travel times is the performance measure for each geohydrologic unit. The overall performance goal desired for the ground-water travel time through the geohydrologic units between the disturbed zone and the accessible environment is a minimum of 1,000 years.

Information from this study will be used to support performance measures needed to assess ground-water travel time in the unsaturated units immediately above the water table and in the saturated zone. Water residence times, water-vapor and gas fluxes, and distances along flow paths will provide the basis for the ground-water travel-time model. The results of the ground-water travel-time model calculations will yield performance parameters for the geohydrologic units.

Performance Issue 1.8
(Favorable and potentially adverse conditions)

This postclosure performance issue addresses the NRC siting criteria that describe human activities and natural conditions, processes, and events that could either enhance or adversely affect the ability of a site to meet waste-isolation performance objectives, as stated in 10 CFR 60.122 (see SCP Tables 8.3.5.17-1 and 8.3.5.17-2).

Two sets of conditions, eight favorable and 24 unfavorable, comprise the criteria. These conditions are enumerated in SCP Section 8.3.5.17. The results of this study relate to Favorable Conditions 3 (geochemical conditions) and 8 (unsaturated-zone geohydrologic conditions) via Issue 1.1, and to Favorable Condition 7 (pre-waste-emplacement radionuclide travel time) via Issue 1.6. The results also relate to Potentially Adverse Conditions 6 (potential for climate-induced changes in hydrologic conditions), 7 (ground-water conditions in the host rock that could increase the solubility or reactivity of the engineered barrier system), 8 (geochemical processes), and 9 (ground-water conditions in the host rock that are not reducing) through Issue 1.1.

Performance Issue 1.9
(Qualifying and disqualifying conditions)

This issue concerns the DOE's postclosure siting guidelines and 100,000-year release evaluations. These are described and discussed in SCP Section 8.3.5.18. The postclosure siting guidelines consist of a system guideline and eight technical guidelines, each of which "...has a qualifying condition that must be met for a site to be acceptable. In addition, five of the technical guidelines have at least one disqualifying condition each. A site is unacceptable if any one of the disqualifying conditions is found to be present" (SCP, p. 8.3.5.18-1). The DOE's postclosure guidelines (10 CFR 960.4) and evaluation guidelines (10 CFR 960.3-1-5) require that four levels of specific findings must be made based on evaluations of the qualifying and disqualifying conditions of the system and technical guidelines. Higher-level findings "...must be made to determine if a site may be recommended for the development of a repository" (SCP, p. 8.3.5.18-3). Study results will apply to the higher-level findings for the geohydrology and geochemistry qualifying and disqualifying conditions through Issues 1.1 and 1.6.

2 RATIONALE FOR STUDY

This section of the study plan describes the approach, measurements to be made, rationales for the measurement selected, and the constraints for each activity.

The saturated zone beneath Yucca Mountain and the adjacent region constitutes a barrier to, and a potential pathway for, the migration of radionuclides from the proposed mined geologic repository to the accessible environment (as described in SCP Section 8.3.1.2.3). The extent to which it will function as a barrier or pathway will depend on the characteristics and amounts of released radionuclides, the extent of thermal perturbation, the physical and chemical characteristics of the engineered and natural barrier systems, and the chemistries of pre- and post-emplacement ground waters.

This study will provide a base of hydrochemical data for site and regional characterization of ground-water chemistry, delineation of plausible chemical and physical processes influencing spatial compositional distributions, chemical model development, and parameter-assessment calculations.

Understanding the geohydrology of the saturated zone is essential to the site-characterization program. As water is a medium for transport of radionuclides, it is important to evaluate the saturated-zone flow system beneath Yucca Mountain.

A description of the saturated zone comprises the integrated results of investigations of the following hydrologic and geologic attributes of the site and region: (1) stratigraphy, (2) geologic structure, (3) mineralogy and petrology, (4) meteorology, (5) surface water, (6) ground water, and (7) hydrochemistry. Stratigraphic and structural studies provide geometric constraints within which characterization efforts operate. Mineralogic and petrologic studies provide spatial distributions of solid-phase morphology and chemistry, and additional insight beyond the analyses of geometric information, to the relative sequence of events in the physical evolution of the geologic system. Meteorologic and hydrologic studies provide temporal information about the movement of water in the geohydrologic system. All of these data provide a framework within which the occurrences and distributions of materials dissolved in saturated-zone ground waters can be studied. The products of this study in turn provide insight to the movement of water within the geohydrologic framework and enable refinements of conceptual models of the geohydrologic system.

2.1 Technical rationale and justification

2.1.1 Approach

Hydrochemical data are available for ground waters from about 275 locations on and in the vicinities of Yucca Mountain and the Nevada Test Site (NTS) (Benson and McKinley, 1985; McKinley and others, 1991). These data cover a region of about 20,000 square kilometers (7,718 square miles), the general boundaries of which are noted in Section 1.1 and shown in Figure 1.1-2. The period of record of the data base is from the 1950s to early 1986. Additional data for that part of southern

Nevada in which the general region is located are available in USGS and EPA files.

The data vary with regard to both spatial distribution and the analytical suite applied to each sample. This variation is the result of several factors. First, depths to water, particularly north of Lathrop Wells (Figure 1.1-2), frequently exceed 300 meters (984 feet), generally rendering development of the water resource economically unfeasible, discouraging the construction of water-supply wells, and significantly increasing the logistical difficulties inherent in collecting satisfactory ground-water samples. Second, known mineral resources, which are commonly located via deep exploratory holes that can serve as data-collection locations, are present only in a small part of the region. Third, some of the previous hydrochemical investigations in the region were of relatively restricted scope and did not yield analyses that enable a reasonably complete description of ground-water chemistry.

The inorganic chemical concentrations and isotopic compositions of saturated-zone ground waters derive initially from those of precipitation. These aspects of water that recharges the saturated zone are modified by physical processes and chemical reactions during overland flow and flow through the unsaturated zone to the water table, and by subsequent water-rock reactions in the saturated zone. Knowledge of the spatial variations in ground-water chemistry provides insight to the physical nature of the geohydrologic system (i.e., flow paths, boundaries, and areas of recharge). The extent of dissolution processes are influenced by the movement of water through the geohydrologic system, which is largely a function of the distribution of permeability within the system. The extent to which water-rock reactions progress at any specific reaction site is in part proportional to the residence time of the water at the site. It is conceivable, therefore, that water within fractures has a composition different from that within the rock matrix. Neglecting chemical considerations, the extent of such a difference is a function of the permeability difference between the two environments and the capacity for fluid to move from one to the other.

The mineralogy of the saturated rocks through which ground water flows and has flowed is reflected to different degrees by the absolute and relative concentrations of individual dissolved species. These data can be used with empirical mineralogic and physio-chemical data and appropriate thermodynamic information to infer plausible reactions that could lead to their occurrence. This information is an essential part of any assessment of the potentials for aqueous transport of radionuclides.

The geohydrologic framework at Yucca Mountain and the adjacent region includes flat-lying, tilted, faulted, and fractured ash-fall and ash-flow Miocene tuffs. In addition, the tuffs are variably welded, devitrified, and altered, and therefore exhibit variable porosities and primary and secondary permeabilities. The spatial distribution of permeabilities determines the movement of water with the framework.

Most of the tuffs are high-silica rhyolites, with a few units of significant volume grading from rhyolite to quartz latite (Lipman and others , 1966; Byers and others, 1976). Based on mineralogic and petrographic data from six boreholes and several outcrop sites on or immediately adjacent to Yucca Mountain, volcanic glass is a major component of the uppermost 375 to 584 meters of tuff and is the chemically most reactive phase present because of its amorphous character and attendant large surface area (Jones, 1966). Glass is less abundant in the underlying rocks, having been largely replaced by smectites and zeolites. The suite of secondary minerals observed in core samples ranges downward from minor amounts of smectite, opal, and zeolites through a zeolitized section (clinoptilolite minerals to mordenite with increasing depth), to a zone with analcime, K-feldspar, quartz and calcite, which is in turn underlain by a zone in which albite is the dominant secondary phase (Broxton and others, 1987). A similar vertical zonation of secondary minerals in volcanic ash accumulations in thick sedimentary sequences was described by Iijima (1975, 1978, and 1980). Hearn and others (1990), in a synthesis of observations of variations in water chemistry and secondary mineral populations in basaltic aquifers in the Columbia Plateau, noted similar mineralogic variation with depth in a system also characterized by abundant volcanic glass with a somewhat rhyolitic composition.

Based on available mineralogic and hydrochemical information, a simplistic conceptual model similar in principle to that of Jones (1966) can be constructed to account for observed variations. Hydrolysis of volcanic glass by ground water and recharging water is likely the most rapid dissolution process occurring in the tuffs. It is likely that acidic dissolution, via the dissolution of CO_2 in the soil zone, also contributes to the diagenetic process. Within the pH range (6.8-9.0) of ground waters in the tuffs at Yucca Mountain (Benson and McKinley, 1985), dissolved aluminum is only slightly soluble and is, in the early part of the evolutionary process, likely removed by precipitation of an amorphous aluminosilicate phase, which over geologic time orders to more stable smectite. The increase in hydroxyl ion concentration attendant to the hydrolysis reaction results in a gradual increase of ground-water pH, which ultimately exceeds the stability of calcite, and effects the loss from solution of some alkaline earths and some other divalent metals. Alkali metals tend to be conserved during this process and their concentrations, together with that of silicon, tend to increase. When these concentrations become sufficiently high, zeolitization occurs, either by direct precipitation or by replacement of smectite. The occurrence of analcime and albite suggest ground-water temperature much higher than those within the currently observed range. Their formation at their location within the present thermal regime would likely require much higher ground-water ionic strength than observed, and there have been no reports of evidence of the past or present occurrence of highly saline waters in the tuffs at Yucca Mountain. This model is the geochemical basis for the design of this study. Data collected in this study will be used to refine and modify the model as appropriate.

2.1.2 Measurements and rationale

Ground-water samples will be analyzed for major and minor inorganic and organic species, including Li, Be, B, F, Na, Mg, Al, Si, P, S, Cl, K, Ca, Mg, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Br, Sr, Mo, Ag, Cd, I, Ba, Pb, NO_3, PO_4, and humic and fulvic compounds. These data, together with field-determined unstable constituents and properties, will be used to describe spatial hydrochemical variations and to provide insight as the physical nature of the ground-water flow system. They will also be used, as appropriate, to thermodynamically assess the stabilities of relevant primary and secondary solid phases in the host rock. They will also be used to examine the feasibility of reaction scenarios in the evolution of ground-water chemistry.

Attempts will be made to isolate high- and low-molecular-weight fractions of dissolved organic carbon compounds present in sampled ground waters. The fractions will be subjected to stable and radiocarbon analyses to provide insight as to the flux of organic material to the water table.

Water that has traveled vertically through the unsaturated zone to the water table, or the zone of complete saturation, at and in the vicinity of Yucca Mountain must have traversed a minimum of 300 meters of unsaturated rock. A lower bounding estimate of vertical travel time from land surface can be made from the uncorrected radiocarbon age of a water sample from Well UE-29 a#2 in Fortymile Canyon, about 12 kilometers northeast of the proposed repository block. An age of 3,800 years and a depth to water of 29 meters, assuming vertical flow and no younger underflow, yields a vertical flux rate of 7.63 mm per year. This rate would necessitate over 39,000 years for a 300-meter thickness. Even the preliminary, uncorrected, radiocarbon age of 11,760 years of a drilling-fluid-contaminated sample collected by the Desert Research Institute from Well UE-25 WT #14, about 3 kilometers east of the block, is still a time interval sufficiently long for thermal equilibrium between water, rock, and gas masses to have occurred. While the rock atmosphere immediately adjacent to the zone of complete saturation is accessible to circulation induced by water table and barometric fluctuations, it is unlikely that this basal part of the unsaturated-zone atmosphere undergoes sufficient input and mixing to alter the thermal state.

Because of the above-noted minimum time intervals, one could also suspect chemical equilibrium between the water and the gases present, and also between the water and some of the solid phases. Aqueous dissolved gas concentrations at equilibrium are proportional to concentrations in the vapor with which the water has equilibrated, and also derive from individual gas solubilities and the temperature and salinity of the water. The reactivities of gases with water vary significantly, the noble gases being essentially non-reactive. Since the aqueous solubilities of the noble gases are well known, and solute concentrations of sampled waters will be determined, estimates of recharge temperature can be calculated from absolute and relative concentrations of helium (He), neon (Ne), argon (Ar), krypton (Kr), and xenon (Xe). These temperatures will be compared with water-table temperatures measured at several locations in the site area. They will also be examined in light of extant and newly measured geothermal gradients at several locations within the site area. They will perhaps provide insight as to the thermal stability of the site area and/or to the thickness of the unsaturated zone in the vicinity of "conventional" recharge. Temperatures calculated with He and Kr will likely be the poorest estimates.

In order to use the temperature-dependent solubilities of the gases to estimate temperatures at which the waters entered the saturated zone, care must be taken to secure samples that are representative of both the dissolved gas suite and the rock atmosphere. Several collection methods will be used to ensure that the data collected are representative of the geohydrologic system. Water samples will be collected with flow-through samplers with a demonstrated satisfactory history of collection of samples for noble-gas determinations. Special precautions to be taken in the field to preserve the sampled gas compositions will include gas transfer and aliquotting in an all-metal vacuum system. Atmospheric samples collected from locations adjacent to the water table will enable a check of the assumption that the relative noble gas concentrations are the same as in atmospheric air. Use of a heated sampling tube for this effort (Section 3.2.3.1) will ensure complete recovery of easily sorbed Xe.

The stable isotopes of hydrogen (H), He, carbon (C), oxygen (O), Ne, Ar, sulfur (S), and strontium (Sr) in the aqueous phase provide additional means of investigating the evolution of ground-water chemistry and the physical characteristics of the geohydrologic system. The ratios of heavy-to-light stable H and O isotopes in water can be indicative of its climatic origin and subsequent history. At Yucca Mountain and vicinity, the extent to which this is discernible is a function of the climatic and recharge history, post-precipitation water/rock interactions, and perhaps the length of the recharge path. Evaporation prior to or during recharge could significantly alter the ratios, partially or completely obscuring the climatic signature. Reactions with solid phases could also alter the ratios, although the magnitudes of these changes is probably small, and would depend largely on the reactivity of the participating solid phases and on the relative reacting masses, larger changes being effected by higher rock-water ratios.

Stable C, H, and O isotopes can be used to examine the state of isotopic equilibrium of the system, using measured water temperatures and measured isotopic fractionations between specific species pairs. Differences between observed and predicted isotopic fractionations indicate either that flux in the vicinity of the water table is too rapid to allow isotopic equilibration, or that the temperature at the water table has changed from the conditions under which equilibrium had been established, or that equilibration occurred at another locale with a different temperature. The distribution of selected radioisotope activities, including tritium (^{3}H) and carbon-14 (^{14}C), will provide some insight as to the appropriate rationale(s) for observed distributions. Species pairs and the relevant stable isotopes that may be considered include those listed in Table 2.1-1.

Stable C- and S-isotope ratios ($^{13}C/^{12}C$ and $^{34}S/^{32}S$) provide insight to the sources of dissolved C and S in the saturated zone, and the reactions in which they might have participated. Carbon-isotope data can also be used to correct calculated radiocarbon ages for dilution by isotopically dead carbon. Stable Sr- and lead (Pb)-isotope ratios ($^{87}Sr/^{86}Sr$, $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$, $^{208}Pb/^{204}Pb$) can indicate the rocks from which dissolved metals originated, and can provide end-member compositions for estimated of ground-water mixing. Examples of such applications include Chaudhuri and others (1987), Collerson and others (1988), Smalley and others (1988), and Åberg and others, (1989). At a minimum, these data should enable differentiation between igneous and sedimentary sources and should provide some insight to ground-water flow paths.

Radioisotopes provide a means of estimating ground- and soil-water ages. Tritium and ^{85}Kr are relatively short-lived environmental isotopes (half lives of 12.43 and 10.8 years, respectively) that can be used to date relatively young waters. Tritium can be used to examine both fracture and matrix (pore) waters in the saturated zone, and pore water and water vapor in the unsaturated zone. Tritium can also be used with ^{85}Kr to estimate the extent of atmospheric contamination resulting from incomplete removal of drilling fluid (surface air) from the system and to assess sample-collection methodologies. The presence of tritium in saturated-zone ground water and unsaturated-zone gas can reflect several mechanisms. These include the recharge of post-bomb precipitation, rapid downward flux of water vapor from land surface, and subsurface tritium production. The latter can likely be expected to result in ground-water tritium levels below those of pre-bomb middle- and low-latitude rainfall (2.0 - 10.0 T.U. [Von Buttlar and Libby, 1955]) (Andrews and others, 1989).

Tritium data can also be combined with ^{3}He data to calculate ground-water ages, since ^{3}He is a product of ^{3}H decay. This may be especially valuable in determining the contribution of recent recharge in washes. On a longer time scale, ^{4}He concentrations can be used for ground-water dating, when combined with radon (^{222}Rn) data to quantify the He production rate. It is conceivable that He concentrations and isotopic compositions could be affected by and provide means of identifying a deep-seated (e.g., magmatic) He contribution. The probability of this effect likely approaches significance only at greater depths in the geohydrologic system, and when sampling in proximity to recent volcanic centers. Attendant use of concentration and isotopic data for the other noble gases will help to sort out which effect dominates the He.

Table 2.1-1. Possible stable-isotope fractionation pairs.

Species pair	Relevant isotopes		
	H	C	O
Water/water vapor	x		x
Water/carbon dioxide			x
Water/calcite			x
Water/sulfate			x
Water/methane	x		
Water/silica			x
Bicarbonate/carbon dioxide		x	
Carbonate/carbon dioxide		x	
Carbon dioxide/methane		x	
Calcite/carbon dioxide		x	

References to the individual pairs are in Friedman and O'Neil (1977).

Radiocarbon dating is an established and widely used dating methodology that will be applied to fracture and matrix ground waters, unsaturated matrix waters, and unsaturated-zone gaseous carbon dioxide. Ages of dissolved inorganic and organic carbon fractions of saturated-zone waters will provide insight to the movement of carbon through the unsaturated zone, and the relative contributions of soil organic matter, organic material within the tuffs, and soil- and/or rock-atmosphere carbon dioxide. Organic-radiocarbon data will also provide additional insight to calculated ground-water ages. Calculation of a radiocarbon age assumes knowledge of the activity of the input carbon. It is therefore necessary to identify, as best as is possible, the relative contributions off all carbon sources. This will be done using extant stable-carbon isotopic data, and data from gas- and liquid-phases sampled in the this study, and from gas and solid phases analyzed in the course of Studies 8.3.1.2.2.7 (Unsaturated-zone hydrochemistry) and 8.3.1.3.2.1 (Mineralogy, petrology, and chemistry of transport pathways).

Chlorine-36 provides the ability to date ground water within a range of about 50,000 yr to 1 m.y. The minimum age will perhaps restrict the application of this radioisotope to saturated-zone waters from downgradient sites within the region. Chlorine-36 can also be used to identify water recharged since the inception of thermonuclear testing, and to estimate the mixing proportions of waters of different ages and/or origins.

Iodine-129 is a naturally-occurring radioisotope that also results from anthropogenic activities (nuclear reactor operation and nuclear weapons testing). While it can be used to date very old waters, its most promising use is the identification of water sources and estimation of mixing ratios. It is also useful as an indicator of post-1950 water, since Man's activities have increased the $^{129}\text{I}/^{127}\text{I}$ ratio above the likely uniform ratio that existed prior to the advent of the nuclear age. The Radiological Monitoring Plan for the NNWSI Project (RMP) (U.S. Department of Energy, 1988b) provides for the determination of ^{129}I in 10-15 percent of the samples to be collected in the course of USGS studies, with the remainder to be archived.

Technetium-99 is a fission-produced radioisotope that has conceivably been added to the geohydrologic system. Because it is identified as an isotope of principal concern in the RMP, it, too, will be sought in 10-15 percent of the samples to be generated by this study. The selection of samples to be analyzed for ^{129}I and ^{99}Tc will be determined by the RMP coordinator and the principal investigator for this study.

2.1.3 Parameters and testing strategies

The work planned for this study was developed based on informational needs as defined in the SCP. Site parameters (activity parameters in SCP usage) 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 site parameters are building blocks to support various aspects of the project. Some (e.g. 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, site parameters for all of the geohydrology program are grouped according to parameter categories. The geohydrologic site parameters associated with each activity of the saturated-zone hydrochemistry study appear in Section 3 in Table 3.2-3 and in Figures 3.1-2, 3.2-3, and 3.3-2. The figures also show parameter categories associated with the site parameters. 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.

Design and performance parameters represent information required for issues resolution. These parameters can either be directly measurable quantities (such as major-ion water chemistry) or properties derived from other, more directly measurable quantities (such as saturated-zone fluid flux). There is no defined one-to-one relationship between a given site parameter and a given design or performance parameter; a single site parameter may support one or more design or performance parameters, and a single design or performance parameter may be supported by one or more site parameters. The site parameters derived from this study, as a set, should provide information to support the determination of the applicable design and performance parameters for the issues discussed in Section 1.2. The relation between the site parameters of this study and design and performance parameters is presented in Section 7.2 (Table 7.2-1).

In addition to supporting design and performance parameters, the site parameters are needed to test hypotheses that support conceptual models, and also as input to numerical models. A sufficient level of confidence in parameter values must exist for the data to be employed for either of these purposes. The data-collection methods selected for the present study have been chosen to minimize uncertainties 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. A greater understanding of, and confidence in, any particular parameter will result from combining test results and studying their relations.

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 to provide the required information.

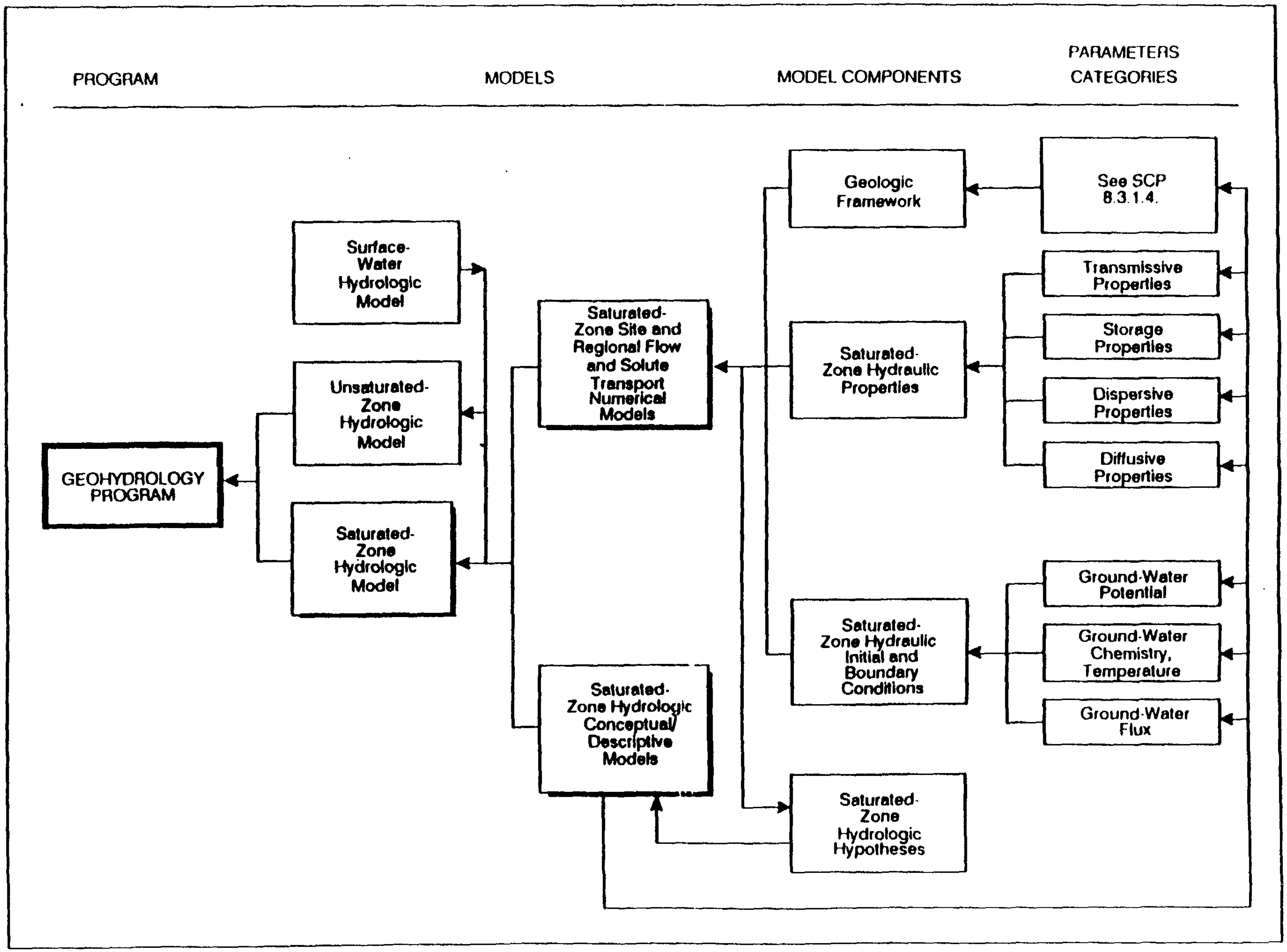


Figure 2.1-1. Logic diagram of the Geohydrology Program, including model components and paramete
gories.

2.1.4 Hydrologic and hydrochemical hypotheses

The alternative conceptual models tables (hypotheses testing tables) of SCP Section 8.3.1.2 (SCP Tables 8.3.1.2-2b) summarize current hypotheses regarding site modeling and parameter estimation, uncertainties in those hypotheses, and alternative hypotheses consistent with current data. The present study will contribute to the evaluation of the current hypothesis that, under present-day conditions, boundary conditions and fluxes are invariant with time. (The alternative hypothesis here is that current and expected future tectonic and thermal processes may cause substantial changes in water-table altitude.) The uncertainty assigned to this hypothesis is low, and will be tested further by saturated-zone hydrochemical data that supports the understanding of temporal changes in water-table altitude.

2.1.5 Relation to hydrologic modeling

Assuming that the overall hydrologic system within the saturated zone at Yucca Mountain can be described by conventional theories of fluid storage and movement in porous and fractured media, the present and probable future spatial distribution and magnitude of hydrologic parameters can be estimated from appropriately constructed hydrologic models. The successful development of calibrated numerical models of the hydrologic system will increase confidence that the geohydrologic framework, distribution of input parameters, and nature of initial and boundary conditions are appropriate for utilization in performance and design analyses. The models can be used as tools to improve understanding of the functioning of the flow system, to test hypotheses, and to further guide data collection.

The spatial and temporal extrapolation of flow within the saturated zone involves complex interactions that can be described only with the aid of hydrologic models, and data from the saturated-zone hydrochemistry study will support the numerical hydrologic modeling of the saturated zone by contributing to the evaluation of initial and boundary conditions. This is shown in Figure 2.1-1, the logic diagram of the saturated-zone component of the geohydrology program. The figure is taken from Figure 8.3.1.2-4 of the SCP, where it is accompanied by similar figures for the surface-water and unsaturated-zone components. The introductory portion of SCP Section 8.3.1.2 addresses the roles and integration of the surface-water, unsaturated-zone, and saturated-zone components of the geohydrology program.

Saturated-zone hydrologic-system synthesis and modeling, as described in Studies 8.3.1.2.1.4 and 8.3.1.2.3.3, will incorporate conclusions from the present study regarding saturated-zone hydrochemistry, and apply them to the interpretation of flow in the saturated zone under varying conditions.

2.2 Constraints on the study

2.2.1 Representativeness of repository scale and correlation to repository conditions

The majority of specified sample collection sites in the saturated-zone hydrochemistry study are on or in the vicinity of Yucca Mountain. Extant and planned boreholes and wells to be sampled penetrate (or will penetrate) some of the same saturated geohydrologic units underlying the planned repository. Geologic units in the saturated zone from which samples will be collected are representative of the units underlying the repository area. Data from sites not in the immediate vicinity of Yucca Mountain will be used to refine the conceptual models of the site and regional ground-water flow systems and to augment the understanding of hydrochemical evolution in the vicinity of the repository area.

2.2.2 Accuracy and precision of methods

Selected and alternate chemical and isotopic analytical methods are discussed in the sections describing the individual activities. These methods were selected on the basis of their precision and accuracy. The accuracy and precision of each of the techniques are discussed in various publications describing the methods and will be defined, as appropriate, in the technical procedures developed for their implementation, as required in Section III of the project Quality Assurance Plan (QAP), NNWSI 88-9, Revision 2.

The levels of accuracy and precision required in this study are commensurate with detection and precision limits of the analytical procedures to be used. For most techniques, the actual accuracies and precisions are affected by a combination of analytical and theoretical uncertainties which make quantification of potential errors difficult. The requirements for accuracy and precision of the various tests will be defined by the investigators, based on their experience and evaluation of the data obtained and through the use of technical procedures as outlined in the QAP. Final uses of the data will, similarly, be constrained by the quality of the results obtained.

2.2.3 Potential impacts of activities on the site

The testing activity described in this study plan will have little or no impact on the natural-state site conditions or construction of the exploratory studies facility (ESF). Ground-water withdrawals will be of relatively small magnitude and will not significantly impact the potentiometric surface beyond the immediate vicinity of the boreholes. Because this study addresses only the saturated zone and the immediately adjacent overlying part of the unsaturated zone, and because the perturbations resulting from this study will be slight, impact at proposed shaft sites will be nil.

2.2.4 Time required versus time available

A tentative schedule of work activities and reports is given for the saturated-zone hydrochemistry study in Section 5. These schedules assume that five years will be available for site-characterization work.

The tests, methods, and chemical analyses of the activities have been selected so that the parameters of interest can be evaluated reasonably within the schedule of the study. Because they are mostly of an analytical nature, it is expected that they can be accomplished within the time scheduled for them.

3 DESCRIPTION OF ACTIVITIES

This study is organized into four activities:

- 8.3.1.2.3.2.1 - Assessment of the saturated-zone hydrochemical data availability and needs,
- 8.3.1.2.3.2.2 - Hydrochemical characterization of water in the upper part of the saturated zone,
- 8.3.1.2.3.2.3 - Regional hydrochemical characterization, and
- 8.3.1.2.3.2.4 - Synthesis of saturated-zone hydrochemistry.

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

3.1 Assessment of saturated-zone hydrochemical data availability and needs

3.1.1 Objectives

The objectives of the activity are to:

1. compile and evaluate extant hydrochemical data for the saturated zone at site and regional scales, and
2. identify data deficiencies and potential sampling sites and assemble requisite materials for sample and field-data collection.

3.1.2 Rationale

A comprehensive description of the geohydrologic system is the ultimate objective of the site and regional geohydrologic investigations. Extant hydrochemical data for the site area and the region describe samples pumped from variable-length discrete intervals as much as one kilometer below the top of the saturated zone, and samples from wells with open vertical intervals hundreds of meters in length. Compilation of these data will enable the identification of spatial hydrochemical variations, and the delineation of areas where additional data are needed Because of the scope of the project, coordination of sample collection with other investigators is required; a thorough assessment of data needs and potential availability is paramount to this effort.

3.1.3 General approach and summary of tests and analyses

This section describes the strategy for assessment of hydrochemical data availability and needs, including the identification of data deficiencies and the coordination and integration of data collection with other studies.

The data compiled in this activity will include information that describes part of the saturated zone underlying the repository area and various parts of the region (Figure 1.1-1). This activity will entail the assessment and analysis of data on site and regional scales. An understanding of hydrochemical characteristics vertically within boreholes and laterally between boreholes will further an understanding of the three-dimensional nature of the saturated-zone geohydrologic system. Similarly, an understanding of present conditions will be part of a basis for predicting future repository conditions.

Figure 3.1-1 summarizes the organization of this activity. A descriptive heading for each test and analysis appears in the box in the second row. Below the test/analysis, there are individual methods that will be used. Figure 3.1-2 summarizes the activity objectives, design- and performance-parameters categories addressed by the activity, and relevant site parameters. These appear in the boxes in the top left side, top right side, and below the test/analysis box.

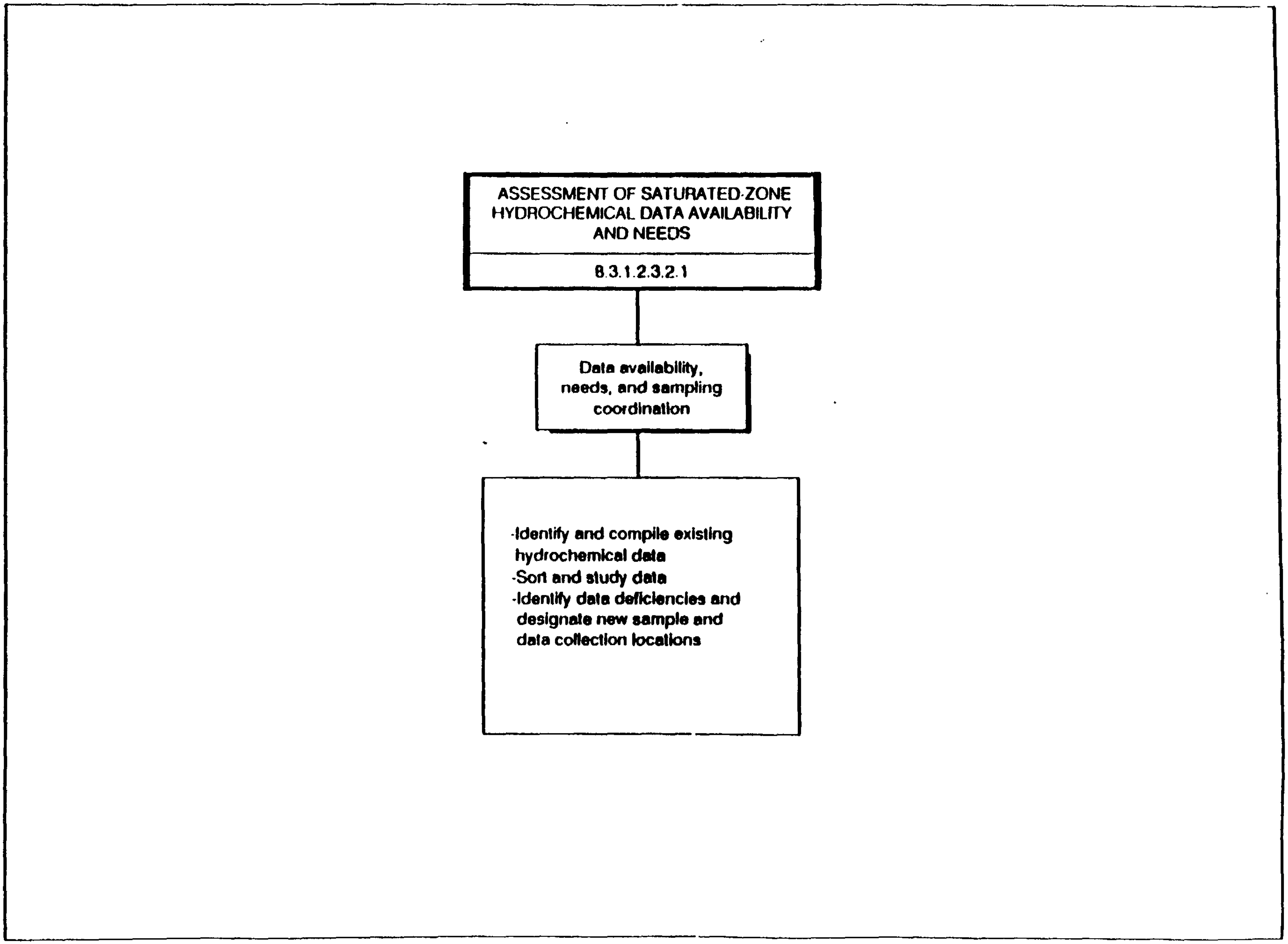


Figure 3.1-1. Logic diagram for hydrochemical data sessment, availability, and needs activity showi t analyses, and methods.

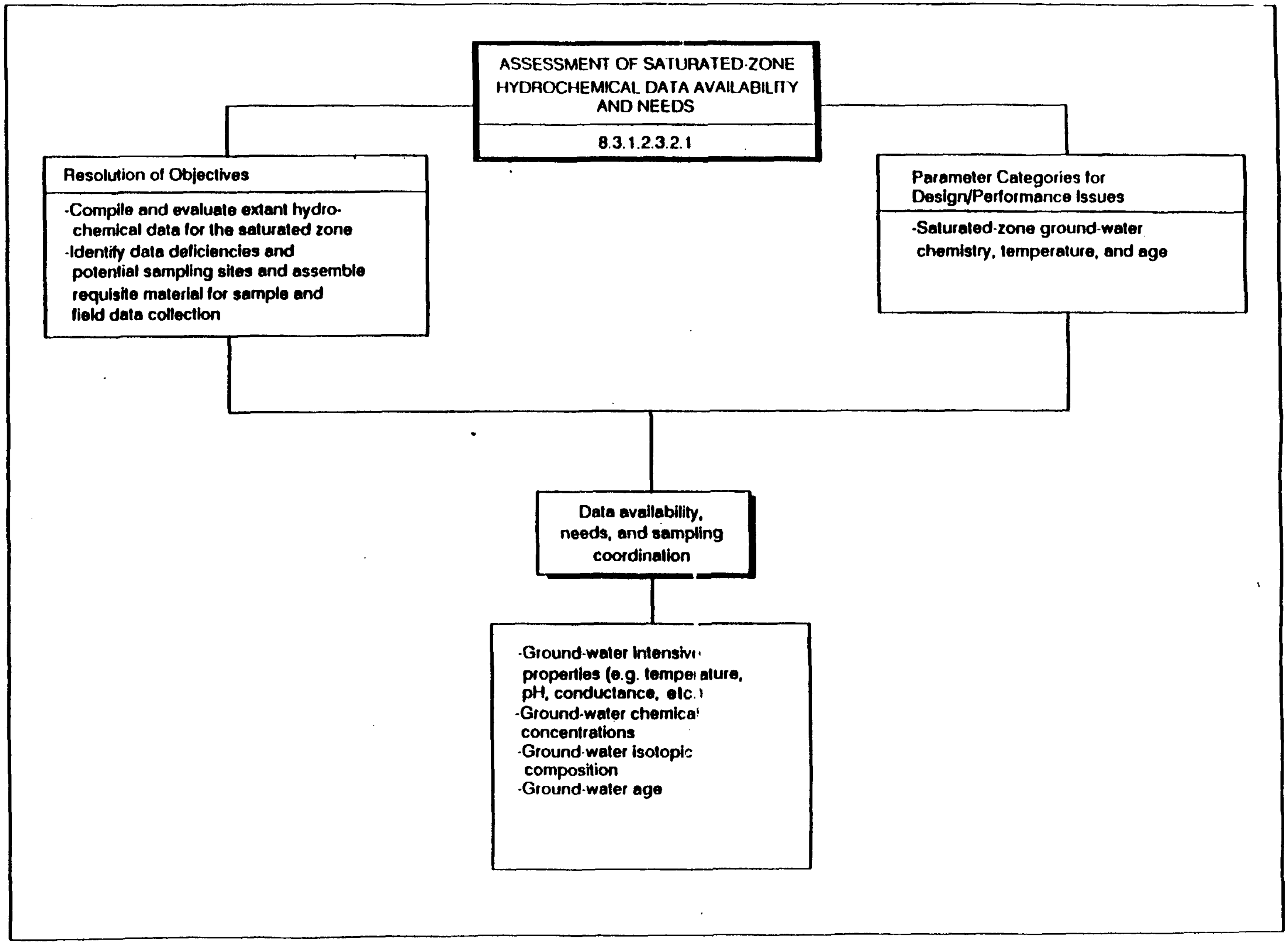


Figure 3.1-2. Logic diagram for hydrochemical data assessment, availability, and needs showing tests, analyses, and site parameters.

The two figures summarize the 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 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.

3.1.3.1 Data availability, needs, and sampling coordination

Extant hydrochemical data will be identified and compiled as they are identified. Each analysis will be examined for species determined, completeness relevant to specific applications, including speciation and saturation calculations and conventional graphical analyses (ex: trilinear diagrams). Each sample site will be examined as to location within the study area, the availability of well-construction information, the geohydrologic unit(s) sampled, sampling and analyzing agencies, and method(s) of collection and field analyses, as appropriate. Based on data age and source, a cation-anion balance will be calculated for sufficiently complete analyses in order to preliminarily assess data quality. Imbalance greater than about 5 percent will limit data utility. Each analysis will also be compared, if possible, to data from nearby wells or springs that are completed in or that issue from the same or similar geohydrologic units in order to assess representativity. The data base will be sorted, to the extent possible, with regard to the geologic units from which the samples were collected, and areal maps and hydrochemical cross sections will be produced for selected dissolved constituents. Discernible spatial variations in the distributions of selected constituents and/or physical properties will be examined relative to extant information describing geohydrologic characteristics, structural features, and formation geometry, lithology, and mineralogy. The products of this effort will enable identification of inadequacies in the data base, with regard to the spatial distribution and comprehensiveness of the data. The identified deficiencies will provide an information base from which planned activities and potential data-collection locations will be examined.

Specific sites, either independent of, or associated with, planned activities, will be designated to augment and improve the hydrochemical data base. Criteria considered in the selection will include geographic location, geologic unit sampled, well construction and history, logistical feasibility, and conceivable application to conceptual model refinement.

Geohydrologic and geologic activities that will likely provide hydrochemical data, water samples, or opportunities to collect samples and field data include those listed in Table 3.1-1. Precipitation and meteorological monitoring (Study 8.3.1.2.1.1) will perhaps provide samples for chemical characterization of

Table 3.1-1. Activities that will likely entail/enable the collection of water samples and field data

	SCP Activity	Title/Description
	8.3.1.2.1.1.1	Precipitation and meteorological monitoring.
	8.3.1.2.1.3.2	Regional potentiometric level studies.
	8.3.1.2.1.3.3	Fortymile Wash recharge study.
	8.3.1.2.1.3.4	Evapotranspiration studies.
	8.3.1.2.3.1.1	Solitario Canyon fault study in the saturated zone.
	8.3.1.2.3.1.2	Site potentiometric level evaluation.
	8.3.1.2.3.1.4	Multiple-well interference testing.
*	8.3.1.2.3.1.5	C-hole conservative tracer tests.
**	8.3.1.2.3.1.6	Conservative tracer tests throughout the site.
	8.3.1.4.2.1.1	Surface and subsurface stratigraphic studies of the host rock and surrounding units.

* Need for sample collection to be determined, based on sample collection in Activity 8.3.1.2.3.1.4.

** Need for sample collection to be determined by well location and construction, study design, and testing/sampling history at each site.

precipitation within the region. In the regional potentiometric level studies (Activity 8.3.1.2.1.3.2), the Solitario Canyon fault study (Activity 8.3.1.2.3.1.1), and site potentiometric-level evaluation (Activity 8.3.1.2.3.1.2) a minimum of eight wells will be completed in the upper part of the saturated zone within the site area. The Fortymile Wash study (Activity 8.3.1.2.1.3.3) will involve construction of at least three wells that will provide saturated-zone water samples. This study will also provide hydrochemical data describing runoff and precipitation in the wash. Evapotranspiration studies (Activity 8.3.1.2.1.3.4) will include up to 20 aquifer tests which will provide sampling opportunities. The Solitario Canyon fault study (Activity 8.3.1.2.3.1.1) will also involve drilling two hydrologic-test holes which will be sampled. Multiple-well interference testing (Activity 8.3.1.2.3.1.4) will entail a 30-day pumping test and up to 20 short-term pumping tests which will provide sampling opportunities. C-hole conservative tracer tests (Activity 8.3.1.2.3.1.6) will provide sampling opportunities. Surface and subsurface stratigraphic studies of the host rock and surrounding units (Activity 8.3.1.4.2.1.1) will entail drilling three geologic-information holes which will be potential sampling locations. The RMP will provide radiochemical data describing monitoring sites throughout the region and at least some of the sites to be sampled in the course of this study. Sampling programs for each activity identified will be designed and coordinated with respective investigators and support contractors. Locations of some of the holes noted above have been selected. In cases where only general locations have been designated, input to site selection based on extant and developed information regarding hydrochemical data needs have been and will be provided.

3.1.4 Technical procedures

There are no technical procedures applicable to this activity.

3.2 Hydrochemical characterization of water in the upper part of the saturated zone

3.2.1 Objectives

The objectives of this activity are to

1. describe the hydrochemistry of the upper part of the saturated zone by collecting representative water samples from intervals within the upper 100 meters, within and adjacent to the site area, and studying their chemical and isotopic compositions; and
2. estimate flux to or from the saturated zone by collecting interstitial water and gas samples from immediately above the water table in the site area and studying their chemical and isotopic compositions.

3.2.2 Rationale

Water samples collected to date from the saturated zone at the site have been primarily from deep saturated intervals of varying lengths. Data from these samples do not describe the upper portion of the saturated zone, nor do they provide information describing that part of the unsaturated zone immediately adjacent to the water table.

More saturated-zone data are needed to enable determination of vertical variations in water chemistry and age. Data from the water-table (WT) wells (Figure 3.2-1) will enable hydrochemical characterization of the upper part of the saturated zone, and comparison with the extant hydrochemical data describing deeper intervals. Comparisons will aid in the development and refinement of a conceptual model of ground-water flow in the saturated zone with respect to ground-water flow paths, velocities, and residence times. The data will also enable hydrochemical characterization of that part of the unsaturated zone adjacent to the water table. These data will augment the conceptualization and refinement of flux at the saturated-unsaturated interface.

3.2.3 General approach and summary of tests and analyses

This activity is designed to collect representative, uncontaminated pore water and gas from the unsaturated zone immediately adjacent to the water table, and water samples from the upper part of the saturated zone within and adjacent to the site area.

There are 14 extant WT wells (Table 3.2-1) that penetrate from 43 to 99 meters (141 to 325 feet) into the saturated zone, and eight planned WT wells and three planned FM boreholes, each of which will penetrate a maximum of about 100 meters (328 feet) below the water table. Each of the completed wells has been equipped with one or two 7.3 cm (2.875 in.) inner-diameter access tubes, each with a 3.6 m (12 ft) screen at the lower end for water-level measurements. Six of the wells are

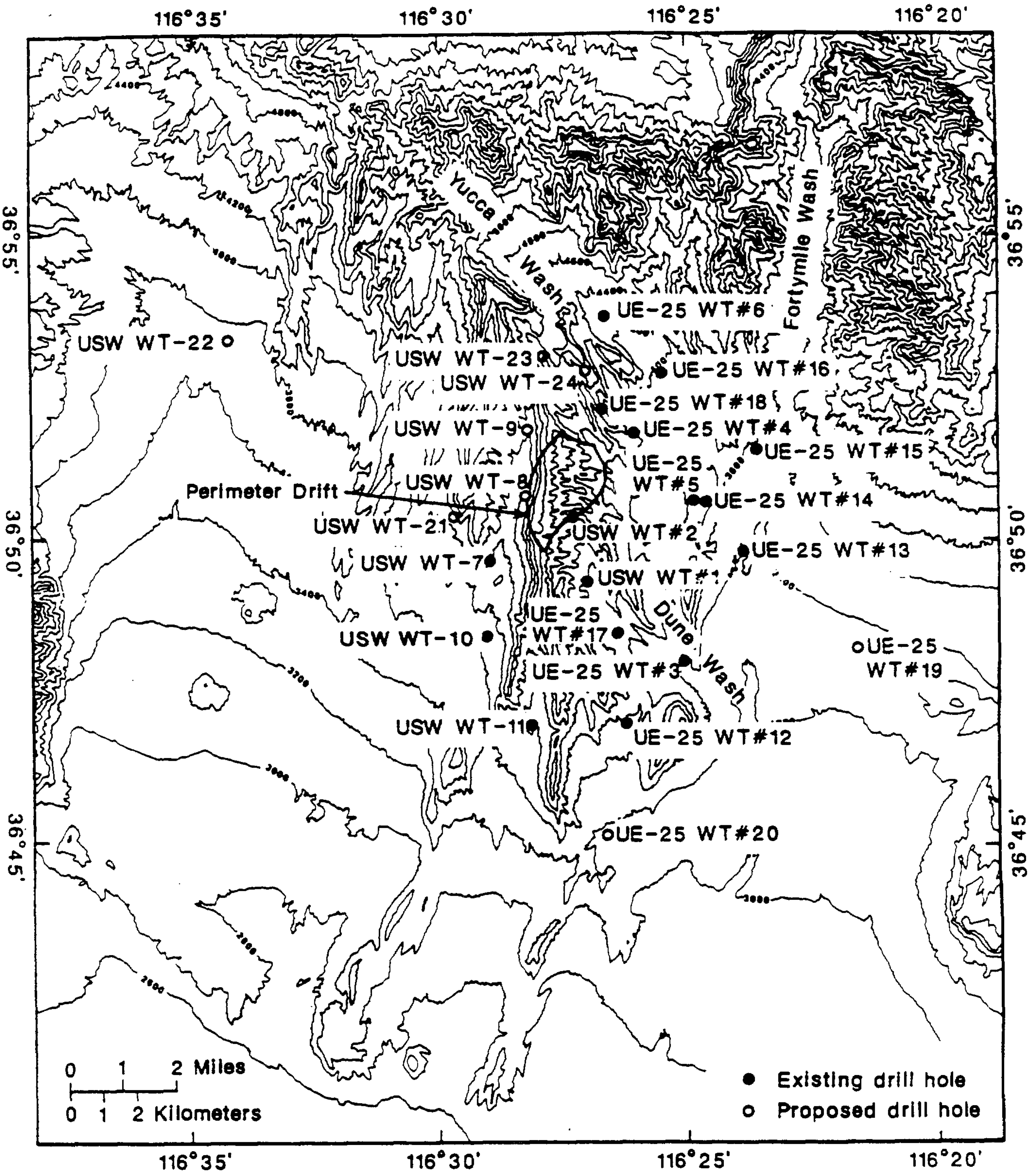


Figure 3.2-1. Map showing locations of existing and planned water-table holes.

instrumented for continuous water-level data collection, and were constructed with two access tubes. The Desert Research Institute, under contract to the State of Nevada, collected water samples from five non-instrumented wells in early 1988 (Table 3.2-1). These samples were collected from within the access tubing with a small-capacity submersible piston pump, and are the only WT samples that have been collected. The adequacy of the data deriving from this activity will be determined by its examination after generation. It is assumed that a single round of sampling at the planned sites will provide sufficient information to describe the upper part of the saturated zone in the vicinity of the proposed repository block. The need to revisit previously sampled sites will be a function of several factors, including departure from expected concentration or activity ranges, problems encountered in sampling, and logistical and schedule coordination with support contractors.

Water and gas samples collected in this activity will be analyzed as discussed in Sections 3.2.3.2 and 3.2.3.3. The resultant data will be analyzed to describe spatial hydrochemical variations both within the uppermost part of the saturated zone and within the entire saturated zone, as described by the extant data base. The data will also be integrated with extant geochemical, mineralogic, and geohydrologic information to refine conceptual geohydrologic models.

Figure 3.2-2 summarizes the organization of this activity. A descriptive heading for each test and analysis appears in the boxes of the second row. Below each test/analysis, the individual methods that will be utilized during testing are given. Figure 3.2-3 summarizes the objectives of the activity, the design- and performance-parameter categories that are addressed by the activity, and the site parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the test/analysis boxes, respectively.

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 to summarize the pertinent relations among (1) the site 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.

The hydrochemical data collected during this activity will provide information that describes the upper part of the saturated zone in the repository area. The spatial variabilities of hydrochemical parameters within the site area will be described using the results of the tests and methods of this activity. These tests involve the chemical and isotopic analyses of samples from the upper part of the saturated zone and that part of the unsaturated zone immediately adjacent to the water table.

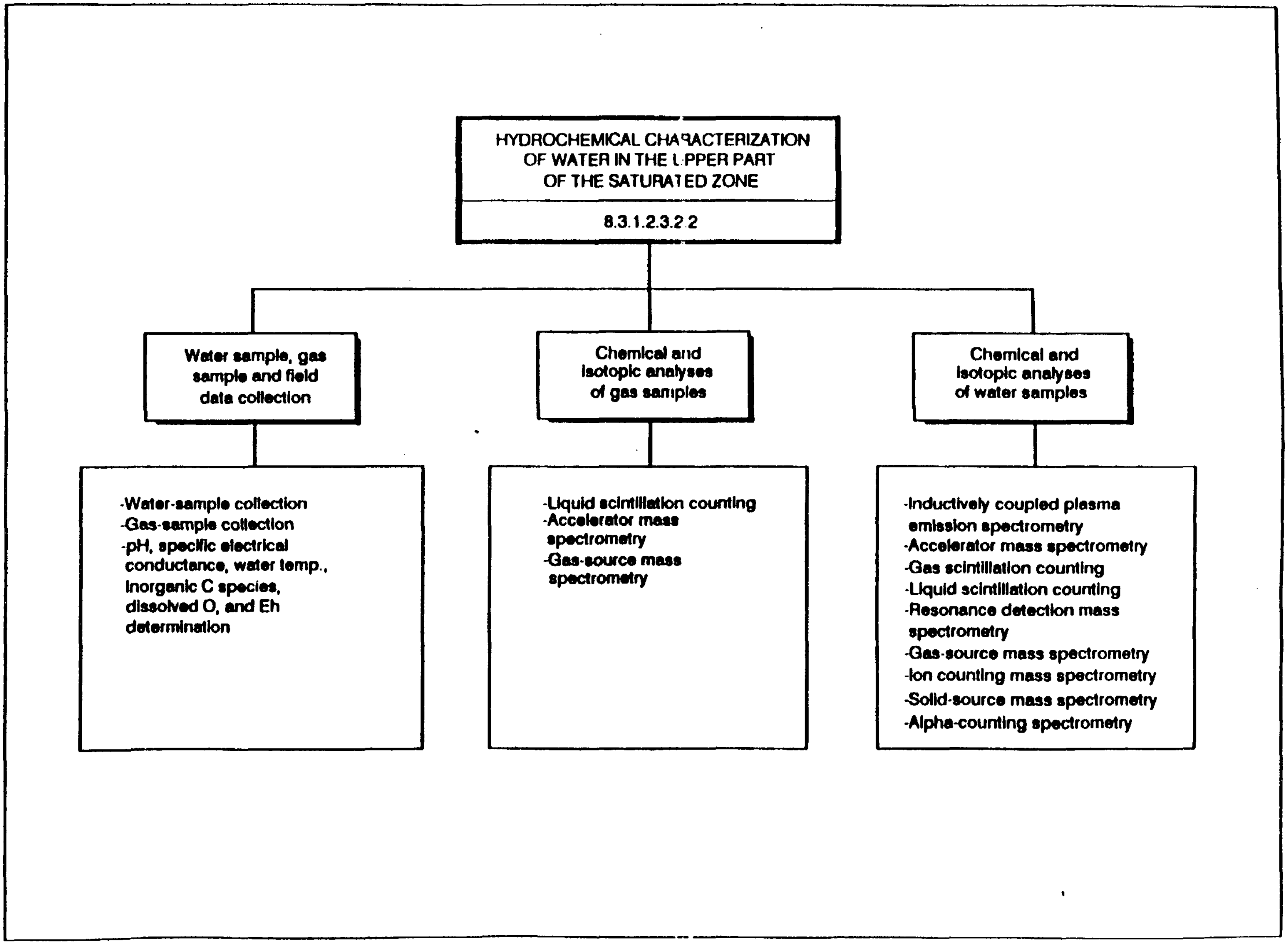


Figure 3.2-2. Logic diagram for hydrochemical characterization of the upper part of the saturated zo ivity showing tests, analyses, and methods.

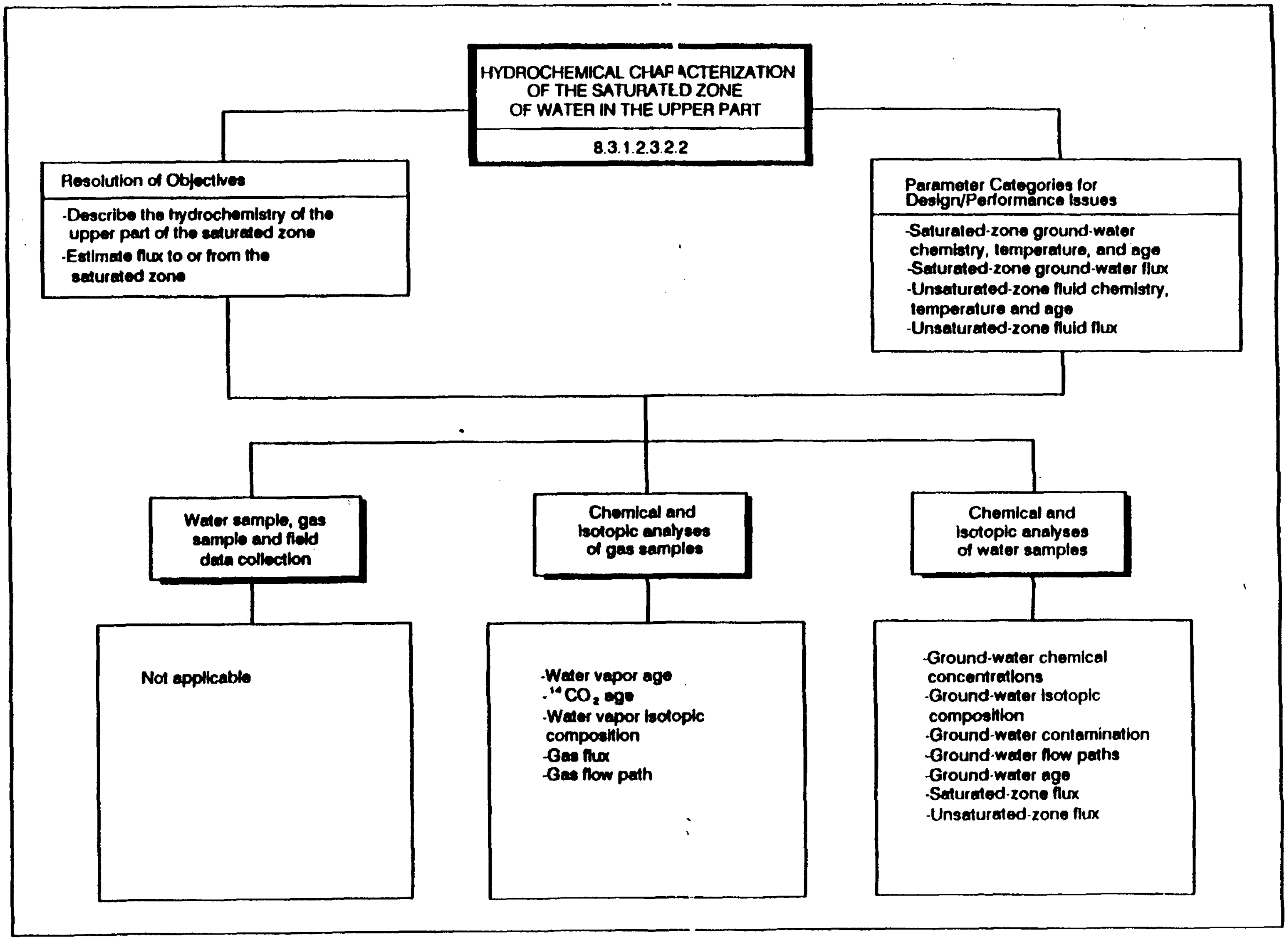


Figure 3.2-3. Logic diagram for hydrochemical characterization of the upper part of the saturated zone activity showing tests, analyses, and site parameters.

3.2.3.1 Water-sample, gas-sample, and field-data collection

Extant hydrochemical data describing the saturated zone beneath the site area derive from samples of two general types. The first were pumped from variably sized discrete intervals as much as one kilometer below the top of the saturated zone. The second were open-hole samples and represent vertical intervals hundreds of meters in length. This activity will collect samples from 14 extant and 8 planned WT wells at or in the vicinity of Yucca Mountain and boreholes to be drilled in Fortymile Wash (Figure 3.2-1, Table 3.2-1, and Figure 3.3-5 of YMP-USGS 8.3.1.2.1.3, Regional ground-water flow system). These wells will be drilled under the SCP activities listed in Section 3.1.3.1. Extant wells have only surface casing, penetrate about 100 meters of the saturated zone, and have nominal diameters of 0.171 or 0.222 meter. Planned wells will be similarly constructed.

As sampling of extant wells will entail temporarily removing all data-collection equipment installed in them, a suite of down-hole geophysical data will be collected in each well prior to sampling. These data will be collected as described in Activity 8.3.1.4.2.1.3 (Borehole geophysical surveys) and will aid in description of physical properties of the geologic units present, inter-well stratigraphic correlation, and estimation of the vertical variation of the water content of the unsaturated zone. The data collected will include magnetometer, magnetic susceptibility, and gravity data, and selected experimental and commercial logs. In addition, sidewall cores will perhaps be collected in selected wells to provide mineralogic and lithologic information that will augment the utility of the geophysical data and expand the mineralogic, lithologic, and stratigraphic data bases.

Field-data and sample collection for extant holes will entail several steps. Currently installed equipment will be removed from each well, as appropriate. Removed tubing will be cleaned of rust and other foreign materials; a submersible electric pump with capacity of about 80 L/min will be attached and installed about 10 m (33 ft) above the hole bottom. The pump will be tested for proper and reliable operation, then operated continuously until field analyses of the discharged water indicate that the water chemistry has stabilized. Stabilization will be indicated by essentially constant values or concentrations, in several consecutive samples, of some or all of the following: pH, dissolved bicarbonate (HCO_3^-), lithium (Li^+), bromide (Br^-), chloride (Cl^-), nitrogen (N_2), carbon dioxide (CO_2), sulfur hexafluoride (SF_6), and selected freon species. The altitude of the potentiometric surface will be continuously monitored during and after this developmental pumping by means of downhole pressure transducers.

Waste water generated in the course of well development, sample collection, and field analyses will, if required by the proximity of on-going or planned activities, be either temporarily stored near

Table 3.2-1 Extant (November 1986) and planned water-table wells to be sampled and logged.

Well Number	Well depth (m/ft)	Approximate depth to water (m/ft)	Thickness of saturated interval penetration (m/ft)
USW WT-1	515/1689	471/1545	44/144
USW WT-2	628/2060	571/1873	57/187
UE-25 WT #3	348/1142	301/ 986	48/156
UE-25 WT #4	482/1580	439/1440	43/140
UE-25 WT #6	383/1256	284/ 932	99/324
USW WT-7 (s)	491/1610	421/1382	69/228
USW WT-8 (p)	640/2100 (e)		
USW WT-9 (p)	670/2198 (e)		
USW WT-10 (s)	431/1413	348/1142	83/271
USW WT-11	441/1446	364/1194	77/252
UE-25 WT #5 (c)			
UE-25 WT #12 (s)	399/1310	345/1132	54/178
UE-25 WT #13	352/1155	303/ 994	49/161
UE-25 WT #14 (s)	399/1310	346/1136	53/174
UE-25 WT #15 (s)	415/1360	354/1162	60/198
UE-25 WT #16	521/1710	473/1552	48/158
UE-25 WT #17	443/1453	395/1296	48/157
UE-25 WT #18 (d)	623/2043		
UE-25 WT #19 (p)		335/1099 (e)	
UE-25 WT #20 (p)		305/1000 (e)	
USW WT-21 (p)	550/1805 (e)		
USW WT-22 (p)	395/1296 (e)		
USW WT-23 (p)	670/2198 (e)		
USW WT-24 (p)	670/2198 (e)		

e -- estimated; p -- planned; s -- sampled in 1988 by Desert Research Institute;
c -- collapsed;
d -- borehole completed above potentiometric surface, will not be sampled.

the well locations and intermittently trucked to a disposal site, or continuously conveyed to a satisfactory discharge or storage site. Coordination with other investigators will perhaps enable the use of some of the pumped water in scheduled studies.

Following stabilization, the transducers, tubing, and pump will be removed. An equipment assembly comprising steel tubing (inner diameter about 62 mm), two to three external-access sliding sleeves, two to three pneumatic packers, and pressure transducers will be assembled and installed. The equipment will have the capacity for variable spacing between the packers. Although vertical isolation of a sampled interval by means of packers is not certain, caliper and televiewer data will be used to identify and delineate relative smooth and sufficiently short borehole sections within which satisfactory packer deployments can be expected. Isolation will be verified during sampling by monitoring heads below, within, and above the sampled intervals as appropriate. Differential-pressure transducers will be used, because the planned stresses on the isolated zones likely will not significantly lower the potentiometric surface within the zones. A pump will be operated at each discrete interval until chemical stability is achieved, as described earlier. At that time, samples will be collected for field analyses of intensive properties, analyses or preservation of selected unstable constituents, and comprehensive chemical and isotopic laboratory analyses (Table 3.2-2). Pumping for collection of most water samples, and in situ determinations of pH, Eh, and temperature will be performed using an umbilical equipment system. The system will include a submersible pump, a hydrochemical tool (Eh, Ph, temperature), a hydraulic shifter to open and close sliding sample ports, and pneumatic packers. The tools, pump, and packer will be lowered using an umbilicus that contains all requisite tubing and signal transmission cables, fibers, etc. The umbilical system will be installed and removed using a trailer-mounted hoist system with supporting air, electric, and hydraulic power supplies, as appropriate.

All sample filtration will utilize filters having maximum pore diameters of 0.1 μmeter. Samples for the analyses of dissolved cations will be filtered, then acidified with 1-2 milliliters of ultrapure concentrated nitric acid. Samples for anion analyses will be filtered. Samples for nutrient analyses (NH_4, NO_3, PO_4) will be filtered, preserved with mercuric chloride, sealed in dark bottles, and stored chilled until analyzed. Samples for radiocarbon determinations of low and high molecular weight (LMW and HMW) dissolved organic fractions will be filtered through well-leached filters, and the organic fractions separated in the field. HMW compounds will be collected on XAD-8 resin, as described by Thurman and Malcolm (1981). LMW compounds will be isolated using either a silica-based molecular sieve, as described by Murphy and others (1989), or another method not yet selected. Possible selection of an alternate method for LMW compound isolation will derive from discussions with geochemists and soils chemists active in this area.

Exceptions to this scheme will occur at those extant holes where gas samples will be collected from that part of the unsaturated zone adjacent to the water table. The procedure for collecting gas samples will be described in the discussion that addresses the planned WT holes.

The planned water-table wells will be constructed as described in Studies 8.3.1.2.3.1 (Characterization of the site saturated-zone ground-water flow system) and 8.3.1.2.1.3 (Characterization of the regional ground-water flow system), except as discussed in the following paragraphs.

Selected new wells will be vertically cored [approximately 6 centimeters in diameter], for about 25 meters immediately above the saturated zone. Three to five sections of the unsaturated core retrieved from each well will be used for extraction and analyses of interstitial water. Extraction methodology will be developed by Study 8.3.1.2.2.7 (Hydrochemical characterization of the unsaturated zone.

On reaching (or approximately reaching) the water-table, a packer or removable plug will be installed about three to five meters above the bottom of the borehole. Heater tubing, which is plumbed through the packer, will be attached to the exterior of the installation tubing during entry. Following packer and tubing installation, a vacuum pump will be used to purge air from the isolated interval through the installation tubing until selected absolute and relative gas concentrations, including CO_2 and N/CO_2, stabilize and the intentional (SF_6, Li, Br) and incidental (detergents, Freon species, ^3H, ^{85}Kr) drilling tracers either fall below detection limits or stabilize at acceptably low levels (background or steady-state levels). Monitoring of several tracers will provide the basis for judgement at each sampling opportunity. The installation tubing will then be sealed, and the heater tubing heated to 50 to 60 °C. Gas samples will then be collected through the heater tubing using a peristaltic pump.

A suite of gas samples will be collected for compositional qualification and quantification, and for selected stable and radioactive isotope determinations (Table 3.2-2). Samples for gas composition will be collected using 10-cc syringes and 250- or 500-ml gas-collecting tubes. Samples for radiocarbon determinations will consist of CO_2 sorbed on a molecular sieve in a flow-through gas cylinder. Carbon dioxide samples for determination of the stable isotopic ratios of C and O will be collected in 250 or 500 ml gas-collecting tubes, as the molecular sieve method has been shown to result in significant fractionation of the stable isotopes. Water-vapor samples for determination of ^3H activity and ratios of stable-isotopes of H and O will be collected by pumping the air stream through a cold trap cooled by a dry ice-acetone slurry. Quantitative transport of water vapor from the sampled interval adjacent to the water table will be assured by the heater tubing, which will maintain the pumped air stream at a temperature sufficient to preclude condensation during transit between the water table and the collection point. Quantification of recovery at the surface will be evaluated using either silica gel towers or a hygroscopic discloser. This observation will be used to determine appropriate pumping rates. Samples for determinations of noble gas concentrations and isotopic compositions will be collected in metal sample tubes that are He tight. Gas samples will be collected at selected extant WT wells, using the procedures described above, prior to the collection water samples.

After gas sampling, the new wells will be cored about 25 m into the saturated zone. Three to five sections of the saturated core will be gravity drained in an inert atmosphere, then squeezed to extract water from the rock matrix, if feasible. Following coring, the wells will be drilled to scheduled depths, and down-hole geophysical data will be collected. Water samples will then be collected as described for extant wells.

3.2.3.2 Chemical and isotopic analyses of gas samples

All analyses will be conducted by existing qualified laboratories that have been approved by the USGS Quality Assurance Program. Stable-isotope ratios ($^{18}O/^{16}O$, $^{13}C/^{12}C$, $^{2}H/H$, and $^{3}He/^{4}He$) will be analyzed using mass spectrometry. Low-level gas counters will be used to determine tritium activity in water vapor samples. Radiocarbon samples will be analyzed by accelerator mass spectrometry (AMS). Tracer analysis will be performed either on site in a mobile laboratory, or in a USGS laboratory using gas chromatography or high performance liquid chromatography (HPLC).

Carbon-14 and ^{3}H data will provide insight to the residence time of the gases in the unsaturated zone. Isotope ratios will provide information regarding the movement of gases in the unsaturated zone as well as their interactions with other phases. Tracer concentrations monitored during pre-sampling pumping and determined in samples collected will indicate both the extent of contamination by drilling operations of the unsaturated-zone atmosphere, and the adequacy of the sampling procedure relative to the representativeness of samples collected.

3.2.3.3 Chemical and isotopic analyses of water samples

Table 3.2-2 lists the chemical and isotopic analyses to be performed on ground-water and/or interstitial-water samples. Not every analysis will be performed on each type of sample; interstitial samples are addressed specifically in the following discussion. All analyses will be conducted at existing qualified

TABLE 3.2-2

CHEMICAL AND ISOTOPIC ANALYSES OF GASES AND WATER

Parameter	Phase		Information/Rationale
	Gas	Liquid	
HOH	•		Gas composition; spatial description.
δ^2H_{HOH}	•	•	Gas composition; spatial description; hydrochemical evolution.
^3HOH	•	•	Spatial description; ground-water ages (^3H and ^3He); drilling fluid contamination; ground-water travel time.
CO_2	•	Calculated	Gas composition; spatial description; equilibrium and speciation calculations.
$^{14}CO_2$	•		Spatial description; gaseous inorganic carbon age; gas flux.
$\delta^{13}C_{CO_2}$	•		Spatial description; isotopic fractionation; gas flux; carbon sources; ground-water age correction; microbial activity.
$\delta^{18}O_{CO_2}$	•		Spatial description; isotopic fractionation; gas flux.
$\delta^{18}O_{HOH}$	•	•	Spatial description; isotopic fractionation; mixing; hydrochemical evolution; paleoclimate; flow path.
H_2	•		Gas composition, spatial description.
He	•	•	Gas composition; gas-phase drilling fluid contamination; UZ/SZ temperature at time of flux to SZ.
^3He	•	•	Gas composition; gas-phase drilling fluid contamination; He sources; ground-water age and gas sources; mixing; flow path; hydrochemical evolution.
^4He	•	•	Gas composition; gas-phase drilling fluid contamination; He sources; ground-water gas sources; mixing; flow path; hydrochemical evolution.
Li		•	Spatial description; drilling fluid contamination; hydrochemical evolution.
Be		•	Spatial description; hydrochemical evolution.
B		•	Spatial description; hydrochemical evolution.
HCO_3		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
$^{14}C_{inorganic}$		•	Spatial description; ground-water age and travel time; flow paths.

TABLE 3.2-2
(Continued)

Parameter	Phase		Information/Rationale
	Gas	Liquid	
$\delta^{13}C_{inorganic}$		•	Spatial description; isotopic fractionation; ground-water age correction; inorganic carbon source(s).
CH_4	•	•	Spatial description; microbial activity; gas-phase drilling fluid contamination.
C_{LMW}		•	Spatial description; organic carbon source(s); hydrochemical evolution.
$^{14}C_{LMW}$		•	Ground-water age; UZ/SZ flux.
$\delta^{13}C_{LMW}$		•	Spatial description; hydrochemical evolution.
C_{HMW}		•	Spatial description; organic carbon source(s); hydrochemical evolution.
$^{14}C_{HMW}$		•	Ground-water age; UZ/SZ flux.
$\delta^{13}C_{HMW}$		•	Spatial description; hydrochemical evolution.
N_2	•		Spatial description; gas-phase drilling fluid contamination.
NO_3^-		•	Spatial description; hydrochemical evolution; UZ/SZ flux.
NO_2^-		•	Spatial description; hydrochemical evolution; UZ/SZ flux.
F		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Ne	•	•	Gas composition; gas-phase drilling fluid contamination; UZ/SZ temperature at time of flux to SZ; $^{3}H/^{3}He$ dating.
^{20}Ne	•	•	Gas composition; gas-phase drilling fluid contamination; mixing; ^{4}He production; spatial description.
^{21}Ne	•	•	Gas composition; gas-phase drilling fluid contamination; mixing; ^{4}He production; spatial description.
^{22}Ne	•	•	Gas composition; gas-phase drilling fluid contamination; Ne source.
Na		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Mg		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Al		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.

TABLE 3.2-2
(Continued)

Parameter	Phase		Information/Rationale
	Gas	Liquid	
Si		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
PO_4^{3-}		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
SO_4^{2-}		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
$\delta^{34}S_{SO_4^{2-}}$		•	Spatial description; hydrochemical evolution; S source(s).
Cl		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
^{36}Cl		•	Spatial description; ground-water age; UZ/SZ flux.
Ar	•	•	Gas composition; gas-phase drilling fluid contamination; UZ/SZ temperature at time of flux to SZ.
^{36}Ar	•	•	Gas composition; gas-phase drilling fluid contamination; hydrochemical evolution.
^{40}Ar	•	•	Gas composition; gas-phase drilling fluid contamination; hydrochemical evolution.
K		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Ca		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Ti		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
V		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Cr		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Mn		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Fe		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Fe^{2+}/Fe^{3+}		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.

TABLE 3.2-2
(Continued)

Parameter	Phase		Information/Rationale
	Gas	Liquid	
Co		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Ni		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Cu		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Zn		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Br		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Kr	•	•	Gas composition; gas-phase drilling fluid contamination; UZ/SZ
^{81}Kr		•	Ground-water age.
^{85}Kr	•		Gas-phase drilling fluid contamination.
Sr		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
^{87}Sr/^{86}Sr		•	Spatial description; mixing; hydrochemical evolution; flow paths; solute source(s).
Mo		•	Spatial description; hydrochemical evolution.
Ag		•	Spatial description; hydrochemical evolution.
Cd		•	Spatial description; hydrochemical evolution.
I^-		•	Spatial description; hydrochemical evolution.
Ba		•	Spatial description; hydrochemical evolution; equilibrium and speciation calculations.
Xe	•	•	Gas composition; gas-phase drilling fluid contamination; UZ/SZ temperature at time of flux to SZ.
Pb		•	Spatial description; hydrochemical evolution.
^{204}Pb		•	Spatial description; mixing; hydrochemical evolution; flow paths; solute source(s).
^{206}Pb		•	Spatial description; mixing; hydrochemical evolution; flow paths; solute source(s).

TABLE 3.2-2
(Continued)

Parameter	Phase		Information/Rationale
	Gas	Liquid	
^{207}Pb		•	Spatial description; mixing; hydrochemical evolution; flow paths; solute source(s).
^{208}Pb		•	Spatial description; mixing; hydrochemical evolution; flow paths; solute source(s).
^{222}Rn	•	•	Ground-water age; hydrochemical evolution; UZ/SZ flux.
^{226}Ra		•	Hydrochemical evolution.

laboratories that have been approved by the USGS Quality Assurance Program, as appropriate.

Cation concentrations will be determined using standard inductively coupled plasma emission (ICP) spectrometric methods. This methodology is preferred over atomic absorption spectrometry (AAS) because it requires less time, requires smaller sample volumes, and yields 20 or more elemental concentrations per analysis. Anion concentrations will be determined using standard ion chromatographic methods. These methods use small sample volumes, yield concentrations of numerous species per analysis, and are the methodologies recommended by the ASTM, the EPA, and Standard Methods for several of the common anions. Both of these analyses will also be performed on interstitial waters, sample size permitting.

Concentrations of selected dissolved atmospheric gases will be determined by the collecting investigators, either in a mobile laboratory onsite, or in a USGS laboratory on the NTS, using standard gas chromatographic methods. Noble gas concentrations and isotopic compositions will be determined by Los Alamos National Laboratory (LANL) analysts at LANL using ion-counting or static-noble-gas mass spectrometric methods.

Ratios of stable H, C, O, and S isotopes in saturated-zone waters will be determined using standard mass spectrometric methods; interstitial samples will be analyzed for $^{2}H/H$ and $^{18}O/^{16}O$ ratios if sufficient sample is available. Ratios of stable Sr isotopes will be determined using the solid-source mass spectrometric techniques described by Peterman and others (1985). Lead isotopic ratios will be determined using standard mass spectrometric techniques, similar to those described by Tatsumoto and others (1972), and modified by Arden and Gale (1974).

Tritium activities will be determined using gas and liquid scintillation counters. Radiocarbon activities in large samples will be conventionally determined using gas scintillation counting. Small volume samples, including the HMW and LMW organic carbon fractions, will be analyzed using AMS. Chlorine-36 activities and ratios will also be determined using AMS. Sampling for ^{36}Cl will be coordinated with the work described in Study 8.3.1.2.2.2 (Water movement tracer tests using chloride and chlorine-36 measurements of percolation at Yucca Mountain). Resonance detection mass spectrometry (RIS) will be used to determine ^{85}Kr activities. Investigators responsible for the RMP will coordinate the analyses of samples for ^{99}Tc, ^{129}I, and other radioisotopes of principal concern. USGS laboratories will perform uranium (U) series analyses (^{238}U, ^{234}U, ^{230}Th). Activities of ^{99}Tc and ^{129}I are anticipated to be so low that sampling for them will be so difficult that their inclusion in an analytical suite for all samples collected would have little or no benefit. These determinations will be performed on samples from the first two or three sites visited, however, and if significant activities are detected, additional determinations will be made on subsequent samples.

Other radioisotopes applicable for age determinations include ^{39}Ar and ^{81}Kr. Use of ^{39}Ar would necessitate sample volumes greater than 1,000 liters to isolate sufficient gas for analysis, and the availability of a special, low-level counting facility. These, together with the large uncertainty of calculated ages as evidenced by the discrepancies noted when compared to ^{14}C ages (Davis and Murphy, 1987), greatly diminish the potential utility of this isotope. The distribution of ^{81}Kr has not been extensively studied, and ground-water atomic concentrations have been reported in only two recent publications (Lehmann and others, 1985; Willis and others, 1988). Accuracy and precision of ^{81}Kr analyses are also limited by uncertainties that arise from the calibration of pre-enrichment treatment of requisite large samples (100-200 liters for RIS), and from uncertainties regarding the magnitude of subsurface production. The possible use of these two radioisotopes as ground-water dating tools will be further evaluated and may be incorporated into this activity.

3.2.4 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.2-3. The selected methods for determining the parameters and the current estimate of the parameter-value range are also listed. Where many approaches to conducting the test exist, only the most common methods are included in the table. The selected methods in Table 3.2-3 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses. The laboratory analyses represent a full range of techniques currently employed by hydrochemists of the USGS, the academic community, and the consulting industry for the investigation of saturated-zone hydrologic systems.

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. The expected ranges of the site parameter have been bracketed by previous data collection or literature survey and are shown in Table 3.2-3.

3.2.5 Technical procedures

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

Table 3.2-4 provides a tabulation of technical procedures applicable to this activity. All of the procedures listed are standard. Approved

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Table 3.2-3. Summary of tests and methods for the hydrochemical characterization of the upper part of the saturated zone activity (SCP 8.3.1.2.3.2.2)
as (--) indicate information is not available or not applicable.]

Methods (selected and alternate)	Site parameter	Expected range
	Water-sample, gas-sample, and field-data collection	
Water-sample collection (selected)	--	--
Gas-sample collection (selected)	--	--
pH, specific electrical conductance, water temperature, inorganic C species, dissolved O, and Eh determinations (selected)	Ground-water intensive properties	pH 5 - 10 Sp. Cond. 0.05 - 50.0 msiemens/cm 5 - 50 Celsius C species 0 - 300 mg/L Eh -0.5 - + .5V (general published literature)
	Chemical and isotopic analyses of gas samples	
Gas scintillation counting (selected)	Water-vapor isotopic composition	^{3}H 0.09 - 500 T.U.
"	Water-vapor age	"
"	Gas flux	"
"	Gas phase composition; ground-water age; UZ/SZ flux	^{222}Rn - 0.0 - 1000 pCi/L
Liquid scintillation counting (selected)	Water-vapor isotopic composition	^{3}H 1 - 500 T.U. ^{14}C 1% - 125%
"	Gas flux	"
"	Water-vapor age	"
Accelerator mass spectrometry (selected)	Water-vapor isotopic composition	^{14}C 1% - 125%
"	$^{14}CO_2$ age	"
Gas-source mass spectrometry (selected)	Water-vapor isotopic composition	del ^{2}H/H -160 - +30 per mil del ^{13}C/^{12}C -30 - +5 per mil del ^{18}O/^{16}O -40 - +10 per mil
	Gas-flow path	del ^{2}H/H -160 - +30 per mil del ^{13}C/^{12}C -30 - +5 per mil del ^{18}O/^{16}O -40 - +10 per mil

Page 2 Table 3.2-3. Summary of tests and methods for the hydrochemical characterization of the upper part of the saturated zone activity (SCP 8.3.1.2.3.2.2)

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

Chemical and isotopic analyses of water samples

Inductively coupled plasma emission spectrometry (selected)	Ground-water chemical concentration	<500 mg/L
Gas scintillation counting (selected)	Ground-water isotopic composition	^{3}H 0.09 - 500 T.U. ^{226}Ra 0.0 - 500 pCi/L
"	Ground-water contamination	^{3}H 0.09 - 500 T.U.
"	Saturated-zone flux	"
"	Unsaturated-zone flux	"
"	Ground-water age	"
"	Gas phase composition; ground-water age; UZ/SZ flux	^{222}Rn - 0.0 - 1000 pCi/L
Liquid scintillation counting (selected)	Saturated-zone flux	^{3}H 1 - 500 T.U. ^{14}C 1% - 125% modern
"	Ground-water isotopic composition	"
"	Ground-water contamination	"
"	Unsaturated-zone flux	"
"	Ground-water age	"
Accelerator mass spectrometry (selected)	Ground-water isotopic composition	^{14}C 1% - 125% modern $^{36}Cl/Cl$ 10^{-16} - 10^{-10} $^{129}I/I$ 10^{-15} - 10^{-10}
"	Ground-water age	"
"	Ground-water flow path	"
Resonance-detection mass spectrometry (selected)	Ground-water isotopic composition	^{85}Kr 1 - 40 pCi/m^{3} (air) 0.1 - 5 pCi/m^{3} (water)
"	Ground-water age	"
"	Ground-water contamination	"
Gas-source mass spectrometry (selected)	Ground-water isotopic composition	del $^{2}H/H$ -160 - +30 per mil del $^{13}C/^{12}C$ -30 - +5 per mil $^{36}Cl/Cl$ 10^{-16} - 10^{-10} del $^{18}O/^{16}O$ -40 - +10 per mil del $^{34}S/^{32}S$ -40 - +40 per mil
Ion-counting mass spectrometry (selected)	"	$^{3}He/^{4}He$ 10^{-10} - 10^{-4} $^{21}Ne/^{20}Ne$ 0.001 - 0.1 $^{22}Ne/^{20}Ne$ 0.01 - 1 $^{40}Ar/^{36}Ar$ 295-400

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Table 3.2-3. Summary of tests and methods for the hydrochemical characterization of the upper part of the saturated zone activity (SCP 8.3.1.2.3.2.2)

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

Solid-source mass spectrometry (selected)	Ground-water isotopic composition	$^{87}Sr/^{86}Sr$ 0.70 - 0.73 $^{206}Pb/^{204}Pb$ 16 - 40 $^{207}Pb/^{204}Pb$ 16 - 22 $^{208}Pb/^{204}Pb$ 37 - 50
Alpha-counting spectrometry (selected)		$^{234}U/^{238}U$ 0.01 - 10 $^{234}U/^{230}Th$ 0.1 - 20
Inductively-coupled plasma emission mass spectrometry (selected)	Ground-water chemical composition and isotopic composition	Variable for 20 elements (general published literature)

Table 3.2-4. Technical procedures for the hydrochemistry of the upper part of the saturated-zone activity (SCP 8.3.1.2.3.2.2)

Technical procedure number (nwm-USGS-)	Technical procedure	Effective date
	Water sample, gas-sample, and field-data collection	
HP-56	Gas and vapor sampling from unsaturated-zone test holes	04/15/88
HP-23	Collection and field analysis of saturated-zone ground-water samples	10/30/91
HP-86	Method for degassing carbon dioxide and water (vapor) samples from unsaturated-zone test holes	05/16/88
HP-125	Method for extraction of pore water from tuff cores by triaxial compression	05/20/88
HP-200	Collection of ground-water samples from wells	In review
	Drill core handling	
HP-131	Methods for handling and transporting unsaturated-core and rubble samples for hydrochemical analysis	06/13/88
MDP-01	Identification, handling, storage, and disposition of drillhole core and samples (Replaced by GP-16, GP-19,R0, and GP-28,R2)	--
	Chemical analysis	
HP-160	Methods for analysis of samples for gas composition by gas chromatography	06/16/88
TBD	Methods for chromatographic determination of dissolved inorganic substances	--

procedures are identified with a USGS number and a procedure effective date. Procedures that require preparation do not have procedure numbers.

Analytical procedures provided by support contractors or other agencies will utilize widely accepted and standardized procedures. The supporting contractors or other agencies will have QA programs subject to pre-acceptance and performance audits.

Procedures that are not identified with an effective date in the table will be completed and available 30 days before the associated testing is started; these procedures are also identified with a "TBD" (To Be Determined) technical procedure number. Many of the needed technical procedures depend on the results of on-going prototype testing and cannot be completed until work is done.

Applicable quality-assurance requirements are presented in Appendix 7.1.

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.

3.3 Regional hydrochemical tests and analyses

3.3.1 Objectives

The objective of this activity is to describe regional spatial variations in ground-water chemistry in the saturated zone by examining extant data and by collecting representative water samples from wells and springs within the region and studying their chemical and isotopic compositions.

3.3.2 Rationale

The regional aspect of ground-water chemistry must be examined for several reasons. An understanding must be available regarding hydrochemical evolution beyond the site area, should ground-water travel times prove sufficiently short to require that downgradient areas beyond the boundaries noted in Section 1.1 (Figure 1.1-2) be evaluated. A second reason, probably more relevant to site characterization, is that regional hydrochemical data provide a means to refine conceptual models of regional ground-water flow. This information contributes to the consideration and evaluation of potentially differing geohydrologic system aspects, such as flow boundaries, flow rates, recharge, discharge, and the extent or significance of vertical flux. These aspects will be incorporated in numerical models of regional ground-water flow, which will, in turn, provide some of the requisite boundary conditions for site-scale models. The activity will also contribute data to geochemistry investigations bearing on geochemical transport (see Section 4.2).

3.3.3 General approach and summary of tests and analyses

Water samples will be collected from wells, springs, and seeps as they are identified or become available. Although many of the sites to be considered for sampling within this region (Figure 1.1-2) are known, some have yet to be discovered, located, constructed, etc. Investigators have not yet initially visited most of the sites to assess the feasibility and desirability of sampling them. As appropriate, newly drilled wells will be sampled, but no drilling is proposed for this activity. Sites selected will include those where alternative conceptual models of the regional geohydrologic system will be tested by Study 8.3.1.2.1.3 (Characterization of the regional ground-water flow system), particularly with regard to ground-water flow rates and directions, and the designation of flow-system boundaries. Hydrochemical data from these sites will also provide insight to the origin of anomalous features in the regional potentiometric surface.

Hydrochemistry of the water samples will be determined by various analytical techniques. The analytical data will be combined with extant data and their interpretations, including those of Claassen (1985), Benson and others (1983), Winograd and Thordarson (1975), Naff (1973), and Walker and Eakin (1963), to describe spatial compositional variations in regional ground-water chemistry.

Figure 3.3-1 summarizes the organization of the regional hydrochemistry tests. A descriptive heading for each test and analysis appears in the boxes of the second row. Below each test/analysis, the individual methods that will be utilized during testing are shown. Figure 3.3-2 summarizes the objectives of the activity, design- and performance-parameter categories which are addressed by the activity, and the site parameters measured during testing. These appear in the boxes in the top left side, top right side, and below the test/analysis boxes, respectively, in Figure 3.3-2.

The two figures summarize the overall structure of the planned activity in terms of methods to be employed and measurements to be made. The descriptions of the following sections are organized on the basis of these charts. Methodology and parameter information are tabulated to summarize the pertinent relationships among (1) the site 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 **Water-sample and field-data collection**

Water samples will be collected from a total of from 15 to 50 wells, springs, and seeps within the region (Figure 1.1-2). The variability within and between the types of sites to be visited necessitates a capacity for adaptability regarding sample collection methodologies. Wells will be pumped using methods noted in Section 3.2.3.1. As this effort will be integrated with Study 8.3.1.2.1.3 (Characterization of the regional ground-water flow system), where feasible, water-level drawdown and recovery will be monitored during the course of sampling regional sites. Spring and seep samples will be collected using a peristaltic pump. Access will be via Tygon or other appropriate tubing which will be inserted into the spring orifice, seep pool, etc., to obtain an unaerated sample. As in well sampling, pumping is preferred to grab-type samples, as the former is more likely to preclude atmospheric or other contamination and is, therefore, more representative of the natural waters. Sample-treatment and field-data collection procedures at springs and seeps will be those used at well sites, as discussed in Sections 3.2.3.1.

Where possible, water samples will be collected from previously sampled sites and compared to investigate temporal changes in hydrochemistry. Samples collected as part of this activity will extend sample coverage to previously unsampled locations within the regional flow system. This information, together with new and extant geohydrologic information describing the saturated flow system, will be used to estimate ground-water travel times and to investigate the relative significances of flow-system geometry, water/rock interactions, and geohydrologic processes with respect to spatial variations in ground-water chemistry.

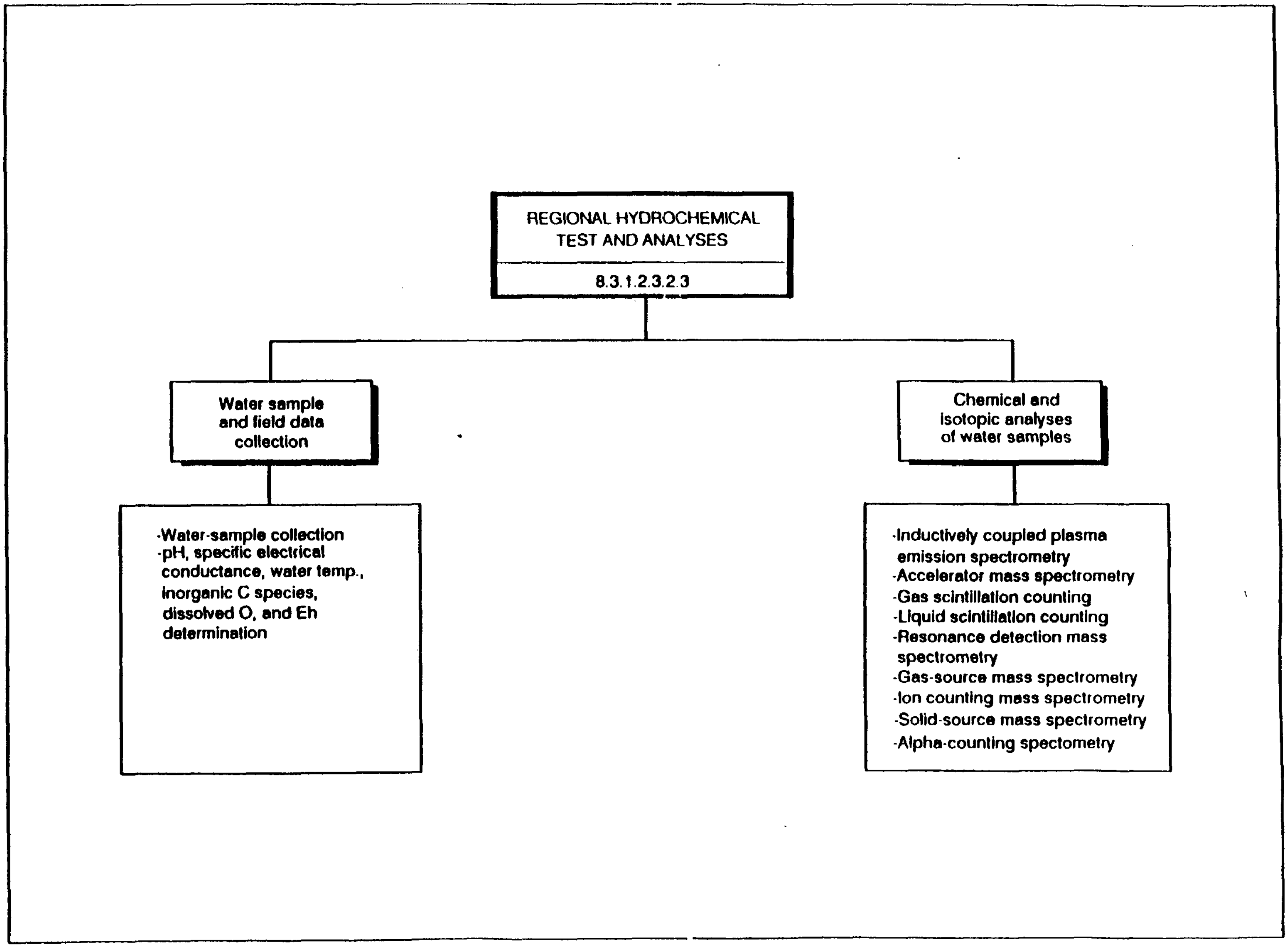

Figure 3.3-1. Logic diagram for regional hydrochemistry activity showing tests, analyses, and methods.

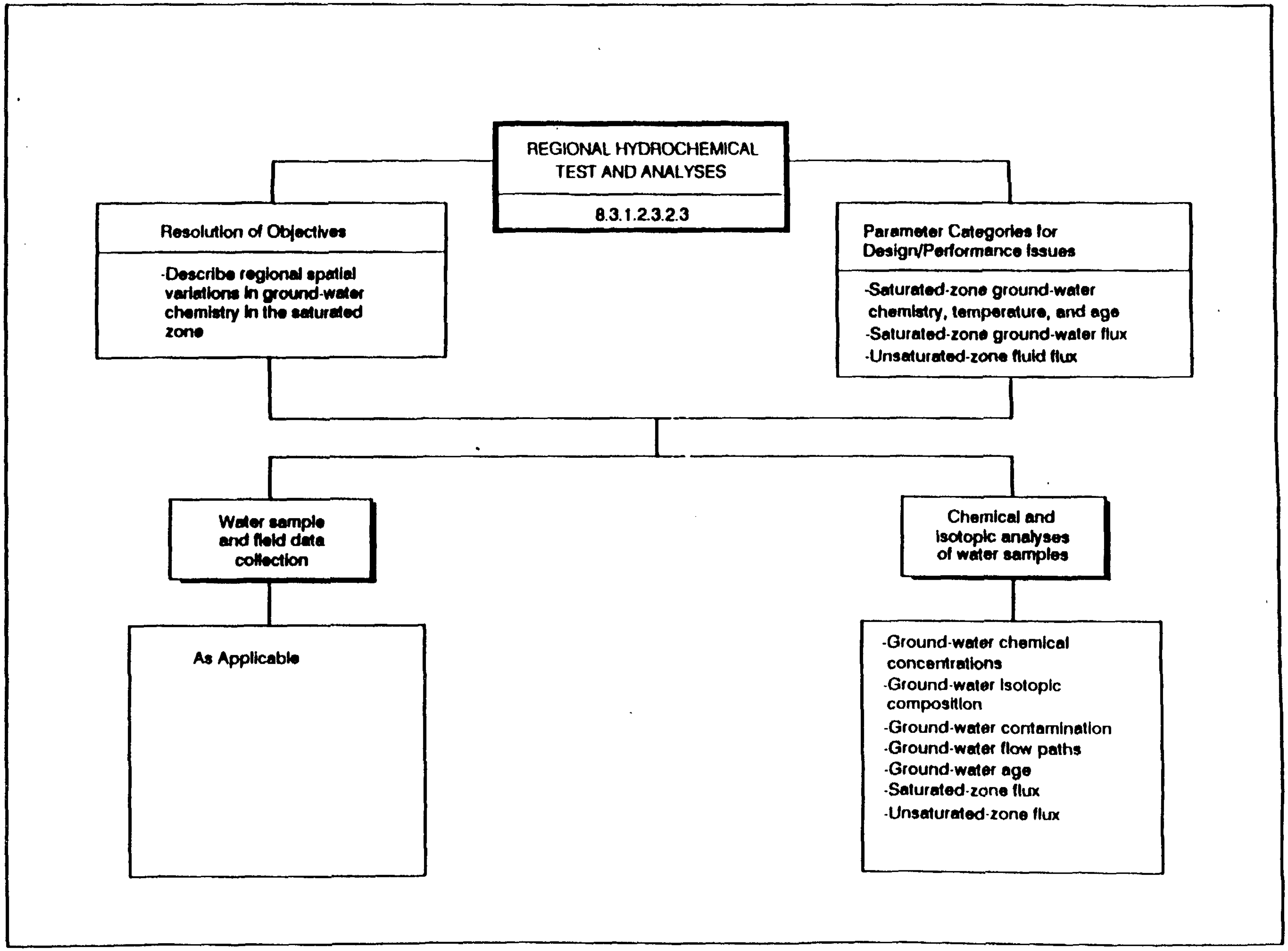

Figure 3.3-2. Logic diagram for regional hydrochemistry activity showing tests, analyses, and site parameters.

3.3.3.2 Chemical and isotopic analyses of water samples

For a detailed discussion and list of chemical parameters to be determined, see Section 3.2.3.3 and Tables 3.2-2 and 3.2-3. As discussed in Section 2.1.1, radioisotope data will enable estimation of ground-water ages and flow rates. Analyses of stable isotopes of C, O, H, Sr, and Pb will provide insight as to the origins, evolution, and mixing of ground waters and will aid in comparisons of site-specific data in order to delineate possible flow paths. These data and those collected in the first two activities of this study will also be used by Activity 8.3.1.2.3.2.4 (Synthesis of saturated-zone hydrochemistry) to identify the chemical and physical processes that influence ground-water chemistry; to aid in the identification and/or quantification of ground-water travel times, flow paths, and fluxes to, from, and within the saturated zone; and to estimate climatic conditions during periods of recharge.

Hydrochemical modeling using the complete hydrochemistry of samples (as well as geologic, petrologic, and mineralogic data) will be performed (in Activity 8.3.1.2.3.2.4) to account for the spatial distribution and variation of ground waters in the regional flow system, and to provide supporting evidence for possible flow paths and mixing mechanisms consistent with the conceptual models of ground-water flow. The data will be used by Investigation 8.3.1.3.1 in its development of a conceptual ground-water chemistry model.

3.3.4 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are the same as those summarized in Table 3.2-3, with the exception of the gas sample analyses section, which is to be excluded in this activity. The selected methods for determining the parameters and the current estimate of the parameter-value range are also listed. Alternate methods will be considered only if the primary (selected) method is impractical to measure the parameter(s) of interest. Where many approaches to conducting the test exist, only the most common methods are included in the table. The selected methods in Table 3.2-3 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The 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. The expected ranges of the site parameter have been bracketed by previous data collection or literature survey and are shown in Table 3.2-3.

3.3.5 Technical procedures

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

Table 3.3-1 provides a complete tabulation of technical procedures applicable to this activity. All of the procedures listed are standard. Approved procedures are identified with a USGS number and a procedure effective date. Procedures that require preparation do not have procedure numbers.

Procedures that are not identified with an effective date in the table will be completed and available 30 days before the associated testing is started; these procedures are also identified with a "TBD" (To Be Determined) technical procedure number. Many of the needed technical procedures depend on the results of on-going prototype testing and cannot be completed until work is done.

Applicable quality-assurance requirements are presented in Appendix 7.1.

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

Table 3.3-1. Technical procedures for the regional hydrochemical characterization activity (SCP 8.3.1.2.3.2.3)

Technical procedure number (NWM-USGS-)	Technical procedure	Effective date
	Water sample, gas sample, and field-data collection	
HP-23	Collection and field analysis of saturated-zone ground-water samples	11/04/83
	Chemical analysis	
HP-200	Collection of ground-water samples from wells	10/30/91
HP-160	Methods for analysis of samples for gas composition by gas chromatography	06/16/88
TBD	Methods for chromatographic determination of dissolved inorganic substances	—

3.4 Synthesis of saturated-zone hydrochemistry

3.4.1 Objectives

The objectives of this activity are to

(1) describe the saturated-zone hydrochemistry;

(2) identify chemical and physical processes that influence the ground-water chemistry; and

(3) relate compositional variations to water/rock interactions and the physical nature of the ground-water flow system to aid in identification and quantification of ground-water travel times, climatic conditions during periods of recharge, flow paths, and fluxes, to, from, and within the saturated zone.

3.4.2 Rationale

A synthesis of saturated-zone hydrochemistry is one means by which the ultimate objectives of geohydrologic characterization studies will be approached. The efforts in this activity will aid in the identification of the geochemical processes that have combined with ground-water flow to determine the present ground-water chemistry. Process identification will also contribute to an understanding of the paleohydrology of the region and to a general resolution of ground-water flow paths, residence times, and recharge conditions.

3.4.3 General approach and summary of test and analyses

This activity will integrate new and extant hydrochemical, geochemical, mineralogic, and geohydrologic data. Hydrochemical data will be related to the chemical composition and mineralogy of the rocks in which the waters are contained, and to the hydraulic characteristics of the geohydrologic system. Data interpretation will include radioactive age determinations, and speciation-solubility, mass-transfer, stable-isotope fractionation, and reaction-path calculations.

Hydrochemical data collected and compiled in the course of the first three activities of this study will be analyzed in several ways. Graphical methods will be used to describe spatial variations in absolute and relative concentrations of selected ground-water constituents. The variations will be examined in light of the results of geochemical calculations together with geohydrologic, geochemical, and mineralogic data. This effort will provide insight to the identities and relative significance of sources and sinks of dissolved constituents and will enable inferences of sources and areas of recharge to the saturated zone and, together with calculated ages, residence times in the geohydrologic system.

Two Geochemistry Program studies comprising Investigation 8.3.1.3.2 (Mineralogy, petrology, and rock chemistry within the potential emplacement horizon and along potential flow paths), and conducted by Los Alamos National Laboratory, will provide the baseline data set for understanding the natural environment in which geochemical and other processes interact. These data will contribute to the saturated-zone hydrochemistry synthesis activity. Study 8.3.1.3.2.1 (Mineralogy, petrology, and chemistry of transport pathways) will provide a three-dimensional distribution of mineral types, rock and mineral compositions, and mineral abundances within the potential host rock and along potential flow paths to the accessible environment. Study 8.3.1.3.2.2 (History of mineralogical and geochemical alteration of Yucca Mountain) will evaluate the history of mineralogic and geochemical alteration at the site.

The data compiled, integrated, and interpreted in this activity will provide information that is approximately representative of the repository area. The tests in this activity will involve the integration and analysis of data from the saturated zone throughout the site and region. An understanding of the relations between hydrochemical, geochemical, mineralogic, and geohydrologic parameters will further an understanding of the geohydrologic system and will provide a means to identify and estimate or refine ground-water flow paths and fluxes. The results of this activity will also provide part of the basis for predicting post-closure repository conditions.

3.4.3.1 Graphical analysis

Graphical methods will be used to describe spatial distributions and relative concentration variations of selected chemical and isotopic data. Variations will be integrated with extant geohydrologic information, spatial distributions of secondary minerals, spatial petrologic variations, and whole-rock and mineralogic compositions.

3.4.3.2 Geochemical calculations

The geochemical code used will be EQ3NR/EQ6 (Wolery, 1983, 1984). Isotopic fractionation calculations will depend on the mineral phases examined. Specific examples of the types of calculations to be made are found in Yeh and Savin (1976), Clayton and others (1972), and O'Neil and others (1969); Friedman and O'Neil (1977) provide a summary. Radioactive age determinations of waters in geohydrologic systems are discussed by Mook (1980).

EQ3NR/EQ6 will be used to calculate the speciation of dissolved materials in saturated-zone waters, and to determine the saturation states of relevant solid phases. Results of the speciation calculations will contribute to the identification of geochemical processes that are of possible significance to the saturated-zone hydrochemistry.

Geohydrologic, hydrochemical, and mineralogic data will be used to develop plausible reaction models for the evolution of ground-water chemistry. Mass-transfer calculations will be used to estimate plausible fluxes to and from solution. The reaction models will be tested using the reaction-path simulation capabilities of the EQ3NR/EQ6 code.

3.4.4 Methods summary

The approach of this activity has been developed by the USGS investigators to provide the most sensible and reasonable interpretations of the data. The approach may be subject to modification if warranted by new or changed hydrochemical hypotheses and/or by the hydrochemical evidence.

3.4.5 Quality-assurance requirements

The current software reference for EQ3NR/EQ6 is Wolery (1983). Additional information regarding development and future plans for EQ3NR/EQ6 is located in SCP Sections 7.4.4 (Geochemical modeling codes: EQ3/6) and 8.3.5.10.3.2, Activity 1.5.3.2 (Develop geochemical speciation and reaction model). Documentation and control of the quality of software used for modeling are subject to the requirements set forth in YMP-USGS QMP-3.03 (Software Quality Assurance). Modeling is an analysis and interpretation activity, the appropriate application of which is assured by technical review as set forth in YMP-USGS-QMP-3.04 (Technical Review, Approval, and Distribution of YMP-USGS Publication).

4 APPLICATION OF STUDY RESULTS

4.1 Application of results to resolution of design and performance issues

The results of this study will be used in the resolution of YMP performance and design issues concerned with fluid flow within the saturated zone beneath Yucca Mountain. The principal applications will be in the assessment of radionuclide migration and of ground-water travel times (Issues 1.1 and 1.6). Issues concerned with assessing the repository design and technical feasibility (Issue 4.4) and issues addressing the NRC siting criteria (Issues 1.8 and 1.9) will also receive input from this study.

The application of site information from this study to design and performance parameter needs required for the resolution of design and performance issues is addressed in Section 1.2. Logic diagrams and tables summarize specific relationships between performance- and design-parameter needs and site parameters determined from this study. Section 7.2 provides additional detailed parameter relationships.

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

The following paragraphs describe how the data collected in this study will be employed in other site-characterization investigations.

Within Investigation 8.3.1.2.1 (Regional hydrologic system), data from the present study will be used in the Fortymile Wash recharge activity of Study 8.3.1.2.1.3 (Regional ground-water flow system), in order to examine the hypothesis that Fortymile Wash is or has been a source of recharge to the ground-water flow system in the vicinity of Yucca Mountain. This hypothesis is based on saturated-zone hydrochemical data along Fortymile Wash and beneath the Amargosa Desert. In Study 8.3.1.2.1.4 (Regional hydrologic system synthesis and modeling), the hydrochemistry data assembled in the present study will be one of several lines of evidence used to evaluate the conceptual model of the regional saturated-zone flow system.

Within Investigation 8.3.1.2.2 (Site unsaturated-zone hydrologic system), data collected in the present study will complement the unsaturated-zone hydrochemical work in the exploratory-shaft hydrochemistry activity of Study 8.3.1.2.2.4 (Unsaturated-zone percolation - ESF studies), and the aqueous-phase and gas-phase chemistry activities of Study 8.3.1.2.2.7 ((Unsaturated-zone hydrochemistry). Data from the present study can assist in evaluating the flow direction and travel time of unsaturated-zone water, as well as its geochemical evolution.

Within Investigation 8.3.1.2.3 (Site saturated-zone hydrologic system), the present study will contribute to Study 8.3.1.2.3.3 (Site saturated-zone synthesis and modeling), because some of the regional saturated-zone data assembled in the present study will support the evaluation of the conceptual model of the site saturated-zone flow system.

Within Investigation 8.3.1.3.1'(Water chemistry within the emplacement horizon and along potential flow paths), the present study will directly assist Study 8.3.1.3.1.1 (Ground-water chemistry model) by the provision of saturated-zone water-chemistry data requisite to the geochemical modeling of pre-emplacement conditions in the saturated zone.

Within Investigation 8.3.1.3.3 (Stability of minerals and glasses), saturated-zone hydrochemical data from the present study will support Study 8.3.1.3.3.2 (Kinetics and thermodynamics of mineral evolution) in assessing the origin of alteration minerals in rock matrices and fractures of the Topopah Spring Member, and support Study 8.1.3.3.3.3 (Conceptual model of mineral evolution) in explaining the observed distribution of minerals in Yucca Mountain, and the general chemical evolution of vitric tuffs.

Within Investigation 8.3.1.3.4 (Radionuclide retardation by sorption processes along flow paths to the accessible environment), saturated-zone hydrochemical data from the present study will be used in Study 8.3.1.3.4.3 (Development of sorption models) in the prediction of sorption coefficients for key radionuclides, under water-rock conditions not included within the experimental parts of the investigation.

Within Investigation 8.3.1.3.5 (Radionuclide retardation by precipitation processes along flow paths to the accessible environment), saturated-zone hydrochemical data from the present study will support Study 8.3.1.3.5.2 (Colloid behavior) in evaluating the stability of waste-element colloids under site-specific conditions that might be encountered at the repository or along flow paths toward the accessible environment.

Within Investigation 8.3.1.3.6 (Radionuclide retardation by dispersive, diffusive, and advective transport processes along flow paths to the accessible environment), saturated-zone hydrochemical data from the present study may be used in the diffusion tests in saturated tuff.

Within Investigation 8.3.1.3.7 (Radionuclide retardation by all processes along flow paths to the accessible environment), saturated-zone hydrochemical data from the present study will support Study 8.3.1.3.7.1 (Retardation sensitivity analysis) in the evaluation of the significant and important geochemical processes affecting transport, and in conceptualization of a geochemical-geophysical model of Yucca Mountain.

Within Investigation 8.3.1.3.8 (Retardation of gaseous radionuclides along flow paths to the accessible environment), gaseous-phase isotopic data from Activity 8.3.1.2.3.2.2 (Hydrochemical characterization of water in the upper part of the unsaturated zone) may be used indirectly in the evaluation of potential models of gaseous radionuclide transport.

Within Investigation 8.3.1.5.1 (Nature and rates of change of climatic conditions to predict future climates), saturated-zone hydrochemical data from the present study will support the past-discharge activity of Study 8.3.1.5.2.1 (Quaternary regional hydrology) by providing saturated-zone water chemistry in regional discharge areas.

Within Investigation 8.3.1.16.2 (Location of adequate water supplies), saturated-zone hydrochemical data from the present study will augment the chemical analyses of saturated-zone water in Study 8.3.1.16.2.1 (Location of adequate water supply for construction, operation, closure, and decommissioning).

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 in the saturated-zone hydrochemistry study. This figure represents a summary of the schedule information which includes the sequencing, interrelations, and relative durations of the activities described in this study. It also shows the SCP major events for the study. Specific durations, and start and finish dates for the activities are being developed attendant to on-going and evolving planning efforts. The development of the schedule for the present study has taken into account how the study will be affected by contributions of data or interferences from other studies, and also how the present study will contribute to, or perhaps interfere with, other studies.

The sampling of the saturated zone for chemical analyses as described in this study plan will be dependent on the drilling schedules of the water-table holes as described in Study 8.3.1.2.3.1 (Characterization of the site saturated-zone ground-water flow system). Accurate characterization of the logistical aspects requisite to the collection of representative saturated- and unsaturated-zone ground waters and gases will require several years of sampling. Because of the relatively long period of time needed, the planned activities provide little time for delay.

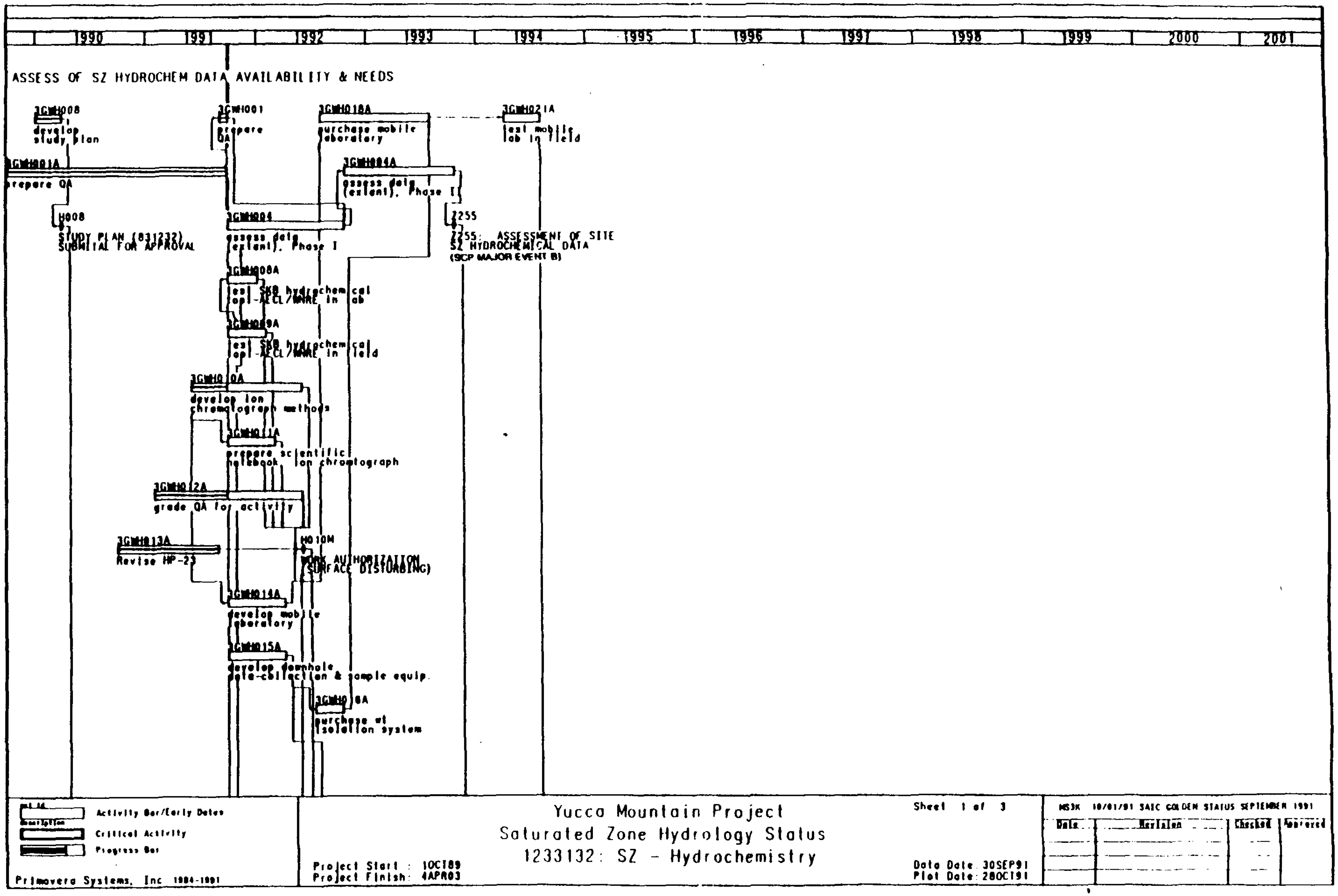

Figure 5.1-1a. Summary network for the saturated-zone hydrochemistry study.

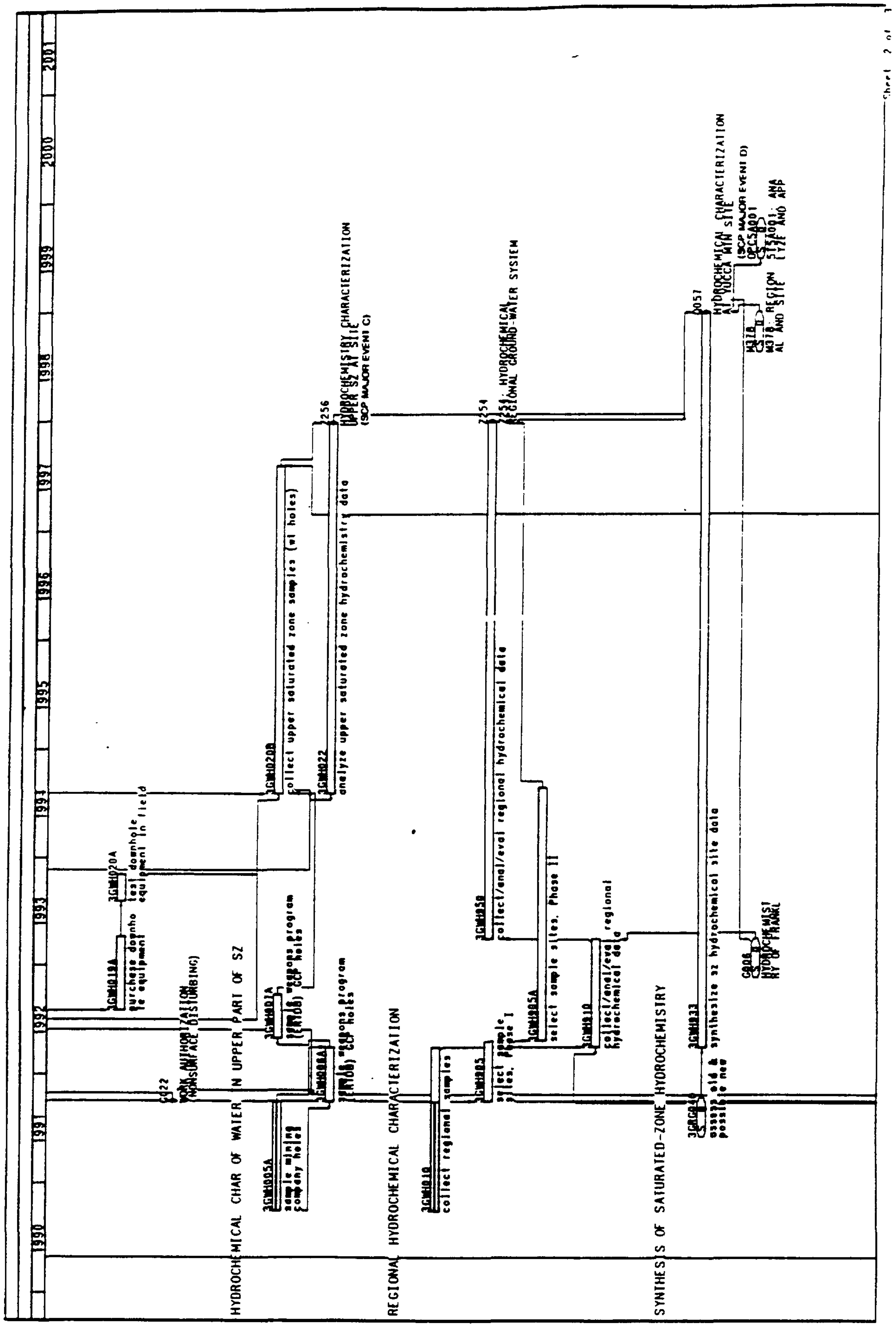

Figure 5.1-1b. Summary network for the saturated-zone hydrochemistry study.

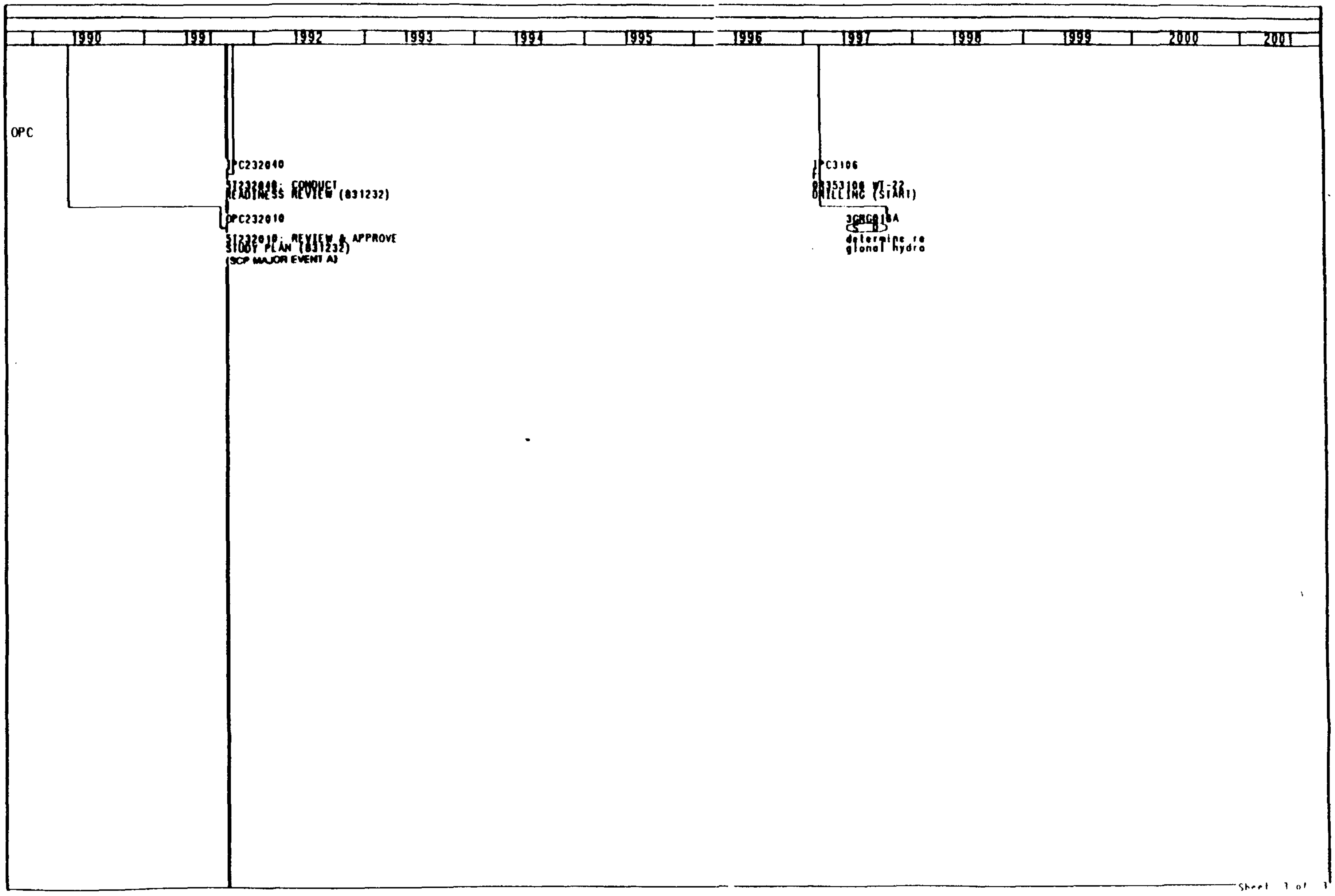

Figure 5.1-1c. Summary network for the saturated-zone hydrochemistry study.

5.2 Milestones

The level, number, and title of milestones associated with the four activities of the characterization of the Yucca Mountain saturated-zone hydrochemistry study are summarized in Table 5.2-1.

The information presented in Table 5.2-1 represents important summary milestones associated with the activities presented in this study plan. Specific dates for the milestone are not included in the tables, as project schedules have been revised from those originally stated in Section 8.5 of the SCP, are subject to further change due to ongoing planning efforts.

Table 5.2-1. Milestone list for work-breakdown structure number-1.2.3.3.1.3.2 (SCP 8.3.1.2.3.2)

[Milestone dates are unavailable at this time.]

Milestone number	Milestone	Milestone level
Characterization of the Yucca Mountain saturated-zone hydrochemistry: 8.3.1.2.3.2		
G022	Work authorization (non-surface-disturbing)	
H008	Study plan submittal for approval	
H010M	Work authorization (surface-disturbing)	
Assessment of site hydrochemical data availability and needs: 8.3.1.2.3.2.1		
Z255	Assessment of site saturated-zone hydrochemical data availability and needs	2
Hydrochemical characterization of water in the upper part of the saturated zone: 8.3.1.2.3.2.2		
Z256	Hydrochemical characterization of water in the upper part of the saturated zone	2
Q067	Hydrochemical characterization of water in the upper part of the saturated zone	2
Regional hydrochemical characterization: 8.3.1.2.3.2.3		
Z254	Issue report on regional ground-water chemistry	2

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

The QA grading packages for the activities in this study plan were approved February 14, 1991.

Applicable NQA-1 criteria for Study 8.3.1.2.3.2 and how they will be satisfied

NQA-1 Criteria #	Documents addressing these requirements
1. Organization and interfaces	The organization of the OCRWM program is described in the Mission Plan (DOE/RW-005, June 1985) and further described in Section 8.6 of the SCP. Organization of the YMP-USGS is described in the following: QMP-1.01 (Organization Procedure)
2. Quality-assurance program	Requirements of the OCRWM Quality Assurance Program are specified in DOE/RW-214, "OCRWM Quality Assurance Requirements Document." The YMP-USGS QA Program is described in the following: QMP-2.01 (Management Assessment of the YMP-USGS Quality Assurance Program) QMP-2.02 (USGS Personnel Qualification) QMP-2.05 (Qualification of Audit and Surveillance Personnel)

QMP-2.07 (YMP-USGS Instruction)

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 (Software Quality Assurance)

QMP-3.04 (Technical Review, Approval, and Distribution of YMP-USGS Publications)

QMP-3.05 (Work Request for NTS Contractor Services [Criteria Letter])

QMP-3.06 (Scientific Investigation Plan)

QMP-3.07 (YMP-USGS Review Procedure)

QMP-3.10 (Verification of Scientific Investigations)

QMP-3.11 (Peer Review)

QMP-3.13 (Design Input)

4. Administrative operations and procurement

QMP-4.01 (Procurement Document Control)

QMP-4.02 (Control of Intra-USGS Acquisitions)

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) QMP-5.03 (Development and Maintenance of Quality Management Procedures) QMP-5.04 (Preparation and Control of the YMP-USGS QA Program Plan) QMP-5.05 (Scientific Notebook)
6. Document control	QMP-6.01 (Document Control);
7. Control of purchased items and services	QMP-7.01 (Control of Purchased Items and Services)
8. Identification and control of items, samples, and data	QMP-8.01 (Identification and Control of Samples) QMP-8.03 (Control and Transmittal of Technical Information to the Project Technical Data Base)
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-17.03 (YMP-USGS Local Records Center)
18.	Audits	QMP-18.01 (Audits) QMP-18.02 (Surveillance)

7.2 Relationships 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 relationships between SCP design- and performance-parameters needs and site parameters to be determined in this study. The relationships 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 relationships.

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). 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 <u>not</u> be made.

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.1	Total system performance				(SCP 8.3.5.13)
Performance Measures: EPPM[a], nominal case, release scenario class E, water pathway release					
Parameter Category: Saturated-zone ground-water chemistry, temperature, and age					
Average length of flow paths through saturated zone from C-area to the accessible environment boundary (hydrochemically determined)	Primary area and extensions; Saturated zone	Goal: To be determined Current: Low Needed: Medium	Ground-water age	Yucca Mountain; site, and region; Saturated zone	8.3.1.2.3.2.1
Saturated-zone fluid flux (hydrochemically determined)	"	"	Ground-water chemical concentration	"	"
Major-ion water chemistry (composition, Eh, pH) ambient rock mass pore fluids	Repository area; Saturated zone	"	Ground-water contamination	"	"
Profiles of bicarbonate concentration in liquid phase	"	"	Ground-water intensive properties (e.g. temperature, conductance)	"	"
Average flux through repository area in saturated zone	"	"	Ground-water isotopic composition ($^{18}O/^{16}O$, D/H, $^{13}C/^{12}C$)	"	"

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 chemistry, temperature, and age					
			Radioisotope activity (^{14}C, ^{3}H)	Yucca Mountain; site, and region; Saturated zone	8.3.1.2.3.2.1
			Ground-water age	Yucca Mountain and vicinity; Saturated zone upper 100 m; USW WT-1, 2, 7, 10, 11; UE-25 WT-3, 4, 6, WT-12, 13, 14, 15, 16, 17, 8, 9, 19, 20, 27, 22, 23, 24	8.3.1.2.3.2.2
			Ground-water chemical concentrations	"	"
			Ground-water contamination	"	"
			Ground-water intensive properties (e.g. temperature, conductance)	"	"
			Ground-water isotopic composition ($^{18}O/^{16}O$, D/H, $^{13}C/^{12}C$)	"	"

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 chemistry, temperature, and age					
			Radioisotope activity (^{14}C, ^{3}H)	Yucca Mountain and vicinity; Saturated zone, upper 100 m; USW WT-1, 2, 7, 10, 11; UE-25 WT-3, 4,6, WT-12, 13, 14, 15, 16, 17, 8, 9, 19, 20, 27, 22, 23, 24	8.3.1.2.3.2.2
			Ground-water age	Nevada Test Site and surrounding region; Saturated zone	8.3.1.2.3.2.3
			Ground-water chemical concentration	"	"
			Ground-water composition ($^{18}O/^{16}O$, D/H, $^{13}C/^{12}C$) $^{87}Sr/^{86}Sr$, $^{34}S/^{32}S$	"	"
			Ground-water contamination	"	"

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 chemistry, temperature, and age					
			Ground-water intensive properties (e.g. temperature, conductance)	Nevada Test Site and surrounding region; Saturated zone	8.3.1.2.3.2.3
			Radioisotope activity (^{14}C, ^{3}H)	"	"
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 paths	Yucca Mountain; site, and region; Saturated zone	8.3.1.2.3.2.1
			Saturated-zone flux	Yucca Mountain and vicinity; Saturated zone	"

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:					
		Parameter Category: Saturated-zone ground-water flux			
			Ground-water flow paths	Yucca Mountain and vicinity; Saturated zone upper 100 m; USW WT-1, 2, 7, 10, 11; UE-25 WT-3, 4, 6, WT-12, 13, 14, 15, 16, 17	8.3.1.2.3.2.2
			Saturated-zone flux	"	"
			Ground-water flow paths	Nevada Test Site and surrounding region; Saturated zone	8.3.1.2.3.2.3
			Saturated-zone flux	"	"
		Parameter Category: Geochemical conceptual/descriptive models			
Water-rock injections, chemical and physical processes that influence ground-water chemistry	Repository area; Saturated zone	Goal: To be determined Current: Low Needed: Medium	Geochemical reaction modeling	Yucca Mountain, site and region; Saturated zone	8.3.1.2.3.2.4

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

Issue 1.6 Pre-waste-emplacement, ground-water travel time (SCP 8.3.5.12)

Performance Measures: Ground-water travel time[e], Topopah Spring welded unit (secondary reliance)
Ground-water travel time[e], Calico Hills non-welded, vitric unit (primary reliance)
Ground-water travel time[e], Calico Hills non-welded, zeolitized unit (primary reliance)
(Supporting parameters used in calculating performance parameters for ground-water travel time.)

Parameter Category: Unsaturated-zone fluid flux

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Flux (q)[b]	Controlled area; TSw[a]	Goal: <0.5 mm/yr[de] Current: Low Needed: Low	Unsaturated-zone flux	Yucca Mountain; site, and region; Unsaturated zone immediately above the water table	8.3.1.2.3.2.1
Flux (q)	Controlled area; CHnv	Goal: <0.5 mm/yr Current: Low Needed: High	Gas flow path	Yucca Mountain and vicinity; Unsaturated zone immediately above the water table	8.3.1.2.3.2.2
"	Controlled area; CHnz	Goal: <0.5 mm/yr Current: Medium Needed: High	Gas flux	"	"
			Unsaturated-zone flux	"	"
			"	Nevada Test Site and surrounding area; Saturated zone	8.3.1.2.3.2.3

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.6	Pre-waste-emplacement, ground-water travel time				(SCP 8.3.5.12)
Performance Measures: (Supporting parameters used in calculating performance parameters for ground-water travel time.)					
Parameter Category: Saturated-zone ground-water chemistry, temperature, and age					
Distance along flow paths (hydrochemically determined)	Controlled area; Saturated zone	Goal: To be determined Current: Low Needed: Medium	Ground-water age	Yucca Mountain; site, and region; Saturated zone	8.3.1.2.3.2.1
Isotopic ratios, ground water residence time (fractures and rock matrix)	Repository area; Saturated zone	"	Ground-water chemical concentration	"	"
			Ground-water contamination	"	"
			Ground-water intensive properties (e.g. temperature, conductance)	"	"
			Ground-water isotopic composition ($^{18}O/^{16}O$, D/H, $^{13}C/^{12}C$)	"	"
			Radioisotope activity (^{14}C, ^{3}H)	"	"

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 chemistry, temperature, and age			
			Ground-water age	Yucca Mountain and vicinity; Saturated zone upper 100 m; USW WT-1, 2, 7, 10, 11; UE-25 WT-3, 4, 6, WT-12, 13, 14, 15, 16, 17, 8, 9, 19, 20, 27, 22, 23, 24	8.3.1.2.3.2.2
			Ground-water chemical concentrations	"	"
			Ground-water contamination	"	"
			Ground-water intensive properties (e.g. temperature, conductance)	"	"
			Ground-water isotopic composition ($^{18}O/^{16}O$, D/H, $^{13}C/^{12}C$)	"	"

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 chemistry, temperature, and age					
			Radioisotope activity (^{14}C, ^{3}H)	Yucca Mountain and vicinity; Saturated zone, upper 100 m; USW WT-1, 2, 7, 10, 11; UE-25 WT-3, 4,6, WT-12, 13, 14, 15, 16, 17, 8, 9, 19, 20, 27, 22, 23, 24	8.3.1.2.3.2.2
			Ground-water age	Nevada Test Site and surrounding region; Saturated zone	8.3.1.2.3.2.3
			Ground-water chemical concentration	"	"
			Ground-water composition (^{18}O/^{16}O, D/H, ^{13}C/^{12}C) ^{87}Sr/^{86}Sr, ^{34}S/^{32}S	"	"
			Ground-water contamination	"	"

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 chemistry, temperature, and age			
			Ground-water intensive properties (e.g. temperature, conductance)	Nevada Test Site and surrounding region; Saturated zone	8.3.1.2.3.2.3
			Radioisotope activity (^{14}C, ^{3}H)	"	"
		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	Ground-water flow paths	Yucca Mountain; site, and region; Saturated zone	8.3.1.2.3.2.1
			Saturated-zone flux	Yucca Mountain and vicinity; Saturated zone	"
			Ground-water flow paths	Yucca Mountain and vicinity; Saturated zone upper 100 m; USW WT-1, 2, 7, 10, 11; UE-25 WT-3, 4, 6, WT-12, 13, 14, 15, 16, 17	8.3.1.2.3.2.2

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:					
		Parameter Category: Saturated-zone ground-water flux			
			Saturated-zone flux	Yucca Mountain and vicinity; Saturated zone upper 100 m; USW WT-1, 2, 7, 10, 11; UE-25 WT-3, 4, 6, WT-12, 13, 14, 15, 16, 17	8.3.1.2.3.2.2
			Ground-water flow paths	Nevada Test Site and surrounding region; Saturated zone	8.3.1.2.3.2.3
			Saturated-zone flux	"	"

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 1.10	Waste package characteristics (postclosure)				(SCP 8.3.4.2)
Performance Measures: Quality of liquid water that can contact the container Quantity of liquid water that can contact the container					
Parameter Category: Unsaturated-zone fluid chemistry and temperature, and age					
Mineralogy and water quality: vadose water composition	Repository area; Repository block: TSw2	Current: Needed: High	CO_2 age	Yucca Mountain and vicinity; Unsaturated zone immediately above the water table	8.3.1.2.3.2.2
			Water vapor isotopic composition	Yucca Mountain; site, and region; Unsaturated zone immediately above the water table	"
			Water-vapor age	Yucca Mountain and vicinity; Unsaturated zone immediately above the water table	"
Parameter Category: Unsaturated-zone fluid flux					
Water quantity: single-phase fluid flow	Repository area; Repository block: TSw2	Current: Needed: High	Unsaturated-zone flux	Yucca Mountain; site, and region; Unsaturated zone immediately above the water table	8.3.1.2.3.2.1

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 1.10	Waste package characteristics (postclosure)				(SCP 8.3.4.2)
Performance Measures: Quantity of liquid water that can contact the container					
		Parameter Category: Unsaturated-zone fluid flux			
Water quantity: two-phase fluid flow	Repository area; Repository block: TSw2	Current: Needed: High	Gas flow path	Yucca Mountain and vicinity; Unsaturated zone immediately above the water table	8.3.1.2.3.2.2
			Gas flux	"	"
			Unsaturated-zone flux	"	"
			"	Nevada Test Site and surrounding area; Saturated zone	8.3.1.2.3.2.3

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 4.4	Repository construction, operation, closure, and decommissioning technologies				(SCP 8.3.2.5)
Performance Measures: Removal rate equal to rate of inflow					
		Parameter Category: Unsaturated-zone fluid flux			
Natural-water inflow	Repository facilities;	Goal: Actual inflow rate to accuracy of +/- 10 gpm Current: Low Needed: Medium	Unsaturated-zone flux	Yucca Mountain; site, and region; Unsaturated zone immediately above the water table	8.3.1.2.3.2.1
			Gas flow path	Yucca Mountain and vicinity; Unsaturated zone immediately above the water table	8.3.1.2.3.2.2
			Gas flux	"	"
			Unsaturated-zone flux	"	"
			"	Nevada Test Site and surrounding area; Saturated zone	8.3.1.2.3.2.3

7.3 Change request notices

The following Change Requests (CR) contain proposed changes to the Site Characterization Planning Basis (SCPB) based on the current draft of this study plan.

SP 8.3.1.2.3.2. R0

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