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Study Plan for
Study 8.3.1.2.1.1

Characterization of the Meteorology for Regional Hydrology

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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T-AD-088
9/90

YUCCA MOUNTAIN PROJECT
STUDY PLAN APPROVAL FORM

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Study Plan Number 8.3.1.2.1.1

Study Plan Title Characterization of the Meteorology for Regional Hydrology

Revision Number 0

Prepared by: U.S. Geological Survey

Date: February 1, 1991

Approved:

[signature] 3/12/91
Director, Regulatory and Site Evaluation Division / Date

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Director, Quality Assurance / Date

Effective Date: March 25, 1991

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ABSTRACT

This study plan describes the meteorological site-characterization activities to be performed on and adjacent to Yucca Mountain, Nevada. This study will contribute to an understanding of the meteorological conditions on and around Yucca Mountain, with particular emphasis on precipitation. Results from this study will provide hydrologic-parameter input for the resolution of design and performance issues. The single activity of this study is

- Characterization of meteorology for site and regional hydrology.

The rationale for the meteorology study is described in Sections 1 (regulatory rationale) and 2 (technical rationale). Section 3 describes the specific activity plan, including tests and analyses to be performed, the selected and alternative methods considered, and the technical procedures to be used. Section 4 summarizes the application of the study results, and Section 5 presents the schedules and associated milestones.

CHARACTERIZATION OF THE METEOROLOGY FOR REGIONAL HYDROLOGY

YMP - USGS - SP 8.3.1.2.1.1, RO

STUDY PLAN

FEBRUARY 1991

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Effective date:

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1 PURPOSE AND OBJECTIVES OF STUDY

1.1 Purpose of the study plan

The U.S. Geological Survey (USGS) is conducting studies at Yucca Mountain, Nevada, as part of the Yucca Mountain Project (YMP). The purpose of these studies is to provide hydrologic and geologic information to evaluate the suitability of Yucca Mountain for development as a high-level nuclear-waste repository, and the ability of the mined geologic-disposal system (MGDS) to isolate the waste in compliance with regulatory requirements. In particular, the project is designed to acquire information necessary for the Department of Energy (DOE) to demonstrate in its environmental impact statement and license application whether the MGDS will meet the requirements of federal regulations 10 CFR Part 60, 10 CFR Part 960, and 40 CFR Part 191.

The purpose of this study plan is to describe and outline strategies for characterizing the meteorology on and around Yucca Mountain. The study is organized into one activity:

- 8.3.1.2.1.1.1 - Characterization of meteorology for site and regional hydrology.

Note that the numbers (e.g., 8.3.1.2.1.1.1) used throughout this plan serve as references to specific sections of the YMP Site Characterization Plan (SCP). The SCP (U.S. Department of Energy, 1988) describes the technical rationale of the overall site-characterization program and provides general descriptions of the activities described in detail in Section 3 of this study plan.

Figure 1.1-1 illustrates the relation of the study to other investigations and studies within the SCP Geohydrology Program. The meteorology study is one of four studies in the regional hydrology investigation, whose overall purpose is to develop a conceptual model of the regional hydrologic system to assist in assessing the suitability of the Yucca Mountain site for containment and isolation of waste. The other three studies in the investigation address characterization of the regional surface-water runoff and streamflow, characterization of the regional ground-water flow system, and the synthesis and modeling of the regional saturated-zone flow system. The activity in the present study was selected on the basis of various factors. Time and schedule requirements were considered in determining the number and types of tests and analyses chosen to obtain the required data. Tests were designed on the basis of design and performance parameter needs, available test and analysis methods, and test scale and interferences. The tests and analyses were also designed such that resulting data will be comprehensive enough to permit interpretations according to alternate meteorological hypotheses that the tests/analyses are investigating. These factors are described in Sections 2 and 3.

The plans for the activity are described in Section 3.1. The descriptions include (a) objectives and parameters, (b) technical rationale, and (c) tests and analyses. Alternate tests and analysis methods are

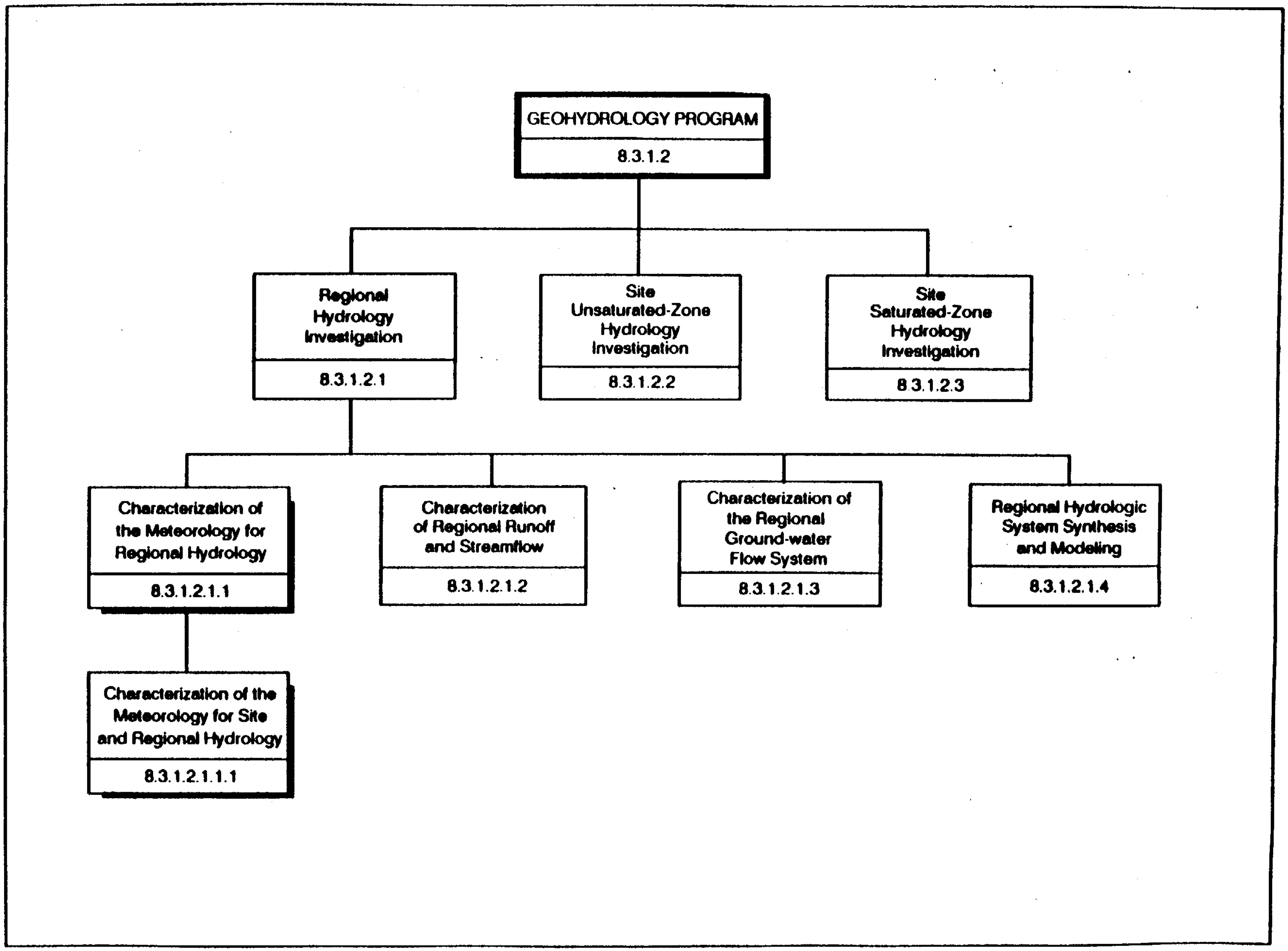


Figure 1.1-1. Diagram showing the location of study within the regional hydrology investigation and organization of the geohydrologic characterization program.

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

Application of the study results is summarized in Section 1.3 and 4, study schedules and milestones are presented in Section 5, and a study-plan reference list is presented in Section 6. Quality-assurance requirements are documented in Section 7.1.

1.2 Objectives of study

The objective of the study is to characterize the meteorological conditions surrounding Yucca Mountain, with particular emphasis on precipitation.

The single activity planned for this study (8.3.1.2.1.1.1) will meet this study objective by collecting precipitation and meteorological data at and around Yucca Mountain. The location of Yucca Mountain is shown in Figure 1.2-1. Additional maps showing the detailed location of the precipitation network appear in Section 3.

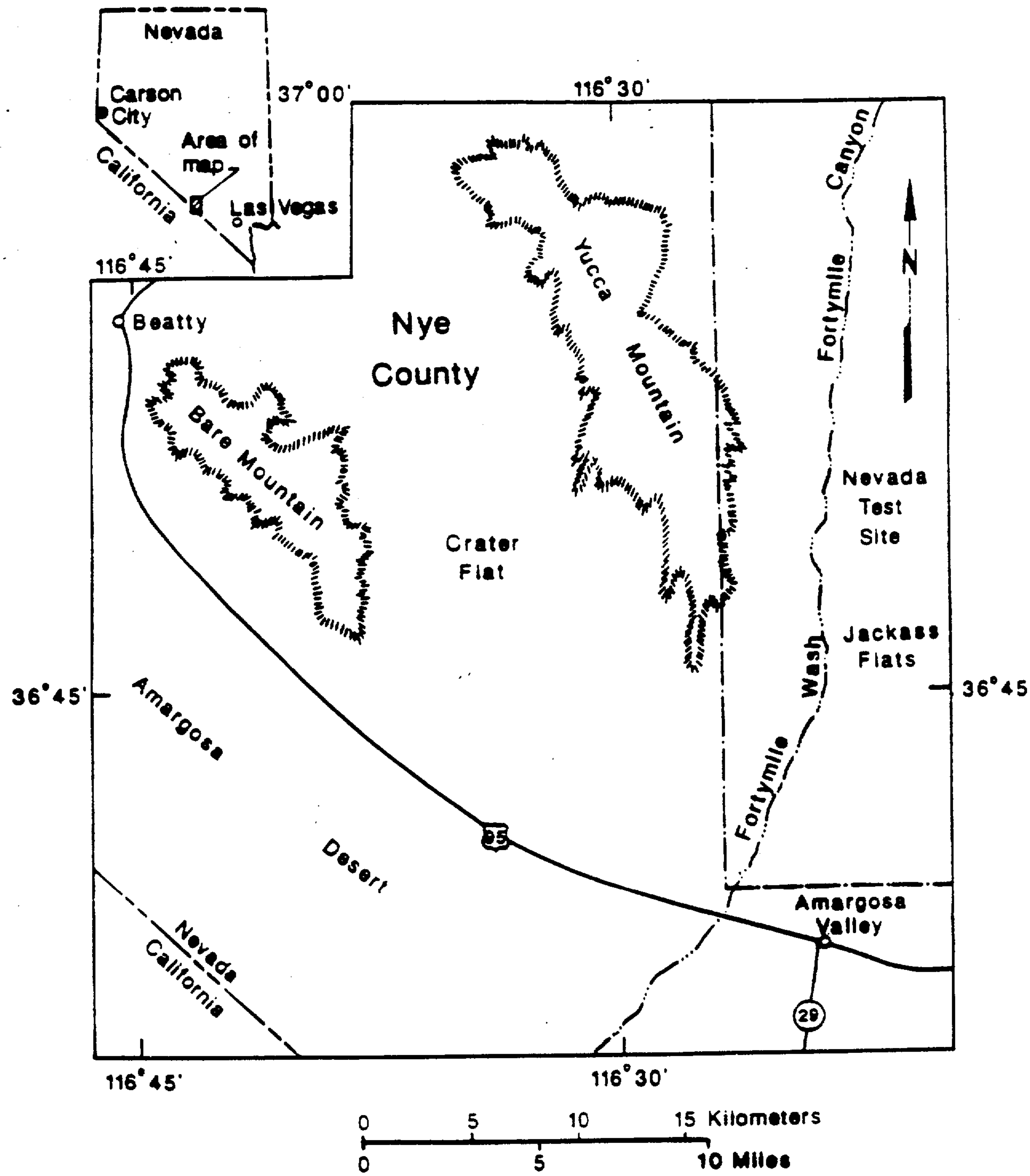


Figure 1.2-1. Map showing location of Yucca Mountain.

1.3 Regulatory rationale and justification

The meteorologic data collected during the study will provide direct and indirect input into several design and performance issues covering design and performance of the repository. The overall regulatory-technical relations between the SCP design and performance information needs and the data collected in this study are presented in the geohydrology testing strategy of SCP Section 8.3.1.2 and the issue-resolution strategies (repository, seals, waste package, and performance assessment) presented in SCP Sections 8.3.2 - 8.3.5. The description presented below provides a more specific identification of these relations as they apply to this study. A detailed tabulation of parameter relations is presented in Section 7.2.

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

In this and other study plans, it has been useful to group the measured and calculated parameters of the various activities (activity parameters) into a limited set of characterization parameters, broader categories of information that encompass activity-parameter data collected in the field and laboratory or calculated by subsequent analytical methods. By introducing this category, it becomes easier to demonstrate how the study relates to satisfying the information requirements of parameters in the design and performance issues. In the case of the meteorology study, the activity parameters (presented in Figure 3.1-2 and Table 3.1-5, Section 3.1) can be grouped under characterization parameters which are listed below:

Activity 8.3.1.2.1.1.1 - Characterization of meteorology for site and regional hydrology	Air temperature: spatial and temporal characteristics
	Precipitation and storm profiles, Yucca Mountain region
	Precipitation: physical, spatial, and temporal characteristics
	Wind speed and direction: spatial and temporal characteristics

The relations between the characterization parameters for this study and their contributing activity parameters are shown in Table 2.1-1, and also in Figure 3.1-2. Relations between characterization parameters and design and performance parameters are shown in Table 7.2-1.

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

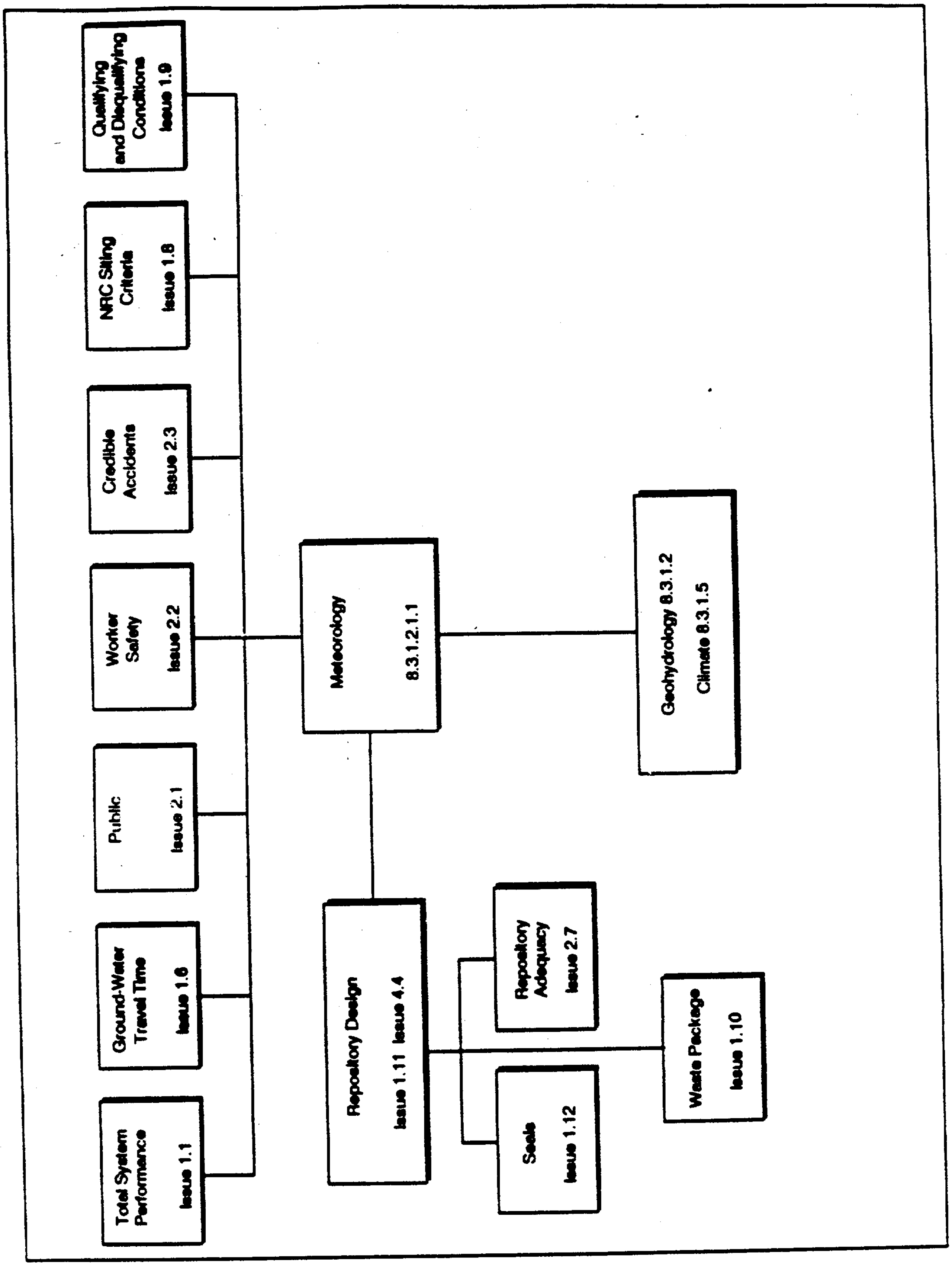


Figure 1.3-1. Diagram showing interfaces of meteorology study with YMP performance and design issues 'other site-characterization programs.

The present study indirectly supports the resolution of the following performance and design issues:

- Performance Issue 1.1 (Total system performance for limiting radionuclide releases)
- Performance Issue 1.6 (Ground-water travel time)
- Performance Issue 2.1 (Public radiological exposures - normal conditions
- Performance Issue 2.2 (Worker radiological safety - normal conditions)
- Performance Issue 2.3 (Prevention of radiological exposure from credible accidents)
- Performance Issue 1.8 (NRC siting criteria)
- Performance Issue 1.9 (Qualifying and disqualifying conditions)
- Design Issue 1.10 (Characteristics and configuration of the waste package)
- Design Issue 1.11 (Characteristics and configurations of repository and engineered barrier systems)
- Design Issue 1.12 (Characteristics and configurations of shaft and borehole seals)
- Design Issue 2.7 (Repository design criteria for radiological safety)
- Design Issue 4.4 (Adequacy of repository construction, operation, closure, and decommissioning technologies)

Site information from the present study will be indirectly used to evaluate the design and performance parameters of these issues mainly through contributions of meteorological data to the following studies: Study 8.3.1.2.1.2 (Regional surface-water runoff and streamflow), Study 8.3.1.16.1.1 (Flood potential and debris hazards), Study 8.3.1.2.2.1 (Unsaturated-zone infiltration), Study 8.3.1.2.2.6 (Unsaturated-zone gas flow), Study 8.3.1.2.1.3 (Regional ground-water flow system), Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system), and Study 8.3.1.5.1.1 (Modern regional climate). The relations of these studies to design and performance issues listed above are treated in detail in Sections 1.3 and 7.2 of their respective study plans.

Through contributions of meteorological data to the Meteorology Program (SCP 8.3.1.12), the present study will provide data that will directly support the resolutions of some issues, but data from the present study will be less important to these resolutions than data from the Meteorology

Program. These issues are 1.11, 1.12, 2.1, 2.2, 2.3, 2.7, and 4.4. Support from the present study is detailed in Table 7.2-1.

2 RATIONALE FOR STUDY

2.1 Technical rationale and justification

2.1.1 Role of study in assessing the surface hydrology

This study has been designed to address the meteorological aspects of the hydrology at Yucca Mountain and vicinity, because precipitation is believed to be a major source of infiltration to the unsaturated zone, and eventually, recharge to the saturated zone. Precipitation is the source of all runoff, and changes in precipitation could result in changes in the surface-water flow regime, which could have significant effects on ground-water flow paths and gradients, and, therefore, radionuclide transport from the site to the accessible environment.

The climate at Yucca Mountain and vicinity is presently semi-arid, therefore, precipitation is the ultimate source of surface water and ground water. Intermittent surface runoff (streamflow) may be an important source of infiltration to the unsaturated zone at Yucca Mountain, and a major source of recharge to the regional saturated ground-water system. Knowledge of the relationships among precipitation, runoff, infiltration, and recharge is essential to an understanding of the regional and site hydrologic systems. Therefore, sufficient data must be collected throughout the region to characterize present-day precipitation as a function of topographic setting and stormtrack. Although the National Weather Service (NWS) has operated a precipitation-gage network at the NTS since late 1957, the gage network was not designed for, and is not ideally suited to, the development of the rainfall-runoff relation.

Systematic streamflow measurements were started in 1983, and since that time a network of precipitation gages was installed (SCP Figure 8.3.1.2-6 and SCP Table 8.3.1.2-3). This network is providing an introductory understanding of the relations between localized rainfall and resultant runoff. In addition, precipitation data from the NWS network complements and supplements the precipitation measurements collected in tandem with the streamflow records.

The precipitation measurement network being operated as part of the streamflow measurement program currently (1990) consists of 14 nonrecording plastic storage rain gages. These storage gages are located at streamflow-measurement network sites. Thus the cumulative precipitation trapped by the storage gages gives some sense of rainfall quantities in specific drainages that promote streamflows of varying magnitudes. They were located at the stream-measurement sites for logistic efficiency in operation and maintenance. Five of the storage gages are located at sites without streamflow gages. These gages were located in places where supplementary rainfall information is needed to fill data gaps between other networks and collection sites. The precipitation data collected by storage gages are not as detailed as those obtained by more sophisticated gages. Because of these limitations, such precipitation data will only be supplementary to those collected by a more formal precipitation-measurement network. These supplementary data will provide added detail to improve interpretations of the areal distribution of precipitation that causes runoff.

An upgrading and expansion of the currently operating network is planned to provide a better accounting of precipitation occurring in the area surrounding Yucca Mountain. A plan to develop an integrated precipitation network, originally discussed in SCP Section 8.3.1.12.1, is fully developed in this study plan. (See Sections 3.1.3.2.1.1 and 3.1.3.2.1.2 for further details.) The network will be of sufficient density to characterize and track storm movement and intensity within the regional study area. The network will be of greater density within the site boundaries to provide input to the infiltration studies for use in water budget calculations (Activity 8.3.1.2.2.1.2, Natural infiltration). Meteorologic data will also be collected at network stations that are located within the boundaries of the site to provide input to the gas-phase circulation study (Activity 8.3.1.2.2.6.1, Gaseous-phase circulation) as well as the infiltration studies (Activity 8.3.1.2.2.1.2). The amount and timing of rainfall will be related to the amount and timing of runoff. The information collected under this study will be correlated with that discussed in SCP Section 8.3.1.12 (Meteorological Monitoring Plan). Findings from this study will be used in conjunction with those of paleoflood studies (Activity 8.3.1.5.2.1.1) to help provide a basis for future flood predictions (Study 8.3.1.16.1.1).

The precipitation data collected as part of this study will span only a short-term duration compared with the length of time nuclear waste will be stored. Preliminary analyses suggest that relatively short-term data can be statistically correlated with regional precipitation data spanning a longer (but also relatively short) time (SCP Section 8.3.1.12.1). Both regional and site-specific data will be correlated with paleoclimatic data. Paleoclimatic data is collected in Studies 8.3.1.5.1.2 (Paleoclimate study), 8.3.1.5.1.3 (Terrestrial paleoecology), 8.3.1.5.1.4 (Paleoenvironmental history), and 8.3.1.5.2.1 (Quaternary regional hydrology) and will be used for modeling future climates by the National Center for Atmospheric Research (NCAR). Overall worth of the short-term, site-specific data will depend on the quality and quantity of data obtained and on the range of variability of the data compared with the long-term range of natural variability of the climatic system. Techniques of data analysis and interpretation will depend on the analytical technology available at the time of analysis and on the quality, quantity, and characteristics of the available data of that time; techniques will also depend on the quality and quantity of regional data and paleoclimatic data available for comparisons and correlations.

The SCP Meteorology Program (SCP Section 8.3.1.12) has been designed around the provision of data for performance and design issues concerned with preclosure and accidental radiation doses to repository workers and members of the public (Issues 2.1, 2.2, and 2.3), higher-level findings relative to preclosure system and technical guidelines (Issue 2.5), and design characteristics of the repository in terms of design criteria and performance issues. Data collected at the site (specifically precipitation amounts used to track storm trajectories) by this study will serve as input to investigations of the Geohydrology Program (SCP Section 8.3.1.2).

The present study will be an important contributor to the study of infiltration to the unsaturated zone (Study 8.3.1.2.2.1). The infiltration boundary (or the surficial units) at Yucca Mountain is one of the most important boundaries that needs to be characterized. Through this boundary water and air can enter, and gases and water vapor can escape the unsaturated zone directly above the repository. The precipitation and other meteorological data from the present study will be needed to estimate present-day net infiltration rates, which in turn are needed for the unsaturated-zone system flow model.

The present study will also be an important contributor to the study of gas flow in the unsaturated zone (Study 8.3.1.2.2.6) because natural gas-phase fluxes are partially driven through Yucca Mountain by seasonal atmospheric density differences between its slopes and summit. Meteorological data collected in the study will aid in quantifying vapor flux in the subsurface.

2.1.2 Relation of the study to geohydrologic models

The Geohydrology Program will develop two hydrologic models that will describe two distinct zones of the ground-water system: the unsaturated zone and the saturated zone. Each of these zones is influenced by surface water, and therefore meteorologic characteristics of the site will be required to provide surface-water boundary conditions. The various models may be used at many stages to perform preliminary analyses, to design and analyze tests and experiments, and to interpret field data. The principal hydrologic modeling effort, however, is to construct mathematical representations of the unsaturated and saturated zones to simulate the natural geohydrologic system and its components.

2.1.3 Parameters and testing strategies

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

In SCP Table 8.3.1.2-1, activity parameters for the Geohydrology Program are grouped according to parameter categories, which also appear in Table 7.2-1. The activity parameters associated with the meteorology activity also appears in Table 3.1-5 of Section 3. Parameter categories serve to group similar types of performance and design parameters supporting design and performance-assessment issues resolutions (SCP Sections 8.3.2-8.3.5) and match them with groups of similar types of activity or characterization 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 SCP Figures 8.3.1.2-2, -3, and -4, the parameter categories are shown supporting specific model components that make up the hydrologic models.

Table 2.1-1 groups the activity parameters of this study according to characterization parameters. In SCP usage, a characterization parameter is a parameter obtained by a characterization program that has a logical, direct tie to a performance or design parameter, and for which a testing basis can be defined. Most characterization parameters will be developed from some combination of activity parameters, and will be the products of data reduction, test analyses, and modeling. Some of the activity parameters listed in Table 2.1-1, although not required directly for resolving performance and design issues, are required to accomplish satisfactory analysis of meteorology, which in turn increases confidence in the accuracy of the characterization parameters that are required for performance and design analyses. Meteorologic data collected in this study can be traced from activity parameters through characterization parameters and to its intended use in satisfying performance- and design-parameter requirements for issues resolutions. This last step is addressed by Table 7.2-1.

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

In addition to supporting design and performance parameters, the activity parameters listed in Table 2.1-1 and Section 3 are needed to test hypotheses that support conceptual models of site and regional meteorology. A sufficient level of confidence in parameter values must exist for the data to be employed for either of these purposes. The approaches to data collection selected for the present study have been chosen to minimize uncertainty in parameter values and in the understanding of parameter interrelations, within the constraints of available resources. Where possible, multiple approaches within the meteorological activity are directed toward evaluating 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 the activity, some approaches may provide only partial information, while others will provide extensive information necessary for

Table 2.1-1 Association of activity parameters with characterization parameters

Activity	Characterization Parameter	Activity Parameters Associated with Characterization Parameter
Characterization of the meteorology for site and regional hydrology	Air temperature: spatial and temporal characteristics	Air temperature
		Solar radiation, incoming/outgoing short wave
		Solar radiation, incoming/outgoing short wave, diurnal cycle
		Net radiation
		Net radiation, diurnal cycle
		Net radiation, seasonal variability
	Precipitation: physical, spatial, and temporal characteristics	Precipitation, intensity and duration
		Precipitation, amounts
		Precipitation, monthly and seasonal variability
		Precipitation, spatial variability
		Precipitation, recurrence frequency, magnitude and duration of extreme events
		Atmospheric pressure
		Relative humidity
		Relative humidity, diurnal cycle
		Relative humidity, seasonal variability

Table 2.1-1 Association of activity parameters with characterization parameters (continued)

Activity	Characterization Parameter	Activity Parameters Associated with Characterization Parameter
	Wind speed and direction: spatial and temporal characteristics	Wind speed
		Wind direction
		Wind speed and direction, diurnal cycles
		Wind speed and direction, seasonal variability
	Precipitation and storm profiles, Yucca Mountain region	Lightning occurrences
		Cloud patterns
		Precipitation and storm profiles, Yucca Mountain region
		Variation of present weather conditions from past conditions
		Origin, moisture source, and lifecycles of storms

determination of a meteorologic activity parameter. By combining the test results and studying their relations, a greater understanding and confidence of any particular parameter can be achieved.

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

2.1.4 Hydrologic hypotheses

The alternative conceptual models table of the SCP for the Geohydrology Program (SCP Table 8.3.1.2-2) shows that the present study will contribute to reducing uncertainty in current representations of two hypotheses concerning the upper boundary of the saturated zone at Yucca Mountain and the surrounding region. The first of these hypotheses is that the average recharge to the saturated zone through the unsaturated zone at Yucca Mountain is small, because annual precipitation is small. Conceptual models of infiltration are addressed in YMP-USGS SP 8.3.1.2.2.1 (Unsaturated-zone infiltration). The second is that recharge to the regional saturated-zone flow system occurs primarily at Rainier and Pahute Mesas, because hydrochemical data show that these areas are direct sources to ground water at Yucca Mountain.

In conducting preliminary performance and design analyses, assumptions must be made regarding the values of some parameters, and surface-water processes and conditions. These preliminary analyses may include assumptions involving values of such parameters as frequencies, magnitudes, and durations of runoff events. The ongoing process of hypothesis testing helps to increase confidence that the assumptions made in preliminary analyses are reasonable.

The frequency, magnitude, and duration of extreme precipitation events will be studied from a historical perspective. Analyses correlating historical extreme events in runoff data will be addressed by Study 8.3.1.2.1.2 (Regional surface-water runoff and streamflow). Although extreme precipitation events are rare, they may have a significant impact on infiltration which will be studied in Activities 8.3.1.2.2.1.2 (Natural infiltration) and 8.3.1.2.2.1.3 (Artificial infiltration).

2.2 Constraints on the study

2.2.1 Representativeness of repository scale and correlation to repository conditions

The study addresses the characteristics of the meteorology for regional hydrology at spatial scales at which they naturally occur. Data such as precipitation amounts will not be scaled up or down to represent values from other areas in which measurements have not been taken. The meteorologic data base will contain data that characterize the area surrounding Yucca Mountain, with a particular emphasis on the Fortymile Wash drainage.

2.2.2 Accuracy and precision of methods

Selected methods for collecting data in each activity are summarized in Table 3.1-5 in Section 3. These methods were selected on the basis of their precision and accuracy, duration, and lack of interference with other tests and analyses. The degree of accuracy and/or precision of each method within the activity is a qualitative, relative judgement based on the investigators' assessment of the applicability of methods, field evidence, and office analyses. For selected methods, if values for accuracy and precision exist, they will be listed in the technical procedures in Table 3.1-6 in Section 3.1.

2.2.3 Potential impacts of activities on the site

The meteorological-measurement stations required for the meteorologic monitoring activity may have some surface impact at the site. The major impacts will be in the forms of new road construction, off-road vehicle use, installation of power lines, grading of gaging-station sites, and emplacement of structures. Overall, the site impacts of the activity are expected to be minimal.

2.2.4 Time required versus time available

The precipitation data collected as a part of the study will probably span only a short-term duration compared to the length of time nuclear waste will be stored. Preliminary analysis suggests that these relatively short-term data can probably be statistically correlated with regional precipitation data spanning a longer time, although further analysis will be done as part of this study.

Time, however, is critical in the collection of meteorological data for the proper characterization of precipitation events. For this reason it is important that collection of meteorological data for this study proceed in as timely a manner as possible.

2.2.5 Potential for interference among activities

Generally, the selected tests of this study will have little or no interference with other planned tests. In cases where tests may interfere, the investigators have planned the testing sequence accordingly, in order to maximize data collection and minimize interference.

3 DESCRIPTION OF ACTIVITIES

The study is organized into one activity:

- 8.3.1.2.1.1.1 - Characterization of meteorology for site and regional hydrology

The plans for this activity are described in Section 3.1.

3.1 Characterization of meteorology for site and regional hydrology

The characterization of meteorology for site and regional hydrology will be accomplished by a detailed field measurement program and the collection and processing of supporting data. Supporting data are data that are available to the YMP but are not specifically collected by the YMP or for the YMP. Data collected by the National Weather Service (NWS) and the Weather Service Nuclear Support Office (WSNSO) are examples of supporting data. There is also historical data available from these and other organizations which will be used in this study. The methods for collecting data necessary for this study are discussed in detail in the following sections.

3.1.1 Objective of activity

Since this study is organized into only one activity, the objective of the activity is the same as that of the study, which is: to characterize the meteorological conditions surrounding Yucca Mountain, with particular emphasis on precipitation.

3.1.2 Rationale for activity

Meteorological data from the Yucca Mountain region are required to support a number of other hydrologic and geologic studies. Each individual study lists the rationale and requirements for meteorological data and should be referred to for specific information. These studies include: Study 8.3.1.2.1.2 (Regional surface-water runoff and streamflow), Study 8.3.1.16.1.1 (Flood potential and debris hazards), Study 8.3.1.2.2.1 (Unsaturated-zone infiltration), Study 8.3.1.2.2.6 (Unsaturated-zone gas flow), Study 8.3.1.2.1.3 (Regional ground-water flow system), Study 8.3.1.2.3.1 (Site saturated-zone ground-water flow system), Study 8.3.1.5.1.1 (Modern regional climate), and Study 8.3.1.5.2.2 (Characterization of the future regional hydrology due to climate changes). The meteorological parameters in the meteorology activity include: precipitation, air temperature, relative humidity, barometric pressure, shortwave radiation, and wind speed and direction. These parameters will be analyzed to provide diurnal, seasonal, and spatial variability. In general, precipitation is of primary interest for site and regional hydrologic studies and will be analyzed in the most detail.

3.1.3 General approach and summary of tests and analyses

The characterization of regional meteorology will be approached by using large- and small-scale monitoring networks for measurement of meteorological conditions. The following will be an overview of the study area, background on climatic and meteorological principles, and details of the plans for the collection, assimilation, and analysis of data.

Figure 3.1-1 summarizes the organization of the meteorology tests. A descriptive heading for each test/analysis appears in the shadowed boxes of the second and fourth rows. Below each test/analysis are the individual methods that will be used during the process. Figure 3.1-2 summarizes the objectives of the activity, the characterization parameters which are addressed by the activity, and the activity parameters measured

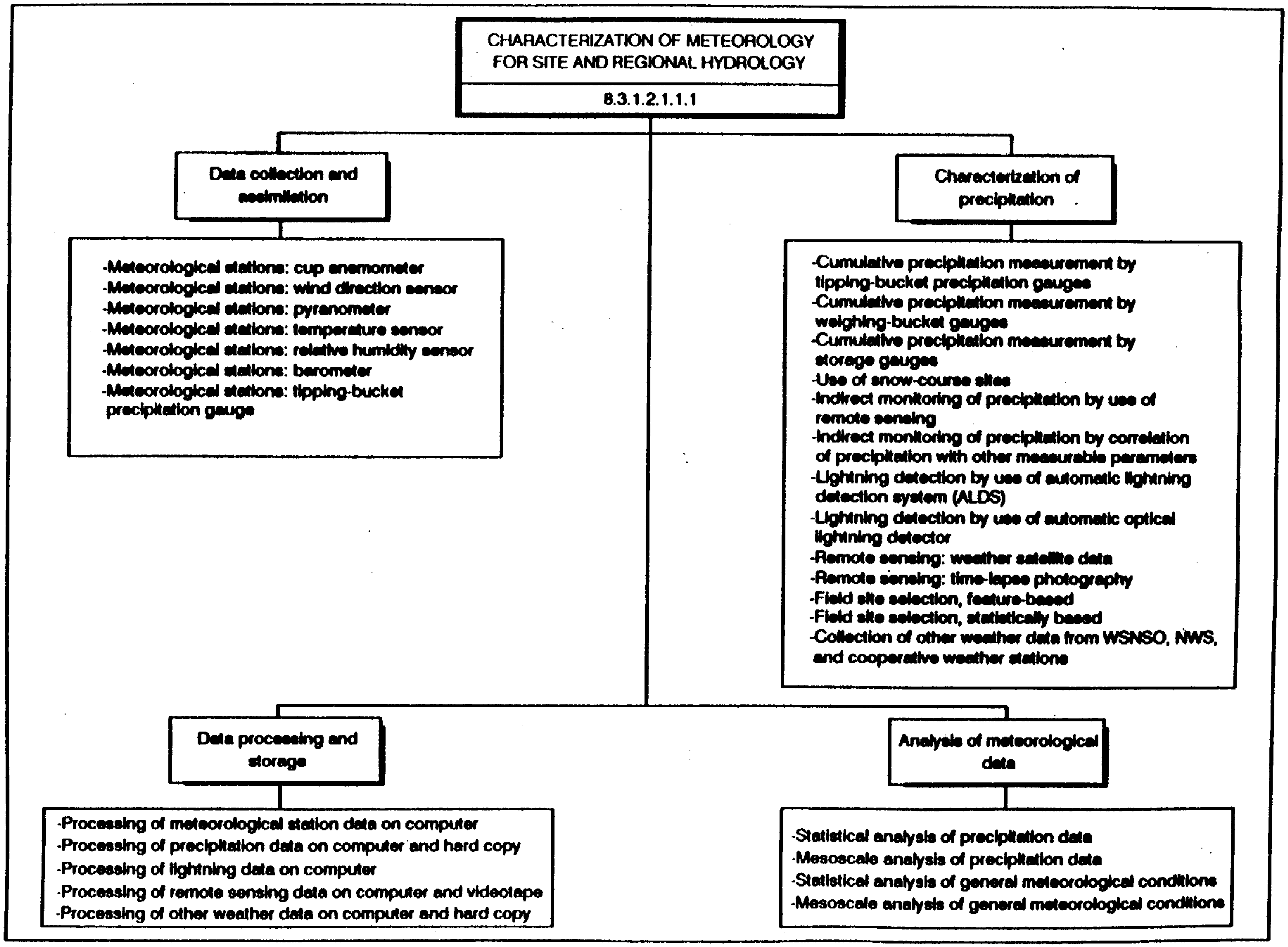


Figure 3.1-1. Logic diagram of meteorology activity, showing tests, analyses, and methods.

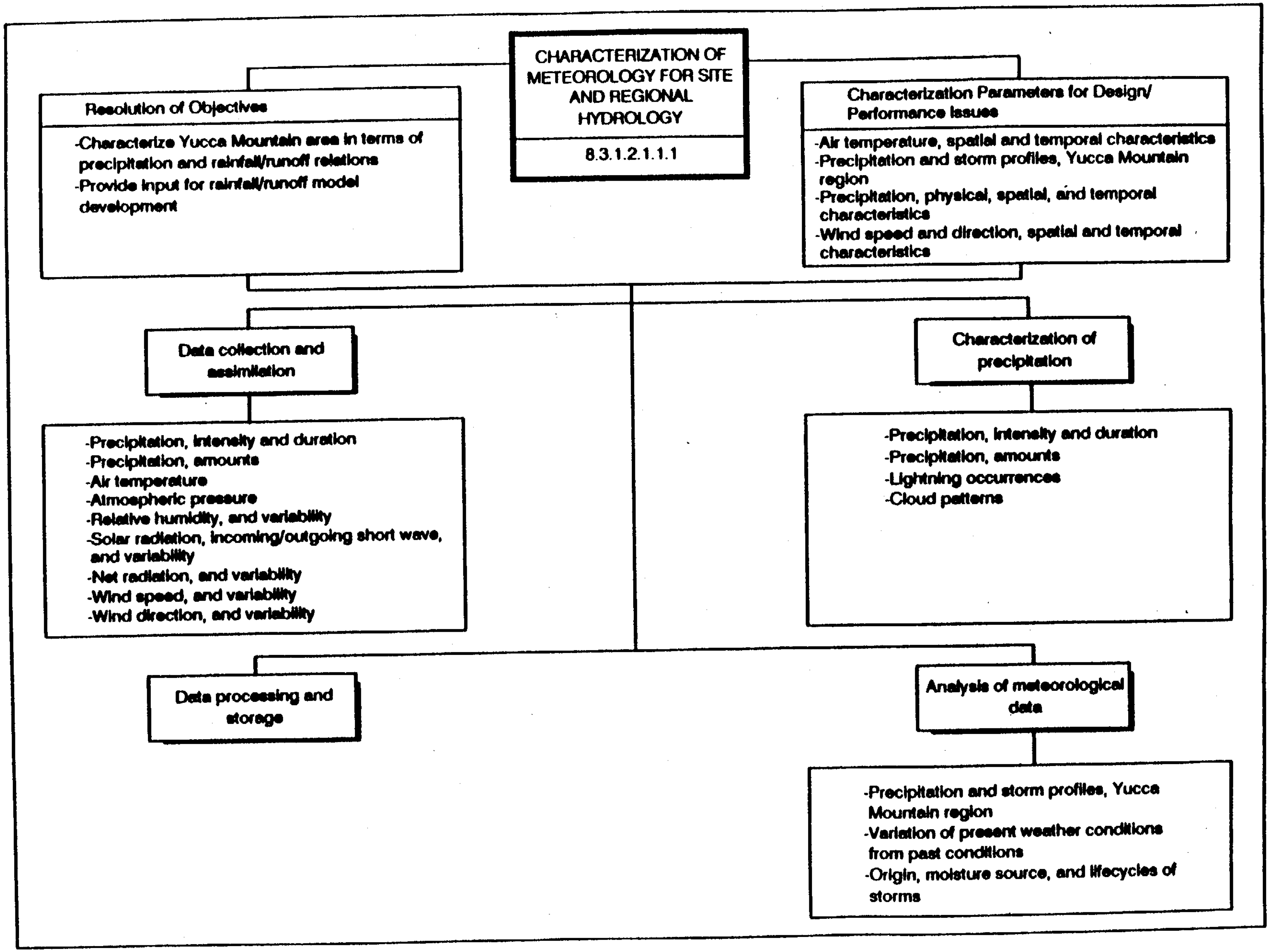


Figure 3.1-2. Logic diagram of meteorology activity, showing tests, methods, and activity parameters.

during the investigative process. These appear in the boxes in the top left side, top right side, and below the test/analysis boxes, respectively, in Figure 3.1-2.

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 diagrams. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations among (1) the activity 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.

This study plan can be summarized by a simple listing of the steps to be conducted. First, an analysis of existing data is used to establish a general overview of the meteorology and precipitation patterns of the area. Second, a temporary meteorological network has been established to collect important site-specific data to help supplement the historical data. Part of the network consists of full-recording meteorological stations, recording precipitation stations only, and manually read precipitation storage gages. Third, data collected from these and other existing meteorological stations on and around the Nevada Test Site are being analyzed to determine the optimum location and methods to establish a permanent meteorological network. Fourth, synoptic data collected concurrently with the above three steps will be incorporated with site-specific meteorological data collected under this study. These will provide a site and regional analysis of the current meteorological conditions. Fifth, all of this information and other supplemental information will be combined to reevaluate the current meteorological program and modify, as necessary, current thinking or strategies to optimize the meteorological monitoring program. This is basically a program best suited to an iterative approach of data collection, analysis, and modification. The data collected are in two general categories. The first category is hard data, which consists of numerical values of precipitation, air temperature, wind direction and wind speed, etc.; the second is soft data, which consists of synoptic inference, such as jet stream influence, storm track, apparent source of precipitation, and a general overview of daily climatic conditions (i.e., sunny, cloudy, hazy). The following discussions are simply a reiteration of the above information with specific details on the methods, equipment, and analytical techniques.

3.1.3.1 General overview

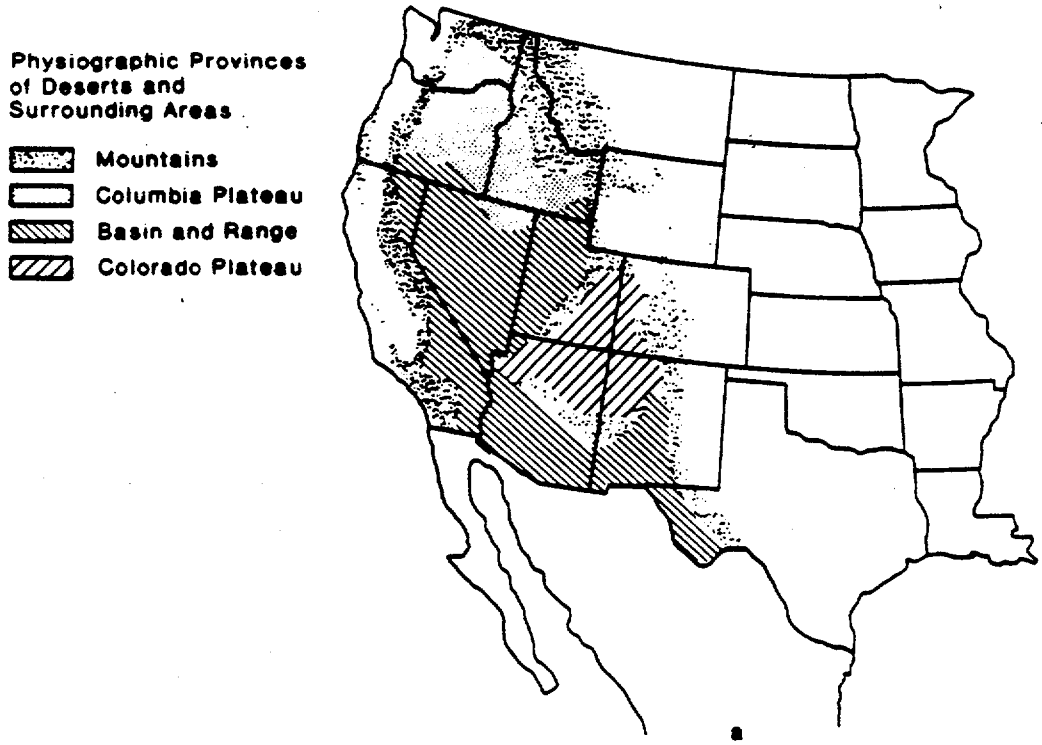
This section describes the regional and site-specific study areas. Also presented is a perspective on experimental scale in climate studies and the parameters that are necessary to be measured in order to describe different scales of meteorologic features.

3.1.3.1.1 General description of the climate of the Basin and Range Physiographic Province

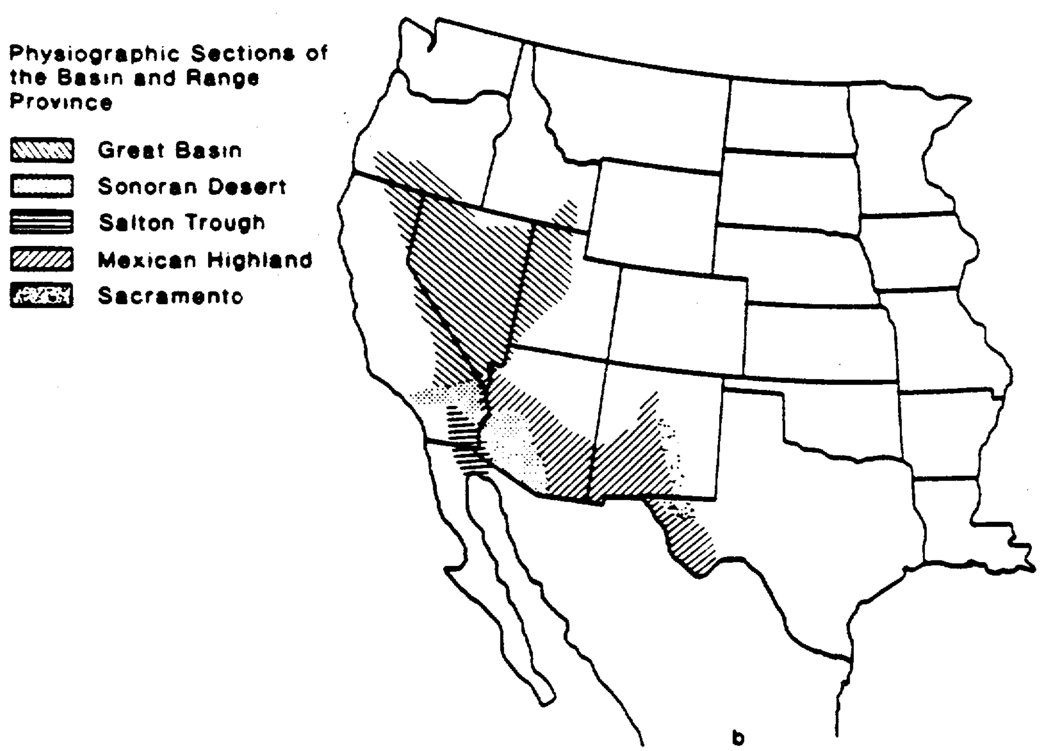
Four physiographic provinces encompass much of the western United States (Figure 3.1-3a). Of particular interest to this study is the Basin and Range Physiographic Province, which essentially contains all of the deserts in the United States. This province can be subdivided into five major sections, the Great Basin, Sonoran Desert, Salton Trough, Mexican Highland, and the Sacramento (Figure 3.1-3b) (McMahon, 1985). Southern Nevada, including Yucca Mountain, is in the Great Basin Section. Although these section boundaries may be of some benefit, for the use of this study it is more beneficial to use the four major desert boundaries (Figure 3.1-4a), which, in general, can be delineated by their climate and precipitation patterns. The following discussion is a general overview of the climate of North American deserts and will provide some insight into the unique character of the Yucca Mountain area.

The Great Basin and Mojave deserts are located primarily between the Rocky Mountains to the east and the Sierra Nevada mountains to the west. The Sonoran desert extends from southern California and southern Arizona to northern Mexico and the Baja peninsula. The Chihuahuan desert extends from southern New Mexico to Central Mexico (Figure 3.1-4a). These four deserts are of two general types, a cold desert (the Great Basin), which receives most its precipitation as winter snow, and the warm deserts (the Mojave, Sonoran, and Chihuahuan), which receive most of their precipitation as rain, either in the winter or the summer.

These deserts lie in a zone where strong seasonal shifts in precipitation occur, caused by seasonal heating of the earth's surface and by global wind patterns. (See Section 3.1.3.1.3 for a description of the atmospheric scales involved.) There are two distinctly different storm patterns affecting the desert climate, one in winter, the other in summer. Winter precipitation tends to be of low intensity and long duration (days), and covers large areas. In contrast, most summer rains result from convective thunderstorms of high intensity and short duration (hours), and are limited in size. Winter storms originate in the eastern Pacific from the gulf of Alaska to southern California. The polar and subtropical jet streams or "storm tracks" steer developing storm systems eastward and inland. In the spring, the west-to-east storm track migrates northward as cold air retreats and warm air invades from the south. By midsummer, air-mass thunderstorms become the dominant storm type in the region. These storms are fueled by the extreme heating over the "hot deserts", and the increased moisture being advected from their major source, the Gulf of California. The Gulf of Mexico may contribute in a limited capacity to the overall moisture content of the atmosphere (Hales, 1972 and 1974).

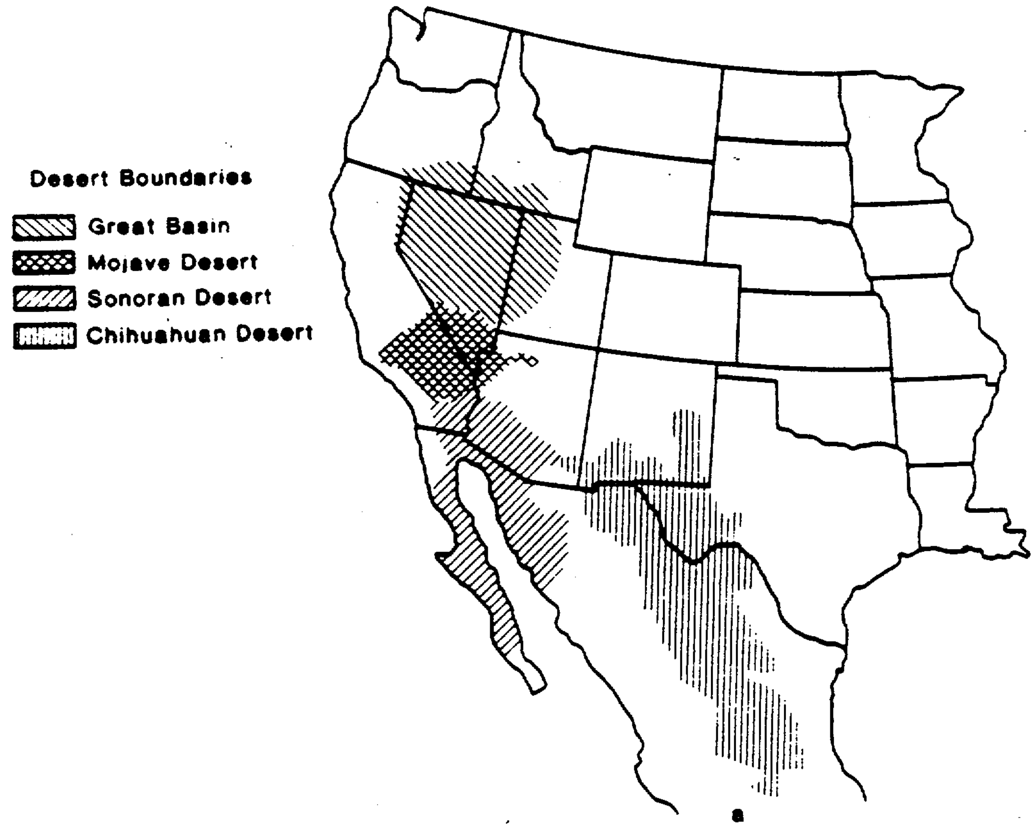


a



b

Figure 3.1-3. The four physiographic provinces of the western U.S. (a) and the physiographic sections of the Basin and Range Province (b) which are of importance to the regional meteorology studies.



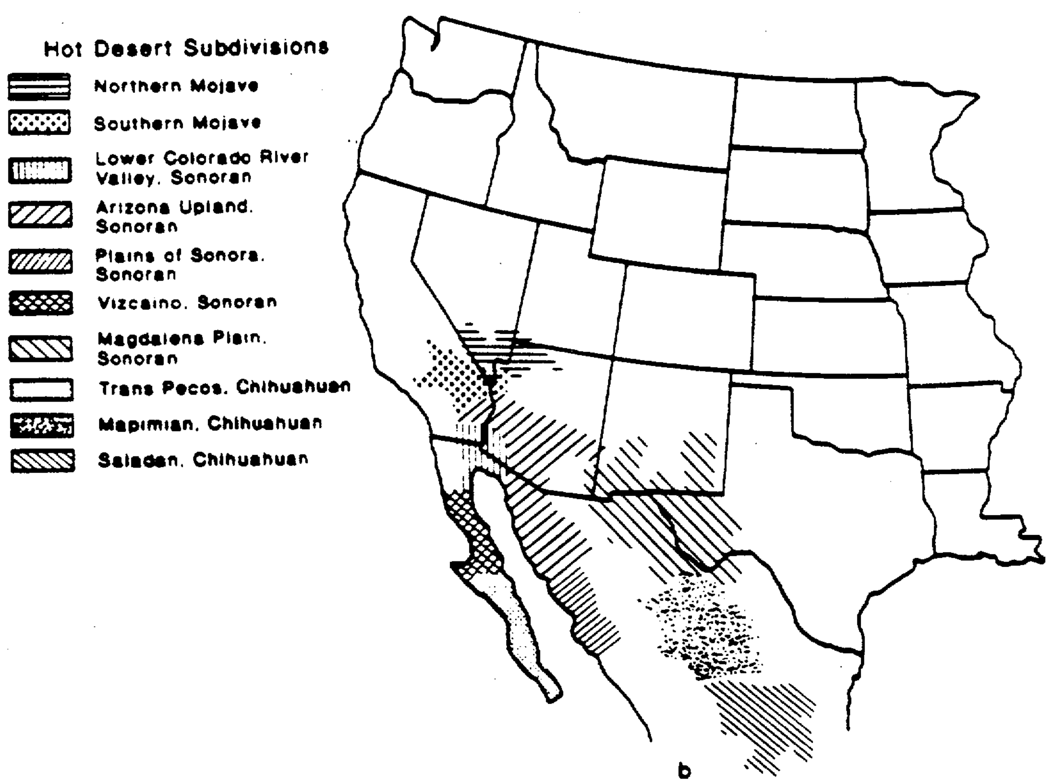


Figure 3.1-4. The four North American desert boundaries (a) and the hot desert subdivisions (b).

Each of these seasonal precipitation patterns becomes less pronounced as it moves overland, farther away from its source, either the Pacific Ocean or the Gulf of Mexico. The Mojave and Great Basin deserts are closer to or directly in the winter storm track and receive most of their precipitation in the winter. The Great Basin (a cold desert) receives most of its precipitation as snow due to its low average annual temperature and high basin elevations (>1500 m), whereas the Mojave (a hot desert) receives most of its precipitation as rain. The Sonoran desert (a hot desert) receives about half of its annual precipitation in the winter as rain. The Chihuahuan desert (a hot desert) lies farthest from the Pacific and receives little winter precipitation. By contrast, the Chihuahuan desert is closest to the Gulf of Mexico and receives most of its precipitation in the summer as thunderstorms. The Sonoran desert, which is intermediate between the winter and summer storm systems, gets the other half of its annual precipitation during the summer. The summer storm tracks from the Gulf of Mexico or the Gulf of California provide some summer precipitation in the Mojave desert, but provide little, if any, in the Great Basin.

The Mojave desert can be further subdivided into the northern Mojave and southern Mojave (Figure 3.1-4b). These two subdivisions represent transition zones between the Great Basin and Sonoran deserts and, therefore, may represent transitional zones between winter precipitation and summer precipitation. Yucca Mountain is in the northern Mojave. The boundary between the northern Mojave and the Great Basin is not well defined but lies somewhere between Beatty, Nevada, 27 km to the west of Yucca Mountain, and Tonopah, Nevada, 170 km to the north. The southern boundary of the northern subdivision, also not well defined, lies near the California-Nevada border 100 km southwest of Las Vegas. Although Yucca Mountain is in the northern Mojave, part of the study area, described in Section 3.1.3.1.2.1, is in the southern Mojave. (The study may help to better define these desert boundaries.)

3.1.3.1.2 Definition of research area

The research area defined for characterization in this study include those areas which directly contribute to the site and regional hydrology of Yucca Mountain. The research area is divided into four sub-areas. Each area, in general, contains the next smaller area.

3.1.3.1.2.1 Regional areas

The largest area (area 4, Figure 3.1-5), consists of a circular area with a radius of 150 km centered on the proposed repository site. The area 4 boundary was arbitrarily selected to coincide with a mesoscale climate model currently being developed at the National Center for Atmospheric Research

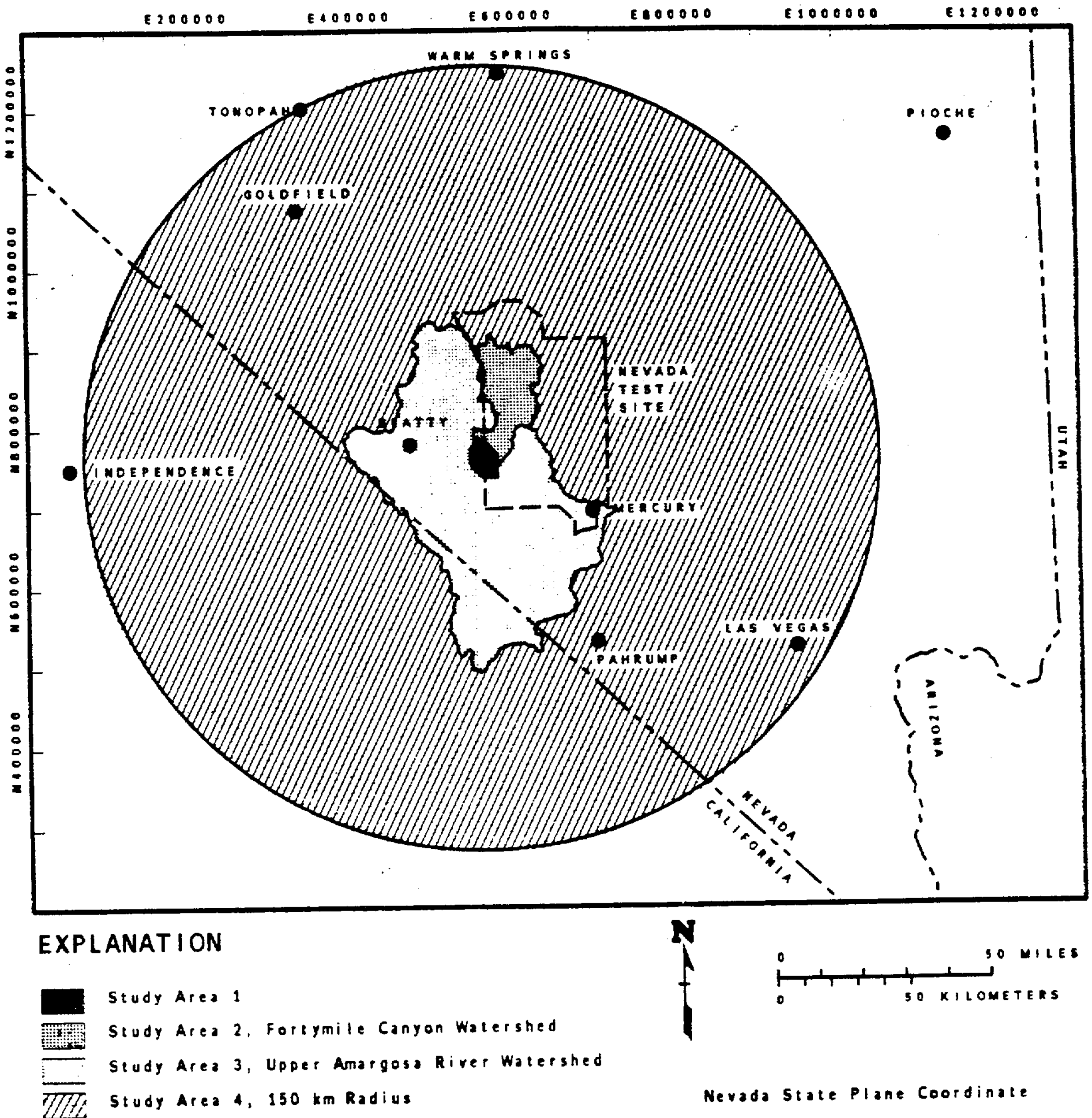


Figure 3.1-5. The four primary study area boundaries for regional and site meteorology.

(NCAR). Data required to define the meteorological conditions at this scale are, in general, provided by the National Weather Service (NWS), and will be compiled, with some duplication, between this study and the study being conducted by Science Applications International Corporation (SAIC), "Meteorological Monitoring Plan", which emphasizes atmospheric stability and turbidity. Since the data collection includes such parameters as wind speed, wind direction, and precipitation, these data will be used to supplement our data set collected in the present study.

The Upper Amargosa River drainage (area 3, Figure 3.1-5), is defined based on surface-drainage boundaries and will provide the boundaries for any new meteorological stations. Although many of the current NWS stations will provide data for this area, several additional stations will be located to improve regional coverage as well as provide an optimized network for statistical and geostatistical analyses. It is expected that five or more new meteorological stations will be located within this area, not covered in area 1 or area 2 (Section 3.1.3.1.2.2). The method of locating these is described in Section 3.1.3.2.1.2.

3.1.3.1.2.2 Site areas

The Upper Fortymile Wash drainage (area 2, Figures 3.1-5 and 3.1-6), will be a more intensely monitored area, mainly in support of Study 8.3.1.16.1.1 (Flood potential and debris hazards), Study 8.3.1.2.1.2 (Regional surface-water runoff and streamflow), Study 8.3.1.2.1.3 (Regional ground-water flow system), Activity 8.3.1.2.1.3.3 (Fortymile Wash recharge study), and Study 8.3.1.5.2.2 (Future regional hydrology due to climate change). It is likely that there will be an additional 20 precipitation stations located in area 2. The precipitation station locations will be optimized using the procedure discussed in Section 3.1.3.2.1.2. The optimization scheme is, in general, designed to provide site-specific or areally averaged estimates of precipitation using geostatistical analysis, with the purpose of locating high-precipitation zones for specific runoff events and estimating total catch in the drainage boundaries of individual drainages.

The final area of interest (area 1, Figures 3.1-5 and 3.1-6) consists of three subdrainages, two of which are in the Fortymile Wash drainage, a major tributary of the Amargosa River. These are the Drillhole Wash subdrainage, which overlies most of the conceptual boundary of the proposed repository, and the Busted Butte subdrainage. The Solitario Canyon subdrainage is the third, and it is of interest because it overlies a small portion of the proposed repository boundary. Area 1 will be the most heavily monitored area in support of Study 8.3.1.2.2.1 (Unsaturated-zone infiltration)

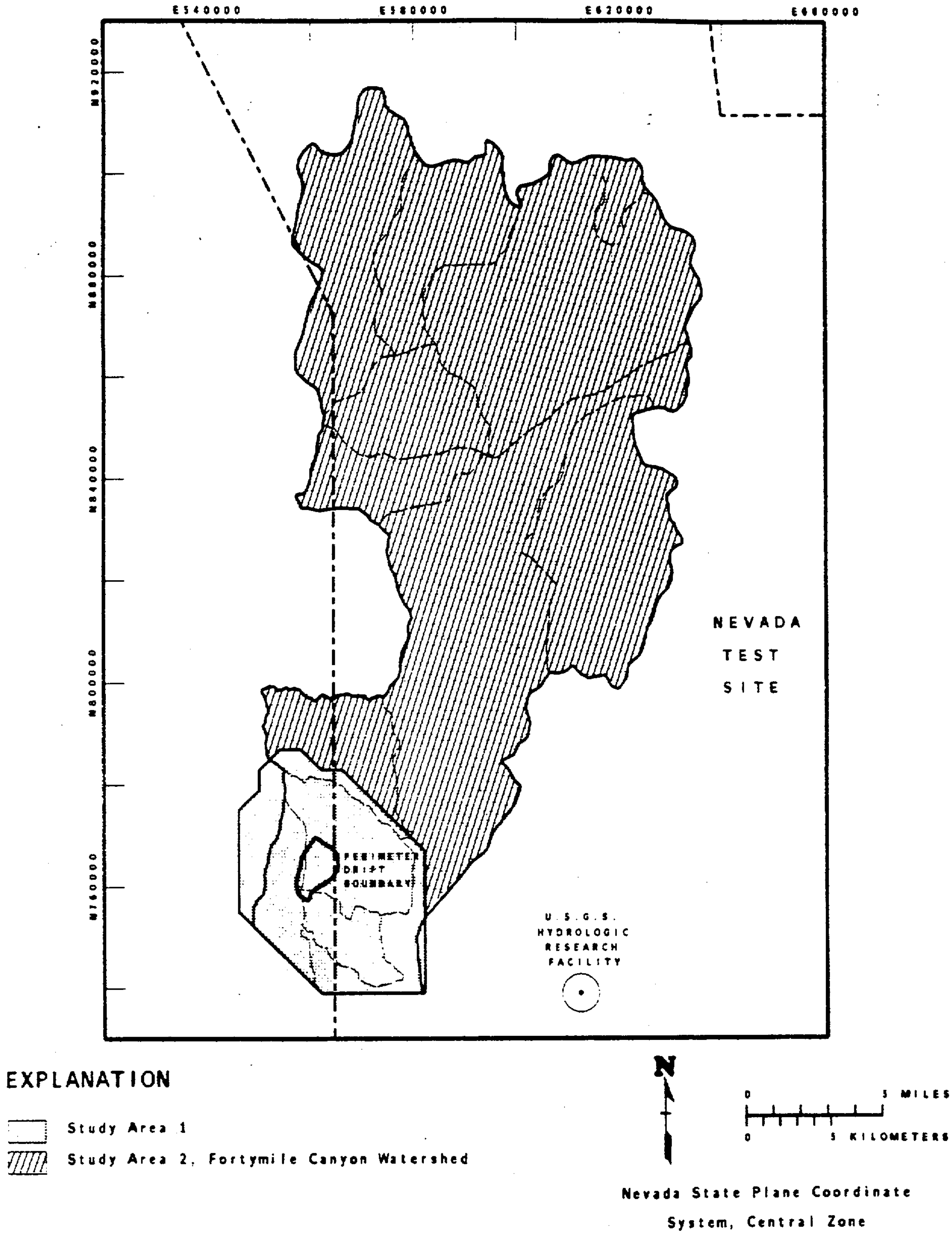


Figure 3.1-6. The details of the boundaries of study areas 1 and 2, including the boundaries of the smaller watersheds within the study areas. The perimeter drift boundary for the conceptual repository site at Yucca Mountain is also shown.

as well as those activities mentioned above. Again, site selection will be based on results of data analysis and will be discussed in Section 3.1.3.2.1.2.

3.1.3.1.3 Scales of meteorologic features and general climatic perspective

Discrete atmospheric disturbances or motions occur over a wide spectrum of time and space. This spectrum is subdivided into four scales within which most atmospheric motions or disturbances can be categorized. These scales, as originally classified by Ligda (1951) are: *planetary scale*, *synoptic scale*, *mesoscale*, *and microscale*. Orlanski (1975) and Fujita (1981) refined this classification scheme based on improvements in capabilities to detect and study sub-mesoscale disturbances. These technological advances were primarily the product of more extensive use of the Doppler radar. For example, multiple Doppler analyses now permit researchers to construct "microsynpotic" charts of airflow in and around atmospheric disturbances as small as a tornado.

The original scales classified by Ligda (1951) are not ridgid and the atmospheric motions they represent may overlap in space and time. Figure 3.1-7 depicts these scales in relationship to each other in time and space. The following discussion is intended to give a relative perspective of how atmospheric motions on the larger scales influence and control the microscale environment of Yucca Mountain.

3.1.3.1.3.1 Planetary scale

The largest scale motions occur on a *planetary scale* because of the unequal heating of the earth's surface. Warm, buoyant air rises from equatorial regions (the intertropical convergence zone) and flows poleward in both hemispheres in a meridional fashion. Rising air converges on the earth's surface, generating the easterly trade winds and divergence aloft, causing the high-altitude westerlies. This large-scale cell of convective circulation, known as the Hadley cell, finally sinks into the subtropical, high-pressure belt at an average latitude of 30 degrees north (south). A weaker circulation cell transports energy toward the poles in a pattern called the Ferrel cell, with cold air rising and warm air sinking. The Ferrel cell is thermally indirect, making this a forced motion. A third, very weak polar cell may exist in each hemisphere (Gedzelman, 1985). Therefore, on a planetary scale, air is rising at 0 and 60 degrees north (south) and sinking at 30 and 90 degrees north (south) (Figure 3.1-8). This basic atmospheric mechanism is responsible for all atmospheric motion.

The predominant planetary features of the atmosphere which control the movement of synoptic-scale systems are the polar and subtropical jet streams or jets. The jets are a combined

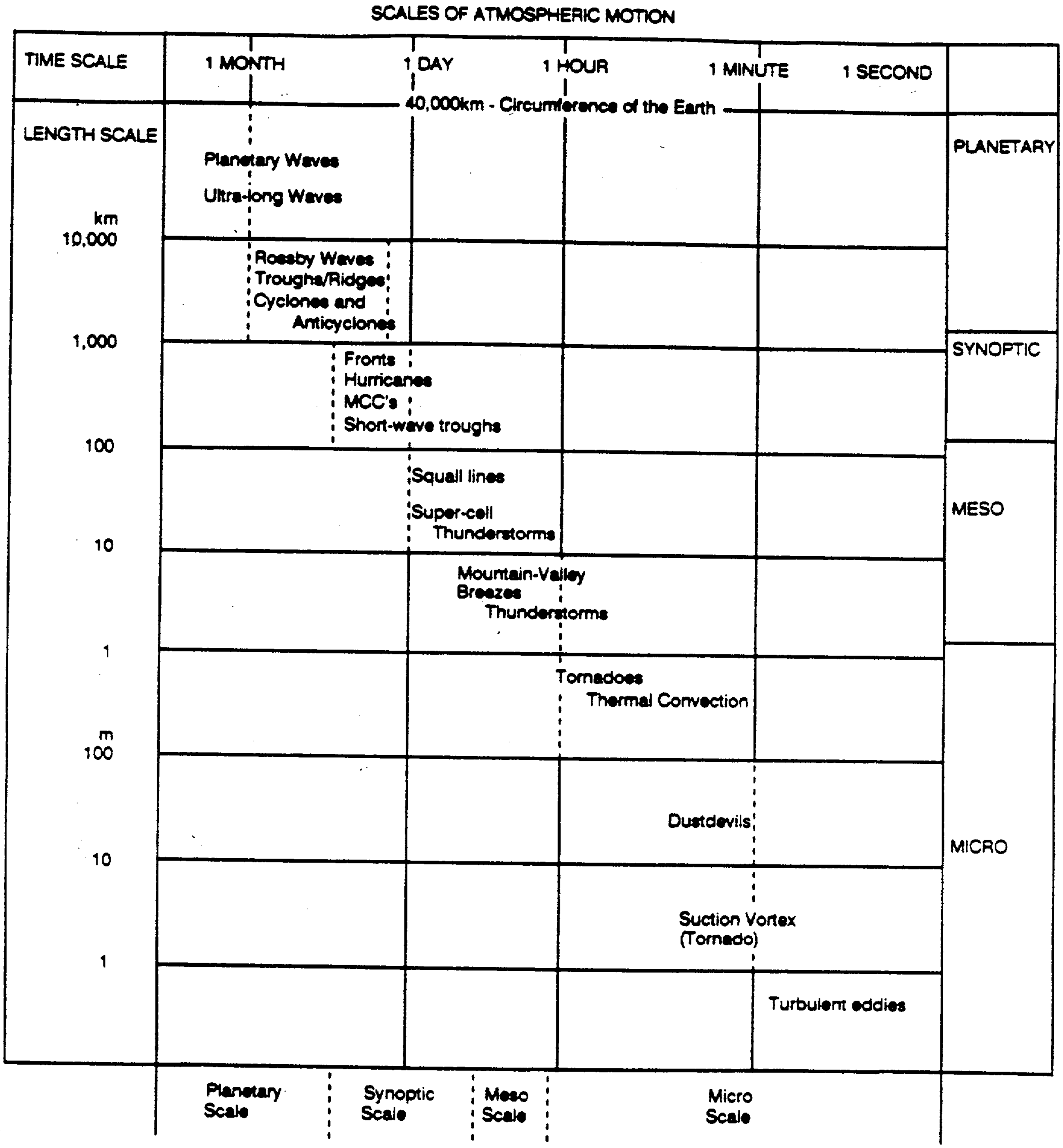


Figure 3.1-7. Examples of atmospheric motions or "disturbances" shown in context of their relationship in space and time. The time and length scales measure the duration and wavelength of each disturbance respectively. (Modified from Hirschboeck, 1987)

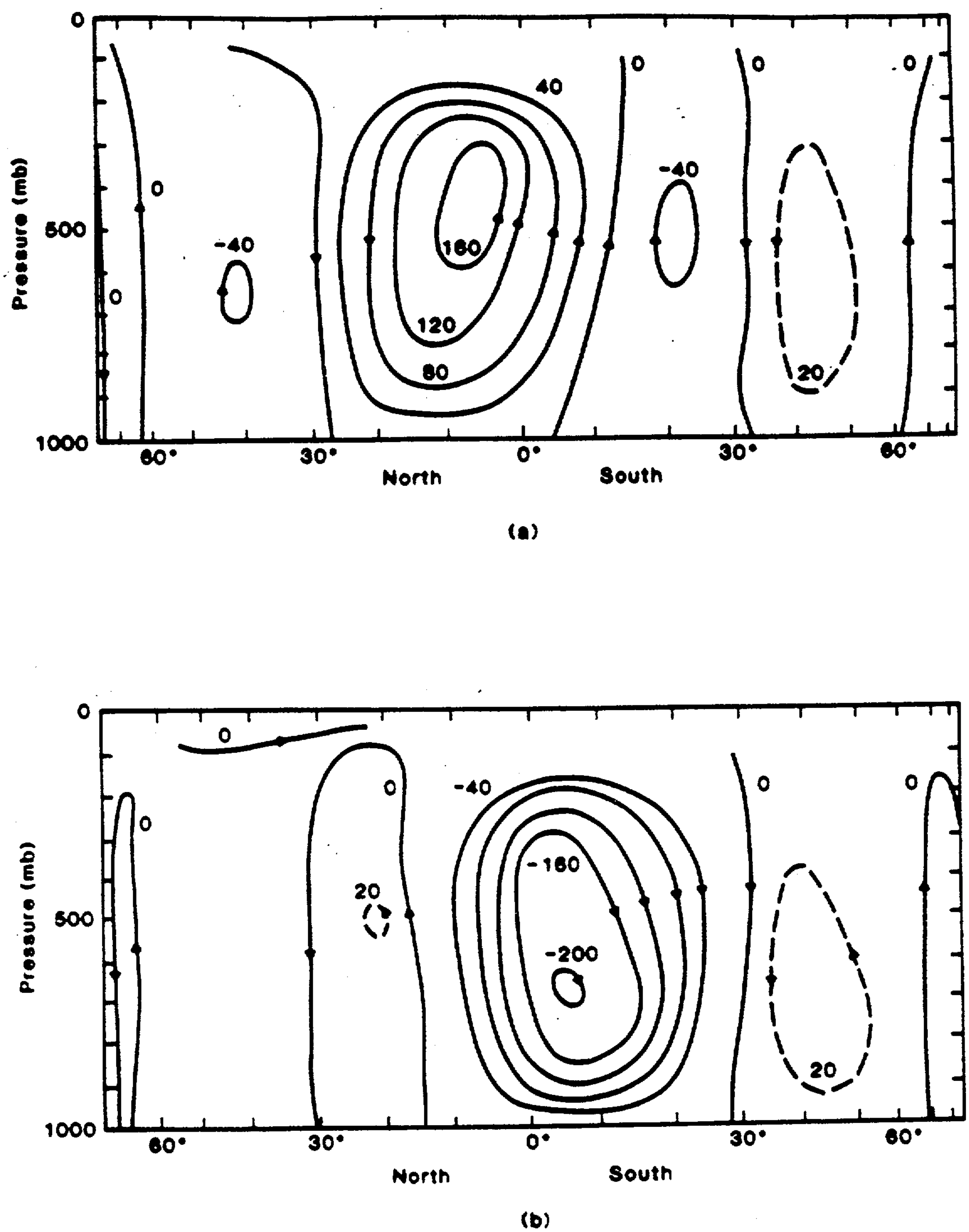


Figure 3.1-8. Mean meridional circulation cells for (a) December-February and (b) June-August. The "Hadley Cell" is shown from the equator to 30 degrees north (a) and south (b) and the Ferrel Cell from 30 degrees to 60 degrees north (south). Units are mass flux of 10^9 kg/s. (After Gill, 1985)

product of the differential heating mentioned earlier and the torque generated by the Earth's rotation. The jet streams generally circumnavigate the earth in a five-wave pattern of troughs and ridges with wavelengths of 2000-4000 km. This pattern may vary from three to eight major waves (Rossby waves) and oscillates northward in summer and southward in winter in the northern hemisphere. The intensity and motion of the atmosphere at any given time depends on many variables including sea surface/continental temperature contrasts. The time and length scales for planetary-scale motion are on the order of weeks and 10^4 km respectively.

3.1.3.1.3.2 Synoptic scale

Synoptic-scale atmospheric disturbances are created by the "cascading down" of the energy generated at the planetary scale. The energy transfer causes differences in temperature, pressure, and moisture content of separate air masses of different origin (cold continental air versus warm, moist tropical air). As these differing air masses interact, low barometric pressure caused by warm rising air must be compensated for by cold air from areas of high barometric pressure. The air flow from high to low pressure is the cause of winds which vary in intensity depending upon the strength of the gradient between high and low pressure centers. The strongest temperature discontinuity is usually found along the polar front. Figure 3.1-9 depicts the average position of the polar front in January. Low-pressure systems forming along the polar front (frontogenesis) over oceans are responsible for the first phase of the hydrologic cycle. These storms generally follow the jet stream or "storm track" on shore and release their precipitation as they move. Wendland and Bryson (1981) provide more detailed insight into mean seasonal and annual frontal positions in the Northern Hemisphere. They discuss the confluences of near-surface airstreams which represent mean surface storm tracks. Terrain features greatly affect the movement and strength of low-pressure frontal systems. Synoptic-scale systems average on the order of 1000-2000 km in size. They exist on a time scale of days. Hurricanes, at a size on the order of 800-1000 km, are also synoptic-scale features.

In winter, many low-pressure systems invade the Pacific coast of the United States. Most do not affect the southern Nevada region, but a few do bring precipitation to that area. In summer, the westerly flow regime over the southwestern United States reverses and becomes southerly or southeasterly. More detail is available in French (1983).

Before the discussion of *mesoscale* and *microscale* weather features, the typical synoptic features affecting the southwestern United States will be treated. Part of the study of regional meteorology will be to identify specific

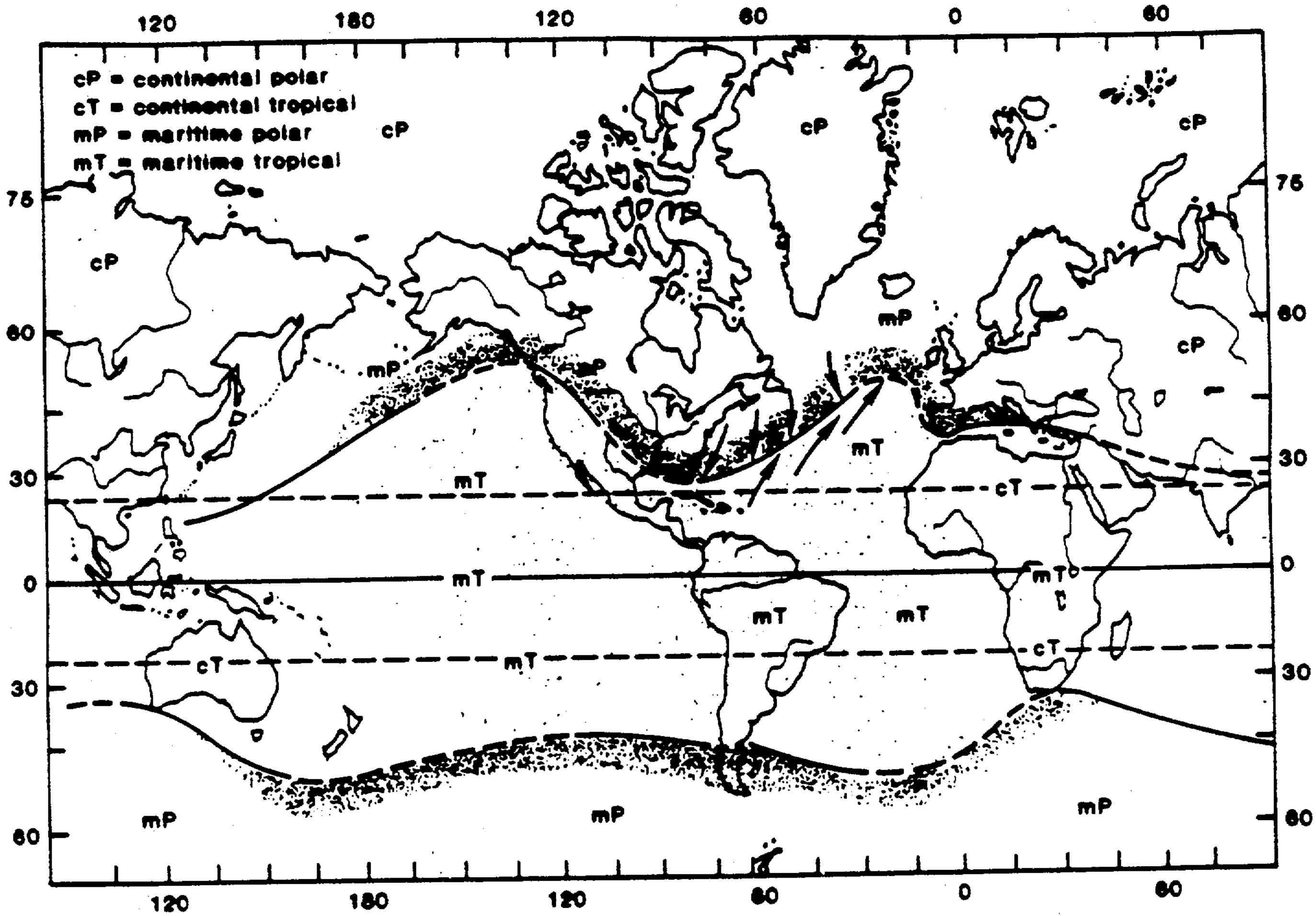


Figure 3.1-9. Average position of the polar front in January. A dashed line indicates the front is not well defined. Air masses are also indicated. (After Gedzelman, 1985)

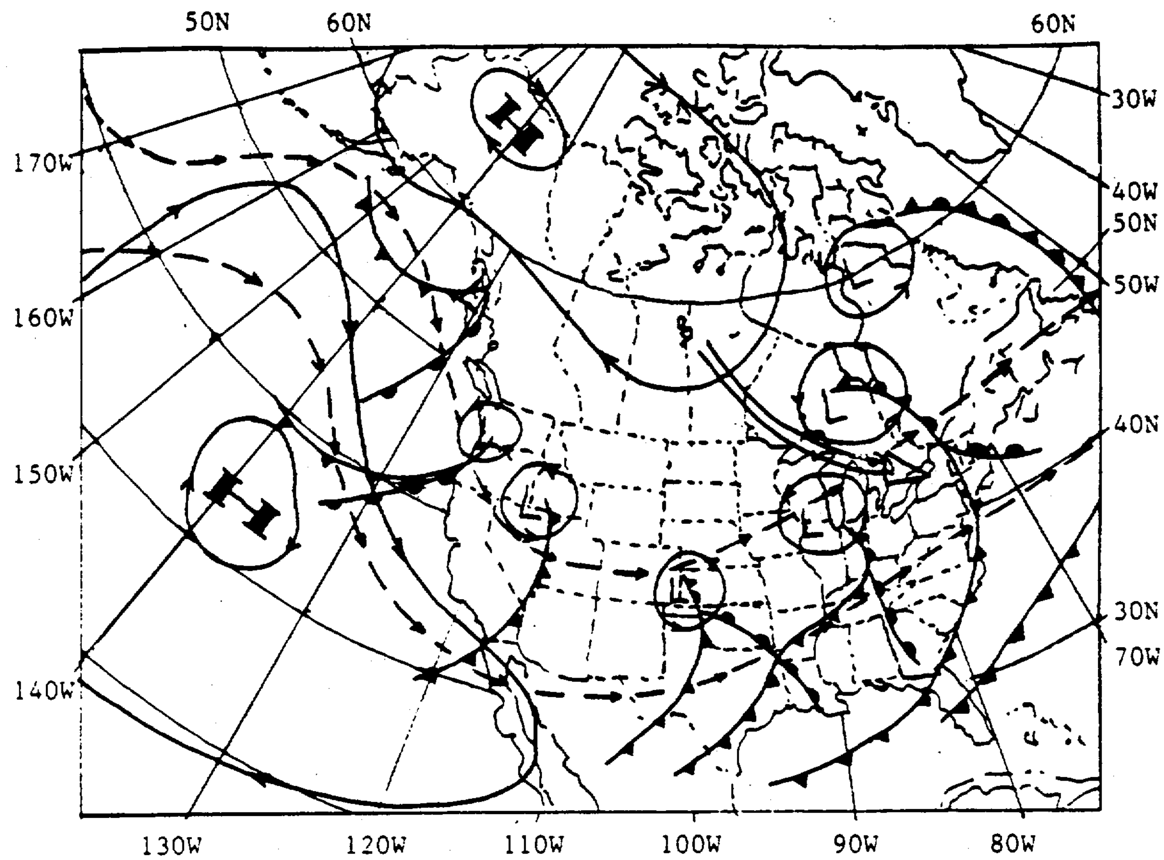
moisture-producing, synoptic-scale processes. Case studies will be performed on storms that provide precipitation to the Yucca Mountain study region. This effort will attempt to document the frequency and source of precipitation that falls within the study area. Although the climate is arid to semi-arid in the Yucca Mountain region, there are two definite, synoptic-scale weather regimes which account for precipitation across southern Nevada, one occurring in winter, the other in summer. First, the winter regime will be discussed.

Frontal activity occurring during the months of November through April accounts for over half of the precipitation in the Mojave Desert (MacMahon, 1985). The physiography of the western U.S., including the Sierra Nevadas, the Santa Monica Mountains, and the southern Basin and Range, forms an effective barrier to these frontal systems moving eastward from the Pacific Ocean, causing air masses to ascend and descend several times before reaching Yucca Mountain. The ascent of moisture-laden air masses over mountain ranges causes adiabatic cooling, often resulting in precipitation. Air descending on the leeward side is relatively depleted in moisture, causing a "rain shadow". Yucca Mountain is within such a rain shadow leeward of the Sierra Nevadas. In discussing the following winter synoptic-scale regimes, these regional orographic influences should be kept in mind.

Examination of historical data reveals that, despite apparent, small-scale, erratic movements of lows, fronts, and troughs, certain large-scale patterns dominate movements of the weather systems. There is a readily recognizable overall pattern to the steering currents that establishes the most probable track that storms will follow. Steering currents that move surface and upper-air lows on long, over-water trajectories to southern California and the southern Great Basin generally may produce precipitation across southern Nevada.

The following discussion describes five winter weather types (A-E) and the predominant summertime storm type, the "Southwest Monsoon." Of the five weather types of the winter regime, only three types produce precipitation in southern Nevada and of those, one produces only an insignificant amount. However, all five types will be discussed for completeness because the lack of precipitation is a major consideration in characterizing Yucca Mountain. Figures 3.1-10 through 3.1-14 depict time-lapse movements of winter storm systems, as discussed by Elliott (1943).

Weather Type A (Figure 3.1-10). A strong ridge in the upper-air steering current is present at about 150 degrees west with a downstream trough near 110 degrees west. At the surface, the eastern lobe of the Pacific High is strong and

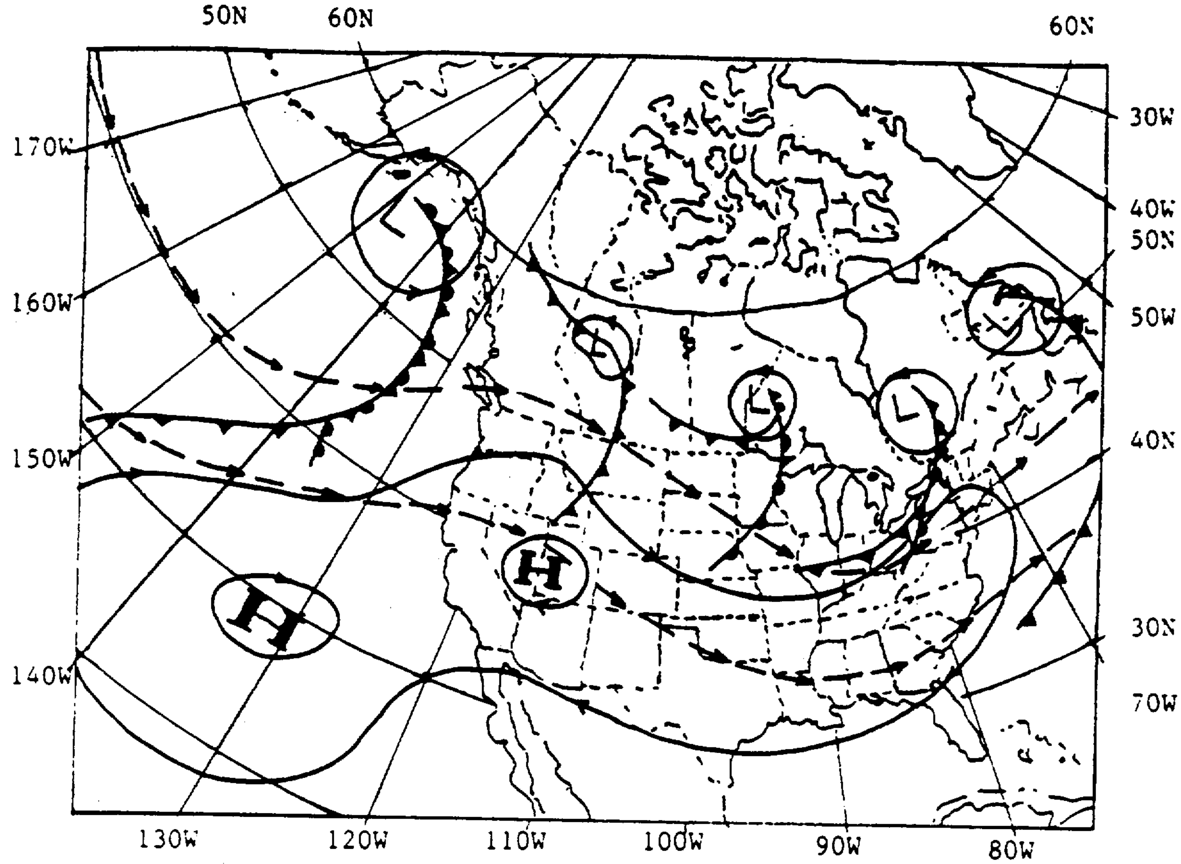


LEGEND

- H = Surface high-pressure center
- L = Surface low-pressure center
- = Cold front
- = Warm front
- = Occluded front
- = Surface wind circulation flow
- = Upper-level wind flow trajectory (jet stream)
- = Trajectory of high pressure center following storm passage

(Polar stereographic projection)

Figure 3.1-10. Winter weather type A. Successive time-lapse positions of the low-pressure cyclone are shown as the system develops and matures. (From Elliott, 1943)

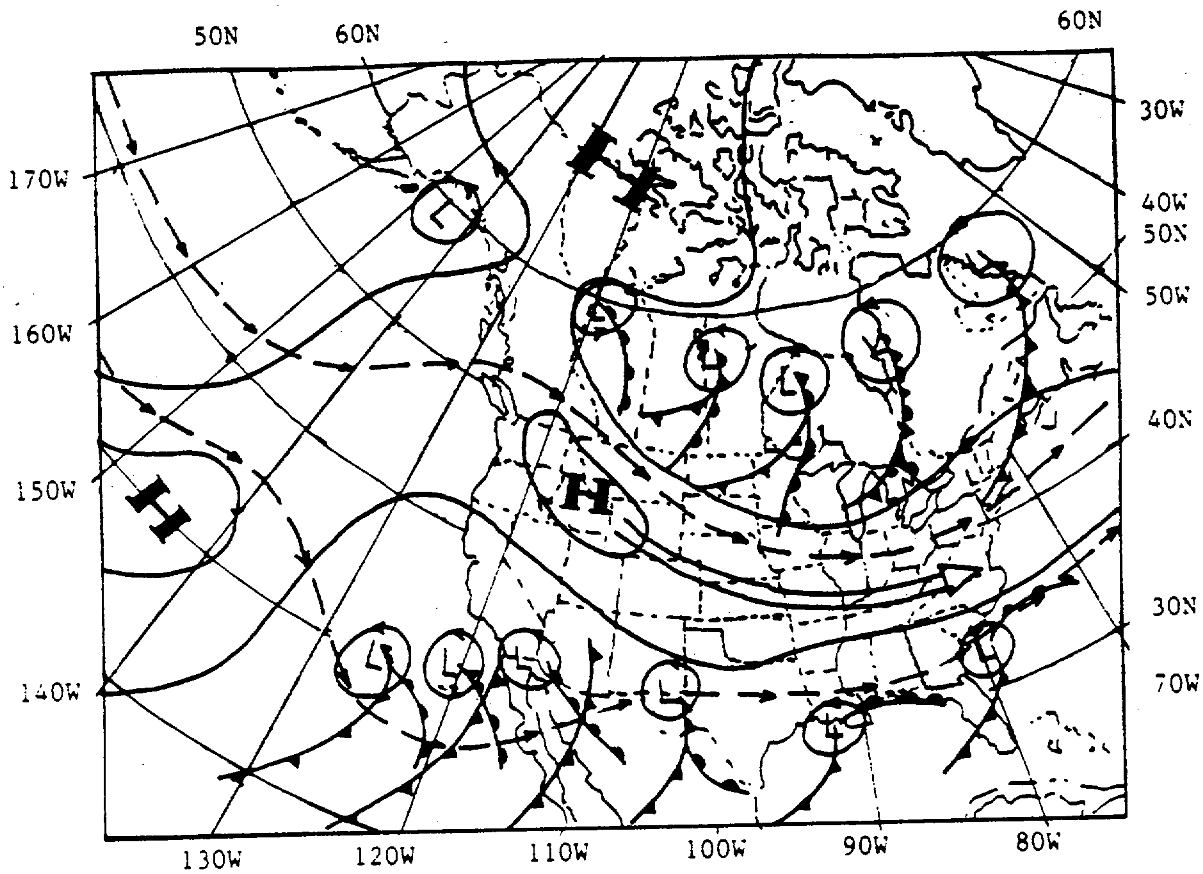


LEGEND

H = Surface high-pressure center
L = Surface low-pressure center
= Cold front
= Warm front
= Occluded front
= Surface wind circulation flow
= Upper-level wind flow trajectory (jet stream)

(Polar stereographic projection)

Figure 3.1-11. Winter weather type B. Shown are the successive time-lapse positions of the low-pressure system as it develops. The system remains well to the north of the U.S., as high pressure dominates the Southwest. (From Elliott, 1943)

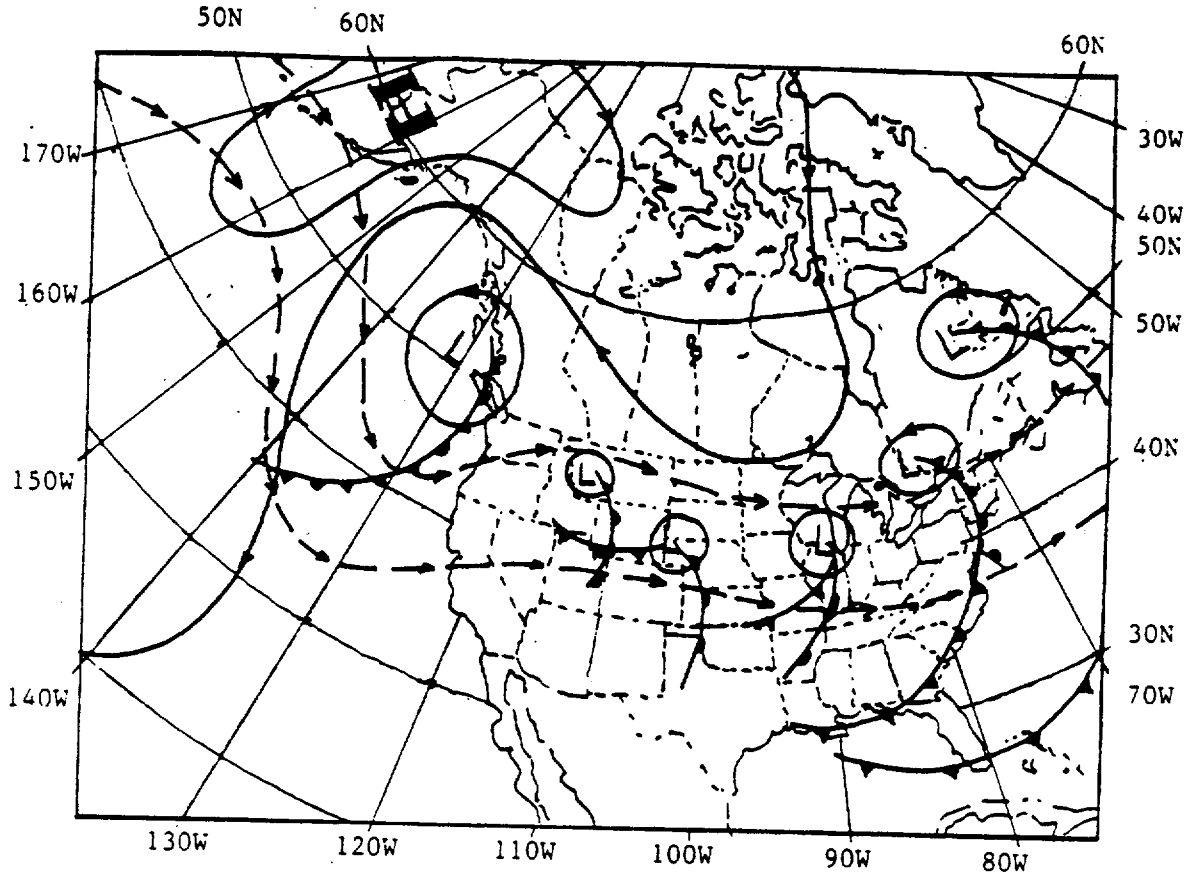


LEGEND

- H = Surface high-pressure center
- L = Surface low-pressure center
- = Cold front
- = Warm front
- = Occluded front
- = Surface wind circulation flow
- = Upper-level wind flow trajectory (jet stream)
- = Trajectory of high pressure center following storm passage

(Polar stereographic projection)

Figure 3.1-12. Winter weather type C. Shown is the belt of high pressure which is displaced northward from its normal position. The low-pressure centers develop in the Gulf of Alaska and off the coast of San Diego. Then they move inland as dipicted in this time-lapse sequence. (From Elliott, 1943)

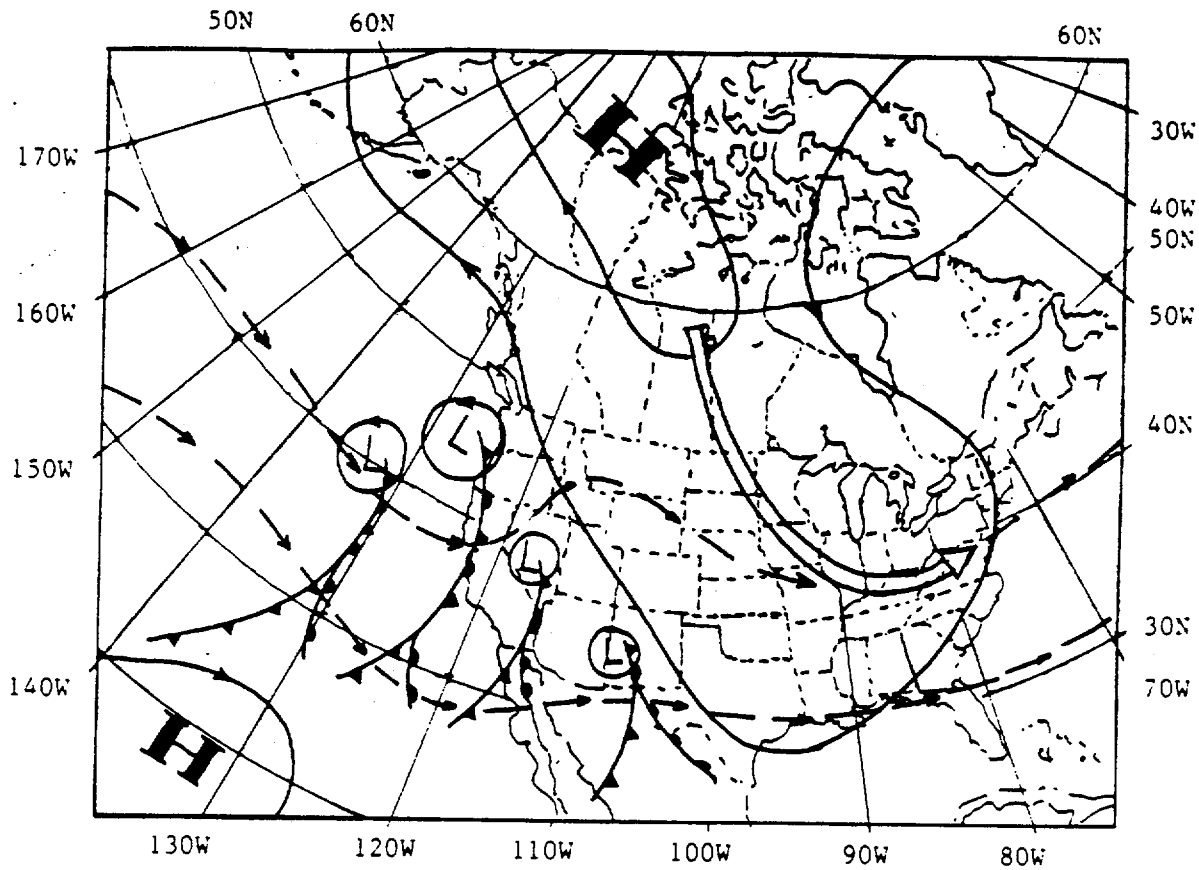


LEGEND

H = Surface high-pressure center
L = Surface low-pressure center
= Cold front
= Warm front
= Occluded front
= Surface wind circulation flow
= Upper-level wind flow trajectory (jet stream)

(Polar stereographic projection)

Figure 3.1-13. Winter weather type D. Depicted are time-lapse positions of the low-pressure center as it tracks across the northern U.S. (From Elliott, 1943)



LEGEND

H = Surface high-pressure center
L = Surface low-pressure center
= Cold front
= Warm front
= Occluded front
= Surface wind circulation flow
= Upper-level wind flow trajectory (jet stream)
= Trajectory of high pressure center following storm passage

(Polar stereographic projection)

Figure 3.1-14. Winter weather type E. The strong Canadian high-pressure ridge is depicted. This ridge forces developing low-pressure systems southward into the Great Basin. These Pacific storms cross the Sierra-Nevada, weaken, then redevelop on lee side of the mountain range. (From Elliott, 1943) located well to the northwest of a normal winter position. Typically, a wave pattern forms along the southern coast of Alaska or near the British Columbia coast and is steered rapidly by the upper-air steering currents down the coast over coastal Washington and onward over the Great Basin. At this point, the wave has occluded and slowed as cold air advancing behind the surface front deepens the system. The surface system begins recurving to a more eastward movement with the low center moving eastward to cross the Rocky Mountains near Denver, Colorado. Typically, southern Nevada experiences no precipitation from this type of weather, but it is included for completeness.

Weather Type B (Figure 3.1-11). This scenario features a belt of high pressure dominating the eastern Pacific and the southern half of the United States. Surface lows are steered from the Gulf of Alaska eastward through northern Canada with fronts trailing southward to southern Canada. As the frontal systems pass to the east of the Continental Divide, a maritime polar air mass from the Pacific Ocean follows, forming a temporary high in the Great Basin. No precipitation results from this type of weather in southern Nevada.

Weather Type C (Figure 3.1-12). This type of weather system produces precipitation in southern Nevada and the Yucca Mountain region. Note the northwardly displaced belt of high pressure and the steering currents to the south of the belt of high pressure. The cyclone centers are displaced southward to near 30 degrees latitude and migrate onshore and then eastward along the United States-Mexico border. This scenario is often referred to as the "San Diego Low." This weather type produces the heaviest non-thunderstorm precipitation known in southern California and Nevada. It generally moves slowly through the area, prolonging the duration of low ceilings and precipitation. As the surface system moves onshore, and until its core moves eastward to 110 degrees longitude, rainfall generally continues throughout southern Nevada. When the trough west of the California coast persists, a succeeding wave develops and moves onshore with similar results; this cycle repeats as long as the high-pressure system to the north continues to feed the trough lying west of the California coast.

Weather Type D (Figure 3.1-13). This weather system is occasionally of importance to southern Nevada but, as a general rule, is of little significance. The movements of the surface low and frontal systems are too far to the north and east. On occasions when type D weather is of importance to southern Nevada, the strong subarctic high and the steering currents are displaced slightly south of the depicted position. A polar outbreak that occurs through Alberta, Montana, and Wyoming carries into the Great Basin and southward to southern Nevada. Strong north to northeast winds occur as the cold air passes. Temperatures drop to well below normal, and light precipitation, with snow near the 4,000-foot level, falls on the mountains.

Weather Type E (Figure 3.1-14). A cold continental high persists in northern Canada and Alaska with the eastern lobe of the Pacific high centered near 20 degrees north and 140 degrees west. The steering currents for the Pacific storm systems lie in the belt of low pressure between the two highs. If the Canadian highs develop to a moderate 1030 millibars, the storm tracks are displaced further to the south. When the Canadian high reaches a strong 1040 millibars and extends itself south-eastward over most of the North American continent, the Pacific storm tracks are at their southernmost limit for the Type E systems. In each sub-group of the Type E systems, the surface low crosses the Pacific coast at 45 to 50 degrees north latitude, following the steering currents as it progresses generally eastward across the western United States. Warm tropical Pacific air is drawn northward up the west coast, ahead of the low, and causes heavy precipitation along the coast. A low-pressure center then develops on the lee side of the Sierra Nevada and moves across south-central Nevada. This development, often termed the "Tonopah Low", may bring precipitation to southern Nevada, depending on the amount of atmospheric moisture available. Speed of the system is gaged by studying the air to the north of the storm trajectory; i.e., when the air to the north is exceptionally cold, the low moves rapidly.

Southwest Monsoon (Figure 3.1-15). The summer (July and August) weather regime in southern Nevada exhibits a totally different type of circulation pattern than is characteristic of winter. It contributes to a secondary, though less discernable, maximum in annual precipitation. Thunderstorm activity over southern Nevada is the hallmark of this pattern known as the "Southwest Monsoon." These storms have a much greater potential for flooding than the frontal precipitation in the winter months. Much more precipitable water is available in summer due to the heated atmosphere's increased ability to hold moisture. Therefore, these storms can release a large amount of precipitation in a relatively short time. (See the related discussion in Section 3.1.3.1.1.)

Summertime atmospheric dynamics exhibit more of a tropical rather than a midlatitude character primarily because of the location of the Rocky Mountains to the east and proximity of the Pacific Ocean to the west. Thermal low pressure dominates the area along the California-Arizona border into northern Mexico, and controls the southerly wind flow into southern Nevada. Defining the locating of the moisture source(s) fueling storm activity in southern Nevada during the summer monsoon season has not been completely resolved. Bryson (1957), Hastings and Turner (1965), Weaver (1962), Tubbs

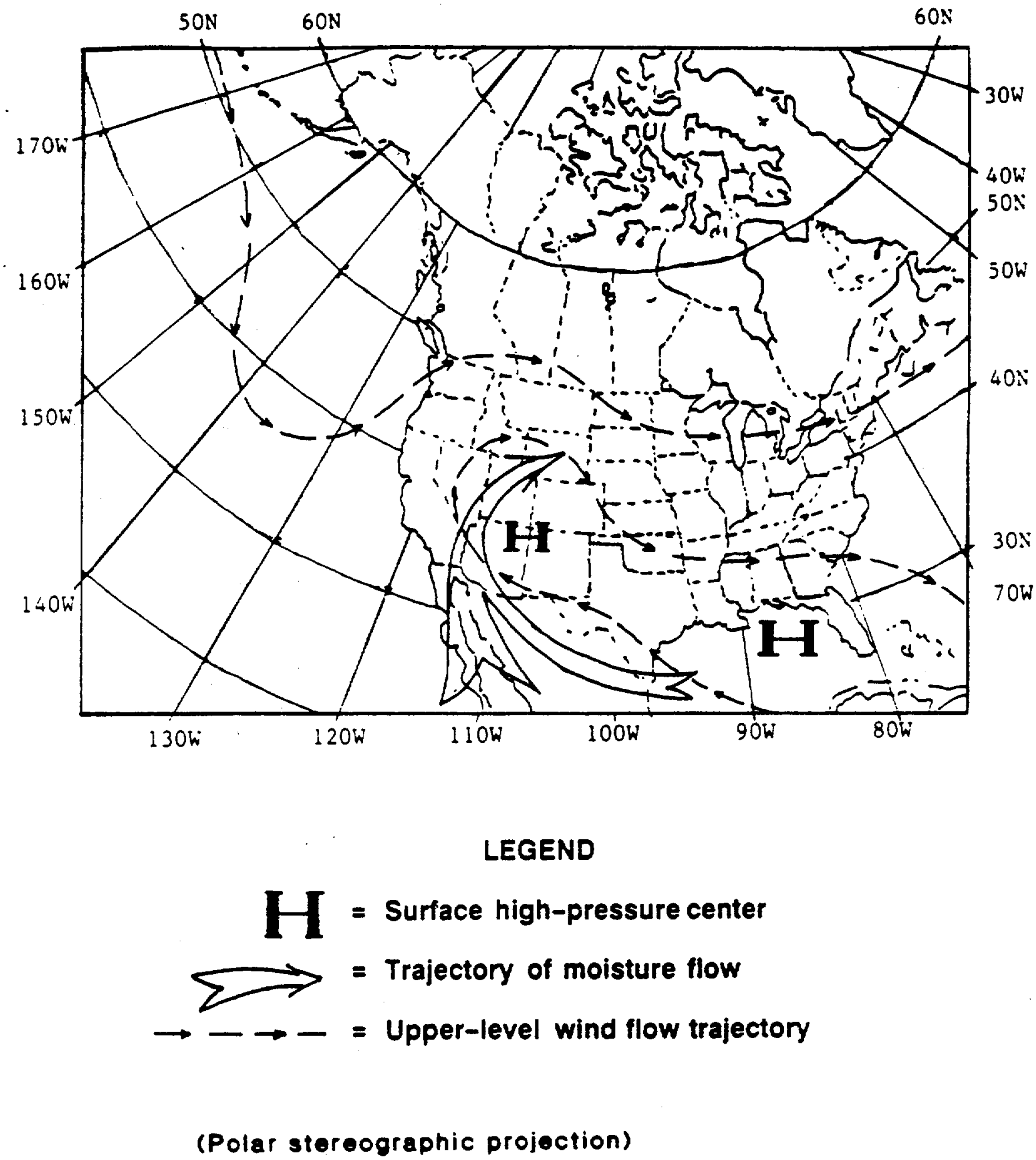


Figure 3.1-15. Summer southwest monsoon. Shown is a lobe of the Bermuda High over the four-corners region. The resulting pressure gradient causes a gentle flow of moisture to begin from the tropical eastern Pacific Ocean. The Gulf of Mexico contributes only an insignificant amount of moisture to the southwestern U.S. (From Elliott, 1943)

(1972), Houghton (1969), and the U.S. Weather Bureau (1966) believed the moisture source to be the Gulf of Mexico for precipitation events in Southern California and the Great Basin. However, Rasmusson (1967) found that low-level moisture flow (below 800 mb) was southwesterly while high-level flow (750-500 mb) was from the south-southeast. In 1972, Pyke stated that he believed late-summer precipitation in the desert southwest was fed by moisture from the warm water of the Gulf of California, the Pacific Ocean south and West of Baja California, and to a certain extent, the Gulf of Mexico. He concluded that easterly waves from the Gulf of Mexico could trigger thunderstorms, and that the most likely source of moisture is the Gulf of California or even the Pacific Ocean west of Baja. Hales (1972 and 1974) held a similar view. He analyzed summer monsoon moisture in southern Arizona and concluded that the greatest percentage of tropical moisture in the southwestern United States and northwestern Mexico comes from the Pacific Ocean via the Gulf of California rather than the Gulf of Mexico. Studies prior to 1970 seem to favor the Gulf of Mexico argument while studies since 1970 favor the Gulf of California conclusion.

In its most active state, the monsoon manifests itself by forming "mesoscale convective complexes" (MCC) over Arizona and New Mexico. On rare occasions an MCC will intrude into southern Nevada, offering the greatest opportunity for localized flash flooding, hail, and strong winds. Hansen (1975) studied heavy rainfall incidents at Elko, Nevada, Phoenix, Arizona, and Morgan, Utah. He concluded that the Pacific Ocean serves as the source of low-level moisture in all three cases. A number of variables influence thunderstorm activity and govern precipitation amounts, intensity, and duration. Individual storms generally complete a thunderstorm cycle in about 2 hours. Storm movement is predominantly on a northerly trajectory, but will move in a northwesterly or northeasterly direction depending on the upper-air flow pattern. As rule of thumb, a summertime dew point of 10°C indicates that enough low-level moisture is available to generate thunderstorms. Figure 3.1-15 illustrates a simplified circulation pattern of the Southwest Monsoon. The Bermuda High intrudes westward into New Mexico with a lobe extending over Arizona. This creates the pressure gradient (mentioned above) which causes low-level moisture flow from the Gulf of California.

3.1.3.1.3.3 Mesoscale

Planetary and synoptic-scale atmospheric motions were discussed with an emphasis on synoptic features predominant in the southwestern U.S. The discussion of atmospheric scales of motion continues with the *mesoscale*. Mesoscale motions of the atmosphere generally occur on a length scale of 10 to 100 km. At this scale not only is topography a significant factor, but surface frictional effects also come into play. The rotation of the earth that greatly affects synoptic-scale weather plays only a secondary role on the mesoscale. One example of mesoscale phenomena is the mountain-valley wind effect. This circulation effect results from diurnal heating and cooling of mountain sides and valley floor throughout the cycle of a 24-hour period. During the day, sunlit slopes and peaks become heated and the air surrounding the mountain becomes warmer than the air in the more-shaded valley floor. This results in an upslope breeze which intensifies throughout the afternoon. This effect is the "valley breeze". After sunset the air against the mountainside cools and begins to flow downhill as it becomes denser than the free air over the valley. This effect is known as a "mountain breeze" and may continue until shortly before sunrise. These breezes are gentle because of frictional effects and the shallowness of the layer (less than 100 meters).

Another and more important mesoscale phenomenon is the thunderstorm. A typical thunderstorm results from thermal convection when the atmosphere is statically unstable. The distribution of thunderstorms is a direct consequence of the heating patterns coupled with the availability of moisture. There are several types of thunderstorms. Those that result purely from local heating are called "airmass thunderstorms" and tend to be less violent. Those that develop in response to a lifting mechanism such as a cold front or mountain range (orographic effect) are sometimes more severe with heavy rain, hail, and strong winds. Although the average single thunderstorm cell may cover an area of only 10 km^2, a cluster mesoscale convective complex (MCC) may form covering a larger area (200 km^2). MCCs may cause heavy flash flooding. The most severe thunderstorms develop into squall lines ahead of a cold front, however, this effect is not common in the southwest U.S.

Many aspects of this study will be confined to the mesoscale environment of Yucca Mountain and vicinity. Although synoptic-scale features (cyclones, frontal systems, and anticyclones) dominate the wintertime environment surrounding Yucca Mountain, resulting precipitation patterns will be analyzed at the mesoscale for the study area. In summer, thunderstorms resulting from the southwest monsoonal flow develop over the study area. Thunderstorms and high-intensity precipitation cells imbedded within regional storm systems are examples of mesoscale storm features that will be considered in this study (see Section 3.1.3.4.1). Mesoscale mountain-valley breezes are not significant in terms of affecting precipitation. However, this study will consider the potential orographic effects of Yucca Mountain on causing or enhancing precipitation.

French (1983) analyzed the distribution of precipitation resulting from the winter and summer weather regimes across southern Nevada. He concluded that two zones (one winter and one summer) of precipitation can be identified and separated by a transition zone. These zones, south of 38.5 degrees north latitude, contain major orographic and topographic features which influence precipitation. In winter, the flow regime is from the west, resulting in a "rain shadow" east of the mountains, as discussed in the previous section. In the summer the primary source of moisture is from the southwest. The air flow curves to the east as it crosses southern Nevada as shown in Figure 3.1-16. The net effect of these two phenomena is to provide some areas of southern Nevada with a relative excess of precipitation while other areas receive a relative deficit.

As discussed previously, orographic influences on precipitation are important to consider in an analysis of precipitation trends resulting from synoptic-scale and mesoscale weather patterns and their relations to sources of moisture.

French (1986) analyzed precipitation-elevation relations and calculated a positive gradient of 28 mm average annual precipitation (AAP) per 1000 vertical ft using linear regression and a sample of 63 selected precipitation stations in the southern Nevada region. He also calculated a gradient of 38 mm per 1000 ft for a sample of 12 stations on the Nevada Test Site with lengths of record of 10 years or more. Hevesi (1990), calculated a gradient of 31 mm per 1000 ft for the subset of French's sample consisting of 42 stations with lengths of record of 8 years or more. In both studies, log-linear relations were found to provide slightly improved regression results compared to linear relations. Figure 3.1-17 shows a plot of AAP as a function of station elevation for the subset of 42 precipitation stations selected by Hevesi (1990). The best-fit curves obtained for this sample and for the two samples analyzed by French (1986) are also plotted for comparison.

3.1.3.1.3.4 Microscale

Finally, the finest scale on which distinct atmospheric disturbances occur is the *microscale*. Examples of effects on this scale are tornadoes and dust devils. Dust devils are a fair-weather phenomenon and are a product of intense heating on the desert floor. They are typically 10 m in diameter with a rotational velocity of 10 m/s. Tornadoes are much more violent products of severe thunderstorms and are very rare in the southwestern U.S. They are on the order of several hundred meters in diameter although some have been reported as wide as 1 km or more. Tornado lifecycles are on the order of

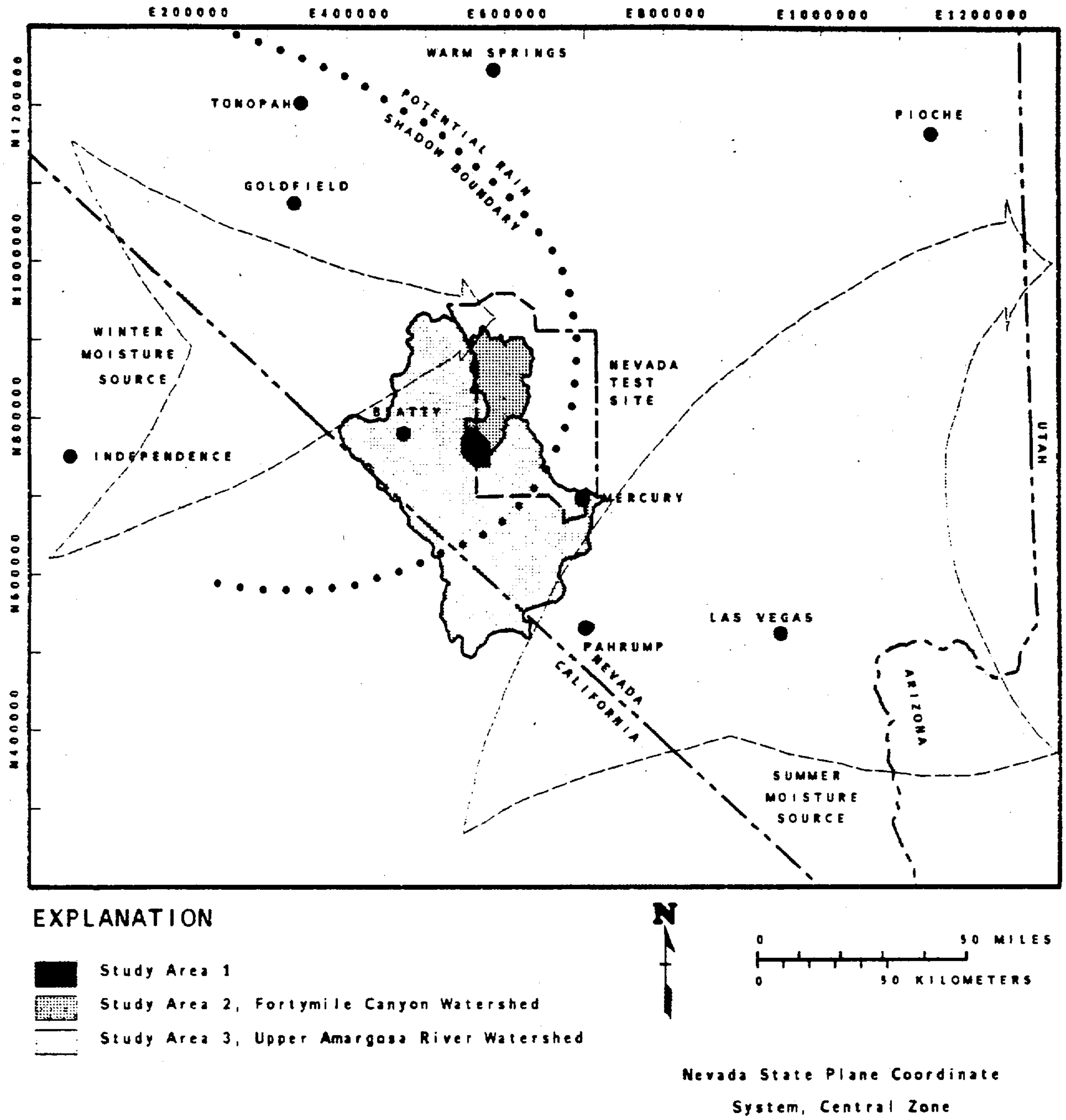


Figure 3.1-16. Dominant summer and winter moisture sources for the southern Nevada area.

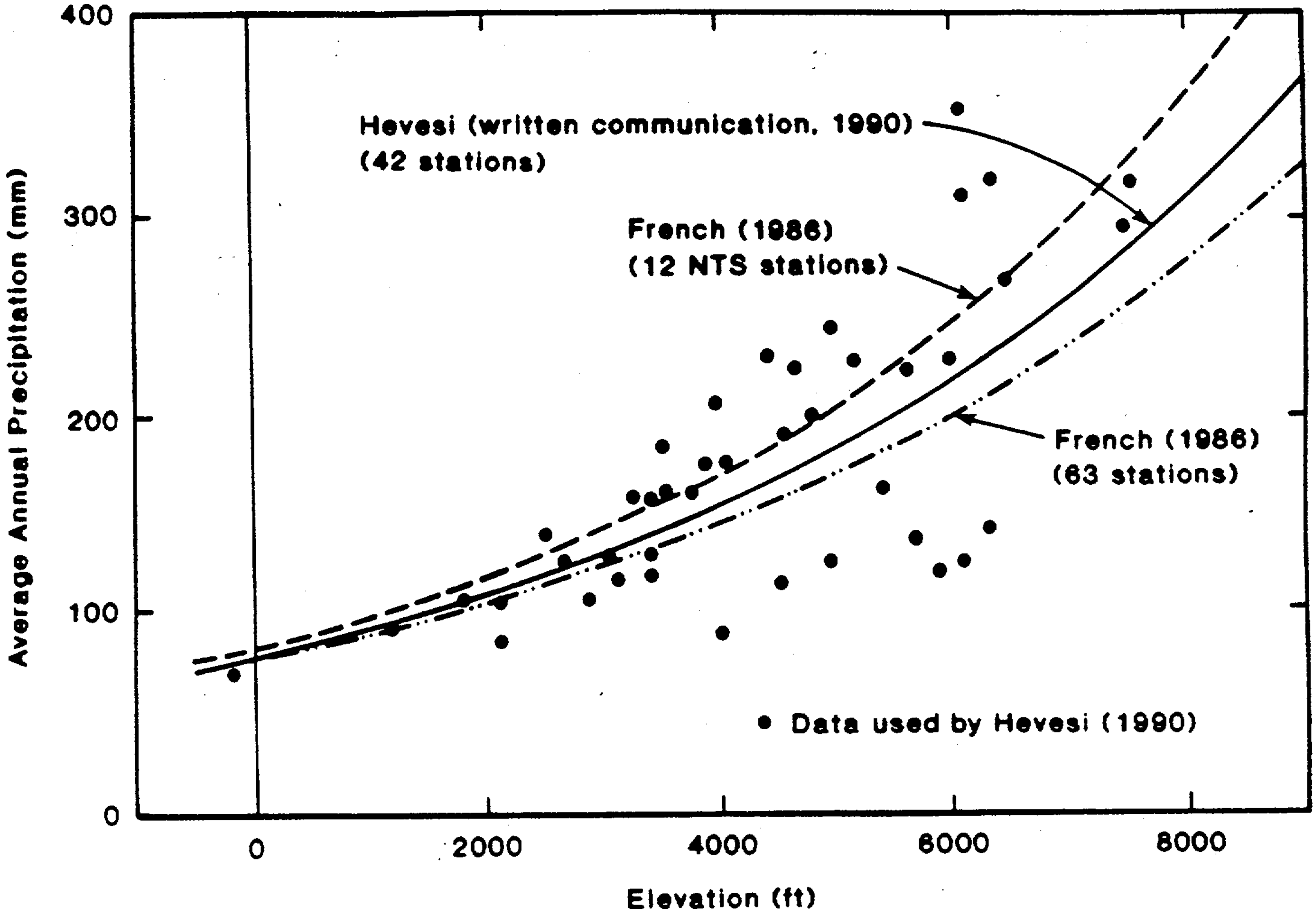


Figure 3.1-17. Regression curves relating annual average precipitation (mm) with precipitation gage elevation (ft). Also included are the data from 42 precipitation stations used to obtain the regression curve by Hevesi.

minutes to one hour. Rotational wind velocities are on the order of 100 to 150 m/s.

This study will consider meteorological effects on all scales but will primarily focus on mesoscale precipitation events. Effects of precipitation on the microscale within areas 1, 2, and 3 will be studied in detail in this and other studies (Study 8.3.1.2.2.1, Unsaturated-zone infiltration). There are a number of hypotheses that this study will address. These hypotheses are important in the development of this study, and they will be further developed as a result.

3.1.3.1.3.5 Important mesoscale considerations

Seven major concerns for study have been proposed, the validity of which will be explored. All deal with different aspects of determining how the upper Amargosa River watershed is affected by the amount, duration, frequency, intensity, timing, and type of precipitation (or lack thereof).

The first concern states that there are two annual precipitation maxima evident in southern Nevada, one winter and one summer. Two synoptic weather types (types C and E discussed in Section 3.1.3.1.3.2) produce the bulk of the wintertime precipitation. The summer weather regime is quite different. The southwest monsoon can produce short-duration but very heavy and intense precipitation. The objective will be to document and evaluate the effects of the type, amount, intensity, duration, and spatial variability of precipitation patterns. These data will be used to evaluate the effects of precipitation on surficial runoff and infiltration into the unsaturated zone at Yucca Mountain (Study 8.3.1.2.2.1, Unsaturated-zone infiltration; and Study 8.3.1.2.1.2, Regional runoff and streamflow).

Second, mountainous regions are well known for their orographic (mechanical lifting) influence on the passage of air masses. This lifting causes or enhances precipitation from frontal activity and thunderstorm development. Higher elevations generally receive increased precipitation. Yucca Mountain may provide sufficient lifting to generate precipitation-producing clouds depending upon the moisture availability and atmospheric stability. The objective is to determine if the presence of Yucca Mountain has an effect on the location of storm development and movement within the Amargosa watershed. For example, do wind direction and speed over the mountain have a bearing on the amount of precipitation, storm duration, intensity, and areal coverage?

Third, intense cloud-to-ground lightning is generally associated with the heaviest precipitation band within a thunderstorm (Goodman and Buechler, 1990). Lighting can also be used to track the progress and life cycle of a thunderstorm. Lightning data will indicate, in real time, where the heaviest runoff will probably originate. Lightning activity using the in-place Nevada Test Site lightning location network will be correlated with ground-based precipitation measurements. The objective will be to determine the origin and movement of thunderstorms in relation to Yucca Mountain.

Fourth, recent studies (Scott, 1989) indicate that cloud-to-cloud (intercloud and intracloud) lightning occurs during the early stages of storm development and is a precursor to cloud-to-ground strikes. Early detection of cloud-to-cloud lighting may provide early warning regarding the development and movement of a thunderstorm. The goal is to provide lead time to researchers studying water runoff and infiltration (Studies 8.3.1.2.2.1 and 8.3.1.2.1.2) so that runoff events may be observed and sampled, and to correlate this lightning activity with potential precipitation areas.

Fifth, it is possible that the topographic relief of Yucca Mountain's washes and canyons may have an effect on the amount of precipitation received at a given location. For example, small canyons may consistently shelter an area while exposed locations receive more precipitation. To determine these effects, a sufficiently dense network of precipitation gages will be deployed (see Section 3.1.3.2.1.2.2). This will enable investigators to measure discrete differences in precipitation amounts and to determine an overall predictor for precipitation falling on a given section of the mountain.

Sixth, southern Nevada, and indeed, much of the southwestern U.S. is experiencing a prolonged drought. As of the end of 1989, the drought was entering its third year. The region has experienced much wetter periods in the recent past, and this drought period is an anomaly in the recent climatology of the region. To determine the actual extent of the drought, past records (40-50 years) of the region will be statistically analyzed using time-series and spectral analyses in order to relate past and present conditions. On a larger scale, investigators will study drought-excess precipitation events in southern Nevada in relation to large-scale controlling influences, such as the El Nino and the Southern Oscillation sea-surface temperature phenomenon (an oscillation of atmospheric pressure in the Pacific Ocean). The overall objective is to put present and future weather events in perspective with normal trends and variations for present climatic conditions.

Seventh, frequent, heavy precipitation is a concern of other studies (see 3.1.2). For example, one or more inches of rainfall, followed within one to two days by a second storm producing one or more inches of rainfall, would most likely result in a runoff situation after the second event. Rainfall of this amount and frequency is probable, especially in summer. Historical precipitation data will be statistically analyzed to determine the probabilities of subsequent episodes of high-intensity precipitation.

3.1.3.1.4 Meteorological parameters of interest

The parameters to be measured during this study are: precipitation, air temperature, relative humidity, barometric pressure, shortwave radiation, and wind speed and wind direction. These parameters will be analyzed to provide diurnal, seasonal, and spatial variability. Precipitation measurements will include the amount, intensity, duration, timing frequency, and type. Also of interest are lightning and cloud data. Lightning-strike patterns have been correlated with sudden gushes of precipitation from a thunderstorm (Moore, and others, 1962 and 1964; Szymanski and others, 1980; Piepgrass and Krider, 1982; and Goodman and Buechler, 1990). Lightning-strike data, collected within the study areas, will indicate if regional topography enhances thunderstorm development, movement, and speed, or modifies precipitation amounts. In addition, lightning data may be a predictor of where the heaviest surface-water runoff will occur. Inter- and intracloud lightning activity is of similar interest. These data will give an early indication of when and where thunderstorm development is occurring within the study area. Cloud information is important for two reasons: 1) satellite-derived data can be used to identify and track major synoptic low pressure systems and thunderstorms moving into the study areas, and 2) time-lapse photography of cloud development can be used to determine if Yucca Mountain or the surrounding peaks have an orographic influence on storm development or modification.

3.1.3.1.5 General climatic overview: current conditions

As discussed in Section 3.1.3.1.1., Yucca Mountain is mainly located in the northern Mojave Desert with part of the study area located in the southern Mojave, and is one of the driest locations in the country. In Section 3.1.3.1.3., it was discussed that Yucca Mountain is in the rain shadow of the Sierra Nevada mountains during the winter atmospheric-flow regime. During summer, air flow from the southwest through southeast crosses into southern Nevada, then recurves eastward into southern Utah and northwestern Arizona. Yucca Mountain is located in the western portion of the transition zone between these seasonal flow regimes. French (1983) concluded annual precipitation to be a deficit west of the transition zone and an excess east of the transition zone, relative to the areal mean average annual precipitation (AAP) for the southern Nevada region (Figure 3.1-16). In other words, flash flooding is more likely in the area of precipitation excess east of the Nevada Test Site (NTS) than in the area of the rain shadow west of the NTS.

As a prototype exercise, an isohyetal map of AAP for study area 4 (Figure 3.1-18) was prepared using kriging interpolation and 42 selected southern Nevada and southeastern California precipitation stations with lengths of record of 8 years or more. Kriging refers to a geostatistical technique of linear interpolation using the available measurements and a spatial correlation model, referred to as a variogram. A selected model variogram defined in a preliminary geostatistical analysis (Hevesi, 1990), was used to calculate estimates. The resulting surface indicates minimum values of less than 100 mm in the Death Valley area and maximum values of more than 300 mm at three separate locations close to the eastern boundary of area 4 (Figures 3.1-5 and 3.1-18).

Recent estimates of AAP for study area 3 were provided by Hevesi (1990) and are indicated by isohyetal mapping of cokriged estimates (Figure 3.1-19). Cokriging is an extension of kriging (defined above) utilizing additional, correlated variables to obtain estimates for one variable using linear interpolation. The estimates were obtained using a relatively large sample of ground elevations in addition to a selected sample of AAP values. These results represent an initial application of geostatistics to model the orographic influence of ground elevation on AAP in an effort to obtain improved estimates. The resulting isohyetal surface indicates a pronounced increase in detail and complexity relative to the isohyetal mapping for area 4 obtained from estimates calculated from the AAP sample only. A maximum estimate within study area 3 of 335 mm occurs at a high point on Pahute Mesa and a minimum estimate of 79 mm occurs at an elevation of 2000 ft in the southern Amargosa Desert. Estimates for Yucca Mountain range from 130 mm to over 200 mm, depending on elevation. An areal average estimate for study area 3 of 157 mm was calculated. An estimate of 165 mm was calculated for a location at the approximate center of the proposed repository site. This estimate is in close agreement with previous estimates of 160 mm (Eglington and Dreicer, 1984) and 150 mm (Quiring, 1983) for the location of the proposed surface facilities, which is at a lower elevation than the approximate center of the proposed repository. An advantage of the geostatistical method is that if assumptions concerning the multivariate model and the multivariate log-normal distribution of AAP are correct, a 95-percent confidence interval of 115 mm to 220 mm is obtained for the current estimate of AAP at the proposed repository site.

Current conditions at Yucca Mountain have been monitored by two USGS weather stations since 1987 and by three additional stations since early 1989 (Section 3.1.3.2.1.1.1). These are described in detail in Section 3.1.3.2.1.2. A summary of the data from station 4 at Yucca Crest is shown in Table 3.1-1. Weather station 4 sampled every 10 seconds and averaged the data every 15 minutes. Although only two complete years of data are available from weather station 4, some important observations concerning current weather patterns can be made.

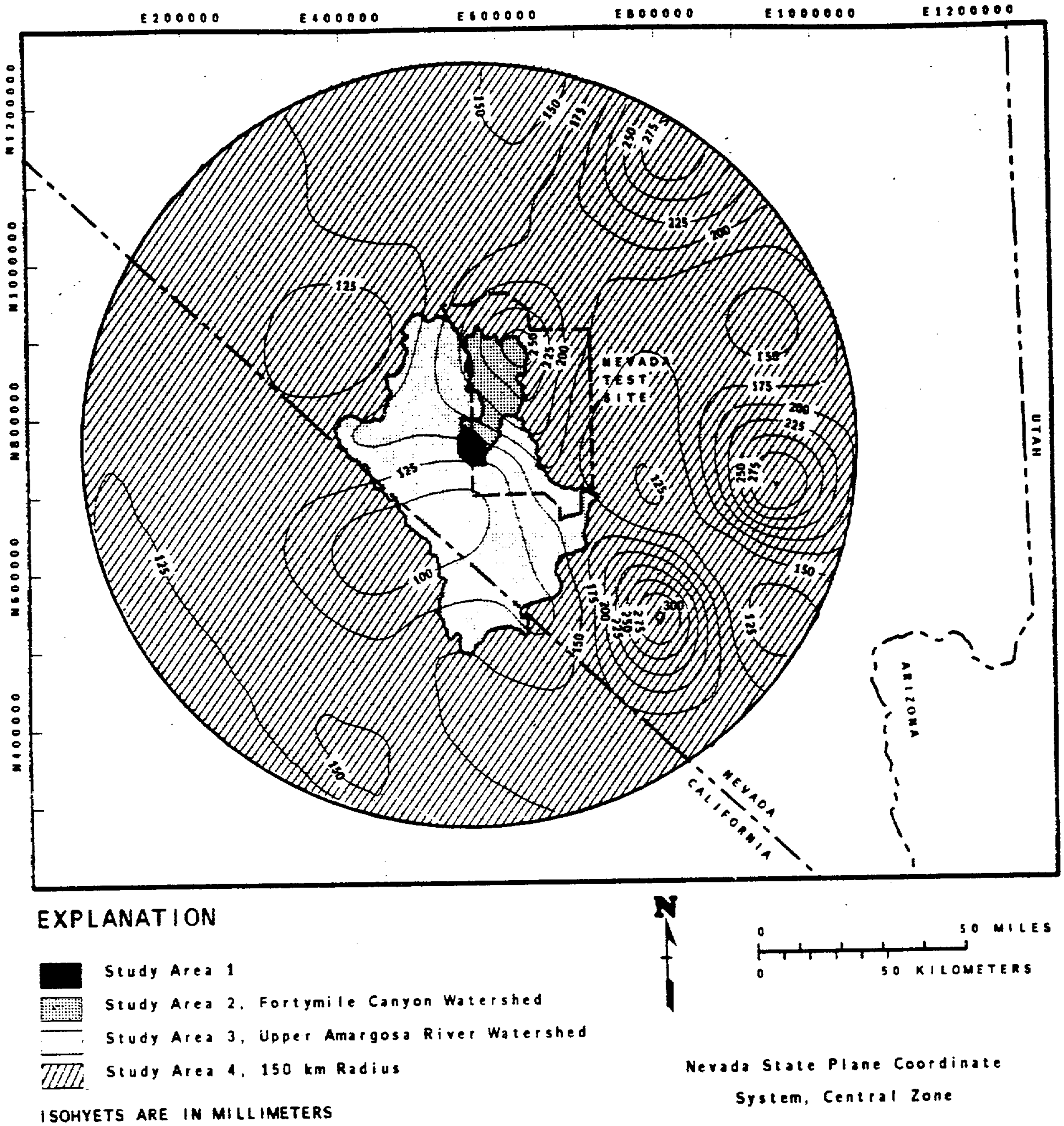


Figure 3.1-18. An estimation of average annual precipitation for study area 4 using kriging interpolation. Estimates were calculated using precipitation data from 42 selected precipitation stations with lengths of record of 8 years or more.

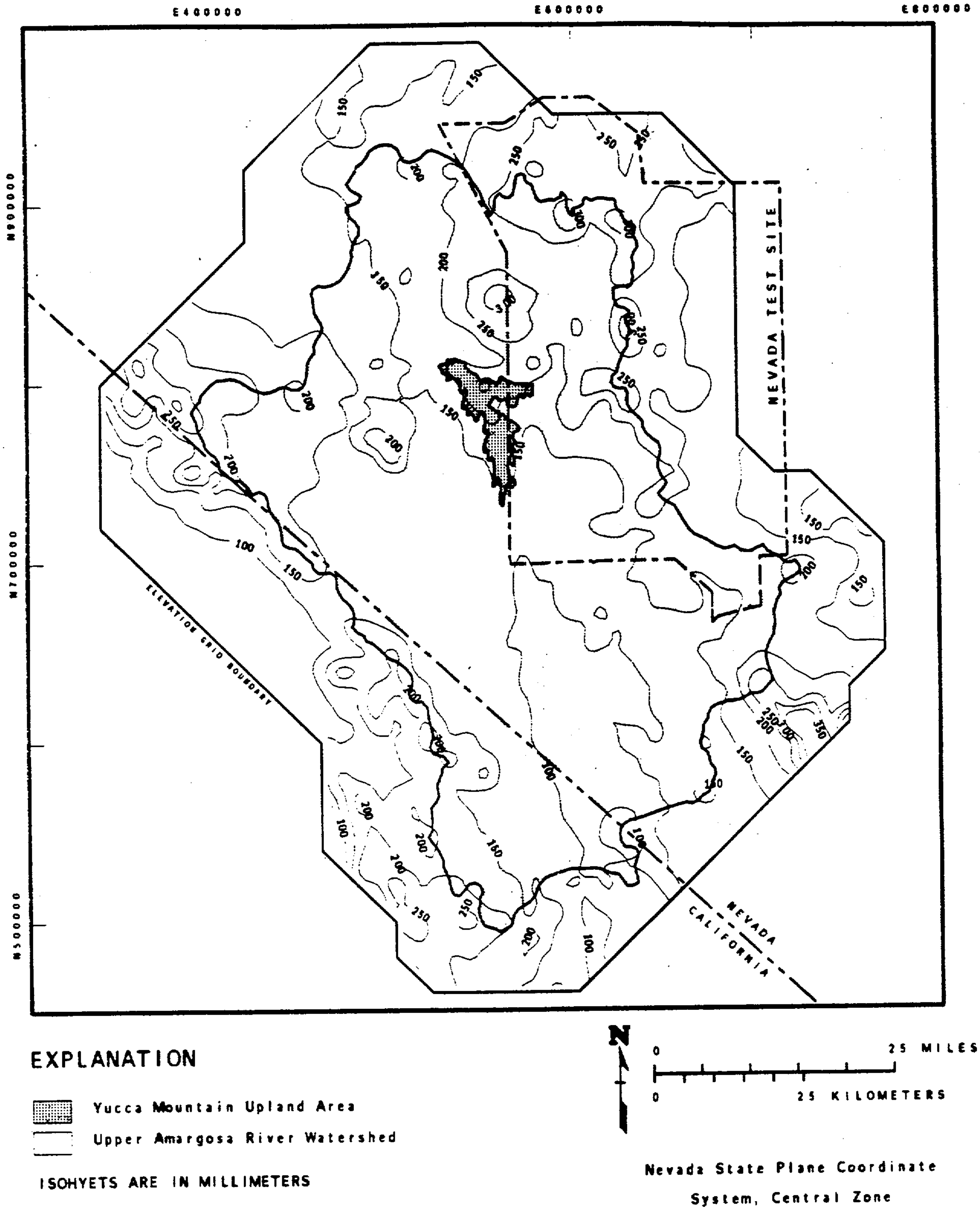


Figure 3.1-19. An estimation of average annual precipitation for study area 3 using cokriging interpolation. Estimates were calculated using precipitation and elevation data from 42 selected precipitation stations with lengths of record of 8 years or more and also ground elevation data from 1,531 regularly spaced grid locations.

Table 3.1-1 Summary of data from Weather Station 4 near the crest of Yucca Mountain, 1988-89

1988 DATA

Month	Extreme Max (°C)	Mean Max (°C)	Mean Monthly (°C)	Mean Min (°C)	Extreme Min (°C)	Mean Direction (Degrees)	Mean Speed (M/S)	Extreme Speed (M/S)	Precipitation (mm)
Jan	14.4	11.0	3.7	-4.5	-8.1	76	3.3	14.7	8.0
Feb	19.0	14.1	8.8	1.1	-2.8	38	3.3	13.2	17.0
Mar	24.5	19.1	9.8	0.7	-3.9	82	3.9	14.7	0.0
Apr	25.5	20.2	12.7	4.5	2.0	132	3.7	13.1	47.0
May	30.5	25.0	17.6	4.8	-1.6	127	4.0	12.9	8.0
Jun	35.8	30.1	23.9	11.9	5.3	135	4.4	12.9	0.0
Jul	39.8	34.0	28.8	24.4	17.8	125	3.6	11.5	3.0
Aug	35.9	30.1	26.0	23.3	17.4	132	3.4	11.8	16.0
Sep	35.1	30.1	22.2	10.1	7.1	107	3.3	10.3	8.0
Oct	30.0	25.2	21.1	16.4	12.7	125	3.3	8.3	0.0
Nov	24.9	19.5	9.1	-0.1	-2.2	107	3.5	11.5	0.0
Dec	19.0	14.4	4.6	-6.4	-10.1	80	3.4	12.3	2.0

1989 DATA

Month	Extreme Max (°C)	Mean Max (°C)	Mean Monthly (°C)	Mean Min (°C)	Extreme Min (°C)	Mean Direction (Degrees)	Mean Speed (M/S)	Extreme Speed (M/S)	Precipitation (mm)
Jan	18.1	11.9	4.1	-3.2	-6.6	68	3.1	10.8	1.0
Feb	21.8	15.8	5.1	-9.8	-13.8	94	3.3	9.4	7.0
Mar	22.6	17.5	11.7	0.0	-5.7	121	3.9	12.8	0.0
Apr	31.2	25.1	18.0	6.5	0.2	73	4.0	12.0	0.0
May	32.3	25.7	18.3	4.5	1.1	118	4.0	12.6	6.0
Jun	36.5	30.5	24.0	18.3	12.2	112	3.9	11.6	0.0
Jul	40.6	34.6	29.0	23.3	17.5	127	3.8	9.1	0.0
Aug	36.2	29.8	24.9	19.9	14.2	134	4.0	14.1	30.0
Sep	32.0	26.6	22.0	11.7	6.8	117	4.2	12.3	11.0
Oct	27.7	22.9	15.4	5.3	-0.9	101	3.9	10.2	4.0
Nov	22.9	18.6	12.3	2.1	-2.3	68	3.1	12.3	0.0
Dec	19.5	15.4	8.4	-0.3	-4.3	100	2.6	11.1	0.0

CUMULATIVE DATA 1988-1989

Month	Extreme Max (°C)	Mean Max (°C)	Mean Monthly (°C)	Mean Min (°C)	Extreme Min (°C)	Mean Direction (Degrees)	Mean Speed (M/S)	Extreme Speed (M/S)	Precipitation (mm)
Jan	18.0	11.5	3.9	-3.9	-8.1	72	3.2	14.7	4.5
Feb	21.8	15.0	6.9	-4.4	-13.8	66	3.3	13.2	12.0
Mar	24.5	18.3	10.8	0.4	-5.7	102	3.9	14.7	0.0
Apr	31.2	22.7	15.3	5.5	0.2	103	3.8	13.1	23.5
May	32.3	25.4	17.9	4.7	-1.6	123	4.0	12.9	7.0
Jun	36.5	30.3	23.9	15.1	5.3	124	4.2	12.9	0.0
Jul	40.6	34.3	28.9	23.9	17.5	126	3.7	11.5	1.5
Aug	36.2	30.0	25.4	21.6	14.2	133	3.7	14.1	23.0
Sep	35.1	28.4	22.1	10.9	6.8	112	3.7	12.3	9.5
Oct	30.0	24.1	18.2	10.9	-0.9	113	3.6	10.2	2.0
Nov	24.9	19.1	10.7	1.0	-2.3	88	3.3	12.3	0.0
Dec	19.5	14.9	6.5	-3.4	-10.1	90	3.0	12.3	1.0

The extreme maximum or minimum is the highest or lowest temperature recorded in each month based on a 15-minute average. The mean maximum and minimum are the monthly average of the daily high or low for the month. The mean monthly is an average temperature for the month based on all the 15-minute data. July is clearly the warmest month with the highest extreme maximum recorded for the year (40.6 °C), the highest monthly mean maximum (34.3 °C), and the highest monthly mean (28.9 °C). In this brief record, the coldest month is either January or February. January features the lowest mean monthly temperature (3.9 °C), while February posts the lowest mean minimum temperature (-4.4 °C) and the lowest extreme low temperature of -13.8 °C.

Wind data at weather station 4 are not representative of the general wind flow past Yucca Mountain because of the location of the station (Table 3.1-1). Note that southeasterly winds dominate from March to October and east to northeast winds are predominant in November through February. Weather station 4 is about 100 m below and east of the crest of Yucca Mountain. Thus, it is sheltered from westerlies (southwest through northwest) which are dominant in winter due to the frequent passage of frontal systems. It has been observed on many occasions that a strong wind with a westerly component at the crest results in an easterly wind component at weather station 4. The apparent effect is one caused by the wind curling over the crest and creating a vertical rotor on the lee side. The bottom (upslope) part of the rotor is detected by the station wind vane. From personal on-site observation, this effect is most pronounced when the prevailing wind is blowing strongly perpendicular to the crest. This phenomenon can be more fully investigated using data from two automated weather stations on the crest of Yucca Mountain, one of which is operated by the U.S. Department of Commerce Weather Service Nuclear Support Office (WSNSO) and located about 150 m southwest of weather station 4. The other is operated by SAIC and is located on the crest about 2000 meters north of weather station 4. In spring through fall, the effect seems to be less pronounced because the prevailing wind direction becomes more southerly. Therefore, it is clear that terrain significantly influences wind direction. Wind speeds are also influenced by this mountain turbulence and should, therefore, only be used with this in mind. This kind of information emphasizes the need to have multiple stations on and around Yucca Mountain as well as to be aware of the deterministic process that may influence the data and restrict its representativeness of the character of atmospheric movement over the Yucca Mountain landscape.

Precipitation, one of the major considerations in this study, is biased by the short record. Even though most of the precipitation in the Mojave comes in the winter (Section 3.1.3.1.1), the last two years (1988 and 1989) have been atypical relative to a 53-year period of measurement at Beatty for the southern Nevada region. In 1989, over half of the annual precipitation came in August in the form of thunderstorms. The average annual precipitation for weather station 4 is estimated to be 175 mm (Hevesi, 1990); however 1988 had only 109 mm and 1989 only 59 mm. This illustrates the variance in AAP and emphasizes the need to have longer-duration precipitation data for Yucca Mountain.

Daily weather conditions at Yucca Mountain and vicinity are currently being recorded. The record includes surface weather observations at Mercury, Las Vegas, Indian Springs, and Nellis Air Force Base. The data, logged at least once per day, consist of sky conditions, visibility, wind, temperature, humidity, and precipitation. Also documented are the daily forecast and the 5-day outlook for southern Nevada. The locations of major frontal systems and jet streams (storm tracks) are drawn on small maps and affixed to the daily log book. Weather chart and map data are provided via a dial-up weather-reporting service. This temporary method of obtaining weather charts will be replaced in the future by a more permanent means via computer link with the National Weather Service. A bulletin board dial-in service (called the Meteorological Alert and Warning System, or MADS) has been recently brought on-line by WSNSO. MADS provides southern Nevada weather observations and forecasts as well instantaneous access to the automated weather stations located on the crest of Yucca Mountain and at Jackass Flats. A visual observation of general weather conditions over Yucca Mountain is also logged each day.

3.1.3.2 Data collection and assimilation

With a few exceptions, data collection will be accomplished by automated data-acquisition platforms. The exact configuration of each platform will depend upon the particular phenomenon being investigated. The details of a particular data-collection effort will be addressed in the pertinent sections of this study plan. Data assimilation involves the incorporation of meteorological data not measured under this study plan. The details of this effort will be outlined in Section 3.1.3.2.1.1.5. Refer to Table 3.1-2 for a complete listing of USGS meteorological and precipitation stations that were active during early 1990.

3.1.3.2.1 Data measurement sites

Meteorological monitoring will be accomplished using a network of monitoring stations installed in the field specifically for this study. Data from these stations will be integrated with data from other networks operated by other agencies for various purposes. Section 3.1.3.2.1.1 describes the instrumentation and operation of the various monitoring stations specific to this study, including both currently existing and planned monitoring stations. Procedures for meteorological monitoring using remote sensing and alternative methods will also be discussed. The location of existing and planned field sites is discussed in Sections 3.1.3.2.1.1 and 3.1.3.2.1.2, with particular emphasis on

Table 3.1-2 List of all USGS active weather stations (1990), including full meteorological stations and precipitation gauges, parameters measured, location, sampling and averaging frequency, and date installed.

U.S. GEOLOGICAL SURVEY
ACTIVE WEATHER STATIONS

STATION	PARAMETERS: WIND DIR	WIND VEL	TEMP	REL HUM	SOLAR RADIA	PRESS	PRECIP	COORDINATES: EASTING (FEET)	NORTHING (FEET)	ELEVATION (FEET)	SAMPLING FREQUENCY	AVERAGING FREQUENCY	DATE INSTALLED
WX STATION 1	X	X	X	X	X	X	TB(2)*	567934	759011	3815	ONCE/10 SEC	15 MIN	12/31/87
WX STATION 2	X	X	X	X	X	X	TB(2)	610564	743968	3492	ONCE/10 SEC	15 MIN	03/07/89
WX STATION 3	X	X	X	X	X	X	TB(2)	560148	771482	4432	ONCE/10 SEC	15 MIN	07/16/87
WX STATION 4	X	X	X	X	X	X	TB(2)*	558356	760134	4915	ONCE/10 SEC	15 MIN	07/01/87
WX STATION 5	X	X	X	X	X	X	TB(2)	554986	782850	5870	ONCE/10 SEC	15 MIN	06/23/88
FRAN RIDGE							TB(2)*	573575	754015	4062	ONCE/10 SEC	15 MIN	02/08/89
USW G-3							TB(2)*	560265	751136	4765	ONCE/10 SEC	15 MIN	05/08/89
UE-25 UZN #1							S	565224	769329	3995	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #2							S	566114	768606	3947	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #3							S	566119	768630	3941	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #4							S	566127	768663	3942	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #5							S	566134	768689	3943	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #6							S	566137	768706	3938	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #7							S	566141	768724	3939	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #8							S	566147	768743	3939	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #9							S	566156	768782	3941	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #10							S	564744	769869	4038	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #12							S	566695	768651	3907	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #13							S	568255	768025	3821	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #14							S	568233	767967	3824	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #18							S	565247	766472	4019	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #19							S	564571	763689	4025	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #20							S	564579	763760	4027	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #21							S	564591	763806	4028	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #22							S	564605	763880	4029	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #23							S	564545	763973	4043	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #28							S	565320	763091	3958	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #29							S	565173	762613	3973	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #30							S	565233	762048	3959	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #56							S	565480	760394	3960	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #60							S	566567	759757	3892	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #85							S	577568	750716	3337	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #92							S	583559	778010	3669	PER PCP EVENT	N/A	JAN 1990
UE-25 UZN #97							S	565321	763094	3958	PER PCP EVENT	N/A	JAN 1990
UE-29 UZN #91							S	585341	797275	3647	PER PCP EVENT	N/A	JAN 1990
USW UZ-N24							S	562054	768005	4227	PER PCP EVENT	N/A	JAN 1990
USW UZ-N25							S	561219	768430	4335	PER PCP EVENT	N/A	JAN 1990
USW UZ-N26							S	561023	768757	4384	PER PCP EVENT	N/A	JAN 1990
USW UZ-N40							S	564221	766176	4079	PER PCP EVENT	N/A	JAN 1990
USW UZ-N41							S	563521	765867	4118	PER PCP EVENT	N/A	JAN 1990

Table 3.1-2 List of all USGS active weather stations (1990), including full meteorological stations and precipitation gauges, parameters measured, location, sampling and averaging frequency, and date installed (continued).

STATION	PARAMETERS: WIND DIR	WIND VEL	TEMP	REL HUM	SOLAR RADIA	PRESS	PRECIP	COORDINATES: EASTING (FEET)	NORTHING (FEET)	ELEVATION (FEET)	SAMPLING FREQUENCY	AVERAGING FREQUENCY	DATE INSTALLED
USW UZ-N42							S	562859	765729	4179	PER PCP EVENT	N/A	JAN 1990
USW UZ-N43							S	563264	765997	4149	PER PCP EVENT	N/A	JAN 1990
USW UZ-N44							S	563140	766193	4162	PER PCP EVENT	N/A	JAN 1990
USW UZ-N45							S	563429	765977	4130	PER PCP EVENT	N/A	JAN 1990
USW UZ-N46							S	559748	772262	4501	PER PCP EVENT	N/A	JAN 1990
USW UZ-N47							S	559784	771968	4480	PER PCP EVENT	N/A	JAN 1990
USW UZ-N48							S	562414	760835	4211	PER PCP EVENT	N/A	JAN 1990
USW UZ-N49							S	562322	760860	4229	PER PCP EVENT	N/A	JAN 1990
USW UZ-N50							S	562912	760776	4173	PER PCP EVENT	N/A	JAN 1990
USW UZ-N51							S	562909	760861	4169	PER PCP EVENT	N/A	JAN 1990
USW UZ-N52							S	562909	760894	4172	PER PCP EVENT	N/A	JAN 1990
USW UZ-N65							S	562537	758627	4372	PER PCP EVENT	N/A	JAN 1990
USW UZ-N66							S	561881	758434	4356	PER PCP EVENT	N/A	JAN 1990
USW UZ-N67							S	563799	753634	3920	PER PCP EVENT	N/A	JAN 1990
USW UZ-N68							S	564006	753962	3925	PER PCP EVENT	N/A	JAN 1990
USW UZ-N69							S	564402	754461	3918	PER PCP EVENT	N/A	JAN 1990
USW UZ-N70							S	560165	769251	4542	PER PCP EVENT	N/A	JAN 1990
USW UZ-N71							S	558406	761026	4925	PER PCP EVENT	N/A	JAN 1990
USW UZ-N72							S	558626	761068	4889	PER PCP EVENT	N/A	JAN 1990
USW UZ-N73							S	558926	761049	4867	PER PCP EVENT	N/A	JAN 1990
USW UZ-N74							S	558560	761362	4904	PER PCP EVENT	N/A	JAN 1990
USW UZ-N75							S	559076	761462	4799	PER PCP EVENT	N/A	JAN 1990
USW UZ-N76							S	559048	761353	4958	PER PCP EVENT	N/A	JAN 1990
USW UZ-N77							S	554397	755526	3901	PER PCP EVENT	N/A	JAN 1990
USW UZ-N78							S	556262	757558	4182	PER PCP EVENT	N/A	JAN 1990
USW UZ-N79							S	556334	757733	4155	PER PCP EVENT	N/A	JAN 1990
USW UZ-N80							S	557201	757634	4332	PER PCP EVENT	N/A	JAN 1990
USW UZ-N81							S	555595	757807	4065	PER PCP EVENT	N/A	JAN 1990
USW UZ-N82							S	554690	757498	3975	PER PCP EVENT	N/A	JAN 1990
USW UZ-N83							S	556349	760624	4157	PER PCP EVENT	N/A	JAN 1990
USW UZ-N84							S	555888	760717	4112	PER PCP EVENT	N/A	JAN 1990
USW UZ-N86							S	556460	760615	4172	PER PCP EVENT	N/A	JAN 1990
USW UZ-N87							S	555887	760714	4112	PER PCP EVENT	N/A	JAN 1990
USW UZ-N88							S	556551	760797	4202	PER PCP EVENT	N/A	JAN 1990
USW UZ-N89							S	555589	760610	4090	PER PCP EVENT	N/A	JAN 1990
USW UZ-N90							S	555587	760608	4090	PER PCP EVENT	N/A	JAN 1990
USW UZ-N93							S	558321	759584	4924	PER PCP EVENT	N/A	JAN 1990
USW UZ-N94							S	558236	759724	4926	PER PCP EVENT	N/A	JAN 1990
USW UZ-N95							S	558172	759899	4929	PER PCP EVENT	N/A	JAN 1990
USW UZ-N96							S	558403	759446	4893	PER PCP EVENT	N/A	JAN 1990
USW UZ-N98							S	562084	767996	4223	PER PCP EVENT	N/A	JAN 1990
USW UZ 13							S	558489	751953	4816	PER PCP EVENT	N/A	JAN 1990

Table 3.1-2 List of all USGS active weather stations (1990), including full meteorological stations and precipitation gauges, parameters measured, location, sampling and averaging frequency, and date installed (continued).

STATION	WIND DIR	WIND VEL	TEMP	REL HUM	SOLAR RADIA	PRESS	PRECIP	EASTING (FEET)	NORTHING (FEET)	ELEVATION (FEET)	SAMPLING FREQUENCY	AVERAGING FREQUENCY	DATE INSTALLED
	PARAMETERS							COORDINATES					
USW GA-1							S	559247	779365	5187	PER PCP EVENT	N/A	JAN 1990
USW G-2							S	560504	778824	5098	PER PCP EVENT	N/A	FEB 1990
UE25 WT-4							S	568040	768512	3835	PER PCP EVENT	N/A	FEB 1990
UE25 WT-18							S	564855	771167	4383	PER PCP EVENT	N/A	FEB 1990
USW H-5							S	558909	766634	4851	PER PCP EVENT	N/A	FEB 1990
HRF							S	601180	738889	3400	PER PCP EVENT	N/A	FEB 1990

LEDGEND

TB = TIPPING BUCKET RAINGAUGE
S = STORAGE RAINGAUGE
X = MEASURED PARAMETERS
* = ONE RAINGAUGE HEATED WITH PROPANE IN WINTER
(2) = TWO EACH TIPPING BUCKET RAINGAUGES

the location of precipitation monitoring sites. Methods of determining network accuracy and for determining the optimum expansion of existing networks in terms of both accuracy and efficiency will be described in Section 3.1.3.2.1.2. Procedures for integrating data from other networks will be discussed in Section 3.1.3.2.2.

3.1.3.2.1.1 Data measurements

Data measurements will provide values of parameters at specific locations for specified applications, meteorological records, statistical analysis, geostatistical analysis, and areal estimation. Measurements will be made for all meteorological parameters listed in Section 3.1.3.1.4. This program is still developing and, therefore, many of the field monitoring sites are not yet operational. The locations of currently active precipitation monitoring sites pertinent to this study are indicated in the following figures: Figure 3.1-20 includes only those active sites within study area 1. Figure 3.1-21 includes sites within study area 2 but not in study area 1. Figure 3.1-22 includes sites within study area 3 but not in areas 1 and 2. Figure 3.1-23 includes all sites not in areas 1, 2 and 3. The indicated network comprises stations installed and operated by the USGS specifically for this study, and also stations installed and operated by other agencies for various purposes. Data from these latter stations will be made available for this study.

Note that other meteorologic parameters are monitored at many sites, as listed in Tables 3.1-2 and 3.1-3. For example, the five USGS precipitation monitoring sites listed as "station 1" through "station 5" are also part of the meteorological network for monitoring temperature, humidity, barometric pressure, wind speed and direction, and solar radiation. The tables also indicate the type of precipitation gage installed at a monitoring site. The following three sections provide a detailed description of the monitoring instruments and techniques that will be utilized at data-collection sites for obtaining point measurements of meteorologic parameters, and describe the program as a fully developed system. In addition to data collected at specific monitoring sites, areal measurements of snowpack, cloud cover, and precipitation will be made using remote sensing. These techniques are discussed in detail in Section 3.1.3.2.1.1.4.

3.1.3.2.1.1.1 Meteorological stations

A "standard" meteorological station, as defined for this study, consists of an automated data collection platform with instruments to measure precipitation, air temperature, relative humidity, shortwave radiation, and wind speed and direction. A limited number of stations will be equipped with barometric-pressure sensors.

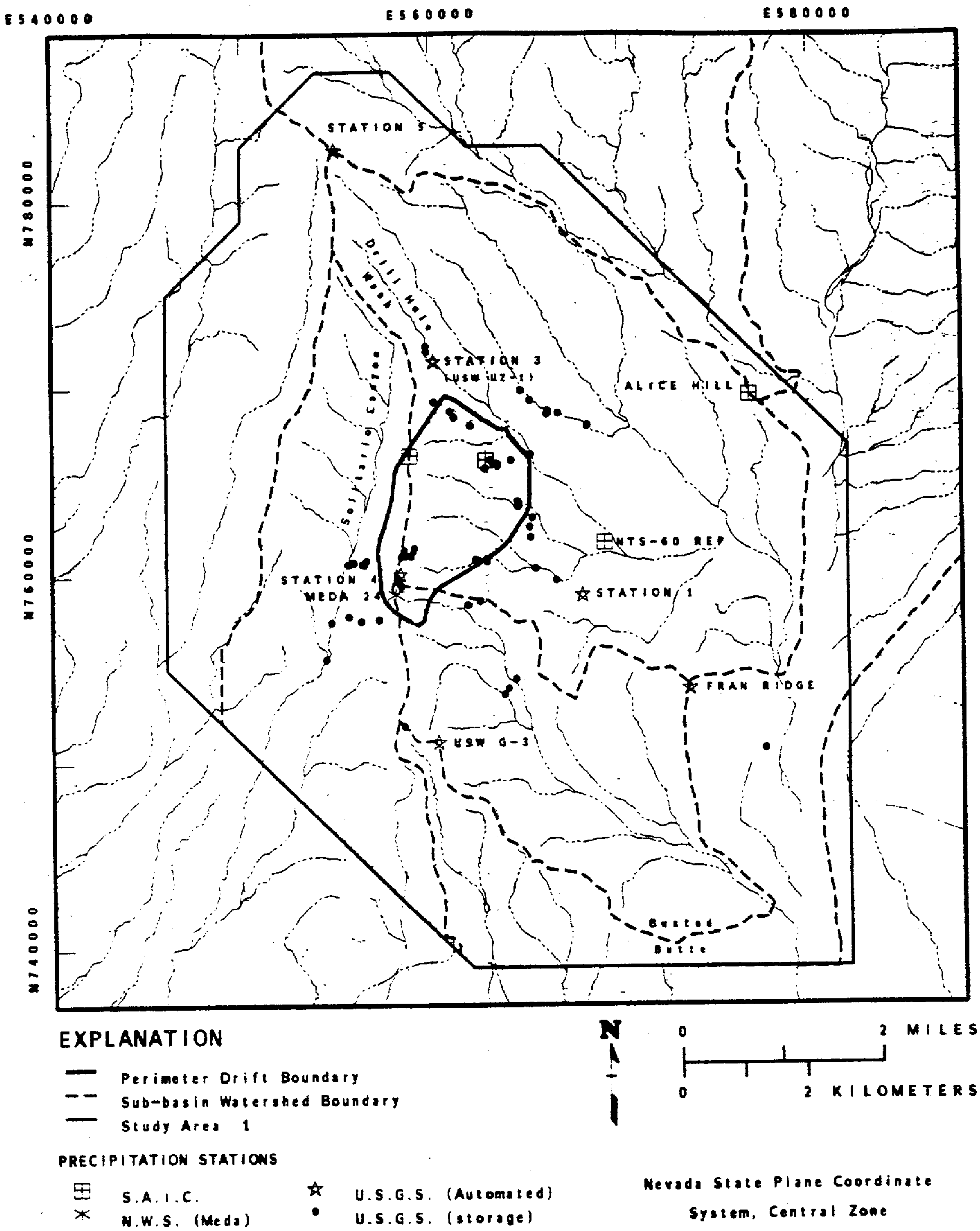


Figure 3.1-20. Active precipitation stations study area 1.

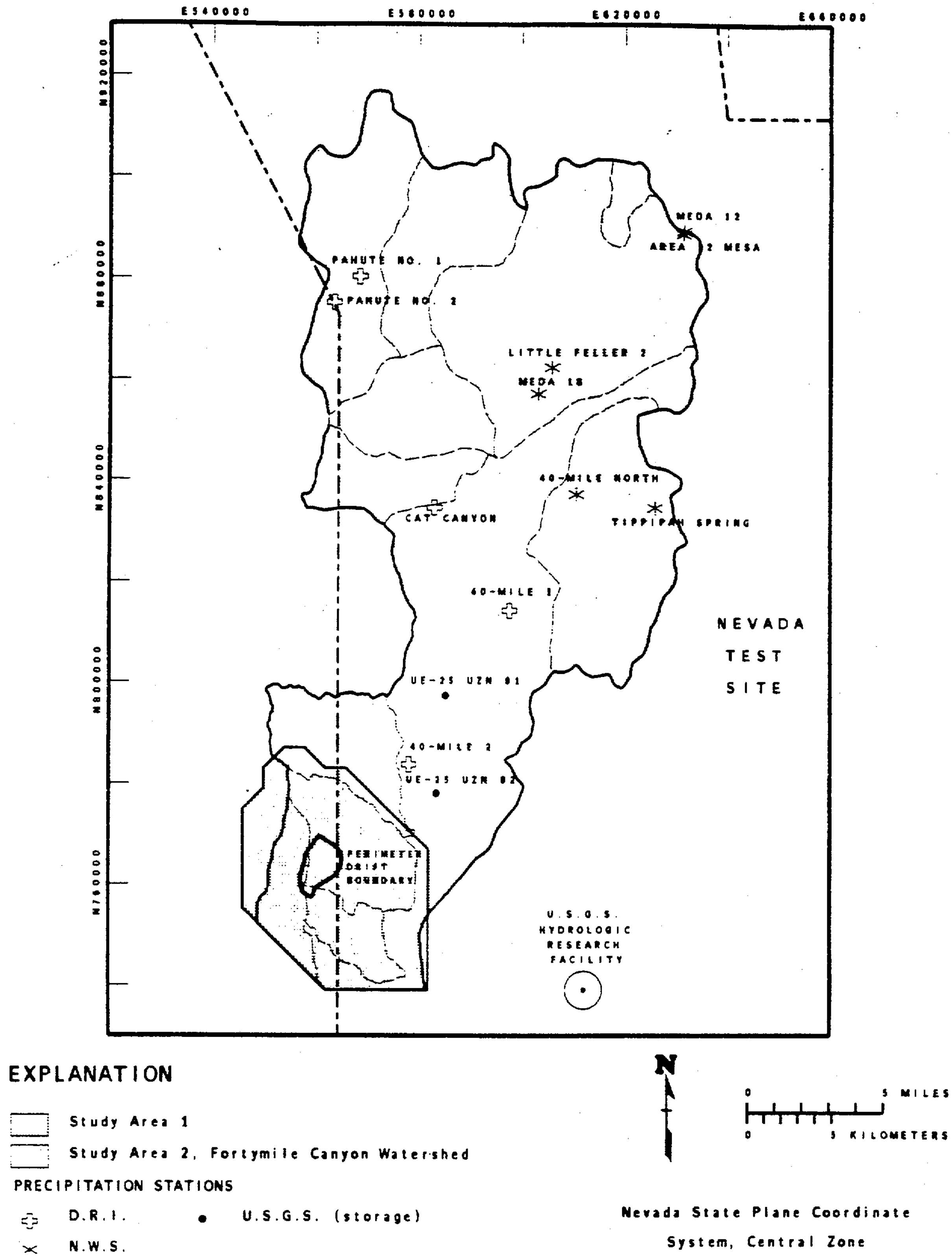


Figure 3.1-21. Active precipitation stations within study area 2 that are not included in study area 1.

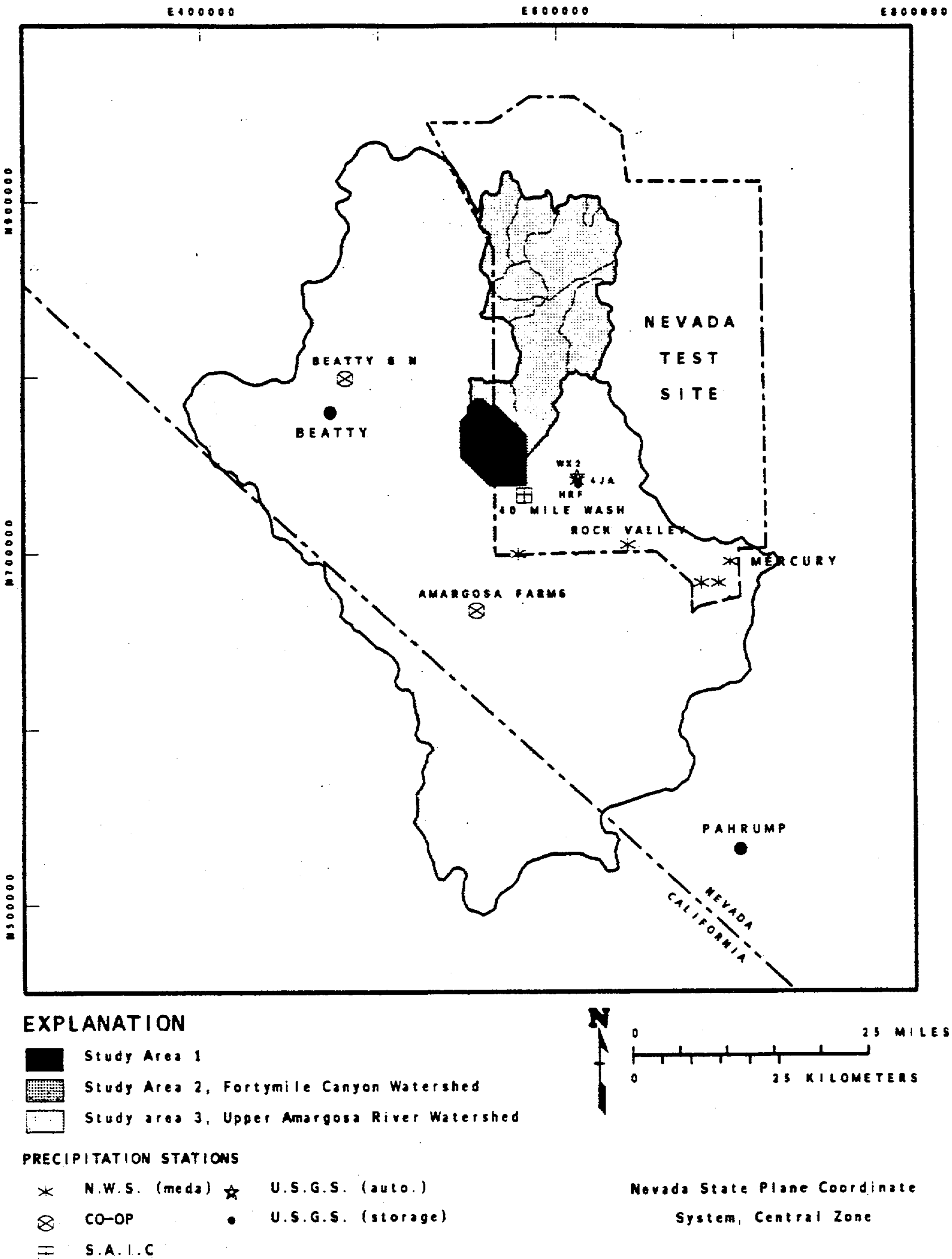


Figure 3.1-22. Active precipitation stations within study area 3 that are not included in study areas 1 and 2.

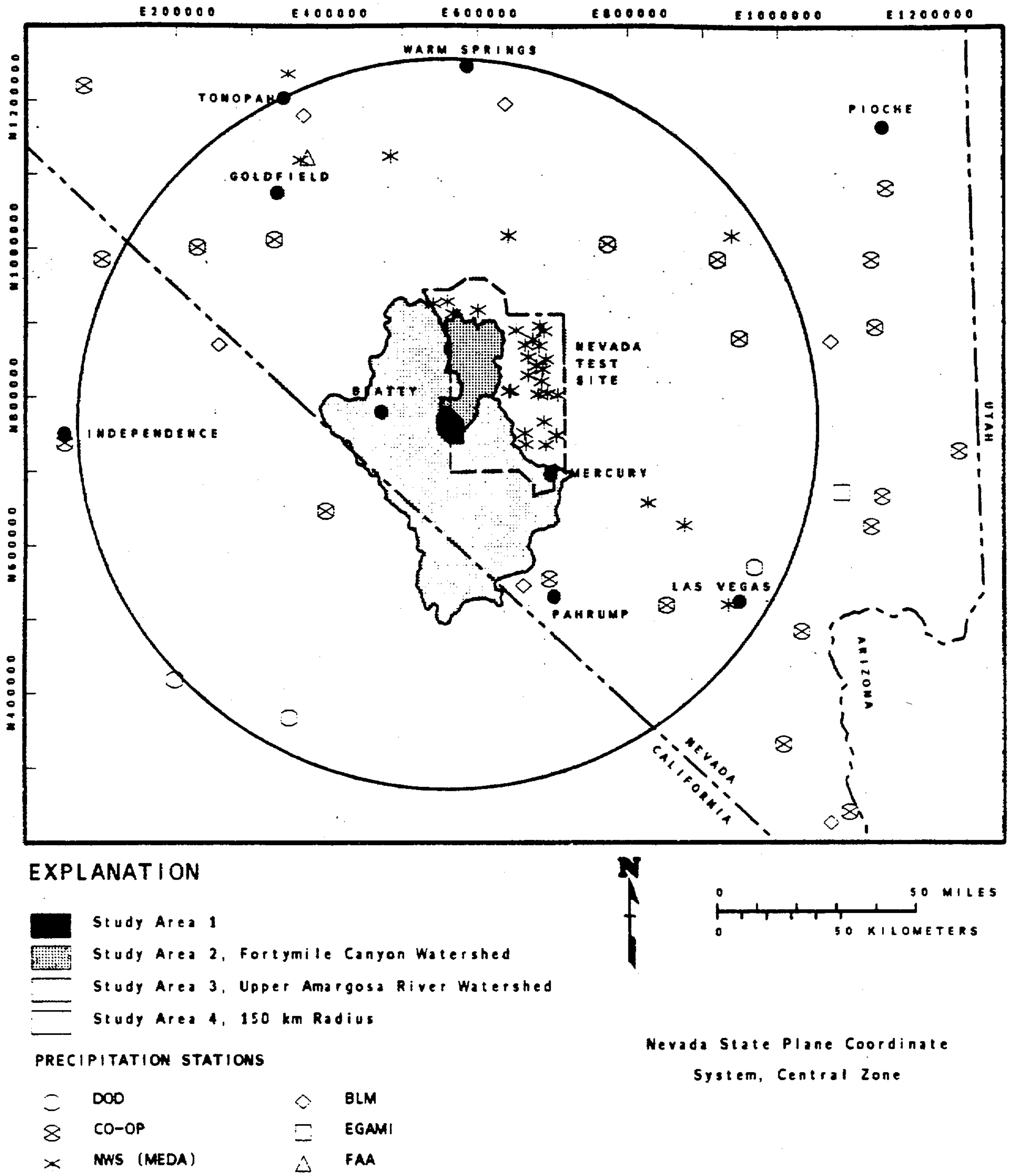


Figure 3.1-23. Active precipitation stations within study area 4 that are not included in study areas 1, 2, and 3.

Table 3.1-3 List of all active regional weather stations, managing agency, parameters measured, location, sampling and averaging frequency, and date installed.

REGIONAL METEOROLOGICAL STATIONS

STATION	AGENCY	PARAMETERS WIND DIR	WIND VEL	TEMP	WET BULB	PRESS	PRECIP	COORDINATES EASTING	NORTHING	ELEV (FEET)	SAMPLING FREQUENCY	AVERAGING FREQUENCY	DATE BEGAN REPORTING
AMARGOSA FARMS	CO-OP			X	X		S	553833	667583	2450	ONCE/DAY	MONTHLY	03-78
BEATTY 8N	CO-OP			X	X		R/S	480750	799390	3550	ONCE/DAY	MONTHLY	11-72
BOULDER CITY	CO-OP			X	X		S	1031312	485081	2530	ONCE/DAY	MONTHLY	07-48
BUNKERVILLE	CO-OP			X	X		S	1240818	728417	1550	ONCE/DAY	MONTHLY	1972
CALIENTE	CO-OP			X	X		S	1123885	986961	4403	ONCE/DAY	MONTHLY	07-48
DESERT NATL WL RANGE	CO-OP			X	X		S	875401	627027	2922	ONCE/DAY	MONTHLY	07-48
DEATH VALLEY	CO-OP	X	X	X	X		S	397922	647305	-194	ONCE/DAY	MONTHLY	05-53
DYER 4SE	CO-OP			X	X		S	100716	986961	4899	ONCE/DAY	MONTHLY	10-50
ELGIN 3SE	CO-OP			X	X		R/S	1128757	895710	3420	ONCE/DAY	MONTHLY	04-65
GOLDFIELD	CO-OP			X	X		R/S	329711	1012309	5693	ONCE/DAY	MONTHLY	10-50
INDEPENDENCE	CO-OP			X	X		X	51993	738556	3950	ONCE/DAY	MONTHLY	1984
KEY PITTMAN WMA	CO-OP			X	X		X	919251	986961	3950	ONCE/DAY	MONTHLY	1964
LAUGHLIN	CO-OP			X	X		S	1094650	241747	680	ONCE/DAY	MONTHLY	
LOGANDALE UN EXP FARM	CO-OP			X	X		R/S	1138501	667583	1410	ONCE/DAY	MONTHLY	01-68
MINA	CO-OP			X	X		S	76355	1220158	4549	ONCE/DAY	MONTHLY	07-48
PAHRANAGAT WL REFUGE	CO-OP			X	X		R/S	948484	880502	3400	ONCE/DAY	MONTHLY	03-64
PAHRUMP GOLF & CC	CO-OP			X	X		S	695128	556054	2670	ONCE/DAY	MONTHLY	10-48
PAHRUMP U OF N LABS	CO-OP						X	695128	556054	2670	ONCE/DAY	MONTHLY	12-80
PIOCHE	CO-OP			X	X		S	1143374	1083282	6167	ONCE/DAY	MONTHLY	08-71
RED ROCK CANYON	CO-OP			X	X		S	851040	520567	3780	ONCE/DAY	MONTHLY	05-77
SEARCHLIGHT	CO-OP			X	X		R/S	1006951	332996	3540	ONCE/DAY	MONTHLY	07-48
SILVERPEAK	CO-OP			X	X		S	227394	1002170	4259	ONCE/DAY	MONTHLY	09-67
SMOKEY VALLEY	CO-OP			X	X		R/S	349200	1341827	5625	ONCE/DAY	MONTHLY	06-49
TEMPIUTE	CO-OP			X	X		X	773084	1007239	4890	ONCE/DAY	MONTHLY	03-70
VALLEY OF FIRE ST PK	CO-OP			X	X		S	1123885	627027	2001	ONCE/DAY	MONTHLY	11-72
TONOPAH AP	FAA	X	X	X	X	X	R/S	373561	1123838	5427	HOURLY	DAILY	05-75
LAS VEGAS WSO AP	NWS	X	X	X	X	X	R/S	933868	520567	2162	HOURLY	DAILY	01-49
DESERT ROCK WSO	NWS	X	X	X	X	X	R/S	680512	682791	3301	HOURLY	DAILY	04-84
NELLIS AFB	DOD	X	X	X	X	X	S	967973	571263	1869	HOURLY	DAILY	1948
CHINA LAKE NAVAL STA	DOD	X	X	X	X	X	X	349200	368483		HOURLY	DAILY	1948
TOWER 8 CHINA LAKE	DOD	X	X	X	X	X	X	198160	419178		DAILY	MONTHLY	1959
EDWARDS AFB	DOD	X	X	X	X	X	X	144566	160633		HOURLY	DAILY	1948
100M TWR (MOAPA)	EGAMI	X	X	X	X	X	R/S	1084907	672653	1602	ONCE/MIN	HOURLY/DAILY	1978
CAT CANYON	DRI						R	583067	834877	5560	ONCE/MIN	HOURLY	1987
MESA	DRI						R	573322	814599		ONCE/MIN	HOURLY	1987
40-MILE NO. 1	DRI						R	597684	814599	5290	ONCE/MIN	HOURLY	1987
40-MILE NO. 2	DRI						R	578195	784182		ONCE/MIN	HOURLY	1987
PAHUTE NO. 1	DRI	X	X	X	X	X	R	568450	880502	5640	ONCE/MIN	HOURLY	1987
PAHUTE NO. 2	DRI	X	X	X	X	X	R	563578	875433	5640	ONCE/MIN	HOURLY	1987
BIG BEND	BLM	X	X	X	X	X	R	1070290	226537	1000	ONCE/SEC	6/HOUR	1986
KANE SPRINGS	BLM	X	X	X	X	X	R	1070290	875433	4590	ONCE/SEC	6/HOUR	1986

Table 3.1-3 List of all active regional weather stations, managing agency, parameters measured, location, sampling and averaging frequency, and date installed (continued).

STATION	AGENCY	PARAMETERS: WIND DIR	WIND VEL	TEMP	WET BULB	PRESS	PRECIP	COORDINATES: EASTING (FEET)	NORTHING (FEET)	ELEV (FEET)	SAMPLING FREQUENCY	AVERAGING FREQUENCY	DATE BEGAN REPORTING
PAHRUMP	BLM	X	X	X	X	X	R	661023	545915	2600	ONCE/SEC	6/HOUR	1986
PANCAKE	BLM	X	X	X	X	X	R	636661	1194811	5200	ONCE/SEC	6/HOUR	1986
ROYSTON HILLS	BLM	X	X	X	X	X	R	368689	1179603	5100	ONCE/SEC	6/HOUR	1986
BRAWLEY PEAKS	BLM	X	X	X	X	X	R	-142896	1184672	8080	ONCE/SEC	6/HOUR	1986
ORIENTAL WASH	BLM	X	X	X	X	X	R	256627	870363	4100	ONCE/SEC	6/HOUR	1986
NTS-60 REPOSITORY	SAIC	X	X	X	X	X	TB	569127	761795	3751	6/MIN	HOURLY	1985
YUCCA MTN	SAIC	X	X	X	X	X	TB	558862	766434	4849	6/MIN	HOURLY	1985
COYOTE WASH	SAIC	X	X	X	X	X	TB	562876	766195	4193	6/MIN	HOURLY	1985
ALICE HILL	SAIC	X	X	X	X	X	TB	576810	769661	4047	6/MIN	HOURLY	1985
40-MILE WASH	SAIC	X	X	X	X	X	TB	580882	733230	3124	6/MIN	HOURLY	1985
MEDA 1	NWS	X	X	X	X	X	TB	667890	829450	4145	4/HOUR	HOURLY	1983
MEDA 2	NWS	X	X	X	X	X	TB	663420	870075	4402	4/HOUR	HOURLY	1983
MEDA 3	NWS	X	X	X		X	TB	686800	837370	4025	4/HOUR	HOURLY	1983
MEDA 4	NWS	X	X					667820	853910	4400	4/HOUR	HOURLY	1983
MEDA 5	NWS	X	X	X	X	X	TB	704960	747520	3085	4/HOUR	HOURLY	1983
MEDA 6	NWS	X	X	X	X	X	TB	680990	803620	3919	4/HOUR	HOURLY	1983
MEDA 7	NWS	X	X					691000	851000	4280	4/HOUR	HOURLY	1983
MEDA 9	NWS	X	X					682490	868900	4228	4/HOUR	HOURLY	1983
MEDA 10	NWS	X	X	X	X			674140	877980	4342	4/HOUR	HOURLY	1983
MEDA 11	NWS	X	X	X	X		TB	706700	805600	4119	4/HOUR	HOURLY	1983
MEDA 12	NWS	X	X	X	X	X	TB	631460	888950	7500	4/HOUR	HOURLY	1983
MEDA 13	NWS	X	X	X				685550	820900	3957	4/HOUR	HOURLY	1983
MEDA 14	NWS	X	X	X	X		TB	642220	807530	4710	4/HOUR	HOURLY	1983
MEDA 15	NWS	X	X	X	X		TB	688480	888860	4470	4/HOUR	HOURLY	1983
MEDA 16/17	NWS	X	X	X	X	X	TB	679110	842450	4176	4/HOUR	HOURLY	1983
MEDA 18	NWS	X	X	X	X		TB	603170	856880	5038	4/HOUR	HOURLY	1983
MEDA 19	NWS	X	X	X	X		TB	600600	917270	7028	4/HOUR	HOURLY	1983
MEDA 20	NWS	X	X	X	X	X	TB	567430	912130	6565	4/HOUR	HOURLY	1983
MEDA 21	NWS	X	X	X	X			651260	889870	5380	4/HOUR	HOURLY	1983
MEDA 23	NWS	X	X	X	X	X	TB	696682	695037	3740	4/HOUR	HOURLY	1983
MEDA 24	NWS	X	X	X	X	X	TB	560714	763009	4814	4/HOUR	HOURLY	1983
MEDA 25	NWS	X	X	X	X	X	TB	577340	699390	2751	4/HOUR	HOURLY	1983
MEDA 26	NWS	X	X	X	X	X	TB	624822	749468	3400	4/HOUR	HOURLY	1983
MEDA 27	NWS	X	X	X	X		TB	664912	735922	4500	4/HOUR	HOURLY	1983
MEDA 28	NWS	X	X		X		TB	688546	766208	3440	4/HOUR	HOURLY	1983
MEDA 29	NWS	X	X	X	X		TB	691603	735182	3260	4/HOUR	HOURLY	1983
MEDA 32	NWS	X	X	X	X			938740	1017379	7475	4/HOUR	HOURLY	1983
MEDA 33	NWS	X	X	X	X			641534	1017379	5775	4/HOUR	HOURLY	1983
MEDA 34	NWS	X	X					347150	1235750	7134	4/HOUR	HOURLY	1983
MEDA 35	NWS	X	X	X	X	X	TB	484000	1124350	5336	4/HOUR	HOURLY	1983
MEDA 36	NWS	X	X	X	X	X	TB	826679	657444	3100	4/HOUR	HOURLY	1983

Table 3.1-3 List of all active regional weather stations, managing agency, parameters measured, location, sampling and averaging frequency, and date installed (continued).

STATION	AGENCY	PARAMETERS: WIND DIR	PARAMETERS: WIND VEL	PARAMETERS: TEMP	PARAMETERS: WET BULB	PARAMETERS: PRESS	PARAMETERS: PRECIP	COORDINATES: EASTING (FEET)	COORDINATES: NORTHING (FEET)	ELEV (FEET)	SAMPLING FREQUENCY	AVERAGING FREQUENCY	DATE BEGAN REPORTING
MERCURY	NWS						W	696738	695045	3770	CONT	N/A	03-71
4JA (JACKASS FLATS)	NWS		X	X			TB/S	610605	740840	3422	4/MIN	4/HOUR	01-67
DESERT ROCK	NWS						S	690040	682790	3298	4/DAY	N/A	10-63
ROCK VALLEY	NWS		X	X			TB/S	639050	704700	3400	4/MIN	4/HOUR	02-63
CANE SPRING	NWS						W	663600	751000	4000	CONT	N/A	09-64
WELL 5B	NWS						W	705600	747600	3080	CONT	N/A	09-63
MID VALLEY	NWS						W	644500	809250	4660	CONT	N/A	09-64
YUCCA LAKE	NWS						W	693382	804596	3920	CONT	N/A	05-58
40-MILE NORTH	NWS						W	610600	837100	4820	CONT	N/A	02-60
TIPPIPAH SPRING	NWS						W	625882	834368	5470	CONT	N/A	02-60
BJY	NWS						W	679100	842300	4070	CONT	N/A	02-60
AREA 12 MESA	NWS						W	631400	888400	7490	CONT	N/A	03-59
LITTLE FELLER #2	NWS						W	605850	862100	5120	CONT	N/A	08-76
PHS FARM	NWS		X	X			TB/S	682870	895640	4565	4/MIN	4/HOUR	10-64
PAHUTE MESA #1	NWS		X	X			TB/S	560000	928700	6340	4/MIN	4/HOUR	01-64
U20K	NWS						S	541300	926000	6070	1/WEEK	N/A	08-77

LEGEND

S = Storage raingage
W = Weighing raingage
R = Recording raingage
X = Parameter measured
TB = Tipping-bucket raingage

CO-OP = PRIVATE AGENCIES PROVIDING WEATHER DATA
FAA = FEDERAL AVIATION ADMINISTRATION
NWS = NATIONAL WEATHER SERVICE
DOD = DEPARTMENT OF DEFENSE
EGAMI = PRIVATE AGENCY
DRI = DESERT RESEARCH INSTITUTE
BLM = BUREAU OF LAND MANAGEMENT
SAIC = SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

Additionally, other sensors may be added as required, such as optical lightning detectors, albedometers, and precipitation storage gages designed for collecting isotopic or chemical samples.

The instrument recording accuracies should fall within the following ranges:

Precipitation (accumulated amount), within 0.2 mm below 10 mm and within 2 percent above 10 mm;
Air temperature, within 1 °C;
Relative humidity, within 5 percent;
Barometric pressure, within 0.1 kPa;
Shortwave radiation, within 5 percent;
Wind speed, within 0.5 m per second below 5 m per second and within 10 percent above 5 m per second; and
Wind direction, within 5 degrees.

Each data collection platform is powered by a 12-volt, deep-cycle, marine/RV storage battery which is kept charged by a solar panel. The datalogger (Campbell Scientific, Model 21X or CR10) and all of the sensors except the precipitation gage are mounted on a steel tripod. This is housed in a weatherproof enclosure which is protected from excessive heat by a radiation shield. Wind speed is measured with a cup anemometer and the data is stored as m per second. Wind direction is measured with a wind vane and the data is stored in degrees from true north. Shortwave radiation (0.3 to 3.0 micrometers wavelength) is measured with a pyranometer. The instantaneous data is stored as watts per m^2 and the daily total solar radiation is stored as megajoules per m^2 per day. The sensor is mounted in a leveling fixture on an arm which extends away from the tripod, in order to keep the sensor away from any shadows or bright reflections. Air temperature is measured with a thermistor and the data stored as degrees C. Relative humidity is measured with a potassium metaphosphate resistance chip and the data is stored as percent saturation. The temperature and relative humidity sensors are shielded from direct solar radiation by a wind-aspirated, gill-plate, radiation shield. Barometric pressure data is measured with a pressure transducer and the data is stored in millibars. The sensor is housed in a weatherproof enclosure with a static pressure port. Precipitation is measured with a tipping-bucket precipitation gage and the data is stored as number of tips, including time of tip to the nearest 10 seconds. The conversion of tips to millimeters of precipitation is described in a technical procedure (HP-180, R0, Table 3.1-6). The storage of precipitation data is event-driven and not averaged over 15-minute periods. Some of the gages are propane-heated in order to measure frozen precipitation (ice or snow). The gages are mounted on the ground in a position such that no tall obstacles interfere with the precipitation (ice or snow) catch.

The meteorological stations are programmed to take all measurements every 10 seconds, average these values every 15 minutes, and store that data along with station ID, date, and time. Additionally, at midnight, that day's maximum and minimum air temperatures and relative humidities, the time of each maximum and minimum (to the nearest 10 seconds), total precipitation, total solar radiation, battery voltage, and a program signature are recorded.

All of the data are stored in the datalogger memory until 1400 PST, generally the warmest part of the day. At that time, the data is written to magnetic tape. This procedure is used in order to avoid problems encountered when the tape recorders are used in extremely cold conditions. One side of a 60-minute cassette tape can store about five months of data. The cassette tapes are collected from the stations about every two months. During these site visits, any error in the datalogger clock is recorded and the clock is reset using a National Institute of Standards and Technology (NIST) standard (WWV radio, Fort Collins, Colorado). The clock is always set to Pacific Standard Time.

Radio telemetry equipment has been installed on some stations to test the feasibility of collecting real-time data. These stations are in particularly remote sites or are critically located for early warning of extreme precipitation events. The radio telemetry system may be expanded if the system is shown to perform satisfactorily.

3.1.3.2.1.1.2 Precipitation stations

The precipitation-data-collection effort involves several different activities. First, as described in the previous section, each meteorological station has a precipitation gage. Second, several automated recording precipitation stations will be installed. These stations will not have the full spectrum of instrumentation of the meteorological stations, but each precipitation station will have a tipping-bucket precipitation gage monitored by a Campbell Scientific CR10 datalogger. Some of the tipping-bucket gages will be propane-heated in order to collect frozen precipitation. The CR10 datalogger is mounted on a vertically mounted steel pole in a weatherproof enclosure. Power is provided by a 12-volt, sealed, lead-acid storage battery which is charged by a solar panel. The gages are mounted on the ground in a position such that no tall obstacles interfere with the precipitation catch (World Meteorological Organization, 1983). All gages are calibrated in millimeters. The storage of precipitation data on the automated platforms is event-driven. The datalogger checks the gage every second; when a tip is detected, that piece of data, with a date and time stamp, is written to a magnetic tape. The tapes are collected from the stations about every two months. During these site visits, any error in the datalogger clock is recorded and the clock is reset using an NIST standard as with the meteorological stations. Also, the station is inspected for such things as instrument cable integrity and propane supply (if installed). Additional sensors may be installed on the automated precipitation station as needed. At USGS meteorological stations within or peripheral to the Fortymile Wash drainage (and, if necessary, at other locations within the Yucca Mountain region), precipitation storage gages will be installed under the present study for the collection of precipitation samples. These samples will be collected under the scope of the present study, and forwarded to the Principal Investigator of Study 8.3.1.2.1.3 (Regional ground-water flow system) for hydrochemical and isotopic analyses under the scope of that study. The exact sites and specific sampling methods for precipitation sample collection will be chosen in consultation between the Principal Investigators of Study 8.3.1.2.1.3 and the present study.

The advantages of the tipping-bucket gage are: 1) the timing, rate, and duration of precipitation are recorded, in addition to total accumulation; 2) the resolution of precipitation rate measurements is high relative to other gages; 3) measurements are recorded and stored automatically; and 4) heated tipping-bucket gages enable the measurement of accumulations and rates of precipitation occurring as snow. Ongoing development of new calibration techniques has reduced the systematic error due to variable precipitation rates. The calibration equation incorporates the time between tips of the bucket to account for increased precipitation rates. Disadvantages of the tipping-bucket gage include: 1) some possibility of mechanical and/or electrical breakdown during operation, 2) the requirement of a power source for the datalogger, and 3) economic considerations which may prevent the development of a monitoring network of sufficient density and areal coverage to meet site-characterization requirements.

The use of weighing-bucket precipitation gages to expand the automated precipitation monitoring network is currently being investigated. The precision and accuracy of the weighing-bucket gage must be more thoroughly analyzed before these instruments can be included in the monitoring effort. Weighing-bucket gages record accumulated precipitation by mechanically or electrically weighing the collected precipitation. Evaporation of collected precipitation is prevented by adding oil to the bucket. The weight of accumulated precipitation is continuously recorded by a stylus which draws a line on a revolving cylindrical chart. The speed of chart rotation is constant and known, which enables the timing of precipitation events to be recorded, and the slope of the recorded line can be used to measure instantaneous precipitation rates. Cylindrical charts are replaced in the field and returned to the laboratory for archiving and analysis (Section 3.1.3.4). Resistance-voltage devices can also be used to output the data directly to dataloggers. The weighing-bucket gages will be used primarily to expand the areal coverage of the precipitation-rate monitoring network consisting of tipping-bucket gages. Advantages of the weighing bucket for measuring precipitation are: 1) recording of measurement is automated, 2) a continuous record of accumulated precipitation through time is collected, 3) precipitation rates are easily derived, and 4) calibration is not rate-dependent. The disadvantages of this instrument are: 1) an energy source must be supplied to power the motor turning the chart, 2) recorded data should be retrieved weekly, 3) the instrument has poor sensitivity, and 4) probability of mechanical breakdown is relatively high.

In addition to the automated precipitation-monitoring network described above, manual monitoring of precipitation will be made using a relatively dense network of storage gages. The storage gages will be used to measure total-storm-event accumulations and monthly accumulations at 74 neutron-logging boreholes (see YMP-USGS-SP 8.3.1.2.2.1, Unsaturated-zone infiltration, Activity 8.3.1.2.2.1.2, Evaluation of natural infiltration). Additional storage-gage sites within study areas 1, 2, and 3 will be selected, providing a total network of between 100 and 150 monitoring sites. Individual storm events will be defined as periods of precipitation separated by periods of no precipitation longer than 6 hours (World Meteorological Organization, 1983). Storm-event accumulations will be recorded manually by a visual reading of the fluid level collected in each gage. The resolution and accuracy of these measurements has been determined to be +/- 0.01 inches (+/- 0.25 mm). The timing of most events will be recorded by correlating the times and dates of readings with data obtained from the automated precipitation gages, as well as by using direct observation of storm events over the study area by visual observation and by automated time-lapse photography of Yucca Mountain. This will provide an accuracy on the timing of storms for the storage-gage network at least to the nearest day.

The advantages of using the storage gage for precipitation monitoring include: 1) low installation costs, 2) the low probability of gage failure during operation, and 3) accurate gage calibration independent of precipitation rates.

Precautionary measures are taken to insure against errors. Collection gages, when properly mounted so that the orifice is located well above the top and sides of the mounting post, are subjected to minimal splashing from the outside. However, due in part to the smaller orifice (36 cm^2 versus 324 cm^2 for an 8-in gage) and also because the plastic collection gage is not calibrated as compared to a carefully calibrated tipping-bucket gage, the resolution is not as good (0.25 mm versus 0.1 mm). Installation of wire mesh, deep enough inside the orifice to eliminate back splashing, is effective in preventing most insect entrapment. Oil is being successfully used to prevent evaporation. We believe that the resulting network of plastic gages does provide an accurate assessment of the actual rainfall.

The advantages of storage gages allow for the timely development of a dense and reliable sampling network and also provide a necessary means of checking accumulations obtained from tipping-bucket gages for storm events and over designated time periods. Disadvantages of the storage gage are: 1) manual retrieval of data is required after each storm event and/or during monthly intervals, 2) measurement resolution is coarse (+/- 0.25 mm) relative to the tipping-bucket gage (+/- 0.2 to 0.1 mm), 3) precipitation rates cannot be measured, 4) areal catch is relatively small (small orifice size), and 5) measuring frozen precipitation is inaccurate or invalid, especially under windy conditions.

At this point, the relative accuracy of various gages is unknown. For measurements of accumulated precipitation, storage gages may actually be the most accurate as errors in tipping- and weighing-bucket gages would be additive. However, weighing- and tipping-bucket gages are probably equal in accuracy in measuring precipitation rates. An analysis of the relative degree of accuracy is still in progress.

Important applications of data obtained from the storage-gage network will be to help identify optimum locations for more costly and permanent automated sites, to expand the sampling network for storm-event accumulations, and to increase the accuracy in defining storm-cell boundaries and the spatial distribution of accumulated precipitation over the three watersheds included in study area 1. (For a more detailed description of the requirements of the various precipitation sampling networks, refer to Section 3.1.3.2.1.2.) The data from storage gages will also be used to expand the analysis of the correlation of precipitation with ground elevation, location, slope, aspect, and exposure. This will be important for characterizing small-scale terrain effects on storm events, as well as on monthly and yearly averages.

3.1.3.2.1.1.3 Lightning detection

Lightning data will be collected from the automated lightning detection system (ALDS) operated by WSNSO for the Nevada Test Site (NTS). The system detects and locates cloud-to-ground lightning strikes on the NTS in real time. The network consists of seven direction finders (DF). Five are located on the NTS with additional DFs located at Blue Diamond and Warm Springs, Nevada. The research area is located on the western edge of the present ALDS network. Although the accuracy of the ALDS is reported to be approximately 1 km with an 85- to 90-percent detection rate within the boundaries of the network, the installation of an additional DF within the research area would enhance the accuracy of lightning data relating to this study.

It is possible to detect cloud-to-cloud lightning using recently-developed optical technology. A field test of a prototype optical lightning detector was conducted by the WSNSO. The test showed that cloud-to-cloud lightning activity precedes cloud-to-ground strikes by 15 minutes (Scott, 1989). This study will employ one or more optical lightning-detector installations. Three detectors can be installed in series to cover a 360-degree horizontal pattern, each sensor viewing a 120-degree segment. These detectors will provide early thunderstorm identification and help track storms across the area of interest. The range of these detectors is restricted only when storms are out of the sensor's line of sight.

3.1.3.2.1.1.4 Remote sensing

Weather-satellite data have proven invaluable in locating and tracking synoptic-scale storm systems as well as in determination of areal coverage of snow. (Satellite data will supplement snow-course measurements from Studies 8.3.1.2.2.1 and 8.3.1.2.1.3.) The National Oceanographic and Atmospheric Administration (NOAA) operates two types of meteorological satellites. Polar orbiting satellites orbit the earth at altitudes on the order of 800-1000 km.

Their orbits are such as to permit complete coverage of the earth twice in a 24-hour period, once in daylight, once at night. Data is available in both visible (daytime) and infrared (day and night) spectra.

Another type of weather satellite is the Geostationary Operational Environmental Satellite (GOES). Orbiting the earth over the equator at an altitude of approximately 36,500 km, this satellite remains stationary relative to the earth's surface. Data are received in the visible, infrared, and microwave spectra. Individual pictures are transmitted every 15-30 minutes.

Time-lapse photography is being considered to survey Yucca Mountain and vicinity. Using a video camera or motion-picture camera, cloud development and movement can be documented. The camera can be operated continuously to document weather conditions that will be related to meteorological conditions recorded by the automated stations. During the thunderstorm season (July-August) the photography may help to determine the influence of Yucca Mountain itself on storm development.

Storm detection radar has been used experimentally for nearly 30 years to measure rainfall. However, operational implementation has been slow. Areal and point-rainfall estimates are often in error by a factor of two or more. Error sources in relatively flat terrain reside in measurement of the radar reflectivity factor, evaporation and advection of precipitation before it reaches the ground, variations in drop-size distribution and vertical air motion, anomalous propagation of the beam, and attenuation by heavy precipitation.

Wilson (1979) conducted a study in which radar rainfall estimates were improved by "calibrating" the radar with a rain-gage network. It was found that combining the radar data with rain-gage data from a sparse rain-gage network (1 gage per 1000-2000 km^2), that resulting measurement errors (10-30 percent) were less than either system taken alone. However, when high-accuracy rainfall measurements are needed (average error less than 10-20 percent), the advantage of radar is diminished because the number of gages required for calibrating is itself sufficient to provide the desired accuracy.

Radar is being considered as a potential tool in measuring rainfall within the Yucca Mountain region. However, in addition to the endemic limitations listed above, the climate and topography offer at least two other limitations. First, thunderstorms and rainshowers tend to be high-based; that is, the cloud bases are generally at altitudes of 2500-3500 meters. Because of the very dry air below, rain often falls and evaporates before reaching the ground. Thus, the preponderance of this effect, known as virga, could cause radar to over estimate rainfall at the surface. Second, the mountainous topography of the study region would tend to mask radar returns by causing "ground clutter", depending upon the location and elevation of the radar antenna. The rainfall accuracy required by this study demands a very dense rain-gage network in research areas 1 and 2 (described in Section 3.1.3.1.2) and may itself provide the necessary accuracy.

Based on these considerations, radar data may fail to contribute successfully to the characterization of precipitation because of technical deficiencies and the high costs involved with procuring and siting instrumentation. However, recent studies using multivariate geostatistics and spatial cross-correlation models between rain-gage and radar-rainfall data indicate the possibility of obtaining improved, merged datasets of storm-event precipitation intensities and accumulations (Seo and others, 1990; Krajewski, 1987). Areal-integrated measurements obtained using radar would be extremely valuable for analysis of storm-cell size, movement, development, and the spatial variability of precipitation intensities and accumulations. Measurements from radar would not be calibrated using "ground truth" point measurements obtained from the rain-gage network. Instead, the radar data would be treated as a separate variable, and would be linked to the primary precipitation dataset by a stochastic correlation function, such as the cross-variogram (Journel and Huijbregts, 1978).

The advantage of this method is that deficiencies or errors in the radar data, as discussed above, can be represented and accounted for by a correctly defined geostatistical model. Errors in the relative values of radar measurements can be represented by the model cross variogram as a diminished spatial cross-correlation structure, which reduces the magnitude of improvement in estimation accuracy but does not introduce bias or systematic error in calculated estimates. In general, a sample correlation coefficient of 0.5 or greater at a 0.05 level of significance would warrant the increased effort of using radar and a multivariate model for obtaining improved estimates of precipitation. Unfortunately, sample correlation coefficients and cross variograms cannot be investigated without a preliminary application of the radar measurement technique at the Yucca Mountain site, which has not yet been done.

3.1.3.2.1.1.5 Other weather data

There are many other sources of data that will be used in this study. Meteorological data collected by other studies (Study 8.3.1.2.2.1, Activity 8.3.1.2.2.1.2; Study 8.3.1.2.1.2; Study 8.3.1.16.1.1; and Study 8.3.1.2.1.3, Activity 8.3.1.2.1.3.3), SAIC, and others will be incorporated as needed. There are other data, collected outside of the YMP, which will be used as supplemental data.

3.1.3.2.1.2 Field site selection

Selection of monitoring sites for obtaining point measurements of meteorologic parameters involves a combination of feature-based and statistically-based considerations. A sampling network must provide an adequate spatial density, spatial configuration, and areal coverage of point measurements as related to scale, accuracy, and application requirements, and yet remain within the constraint of economic limitations.

According to the definition provided by the World Meteorological Organization (Jones, 1981), an optimum network should provide measurements such that: "By interpolation between values at different stations, the determination of the characteristics of the basic meteorological elements (parameters) anywhere within the area of interest is possible, with sufficient accuracy for practical purposes. Characteristics of meteorologic elements (parameters) include all quantitative data, averages, and extremes that define the statistical distribution of the element (parameter) studied."

If spatial distributions are known or can be estimated, packing techniques can be used in conjunction with a geostatistical analysis to determine both the optimum number and optimum locations of additional sites required. If sufficient information concerning the first and second statistical moments of a given parameter is not available *a priori*, or cannot be assumed using data from other adjacent or similar study areas, an initial sampling network consisting of a relatively small number of feature-based field sites will be installed to gather preliminary data by which a more permanent, statistically-based sampling scheme can be developed.

Most of the current monitoring sites have been located according to feature-based considerations, with an emphasis on site accessibility and proximity to centers of population. Initial sites for future and developing networks will also include sites located according to feature-based considerations. For example, an additional weather station (for the measurement of several meteorological parameters at one site) for study area 3 will be located at Franklin Lake at the southern extent of the upper Amargosa River watershed boundary. This site was selected based on the need to obtain measurements of precipitation and solar radiation data at the future site of a stream-flow monitoring station (flume) at Eagle Mountain for Study 8.3.1.2.1.2 (Regional runoff and streamflow), and also because this site is the lowest elevation within the study area 3 boundary.

Data from inactive, historical sampling networks previously operational within or adjacent to a particular study area will also be used to develop statistically-based sampling networks for current and future meteorological characterization needs. This will be especially important for parameters such as AAP, which require long periods of measurement to obtain reliable values in the southern Nevada region (French 1987).

Dense sampling networks are important in arid and mountainous environments for the accurate characterization of precipitation and storm-cell development, movement, distribution, and cell size (Jones, 1981). Based on a preliminary analysis of both current and historical data, a dense sampling network consisting of 100 to 150 monitoring sites for study areas 1 and 2 will be necessary to meet accuracy requirements of 10-percent error for areal estimations and for the characterization of the spatial variability of meteorologic parameters at the proposed repository site. Unfortunately, economic and practical limitations prevent the installation of a dense sampling network on the scale of the regional study areas. The areal coverage provided by a relatively sparser network consisting of a reasonable number of point measurements on such scales, however, will be essential for monitoring synoptic and mesoscale meteorologic phenomena, such as the genesis and movement of storms reaching Yucca Mountain and the analysis of regional precipitation trends.

Feature-based and statistically-based field-site selection schemes will both include the following considerations: 1) the economic and/or practical limitations of establishing additional monitoring sites, 2) surface disturbances caused by establishing a monitoring site, 3) the period of time for which a monitoring site needs to be active, 4) the application for which measurements are needed, 5) currently existing and historical monitoring sites, 6) the boundary configuration and boundary conditions of the designated study area, and 7) site accessibility.

3.1.3.2.1.2.1 Feature-based site selection

Feature-based considerations involve some *a priori* knowledge of known deterministic processes affecting the parameter to be measured or the method of measurement. Deterministic processes governing some meteorological parameters, such as air temperature, solar radiation, and atmospheric pressure, are relatively well understood, well defined, and tend to exhibit predictable behavior. Such parameters tend not to require dense sampling networks, provided that other variables by which the deterministic processes can be modeled are known. The recently installed net-radiometer calibration site (see USGS-YMP-SP 8.3.1.2.2.1, Section 3.2.3.4.2.3.2) was selected according to considerations of exposure, surrounding terrain (blocking topography), and site accessibility. Using radiation data for model calibration obtained at only a few installed monitoring sites, solar radiation was modeled for study areas 1 and 3 using readily obtained ground elevation, geographic location, and sun-angle data, (Flint and others, 1989). Results from the model were analyzed to evaluate scale and accuracy requirements concerning the adequacy and expansion of the radiation monitoring network. This information can now be used for a combination of feature-based and statistically-based site-selection decisions.

Deterministic processes governing other meteorologic parameters and phenomena, such as precipitation, storm evolution, and wind speed and wind direction, can be too complicated and chaotic in nature to allow for accurate deterministic modeling. A greater sampling density is necessary to develop statistical models for parameter characterization (Section 3.1.3.2.1.2.2). However, knowledge of deterministic processes can still be utilized to make feature-based decisions on site selection in conjunction with a statistically based analysis. For example, knowledge of ground elevation and terrain effects are very important for site selection (Jones, 1981; World Meteorological Organization, 1983; Green and Helliwell, 1972; Kirigín, 1972; Huff, 1970). The effect of variables such as site exposure, slope, aspect, and relation to surrounding topography and prevailing weather patterns, must be carefully considered if a representative characterization of precipitation or wind, using a limited number of monitoring sites, is to be achieved.

The five weather-station sites discussed previously were selected using feature-based considerations of terrain (exposure), elevation, geomorphology (canyon verses ridge-top locations, etc.), study-area boundaries, and knowledge of mean seasonal weather patterns, in conjunction with application requirements. Weather station 1 is located east of the mouth of Split Wash between Yucca Mountain and Fran Ridge (Figure 3.1-20). This location is representative of inter-ridge areas of the study area. Station 2 is located on Jackass Flats about 0.4 km north of the Hydrologic Research Facility (HRF) next to NWS station 4JA (Figure 3.1-21). This station was located next to the Class A evaporation pan in order to supply vital data to the potential evaporation study (YMP-USGS-SP 8.3.1.2.2.1). Station 3 is located about 60 m northwest of borehole USW UZ-1 in Drillhole Wash (Figure 3.1-20). This station was cited for this study in order to collect meteorological data representative of narrow canyons on Yucca Mountain. Additionally, there is a long record of meteorological data for that location. Weather station 4 is located just east of the crest of Yucca Mountain, about 300 m north of USW UZ6 (Figure 3.1-20). This location was picked in order to collect data representative of the ridges. Also, there is a long record of meteorological data for that site. Weather station 5 is located about 1 km southeast of the prow on the highest point on Yucca Mountain (Figure 3.1-20). The elevation of this location makes it an important point for feature-based sampling.

A tipping-bucket precipitation gage is located at each weather station (see Section 3.1.3.2.1.1.2.). Two additional tipping-bucket-gage sites are located in the southern portion of study area 1 to improve the areal coverage of gages within this boundary (Figure 3.1-20). Site 6 is located at a relatively high elevation of 4765 ft on the southern extension of the crest of Yucca Mountain, and is important for monitoring storm systems traveling north from the Amargosa Desert towards the proposed repository site. Site 7 is located at an intermediate elevation of 4062 ft on an exposed ridge in the eastern portion of area 1, and is important for improving the areal coverage of sites within study area 1.

Application requirements were important for feature-based site selection of 74 storage-type precipitation gages attached to neutron-monitoring borehole casings (Figure 3.1-20). The primary purpose was to enable precise recordings of total storm and monthly precipitation depths at each borehole. The precipitation data is then correlated with the rate of infiltration of moisture into the unsaturated zone. Additional storage rain gages were installed at other locations within study areas 1 and 2 in order to expand the current network (Figures 3.1-20 and 3.1-21). A gage will also be installed near each tipping-bucket gage as that network is completed. All rain gages are easily accessible by vehicle because the gages must be manually read after each precipitation event. In addition, the low cost of each instrument and ease of installation permitted the establishment of a large network. In contrast, instrumentation for weather stations is more costly, reducing the number of possible sites, which, in turn, requires a more careful statistically-based analysis to help identify optimum locations.

The final network of meteorological monitoring sites, which will include all active sites operated by the USGS, National Weather Service (NWS), Yucca Mountain Project (YMP), etc., will be developed to meet the different characterization needs for study areas 1, 2, 3, and 4. The currently operating meteorological-monitoring network pertinent to this investigation for study areas 1 and 2 includes sites installed and maintained by this investigation (USGS), as well as sites operated by various other agencies for various purposes (Figures 3.1-21 and 3.1-20). Existing networks for study areas 3 and 4 are also maintained and operated by various agencies (Figures 3.1-23 and 3.1-22).

3.1.3.2.1.2.2 Statistically-based site selection

Statistically-based considerations for site selection include, (1) the level of accuracy desired for calculating areal averages and estimates at specified locations, (2) the level of accuracy needed for estimating parameter distributions, (3) the need to obtain a representative, unbiased sample of the parameter population, (4) the effects of scale on both accuracy and bias, (5) correlations between variables, and (6) the need to characterize and model the spatial variability of a given parameter. In order to implement a statistically-based sampling design, a sufficient number of existing or prior measurements are needed to estimate the efficiency of additional sites on improving accuracy, reducing bias, and defining spatial variability. Statistically-based sampling designs should also be flexible to allow for the refinement of statistical models as new data are accumulated.

The level of accuracy desired will be determined by the application of a parameter to the resolution of design and performance issues, the level of the study area being considered, and the sensitivity of models and derived parameters to the parameter being considered.

Knowledge of spatial distributions of meteorologic parameters in previous studies and in similar climates, environments and conditions, along with knowledge of the physical processes governing the behavior of meteorologic parameters, can be used to predict spatial distributions in order to establish the initial sampling network density and configuration. This network usually consists of a low cost, semi-permanent installation precursor to the final, long-term network that will be established for measuring meteorologic parameters.

In addition to sample size requirements, careful consideration must be given to the spatial configuration of the monitoring network both within and adjacent to the area of interest, because meteorological parameters may not have homogenous (i.e., "stationary") or isotropic spatial distributions. For example, meteorological parameters can be expected to display greater spatial variability over more rugged, mountainous topography than over the relatively flat topography characteristic of basins in the southern Nevada-southeastern California region. Sample-network densities over mountainous terrain would thus have to be greater than over basins in order to achieve similar levels of accuracy for characterizing spatial distributions and calculating areal estimates. Parameters such as average-annual precipitation may also be more variable at higher elevations, which would also require greater sampling densities over mountainous areas.

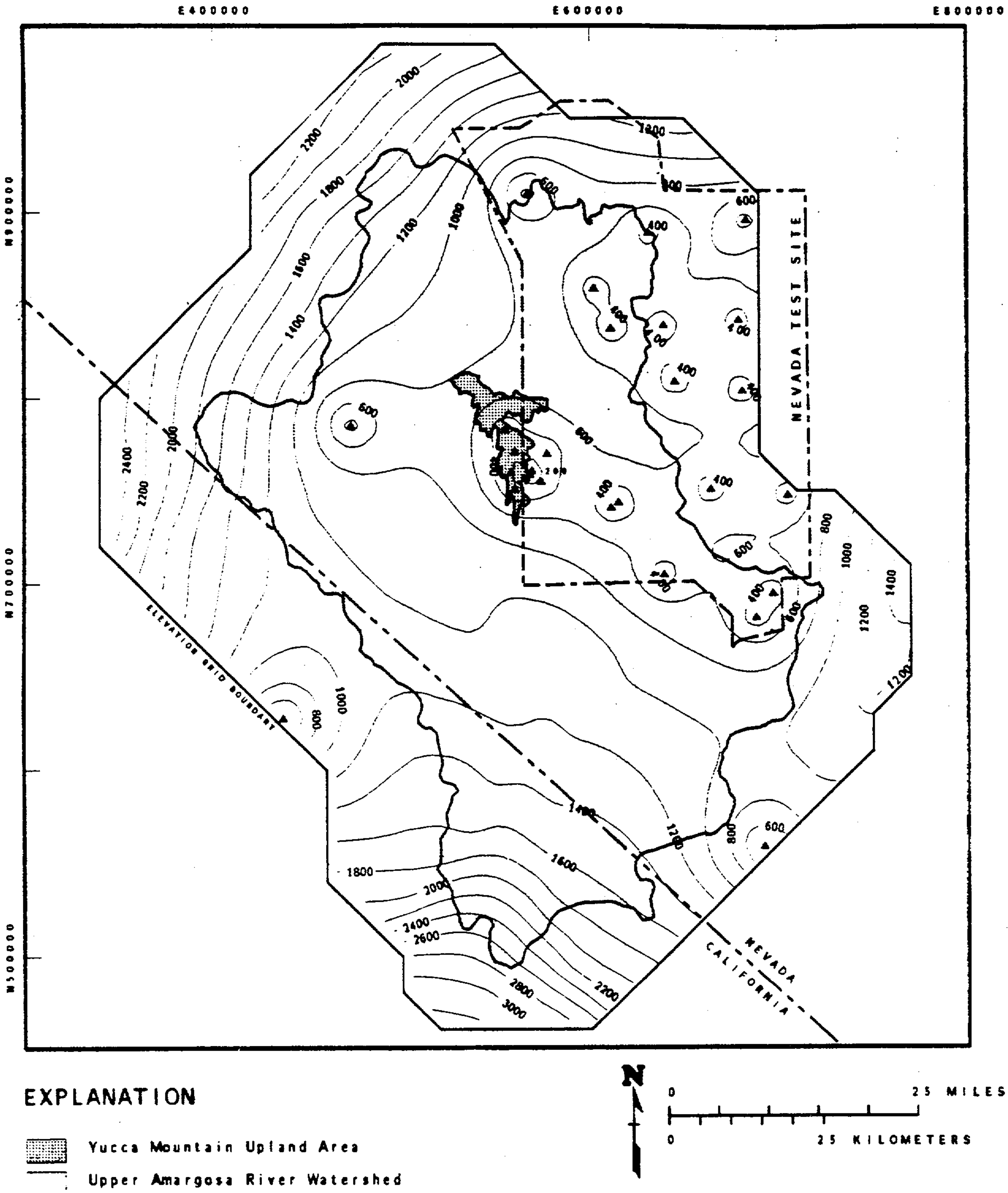
The possible existence of bias in statistical and geostatistical analysis caused by clustering of field sites within certain sub-domains of the total area of interest will be carefully investigated. A biasing of results was identified in the analysis of spatial structure for AAP and elevation over the Upper Amargosa River drainage (study area 3) using the selected subset of 42 precipitation stations with lengths of record of 8 years or longer (Hevesi, 1990). Fortunately, for that particular study, the clustering occurred within and adjacent to the area of interest, and the resulting bias was not considered problematic in terms of application needs.

Available data will be analyzed geostatistically in order to model spatial correlations and cross-correlations for various parameters. The models will be applied to predict sampling efficiency based on a combination of site location and sample size (the number of sites). Sampling efficiency will be evaluated according to the expected reliability of estimates within a specified area using a given network of measurements. The reliability of estimates will be evaluated using calculated estimation variances. (For additional information on geostatistics see Journel and Huijbregts, 1978, and Delhomme, 1978. For specific information on the application of geostatistics to precipitation analysis see Hevesi, 1990; Creutin and Obled, 1982; Lebel and others, 1987; Tabios and Salas, 1985; and de Montmollin and others, 1980.)

Predictions concerning the efficiency and optimum configuration of additional sites for measuring precipitation (AAP) within study area 3 have recently been made using geostatistical models (Hevesi, 1990). Figure

3.1-24 indicates the locations of active precipitation stations within and adjacent to study area 3, as identified by Hevesi and by others (this did not include the complete network as identified in this study plan), and the resulting field of estimation variances. Figure 3.1-25 indicates the field of estimation variances resulting from the addition of 20 new sites to the existing network by identifying locations of maximum estimation variance. Results from the exercise indicated the following points. First, additional sites within area 3 are most needed at the southern portion of the Amargosa Desert (in the general area of Franklin Lake), the summit areas of Quartz Mountain (or Black Mountain) at the northern limit of area 3, and a location directly to the southeast of Grapevine Peak (Wayguyhe Peak). In general, additional sites are needed in the Amargosa Desert to the south and the southwest of Yucca Mountain, and in Oasis Valley and Thirsty Canyon to the northwest of Yucca Mountain. Second, as shown in Figure 3.1-26, expanding the existing network to include 20 additional sites at optimum locations within area 3 reduces the average estimation variance from 974 mm^2 to 464 mm^2 (or from 63 mm to 42 mm, in terms of an estimation error with 95-percent confidence). The maximum estimation error is reduced from 2,690 mm^2 to 597 mm^2 (from 105 mm to 48 mm, in terms of an estimation error with 95-percent confidence). Third, no significant reductions in estimation variance occur at the repository site when expanding the network to improve coverage in area 3, because of the network of precipitation stations currently operating within areas 1 and 2. Fourth, the use of a multivariate geostatistical model, which incorporates a large sample of elevation data (such as existing DEMs), provided approximately a 50-percent improvement in estimation accuracy relative to estimates of precipitation calculated using only measurements of precipitation. This result was observed for both the existing network (as defined by Hevesi, 1990) and the expanded network of 20 additional sites.

The relatively simple procedure used in this preliminary analysis will be modified to identify optimum sites based on the minimized average local estimation variance. Various procedures ranging from simple trial-and-error algorithms to more sophisticated packing procedures are being investigated. In general, minimizing average estimation variances will be considered to be more important for obtaining areal averages. Site locations based on both procedures will be compared, and decisions on final site selection will be made by a subjective analysis of application, statistical, economic, and feature-based considerations.



EXPLANATION

Yucca Mountain Upland Area

Upper Amargosa River Watershed

PRECIPITATION STATION

▲ Active

ISOLINES ARE IN MILLIMETERS SQUARED

Figure 3.1-24. Estimation variances (mm ^{2}) for estimated average annual precipitation using cokriging interpolation. Variances were calculated using a network of 38 active precipitation stations and also 1,531 grid locations for ground elevation.

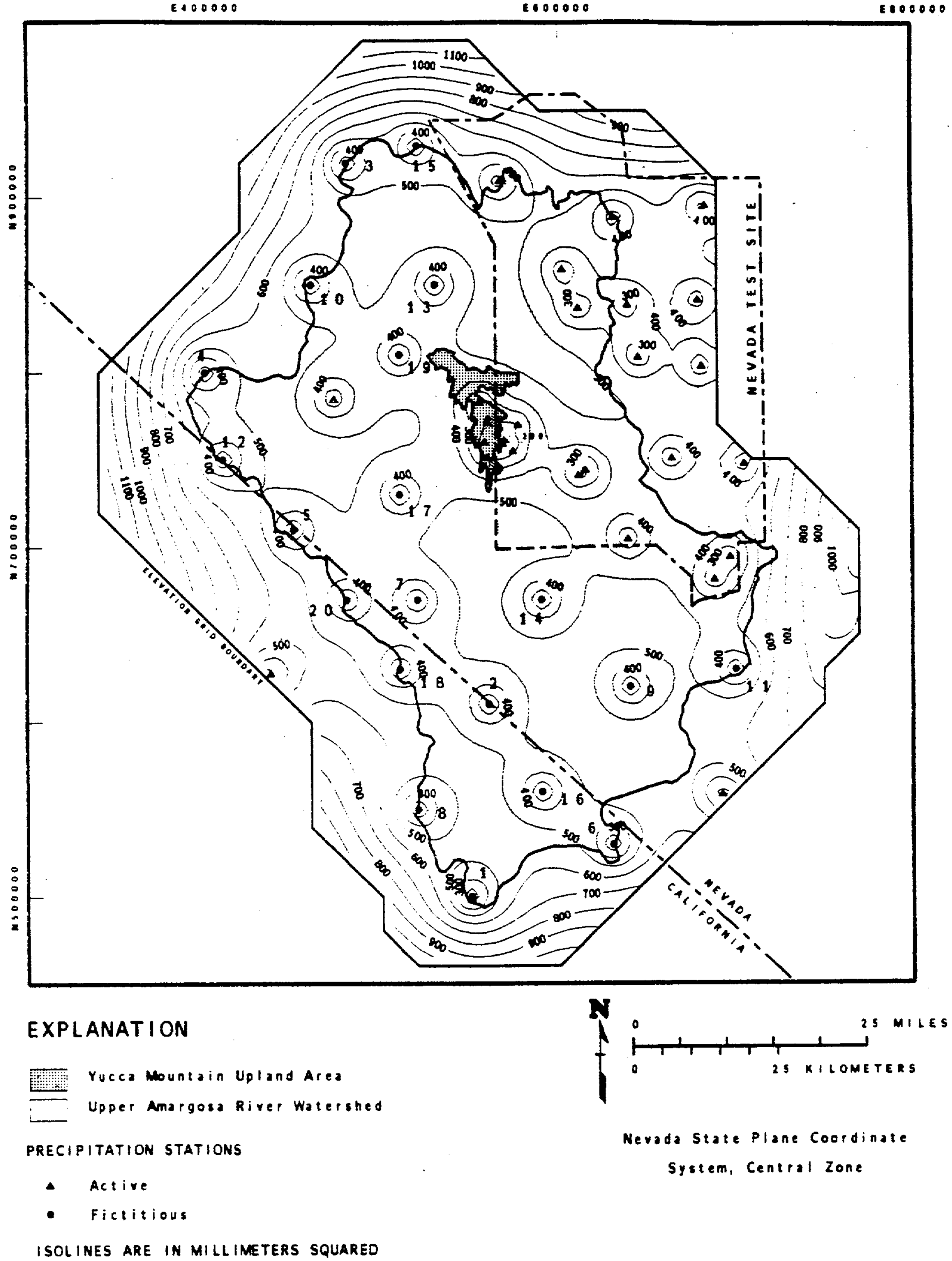


Figure 3.1-25. Estimation variances (mm^2) for estimated average annual precipitation using cokriging interpolation. Variances were calculated using a network of 38 active and 20 fictitious (hypothetical) precipitation stations and also 1,531 grid locations for ground elevation.

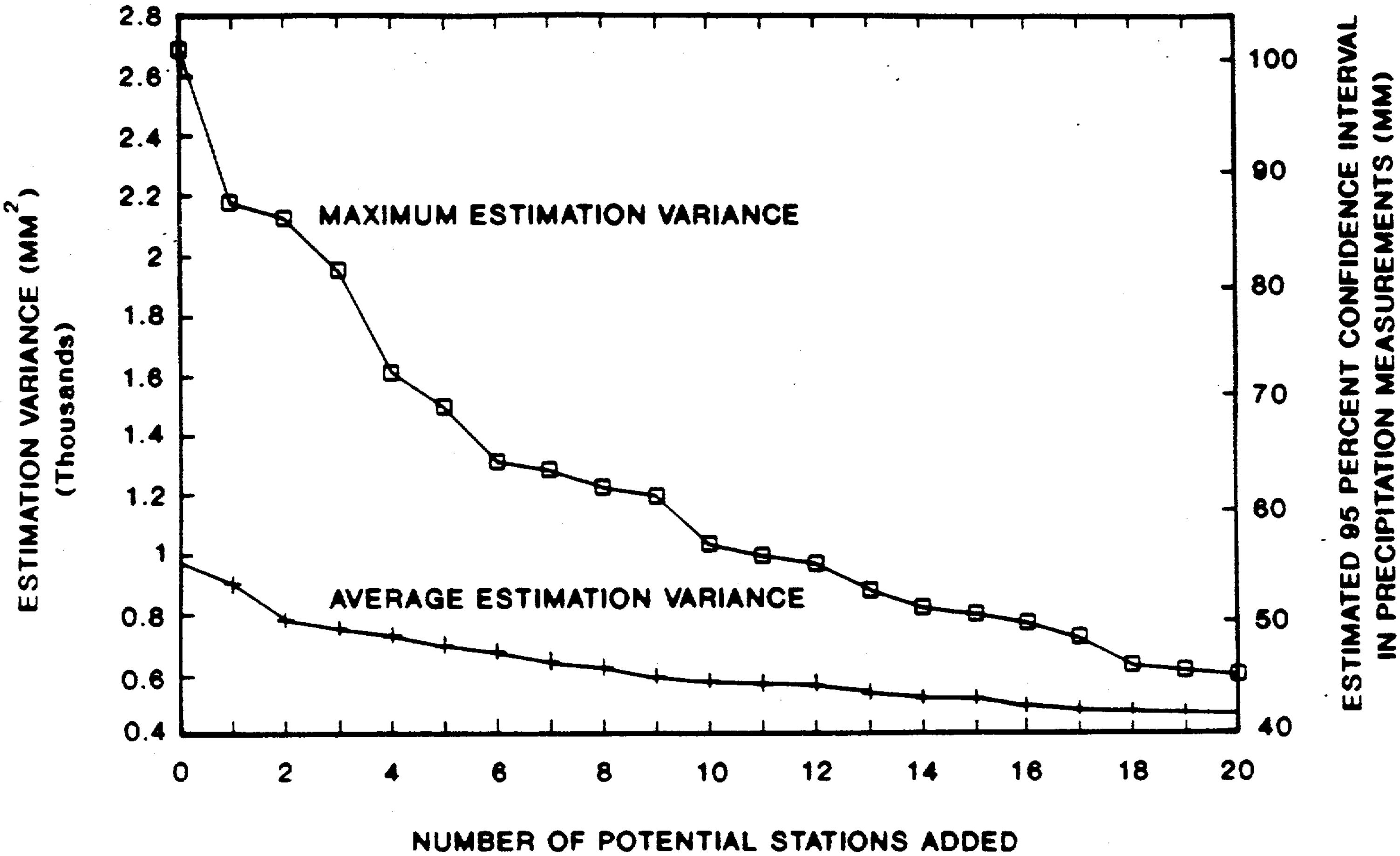


Figure 3.1-26. Reduction in average and maximum estimation variance within study area 3 as a function of the number of precipitation stations added to an existing network. Right axis indicates estimated 95 percent confidence interval in precipitation measurements.

Predictions concerning sample-size requirements for desired levels of accuracy, in terms of percent error for local estimates of AAP within study area 3, could be made using the results obtained in the analysis by Hevesi (1990) and the fact that the calculated average estimation error for the 747 grid points within area 3 is equal to zero if stations are located at all points. Note that achieving a zero-percent error is possible only for the model, but the selected grid spacing of 10,000 ft was considered reasonable for a representative analysis on the scale of study area 3. This grid would be considered too coarse for study areas 1 and 2.

Figure 3.1-27 indicates the fitted curve and the first 20 known values (the 0-percent error value for 747 added stations is not shown on this scale). The curve was used to predict that an additional 180 stations are required to achieve an average accuracy of 10 percent for local estimates of AAP within study area 3. This technique allows an estimate of the number of stations required to achieve a desired accuracy. For example, if an error of 30 percent for AAP is acceptable, then 10 additional precipitation stations would be required (Figure 3.1-25).

Relatively inexpensive temporary or preliminary field monitoring sites (discussed in Section 3.1.3.2.1.2.1) will be used to develop statistical models which can then in turn be used to help locate sites for the more expensive and more permanent monitoring sites. For example, the storage precipitation gages are currently being used to help model the spatial correlation of precipitation depths during storm events and monthly intervals.

3.1.3.2.2 Supporting measurements and historical data

The USGS has primary responsibility for installing and operating weather stations within study areas 1, 2, and 3. However, there are a number of agencies within southern Nevada and southern California that collect weather data for their own purposes. Data from these sources can corroborate USGS data collected under this study and can provide researchers additional insight into the regional meteorology of Yucca Mountain. Figures 3.1-20, 3.1-21, 3.1-22, and 3.1-23 depict the locations of these stations. Table 3.1-3 lists these active data sources and provides information on the operating agency, geography, meteorological parameters collected, frequency of data collection, and the period of operation. These data from throughout the study region are also valuable from their historical perspective. Researchers will be able to relate present-day weather conditions with those conditions recorded 40 to 50 years in the past. These corroborative data are available from private sources and from Nevada state and Federal governmental agencies.

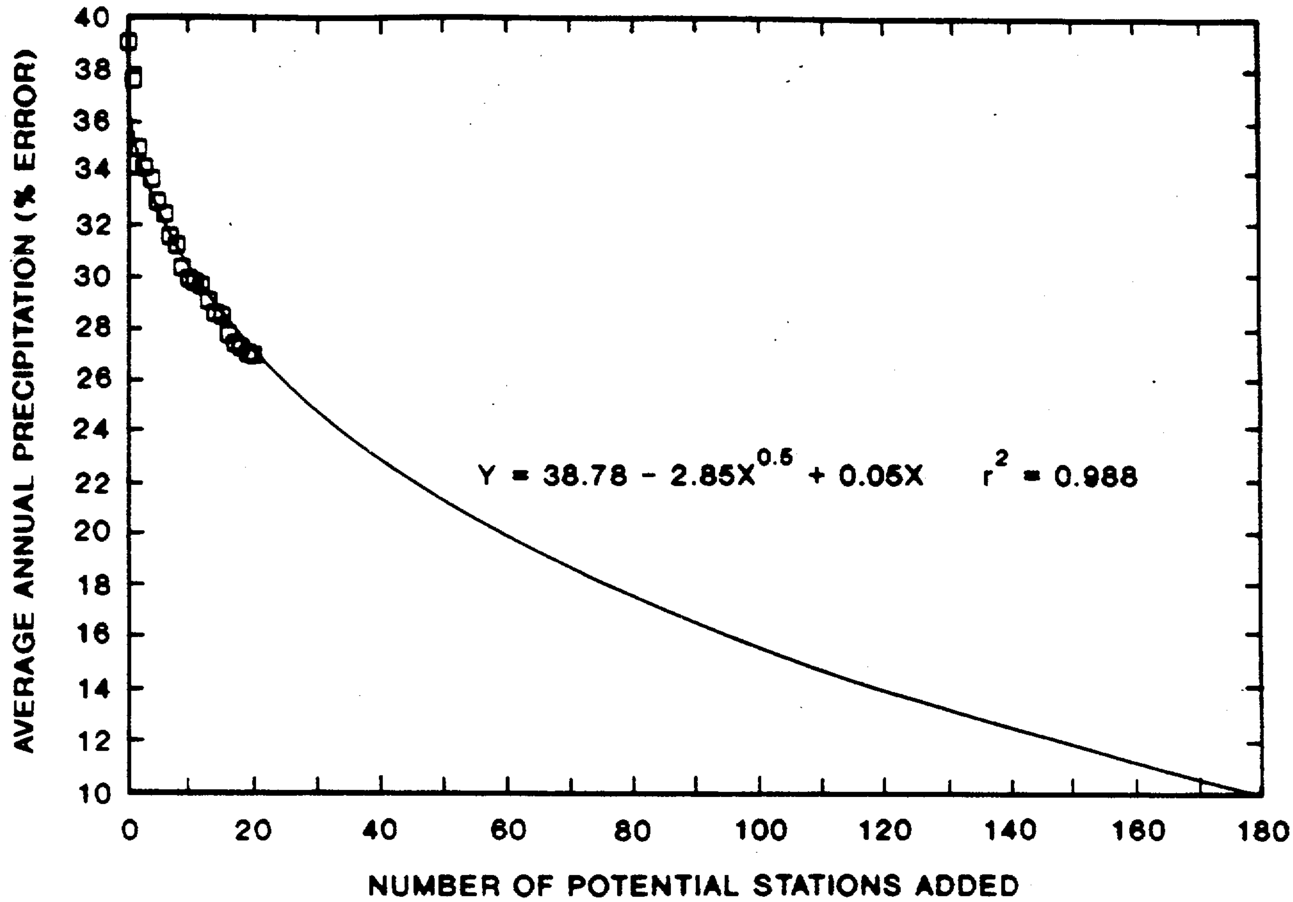


Figure 3.1-27. Percent error predicated as a function of the number of precipitation stations added to an existing network.

The WSNSO operates the mesoscale Meteorological Data Acquisition (MEDA) Network on the NTS (Figures 3.1-20, 3.1-21, 3.1-22, and 3.1-23). The MEDA network currently consists of 32 stations. Observed parameters include wind speed, wind direction, precipitation, air temperature, dew point temperature, barometric pressure, and relative humidity. They also operate an NTS network of 16 precipitation gages (Figures 3.1-21 and 3.1-22, and Table 3.1-4) that is still active and predates the establishment of the MEDA network.

The National Weather Service (NWS) operates three official weather stations at Las Vegas, Tonopah, and Desert Rock airports (Figures 3.1-22 and 3.1-23). These stations collect a full range of data 24 hours per day and provide valuable continuity in the weather record; they also provide a long historical record. To expand its data-collection network, the NWS solicits help from private citizens or other governmental agencies to record daily observations of maximum and minimum temperature and precipitation. These 25 co-operatives (co-ops) report monthly to the Nevada state climatologist who, in turn, reports to the National Climatic Data Center (NCDC), Asheville, North Carolina (Figure 3.1-23). There the data are entered into the official climatological record for Nevada. Then NCDC prepares a final report called Climatological Data for Nevada which lists the month's data and includes analyses and comparisons with past years. Finally, other agencies, including the military, collect meteorological data for various reasons within southern Nevada and southeastern California. Data from these sources will be evaluated for use following their availability and verification.

3.1.3.3 Data processing and storage

The large volume of data from meteorological stations and precipitation stations will be collected by an automated data-acquisition platform. The magnetic tapes which are periodically removed from the stations are considered to contain the "original" raw data. A working copy of the data will be downloaded on to IBM PC-compatible storage media such as floppy disks. The cassettes will then be archived in accordance with accepted technical procedures. The raw data will be processed into a form compatible with needs of the end user. For example, 15-minute data can be processed into monthly averages for climatological studies.

Currently, the feasibility of long-term data storage on optical media is being investigated. This form of storage has the advantage of providing huge data capacities in a compact and extremely durable package. The shelf life of optical media far exceeds that of magnetic media.

Lightning-detection data will be collected only by automated systems. The lightning data will be correlated with precipitation distribution and intensity. Nevada Test Site lightning data,

Variable	Total Precipitation, mm		
	Storm 1/14/90	Storm 1/17/90	Storm 2/02/90
Sample size	46	50	74
Mean	1.94	7.31	2.35
Median	1.90	7.31	2.54
Mode	2.03	7.62	2.79
Variance	0.359	5.76	0.808
Coefficient of variation	0.305	0.325	0.379
Standard deviation	0.599	2.40	0.899
Standard error	0.088	0.339	0.104
Minimum	0.508	2.00	0.254
Maximum	3.56	13.00	5.84
Skewness	0.531	-0.250	0.704
Standardized skewness	1.47	-0.710	2.47
Kurtosis	0.688	0.510	2.88
Standardized kurtosis	0.953	0.740	5.06
Correlation coefficients			
Precip-Elevation	-0.268	-0.440	-0.490
Precip-Easting			0.669
Precip-Northing			0.853

Table 3.1-4. Statistical analyses of three storm events.

collected in cooperation with the WSNSO, will be processed and displayed via computer terminal and archived on removable hard disks, if possible. The optical lightning-detection network may be used as an "alerting" mechanism. The sensors will send out a signal each time lightning is detected. This system will be used to alert responsible investigators of the likelihood of a potential rainfall-runoff event. The data from this network will be stored in computer files on removable hard disks for future correlation with rainfall and other lightning-strike data.

Satellite data will be processed and displayed on an IBM-compatible PC and stored on removable hard disks. Cloud data recorded via video or motion-picture camera will be archived on video tape or film.

Data received from the NTS, NWS locations, and cooperatives will be stored on removable hard disks and in paper form. Other historical data (1949-1983) are also stored on removable hard disks and in paper form.

3.1.3.4 Analysis of meteorological data

The collection of meteorological data will provide needed information for a variety of studies (see Section 3.1.2). The present study (8.3.1.2.1.1) will also contribute to these other studies by providing analyses and interpretations of the data. The following sections will provide detailed information on the methods of analysis and interpretation for precipitation data as well as the general meteorological conditions. Analyses will deal with both the statistical and deterministic process of meteorology. These analyses will use historical storm data as a supplement to the collected data set as necessary (see Section 3.1.3.2.2).

When possible or applicable, individual storm events will be standardized to remove proportional effects between storms. A proportional effect can be caused by an increase in absolute variability with increasing mean storm depth. Removing this influence on variability will allow spatial variability to be defined in terms of the coefficient of variation for individual storm events. The development of standardized model variograms for specific types of storm events is currently being investigated, and will be described more fully in Section 3.1.3.4.1.1.

3.1.3.4.1 Precipitation

Precipitation is of primary interest in this study characterizing regional meteorology and climatic patterns at and in the vicinity of Yucca Mountain. Analyses will be performed to define precipitation as it occurs, to characterize small- and large-scale patterns in precipitation, and to characterize the spatial and temporal distributions of precipitation. Techniques will also be used to predict storms in support of Studies 8.3.1.2.2.1 (Unsaturated-zone infiltration) and 8.3.1.2.1.2

(Regional runoff and streamflow) for on-site analyses of runoff events contributing to surface infiltration.

The characterization of precipitation will involve analyses of the following measured, calculated, and/or estimated parameters: accumulations of precipitation during designated time intervals (days, months, years), rates of precipitation (instantaneous, hourly, average for storm event), durations of specified rates and storm events, and the frequencies and/or timing of specified accumulations, rates, and storm events. Of particular interest are extreme precipitation events, their related magnitudes, and recurrence intervals. Due to the rarity of extreme events, extensive use of historical data will be used in the analysis. In addition, the relation of these parameters to the various types of precipitation (snow, rain, hail, and sleet) and types of storm events (frontal, cyclonic, convective, and orographic) will be defined for a thorough characterization of precipitation.

Statistical analyses of parameters will be performed where applicable, for the purposes of determining confidence intervals, estimations, and predictions, and for the comparisons of precipitation events. All data, including measured values, computed values, and calculated statistics, will be stored and processed using GIS (PC ARC/INFO) to allow for a combined statistical, spatial, and deterministic analysis of precipitation, and also to enable the timely processing of data for a geostatistical analysis. Geostatistical analyses will be performed to analyze spatial and temporal variability, and to define models for estimation and sampling network analysis (Section 3.1.3.2.1.2.2). Point and areal estimations will be used to expand the GIS data base; this will allog for a deterministic analysis of results using overlays, profiles, slices, surface area, volume, and density calculations. Deterministic analyses will include comparisons of storm hyetographs and histographs from recording stations to determine storm tracks and velocities (Niemczynowicz, 1988). Parameter estimation will be necessary for areal mapping and for the characterization of precipitation over the complete coverage of each study area. Estimated values will also be important for other applications, including water-budget analysis, precipitation-runoff modeling, and infiltration modeling.

3.1.3.4.1.1 Statistical analyses

Data from all sources will be compiled and appropriate statistics will be calculated. The data will include total storm depth, maximum instantaneous-precipitation rates, average hourly-precipitation rates, and durations. The mean, median, mode, maximum, minimum, variance, standard error, coefficient of variation, skewness, and kurtosis will be documented and stored for each precipitation event and for specified time intervals. Sample distributions will be investigated and compared with standardized curves. When appropriate, variable transformations will be performed to allow for the use of confidence intervals and various statistical tests. Precipitation depths for individual storms will be standardized for investigating average variability for specific types of storm events, and also for distinguishing various types of storms based on variability. Analysis of variance tests will be performed to investigate sources of variability within and between individual storm events. Appropriate statistics concerning average accumulations, rates, and durations will also be computed after each storm for each monitoring site to provide data for a temporal analysis of precipitation. Time-series analysis and cumulative deviations from mean precipitation will be used for preliminary investigations of short-term climatic behavior (Jones, 1981).

Sample correlations with various feature-based parameters will be investigated for individual storms, as well as for monthly, seasonal, and yearly accumulations. Parameters will include elevation, slope, aspect, and various index elevations. Correlations with vegetation type and density will be investigated for average annual precipitation. Elevations of measurement sites will be obtained from 1:24,000 USGS topographic maps or from USGS DEM models. Slope, aspect, and index elevation parameters will be calculated using the elevation data base or topographic maps. Index elevations are representative elevations calculated by various weighted neighborhood averaging techniques over a range of neighborhood shapes and sizes (Schermerhorn, 1967). The analysis of the correlations of precipitation and feature-based parameters will be important for defining the influence of large- and small-scale terrain effects on precipitation, such as regional and local orographic influences, "rain-shadow" effects, and site exposure.

Sample correlations with precipitation and various other measured meteorological parameters will be analyzed. Important parameters include air temperature, wind speed, wind direction, and lightning intensity. Changes in relative gage catch as dependent on the occurrence of frozen precipitation will need to be investigated for the purpose of determining gage error, which is known to increase as a function of increased wind speed and increased amounts of precipitation occurring as snow. Also, variables such as index elevation, slope, aspect, and geographic location will be included in a partial correlation analysis, indicating the relative importance of the different factors on influencing gage catch. Correlations for gage catch between separate storm events will be investigated to help identify common characteristics in precipitation depth patterns for individual events during different seasons. This will be useful in determining the likelihood of precipitation patterns for specific types of storms, especially in terms of orographic and terrain influences, as a function of storm genesis, storm size, and storm track.

A careful subjective analysis of variograms will be performed in order to characterize the spatial variability of precipitation. Variograms will be computed for storm accumulations, monthly accumulations, seasonal accumulations, and yearly accumulations. Variograms will also be computed for measured maximum and calculated average rates and durations. The signatures of various types of storms will be characterized by an "average" standardized variogram (Lebel and others, 1987). Heterogeneity and anisotropy in the structure of spatial variability will be investigated using directional and local variograms. An attempt to characterize the various types of storm events and seasonal precipitation, based on the results of variogram analysis, will be made. Model variograms will be fitted to the appropriate sample variograms and tested using various cross-validation procedures. Selected models will then be used to compute estimates for precipitation accumulations, rates, and durations.

Geostatistical estimation techniques have been shown to provide improved performance in terms of bias and estimation accuracy relative to less sophisticated interpolation methods (Hevesi, 1990; Creutin and Obled, 1982; Lebel and others, 1987; Tabios and Salas, 1985). The use of geostatistical models for the purpose of locating new field sites is discussed in Section 3.1.3.2.1.2.

Multivariate geostatistical models will be utilized when possible to augment and improve the spatial coverage of point measurements. The application of radar to obtain improved areal estimates of storm event rates and depths using multivariate geostatistics was addressed in a previous section. A strong positive correlation of storm event rates and depths with the number of cloud-to-ground lightning strikes has been documented (Moore and others, 1962; Szymanski and others, 1980; Piepgrass and Krider, 1982; and Goodman and Buelcher, 1990), and the application of multivariate geostatistics to expand the spatial coverage of direct measurements of precipitation using data obtained from a lightning-detection network will be investigated. Lightning-strike data can also be used for the monitoring of storm-cell size, genesis, movement, and the indirect measurement of the relative distribution of precipitation rates and depths within storm cells and/or systems.

Other parameters known to be related to precipitation within the study area include vegetation type and/or density and ground elevation. The use of ground-elevation data to improve the efficiency of the historical-precipitation-sampling network using multivariate geostatistics for the characterization of average annual precipitation within Area 3 has been investigated by Hevesi, (1990). Their results indicated that, on average, an improvement of 55 percent can be expected in the efficiency of the existing sampling network by incorporating elevation data for the measurement of average annual precipitation. The use of elevation to improve sampling efficiency for the measurement of precipitation rates, storm accumulations, seasonal accumulations, storm frequency, storm duration, and also for the measurement of the variability of these parameters in space and time, is currently being investigated.

The analysis of temporal variability will consist of statistical and one-dimensional geostatistical analysis at each field site over the total period of record. Measurement requirements concerning temporal characterization are restricted to time intervals of measurement and length of record. Measurements taken at smaller time intervals will yield the most accurate and detailed temporal characterizations. Measurements obtained from weather stations recorded at intervals of 10 seconds will provide the most accurate temporal characterizations. Measurements for all parameters will be taken at a minimum of monthly intervals. For example, measurements obtained from the storage precipitation-gage network for accumulated precipitation depths will be collected at least once a month, regardless of precipitation-event frequency.

Table 3.1-4 provides an example of a preliminary statistical analysis of three precipitation events that occurred in the winter of 1990. The data for this analysis was collected using only the storage precipitation gage network, and includes only the total depth per storm measured at each location. Not all currently active storage gages were operational at the time these storms occurred. Several important comparisons of the three storm events can be made using the statistics listed in Table 3.1-4. The sample variance is observed to increase with an increase in the sample mean. This may be evidence of a proportional effect concerning winter-season storm-to-storm variability, though the number of storms analyzed needs to be much greater for such evidence to be conclusive. A proportional effect can be defined as an increase in the sample variance in proportion to an increase in the sample mean. This often occurs as a certain type of heterogeneous spatial structure for log-normally distributed variables (Journel and Huijbregts, 1978). The possible existence of a proportional effect indicates the importance of using standardized storm depths and coefficients of variation for comparing storm-to-storm variability, for identifying differences in various types of storm events, and for characterizing different types of storms according to sample variability.

Variograms of the standardized storm depths show roughly similar characteristics in spatial structure for three winter storms (Figure 3.1-28). Fair-to-good spatial correlation within study area 1 is evident for the storms on 1-14-90 and 2-02-90. For these two events, the range of spatial correlation appears to be greater than at least one-half the longest dimension of the sample domain spanned by the storage-gage network. In other words, the storm-cell size of the average winter-season storm is shown to be greater than study area 1. The decreased spatial correlation for storm 01-17-90, especially over a relatively small distance, was interpreted to be a combination of higher wind speeds over the crest of Yucca Mountain and the occurrence of snow at the higher elevation gages.

The correlation coefficients for precipitation and gage elevation for all three storms listed in Table 3.1-4 indicate a poor-to-negative relation between precipitation and elevation. The lack of a significant ($p = 0.05$) positive correlation between gage elevation and total storm depth is hypothesized to be the result of a combination of site exposure, terrain effects, and the occurrence of precipitation in the form of snow influencing gage catch. The observed negative correlations (although not significant for $p = 0.05$) indicate a decrease in measured precipitation with an increase in gage elevation, which is contradictory to the observed positive correlation between measured annual precipitation depth and gage elevation for the southern Nevada region (French, 1983, 1986; Quiring, 1983; and Hevesi, 1990).

One explanation for these conflicting results is that the present storage-gage network provides a bias of relatively more exposed sites for the higher-elevation gages. The higher wind speeds at the more exposed sites tend to decrease the catch. Also, eddy effects (turbulence around and above the gage), tend to increase with increased wind velocities, which in turn, tends to increase gage error in terms of a deficit of measured precipitation relative to the amount of precipitation reaching the ground surface. Finally, both of these wind-induced influences on gage catch are greatly compounded for precipitation occurring as snow. In general, the storage precipitation gages are not designed for measuring snow accumulations, even though readings are taken after the accumulated snow has changed to the liquid state. The analysis of all three storm events indicates that errors in snow measurements are largest at high elevations, where the gages are most likely to be exposed to high winds.

Figure 3.1-29 indicates a negative spatial correlation between standardized storm depth for the 2-02-90 event and standardized gage elevation. Note the greater relative spatial variability of precipitation compared to gage elevation. As discussed above, these observations were

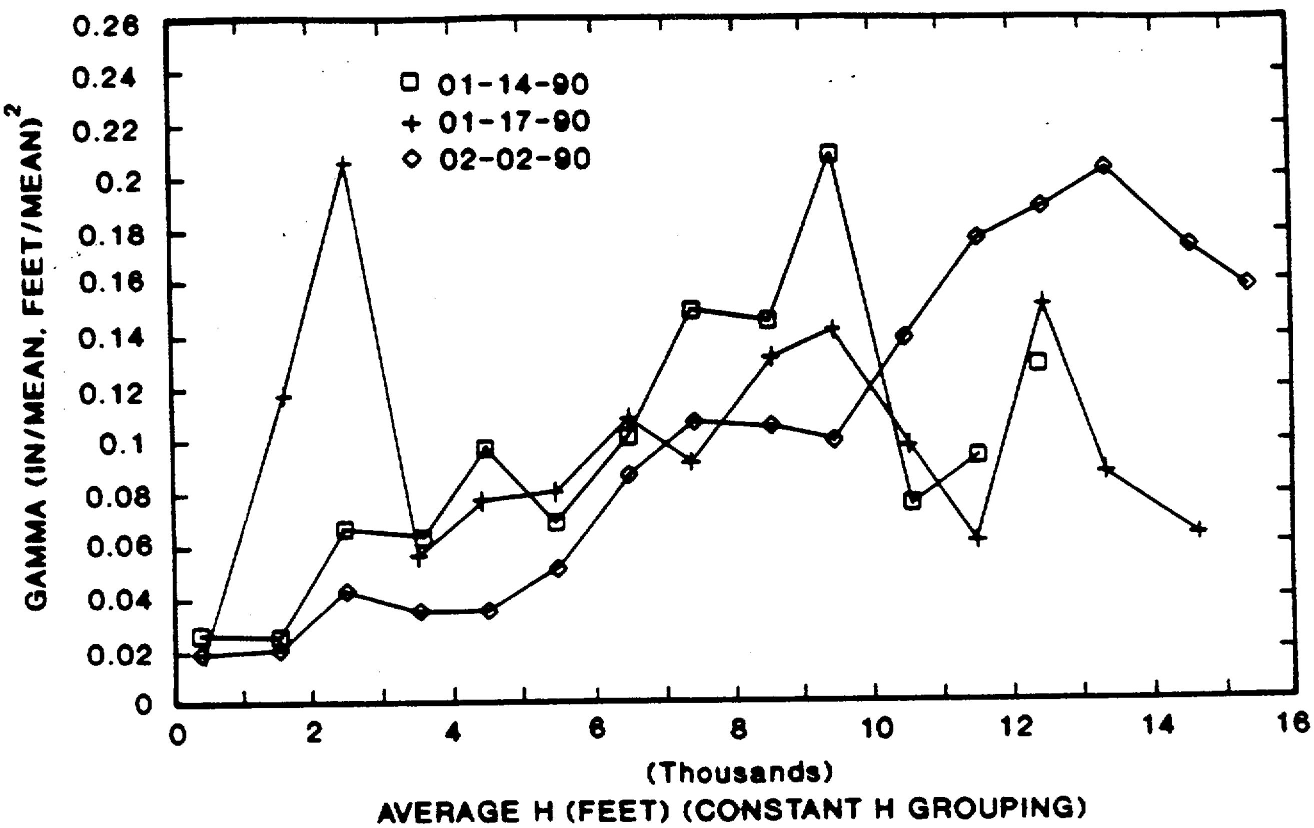


Figure 3.1-28. Isotropic direct variograms for precipitation depths of three separate storm events in 1990. Variograms were calculated using a constant H (lag distance) grouping and standardized data for precipitation depths (mm/mm).

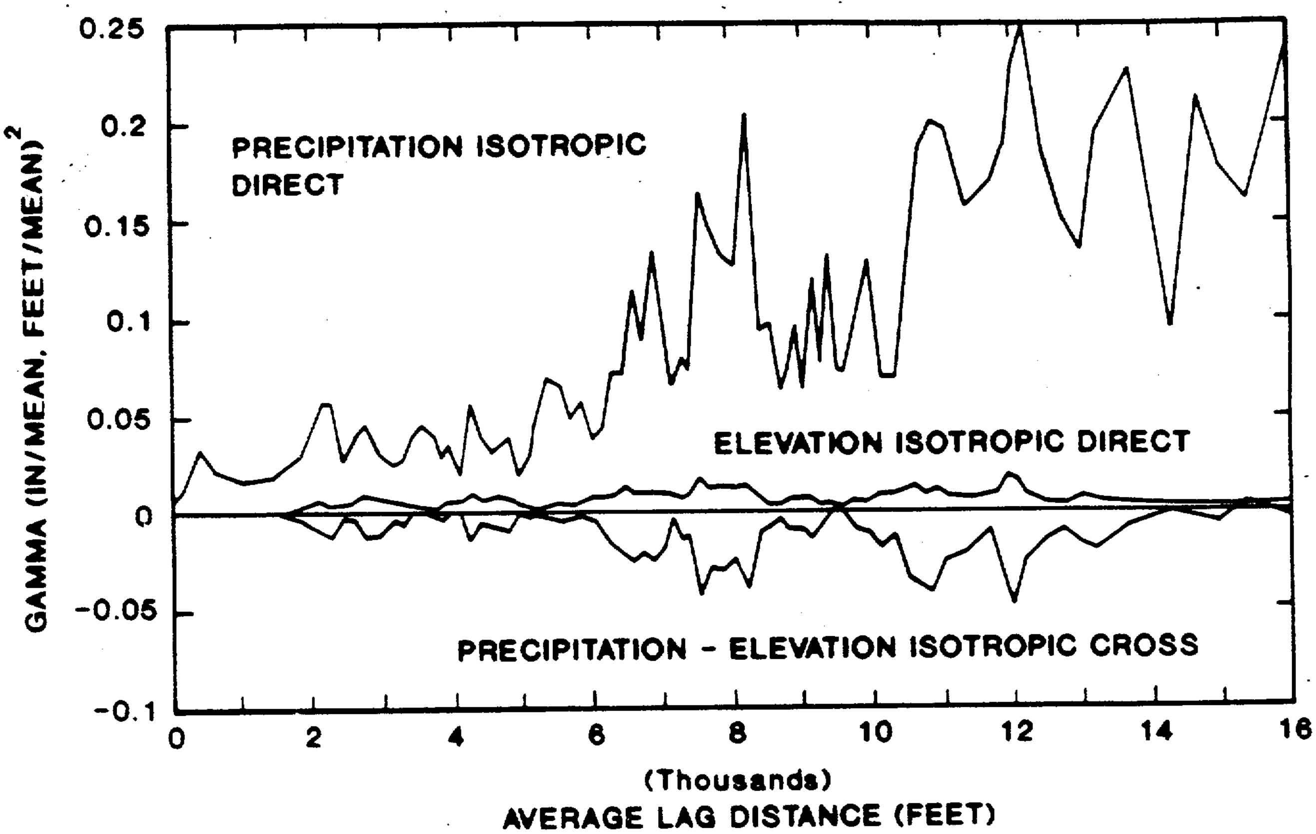


Figure 3.1-29. Isotropic direct and cross variograms for precipitation depth and gage elevation for the storm event ending 2/2/90. Variograms were calculated using a constant 30 pairs grouping method and standardized data for both precipitation (mm/mm) and elevation (ft/ft).

determined to be an indication of increased site exposure and increased precipitation occurring as snow with increased gage elevation. In this case, a multivariate model using elevation data would probably not be very useful in providing improved estimates of precipitation. The correlation of gage catch to index elevations, which would take into account terrain effects, is currently being investigated.

In general, this type of analysis will be important for defining average model variograms for standardized storm depths for specific storm types and seasons (i.e. convective verses frontal), and for delineating terrain and exposure influences from larger scale orographic influences on gage catch. Geostatistical models of average storm variograms will also be used to help identify optimum sites for approximately 30 tipping-bucket gages within area 1, and 20 within area 2, and for predicting the accuracy of areal estimates using various proposed sampling networks, as discussed in Section 3.1.3.2.1.2.

Sample distributions for all three events indicate a better approximation of sample values to a normal distribution than to a log-normal distribution for these winter-type storms. This is somewhat atypical of current assumptions regarding precipitation sample distributions in arid environments (Jones, 1981). However, it is noted that in each case only a small portion of the total storm-cell area was sampled using the storage-gage network. Data for these storms from surrounding weather stations on the NTS and in the southern Nevada region will be incorporated with the storage-gage data in order to perform a more complete and representative statistical analysis of wintertime precipitation.

A comparison of the coefficients of variation for the three storms listed in Table 3.1-4 indicates an increase of this statistic with an increase in sample size. Analysis of the areal coverage of measurements obtained for each event revealed an increase in the areal coverage of the sample domain with an increase in sample size. It can be hypothesized that the increase in the coefficient of variation as a function of sample size is caused by the existence of trends in the spatial distribution of precipitation depths for winter-season storms. The existence of such trends is also suggested by significant ($p = 0.05$) positive correlation coefficients for precipitation and geographic location (easting and northing coordinates, Table 3.1-4). Identifying spatial trends will be important concerning assumptions on heterogeneity that must be made for a geostatistical analysis, to obtain areal mappings of parameters characterizing precipitation. Again, the number of storm events analyzed will need to be much greater (20 to 50 separate events, or at least two complete years of data) before a meaningful analysis can be made. Current results are presented primarily as examples of the types of analysis that will be conducted.

Figure 3.1-30 provides an example of isohyetal mapping of total precipitation depth for the event on 2-02-90. The estimates needed for the plotting of isohyets were obtained using the inverse-distance-squared interpolation technique. These maps will be important for identifying trends and patterns in storm precipitation.

A model variogram was fitted to the isotropic direct-sample variogram for the event on 2/02/90 for the purpose of isohyetal mapping of storm depths using kriging as an alternate-interpolation technique (Figure 3.1-31). Model fitting was accomplished using the cross-validation technique (Delhomme, 1978; Cooper and Istok, 1988; Hevesi, 1990). The resulting isohyetal map of total storm depth (Figure 3.1-32) appears much different than that obtained using inverse-distance-squared interpolation (Figure 3.1-30). This is because of the existence of a trend of increasing precipitation depth from south to north, as indicated by the distribution of values in the sample and the general shape of the sample variogram (Figure 3.1-31). The selected model variogram incorporates this trend effect in the statistical model by smoothing estimates over clusters of data and increases the significance of isolated data, such as at station 85 and at two stations located in Fortymile Canyon to the northeast (not shown on map). The use of an inherent measurement variability, termed nugget structure, of 0.12 mm^2 in the model variogram also causes a smoothing of estimated values. The existence of a nugget structure is caused by a combination of measurement error (due to reading errors, gage resolution, orifice size, and turbulence about the gage) and small-scale terrain effects influencing gage catch over distances of only a few hundred feet. A nugget structure is simply an added model component that allows for the existence of random measurement errors. This component is added to the variogram model so that erroneous data at one or more locations does not strictly control the resultant isohyetal map, and so that the model allows for a general smoothing which more readily fits the expected rainfall distribution determined from the larger data set. Clearly, a subjective analysis of precipitation patterns will be different according to the estimation technique selected, and calculated areal estimates of total storm depth will also vary according to the method of estimation. A more detailed analysis of the sample variogram, using residual storm depth obtained by factoring out statistically modeled trend components, is in progress. Incorporating the trend model as a deterministic component in the geostatistical model allows for significant reductions in estimation variances by universal kriging and cokriging.

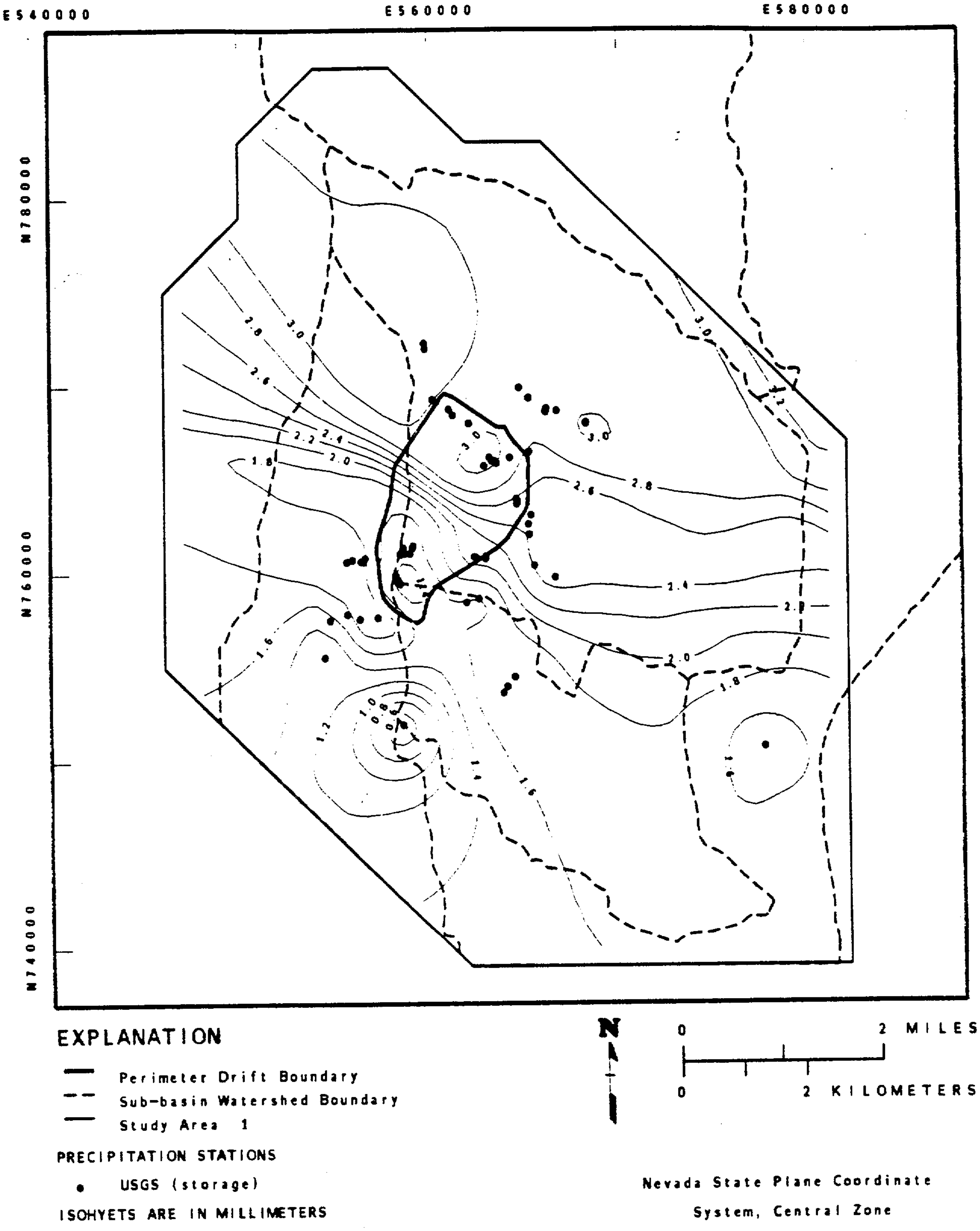


Figure 3.1-30. Estimation of total precipitation depth (mm) from the storm event ending 2/2/90 using inverse-distance-squared interpolation and date from 74 USGS storage gages.

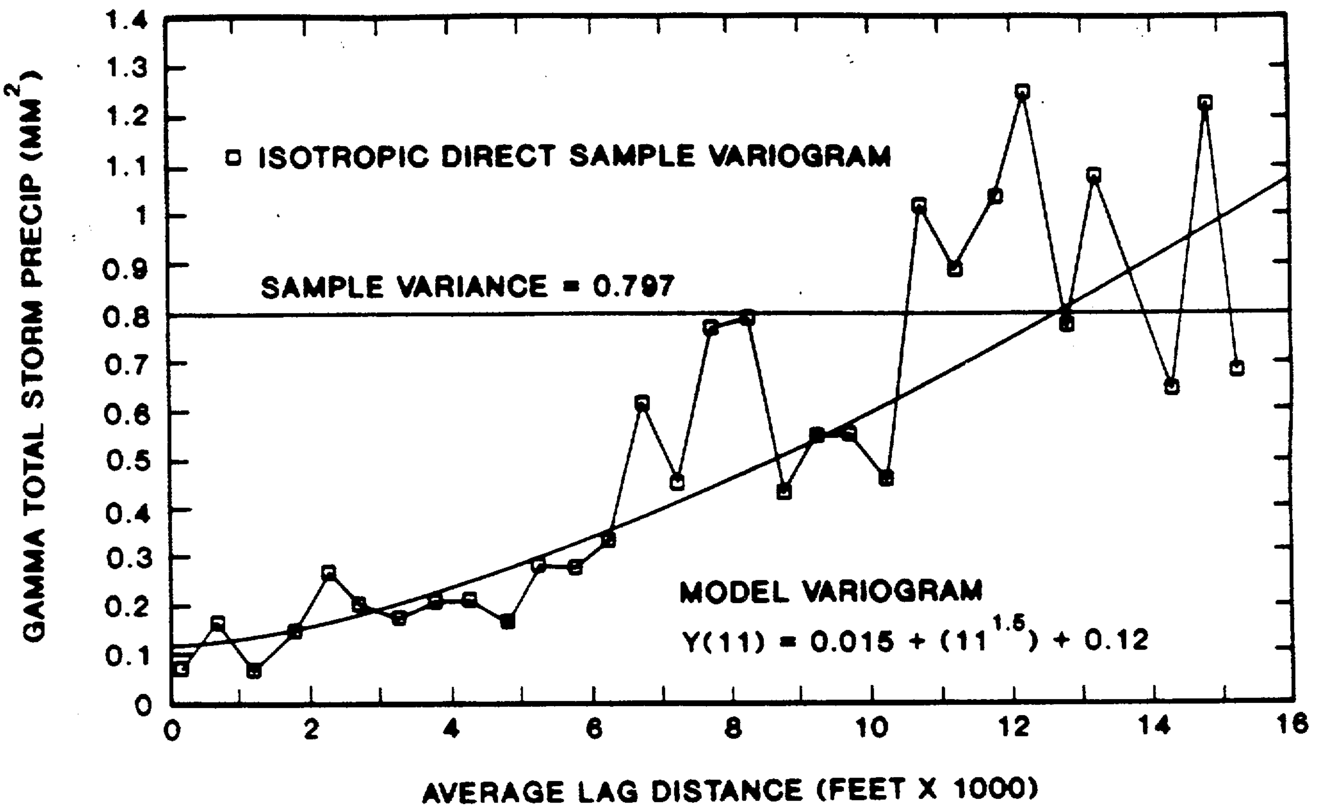


Figure 3.1-31. Fitted model variogram for the 02/02/90 storm.

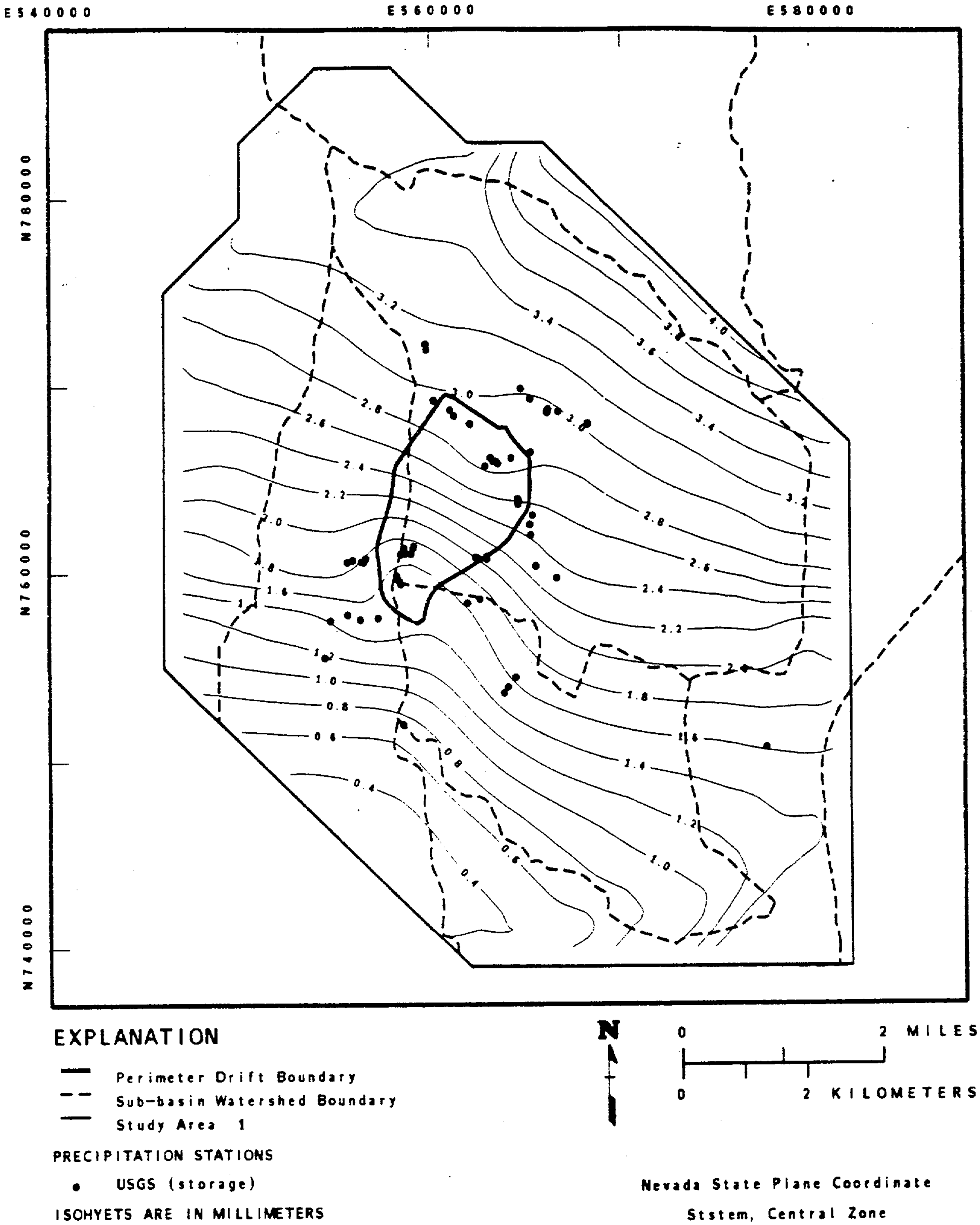


Figure 3.1-32. Estimation of total precipitation depth (mm) from the storm event ending 2/2/90 using kriging interpolation and data from 74 USGS storage gages.

The current model variogram can also be applied in an analysis of the reliability of estimates and the efficiency of the existing network (Section 3.1.3.2.1.2) by calculating and mapping estimation variances for estimated storm depth (Figure 3.1-33). The need for expanding the areal coverage of the storage-gage network by adding sites to the northern, western, and southern perimeter regions of the area 1 boundary is clearly indicated. Note that this particular analysis did not include the tipping-bucket-gage network. Using only the current storage-gage network, the average reliability of estimates over the area of the proposed repository site is approximately +/- 0.9 mm for an average storm depth of 2.35 mm at a 95-percent level of confidence. This represents an average 38-percent error for estimates of storm precipitation over the proposed repository site. Analysis of reliabilities will be important for determining the efficiency of existing and planned monitoring networks.

3.1.3.4.1.2 Deterministic analyses

Precipitation data will be analyzed on a storm-by-storm basis. Data from the research areas (discussed in Section 3.1.3.1.2.1) will be of primary importance; however, data from other sources outside the study areas will play an important role in the larger-scale analyses. The analysis of the sources and types of precipitation-producing storms is important to the other studies involved with site characterization of Yucca Mountain (See Section 3.1.2). Precipitation data, taken with other data (satellite, lightning, wind direction and speed, temperature, humidity, and solar radiation) will be used to characterize the type, source, development, movement, and intensity of each storm. Histographs and hyetographs obtained at each recording gage will be used to help determine storm development and movement (Niemczynowicz, 1988).

The hypotheses put forth by French (1983 and 1986) state that there are two seasonal variations in the sources of precipitation-producing weather regimes (winter and summer) with Yucca Mountain being in the transition zone between a relative precipitation deficit area in the west and a relative precipitation excess area to the east in southern Nevada. (See Section 3.1.3.1.3 for a detailed discussion). The deficit precipitation area is caused by the wintertime rain shadow of the Sierra Nevada range and the excess is caused by the mid-summer southwest monsoonal flow. Also discussed in Section 3.1.3.1.3 are the five winter synoptic weather types and the single summertime weather type effecting southern Nevada.

Synoptic-scale analyses will be done to determine the storm signatures and frequency of synoptic systems that ultimately affect the Yucca Mountain region and to determine

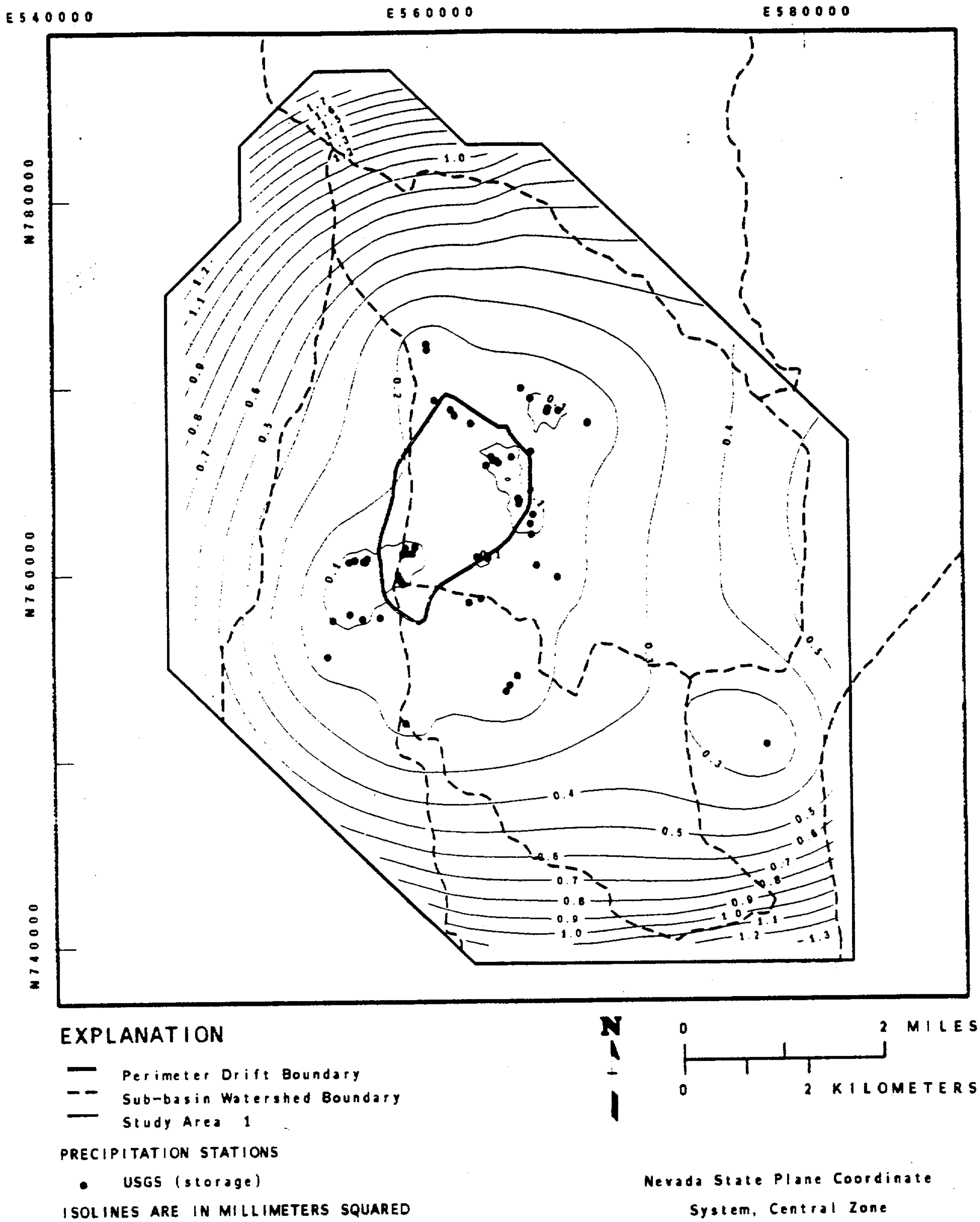


Figure 3.1-33. Estimation variances (mm ^{2}) for estimated precipitation depth from the storm on 2/2/90 using kriging interpolation and the locations of 74 USGS storage gages.

under what synoptic conditions Yucca Mountain may be susceptible to catastrophic flash floods (Hirschboeck, 1987). Mesoscale analyses will be done to more precisely locate the extent of the rain shadow, determine if the study region falls wholly or partially within it, and to determine if Yucca Mountain falls within a relative precipitation excess or deficit within southern Nevada. Microscale analyses will determine if Yucca Mountain, or the highest peaks in the study areas, are of sufficient elevation relative to the surrounding topography to orographically effect precipitation events, particularly of convective origin.

Analyses of lightning strikes may indicate if terrain has an effect on storm growth or trajectory. Also, lightning ground strikes have been shown to correlate with heavy rain. Analyses will be done to determine if that relationship holds in a mountainous desert climate and if the frequency of lightning strikes increases over higher terrain which, in turn, could signify increased precipitation amounts.

3.1.3.4.2 General meteorological conditions

Spatial and temporal patterns in meteorology, along with historical trends, will be determined for the Yucca Mountain region.

3.1.3.4.2.1 Statistical analyses

In addition to precipitation, the meteorological parameters of air temperature, relative humidity, wind speed, wind direction, barometric pressure, and solar radiation will also be statistically analyzed. Descriptive statistics, such as those presented in Table 3.1-1, will be compiled for each meteorological station. Additional statistics will be calculated when appropriate. These data will also be used with other statistical tests. As with precipitation, correlations will be investigated to obtain more accurate mapping and characterizations of parameters. Correlations between average wind speed and direction and terrain characteristics can be modeled and used to estimate parameters at unmeasured points. These areal or point estimates can be used with models to estimate other important parameters. For example, an areal estimate of barometric pressure can be made using elevation data. The estimate of barometric pressure is then used in models for estimation of clear-sky, solar radiation. These meteorological parameters will be estimated over a large area but not with the same coverage as for precipitation.

3.1.3.4.2.2 Deterministic analyses

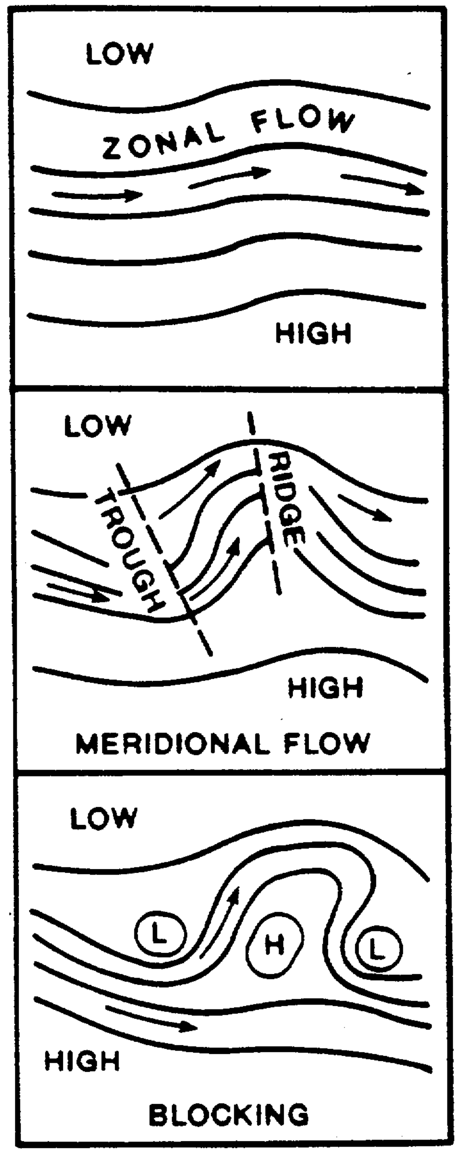
The southwestern United States has been undergoing a drought over the past 3 to 4 years, while other parts of the country, primarily the east, have been receiving excess amounts of precipitation. These conditions of persistent drought and flooding are controlled on the planetary scale by atmospheric "anomalies." A departure from the climatic mean is referred to as an "anomaly", and if this condition exists for an inordinate period of time, the event may be referred to as a "persistent anomaly" (Dole, 1986). Over continents, various configurations of Rossby waves in the upper atmosphere can establish themselves in a blocking pattern and remain quasi-stationary for extended periods of time. Or alternately, these large-scale waves may repeatedly redevelop in nearly the same location. "Blocking" is one mechanism that may result in persistent anomalies. Once these blocking anomalies are in place, one area under a persistent high-pressure ridge will encounter drought conditions while the region underlying the southeastern sectors of troughs, where frontal activity follows the storm track, will encounter wetter than normal conditions (Hirschboeck, 1987).

Figure 3.1-34 illustrates the two primary variations of large-scale motion in the upper atmosphere. The zonal regime flow (low-amplitude Rossby waves) is generally east-west. Storm systems move quickly through the pattern, not affecting any given location inordinately. Under strongly meridional flow (high-amplitude Rossby waves) a blocking situation is created. Storms cannot move quickly in an easterly direction as before and are slowed as they encounter the strong blocking ridge of high pressure. Winds are steered in a more northerly-southerly trajectory. Blocking is an example of an extreme high-amplitude condition. The region directly beneath the ridge will encounter no precipitation as long as the blocking pattern persists. On the other hand, storms slowed by the blocking ridge could stall over one locale and produce catastrophic flooding. Studies have shown that blocking anomalies are linked to variations in sea-surface temperatures, and to the El Nino and the Southern Oscillation (ENSO) events in the past. Since 1950 there has been an increase in meridional or blocking types of circulations that appear to accompany an increase in ENSO events (Knox, 1984; Horel and Wallace, 1981; and White and Clark, 1975).

In this study, correlations of wind, temperature, humidity, precipitation, and other data collected from the Yucca Mountain region (described in Section 3.1.3.1.2) with upper-atmospheric wind-flow patterns will be used to identify persistent blocking anomalies, if they occur. In this way, an accurate picture of the effects of this present drought can be determined in terms of severity, duration, and repeatability.

3.1.3.4.3 Applications of results

This study will contribute in two ways to the overall goal of site characterization. First, the meteorology of the Yucca



Legend

H = High pressure center

L = Low pressure center

⟶ = Wind flow trajectory or storm track

Figure 3.1-34. Schematic diagram of upper atmospheric blocking in relation to more typical zonal and meridional flow.

Mountain region will be well understood in terms of the source and frequency of precipitation-producing storm events, the potential for catastrophic flooding, and the potential for the present-day semi-arid climate to persist into the future. Second, precipitation data and analysis are of primary importance to, and will be integrated into, other studies (see Sections 3.1.2 and 4.2) characterizing the surface and subsurface hydrology of Yucca Mountain.

3.1.3.5 Methods summary

The activity parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.1-5. Also listed are the selected methods for determining the parameters. The selected methods in Table 3.1-5 were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and lack of interference with other tests and analyses.

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

3.1.3.6 Equipment lists

Instruments:

- o Campbell Scientific Model 207 temperature and relative humidity probe
  Published accuracy: temperature +/- 0.4 C
  relative humidity 5 percent
- o Campbell Scientific SBP270 barometric pressure sensor
  Published accuracy: 0.2 mbar (0.02 kPa)
- o Met One Model 024A wind-direction sensor
  Published accuracy: 5 degrees
- o Met One Model 014A wind-speed sensor
  Published accuracy: 0.11 meters per second
- o Li-Cor model 200S pyranometer
  Published accuracy: 5 percent
- o Sierra Misco Model 2501 tipping-bucket rain gage
  Published accuracy: 2 percent
- o Qualimetrics Model 6011B tipping-bucket rain gage
  Published accuracy: 0.5 percent
- o Qualimetrics Model 6041B tipping-bucket, propane-heated rain and snow gage
  Published accuracy: 0.5 percent
- o Qualimetrics Model 6320 fence-post rain gage
  Published accuracy: 0.1 mm
- o Airborne Research Associates Model M-01 optical lightning detector.

Table 3.1-5. Summary of tests and methods for characterization of meteorology (SCP 8.3.1.2.1.1.1)

Methods (selected and alternate)	Activity parameter
Data collection and assimilation	
Meteorological stations: cup anemometer (selected)	Wind speed
Meteorological stations: wind direction sensor (selected)	Wind direction
Meteorological stations: pyranometer (selected)	Net radiation
"	Solar radiation, incoming/outgoing short wave
Meteorological stations: temperature sensor (selected)	Air temperature
Meteorological stations: relative humidity sensor (selected)	Relative humidity
Meteorological stations: barometer (selected)	Atomospheric pressure
Meteorological stations: tipping-bucket precipitation gauge (selected)	Precipitation, amounts
"	Precipitation, intensity and duration
Characterization of precipitation	
Cumulative precipitation measurement by tipping-bucket precipitation gauges (selected)	Precipitation, amounts
"	Precipitation, intensity and duration
Cumulative precipitation measurement by weighing-bucket gauges (selected)	Precipitation, amounts

Table 3.1-5. Summary of tests and methods for characterization of meteorology (SCP 8.3.1.2.1.1.1)--Continued

Methods (selected and alternate)	Activity parameter
Characterization of precipitation--Continued	
Cumulative precipitation measurement by weighing-bucket gauges (selected)	Precipitation, intensity and duration
Cumulative precipitation measurement by storage gauges (selected)	Precipitation, amounts
"	Precipitation, intensity and duration
Cumulative precipitation measurement by use of snow-course sites (selected)	Precipitation, amounts
"	Precipitation, intensity and duration
Indirect monitoring of precipitation by use of remote sensing (selected)	"
Indirect monitoring of precipitation by correlation of precipitation with other measurable parameters (selected)	Precipitation, amounts
"	Precipitation, intensity and duration
Lightning detection by use of automatic lightning detection systen (ALDS) (selected)	Lightning occurences
Lightning detection by use of optical lightning detector (selected)	"
Remote sensing: weather satellite data (selected)	Cloud patterns
"	Precipitation, amounts
"	Precipitation, intensity and duration

Table 3.1-5. Summary of tests and methods for characterization of meteorology (SCP 8.3.1.2.1.1.1)--Continued

Methods (selected and alternate)	Activity parameter
Characterization of precipitation--Continued	
Remote sensing: time-lapse photography (selected)	Cloud patterns
"	Precipitation, amounts
"	Precipitation, intensity and duration
Field site selection, feature-based (selected)	(Does not directly generate activity parameters)
Field site selection, statistically based (selected)	"
Collection of other weather data from WSNSO, NWS, and cooperative weather stations (selected)	"
Data processing and storage	
Processing of meteorological station data on computer (selected)	(Does not directly generate activity parameters)
Processing of precipitation data on computer and hard copy (selected)	"
Processing of lightning data on computer (selected)	"
Processing of remote sensing data on computer and videotape (selected)	"
Processing of other weather data on computer and hard copy (selected)	"

Table 3.1-5. Summary of tests and methods for characterization of meteorology (SCP 8.3.1.2.1.1.1)--Continued

Methods (selected and alternate)	Activity parameter
Analysis of meteorological data--Continued	
Statistical analysis of precipitation data (selected)	Origin, moisture source, and life cycle of storms
"	Precipitation and storm profiles, Yucca Mountain region
"	Variation of present weather conditions from past conditions
Mesoscale analysis of precipitation data (selected)	Origin, moisture source, and life cycle of storms
"	Precipitation and storm profiles, Yucca Mountain region
"	Variation of present weather conditions from past conditions
Statistical analysis of general meteorological conditions (selected)	Origin, moisture source, and life cycle of storms
"	Precipitation and storm profiles, Yucca Mountain region
"	Variation of present weather conditions from past conditions
Mesoscale analysis of general meteorological conditions (selected)	Origin, moisture source, and life cycle of storms
"	Precipitation and storm profiles, Yucca Mountain region
"	Variation of present weather conditions from past conditions

Support Equipment:

- Campbell Scientific Model 21X micrologger
- Campbell Scientific Model CR10 micrologger
- Campbell Scientific Model CR10KD micrologger keyboard
- Campbell Scientific Model CR10WP micrologger wiring panel
- Campbell Scientific Model SC92A cassette interface
- Campbell Scientific Model SC93A cassette interface
- Campbell Scientific Model RC35 cassette recorder
- Campbell Scientific Model PC201 computer interface
- Campbell Scientific Model SC32A optically isolated RS232 interface
- Campbell Scientific Model CM10 instrument tripod
- Campbell Scientific Model MSX10 10-watt solar panel
- Campbell Scientific Model MSX5 5-watt solar panel
- Campbell Scientific Model 021 21X enclosure with radiation shield
- Campbell Scientific Model 10TCRT thermocouple reference thermistor Campbell Scientific Model 021/LA CR10 enclosure with sealed rechargeable batteries
- Campbell Scientific Model RF95 RF (radio telemetry) modem
- Campbell Scientific Model RF232 RF (radio telemetry) base station
- Campbell Scientific Model P50 VHF 5-watt VHF transceiver
- R. M. Young model 41301-5 radiation shield
- Li-Cor Model 2003S pyranometer base and leveling fixture
- Deep Cycle Marine/RV storage battery
- Qualimetrics Model 6410 rain/snow gage wind screen

- Weather satellite station:
  - Two antennae (one for GOES and one for Polar orbiters)
  - FM radio receiver operating at 137 MHz
  - 1691 MHz to 137 MHz converter
  - Image-display software
  - IBM-compatible computer
  - Data-storage units (optical or removable disks)

- Lightning data station
  - IBM-compatible computer
  - Modems
  - Data-display software
  - Data-storage units (optical or removable disks)

3.1.3.7 Technical procedures

The USGS quality-assurance program plan for the YMP (USGS, 1986) requires assignment of technical procedures for all technical activities that require quality assurance. Table 3.1-6 provides a complete tabulation of technical procedures applicable to this activity. Approved procedures are identified with a USGS number and the effective beginning date of the procedure implementation.

Table 3.1-6. Technical procedures for characterization of meterology for site and regional hydrology (SCP Activity 8.3.1.2.1.1.1)

Technical procedure number (NWM-USGS-)	Technical procedure	Effective date
	Data collection and assimilation	
HP-97,R0	Measurement of temperature and relative humidity using a Campbell Scientific, Inc. 207 temperature and relative humidity probe	08/14/89
HP-59,R0	Method for calibrating digital thermometers	10/06/88
HP-170,R1	Method for measuring temperature using a Campbell Scientific, Inc. 107 temperature probe	05/27/88
HP-177,R0	Operation of the Setra Model 270 barometric pressure transducer	05/27/88
HP-168,R0	Measurement of energy flux density by a pyranometer	06/09/88
HP-95,R0	Measurement of wind direction using a Met-1 Model 024A wind direction sensor	08/14/89
HP-96,R0	Measurement of wind speed using a Met-1 Model 024A wind speed sensor	08/14/89
	Characterization of precipitation	
HP-43,R1	Installation, operation, and inspection of two types of non-recording rain gages	06/07/88
HP-179,R0	Field measurement of precipitation using a tipping-bucket rain gage	05/20/88
HP-167,R0	Precipitation measurement using a Belfort weighing rain gage	06/09/88
HP-180,R0	Field measurement of precipitation using a propane-heated, tipping-bucket rain and snow gage	06/15/88

Table 3.1-6. Technical procedures for characterization of meterology for site and regional hydrology (SCP Activity 8.3.1.2.1.1.1)--Continued

Technical procedure number (NWM-USGS-)	Technical procedure	Effective date
	Characterization of precipitation	
HP-167,R0	Precipitation measurement using a Belfort weighing rain gage	06/09/88
HP-180,R0	Field measurement of precipitation using a propane-heated, tipping-bucket rain and snow gage	06/15/88
HP-165,R0	Method for measuring snow water content	06/23/88

Equipment requirements and instrument calibration are described in the technical procedures and Section 3.1.3.6. 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 also included in these documents.

4 APPLICATION OF STUDY RESULTS

4.1 Application of results to resolution of design and performance issues

The present study contributes indirectly to the resolutions of performance issues (1.1, 1.6, 2.1, 2.2, 2.3, 1.8, and 1.9) and design issues (1.10, 1.11, 1.12, 2.7, 4.4) through its support of other studies in the Geohydrology and Climate Programs. It contributes directly to resolutions of performance issues (2.1, 2.2, and 2.3) and design issues (1.11, 1.12, 2.7, and 4.4) through its support of the Meteorology Program. More detail on applications to repository design and performance is provided in Section 1.3 and Table 7.2-1.

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

Potential meteorological data requirements from the present study to support other site-characterization efforts are listed in Table 4.2-1. The following text expands upon the relation of this study to the meteorological monitoring program of SCP 8.3.1.12 (Meteorology Program).

The purpose of the meteorological monitoring in the Meteorology Program is to provide data that can be used in resolving design and performance issues associated with preclosure radiological safety. (These are cited in Section 1.3 and Table 7.2-1). The emphasis in that program is on wind-flow patterns in the vicinity of Yucca Mountain. The present study focuses on collection of meteorological data for use in the Geohydrology and Climate Programs, particularly upon precipitation data. Inasmuch as it is feasible, data will be shared between the present study and the Meteorology Program, but the different objectives of the two efforts cause their types of data collected, methods of data collection, and interpretation approaches to be very different.

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
8.3.1.2.1.2.1	Surface-water runoff monitoring	Precipitation: quantity and timing	Evaluate precipitation/runoff relations	Measured by use of storage gages and recording gages	Regional precipitation stations shown in Fig. 3.1-3, proposed Yucca Mountain stations shown in Fig. 3.1-4	Indefinite -- throughout site characterization
8.3.1.2.1.2.1	Surface-water runoff monitoring	Air temperature	Evaluate precipitation/runoff relations	By continuous-recording thermographs	Selected sites, Yucca Mountain and vicinity	Indefinite -- throughout site characterization
8.3.1.2.1.2.1	Surface-water runoff monitoring	Snowpack	Evaluate precipitation/runoff relations	Monitoring snow courses and(or) snow pillows	Yucca Mountain region - particularly upper Fortymile Wash Basin	Indefinite -- throughout site characterization and repository operation
8.3.1.16.1.1.1	Site flood and debris hazards studies	Meteorological data supporting Study 8.3.1.2.1.2	Characterization of flood potential and debris hazards	(See SP 8.3.1.2.1.2 and SP 8.3.1.16.1.1)	(See SP 8.3.1.2.1.2 and SP 8.3.1.16.1.1)	(See SP 8.3.1.2.1.2 and SP 8.3.1.16.1.1)
8.3.1.2.2.1.2	Evaluation of natural infiltration	Precipitation: quantity and timing	Prototype testing to collect meteorological data for calculation of net infiltration by water-budget methods	Instrumentation installed at full weather stations	Adjacent to prototype water-budget sites at Yucca Mountain and immediate vicinity	
8.3.1.2.2.1.2	Evaluation of natural infiltration	Air temperature	Prototype testing to collect meteorological data for calculation of net	Instrumentation installed at full weather stations	Adjacent to prototype water-budget sites at Yucca Mountain and	

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
			infiltration by water-budget methods		immediate vicinity	
8.3.1.2.2.1.2	Evaluation of natural infiltration	Relative humidity	Prototype testing to collect meteorological data for calculation of net infiltration by water-budget methods	Instrumentation installed at full weather stations	Adjacent to prototype water-budget sites at Yucca Mountain and immediate vicinity	
8.3.1.2.2.1.2	Evaluation of natural infiltration	Wind speed and direction	Prototype testing to collect meteorological data for calculation of net infiltration by water-budget methods	Instrumentation installed at full weather stations	Adjacent to prototype water-budget sites at Yucca Mountain and immediate vicinity	
8.3.1.2.2.1.2	Evaluation of natural infiltration	Evaporative flux	Prototype testing to collect meteorological data for calculation of net infiltration by water-budget methods	Class A evaporation pans and ceramic-tip evaporative-flux instruments, other field techniques	Adjacent to prototype water-budget sites at Yucca Mountain and immediate vicinity	
8.3.1.2.2.1.2	Evaluation of natural infiltration	Solar radiation	Prototype testing to collect meteorological data for calculation of net infiltration by water-budget methods	Instrumentation installed at full weather stations	Adjacent to prototype water-budget sites at Yucca Mountain and immediate vicinity	

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
8.3.1.2.2.1.2	Evaluation of natural infiltration	Evapotranspiration	Prototype testing to collect meteorological data for calculation of net infiltration by water-budget methods	Measure evapotranspiration by Bowen-ratio method	Adjacent to prototype water-budget sites at Yucca Mountain and immediate vicinity	
8.3.1.2.2.1.2	Evaluation of natural infiltration	Evapotranspiration	Prototype testing to collect meteorological data for calculation of net infiltration by water-budget methods	Measure evapotranspiration by atmometers	Adjacent to prototype water-budget sites at Yucca Mountain and immediate vicinity	
8.3.1.2.2.1.2	Evaluation of natural infiltration	Barometric pressure	Prototype testing to collect meteorological data for calculation of net infiltration by water-budget methods	Instrumentation installed at full weather stations	Adjacent to prototype water-budget sites at Yucca Mountain and immediate vicinity	
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Precipitation: quantity and timing	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for small-plot rainfall-simulation (SPRS) tests	Throughout prototype and site-characterization SPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Air temperature	Monitoring infiltration and runoff from natural rainfall, evapotranspiration	Meteorological data collection	Control and test plots for small-plot rainfall-simulation (SPRS) tests	Throughout prototype and site-characterization SPRS testing

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
			calculations			
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Relative humidity	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for small-plot rainfall-simulation (SPRS) tests	Throughout prototype and site-characterization SPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Wind speed and direction	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for small-plot rainfall-simulation (SPRS) tests	Throughout prototype and site-characterization SPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Barometric pressure	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for small-plot rainfall-simulation (SPRS) tests	Throughout prototype and site-characterization SPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Evaporative flux	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for small-plot rainfall-simulation (SPRS) tests	Throughout prototype and site-characterization SPRS testing
8.3.1.2.2.1.3	Evaluation of	Solar radiation	Monitoring infiltration and	Meteorological data	Control and test plots	Throughout prototype and

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
	artificial infiltration		runoff from natural rainfall, evapotranspiration calculations	collection	for small-plot rainfall-simulation (SPRS) tests	site-characterization SPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Evapotranspiration	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for small-plot rainfall-simulation (SPRS) tests	Throughout prototype and site-characterization SPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Precipitation: quantity and timing	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for large-plot rainfall-simulation (LPRS) tests	Throughout prototype and site-characterization LPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Air temperature	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for large-plot rainfall-simulation (LPRS) tests	Throughout prototype and site-characterization LPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Relative humidity	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for large-plot rainfall-simulation (LPRS) tests	Throughout prototype and site-characterization LPRS testing

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Wind speed and direction	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for large-plot rainfall-simulation (LPRS) tests	Throughout prototype and site-characterization LPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Barometric pressure	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for large-plot rainfall-simulation (LPRS) tests	Throughout prototype and site-characterization LPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Evaporative flux	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for large-plot rainfall-simulation (LPRS) tests	Throughout prototype and site-characterization LPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Solar radiation	Monitoring infiltration and runoff from natural rainfall, evapotranspiration calculations	Meteorological data collection	Control and test plots for large-plot rainfall-simulation (LPRS) tests	Throughout prototype and site-characterization LPRS testing
8.3.1.2.2.1.3	Evaluation of artificial infiltration	Evapotranspiration	Monitoring infiltration and runoff from natural rainfall, evapotranspiration	Meteorological data collection	Control and test plots for large-plot rainfall-simulation (LPRS) tests	Throughout prototype and site-characterization LPRS testing

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
			calculations			
8.3.1.2.1.3.3	Fortymile Wash recharge study	Precipitation: quantity and timing	Rainfall-runoff modeling for Fortymile Wash, average annual recharge at Fortymile Wash	Continuously recording precipitation gages	Locations are: 1) upper Fortymile Canyon at the narrows, 2) mouth of Yucca Wash, 3) above Drill Hole Wash, 4) mouth of Drill Hole Wash, 5) mouth of Busted Butte Wash, 6) Fortymile Wash at well J-12	Throughout Fortymile Wash recharge study
8.3.1.2.1.3.3	Fortymile Wash Recharge study	Air temperatures	Rainfall-runoff modeling for Fortymile Wash, average annual recharge at Fortymile Wash		(Same locations as precipitation stations)	Throughout Fortymile Wash recharge study
8.3.1.2.1.3.3	Fortymile Wash recharge study	Snowpack	Rainfall-runoff modeling for Fortymile Wash, average annual recharge at Fortymile Wash	Snow pillows, manual measurement along designated snow courses	Upper Fortymile Wash Basin. Sites not yet selected	Throughout Fortymile Wash recharge study
8.3.1.2.1.3.3	Fortymile Wash recharge study	Precipitation samples	For chemical and isotopic analyses of water samples	Passive trap-type collectors	At stream-gaging stations used for Fortymile Wash recharge study	Throughout Fortymile Wash recharge study

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
8.3.1.2.2.2.1	Chloride and chlorine-36 measurements of percolation at Yucca Mountain	Precipitation measurements	Define areal and part of vertical distribution of chloride and its isotopes		Yucca Mountain and vicinity	
8.3.1.2.2.6.1	Gas-phase circulation study	Air temperature	Meteorological data for model simulation of total drillhole circulation		Existing weather station located near USW UZ-6	Throughout gas-phase circulation study
8.3.1.2.2.6.1	Gas-phase circulation study	Relative humidity	Meteorological data for model simulation of total drillhole circulation		Existing weather station located near USW UZ-6	Throughout gas-phase circulation study
8.3.1.2.2.6.1	Gas-phase circulation study	Atmospheric pressure	Meteorological data for model simulation of total drillhole circulation		Existing weather station located near USW UZ-6	
8.3.1.2.3.1.3	Analysis of single-well and multiple-well hydraulic-stress tests	Atmospheric pressure	Correlation of water level fluctuations to variations in barometric loading, to distinguish between confined and unconfined responses		C-hole complex, UE-25p#1, USW H-1, USW H-4, USW WT-2, UE-25 WT#3, UE-25 WT#13, and possibly other holes	Throughout SZ program
8.3.1.5.1.1.1	Synoptic characterization of regional climate	Air temperature, monthly and annual values	Development of modern vegetation-climate calibration relationships,	Temperatures recorded at 15-minute intervals	Network of weather stations to be set up in region in cooperation	Throughout climate program.

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
			assessment of lake-climate relationships, development and testing of climate circulation models, specifying relations between global-scale and regional and local climate features		with meteorology program (8.3.1.12) and geohydrology program (8.3.1.2).	
8.3.1.5.1.1.1	Synoptic characterization of regional climate	Precipitation: quantity and timing	Development of modern vegetation-climate calibration relationships, assessment of lake-climate relationships, development and testing of climate circulation models, specifying relations between global-scale and regional and local climate features	Tipping-bucket water samples to be collected whenever possible within 24 hours of a storm event	Network of weather stations to be set up in region in cooperation with meteorology program (8.3.1.12) and geohydrology program (8.3.1.2)	Throughout climate program
8.3.1.5.1.1.1	Synoptic characterization of regional climate	Cloud cover, spatial and temporal variation	Development of modern vegetation-climate calibration relationships, assessment of lake-climate relationships, development and testing of climate circulation models, specifying relations between global-scale and		Network of weather stations to be set up in region in cooperation with meteorology program (8.3.1.12) and geohydrology program (8.3.1.2)	Throughout climate program

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
			regional and local climate features			
8.3.1.5.1.1.1	Synoptic characterization of regional climate	Wind velocity: spatial and temporal variation	Development of modern vegetation-climate calibration relationships, assessment of lake-climate relationships, development and testing of climate circulation models, specifying relations between global-scale and regional and local climate features		Network of weather stations to be set up in region in cooperation with meteorology program (8.3.1.12) and geohydrology program (8.3.1.2)	Throughout climate program
8.3.1.5.1.1.1	Synoptic characterization of regional climate	Other meteorological measurements	Development of modern vegetation-climate calibration relationships, assessment of lake-climate relationships, development and testing of climate circulation models, specifying relations between global-scale and regional and local climate r\features		Network of weather stations to be set up in region in cooperation with meteorology program (8.3.1.12) and geohydrology program (8.3.1.2)	Throughout climate program

Table 4.2-1 POTENTIAL CONTRIBUTIONS FROM THE METEOROLOGY STUDY TO OTHER SITE-CHARACTERIZATION ACTIVITIES

SCP ACTIVITY NUMBER	SCP ACTIVITY	DATA NEEDED	PURPOSE OF DATA	DESCRIPTION	LOCATION OF MEASUREMENTS	DURATION OF MEASUREMENTS
8.3.1.12	Meteorology program	Wind, temperature, and barometric data	(See Sec. 4.2 text.)	(See SCP Section 8.3.1.2.)		

5 SCHEDULES AND MILESTONES

5.1 Schedules

The proposed schedule presented in Figure 5.1-1 summarizes the logic network and reports for the meteorology 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. Specific durations and start and finish dates for the activity are being developed as part of ongoing planning efforts. The development of the schedule for the present study has taken into account how the study will be affected by contributions of data from other studies, and also how the present study will contribute to or may interfere with other studies. Milestones shown on the schedule include the major milestones cited in SCP Table 8.3.1.2-11 (Major events and planned completion dates for studies in the Geohydrology Program). Figure 5.1-1 reflects the most recent available project participant schedule.

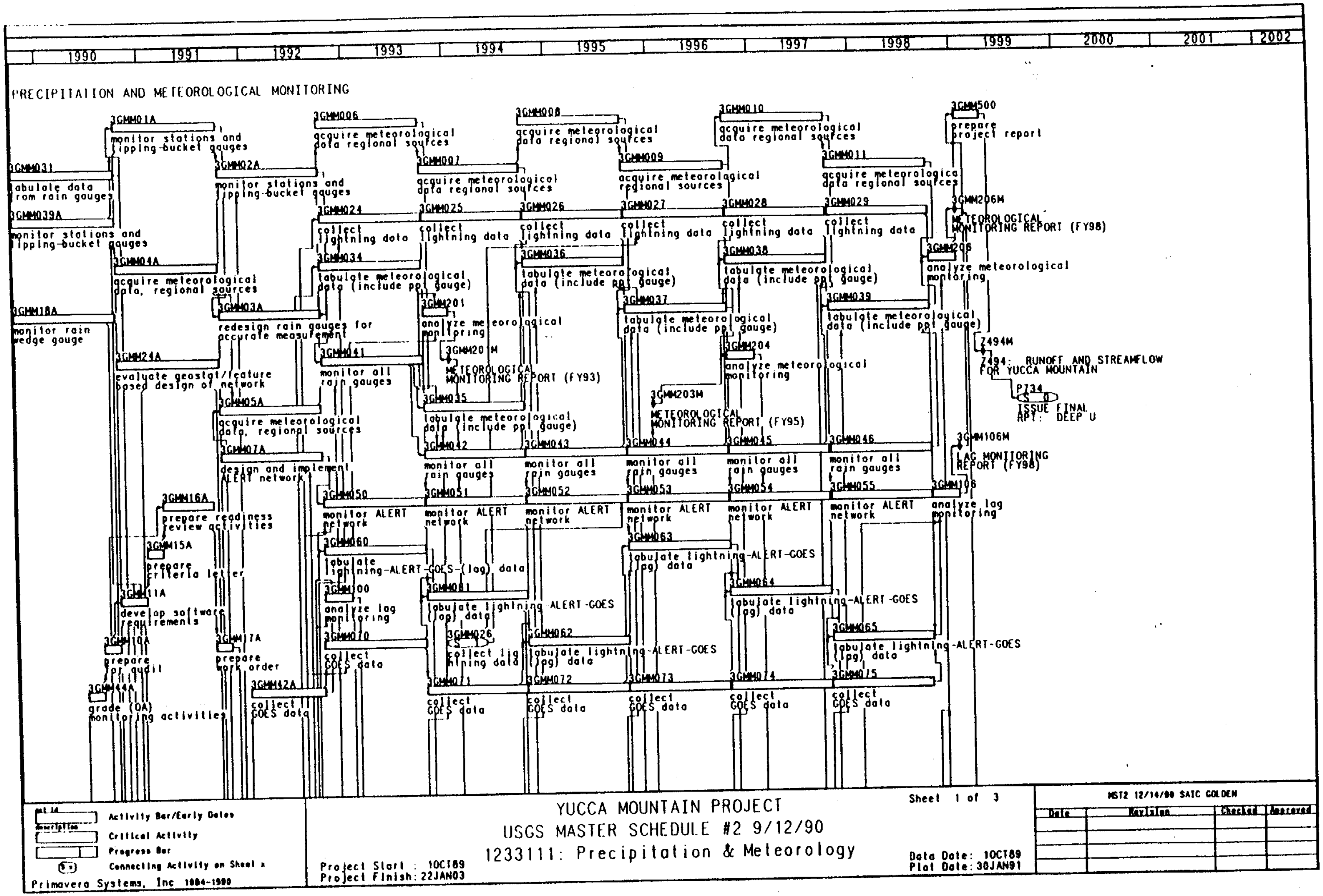


Figure 5.1-1a. Summary network for the meteorology study.

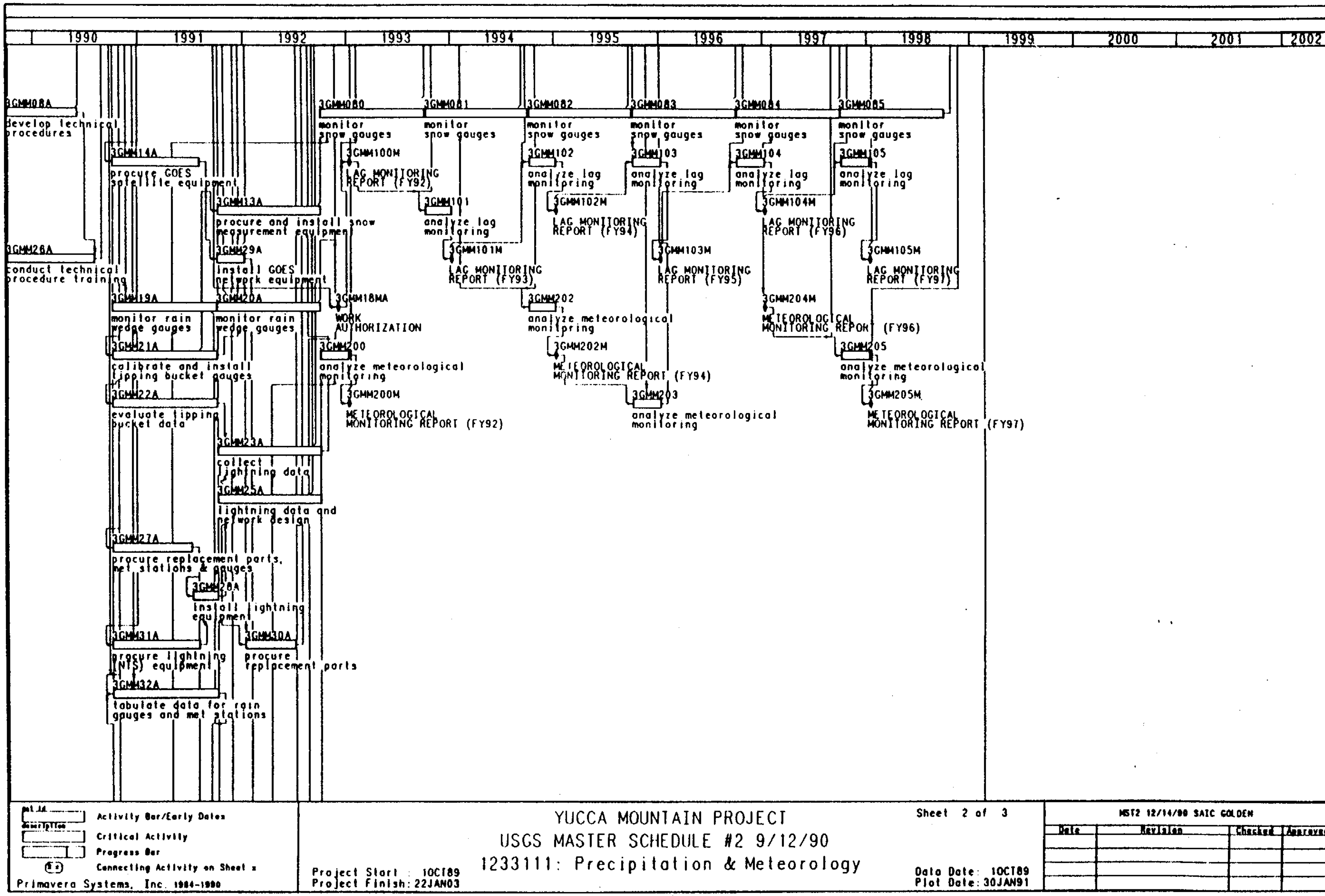


Figure 5.1-1b. Summary network for the meteorology study.

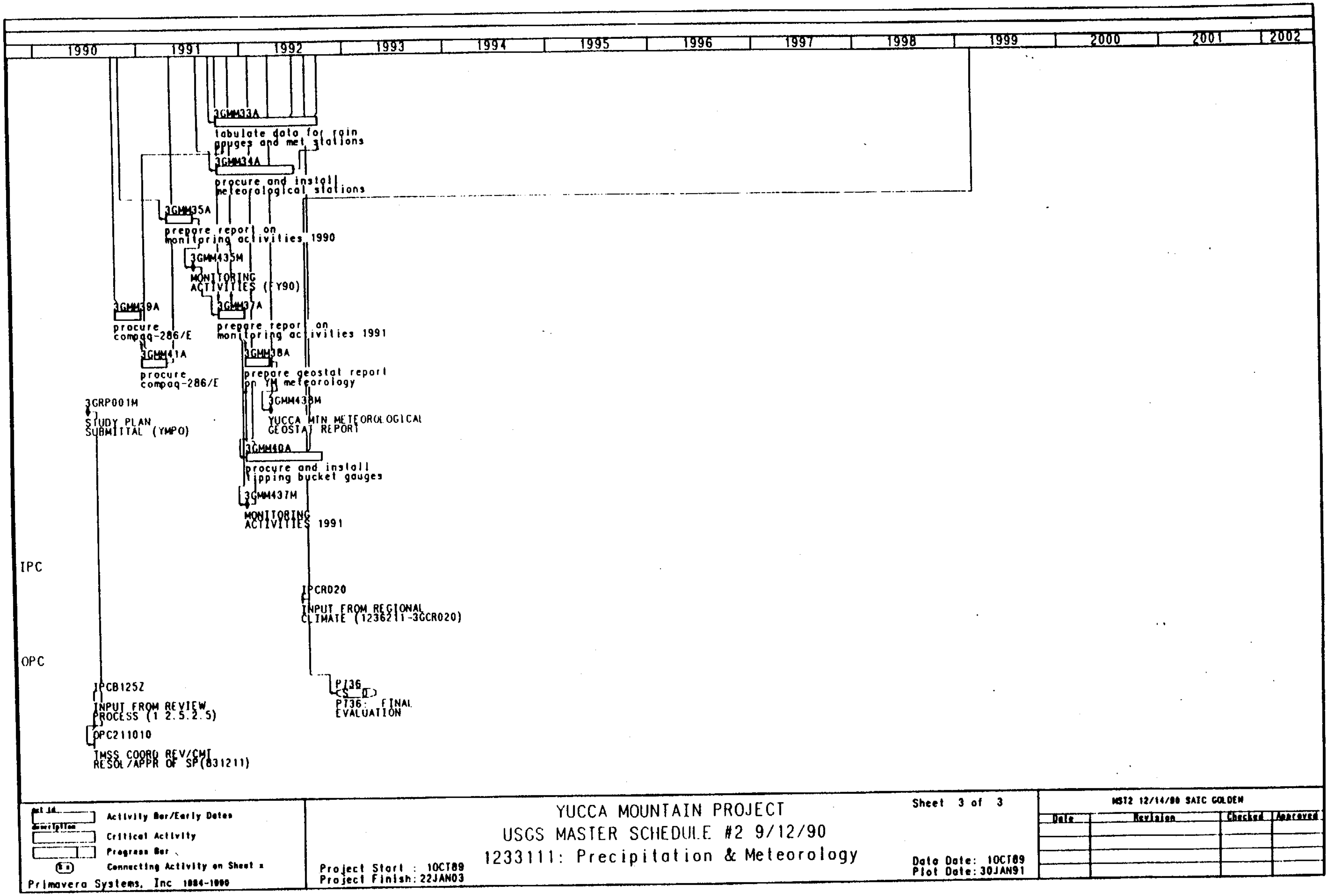


Figure 5.1-1c. Summary network for the meteorology study.

5.2 Milestones

The milestone numbers, titles, levels, and corresponding work breakdown structure (WBS) number associated with the meteorology activity are summarized in Table 5.2-1.

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

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Table 5.2-1. Milestone list for work-breakdown structure number-1.2.3.3.1.1.1 (SCP 8.3.1.2.1.1)

[Milestone dates are unavailable at this time.]

Milestone number	Milestone	Milestone level
Precipitation and meteorological monitoring: 8.3.1.2.1.1.1		
3GMM100M	LAG MONITORING REPORT (FY92)	3
3GMM101M	LAG MONITORING REPORT (FY93)	3
3GMM102M	LAG MONITORING REPORT (FY94)	3
3GMM103M	LAG MONITORING REPORT (FY95)	3
3GMM104M	LAG MONITORING REPORT (FY96)	3
3GMM105M	LAG MONITORING REPORT (FY97)	3
3GMM106M	LAG MONITORING REPORT (FY98)	3
3GMM18MA	WORK AUTHORIZATION	3
3GMM200M	METEOROLOGICAL MONITORING REPORT (FY92)	3
3GMM201M	METEOROLOGICAL MONITORING REPORT (FY93)	3
3GMM202M	METEOROLOGICSL MONITORING REPORT (FY94)	3
3GMM203M	METEOROLOGICAL MONITORING REPORT (FY95)	3
3GMM204M	METEOROLOGICAL MONITORING REPORT (FY96)	3
3GMM205M	METEOROLOGICAL MONITORING REPORT (FY97)	3
3GMM206M	METEOROLOGICAL MONITORING REPORT (FY98)	3
3GMM435M	MONITORING ACTIVITIES (FY90)	3
3GMM437M	MONITORING ACTIVITIES 1991	3
3GMM438M	YUCCA MTN METEOROLOGICAL GEOSTAT REPORT	3

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Table 5.2-1. Milestone list for the study (SCP 8.3.1.2.1.1)--Continued

Milestone number	Milestone	Milestone level
Precipitation and meteorological monitoring: 8.3.1.2.1.1.1		
3GRP001M	STUDY PLAN SUBMITTAL (YMPO)	3
Z494M	RUNOFF AND STREAMFLOW FOR YUCCA MOUNTAIN	3

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7 APPENDICES

7.1 Quality-assurance requirements

7.1.1 Quality-assurance requirements matrix

Determination of the quality status for the 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.

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

Applicable NQA-1 criteria for Study 8.3.1.2.1.1 and how they will be satisfied

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

	QMP-2.05 (Qualification of Audit and Surveillance Personnel) QMP-2.06 (Control of Readiness Review) QMP-2.07 (Development and Conduct of Training) Each of these QA programs contains Quality Implementing Procedures further defining the program requirements. An overall description of the QA Program for site characterization activities is described in Section 8.6 of the SCP.
3. Scientific investigation control and design	This study is a scientific investigation. The following QA implementing procedures apply: QMP-3.02 (USGS QA Levels Assignment [QALA]) QMP-3.03 (Scientific and Engineering Software) QMP-3.04 (Technical Review of YMP-USGS Publications) QMP-3.05 (Work Request for NTS Contractor Services [Criteria Letter]) QMP-3.06 (Scientific Investigation Plan) QMP-3.07 (Technical Review Procedure) QMP-3.09 (Preparation of Draft Study Plans) QMP-3.10 (Close-out Verification for Scientific Investigations) QMP-3.11 (Peer Review)
4. Administrative operations and procurement	QMP-4.01 (Procurement Document Control) QMP-4.02 (Acquisition of Internal Services)
5. Instructions, procedures, plans, and drawings	The activities in this study are performed according to the technical procedures listed in Section 3 of this study plan, and the QA administrative procedures referenced in this table for criterion 3.

	QMP-5.01 (Preparation of Technical Procedures)
	QMP-5.02 (Preparation and Control of Drawings and Sketches)
	QMP-5.03 (Development and Maintenance of Management Procedures)
	QMP-5.04 (Preparation and Control of the USGS QA Program Plan)
6. Document control	QMP-6.01 (Document Control);
7. Control of purchased items and services	QMP-7.01 (Supplier Evaluation, Selection and Control)
8. Identification and control of items, samples, and data	QMP-8.01 (Identification and Control of Samples)
	QMP-8.03 (Control of Data)
9. Control of processes	Not applicable
10. Inspection	Not applicable
11. Test control	Not applicable
12. Control of measuring and test equipment	QMP-12.01 (Instrument Calibration)
13. Handling, shipping, and storage	QMP-13.01 (Handling, Storage, and Shipping of Instruments)
14. Inspection, test, and operating status	Not applicable
15. Control of nonconforming items	QMP-15.01 (Control of Nonconforming Items)
16. Corrective action	QMP-16.01 (Control of Corrective Action Reports)
	QMP-16.02 (Control of Stop-Work Orders)
	QMP-16-03 (Trend Analysis)

17.	Records management	QMP-17.01 (YMP-USGS Records Management) QMP-17.02 (Acceptance of Data Not Developed Under the YMP QA Plan)
18.	Audits	QMP-18.01 (Audits) QMP-18.02 (Surveillance)

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

This section tabulates in Table 7.2-1 the specific technical information relations between SCP design- and performance-parameters needs and characterization parameters to be determined in this study. The relations were developed using model-based parameter categories that provide common terminology and organization for evaluation of site, design, and performance information relations. The table shows only the direct contributions of the study to repository design and performance issues through the Meteorology Program (SCP Section 8.3.1.12). The indirect support given by the study to design and performance issues is discussed in Section 1.3.

For each issue, the characterization parameters from Table 2.1-1 are related to the design and performance parameters reported in the performance allocation tables (from SCP 8.3.2 - 8.3.5). At the beginning of each issue group, the performance measures addressed by the design or performance parameters for the issue are listed. Parameter categories, as noted above, are used to group the design and performance parameters with the characterization 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 characterization parameters are listed with information about the site location and the site activity providing the information.

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 (characterization parameters) within a parameter category should <u>not</u> be made. For a discussion of the design and performance issues that obtain data from this study see Section 1.3. Similarly, a discussion of how the characterization parameters determined in this study are interpreted from the data collected can be found in Section 2.1.3.

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 1.11	Have the characteristics and configurations of the repository and repository engineered barriers been adequately established to show compliance with postclosure design criteria (10CFR 60.133) and provide information for the resolution of the issues			(SCP 8.3.2.2)	
Performance Measures: Temperature					
		Parameter Category: Meteorological characteristics			
Initial temperature for thermal modeling (Mean annual air temperature for primary area)	Primary area; Land surface	Goal: Temperature accurate to +/- 3°C Current: Medium Needed: Medium	Air temperature: spatial and temporal characteristics		8.3.1.2.1.1.1
			Precipitation and storm profiles, Yucca Mountain region		"
			Precipitation: physical, spatial, and temporal characteristics		"
			Wind speed and direction: spatial and temporal characteristics		"

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

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

Performance Measures: Quantity of water

Parameter Category: Meteorological characteristics

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Meteorological environment; temperature variations at ground surface	Shaft and ramp entry points; Land surface	Goal: To be determined by laboratory testing and activities Current: Low Needed: To be determined by laboratory and design activities	Air temperature: spatial and temporal characteristics		8.3.1.2.1.1.1
Meteorological environment; pH of rainfall	At shaft and ramp locations; Atmosphere, near land surface	Goa:: >4.5 Current: Low Needed: Medium	Precipitation and storm profiles, Yucca Mountain region		"
			Precipitation: physical, spatial, and temporal characteristics		"
			Wind speed and direction: spatial and temporal characteristics		

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 2.2	Can the repository be designed, constructed, operated, closed, and decommissioned in a manner that ensures the radiological saftey of workers under normal operations as required by 10 CFR 60.111, and 10 CFR part 20?			(SCP 8.3.5.4)	
Performance Measures: Transport characteristics of atmosphere within site boundaries					
Parameter Category: Meteorological characteristics					
Wind speeds	Site area; Atmosphere, near land surface	Goal: Tentative goal is to have further measurements of this parameter to verify the range of expected values listed here Current: Medium Needed: High	Air temperature: spatial and temporal characteristics		8.3.1.2.1.1.1
Wind direction	"	"	Precipitation and storm profiles, Yucca Mountain region		"
Atmospheric stability	"	Goal: Tentative goal is to have further measurements of this parameter to verify the range of expected values listed here Current: Medium[c] Needed: Medium	Precipitation: physical, spatial, and temporal characteristics		"

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 2.2	Can the repository be designed, constructed, operated, closed, and decommissioned in a manner that ensures the radiological saftey of workers under normal operations as required by 10 CFR 60.111, and 10 CFR part 20?			(SCP 8.3.5.4)	
Performance Measures: Transport characteristics of atmosphere within site boundaries					
		Parameter Category: Meteorological characteristics			
Mixing-layer depth	Site area; Atmosphere, near land surface	Goal: Tentative goal is to have further measurements of this parameter to verify the range of expected values listed here Current: Medium Needed: Medium	Wind speed and direction: spatial and temporal characteristics		8.3.1.2.1.1.1
Average ambient temperature	"	"			
Atmospheric moisture	"	"			
Precipitation; type, amount, intensity, etc.	"	"			
Barometric pressure	"	"			

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 2.2	Can the repository be designed, constructed, operated, closed, and decommissioned in a manner that ensures the radiological saftey of workers under normal operations as required by 10 CFR 60.111, and 10 CFR part 20?				(SCP 8.3.5.4)
Performance Measures: Transport characteristics of atmosphere within site boundaries					
Parameter Category: Meteorological characteristics					
Dust-particle size distributions	Site area; Atmosphere, near land surface	Goal: 1 to 10 micron, normal Current: -- Needed: High			
Issue 2.3	Can the repository be designed, operated, costructed, closed, and decommissioned in such a way that accidents do not result radiological exposures of the public at the nearest boundry of the area, or workers in the restricted area, in excess of limits?				(SCP 8.3.5.5)
Performance Measures: Consequences of credible site-related accidents Quick-acting dispersion and transport characteristics of the site Consequences of credible offsite accidents that could affect the repository and the essential workers					
Frequency and magnitudes of tornadoes	Repository facilities; Atmosphere, near land surface	Goal: Tentative goal is to have further measurements of this parameter to verify the range of expected values listed here Current: Medium Needed: High	Air temperature: spatial and temporal characteristics		8.3.1.2.1.1.1

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 2.3	Can the repository be designed, operated, costructed, closed, and decommissioned in such a way that accidents do not result radiological exposures of the public at the nearest boundry of the area, or workers in the restricted area, in excess of limits?			(SCP 8.3.5.5)	
Performance Measures: Consequences of credible site-related accidents Quick-acting dispersion and transport characteristics of the site Consequences of credible offsite accidents that could affect the repository and the essential workers					
		Parameter Category: Meteorological characteristics			
Frequency and magnitudes of cloud-to-ground lightning strikes	Repository facilities; Atmosphere, near land surface	Goal: Tentative goal is to have further measurements of this parameter to verify the range of expected values listed here Current: Medium Needeu: Medium	Precipitation and storm profiles, Yucca Mountain region		8.3.1.2.1.1.1
Frequency and magnitudes of sandstorms and windstorms	"	Goal: Tentative goal is to have further measurements of this parameter to verify the range of expected values listed here Current: Medium Needed: High	Precipitation: physical, spatial, and temporal characteristics		"

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 2.3	Can the repository be designed, operated, costructed, closed, and decommissioned in such a way that accidents do not result radiological exposures of the public at the nearest boundry of the area, or workers in the restricted area, in excess of limits?				(SCP 8.3.5.5)
Performance Measures:	Consequences of credible site-related accidents Quick-acting dispersion and transport characteristics of the site Consequences of credible offsite accidents that could affect the repository and the essential workers				
		Parameter Category: Meteorological characteristics			
Frequency and magnitudes of snow fall and ice storms	Repository facilities; Atmosphere, near land surface	Goal: Rare, low magnitude Current: Medium Needed: High	Wind speed and direction: spatial and temporal characteristics		8.3.1.2.1.1.1
Wind speeds	80 mi radius; Atmosphere, near land surface	Goal: Tentative goal is to have further measurements of this parameter to verify the range of expected values listed here Current: Medium Needed: High			
Wind direction	"	"			

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 2.3	Can the repository be designed, operated, costructed, closed, and decommissioned in such a way that accidents do not result radiological exposures of the public at the nearest boundry of the area, or workers in the restricted area, in excess of limits?				(SCP 8.3.5.5)
Performance Measures:	Quick-acting dispersion and transport characteristics of the site Consequences of credible offsite accidents that could affect the repository and the essential workers				
		Parameter Category: Meteorological characteristics			
Atmospheric stability	80 mi radius; Atmosphere, near land surface	Goal: Tentative goal is to have further measurements of this parameter ot verify the range of expected values listed here Current: Medium Needed: Medium[j]			
Mixing-layer depth	"	Goal: Tentative goal is to have further measurements of this parameter to verify the range of expected values listed here Current: Medium Needed: Medium			
Average ambient temperature	"	"			

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 2.3	Can the repository be designed, operated, costructed, closed, and decommissioned in such a way that accidents do not result radiological exposures of the public at the nearest boundry of the area, or workers in the restricted area, in excess of limits?				(SCP 8.3.5.5)
Performance Measures:	Consequences of credible offsite accidents that could affect the repository and the essential workers Quick-acting dispersion and transport characteristics of the site				
		Parameter Category: Meteorological characteristics			
Atmospheric moisture	80 mi radius; Atmosphere, near land surface	Goal: Tentative goal is to have further measurements of this parameter to verify the range of expected values listed here Current: Medium Needed: Medium			
Precipitation type, amount, intensity, etc.	"	"			
Barometric pressure	"	"			

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 2.7	Have the characteristics and configurations of the repository been adequately established to (a) show compliance with preclosure design (b) provide information for the resolution of performance issues				(SCP 8.3.2.3)
Performance Measures: Ability to detect radioactive materials in repository effluent streams Decontamination factor					
		Parameter Category: Meteorological characteristics			
Dust and particle size distributions (Underground and at site)	Repository area; Atmosphere, near land surface; Repository underground openings	Goal: 1 to 10 micron, normal Current: Data not available Needed: High	Air temperature: spatial and temporal characteristics		8.3.1.2.1.1.1
Wind speed (80 km radius)	Area within 80 km of site; Atmosphere, near land surface	Goal: See footnote (d) Current: Medium Needed: High	Precipitation and storm profiles, Yucca Mountain region		"
Wind direction (80 km radius)	"	"	Precipitation: physical, spatial, and temporal characteristics		"
Atmospheric stability (80 km radius)	"	Goal: See footnote (d) Current: Medium Needed: Medium	Wind speed and direction: spatial and temporal characteristics		"
Average ambient temperature (80 km radius)	"	"			

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 2.7	Have the characteristics and configurations of the repository been adequately established to (a) show compliance with preclosure design (b) provide information for the resolution of performance issues				(SCP 8.3.2.3)
Performance Measures:	Ability to detect radioactive materials in repository effluent streams Decontamination factor				
		Parameter Category: Meteorological characteristics			
Atmospheric moisture (80 km radius)	Area within 80 km of site; Atmosphere, near land surface	Goal: See footnote (d) Current: Medium Needed: Medium			
Precipitation: type, amount, intensity, etc. (80 km radius)	"	"			
Barometric pressure (80 km radius)	"	"			
Frequency and magnitudes of tornadoes (At facility)	Repository area; Atmosphere, near land surface	Goal: See footnote (d) Current: Medium Needed: High			
Cloud-to-ground lightning strikes (At facility)	"	Goal: See footnote (d) Current: Medium Needed: Medium			
Sandstorms/windstorms (At facility)	"	Goal: See footnote (d) Current: Medium Needed: High			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 2.7	Have the characteristics and configurations of the repository been adequately established to (a) show compliance with preclosure design (b) provide information for the resolution of performance issues			(SCP 8.3.2.3)	
Performance Measures: Decontamination factor					
		Parameter Category: Meteorological characteristics			
Snowfall/ice storms (At facility)	Repository area; Atmosphere, near land surface	Goal: Rare, low magnitude Current: Medium Needed: High			
Issue 4.4	Are the technologies repository construction, operation, closure, and decommissioning adequately established for the resolution of the performance issues			(SCP 8.3.2.5)	
Performance Measures: Facilities adequate to withstand natural-weather phenomena without damage to functional capability Compliance with 30 CFR Part 57 Compliance with threshold limit values and biological exposure indices specified in ACBIH[2] (1986)					
Design wind load at surface facility locations;(normal winds)	Repository facilities; Atmosphere, near land surface	Goal: 80 mph Current: Medium Needed: Medium	Air temperature: spatial and temporal characteristics		8.3.1.2.1.1.1
Design-basis tornado: probability of occurrence	"	Goal: $<1 \times 10^{-7}$ per yr Current: Low Needed: Medium	Precipitation and storm profiles, Yucca Mountain region		"

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

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

Performance Measures: Facilities adequate to withstand natural-weather phenomena without damage to functional capability
Compliance with 30 CFR Part 57
Compliance with threshold limit values and biological exposure indices specified in ACBIH[2] (1986)

Parameter Category: Meteorological characteristics

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Design-basis tornado: maximum wind speed	Repository facilities; Land surface	Goal: 180 mph (combined translational and rotational velocity) Current: Medium Needed: High	Precipitation: physical, spatial, and temporal characteristics		8.3.1.2.1.1.1
Design-basis tornado: maximum drop in atmospheric pressure	"	Goal: 0.7 psi Current: Low Needed: High	Wind speed and direction: spatial and temporal characteristics		"
Diurnal temperature and humidity variation of ambient air; at intake and exhaust locations	"	Goal: Temperature and humidity versus time-of-day plots for year (based on historical data) Current: -- Needed: --			

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

Design and Performance Parameters	Parameter Location	Parameter Goal and Confidence (Current and Needed)	Site Parameters	Parameter Location	Site Activity
Issue 4.4	Are the technologies repository construction, operation, closure, and decommissioning adequately established for the resolution of the performance issues				(SCP 8.3.2.5)
Performance Measures: Compliance with threshold limit values and biological exposure indices specified in ACBIH[2] (1986)					
Parameter Category: Meteorological characteristics					
Seasonal temperature and humidity variations of ambient air; at intake and exhaust locations	Repository facilities; Land surface	Goal: Temperature and humidity versus time-of-day plots for year (based on historical data) Current: -- Needed: --			

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ccession number: NNA.910219.0067