Study Plan for
Study 8.3.1.5.1.1

Characterization of Modern Regional Precipitation

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
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Prepared by
United States Geological Survey

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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
STUDY PLAN APPROVAL FORM

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Revision Number 0

Prepared by: U.S. Geological Survey

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STUDY PLAN

FOR

STUDY 8.3.1.5.1.1

CHARACTERIZATION OF MODERN REGIONAL PRECIPITATION

Rev 0

July 14, 1994

U. S. GEOLOGICAL SURVEY

ABSTRACT

Study 8.3.1.5.1.1 will gather stable and radiogenic isotopic data (deuterium, oxygen, strontium) from precipitation samples to establish baseline data for comparison with data gathered from the geological and hydrological records by other studies in the Yucca Mountain Site Characterization Program. Comparison of modern isotopic data with paleoclimate data provides information about the nature of past climatic and hydrologic conditions that will assist in predictions of future conditions which may affect the ability of the proposed repository site to contain high-level nuclear wastes, especially as this information relates to future ground water recharge rates and possible elevation of the existing water table.

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FIGURES

STUDY 8.3.1.5.1.1
CHARACTERIZATION OF MODERN REGIONAL PRECIPITATION

Study 8.3.1.5.1.1, consisting of one activity (8.3.1.5.1.1.1, Stable isotopic composition of modern regional precipitation), is part of the climate program. The SCP states that the parameters for this activity (originally titled "Syncptic characterization of regional climate") are:

- Meteorological data, such as monthly and annual values for temperature, precipitation, wind velocity, from a regional network of sites.
- Synoptic climate, such as spatial and temporal variation of precipitation, air temperature, cloud cover, and wind velocity.

These data, however, are already being collected by other studies and activities. Meteorological data in the vicinity of Yucca Mountain are being collected by Activities 8.3.1.2.1.1.1, Characterization of meteorology for site and regional hydrology, and 8.3.1.12.2.1.1, Site meteorological monitoring program; and synthesis of regional meteorology (i.e., synoptic climate) is being performed under Study 8.3.1.12.1.1, Characterization of the regional meteorological conditions. Implementation of the complete investigation outlined in the SCP for Study 8.3.1.5.1.1 would be costly and redundant. Data from this study, as well as the meteorological data from the other studies cited above, will be utilized in Study 8.3.1.5.1.5 (Paleoclimate-paleoenvironmental synthesis), which will synthesize modern climate data as well as paleoclimate data.

Meteorological data are critically needed within the climate program to (1) develop relationships between climate and plant species distributions, lake levels and distributions, and atmospheric circulation models; (2) provide an understanding of the spatial and temporal variability of modern regional climate; and (3) determine the climate conditions conducive to ground water recharge. Reconstruction of past climate from fossil records, such as stable isotope records from biogenic carbonates in ancient sediments or from spring-deposited carbonates, demands a thorough understanding of these settings in modern environments and their relationship to the stable isotopic composition of modern precipitation.

Measurement of the hydrogen and oxygen isotopic composition of precipitation from a regional network of collectors is called for within Activity 8.3.1.5.1.1.1. This limited implementation of the activity for the purpose of determining the stable isotopic composition of modern regional precipitation will provide the needed data without duplicating data collection efforts already underway in other studies.

Strontium isotope ratios have been proven to be sensitive tracers of the source of dissolved components in hydrologic (Peterman and Stuckless, 1993) and paleohydrologic (Marshall et al., 1993; Stuckless et al., 1991) studies. Activity 8.3.1.5.1.1.1 will measure the

$\delta^{87}Sr$ values of selected precipitation samples as a test on the magnitude of storm-related dust input to the local and regional soil environments, the distance that storm-transported dust may travel, and the input of storm-transported dust (or components dissolved from it) to the ground water system (especially the unsaturated zone). These Sr isotope tracer studies will aid in defining the climate parameters responsible for the temporally and spatially widespread calcified paleosols in the Yucca Mountain area and, hence, the significance of these paleosols to cycles of past climate change. In addition, determination of the isotopic composition of the discharge from springs of shallow flow path and whose temperature is within a few degrees (± 5°C) of local mean annual temperature will evaluate the effects of processes such as evaporation on the isotopic composition of meteoric waters that actually recharge the ground water system. Sites such as Cane Springs on the NTS and Pahrock Spring at the southern tip of N. Pahrock Mtns. are examples of such shallow discharge; other sites will be included as they are identified.

Precipitation and runoff monitored during the implementation of other studies, such as those cited above, will provide the samples for these measurements. If necessary, limited collection of precipitation samples will be performed within 8.3.1.5.1.1.1 itself.

Carbon isotopic data are being collected within (1) 8.3.1.5.2.1.5, Studies of calcite and opaline silica, from carbonate minerals and soil gases from a wide range of setting; (2) 8.3.1.2.3.2, Saturated zone hydrochemistry, from dissolved organic and inorganic carbon species in ground waters; and (3) 8.3.1.2.2.7, Unsaturated zone hydrochemistry, from organic and inorganic carbon species from fluids and gases. Carbon isotope data will not be collected as part of this activity.

1. PURPOSE AND OBJECTIVES OF STUDY

1.1 Information to be obtained and how that information will be used

Evaluation of the probability of increased flux through Yucca Mountain due to an increase in effective moisture within the next 10,000 yr is an important component of the climate program. Study 8.3.1.5.1.1 intends to gather stable and radiogenic isotope data from precipitation to establish baseline data for comparison with data gathered from the geological and hydrological records. Other studies will generate the isotope data from the geological record, including Study 8.3.1.5.1.2 (Paleoclimate study: lakes, playas, and marshes), Study 8.3.1.5.1.3 (Climatic implications of terrestrial paleoecology), and Study 8.3.1.5.2.1 (Characterization of the Quaternary Regional hydrology). Those data will typically come from various inorganic and biogenic carbonates, as well as plant cellulose. The hydrological data will come from either ground water or water in the unsaturated zone.

The isotopic data gathered by 8.3.1.5.1.1 will be of value to other meteorological studies such as 8.3.1.2.1.1, Characterization of the meteorology for regional hydrology, and to many of the paleoclimate activities. Paleoclimate reconstructions frequently rely on analog settings. The response of plant and animal species (and the isotopic record therein) to modern regional climate variability provides important baseline data and permits recent settings to function as analogs for the inference of past climate from fossil records.

Data gathered within other studies, such as 8.3.1.2.1.1, 8.3.1.12.1 (Characterization of the regional meteorological conditions), and 8.3.1.12.2.1 (Meteorological data collection at the Yucca Mountain site) will be important for interpretation of the data collected within 8.3.1.5.1.1. Air temperature and air mass trajectory of individual precipitation events, for example, is necessary for correlation of the isotopic signatures of precipitation events with seasonality and storm track.

1.2 Rationale and justification for the information to be obtained: why the information is needed

Analysis and interpretation of isotope data from modern precipitation provide an understanding of its seasonal and spatial variability. These isotopic data, and the processes controlling isotopic variation of precipitation (moisture source, temperature of evaporation and condensation, air mass trajectory, topographic rainout effects, etc.), provide the baseline information needed for comparison with isotope data collected from the geological record. Differences or similarities of paleoisotope data relative to baseline data provide indications about the nature of past climate and hydrology.

The results of studies within the climate program using data gathered in this study will ultimately be integrated into Study 8.3.1.5.2.2 (Characterization of the future regional hydrology due to climate changes) to assist in evaluating the effects of future climate on surficial, unsaturated zone, and saturated zone hydrology as shown in Figure 1-2. Such evaluations are required by certain performance and design issues, as also shown in Figure 1-2. The resulting data will be used by other studies to address the objective of projecting the magnitude of possible future radionuclide releases to the accessible environment as required by 10CFR60 and 40CFR191.13, and as embodied in Issue 1.1.

Issue 1.1, for example, states that a tentative parameter goal for site selection be an expected rise in the water table of less than 100 m during the next 10,000 years owing to climate change. This same limitation in water-table elevation change applies in the resolution of Issue 1.9b, wherein the time period involved is 100,000 yr. New data suggests that past elevations of the water table approached or exceeded this 100m limit (Paces et al, 1993; Marshall et al., 1993). Confidence levels in both these parameters need to be improved from their current low status to a high category. Information on present regional climate that is needed to satisfy Issues 1.1 and 1.9b is also sufficient to assist in resolving the other issues shown on Figure 1-2.

Study 8.3.1.5.1.1 Characterization of Modern Regional Precipitation

A second and equally important goal of the climate program will be the evaluation of flux through the unsaturated zone that might mobilize radionuclides. A higher water-table together with an increase in flux would shorten the path to the water-table and might significantly reduce travel time to the accessible environment.

2. RATIONALE FOR SELECTING THE STUDY

Future climatic fluctuations, as have fluctuations in the recent past (Paces, et al., 1993), may significantly affect the hydrologic regime at Yucca Mountain and in the surrounding region. Climate change must therefore be considered when evaluating the suitability of the potential repository site to isolate and contain radioactive wastes. The isotope data gathered from Study 8.3.1.5.1.1 will be used by other studies such as 8.3.1.5.2.2 (Characterization of the future regional hydrology due to climate changes) to estimate the impact of future climate change on (1) the elevation of the water table, (2) flux through the unsaturated zone, and (3) potential of establishing fast radionuclide flow paths.

The water samples for isotopic analysis (see sec. 3) will come from both regional and local networks of weather and stream-gaging stations as part of the planned work for Study 8.3.1.2.1.1 (Characterization of the meteorology for regional hydrology). Figures 2-1, 2-2, and 2-3 show the areas involved in the data-gathering activities of that study. The isotope data will be used to establish spatial and temporal variations.

Timing and duration of the study is dependent upon the schedule established for data collection in Study 8.3.1.2.1.1. Characterization of the stable isotopic composition of precipitation is complicated in arid environments because of the irregularity of precipitation events and large annual variability of precipitation amounts. Accurate characterization of the average isotopic composition of precipitation available for recharge and utilization by plants and animals requires long term monitoring in arid settings. Collection of modern isotope data from water, therefore, will be an ongoing activity whose value for the interpretation of past climate records and for prediction of the effects of possible future climate changes will increase with time. As such, data collection should continue for as long as possible.

There are no constraints on the study in terms of its impact on the site, simulation of repository conditions, or its interference with other studies or the design and construction of the exploratory study facilities. With regard to the limits, capability, scale, and accuracy and precision of the methods being used in analyzing and synthesizing pertinent isotope data (see sec. 3), such methods are considered to represent a reliable and satisfactory means for characterizing modern isotope input.

3. DESCRIPTION OF TESTS AND ANALYSES

3.1 Activity 8.3.1.5.1.1.1 Stable isotopic composition of modern regional precipitation

The objectives listed in the SCP for this activity are:

- Provide the basis for developing vegetation-climate relationships, and climate-circulation models
- Provide an understanding of spatial and temporal variation in climate
- Determine the climate conditions (i.e., time, temperature, seasonality, and air masses) under which recharge occurs

The collection of deuterium, oxygen, and strontium isotope data from precipitation or, in some cases, from runoff or shallow discharge waters, within Activity 8.3.1.5.1.1.1 is primarily related to the second item listed above. These modern baseline data will be used by Study 8.3.1.5.1.3 (Climatic implications of terrestrial paleoecology) for developing the relationships and models listed in the first item, and by Studies 8.3.1.5.1.2 (Paleoclimate study: lake, playa, marsh deposits) and 8.3.1.5.2.1 (Characterization of the Quaternary Regional Hydrology) in addressing the objective of the third item (Figures 1-1 and 1-2).

3.1.1 General approach

The D/H and $^{18}O/^{16}O$ isotopic compositions of precipitation, on an event scale, was monitored from 8/83 to 8/86 from 12 stations in southern Nevada by the YMP (Milne, Benson, and McKinley, 1987). Seven of these stations were within 20 km of Yucca Mountain; the others were as much as 100 km distant. Precipitation has also been collected and analyzed as part of Activity 8.3.1.5.2.1.4a, Analog Recharge Studies, at Stewart and Kawich Valleys to the north of Yucca Mountain since 1985; these sites are still being monitored and the isotopic analyses of these precipitation samples will be assumed by Study 8.3.1.5.1.1. Regional precipitation stable isotope data are also being collected by several non-YMP (e.g., USGS, UNLV, DRI) projects. Published or qualified data from these outside studies can enhance (1) the long term framework within which to evaluate the data collected by this study, and (2) the regional data base within which to reconstruct local (Yucca Mountain area) topographic and rainout effects on individual storms.

Water samples will be collected from selected precipitation monitoring stations, primarily from a subset of the precipitation monitoring network created within Study 8.3.1.2.1.1, and analyzed for D/H, $^{18}O/^{16}$, and $^{87}Sr/^{86}Sr$ isotopic composition in Activity 8.3.1.5.1.1.1. At the present time samples are being collected under Study 8.3.1.2.1.1 from 9 sites within the potential site area (Fig. 2-2) and from 5 regional sites at Stockade Pass, Rattlesnake Wash, Fortymile Canyon (at confluence with E. Cat Canyon), and from Beatty and Stateline, Nevada (Fig. 2-3). Efforts are made to collect samples on an event basis, except as the sampling frequency may be limited by budgetary or logistical constraints.

3.1.2 Methods and procedures

Precipitation samples will be collected according to Technical Procedures HP-16, Collection and preservation of atmospheric precipitation samples for deuterium and oxygen-18 analysis; GCP-35, Sampling of precipitation collector waters for stable isotope analysis; or other approved procedures. Sampling of water from precipitation collectors is not involved, although it does require that the collected water be protected from evaporation prior to sampling. This is typically done by leaving a small quantity of non-volatile oil, such as mineral oil, in the collector; this oil then floats on the collected precipitation, preventing evaporation. Snow collectors may be black to facilitate solar heat absorption and melting of the snow, or they may have automated heaters; antifreeze may not be used, as it will mix with the water.

Isotope analysis of the precipitation samples will follow procedures described in GCP-12, Rb-Sr isotope geochemistry; GCP-17, Determination of the isotopic ratio H/D in H_2O (in revision); GCP-26, Determination of the $\delta^{18}O$ value of H_2O (in preparation); or other approved procedures. These are established techniques in widespread use for the extraction of hydrogen and oxygen for stable isotope analysis. Hydrogen is liberated from H_2O by reduction with heated U or Zn metal and then introduced directly to a mass spectrometer where the ratio of ^1H to ^2H (deuterium) is measured. The oxygen isotopic composition of water is measured by equilibrating an aliquot of the water with a known amount of CO_2 at 25°C and then measuring the isotopic composition of the CO_2; the isotopic composition of the oxygen in the water is then calculated from the change in the isotopic composition of the equilibrated CO_2. Strontium is extracted from water by evaporation of a known quantity of water to dryness. The residue is then dissolved in 1.0 N HC1, the strontium is purified with ion exchange resins, and its isotopic composition determined by mass spectrometry.

3.1.3 QA requirements

Quality Assurance (QA) requirements will be specified in a Yucca Mountain Project QA Grading Report which will be issued as a separate document. All applicable procedures will be identified on the basis of the findings in the Grading Report and will be prepared in accordance with applicable QA requirements.

3.1.4 Range of expected results

The ratios of D/H and $^{18}O/^{16}O$ are reported as the permil (‰) deviations of the unknowns from that of Standard Mean Ocean Water (SMOW) where

$$\delta D_{SMOW} = \left[\left[(^2H/^1H)_{unknown} - (^2H/^1H)_{SMOW}\right] / (^2H/^1H)_{SMOW} \right] * 10^3$$

and

$$\delta^{18}O_{SMOW} = \left[\left[(^{18}O/^{16}O)_{unknown} - (^{18}O/^{16}O)_{SMOW}\right] / (^{18}O/^{16}O)_{SMOW} \right] * 1;$$

and $\delta^{18}O_{SMOW}$ and δD_{SMOW} are both equal to 0‰, by definition.

The δD and $\delta^{18}O$ values of precipitation are controlled by several processes: (1) the air and water temperatures at the time that an air mass picks up water vapor and the δD and $\delta^{18}O$ values of the water source control the initial isotopic composition of an air mass. The isotopic fractionation between the water and the air mass vapor increases with decreasing temperature with ^1H and ^{16}O enriched in the vapor phase (i.e., lower δD and $\delta^{18}O$ values in the vapor). Since most continental air masses originate over the oceans they, therefore, begin with H and O isotopic compositions near, but somewhat less than, 0‰. (2) the air temperature at the time of condensation of moisture from the air mass that results in precipitation. As the temperature of condensation decreases the isotopic fractionation between water vapor and the condensate increases with ^2H and ^{18}O enriched in the condensate. This results in the rapid ^2H and ^{18}O depletion of the water vapor in the air mass and, hence, a regular decrease in the δD and $\delta^{18}O$ values of precipitation from an air mass with time. Precipitation in the form of snow amplifies this depletion effect, because the isotopic fractionation between vapor and ice is larger than between vapor and liquid water. (3) the loss of the heavy isotopes from the air mass as a result of precipitation, or the "rainout" effect. As a moist air mass travels from a coastline to the interior of a continent, the precipitation from it becomes increasingly depleted in the heavy isotopes, a depletion amplified by precipitation as snow or topographic obstacles such as mountain ranges, which precipitate much of an air mass' moisture through adiabatic cooling. The processes just outlined are described in greater detail in Welhan (1987). Their combined effect on the stable isotope systematics of continental precipitation results in the general decrease of δD and $\delta^{18}O$ values with increasing latitude and altitude along a line described by

$$\delta D = 8 * \delta^{18}O - 10‰.$$

This line, known as the "meteoric water line", has been determined from isotopic analyses of precipitation from a global network of collection sites. Precipitation samples collected from more regional networks may describe "lines" with slightly different slopes and intercepts; in particular, arid regions may have "lines" with smaller slopes and less negative intercepts due to evaporative isotopic fractionation effects that can affect precipitation falling through very dry air.

Deuterium and oxygen-18 isotopic data from precipitation samples reported by Milne, Benson, and McKinley (1987) and Benson and Klieforth (1989) show a wide range of compositions from ~ -160 to ~ +30‰ for δD and from nearly -21 to +8‰ for $\delta^{18}O$. For water samples largely representing individual precipitation events (both rain and snow) produced by weather systems following different paths, and comprising a multiple of collection sites, these wide ranges are not surprising. A similar, or even larger, range of values may well be observed as part of Study 8.3.1.5.1.1. Weighted mean values of the δD and $\delta^{18}O$ values for annual and seasonal (summer vs. winter) precipitation at the individual collection sites will be calculated from the measured amounts and stable isotopic compositions of individual precipitation events.

3.1.5 Required accuracy and precision

There are no specific requirements for accuracy or precision designated in the SCP for this activity. Scientifically acceptable analytical precision for the extraction and mass spectrometric measurement of the stable isotopic composition of meteoric waters, however, is typically ± 0.1‰ for $\delta^{18}O$ and ± 1.0‰ for δD. Caution must be exercised when collecting and handling water samples to avoid or minimize evaporation that can change the δD and $\delta^{18}O$ values.

3.1.6 Equipment

Items of required equipment are identified in the appropriate technical procedures.

3.1.7 Data-reduction techniques

Data will be tabulated and plotted on (1) maps contouring variations in climate parameters such as rainfall, δD, and $\delta^{18}O$; (2) charts plotting seasonal or monthly values for various climate parameters for the different weather stations; (3) graphs showing the degree of correlation between different climate parameters such as δD vs. rainfall amount or δD vs. storm track; and (4) plots of δD vs. $\delta^{18}O$ for individual or groups of precipitation collection sites. Computers will be used to perform standard statistical operations (means, standard deviations, and regression analyses) and to create graphic output.

3.1.8 Representativeness of results

The data resulting from this activity are intended to form a baseline data set. Because the samples are being collected from regional and local arrays of precipitation stations (in Study 8.3.1.2.1.1), the resulting values are considered to be representative of the storms at large.

3.1.9 Relation to performance goals and confidence levels

See sections 1.2 and 4.

4. APPLICATION OF RESULTS

As indicated in section 1.2, data from Study 8.3.1.5.1.1 will be integrated into Study 8.3.1.5.2.2 (Characterization of the future regional hydrology due to climate changes) to assist in evaluating the effects of future climate on surface water, unsaturated zone, and saturated zone hydrology. Data on modern regional precipitation, combined with the results of Study 8.3.1.5.1.2 (Paleoclimate Study: lake, playa, marsh deposits) Study 8.3.1.5.1.3 (Climatic implications of terrestrial paleoecology), and Activity 8.3.1.5.2.1.5 (Studies of calcite and opaline silica vein deposits), will also be applied in Study 8.3.1.5.1.5 (Paleoclimate-paleoenvironmental synthesis) for estimating the source and seasonality of ground water recharge that occurred in the region during Quaternary time.

5. SCHEDULE AND MILESTONES

Figure 5-1 shows the schedule of work being planned for Study 8.3.1.5.1.1.

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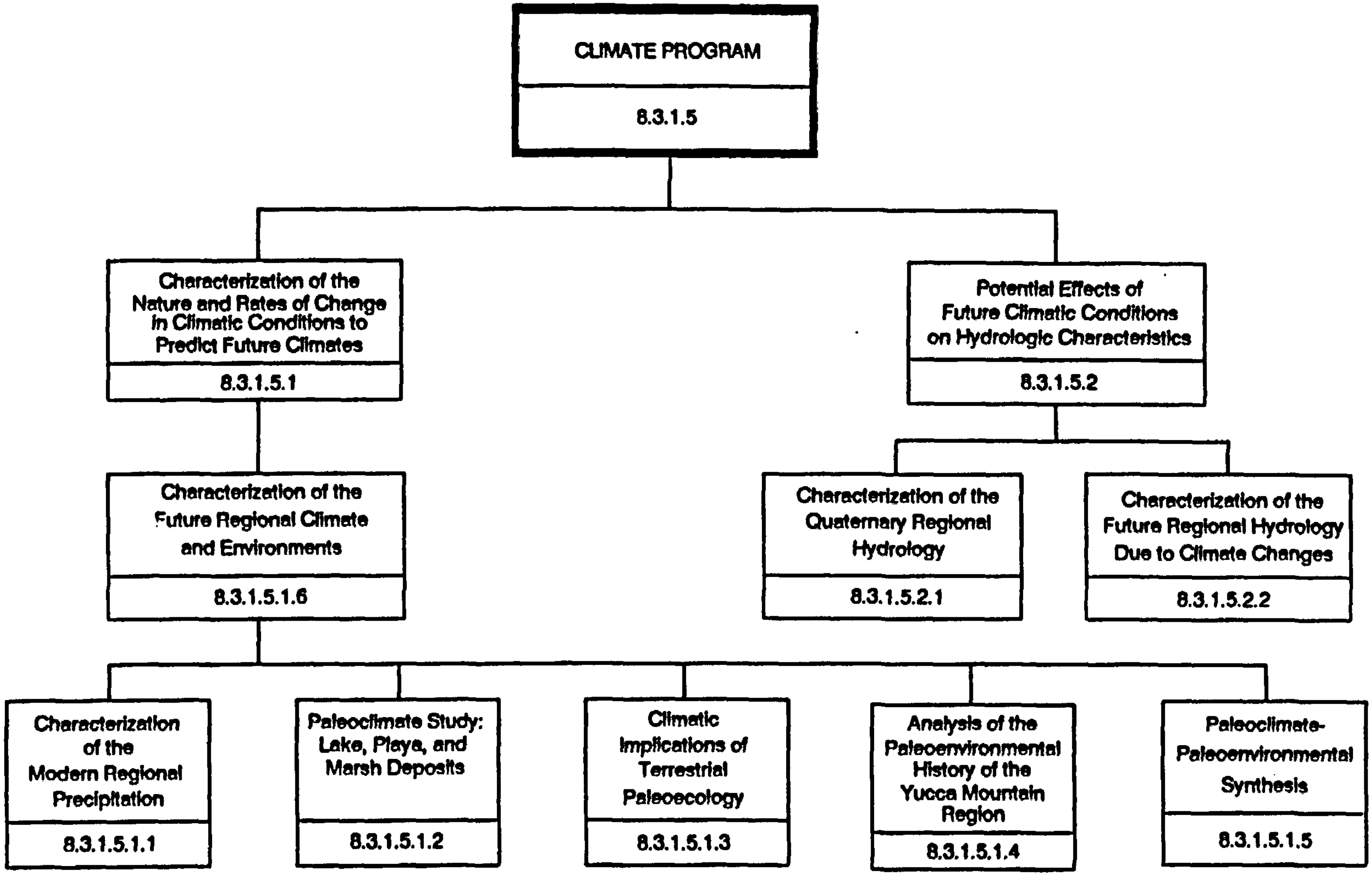

Figure 1-1. Relation of Study 8.3.1.5.1.1 to other studies in the climate program.

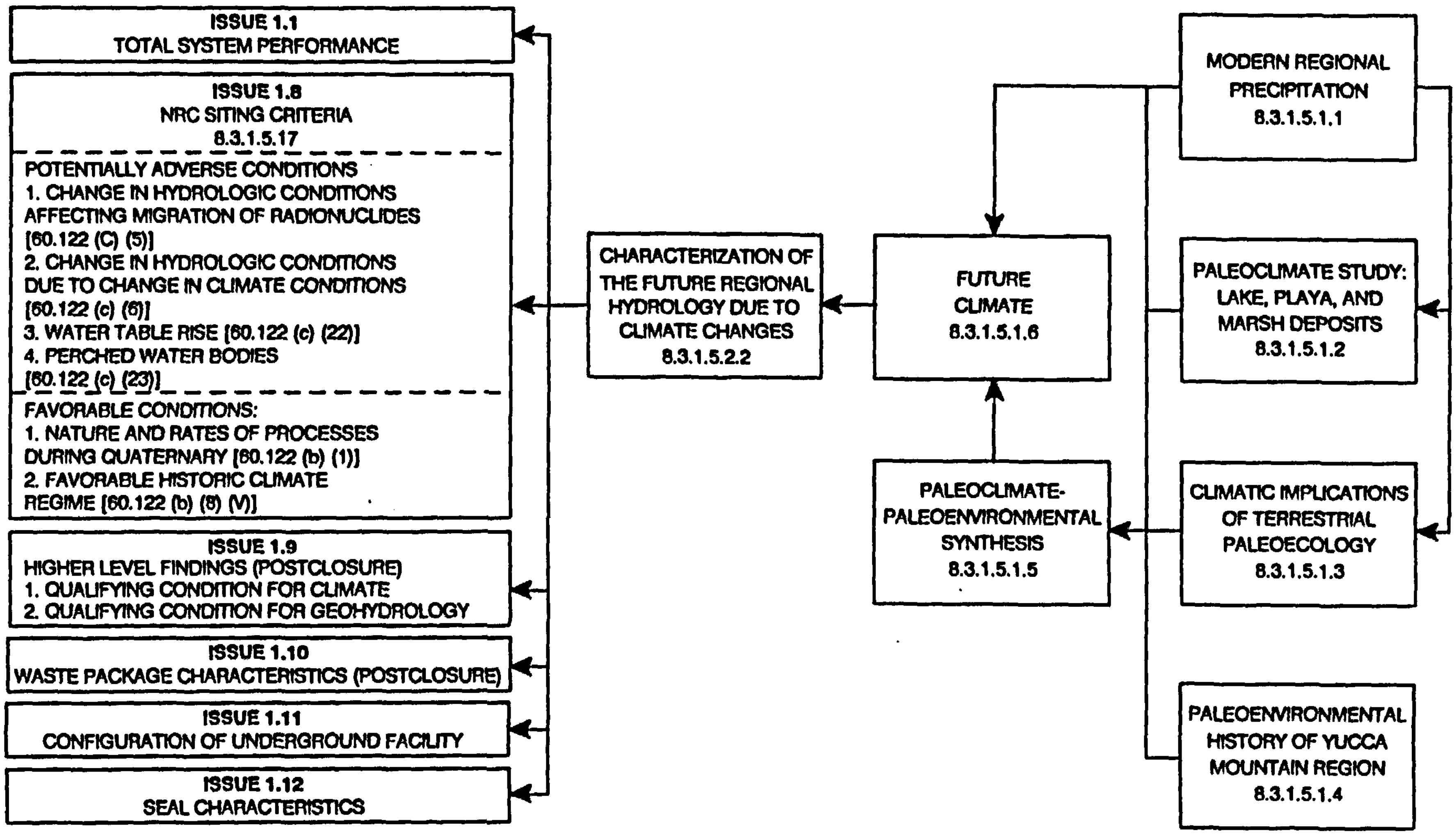

Figure 1-2. Relation of Study 8.3.1.5.1.1 to performance and design issues.

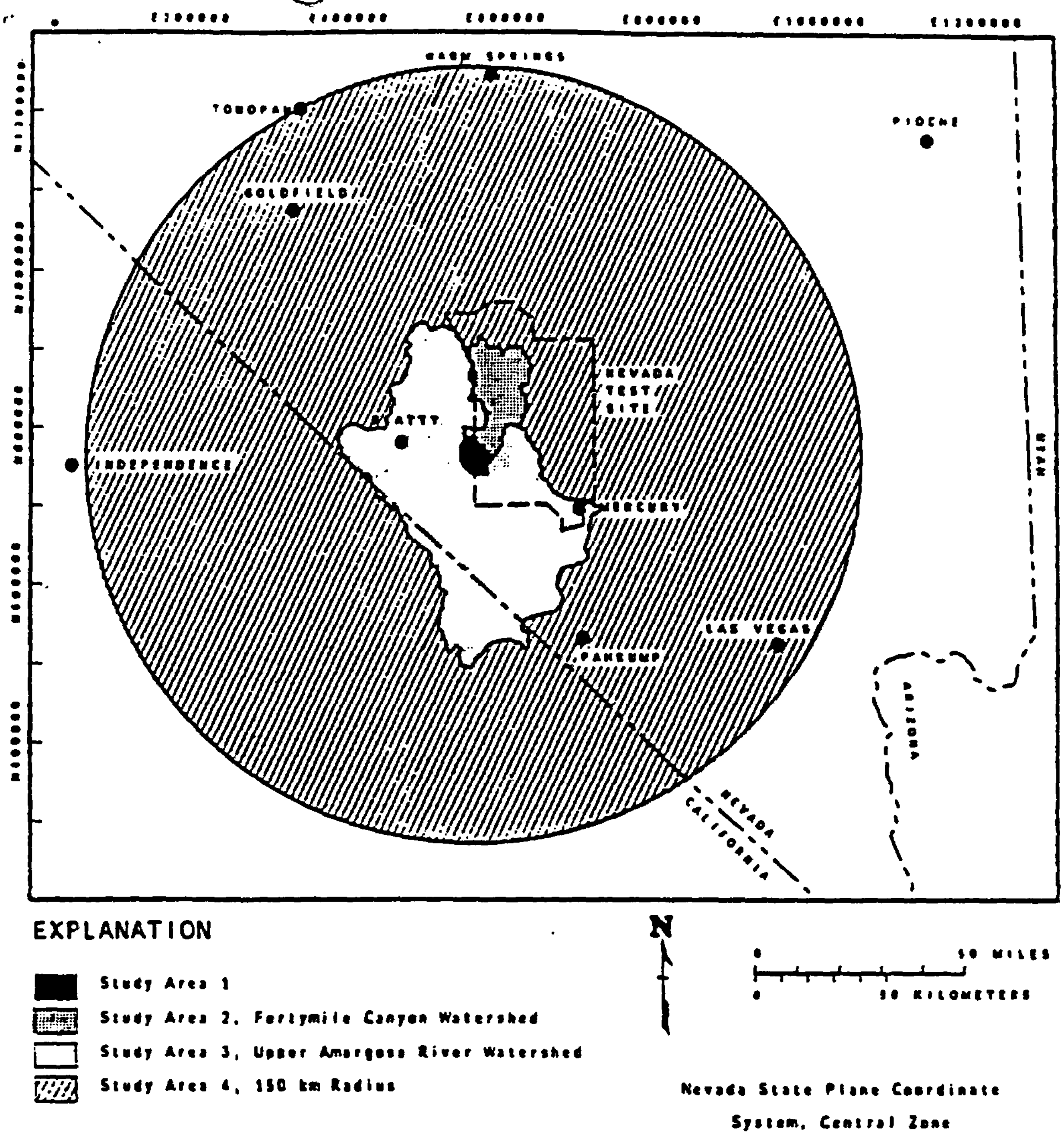

Figure 2-1. Map showing the study area boundaries for regional and site meteorology in Study 8.3.1.2.1.1 (Characterization of the meteorology for regional hydrology).

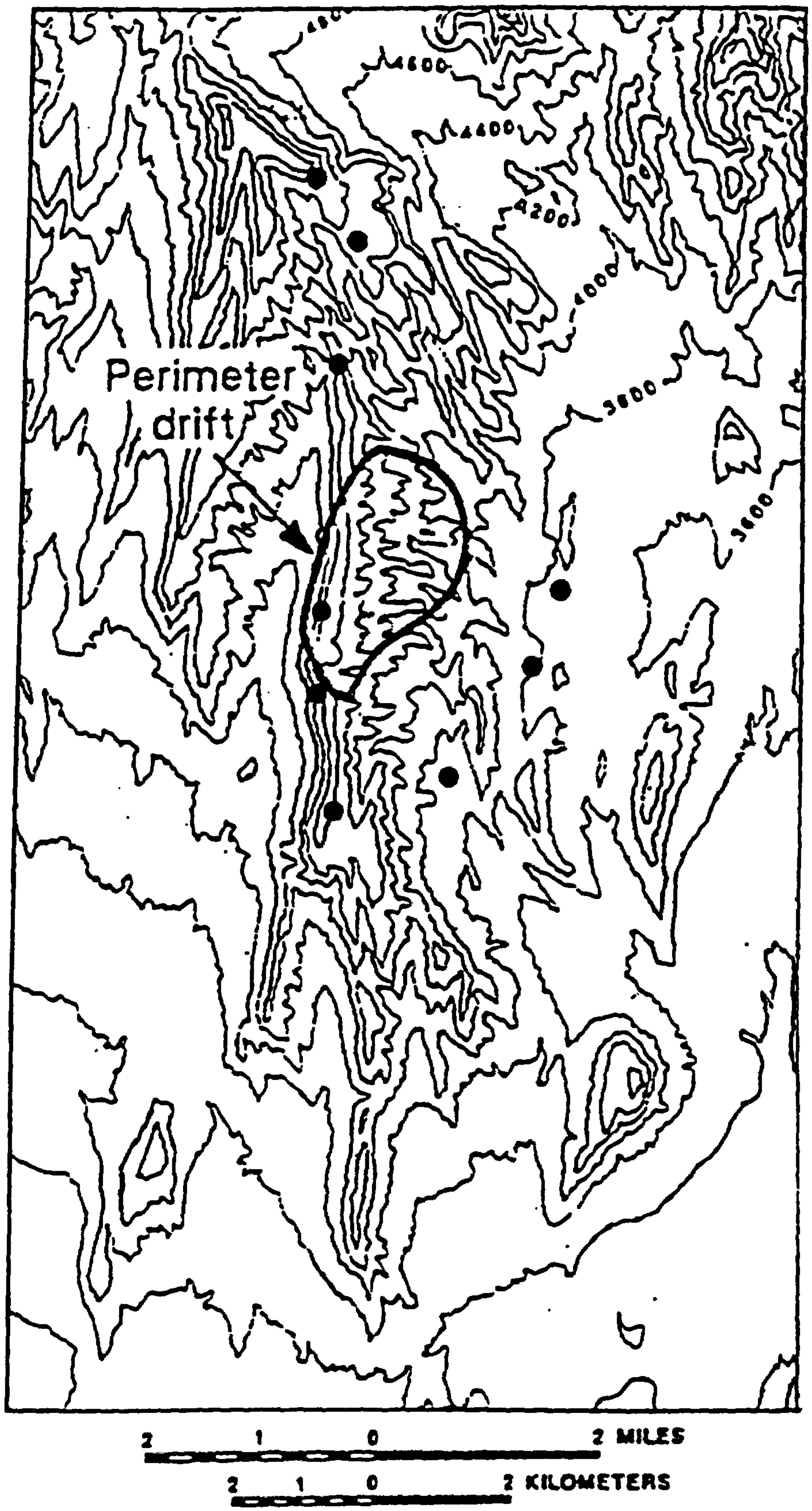

Figure 2-2. Index map of potential site area, showing location of precipitation collection sites (solid circles) by Study 8.3.1.2.1.1, Characterization of the meteorology for regional hydrology.

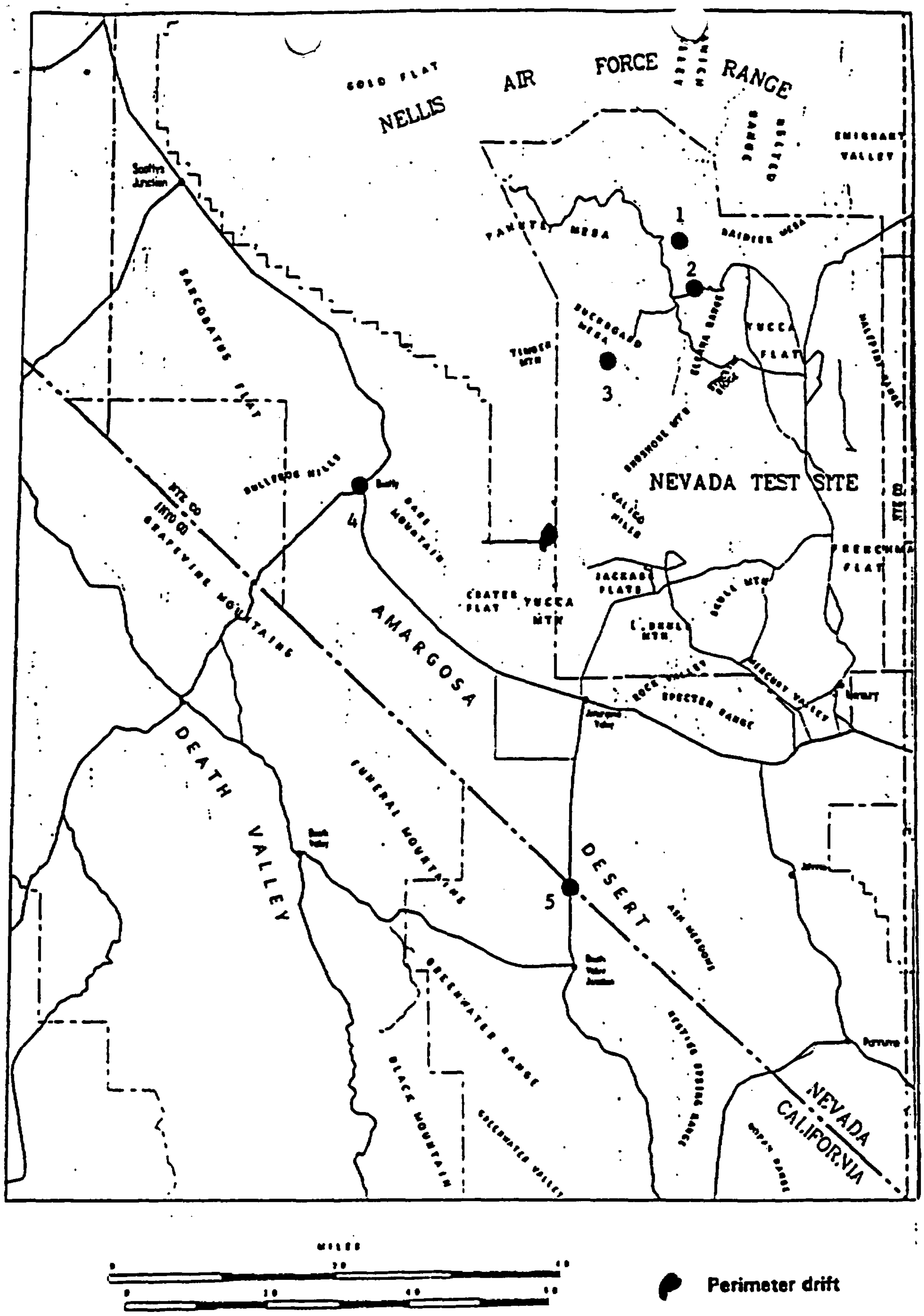

Figure 2-3. Index map of southwestern Nevada showing five precipitation collection sites (solid circles) for Study 8.3.1.2.1.1. (1-Rattlesnake Wash; 2-Stockade Pass; 3-Fortymile Canyon at confluence with East Cat Canyon; 4-Beatty; 5-Stateline).

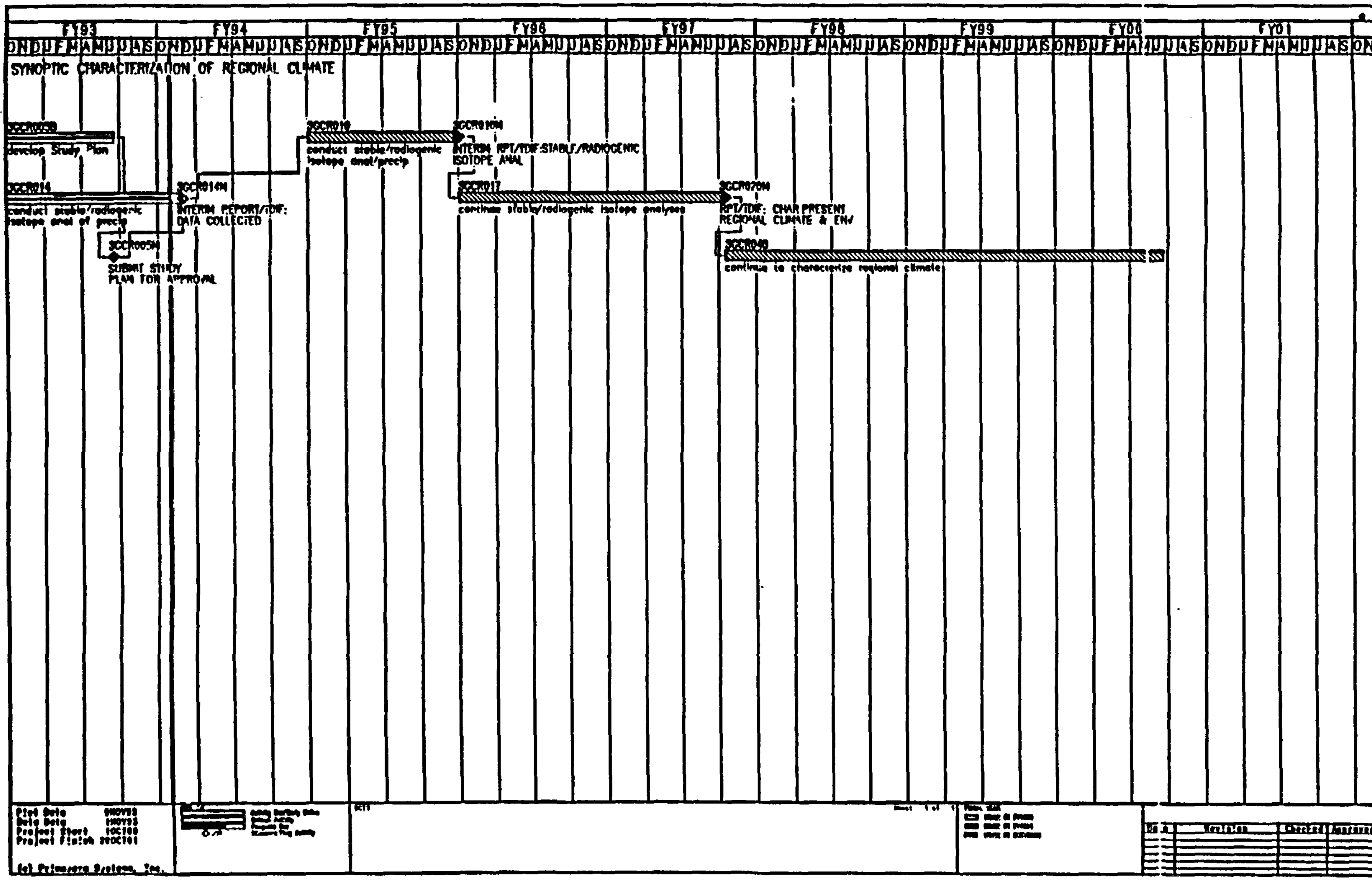

Figure 5-1. Planned schedule of work on Study 8.3.1.5.1.1

YMP-USGS-SP 8.3.1.5.1.1

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TECHNICAL PROCEDURES
FOR STUDY PLAN 8.3.1.5.1.1

Following is a list of technical procedures for the subject study:

GCP 12, R4	Rb-Sr Isotope Geochemistry
GCP 17, R3	Determination of the Isotopic Ratio of H/D in H_2O
GCP 26, R0	Determination of the $\delta^{18}O$ Value of H_2O. (This procedure is in preparation; currently, the procedure is in the form of a scientific notebook [SN-0058, Extraction techniques for the determination of $\delta^{18}O$ in H_2O] which will be the basis for GCP 26.)

In addition to the above, technical procedures for the collection of precipitation samples (being collected in another study) that will be analyzed in Study 8.3.1.5.1.1 include:

GCP 35, R0	Sampling of Precipitation Collector waters for Stable Isotope Analysis
HP 16, R3	Collection and Preservation of Atmospheric Precipitation Samples for Deuterium and Oxygen-18 Analysis