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Nye County Nuclear Waste Repository Project Office
Independent Scientific Investigations Program Final Report, Fiscal Years 1996—2001

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DEDICATED TO THE MEMORY OF NICK STELLAVATO

This volume is dedicated to the memory of Nick Stellavato—a good friend and respected colleague. Nick was also a devoted family man who is survived by his wife Sandra, three children, and three grandchildren.

Nick Stellavato is remembered as an admirable man and dedicated professional who was highly respected for his exemplary standards in scientific research. In a professional career spanning more than 25 years, Nick Stellavato gained experience in such subjects as geology, mining, hydrology, hydrogeology, core sample management, petroleum, oil shale, and drilling. Nick's diverse experience and creative thinking abilities enabled him to make major contributions as Nye County's first On-Site Representative to the Yucca Mountain Project.

Nick Stellavato brought together and managed a team of experts from many different fields to support the Nuclear Waste Repository Project Office activities. Nick had a rare talent of being able to dissect complicated analyses and identify the links that were missing. This process led to the Early Warning Drilling Program. Nick insisted that data collected by Nye County should be qualified so that it could be useful to everyone, and he was a firm believer that data analysis should be conducted quickly, so that the results could be made available to the public and the Yucca Mountain Project in as timely a manner as possible.

Nye County is committed to continuing the high professional and scientific standards set by Nick Stellavato.

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ACRONYMS AND ABBREVIATIONS

ATC	Alluvial Testing Complex
AVYM	Amargosa Valley/Yucca Mountain
BGMW	Bond Gold Monitoring Well
CDT	Canyon Diablo troilite
CFC	chlorinated fluorocarbon
DOE	U.S. Department of Energy
DVRFS	Death Valley regional groundwater flow system
ECRB	enhanced characterization of the repository block
ESF	Exploratory Studies Facility
EWDP	Early Warning Drilling Program
FBA	fluorobenzoic acid
ISIP	Independent Scientific Investigations Program
NRC	U.S. Nuclear Regulatory Commission
NWRPO	Nuclear Waste Repository Project Office
PTn	Paintbrush Tuff non-welded
QA	quality assurance
QAPP	Quality Assurance Program Plan
SEM	scanning electron microscope
TSw	Topopah Spring welded
USGS	U.S. Geological Survey
YMP	Yucca Mountain Project

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1.0 INTRODUCTION

This document briefly describes major activities and findings of the Independent Scientific Investigations Program (ISIP) conducted by the Nye County Nuclear Waste Repository Project Office (NWRPO) for the 5-year period beginning in fiscal year 1996 and ending in fiscal year 2001. Funding for this program has come solely from the U.S. Department of Energy (DOE) Yucca Mountain Project (YMP). The main goal of the ISIP has been, and will continue to be, the independent evaluation of selected site characterization, repository design, and performance issues potentially affecting human health, safety, and the environment in Nye County.

1.1 INDEPENDENT SCIENTIFIC INVESTIGATIONS PROGRAM GRANTS AND OBJECTIVES

During calendar year 2001, the NWRPO will complete two major grant studies conducted under the ISIP. The first study is the 5-year Exploratory Studies Facility (ESF) Technical Grant (sometimes referred to as the ISIP Grant), and the second is the three-year Early Warning Drilling Program (EWDP) Grant. The NWRPO has used the ESF Technical Grant primarily to fill data gaps and address technical issues within and in the vicinity of the proposed repository. Specific technical objectives of this grant include the evaluation of:

- Potential impacts of ESF mining activities on pneumatic pathways in the unsaturated zone
- In situ permeabilities and transport parameters of lithostratigraphic units in the vicinity of the repository on a large scale
- Alternative models to simulate heat and mass transfer in repository tunnels and host rock
- Alternative repository designs, such as a naturally ventilated repository
- Limitations of DOE YMP unsaturated zone infiltration and percolation models.

The EWDP Grant has been used to fill data gaps and address technical issues on a much larger scale (i.e., an expanded site scale), including studies of the Fortymile Wash, Crater Flat, and Amargosa Desert areas. More specifically, EWDP Grant studies have focused on four main objectives:

- Development of a long-term groundwater monitoring program in Nye and Inyo Counties downgradient from the proposed repository
- Filling in data gaps in the subsurface hydrogeologic flow and transport system between the proposed repository and the populated areas in Amargosa Valley, the Furnace Creek area of Death Valley, and tributary hydrographic basins
- Evaluation of the U.S. Geological Survey (USGS) regional groundwater flow model and the DOE YMP site-scale models with regard to hydrogeologic unit conceptualizations, modeling assumptions, and the availability and suitability of data

- Collection of surface-based geophysical and geologic mapping data to support refinement of the NWRPO conceptual hydrogeologic regional model and the USGS regional groundwater flow model.

1.2 QUALITY ASSURANCE REQUIREMENTS

The scientific data generated during the course of the ISIP have been collected under the Nye County NWRPO Quality Assurance (QA) Program. More specifically, ISIP data have been gathered under the constraints and controls of the *NWRPO Quality Assurance Program Plan* (QAPP) (NWRPO, 1999). Constraints and controls necessary to produce valid data include QA Program elements such as design control, calibration of equipment, adequate training, use of formal procedures, a records and data management system, control of nonconforming items, corrective action, audits, and surveillances.

The NWRPO QAPP (NWRPO, 1999) has been evaluated and audited by the staff of the U.S. Nuclear Regulatory Commission (NRC). The NRC's evaluation took the form of a formal acceptance evaluation, which resulted in the following statement:

> NRC staff finds that the Nye County QAPP [NWRPO, 1999] is in conformance with the relevant criteria of Title 10 of the Code of Federal Regulations (10 CFR) Part 60, Subpart G, and 10 CFR Part 50, Appendix B. Accordingly, NRC staff finds the Nye County QAPP [NWRPO, 1999] acceptable for the type of activities to be conducted for the early warning drilling program. (Reamer, 1999)

The QA Program is based on the interpretation of federal regulations and industry standards (10 CFR Part 50, Appendix B; ANSI/ASME NQA-1) for nuclear power plants, adapted for geologic waste repository research. All NWRPO personnel and contractors who perform or manage quality-affecting functions work under the procedures outlined in the QAPP (NWRPO, 1999). These procedures include QA administrative procedures, as well as technical procedures and work plans that specify all necessary controls to ensure conformance with the requirements.

In summary, the NWRPO QA Program helps to ensure that ISIP investigations yield valid data that can be used by the scientific and engineering community to support nuclear waste repository site characterization, performance assessment, and design.

1.3 PUBLICATION OF DATA AND ANALYSES

Samples, data collected, and analyses performed under the ISIP directly support Nye County NWRPO efforts to protect the health and safety of Nye County residents. These data and analyses also support ongoing studies by the DOE YMP. Accordingly, the timely distribution and access to ISIP data and analyses are important objectives of the ISIP.

As part of the NWRPO's effort to provide information in a timely manner, ISIP data and analyses have been published in annual program summary reports and numerous reports on specific topics. These reports will be referenced, as needed, in the following sections. In addition, summaries of methods, data, and analyses of major ISIP studies have been communicated by NWRPO staff and contractors to the scientific community through numerous presentations. Recipients of these presentations have included the Nuclear Waste Technical Review Board, NRC Technical Exchanges, the Devils Hole Workshop, Death Valley Regional Groundwater Flow Model Technical Interactions, and the Nevada Test Site's Community Advisory Board, among others.

In order to broaden the public and scientific community's access to ISIP data and analyses, a Nye County web site (www.nyecounty.com) (Nye County, 2001) was developed. Several key reports and a significant portion of the QA-qualified data collected under the ISIP are available on the web site. Efforts to add key data and analyses to the web site are ongoing and will continue as part of Nye County's participation in the NRC's Licensing Support Network.

1.4 OVERVIEW OF REPORT

The remainder of this report is divided into four sections. Regional geologic studies are described in Section 2. The focus of studies in this section is on the collection and analysis of geologic-related data from the Amargosa Desert and Pahrump Valley hydrographic basins for the purpose of refining the geologic framework model for these areas. These studies have been funded primarily from the EWDP Grant.

Unsaturated zone studies conducted in the vicinity of the repository and funded from the ESF Technical Grant are summarized in Section 3. These studies address the impacts of ESF mining on pneumatic pathways, the characterization of pneumatic flow and transport parameters, natural ventilation modeling, and limitations in DOE YMP models for infiltration and seepage.

Saturated zone studies funded from the EWDP Grant and conducted primarily in the region between Yucca Mountain and Highway 95 are discussed in Section 4. These studies are primarily concerned with filling in hydrogeologic characterization data gaps using borehole drilling, logging, testing, and monitoring methods. In addition, preliminary hydrogeologic conceptual and numerical models for this region are presented and discussed.

Several studies not falling into one of the previous section categories are presented in Section 5. These studies include Nye County geothermal resource evaluations and Inyo County's studies in the Death Valley region. Finally, conclusions and recommendations are presented in Section 6.

2.0 REGIONAL GEOLOGIC STUDIES

This section summarizes the regional geologic studies conducted by Nye County and cooperating organizations. These studies focused on collecting and analyzing geologic data from the Amargosa Desert and Pahrump Valley basins to refine the geologic framework model for the Yucca Mountain region. First, the results of geophysical surveys and geologic mapping sponsored by Nye County are presented and discussed (Section 2.1). Next, the results of a structural analysis are presented in Section 2.2. This analysis used the results of the geophysical surveys to identify potential compartmentalization of the aquifers in the vicinity of Yucca Mountain, an important consideration in evaluating the likely pathways for groundwater flow in the region. Surface geologic mapping in Nye and Inyo Counties designed to help refine the regional geologic framework model and to help address local hydrogeologic issues is described in Section 2.3. Lastly, a conceptual geologic model of the Yucca Mountain region is presented and discussed in Section 2.4. This conceptual model is based upon the results of the geophysical surveys, the geologic mapping, and the well boring data that have been compiled by Nye County.

2.1 AEROMAGNETIC AND GRAVITY SURVEYS

In 1998, the USGS completed a gravity survey of Amargosa Desert, Pahrump Valley, and adjacent areas, and, in 1999, it completed a high-resolution airborne magnetic survey of the area as part of a cooperative effort between Nye, Clark, and Inyo Counties. The geophysical surveys were performed to augment subsurface information in the areas proximal to Yucca Mountain and the southern part of the regional groundwater flow model domain (D'Agnese et al., 1997).

The goals of these surveys were to:

- Provide additional data for the regional hydrogeologic framework model
- Assist in defining subsurface structures in the valley-fill deposits of the basins
- Refine the definition of the depth to the pre-Cenozoic basins
- Further define the size and distribution of subsurface volcanic features
- Provide information on the nature and significance of the State Line fault
- Evaluate spring deposits on the southwest flank of Bare Mountain.

The area of the magnetic survey, including flight lines, is shown in Figure 2.1-1, and the locations of the gravity stations and profile lines are shown in Figure 2.1-2. The magnetic survey consisted of 14,500 miles (23,330.5 km) of survey lines. Base stations deployed at North Las Vegas and Beatty were in operation throughout the survey. Gravity stations were established at 252 locations in Amargosa Desert and 278 locations in Pahrump Valley, including the western slopes of the Spring Mountains. Two high-resolution gravity profiles were established through the spring deposits between Bare Mountain and Highway 95. After the gravity and magnetic data were collected, the data were processed in accordance with established USGS methods.

Results and findings of the geophysical surveys are summarized in the following section. Two administrative reports detail the planning, organization, and running of the surveys and the interpretations of the USGS (Blakely et al., 1998, 2000a). One open-file report has been published on the magnetic survey (Blakely et al., 2000b); the complete text of this report and summary information on the procedures used to conduct these surveys are available on the Internet (http://geopubs.wr.usgs.gov/open-file/of00-188/; see Section 7).

2.1.1 Yucca Mountain–Amargosa Desert Results

The results of the magnetic survey were processed to identify aeromagnetic anomalies, residual magnetic anomalies, and magnetization boundaries. Figure 2.1-3 shows linear magnetic anomalies (lineaments) on the basement surface. The major interpretive results shown on this figure include:

- North-northeast striking lineaments over the volcanic terrain north of Highway 95 (see A on Figure 2.1-3)
- North trending lineaments along Fortymile Wash, suggesting that the presence and location of the wash may not be controlled by structures, or is controlled by structures that juxtapose rocks with differing magnetic characteristics but with no vertical offset (see B on Figure 2.1-3)
- Northeast striking lineament across southern Yucca Mountain that coincides with the Stagecoach Road fault (see C on Figure 2.1-3)
- Three east-west magnetic patterns, suggesting deep structures or lithologic contrasts beneath the volcanic terrain (see D on Figure 2.1-3)
- Lack of offset on lineaments that cross the Carrara (Highway 95) fault, suggesting that this structure is not a through-going feature (see E on Figure 2.1-3)
- The southwestern limits of the Rock Valley fault zone and the shallow subsurface volcanic feature at the intersection of the fault zone with the Amargosa Trough (see F on Figure 2.1-3)
- North-northeast trending lineaments in the Indian Pass area of the Funeral Range that coincide with faults in the Stirling Quartzite (see G on Figure 2.1-3).

The gravity data were separated into two components: valley-fill deposits and basement rocks. The Paleozoic rocks that underlie the valley-fill sediments and outcrop in some areas of Amargosa Desert are referred to as the "basement" in this document. Maps were prepared to show the isostatic residual gravity, the gravity caused by basement rocks, and the thickness of valley-fill sediments. Based on these maps, a three-dimensional representation of the subsurface beneath greater Amargosa Desert was prepared (Figure 2.1-4). The basement surface is complex; it is relatively flat and shallow around the margins of the basin, but it contains deep, steep-sided sub-basins under the central portions of the basin. The figures in Section 2.4 provide additional perspectives of the basement surface that graphically demonstrate the variability of the carbonate rocks underlying the volcanic and valley-fill deposits in the Yucca Mountain region.

The most striking feature in the basement surface is the Amargosa Trough, a deep, relatively narrow trough that extends from the volcanic highlands under Yucca Mountain to the Black

Mountains south of Shoshone, California. The trough is separated into segments, or sub-basins, by ridges in the basement surface. These ridges correspond with the location of major structural elements: the Rock Valley fault, the State Line fault, and the Furnace Creek fault. Blakely et al. (1998, p. 2) noted that springs, seeps, marshes, and phreatophytes located along parts of the eastern and western margins of the Amargosa Trough suggest that groundwater flow is influenced by permeability contrasts along the margins of the trough. For example, the springs and wetlands at Ash Meadows occur at the eastern trough boundary, where flow through the transmissive carbonate aquifer system is impeded by as much as 7,000 ft (2,133.6 m) of fine-grained sediments deposited in the trough.

A similar contrast in rock type and permeability may be responsible for the high water table beneath spring deposits located approximately 10 km southeast of point F on Figure 2.1-3. Gravity data and aeromagnetic data, together with lithologic data collected as part of the EWDP activities in the area, suggest the present-day high water levels and past paleospring discharge are the result of the contrast in lithologies across the Carrara-Highway 95 fault, with southward-flowing groundwater from Crater Flat being impeded by the low-permeability volcaniclastic sediments that are deposited in Amargosa Desert.

2.1.2 Pahrump Valley Results

The new gravity data for Pahrump Valley show that the basement surface under much of the valley is relatively flat and within 2,500 ft (762 m) of the land surface, except for two distinct sub-basins on either side of the State Line fault (Figure 2.1-4). Both of these sub-basins are elongated in the northwest-southeast direction and are quite steep. The top of the basement surface is more than 16,000 ft (4,876.8 m) below land surface in the Nevada sub-basin and about 6,600 ft (2,011.68 m) below land surface in the California sub-basin.

The bedrock high that separates the two sub-basins in Pahrump Valley appears to have a controlling effect on groundwater flow. Blakely et al. (1998, p. 6) noted that this ridge is presumably composed of carbonate rocks and that bounding reverse faults may act as barriers to groundwater flow, as evidenced by springs on the northeastern margin of the bedrock high. Similar to the conditions in Amargosa Desert, the thick accumulation of valley-fill sediments in the sub-basins and the contrast in hydraulic properties between the valley fill and the carbonate rocks are likely contributing to the shallow groundwater conditions upgradient of the sub-basins.

The new magnetic data for Pahrump Valley delineate a number of linear magnetic anomalies associated with the State Line fault (see lower right corner of Figure 2.1-3). Some of these lineations correspond with Quaternary faults. To the northwest, similar lineaments are present in Stewart Valley. Blakely et al. (2000a, p. 13) noted that further to the northwest, some lineaments veer northward from the State Line fault, pass near Devils Hole, and terminate near the Rock Valley fault zone. Blakely et al. (2000a) further noted that this set of anomalies might indicate a hydraulic connection between the faults and Devils Hole. A hydraulic connection between Pahrump Valley and Devils Hole via Stewart Valley would be significant and additional characterization of this potential flowpath is warranted.

2.2 STRUCTURAL ANALYSES AND GEOLOGICAL COMPARTMENTALIZATION

Study of structural relationships and kinematic analysis of fault patterns at Yucca Mountain and the surrounding region reveals fault systems that bound basins containing aquifers. These basins act as compartments in which groundwater may collect. Structural analysis of mapped faults was integrated with geophysical information by means of a geographical information system. The structural analysis, complemented by stratigraphic considerations and a brief field study, led Lauffer-Aho and Anderson (2000) to conclude that crust of the Yucca Mountain region records two episodes of extension characterized by pull-apart basins (Figure 2.2-1). The episodes are different ages (~25 to 15 Ma and ~15 to 10 Ma). Basins of the older episode trend northwest, and basins of the younger (Basin and Range) episode trend north-south. Recognition of these fault systems and the strata that fill the basins helps to improve understanding of groundwater flow and constrain the number and locations of pathways along which fluids may move away from the repository and test areas.

Groundwater may move along connected faults that can act as conduits if the fault zone is permeable. If rock units with different permeabilities are juxtaposed along a fault, then the flow of groundwater across the fault may be impeded. Therefore, the identification of regional fault sets and basins helps to provide insight into:

- Prospects for groundwater sources
- Paths along which fluids may move toward Amargosa Valley
- Sources of springs, such as those related to the endangered pup fish living at Devils Hole
- Groundwater pathways from Amargosa Valley to Death Valley National Park.

2.2.1 Existing Structural Data Revisited

Yucca Mountain lies within the Basin and Range physiographic province, which is characterized by approximately parallel ranges and valleys, resulting from deformation during Tertiary extensional episodes. The strata at Yucca Mountain record three distinct sets of faults (Figure 2.2-2), including:

- Northerly striking normal faults
- Northeasterly striking left-lateral strike-slip faults
- Northwesterly striking right-lateral strike-slip faults.

Where lateral fault segments are linked by short connecting faults, pull-apart or extensional basins may form. The overstep direction forms a transpressional or transtensional step, depending upon the sense of displacement.

Further study, involving consideration of stratigraphic information and results from aeromagnetic mapping away from Yucca Mountain, indicates an additional older extensional fault system, which bounds basins older than those associated with Yucca Mountain. This older fault system also includes three sets:

- Northwesterly striking normal faults
- West-northwesterly striking right-lateral strike-slip faults
- Northerly striking left-lateral strike-slip faults.

Each episode of extension resulted in fault-bounded pull-apart basins linked by strike-slip faults. North-south trending pull-apart basins formed during Late Miocene, and northwest-southeast trending basins formed during Late Oligocene to Early Miocene.

The pattern of faults and structural domains within the Yucca Mountain region resembles those produced with pure shear. Strike-slip and normal faults, especially those that cut into deeply buried carbonate strata, may influence the flow and distribution of groundwater by providing preferential flow zones between aquifers.

2.2.2 Compartmentalization Based on New Aeromagnetic Survey Data

Basins, formed by intersecting sets of faults, may serve as individual groundwater compartments. Figure 2.2-3 shows a simplified interpretation of major lineaments from a map of residual magnetic anomalies by Blakely et al. (2000b) that may correspond to the boundaries between major groundwater compartments. These lineaments are 10 to more than 20 km long and commonly trend north-south or east-west. Strong magnetic signatures may result from the magnetic character of the Paleozoic Eleana Formation, Cretaceous intrusions, or Precambrian basement. Anomalies also may be caused by faults that offset shallow gently dipping units, such as flow tuffs, lava flows, and other subhorizontal units with a uniform direction of magnetization.

Alluvial deposits are generally nonmagnetic and produce weak aeromagnetic anomalies. Shallow Tertiary volcanic rocks have strong magnetic signatures associated with high-amplitude, short-wavelength anomalies. This type of magnetic anomaly is particularly evident at the northern end of Amargosa Valley, just south of Yucca Mountain on Figure 2.2-3.

East-west magnetic lineations are interpreted as subsurface faults that may be pre-Cenozoic. They do not truncate Miocene volcanic rocks or north-south trending faults. They are interpreted as normal faults that offset Mesozoic and older rocks, perhaps formed during Mesozoic extension. North-south lineations are interpreted to be coincident with young faults or reactivated Mesozoic faults, which truncate Miocene volcanic rocks.

A map of the depth to basement shown on Figure 2.1-4 (Blakely et al., 2000b) reveals subsurface basins that are interpreted to correspond to pull-aparts. Figure 2.2-3 outlines the interpreted boundaries of Early and Late Miocene basins. In places, Late Miocene basins are superposed upon Early Miocene basins. Pahrump Valley and Stewart Valley are interpreted as Late Miocene pull-aparts, associated with releasing steps on the right-lateral State Line fault. The Pahrump Valley pull-apart extends to the north along the Spring Mountains. North-south trending Late Miocene extensional basins occur under the Amargosa Valley, and extend northward under the Yucca Mountain region. These are interpreted as being associated with right-lateral movement, along northwest-striking strike-slip faults.

2.3 GEOLOGIC MAPPING

Although recent geologic map coverage is available for much of the Yucca Mountain area and the Nevada Test Site, large areas of the southern part of Nye County have not been mapped at similar scales or levels of detail. Detailed geologic maps are not available for much of Pahrump

Valley or southern Amargosa Desert (including areas in Clark County and Inyo County, California). This region includes key features in the DOE's hydrogeologic framework model, such as the recharge areas in the Spring Mountains and the discharge areas in Amargosa Desert. To address this deficiency, Nye County is co-sponsoring a cooperative geologic mapping effort with the USGS and the Nevada Bureau of Mines and Geology. The goal of this effort is to complete detailed geologic mapping for those portions of the region for which existing map coverage is outdated or inadequate. Inyo County, California, and the National Park Service are also contributing toward this mapping effort.

Figure 2.3-1 shows the locations of 1:24,000-scale quadrangles in southeastern Nye County for which mapping has been completed, is underway, or is planned. The Mound Spring quadrangle map has been published (Lundstrom et al., 1999) under the NWRPO program and two more quadrangles (Sixmile Spring and Horse Spring) are underway. These maps complement similar state-funded coverage of the Pahrump Quadrangle (dePolo et al., 1999). The geologic mapping initiative is making progress toward a better understanding of a number of technical issues, including:

- Potential hydraulic connection between Pahrump Valley and Amargosa Desert
- Recharge over the southwestern slopes of the Spring Mountains
- Flooding in Pahrump Valley
- Groundwater discharge in Stewart Valley
- Surficial geologic conditions and subsidence features in Pahrump Valley.

Nye County's priorities include the rest of the western slopes of the Spring Mountains and southern Pahrump Valley. YMP priorities include the southeastern portions of Amargosa Desert and Stewart Valley. Inyo County's priority at this time is the Nopah Peak Quadrangle in southern Pahrump Valley. The National Park Service has prioritized the Twelve Mile Spring quadrangle.

The geologic mapping co-sponsored by Nye County is providing additional new detail in key areas of the regional framework model. Beyond this contribution, the Nye County mapping effort is providing spin-off benefits in land and water resource management and planning. Specifically, the maps are being used in evaluations of the subsidence and flooding potential of the basin and the effect of geologic structures on groundwater flowpaths. Assuming continuity of funding, the NWRPO mapping initiative will continue for the next several years.

2.4 CONCEPTUAL GEOLOGIC MODEL OF THE AMARGOSA VALLEY AND YUCCA MOUNTAIN REGION

This section summarizes the NWRPO's ongoing activities toward developing a conceptual geologic model of the Amargosa Valley/Yucca Mountain (AVYM) region. The main goals of this effort are to:

- Provide a framework whereby alternative hydrogeologic conceptual models can be developed, assessed, and screened using information obtained from field observations, testing, and simulations

- Improve the understanding of groundwater flow and the transport of potential contaminants in the AVYM region.

The geologic model of the Yucca Mountain area was adapted from data in the DOE YMP (DOE, 1997a) geographical information system. The top surface of the geologic model (the land surface) was created using a digital elevation model (USGS, 2001a). The lower boundary of the model was based on an interpretation of the depth to Paleozoic basement from a residual isostatic gravity survey (Blakely et al., 2000b).

2.4.1 Geologic Database Development

A geologic database has been developed and maintained by the NWRPO for hydrogeologic modeling purposes in support of YMP site characterization oversight and for evaluation of YMP repository performance assessments. Table 2.4-1 summarizes the database tables. Information about boreholes and other geographic features, such as springs and weather stations, is maintained in the "Boreholedata" table. The "Labdata" table contains information about water level elevations in boreholes and wells, discharge of springs, stream flow for selected gauging stations, and precipitation at pertinent weather stations. Geologic information is maintained in the "Soil Detail" table. Most boreholes have detailed geologic information, represented in this table as segments. Each segment is cross-referenced with the "Soil Type" table. The "Soil Type" table contains descriptive information about geologic units, including abbreviations and desired color for plotting. Currently, there are no image data in this database. However, future work may include scanning and digitizing well log information for ease of access and QA purposes.

To date, only historical hydrogeologic data collected prior to the initiation of the EWDP have been entered into this database. Plans have been made and funding tentatively approved to enter all EWDP data into this database, or one or more new databases designed especially for data collected under the NWRPO QA Program (i.e., the EWDP and possible future similar ISIP programs). If the latter option is selected, Nye County will use its existing geologic database for historical pre-EWDP data only. Finally, it should be noted that QA review and verification of the historical data in the database have not been conducted to date by the NWRPO. Therefore, any results based on these data discussed in the following sections should be considered preliminary and subject to revision.

Preliminary analysis of historical data in this database identified several major data gaps, especially in the area between Yucca Mountain and Amargosa Valley. These data gaps provided, in part, justification for launching the Nye County EWDP. For example, in the Fortymile Wash area, the saturated and unsaturated thickness and distribution of alluvium are uncertain, and future ISIP boreholes and surface geophysical surveys are planned to help fill in this important missing information.

2.4.2 Preliminary Conceptual Geologic Model

Figure 2.4-1 shows a three-dimensional view of the preliminary conceptual geologic model. A coarse grid spacing (400 m by 400 m) was used in the model. The grid spacing in the EWDP area may be refined in the future to 200 m by 200 m, or smaller, where justified by new data. Data obtained from EWDP investigations have not yet been incorporated into this model.

This model consists of two surfaces that are regionally present and form the top and bottom of the geologic model. These surfaces are topographic (the land surface) and the top of the Paleozoic basement. The Paleozoic basement underwent numerous structural deformations after its formation. These deformations created deep depositional basins in which sedimentary and volcanic materials have accumulated. In the current geologic model, these deposits are collectively referred to as Quaternary and Tertiary valley-fill deposits. Attempts have been made to separate the Quaternary and Tertiary alluvium from the volcanic deposits (DOE, 1997b). However, Nye County's EWDP efforts have revealed that in the AVYM area, the intercalated nature of these deposits makes them practically inseparable.

The valley-fill deposits are generally more permeable near the stream channels (i.e., Holocene alluvial deposits). The older lacustrine valley-fill deposits generally exhibit lower permeability because of the deposition of finer grained material associated with detrital depositional events. Also, in the desert environment that has prevailed for extended geologic times in this area, calcification and soil development processes have substantially reduced the permeability of some of the valley-fill deposits. During EWDP Phase I and II investigations, it was observed that the valley-fill deposits near the sides of the valley (as in NC-EWDP-5SX) generally consisted of lower-permeability material than those near more recent stream channels toward the center of the valley (as in NC-EWDP-2DB and -19D).

Figures 2.4-2 and 2.4-3 show the relations between the land surface and the Paleozoic basement surfaces, and the alluvial deposits in different cutouts from the model. Figure 2.4-2 shows the widespread distribution of the alluvial deposits. In Figure 2.4-3, the dramatic change in the thickness of the valley-fill deposits between Yucca Mountain and Amargosa Desert is particularly of interest. This feature is part of the Amargosa Trough, a relatively narrow trough in the basement rock surface that extends from Yucca Mountain to the Black Mountains (see Section 2.1.1). The change in thickness and properties of the valley-fill deposits in this area likely has significant impact on the flow of groundwater and potential migration of contaminants between Yucca Mountain and Amargosa Desert.

The basement rock surface is shown in Figure 2.4-4. This is a three-dimensional view of the bottom of many of the structurally controlled basins identified in Figure 2.2-1 and discussed in Section 2.2. The Amargosa Trough (mentioned above), as well as several ridges corresponding to major faults that divide the trough into sub-basins, is shown in Figure 2.4-4. Many of the steep sides of the valleys are controlled by deep-seated faults. Some of these faults and their interpreted relations are shown in a simplified cross-section in Figure 2.4-5. This cross-section includes data from two EWDP wells (NC-EWDP-1DX and -2DB).

The future emphasis in this task will be to incorporate hydrogeologic data into the geologic model from the EWDP and future similar ISIP characterization programs. Major areas of uncertainty in the geologic model include variations in thickness of the alluvial and valley-fill deposits in the Fortymile Wash and Amargosa Valley areas. EWDP drilling and geophysical investigations are planned to provide additional data and improve confidence in the model geometry in these areas.

3.0 UNSATURATED ZONE STUDIES

The unsaturated zone in Yucca Mountain provides a natural barrier that limits percolation to and away from the potential repository horizon, thereby limiting the transport of potential contaminants to the underlying groundwater aquifer. The DOE has undertaken characterization of the Yucca Mountain unsaturated zone primarily to quantify the rate of this percolation under present and future climates to support performance assessment analyses. The NWRPO has undertaken independent scientific studies of the unsaturated zone at Yucca Mountain to evaluate the efficacy of DOE studies and to ensure the protection of the health and safety of the residents of Nye County and their future water supplies.

Section 3.1 provides an overview of the data collection activities and analyses in UE-25 ONC#1, USW NRG-4, the ESF, and the enhanced characterization of the repository block (ECRB) tunnel. These activities were designed to further the understanding of unsaturated zone pneumatic and liquid flow pathways and parameters, and to evaluate in situ gas chemistry and its usefulness in age-dating unsaturated zone pore water and air. Section 3.2 briefly describes preliminary numerical modeling that demonstrates potential benefits of natural and active ventilation. In Section 3.3, some of the concerns with the current unsaturated zone conceptual model are outlined.

3.1 INVESTIGATIONS AT UE-25 ONC#1, USW NRG-4, THE EXPLORATORY STUDIES FACILITY, AND THE ENHANCED CHARACTERIZATION OF THE REPOSITORY BLOCK TUNNEL

Figure 3.1-1 shows the locations of boreholes UE-25 ONC#1 and USW NRG-4, the ESF, and the ECRB subsurface excavations at Yucca Mountain. The successful drilling, completion, and instrumentation of UE-25 ONC#1 and instrumentation of USW NRG-4 by Nye County (NWRPO, 1995) demonstrated to the DOE and other interested parties that:

- Relatively inexpensive drilling methods, such as dual-wall reverse air circulation, can produce minimally disturbed drill cuttings and unsaturated zone boreholes suitable for acquiring high-quality hydrogeologic data.

- A removable vadose zone monitoring instrumentation system (Westbay®) could be successfully installed and operated in unsaturated zone boreholes.

Several types of monitoring and analysis investigations were conducted in these boreholes, in the ESF, and in the ECRB. These studies included pneumatic pressure, temperature, and humidity monitoring; pneumatic permeability testing; environmental tracer gas analyses; and petrographic analyses. Each of these studies is briefly discussed separately in the following sections. More detailed discussions, as well as a complete listing of all data collected, are presented in NWRPO (1995, 1996, 1997, 1998, 2000).

The major conclusions and contributions from these monitoring and analysis studies are as follows:

- Pneumatic pressure monitoring conducted in unsaturated zone borehole USW NRG-4 before and after the excavation of the ESF through the Paintbrush Tuff non-welded (PTn) unit demonstrated that this unit slows the downward movement of gases from overlying units to the repository horizon and vice versa.

- Significant chlorinated fluorocarbon (CFC) concentrations more than 1,000 ft (304.8 m) below ground surface suggest that the Yucca Mountain unsaturated zone is a pneumatically open system in direct communication with atmospheric air.

- Trends in measured carbon-14 concentrations (in carbon dioxide) in unsaturated zone air suggest that they may be in equilibrium with the liquid-water phase in rock. If this is true, the age of unsaturated zone air is an indicator of some unknown combination of pore-water and fracture-water ages.

- Preliminary Nye County ventilation studies in the ESF demonstrate that air movement in the repository tunnels is an effective method for removing heat and moisture from the repository.

- Subsequent numerical simulations indicated that natural ventilation could be used to keep the repository cool and dry for thousands of years assuming the repository can be kept open during this time period and potential tunnel stability problems can be avoided.

3.1.1 Pneumatic Monitoring and Testing in Surface-Based Boreholes UE-25 ONC#1 and USW NRG-4

In order to assess the natural barrier effects of the unsaturated zone (i.e., its contribution toward isolating nuclear waste-related contaminants from the accessible environment), it is necessary to understand the pneumatic processes, properties, and conditions in the vicinity of the proposed repository. Pneumatic properties, such as pneumatic permeability and diffusivity, are needed to calculate the interaction of ventilation air with heat and moisture transferred through the rock mass. While gas-phase radionuclides do not present a significant hazard from the waste forms being considered, gas flow through the rock mass has a substantial impact on the repository's isolation potential, both for a ventilated, low-temperature repository design and a back-filled, high-temperature repository design. In addition, pneumatic monitoring provides useful qualitative information regarding the degree of connectivity of some of the geologic structures near the repository.

Pneumatic monitoring data obtained since 1995 have been maintained in a Nye County preliminary database. Work is underway to make this database available on the Nye County web site (www.nyecounty.com; Nye County, 2001).

3.1.1.1 Pneumatic Monitoring

In 1995, Nye County installed instrumentation and initiated pressure and temperature monitoring in boreholes USW NRG-4 and UE-25 ONC#1 (Figures 3.1-2 and 3.1-3). The main goal of this monitoring was to evaluate long-term pneumatic conditions at strategic depths in the subsurface, both in response to fluctuations in atmospheric conditions and to other possible disturbances resulting from site characterization activities, such as the ESF and ECRB tunnel construction. Illustrative examples of these monitoring data are presented in the following section.

Figure 3.1-4 shows the pneumatic pressure heads in the atmosphere (Probe 0) and in seven probes located in the unsaturated zone in USW NRG-4 prior to and immediately after the ESF broke through the PTn unit around June 15, 1995. Before the breakthrough, there was a distinct time lag between barometric fluctuations indicated at the atmospheric probe (Probe 0 in Figure 3.1-2), and the lower four probes (Probes 4 through 7 in Figure 3.1-2) in the Topopah Spring welded (TSw) unit. In addition, the pressure-wave signature was substantially attenuated in these four probes before the breakthrough. The upper two probes (Probes 1 and 2), in the Tiva Canyon welded unit, did not show significant arrival time lag either before or after the breakthrough. Probe 3, in the lower part of the PTn unit, showed a slight time lag and an intermediate pressure-wave attenuation before the breakthrough. After the breakthrough, all seven probes responded synchronously with the atmospheric probe.

The fact that the atmospheric probe and the probes located in the TSw unit responded asynchronously before the ESF breakthrough indicates that the PTn unit, in its natural state, retarded and attenuated the barometric-pressure waves. Because the ESF passed within 50 m of USW NRG-4, the impact of the June 15, 1995, ESF breakthrough was immediately noticeable. The USW NRG-4 observations substantiated the ability of short packers (1-m-long) to isolate between intervals. Packers 3 and 4 (Figure 3.1-2) are the only barriers in this borehole located between the highly fractured Tiva Canyon welded and TSw units. If there were a substantial air leakage around Packer 4, which separates Probes 3 and 4, the pressure fluctuations in Probe 4 would have been the same as pressure fluctuations in Probe 3. Instead, substantial differences in the pressure of the two units were clearly recorded in Probes 3 and 4. From these data, it appears that the lowermost portion of the PTn unit has the lowest permeability in this unit (see the following section for quantitative analyses).

The PTn unit has low permeability and is almost devoid of fractures, which might indicate that the effective isolation by Packer 4 is unique to this unit and may not apply to the highly fractured TSw unit at greater depths. However, pressure fluctuations observed in Probes 6 and 7, before and after ESF breakthrough, provided confirmation that Packer 7 effectively isolated these two probes. Before the breakthrough, the two probes showed a small time lag in pressure arrivals. If there were substantial leakage around this packer, there would have been no time lag in between these two probes, which are only 24 ft (7.3 m) apart. After breakthrough, the time lag completely vanished.

Borehole UE-25 ONC#1 is located nearly a mile from the ESF (Figure 3.1-1). It is therefore not surprising that little or no difference has been noted between the barometric pressure time lag in subsurface probes located in the TSw unit before, during, and after the construction of the ESF. Nye County will continue to monitor pneumatic pressures in UE-25 ONC#1 to identify long-term impacts (if any) of ESF construction and operation on pneumatic conditions in the TSw unit.

3.1.1.2 Pneumatic Permeability Testing and Analyses

Subsurface pneumatic pressure responses in UE-25 ONC#1 and USW NRG-4 to atmospheric barometric pressure changes (described in Section 3.1.1.1) and pressure responses to vacuum testing in UE-25 ONC#1 were analyzed to estimate rock mass pneumatic permeabilities. Analytical methods used included one- and two-dimensional inverse modeling using A-TOUGH© (MET, 1995) and Fourier series analysis (QEC, 1998). The results of atmospheric barometric pressure response analyses are shown in Tables 3.1-1a and 3.1-1b, and vacuum testing analyses are summarized in Table 3.1-1c.

The analysis of the atmospheric barometric pressure response led to computed values for the pneumatic diffusivity, which is equal to the transmissivity divided by the storativity. Because there is no measurement of the actual air flow rates involved, it is not possible to uniquely separate the effects of these variables. In addition, the actual flow patterns are complicated by three-dimensional flow effects, including influences from faults, outcrops, and horizontal flow. Even so, the differences between the computed diffusivities indicate permeability in the unsaturated zone varies by several orders of magnitude.

Vacuum tests were conducted in UE-25 ONC#1 in conjunction with gas sampling efforts in June 1997. The vacuum test analysis included the effects of wellbore storage, skin effect, well loss effect, and both cylindrical and spherical flow. Test results presented in Table 3.1-1c indicate generally larger permeability in the faulted Calico Hills non-welded unit (depth of approximately 1,200 ft [366 m]) than in the TSw unit (depth of between 650 and 1,200 ft [198 and 366 m]). A similar trend is found in atmospheric barometric pressure response test results for pneumatic diffusivity in Table 3.1-1a. DOE data from other wells generally show the opposite trend (DOE, 2000a); however, the proximity of the pressure probes to the Bow Ridge fault may be responsible for the observed higher permeabilities in the Calico Hills non-welded unit.

3.1.2 Environmental Tracer Gas Analyses in UE-25 ONC#1

Nye County collected and analyzed gas samples from the vadose zone in UE-25 ONC#1 on three different occasions to establish background conditions and to evaluate changes (if any) in the chemical composition of the gases. Over time, chemical composition changes may be used to evaluate impacts of ESF construction and to obtain transport properties of the rock mass. In addition, the sampling and analysis of isotopes, such as carbon-14 and tritium, in gas samples was conducted to provide insights into unsaturated zone water age dates and gas transport mechanisms in the unsaturated zone.

Environmental chemicals (e.g., fluorocarbons) and isotopes (e.g., carbon-14, carbon-13, and tritium) were introduced into the ESF tunnel from the atmospheric air pumped through the tunnel ventilation system. Concentrations of these compounds in the tunnel are similar to atmospheric concentrations. These gases are transported from the tunnel into the unsaturated zone by advective, dispersive, and diffusive processes. Once the pre-excavation concentrations of these compounds were established at UE-25 ONC#1 by sampling and analyses (Tables 3.1-2 and

3.1-3), future changes in the chemical composition of the pore gas with time can be analyzed to evaluate the arrival of these environmental tracers in UE-25 ONC#1.

3.1.2.1 Gas Sampling Approach

Gas sampling was conducted in UE-25 ONC#1 in October 1996, June 1997, and April 1998 to establish pre-ESF excavation concentrations of a number of potential tracer compounds. The October 1996 samples were tested for carbon-14, tritium, and CFCs. The detection limit for CFC was too high in the first sampling effort, so the sampling and analysis effort was repeated in June 1997 with much lower CFC detection limits. The June 1997 analysis also included many compounds not tested for in October 1996, including methane, carbon dioxide, carbon monoxide, nitrous oxide, trichloroethane, carbon tetrachloride, nitrogen, oxygen, and deuterium. Additional sampling conducted in April 1998 included carbon-14 samples from the two ports near the Bow Ridge fault intersected by UE-25 ONC#1 at a depth of about 1,150 to 1,200 ft (350 to 366 m) to confirm results obtained in previous sampling events.

The sampling procedure consisted of opening a small sliding sleeve in the Westbay® downhole string and exposing a short (1-ft-long [0.305-m-long]) screen. Vacuum was applied at the well head and samples were collected using pre-vacuumed canisters, Tedlar bags, microsieve pellets, and cold distillation traps (NWRPO, 1998). Preliminary results from all three sampling events indicated this sampling method is efficient and produces results comparable to results of other unsaturated zone sampling techniques used at the Yucca Mountain site (Yang et al., 1996). Selected results are briefly presented and discussed in the following section.

3.1.2.2 Discussion of Selected Results

Tables 3.1-2 and 3.1-3 summarize the results of the analyses (with the exception of tritium) conducted on the June 1997 samples. Analytical results for tritium were below detection limits (NWRPO, 1998).

Several interesting trends can be observed in Tables 3.1-2 and 3.1-3. For example, in Table 3.1-2, carbon dioxide concentration increases between the atmosphere and the 638 ft (194 m) sampling depth, decreases in the region of the fault zone at 1,150 and 1,195 ft (350 and 364 m) sampling depths, and increases again at 1,225 ft (373 m). Although an increase in carbon dioxide with depth has been observed in other boreholes at Yucca Mountain (Yang et al., 1996), the decrease at the fault zone seems to be an anomaly. Reasons for this trend are not known at this time.

Table 3.1-2 also shows that concentrations of CFC in the ESF tunnel were similar to atmospheric concentrations, as was expected. Although this table also shows a general decrease in CFC concentration with depth in UE-25 ONC#1, it is important to note that there were still significant concentrations of CFCs at more than 1,000 ft (305 m) below ground surface. The diffusion and advection of modern gases (CFCs) to depths greater than 1,000 ft (305 m) indicates that the Yucca Mountain vadose zone is a pneumatically open system in direct communication with atmospheric air. These results also indicate that CFCs are good tracers for the transport of atmospheric gases in the vadose zone of Yucca Mountain.

Data in Table 3.1-2 also indicate that trichloroethane is the best tracer for unsaturated zone gaseous migration studies. Trichloroethane was absent in the unsaturated zone samples. However, its concentration was elevated in the ESF, probably as a result of the use of aerosol sprays in the tunnel. Its concentration in the atmosphere was an order of magnitude lower than that in the ESF.

Carbon-14 activity was significantly depleted, being less than 52 percent of modern values at depth (Table 3.1-3). This might indicate that the carbon dioxide in the air of the vadose zone is in equilibrium or partial equilibrium with aqueous-phase carbonates. If carbon dioxide in the gaseous phase were not in equilibrium with the liquid phase, the carbon-14 activity should have been close to 100 percent of modern activity, because the level of CFCs present at depth indicates the air at that location is much less than 100 years old. If the gas-phase carbon-14 activity is representative of the rock-moisture liquid phase, the inferred age of water in the TSw unit would range from approximately 5,000 to 8,000 years. Carbon-14 movement, depletion, and isolation can result from other factors as well, so alternative explanations are possible.

3.1.3 Subsurface Data from the Exploratory Studies Facility and the Enhanced Characterization of the Repository Block Tunnel

Nye County also installed instruments to measure temperature, pressure, humidity, and wind speed within the ESF and the ECRB tunnels. These data were collected and analyzed to evaluate the effect of ventilation air on removing moisture and heat from repository rock. These data have important implications for designing a ventilated repository. Nye County QA verification requirements have not been conducted for these data. Therefore, analyses and interpretations presented in the following section should be considered preliminary.

Figure 3.1-5 shows the location of the probes in the ECRB. Figures 3.1-6a through 3.1-6c show samples of data collected during construction of the ECRB from Nye County instruments located in the ECRB tunnel. At the same time that Nye County was collecting these data, matric potential data were collected using heat dissipation probes installed at various depths in the ECRB tunnel wall by the USGS (personal communication to the NWRPO [Muirhead, 1999]). Both Nye County and the USGS continued to collect these data after the completion of the ECRB. Nye County plans to analyze these data rigorously in the near future.

As expected, the air velocity near the center of the ECRB tunnel is generally larger than near the wall. The differences in relative humidity and temperature between the probe near the wall and probes away from the wall were not as significant as those observed in the ESF. This indicates the importance of the size of the opening in the thermal and moisture concentration gradients. These gradients are important in determining the mass and energy transfer parameters.

Of particular interest is the change in temperature and relative humidity as a result of variation in the air flow velocity. On June 23, 1998, a sudden increase in the air flow seems to have caused a significant drop in temperature and an associated increase in relative humidity. However, a similar increase in flow late on June 24, 1998, resulted in an opposite response in temperature and relative humidity. A slight drop in humidity late on June 22, 1998, cannot be explained, as the ventilation system was shut down during that time. Nye County plans to attempt to identify the cause of these and similar variations in ECRB data in preparation for future extensions of detailed natural ventilation modeling described in Section 3.2. Calibration to date of the simple ventilation models described in Section 3.2 has been accomplished using the ESF data alone.

3.1.4 Petrographic Analyses

Petrographic analyses were used to evaluate past and present fluid transport pathways in tuff. Scanning electron microscope (SEM), SEM with energy dispersive X-ray, SEM with cathodoluminescence, and standard optical petrographic analyses were conducted to obtain textural and mineralogical data on matrix and fracture lithologies. Twenty-nine drill cuttings samples from UE-25 ONC#1 at depths from 208 to 1,432 ft (63.4 to 436.5 m) below ground surface were analyzed. Details of the analyses, results, and interpretations are presented in two reports (Morgenstein, 1998a, 1998b).

The results and interpretations presented here are based on analysis of drill cuttings from a single well, and may not be representative of larger-scale samples or other locations at Yucca Mountain. Analysis was performed only on samples of welded and poorly welded tuffs. The samples from non-welded tuff units were ground into powder during drilling and were unsuitable for analyses. It was assumed that past authigenic mineral-forming events were controlled by fluid-rock interactions, so that current mineralogy is an indicator of past fluid transport at Yucca Mountain.

Diagenetic events identified in this study are summarized in Table 3.1-4. These events produced distinct mineral associations primarily in fractures and in the matrix near fracture walls. Authigenic mineralization occurred at locations where fluids existed with unstable syngenetic minerals and glass. Because fracture systems in welded tuffs host much of the authigenic mineral deposits, it is concluded that much of the fluid transport in welded tuffs occurred through fractures.

Petrographic observations of the spatial distribution of authigenic minerals also suggest that fluid transport in the unsaturated and saturated zones is mostly through fractures. Fluid transport caused weathering along fracture walls and formed high-porosity bleached zones (Figure 3.1-7). Authigenic minerals then formed within these higher porosity zones from mobilized ionic species made available by the dissolution reactions. Different authigenic mineral associations thus formed as a function of unsaturated and saturated zone transport, and filled matrix pores and fractures. Quartz and its polymorphs are mostly associated with fracture-filling events. Quartz is observed filling pores, but only where those pores are connected to a fracture. Transition metal oxyhydroxides, however, are observed filling both fractures and pores.

In general, the authigenic mineral products formed in response to weathering reactions were phyllosilicates with significant cation exchange capacity, transition metal oxides and oxyhydroxides with surface-sorption capabilities, and quartz and its polymorphs, which have negligible sorption capacity. Subsequent mineralization formed higher sorption capacity minerals, such as smectites and zeolites.

Significant selective radionuclide retardation due to sorption and filtration should occur in flow through intervals with bleach zone fractures. Insufficient information exists to determine the proportion of fractures that have this bleach zone morphology. Non-bleach zone fractures may also contribute to radionuclide retardation by sorption if their surface-coating minerals are oriented with appropriate sorptive crystal faces exposed to the transporting fluids. In many cases, however, the sorptive minerals are not appropriately oriented or are coated by opal or other non-sorptive minerals.

3.2 NATURAL VENTILATION NUMERICAL MODELING

The location of the proposed repository at Yucca Mountain is shown in Figure 3.1-1. Current plans for the repository involve a pre-closure period of approximately 100 years, after which the repository excavation will be back-filled and closed (DOE, 2001). DOE YMP calculations and computer simulations predict temperatures after closure will be elevated to near boiling, accompanied by high humidity conditions. Such conditions may have unpredictable consequences in terms of flow and transport of radionuclides through the unsaturated zone, and might adversely affect the stability of the engineered barrier system.

Nye County has conducted preliminary simulations to investigate alternative designs to alleviate the high temperature and humidity conditions. These simulations suggest that natural ventilation can remove substantial amounts of moisture from the drift walls in a very short period of time, leading to a cooler, drier repository design, especially during the first 1,000 years. As a result, Nye County believes that ventilation is a key design and operation feature that may reduce uncertainty in repository performance and safety-related demonstrations.

3.2.1 Modeling Methods and Results

Nye County conducted numerical simulations of air, liquid, and heat flow in a naturally ventilated tunnel and adjacent repository host rock in two phases using the computer code A-TOUGH© (MET, 1995).

A-TOUGH© simulations were initiated using an axisymmetric grid mesh. Figure 3.2-1 is a schematic diagram of this model. The emplacement tunnel was assumed to be horizontal. Gravity effects were ignored and fluid flow was assumed to be caused solely by pressure gradients. Because of the strong influence of the ventilation flow, the error introduced by ignoring the gravitational force was small. The axisymmetric mesh simulates a 560-m-long portion of an emplacement drift in the proposed repository. It consists of 16 cylindrical slices, with 20 concentric cylinders in each slice. The first five cylinders represent the tunnel, and other cylinders represent the surrounding wall rock. The axisymmetric mesh model indicated that natural ventilation held considerable promise for cooling and drying the repository (NWRPO, 1996, 1997).

A more comprehensive model was then prepared based on the three-dimensional unsaturated zone site-scale model (Bodvarsson and Bandurraga, 1996). A series of nodes representing the ESF and a conceptual repository was used, and four shafts were added for ventilation. An oblique view of the model mesh is shown in Figure 3.2-2. The spatial distribution of simulated saturations after 1,000 years is shown in Figure 3.2-3, and temporal variations in temperature with distance away from the tunnel wall (into the rock formation) are shown in Figure 3.2-4.

In both the axisymmetric and three-dimensional model simulations, rock properties were assumed to be fixed, based on previous studies (Bodvarsson and Bandurraga, 1996). Ventilation air flow velocity was assumed to be 1 m/s. The only parameter varied in these simulations was eddy diffusivity, which determines the coefficient of turbulent heat and mass transfer between the host rock and the tunnel air. The models are very sensitive to this parameter.

The results of the three-dimensional model confirmed the conclusions of the axisymmetric model (NWRPO, 1998). The ventilation modeling suggests that natural ventilation can greatly reduce the temperature and moisture conditions of the repository. DOE is now considering the possible use of ventilation (natural or forced) as a repository design alternative.

3.2.2 Calibration and Comparison with Monitoring Data

True calibration was not possible with either model because the required data set is not available. Such data would include accurate ventilation air flow and temperature measurements in an open tunnel, coupled with temperature and moisture conditions in rock adjacent to an open tunnel. It would be necessary to make such measurements at a series of elevated temperatures and ventilation rates. The only data available for a partial ventilation model calibration at Yucca Mountain were the limited set of ESF and ECRB measurements collected by Nye County. These data include air velocity, pressure, relative humidity, and temperature measurements at various points in the tunnel.

Figures 3.2-5 and 3.2-6 compare simulated and measured temperature and humidity values during a weekly work cycle in the ESF. During the work week, ventilation started early Monday morning and shut down late Friday evening. The cooler and drier outside temperature during September lowered the temperature and humidity in the tunnel. During weekends, the air approached equilibrium with the rock temperature and humidity. The simulations reasonably predict the response of measured values of humidity and temperature to ventilation.

Figure 3.2-5 compares simulated and measured relative humidity data during the last week in September 1995. At that time, humidity was being measured at ESF Station 20+00, which is 2,000 m from the North Portal. Simulated humidity values shown in Figure 3.2-5 are for locations 101, 141, and 181 m from the portal. Best agreement between observed and measured values was obtained for the simulation located 141 m from the portal.

Figure 3.2-6 compares simulated and measured temperature data for the same week in September 1995. Simulated temperature values shown in Figure 3.2-6 are for locations 0.5, 21, and 101 m from the portal. Again, actual temperatures were measured 2,000 m from the portal. Best agreement between observed and measured values was obtained for the simulation located 21 m from the portal.

The reasons for better agreement in simulations of humidity and temperature at points located closer to the portal than further away are likely related to the differences in the initial modeling conditions (initial temperature of 25 °C, a host-rock matrix saturation of 80 percent) and actual conditions (cooler and moister) in the tunnel after 9 months of excavation. Differences in simulated and observed values are discussed further in NWRPO (1998).

3.3 UNSATURATED ZONE CONCEPTUAL MODEL EVALUATION AND REVISION

The YMP has performed extensive studies of flow and transport in unsaturated fractured rocks in the area of Yucca Mountain. However, numerous questions still remain unanswered or are debatable. Some important unresolved repository performance issues from Nye County's perspective include:

- Mechanisms and magnitude of infiltration into exposed fractured rocks, as compared to infiltration into rocks covered by alluvium
- The role of psychrometric processes in controlling interactions between tunnels and fractures
- The mechanisms of the shadow effect in fractured rock.

The first issue will be briefly addressed below. The second issue is being addressed through Nye County's ventilation numerical modeling efforts described in Section 3.2. The third issue is being addressed through YMP modeling efforts.

The DOE YMP calculates net infiltration by a form of coupling between atmosphere and soil moisture, and energy transfer at the ground surface (DOE, 2000b). This net infiltration is then applied as a flux boundary in the unsaturated zone flow model (Bodvarsson and Bandurraga, 1996). Nye County believes that the YMP approach to calculating net infiltration may result in unreasonably high infiltration rates for present and future climates. Moreover, these potentially overly conservative infiltration values may cause the YMP to implement unnecessary and overly costly protective measures (i.e., additional engineered barrier components) that could jeopardize other important safety aspects of the program (i.e., providing better transportation safety or increasing stability of open tunnels so that the length of time the repository is open and ventilated can be extended). The following section briefly describes simple calculations that suggest that YMP net infiltration rates used in unsaturated zone flow models are unreasonably high in value. Additional work that should be done to resolve this issue is outlined in Section 3.3.2.

3.3.1 Evaluation of Percolation Calculations of Net Infiltration at Yucca Mountain

In order to illustrate the problem, a simplified example based on order-of-magnitude estimates of several key parameters is presented below. This example demonstrates some of Nye County's concerns with the YMP percolation calculations.

Pertinent YMP matrix and fracture properties, as well as net infiltration rates (percolation fluxes) for the TSw unit used in YMP unsaturated flow and transport models, include the following:

- Matrix permeabilities in hydrostratigraphic units TSw34, TSw35, and TSw36 (about the repository horizon) range from about 1×10^{-19} to 1×10^{-17} m^2, or in hydraulic conductivity units, from about 9.8×10^{-11} to 9.8×10^{-9} cm/s (3.09×10^{-2} to 3.09 mm/yr.) (DOE [2000a, Table 3]).
- Fracture permeability values range from 1×10^{-13} to 1×10^{-12} m^2 or 9.8×10^{-5} to 9.8×10^{-4} cm/s (3.09×10^4 to 3.09×10^5 mm/yr.) (DOE [2000a, Table 3]).

- Fracture frequency is reported in the same table to be about 4/m for these hydrostratigraphic units (DOE [2000a, Table 3]).

- Percolation fluxes are calculated to average about 2, 7, and 12 mm/yr. for the present-day climate lower-bound, mean, and upper-bound infiltration scenarios, respectively (DOE [2000c, Figures 6-11, 6-12, 6-13]).

- Percolation fluxes calculated based on various climate conditions average about 20 and 30 mm/yr. for monsoon and glacial transition, respectively (DOE [2000c, Figures 6-11, 6-12, 6-13]).

The example is conceptualized in Figure 3.3-1, which shows a simplified model of fractured tuff. In this example, the vertical flux is equivalent to hydraulic conductivity assuming a unit vertical hydraulic gradient. The matrix is assumed to have a hydraulic conductivity of 1 mm/yr. (3.15×10^{-9} cm/s), which is near the upper bound for matrix permeability reported above. Accordingly, the maximum flux through the matrix under a unit vertical hydraulic gradient is 1 mm/yr. Percolation flux in excess of the matrix flux capacity must flow through the fracture system. A percolation flux of 2 mm/yr. would then be split into a 1 mm/yr. matrix flux and another 1 mm/yr. flux through vertical fractures. Assuming a cubic law relationship between fracture aperture and permeability (Bear et al., 1993), an effective porosity of 0.0008 is calculated using a fracture permeability of 1×10^{-12} m^2. The actual velocity of a particle in the fluid is obtained by dividing the fracture flux (1 mm/yr.) by the effective porosity (0.0008), which yields a particle velocity through the fractures of 1,250 mm/yr. This is the velocity that must be attained in order for 1 mm/yr. of excess flux to flow through these vertical fractures intersecting the example block of rock. Moreover, this is the rate at which water must enter and/or exit a vertical fracture annually.

Estimates of this type are useful for providing reasonable bounds on parameters, but should not be considered exact values, because they do not include all potentially relevant factors. For example, the incorporation of fracture roughness or aperture variation would require greater computed porosity for the specified permeability, and would therefore lead to a lower fluid velocity. Alternatively, the consideration of flow through partially saturated fractures or fast pathways could lead to even higher fluid velocities. The purpose of these calculations is not to determine an exact answer, but rather to identify the correct conceptual order of magnitude.

Using this same conceptual model for the division of flow between the matrix and fractures, particle velocities through the fracture network were calculated in Table 3.3-1 from percolation rates, effective porosity, and matrix permeability values presented in various YMP analysis and modeling reports (e.g., DOE [2000a, 2000b, 2000d]; Bodvarsson and Bandurraga [1996]) as summarized above. Fluid velocities were calculated in this table by subtracting the matrix hydraulic conductivity value (equal to matrix flux assuming a unit hydraulic gradient) from the infiltration/percolation rate (for different climates) and then dividing this result by the effective porosity.

The calculated fluid velocities through the fractures in Table 3.3-1 are very high for present-day climate upper-bound percolation fluxes and even higher for extreme climate percolation fluxes. For example, in the present-day climate upper-bound infiltration scenario, there is 4 mm/yr.

excess water flux. In this case, the fluid velocity through the fractures would be as much as 22 m/yr. Similarly, in the glacial transition scenario, fluid velocities through the fractures would be 25 to 50 m/yr.

It is likely that such velocities over thousands of years would have created many perched zones in dead-end fracture systems. Considering that flow through fractures is not uniform, certain portions of the system would be expected to carry much higher fracture velocities than calculated. Considering the sheer number of fractures that are present, many visible seeps should have been observed in the ESF and/or the ECRB. The number of potential dead-end fracture systems is so large as to make it unlikely, statistically, to have missed such features considering the number of dry drifts and niches that have been constructed at the site. Even so, only one wet fracture has been reported (Hinds and Bodvarsson, 2001) in one of the alcoves in the ESF, and it is not certain whether the water in this fracture is a result of percolation or water usage during the ESF construction. It therefore appears likely that other factors not yet accounted for are influencing the net flux through the fracture system at Yucca Mountain. Possible explanations include lower fluxes than the current estimates, greater concentration of percolation flux through a smaller number of fractures (therefore more difficult to observe), or even effects related to tunnel construction, ventilation, or operation.

3.3.2 Proposed Additional Work to Reduce Error in Yucca Mountain Project Percolation Rates

Future work is needed regarding the net infiltration rate calculations. A coupled atmospheric-soil code (e.g., A-TOUGH© [MET, 1995]) will provide more realistic estimates of infiltration. A-TOUGH© not only considers the thermodynamic processes of the boundary layer near the ground surface, but also allows these processes to determine the amount of net flux that could percolate deep into the unsaturated zone. There is no forced fixed flux in this type of simulation, as has been the case with the YMP calculations. The YMP calculation is restricted to the near surface and there are no provisions for it to allow reversal of flow in the unsaturated zone during extended dry climates, which have likely occurred in the past and will likely occur in the future at Yucca Mountain.

4.0 SATURATED ZONE STUDIES

Nye County saturated zone studies have been conducted primarily under the EWDP. This program has focused on the hydrogeologic characterization of the saturated zone in the area between Yucca Mountain and the potentially-affected environment of Amargosa Desert.

The following sections provide a summary of the EWDP and related studies. First, an overview of the EWDP, its goal and objectives, and its overall scope are summarized (Section 4.1). Details are then provided on EWDP well drilling and construction (Section 4.1.1), logging (Sections 4.1.2 and 4.1.3), aquifer testing (Section 4.1.4), water chemistry sampling and analysis (Section 4.1.5), water level monitoring (Section 4.1.6), petrographic and geochemical analyses (Section 4.1.7), and preliminary conceptual hydrogeologic model development (Section 4.1.8). Several related studies are then described, including investigations at the Alluvial Testing Complex (ATC) (Section 4.2) and modeling-related studies of an expanded EWDP area, including most of Amargosa Desert (Section 4.3).

4.1 EARLY WARNING DRILLING PROGRAM

The purpose of the EWDP is two-fold: (1) to develop the capability of an early warning groundwater monitoring network between Yucca Mountain and populated (or potentially populated) areas of Amargosa Desert, and (2) to fill in hydrogeologic data gaps in this area and reduce uncertainty in DOE YMP saturated zone performance assessment models. The justification and specific objectives for this program are outlined below.

It is the policy of Nye County to protect the health, welfare, and economic well-being of the county and its residents. All water supplies in southern Nye County are derived from water wells or groundwater that discharge to the surface at springs. To ensure public health, these water supplies must be protected in full compliance with state and federal requirements. Since the DOE's performance assessment models indicate that releases from the repository may occur and that groundwater contamination may result, the NWRPO EWDP has undertaken to install a network of strategically-placed monitoring wells along potential pathways for contaminant transport downgradient of Yucca Mountain.

In addition, prior to the initiation of the EWDP, basic geologic and hydrologic data were lacking for a large area in the vicinity of Yucca Mountain. Past studies conducted by the DOE concentrated on characterizing the conditions in the immediate vicinity of the proposed repository site. The *Yucca Mountain Site Characterization Project Site Atlas 1997* (DOE, 1997c) shows an area of roughly 350 mi^2 (906.5 km^2) where basic hydrologic data are lacking. These same data deficiencies were also found in Nye County's geologic database (described in Section 2.4.1). The "data gap," or "area of uncertainty," as it has come to be called, encompasses portions of southern Jackass Flats, southern Crater Flat, western Rock Valley, and northern Amargosa Desert. Nye County determined the need for data collection in these basins to identify and evaluate the geologic and hydrologic conditions and the risks associated with disposal of wastes at Yucca Mountain. The EWDP was designed to meet the need for additional data in these areas.

The specific technical objectives of the EWDP are as follows:

- Develop the capacity to detect potentially contaminated groundwater that may travel from the Yucca Mountain repository site to aquifers and discharge areas of the Amargosa Desert.

- Identify and assess potential preferential pathways for the movement of groundwater and solutes between the Yucca Mountain site and the aquifers and discharge areas of the Amargosa Desert.

- Evaluate the potential interactions between groundwater/solutes and geologic media between Yucca Mountain and the aquifers and discharge areas of the Amargosa Desert.

- Collect and evaluate hydrogeologic data necessary to refine the geologic and hydrologic conceptual models between Yucca Mountain and the aquifers and discharge areas of the Amargosa Desert.

- Provide quantitative and comprehensive baseline data sets on the subsurface geologic and hydrologic conditions and properties downgradient of Yucca Mountain.

- Generate the field and laboratory information needed to allow better definition of the actual threat to drinking water supplies and to reduce the uncertainty in risk assessments and contaminant transport predictions.

Figure 4.1-1 shows locations of the wells that were completed during EWDP Phases I and II, which were conducted in 1998-1999 and 2000-2001, respectively. In total, eight monitoring wells, nine piezometers, two deep exploratory boreholes, and three conductor casings were drilled, constructed, and tested (where applicable) at 12 locations. Some of the wells were completed in a single zone or horizon, while others were completed in a manner that allows for monitoring pressure, temperature, and water chemistry from several horizons within a single well.

Phase III EWDP well drilling, construction, and testing is scheduled to be completed in 2001. Up to seven monitor wells and three piezometers are scheduled to be installed at four locations along Fortymile Wash between Highway 95 and Yucca Mountain.

4.1.1 Well Drilling and Construction

This section summarizes the methods and procedures used in drilling and constructing Phase I and II EWDP wells. Table 4.1-1 provides information on the drilling method and the well type, depth, diameter, and completion for each well. More detailed information, including the as-built drawings for EWDP wells, is available at www.nyecounty.com (Nye County, 2001).

4.1.1.1 Coring and Drilling Methods

As noted in Table 4.1-1, five drilling and coring and methods were used during EWDP Phases I and II:

- Diamond drill coring
- Percussion hammer drive coring
- Dual-wall hammer drilling with casing advance
- Dual-wall reverse-circulation air-rotary
- Reverse-circulation flooded-mud rotary.

Diamond drill coring was performed at NC-EWDP-1D and -9S using HX rod (3.8 x 2.4 in. [9.652 x 6.096 cm]) with a wireline retrievable core tube. This method was selected to obtain samples of paleospring deposits at these locations. Core recovery was limited because of the very fine-grained and friable nature of the deposits.

The dual-wall hammer drilling with casing advance method was well suited for the drilling and completion of small diameter boreholes in unconsolidated or weakly-consolidated formations. The main advantages of this method are its speed, ability to advance through unstable materials, production of high quality samples for geologic logging, and the capability to clearly define the first occurrence of groundwater. The primary disadvantages of this method are borehole deviation, the refusal of the bit to advance in harder formations, and depth limitation of 500 to 800 ft (152.4 to 243.8 m), depending upon the diameter of the drill casing.

The dual-wall hammer-drill method was used for most of the EWDP piezometers. A dual-wall drill pipe (9 in. [22.7 cm] or 11 in. [27.9 cm] in diameter) was fitted with a simple open face bit. The bit and drill pipe were advanced using a top-drive diesel hammer. Compressed air was circulated to the bit through the space between the dual walls of the drill pipe. The air forced the cuttings to the surface through the inner drill pipe. As the borehole advanced, additional joints of drill pipe were added to serve as temporary casing. This method produced samples with minimal contamination from outside the sample interval. Drill cuttings were blown to the surface into a standard air cyclone separator, and then into collection buckets. With each 5 ft (1.5 m) of casing advance, the percussion hammer was stopped, air was circulated to remove the cuttings, and the drill cuttings were sampled, described, and packaged.

At NC-EWDP-9SX, the hammer drill method was modified to obtain drive samples. A split spoon sampler was used to obtain core samples of the upper 77.7 ft (23.7 m) of paleospring deposits. The sampler was "pushed" down 1 to 2 ft (0.3 to 0.6 m) using the percussion hammer. The split spoon sampler was retrieved, the sample was removed, and the process was repeated. Total core recovery was only 3.4 ft (1.04 m) and samples were generally highly disturbed.

The dual-wall reverse-circulation air-rotary method was used for drilling both shallow and deep monitoring wells. The advantages of this method are that it has a depth capability of 2,500 ft (762 m) or more, it produces high-quality samples, and it has rapid drilling speed in hard formations. Disadvantages include borehole deviation, difficulty maintaining circulation in unconsolidated zones, and sample contamination by materials dislodged from the previously drilled portions of the borehole.

In this method, a dual-wall drill pipe fitted with a tricone bit was advanced by rotary drilling. Compressed air was circulated downward through the space between the inner and outer drill pipe and the cuttings were blown through the inner pipe to the surface. Samples were again collected at 5-ft (1.5-m) intervals after discharging into an air cyclone separator and passing through an Anaconda rotating splitter. Upon drilling to the target depth, a suite of geophysical logs was run. The borehole was then enlarged with an 11-in. (28-cm) reaming bit to facilitate well completion.

At NC-EWDP-2DB, the dual-wall reverse-air method was modified to use flooded-mud reverse circulation. The modification consisted of adding an air-jet sub in the drill string to allow air from the outer drill pipe into the inner drill pipe to lift the drilling fluid and cuttings to the surface. Using this drilling system, a 14.75-in. (37.5-cm) hole was advanced inside the previously installed conductor casing to 2,475 ft (754.4 m) and then reduced in diameter to 9.875 in. (25.08 cm) to a total depth of 3,075 ft (937.3 m). The borehole was then reamed out to 14.75 in. (37.5 cm) from 2,475 to 2,700 ft (754.4 to 822 m) and cased to that depth. The final clean-out of the open-hole section of the well was started but not completed.

Conventional flooded-mud reverse-circulation rotary drilling equipment and methods were used for drilling and setting conductor casings at planned deep monitoring wells and test wells. Conductor casings were installed by first drilling a smaller diameter (19.5 in. [49.5 cm]) pilot hole and then reaming the borehole to 26 to 48 in. (66.04 to 121.9 cm) in diameter with a hole-opener bit. The flooded-mud reverse-circulation method used single wall drill pipe with rotary tricone bits and a drilling fluid of water and bentonite. The drilling fluid was mixed in a mud pit and flooded down the annular space between the borehole and the drill pipe. The drilling fluid washed the borehole and circulated the cuttings upward through the center of the drill pipe. The fluid was circulated by pumping air through an airline into the drill pipe below the fluid level, essentially air-lifting the drilling fluid to the surface. Samples from this method were contaminated with drilling mud and potentially with material dislodged from upper portions of the borehole.

The advantages of the flooded-mud rotary method used in conductor boreholes and in NC-EWDP-2B over air methods described previously are the increased speed of drilling, increased borehole stability, and reduced borehole deviation. The disadvantages are the contamination of samples with the mud drilling fluid and increased difficulties in drilling through lost circulation zones.

4.1.1.2 Well Completion Methods

Three basic types of EWDP wells were constructed during Phases I and II: piezometers, shallow monitoring wells, and deep monitoring wells. Piezometers are small-diameter wells screened over a limited depth interval that permit measuring potentiometric heads and collecting water samples, but are too small in diameter to conduct standard aquifer tests. Shallow and deep monitoring wells share some design features but employ different sizes and depths of conductor and well casings. Table 4.1-1 provides summary information on each well completion. Figures 4.1-2, 4.1-3, and 4.1-4 show typical well completion diagrams for each basic type of well. As-built drawings for the EWDP wells are maintained on the Nye County web site (www.nyecounty.com; Nye County, 2001).

Steel casing was used in all EWDP wells, except for the Phase I piezometers at NC-Washburn-1X, -5S, and the shallow piezometer in -1DX, where polyvinyl chloride casing was used. Machine-slotted casing with 0.020 in. (0.051 cm) slot sizes was used as well screen. The casing was flush threaded, except at NC-EWDP-2DB, where threaded and coupled casing joints were required to provide the additional strength needed for safe casing installation. Ten-foot (3.05-m) nominal blank casings and bottom caps were included in each casing string, except at NC-EWDP-2DB and -3S below 295 ft (89.9 m), which is an open borehole completion below a depth of 2,685 ft (818.4 m). The blank casing at the bottom serves as a sediment trap to prevent plugging of the lowermost screen. All well construction was in compliance with the Nevada Division of Water Resources (1998) requirements for monitoring wells.

After the casing string was installed in each EWDP well, sand or gravel packs were emplaced around well screens, typically with a tremie line. The sand or gravel pack (#8/12 mesh material) was installed at least 5 to 10 ft (1.5 to 3 m) below and above the screened interval and was typically installed much further above the well screen. In some instances, fine-grained sand (typically #60 mesh) was emplaced in the uppermost part of the sand pack to prevent downward migration of grout into the sand pack. Seals comprised of bentonite, cement, or a cement/bentonite grout mixture were then emplaced between the sand packs. The annular space between the top sand pack and land surface was then sealed with bentonite or cement grout. After the grout seals had set, the well was developed using airlift techniques. In some instances, the inside of a casing was agitated using a swab. The well was developed until the discharged water was relatively clear of sediment and a protective well pad, traffic posts, and protective locking vault or protective surface casing were installed.

The final step in well construction was the instrumentation of selected wells with Westbay® monitoring equipment. This equipment is comprised of a modular casing system that allows multiple monitoring zones to be established in a single borehole or well. The system is essentially a string of ports, packers, and separator casings. Couplings with separate valved ports for pressure monitoring and temperature monitoring, and groundwater sampling were placed opposite the screened intervals in the well. Packers were placed adjacent to the sections of blank casing above and below each screened interval. The only exception occurred in NC-EWDP-3S, where three packers were located in the open uncased portion of the borehole to isolate the monitoring interval. The packers were then inflated with water to seal the packer against the inner wall of the well casing, preventing vertical flow between monitoring zones. Quality control tests were conducted for each monitoring zone to confirm the performance of the packers. A probe cable containing pressure and temperature sensors for continuous monitoring of screened intervals was then installed in the well. Groundwater sampling ports opposite screened intervals have sliding sleeve valves that can be independently opened for each zone to allow purging and sampling.

A report was prepared for each monitor string installation. These reports document the installation process, the final packer and port settings, and the quality control testing. Summary completion diagrams are posted on Nye County's web page (Nye County, 2001) and the full reports are maintained in Nye County's QA Program files.

4.1.2 Geophysical Logging

One or more suites of geophysical logs was run in each EWDP borehole using down-hole wireline techniques. Four general categories of logs were run:

- Logs run through the drill pipe during drilling operations (cased logs)
- Logs run in the open borehole (standard logs)
- Logs run in wells after construction and development (completion logs)
- Spinner flowmeter logs run prior to and during aquifer tests.

The methods and geophysical tools used at a given well or borehole depended on the log type needed, the borehole conditions, and technical considerations. A summary of the logs run in each EWDP location is provided in Tables 4.1-2 and 4.1-3. Logging was conducted in accordance with Nye County's *Early Warning Drilling Program Geophysical Logging Work Plan* (NWRPO, 2001a). Log results were provided in two formats: paper strip copies, and data files that are transportable into spreadsheets or commercially-available software packages for the display of logs. The EWDP Phase I and II geophysical logs are available on the Nye County web site (www.nyecounty.com; Nye County, 2001).

During the advancement of a borehole, selected geophysical logs were run inside the drill pipe. Cased logs were commonly collected in air reverse circulation and casing advance boreholes as a contingency against borehole instability and subsequent inability to log in the open borehole. These logs typically included a gamma-gamma density log, neutron moisture log, and a deviation log. These logs are capable of penetrating the drill steel and providing information on lithologic contacts, clay content, and the moisture in the formation. The deviation log measures both the hole deviation and azimuth of the borehole.

Where borehole conditions permitted, open hole logs were run to provide more detailed information on formation properties, borehole conditions, and aquifer characteristics. In general, open hole logging included the following: normal, lateral, and single point resistivity logs (commonly referred to as electric logs), natural gamma logs, spontaneous potential logs, fluid temperature and fluid resistivity logs, caliper logs, and deviation logs. In some instances, logs had to be "pieced" together; that is, multiple logs were run either as the borehole was advanced or as the drill pipe was being removed from the borehole after total depth had been reached.

After the wells were completed, spinner flowmeter logs were run during aquifer testing. Spinner logs provide a measure of fluid movement in cased/screened holes and are used to identify which intervals are more productive. Temperature logs were also run in some wells after the construction and testing was completed and the well, groundwater, and formation had been allowed to return (to the extent possible) to natural conditions. In some cases, temperature and/or spinner logs were run in open boreholes.

The suite of geophysical logs that were run in the EWDP boreholes and wells has many uses. The natural gamma ray, electric (spontaneous potential and resistivity), temperature, and caliper logs were used in conjunction with the detailed lithologic logs to determine appropriate settings for well screens and blank casing intervals, the location of sampling and pressure ports, and the total depth.

Figure 4.1-5 shows a comparison between the results of temperature logs for three EWDP wells along with the results of logs run in YMP boreholes near Yucca Mountain (Sass et al., 1988). The temperature gradients are much higher in the deep EWDP wells than in the boreholes near Yucca Mountain. It is possible that a shallow heat source associated with the Lathrop Wells volcanic center may be a contributing factor to these higher gradients. However, as discussed in more detail in Section 5.1, these higher temperature gradients more likely reflect the regional temperature regime. For example, at NC-EWDP-1DX, the temperature log confirms that warm water is upwelling via fracture flow and that the carbonate aquifer underlying the valley-fill sediments is the source of the warm water. This finding is consistent with a regional boundary in the thermal regime, probably represented by the shallowing of the carbonate rocks on the southern flanks of the deep Tertiary basin underlying Crater Flat and Yucca Mountain (see Sections 2.2, 2.3, and 5.1).

Figure 4.1-6 shows the natural gamma log for NC-EWDP-3D at two scales. The upper plot in this figure shows the entire logged interval. A pronounced increase in the gamma ray counts per second is apparent on this log between 490 and 510 ft (149.4 and 155.4 m). This anomaly came to be known as "the gamma spike." The lower plot on the right shows the interval between 485 and 515 ft (147.8 and 156 m) at an expanded scale. Upon this finding, Nye County selected samples from this horizon for detailed petrographic analyses. The results of these analyses, which are summarized in Section 4.1.7, found that the gamma spike is present because of low-grade uranium mineralization. Because of the gamma spike, a groundwater monitoring port was installed adjacent to this mineralized zone in adjacent NC-EWDP-3S. Any assessments of risks to groundwater receptors resulting from any potential releases from the proposed repository at Yucca Mountain must take into account naturally-occurring uranium in the groundwater.

4.1.3 Geologic Logging

This section is a summary of the geologic logging description of cuttings from the EWDP boreholes. Samples were collected and described in accordance with NWRPO QA TP-8.0, *Field Logging and Handling of Borehole Samples*, and the governing QAPP (NWRPO, 1999).

During drilling operations, lithologic grab samples were collected at 5-ft (1.524-m) intervals. Two approximately 8-lb (3.6-kg) split samples were collected where possible from each depth interval for Nye County and DOE YMP use. A small subsample split was taken from the Nye County sample for field descriptions and packaged in chip trays. The remaining Nye County sample was packaged in a pre-labeled bag and transported under chain-of-custody to the DOE's Sample Management Facility on the Nevada Test Site.

Detailed geologic logs were prepared in the field and described lithologic type, color, grain size, degree of cementation, acid reaction, and sedimentary fabrics. The detailed logs were scanned and are available on the Nye County web page (Nye County, 2001) for all Phase I and II EWDP wells. The detailed geologic logs were then used to prepare one-page summary logs. An example summary log for borehole NC-EWDP-3D is shown in Figure 4.1-7. The summary logs for other EWDP wells and boreholes are also available on the Nye County web page (Nye County, 2001).

After preparation of the summary geologic logs, Nye County categorized the units penetrated in the EWDP borings into informal hydrogeologic units for the valley-fill deposits, and formal units for the volcanic deposits and the sediments of Paleozoic age. The first step in categorizing the units was a thorough literature search that included published classification schemes (e.g., Winograd and Thordarson [1975] and the *Yucca Mountain Project Stratigraphic Compendium* [DOE, 1997d], and other sources). The second step was to participate in workshops with YMP representatives (the USGS, representatives from DOE's national laboratories) and other scientists, who provided chemical, physical, and geophysical data to support their assignment of formal units for the volcanic rocks and sediments that were penetrated. Nye County has adopted these assignments for the volcanic units.

Figures 4.1-8, 4.1-9, and 4.1-10 show hydrostratigraphic columns and summary descriptions for the valley-fill deposits, the volcanic rocks, and the Paleozoic and older units, respectively. Valley-fill deposits are grouped into seven units: alluvial deposits, fluvial deposits, marsh deposits, basalts, volcanic deposits, undivided Tertiary sediments, and lower valley-fill deposits. Volcanic rocks and deposits are grouped into five hydrologic units: upper, middle, and lower aquifers; and upper and lower confining units. The major Paleozoic and Precambrian rocks are categorized following the classification scheme developed by Winograd and Thordarson (1975).

There is some uncertainty regarding the assignment of samples to a specific hydrogeologic unit. As noted in the preceding section, some contamination of samples with sediments from overlying horizons may occur with some drilling methods. In some instances, such contamination may be readily apparent, but in other cases, it may be difficult to accurately determine whether contamination is affecting a sample. For example, when drilling through a conglomerate, the cuttings returned to the surface may include pieces of the clasts, the matrix, and contamination from above the horizon.

With two exceptions, Nye County's assignments of samples to specific units have agreed with those assigned by USGS scientists. In the first case, USGS interpretations of some volcanic rock samples suggest those samples are tuffs, while Nye County has interpreted the same samples as volcaniclastic sediments that were derived from the erosion and transport of the tuffs.

In the second case, the USGS indicated at a workshop in May 2001 that the top of Paleozoic rock in NC-EWDP-2DB is at a depth of 2,676 ft (815.6 m) in a quartzite of probable Devonian to Ordovician age. In contrast, Nye County logged a thick sequence of predominantly interbedded claystone, siltstone, and sand and gravel deposits from 1,205 to 2,685 ft (367.3 to 818.4 m), underlain by a conglomerate from 2,685 to 2,830 ft (818.4 to 862.6 m), a distinctive red clay at 2,830 to 2,835 ft (862.6 to 864.1 m), silty claystone from 2,835 to 2,850 ft (864.1 to 868.7 m), calcareous siltstone and sandstone with limestone interbeds from 2,850 to 3,000 ft (868.7 to 914.4 m), dolomitic sandstone and siltstone from 3,000 to 3,015 ft (914.4 to 918 m), and dolomite from 3,015 to 3,075 ft (918 to 937.2 m). The logged sequence of a conglomerate underlain by red clay is similar to the sequence mapped by Swadley and Carr (1987) as the contact between the Tertiary and Paleozoic rocks. The red clay horizon in NC-EWDP-2DB is underlain by a 15-ft (4.6-m) thick sequence of silty sandstone and a 150-ft (45.7-m) thick sequence of siltstone and sandstone with limestone interbeds, which in turn is underlain by massive dolomite with traces of fissile shale. This sequence of rock types corresponds to descriptions for the Smoky Member of the Nopah Formation, which indicated to the Nye County scientists that the top of the Paleozoic sequence at NC-EWDP-2DB may be the silty sandstone at a depth of 2,835 ft (864.1 m).

There are, however, alternative interpretations. The red clay and the underlying interbedded claystones, calcareous siltstones, and limestones could represent the earliest Tertiary sediments in the basin, roughly equivalent to the Horse Spring Formation. If this were the case, then the top of the Paleozoic rocks would be at a depth of 3,000 to 3,015 ft (914.4 to 918 m), either at the top of the dolomitic sandstone, or the top of the dolomite. Alternatively, the sequence of rocks might be overturned. Harris et al. (1994) and Grow et al. (1994) reported that the Paleozoic rocks in the Felderhoff 25-1 oil and gas exploration borehole (located about 9 miles southeast of NC-EWDP-2DB) are overturned with Upper Cambrian and Lower Ordovician rocks underlain by younger Ordovician rocks.

The differences in potential interpretations lead to greater uncertainty in the effectiveness of the saturated zone to retard or prevent fluid movement from Yucca Mountain to Amargosa Valley. If, for example, these beds were overturned, it would indicate a much greater degree of complexity than had been incorporated in the flow models.

Additional work will be needed before agreement is reached on the precise location of the Tertiary-Paleozoic contact and the assignment of formal stratigraphic units. Nye County is investigating the suitability of micropaleontology methods and chemical methods to further characterize the units. Future EWDP plans include cleaning out drill cuttings that remain in the bottom portions of NC-EWDP-2DB, and logging the lower portions of the borehole with a standard suite of geophysical tools and an optical televiewer log (water clarity and borehole conditions permitting). These additional characterization activities should help resolve outstanding uncertainties in assigning hydrogeologic units in the lower portion of this well.

4.1.4 Aquifer Testing

The NWRPO has tested seven wells through May 2001 in the EWDP. Analysis results for all seven wells and three interference (observation) wells are summarized in Table 4.1-4. The five well locations tested between Yucca Mountain and Amargosa Valley (NC-EWDP-1S, -3D, -3S, -7SC, and -9SX) are shown on Figure 4.1-1. The remaining two wells are located in central Amargosa Valley (Aeropark AD-2) and near the western edge of Amargosa Valley (Bond Gold Monitoring Well-13 [BGMW-13]).

The test results have been summarized at various technical meetings, including a peer-reviewed technical presentation/paper at the Society of Petroleum Engineers 2000 annual meeting (Cox et al., 2000) and the 1999 and 2000 meetings of the Devils Hole Workshop. The tests demonstrated generally high permeability in the valley-fill sediments and the volcanics. Flow barriers were inferred from the head response of several of the tests.

The presence of high permeability zones and flow barriers has important implications for conceptual geologic models of the aquifer system. High permeability zones that are continuous over significant distances can lead to rapid fluid movement through these zones. Barriers can cause flow to be locally channeled into the high permeability zones, again promoting rapid fluid movement. Low storage coefficients, such as the one inferred from the rapid interference response of the Garlic well to the Aeropark test (Table 4.1-4), also can promote high flow velocities. The combination of these factors suggests the aquifer system penetrated by EWDP boreholes is characterized by zones of rapid fluid movement, separated (at least in part) by various barriers or restrictions in the flowpaths.

Based on these test results, Nye County has developed a preliminary generalized conceptual model for flow (Figure 4.1-11) through the area. This model involves a series of fast flow pathways separated by lower permeability connections between the fast paths resulting in a series of head "stair steps" between fast flow compartments in contrast to the smooth trend of head versus distance that would be obtained in areas with uniform properties. Most of the distance a particle travels along a pathline will occur in one or more fast pathways. In contrast, depending on the geometry of the connections, most of the time a particle takes to travel along a pathline could be taken up in lower transmissivity connections between the fast pathways.

Evidence supporting a "compartment-like" flow model is found in geologic structural analyses (Sections 2.2 and 2.4), water chemistry analyses (Section 4.1.5), and big-picture analyses of hydrogeologic data (Section 4.1.8). As more data are gathered regarding the properties of the fast pathways and of the flow restrictions, these data will be used to refine the preliminary flow model described above.

These results also have implications for future work. Identifying and confirming the properties of the fast pathways and the flow restrictions are critical to understanding and assessing the contribution of the saturated zone to the multiple barrier safety strategy proposed by the DOE YMP.

The well tests were analyzed using standard techniques, along with sophisticated software packages and custom-programmed analysis tools when necessary. Over the last decade, advances in well test interpretation techniques in the petroleum industry have allowed more information to be obtained from tests using computer-assisted software analysis packages. The analyses reported here were conducted using Kappa Engineering's SAPHIR™ and Fekete Advanced Software Technology's WellTest™ packages. With these tools, along with additional interpretation methods developed on an as-needed basis, it was possible to account for variable flow rates, multiple layers, flow barriers, changing wellbore storage, and many other factors not addressed by common analysis techniques.

4.1.4.1 Description of Analysis Methods for NC-EWDP-3D

The interpretation of the NC-EWDP-3D test exemplifies the analysis methodology (QEC, 1999a). The NC-EWDP-3D borehole was developed and tested with a submersible pump beginning on February 17, 1999. An open-hole spinner log was run to determine fluid entry depths during the initial testing. On February 18, 1999, a 48-hr. pump test was initiated. The well was pumped at an average rate of 170 gpm (0.0107 m^3/s) with a maximum drawdown of 19.6 ft (6.0 m). Only the first 29 ft (8.8 m) of tuff below the casing shoe contributed to flow on the spinner measurements, even though 2,074 ft (631 m) had been drilled and left open below the productive interval.

After obtaining the test data and verifying quality control under NWRPO TP-9.0, *Pump-Spinner Logging of Precompleted Boreholes,* and TP-9.2, *Instrument Calibration and Collection and Processing of Data from Boreholes,* the first step in the test interpretation procedure was to prepare a log-log diagnostic plot of drawdown versus producing time (Figure 4.1-12). In addition to the measured response, the logarithmic derivative was also computed and plotted using a technique described by Horne (1997). This type of plot provides important information regarding flow regimes, including, for example:

- An initial unit slope (+1) on the drawdown and the derivative indicates wellbore storage.
- A later flat line (0 slope) in the derivative response indicates radial cylindrical flow, and the distance between the drawdown curve and the derivative curve is a measure of wellbore damage or skin effect.
- Multiple stable flat regions can be caused by flow barriers or multiple layers.
- A positive half slope (+½) on the derivative data indicates linear flow between barriers. The distance to the barriers is determined from the time needed to reach the derivative half slope, with closer boundaries causing the half slope to develop more quickly.
- A negative half slope (-½) on the derivative response is diagnostic of spherical or hemispherical flow.

The recognition that different flow regimes may be present was an integral factor in the test analysis. Failure to properly identify changes in flow regimes over time can lead to incomplete or erroneous interpretations of data. For example, if a straight line were drawn through the semilog head data plot (Figure 4.1-13) from NC-EWDP-3D following the method of Cooper and Jacob (1946), this straight line would yield an incorrect transmissivity because that method assumes a radial flow regime, when, in fact, hemispherical flow occurred during that test.

The next step in the analysis was to prepare a preliminary interpretation of the test based on a conceptual model identified from reviewing the diagnostic plot (e.g., Figure 4.1-12). The SAPHIR™ and WellTest™ packages contain hundreds of different models for the wellbore, different flow regimes, different types of boundaries, multiple layers, and other factors. These software packages were used to obtain more complete interpretations of the tests by setting up appropriate models for flow in the aquifer during the test, and then allowing the software package to compute the response that would have resulted from those parameters. Judgment was necessary to ensure that appropriate models were considered.

In the NC-EWDP-3D test, the derivative data exhibited a negative half slope in the latter part of the test (Figure 4.1-12), indicating the presence of spherical or hemispherical flow. This is consistent with the spinner measurements, which indicated the inflow into the well occurred in the bottom-most 29 ft (8.8 m) at the base of a thick productive interval. A partial penetration model was therefore selected that included the effects of the finite wellbore size, partial penetration effects, and differences between the horizontal and vertical permeability of the formation.

After a preliminary interpretation was selected, the test parameters were varied to determine a "best fit" using nonlinear regression techniques. The match results were examined on log-log, semilog, and Cartesian plots, as well as other specialized plots as needed. The interpretation was finalized after further review and discussion between the various test analysts and other interested parties, and a report was written to document the interpretation (e.g., QEC, 1999a).

The NC-EWDP-3D test interpretation indicated horizontal permeability of 1.34×10^{-11} m^2 (13.6 darcy) and vertical permeability of 3.2×10^{-12} m^2 (3.2 darcy). No boundaries were identified from the test. The radius of investigation was approximately 150 ft (about 50 m) horizontally and 70 ft (about 20 m) vertically.

4.1.4.2 Summary of Results from Remaining Well Tests

The interpretations of other well tests conducted in this program are described below.

NC-EWDP-1S was tested from February 21 to 23, 1999, with a 48-hr. pump test (QEC, 1999b). Two screened intervals across welded tuffs were pumped at an average rate of 173 gpm (0.0109 m^3/s), with only 1.7 ft (0.5 m) of drawdown. High permeability led to low observed drawdown, which necessitated a correction for barometric pressure changes during the test. The log-log diagnostic plot (Figure 4.1-14) indicated cylindrical radial flow during the first 0.2 hr. The computed permeability of the 80 ft (24.4 m) screened interval was 3×10^{-10} m^2 (300 darcy). At later times, there was an extended linear flow period indicated by a positive half slope (+½) on the derivative response. The implied aquifer geometry is a 200-ft (about 60-m) wide linear trend of high permeability, between two boundaries that effectively act as flow barriers. The high permeability trend extends at least 1,800 ft (about 500 m) in offsetting directions from the well.

NC-EWDP-3S was tested from April 5 to 8, 2001, with a 24-hr. pump test and a 2-hr. recovery. NC-EWDP-3D, located 18 ft (5.5 m) from NC-EWDP-3S, was monitored during the test. QA review of these test data has not been completed as of the date of this report. Therefore, the results presented regarding the NC-EWDP-3S test are subject to change and verification, and should be considered preliminary. Sedimentary rocks, volcanic tuffs, and ash-flow intervals were pumped at an average rate of 41 gpm (0.0026 m^3/s) with 20.8 ft (6.3 m) of drawdown. Preliminary analysis indicated a transmissivity of 45 ft^2/d (4.2 m^2/d), corresponding to a permeability of 4.3×10^{-14} m^2 (0.044 darcy). This value is more than 200 times lower than that observed in the NC-EWDP-3D test. The different results from the NC-EWDP-3D test and the NC-EWDP-3S test are probably related to lost circulation and grouting operations following the NC-EWDP-3D testing.

NC-EWDP-7SC was tested from March 26 to 30, 2001, with a pump-spinner test, a 48-hr. pump test, and a 17-hr. recovery. QA review of this test has not been completed as of the date of this report. Furthermore, the gauge used to monitor the NC-EWDP-7S test was not calibrated in accordance with the Nye County QA program. Therefore, interpretations presented regarding the NC-EWDP-7SC test and the NC-EWDP-7S response are subject to change and verification, and should be considered preliminary. The well was completed in four screened intervals at depths from 80 to 90 ft (24.4 to 27.4 m), 180 to 210 ft (54.9 to 64.0 m), 270 to 370 ft (82.3 to 112.8 m), and 430 to 450 ft (131.1 to 137.2 m). Most of the flow came from the upper two intervals. The uppermost interval consisted of gravel, sand, silt, and clay, while the second interval was completed in a tuff. The NC-EWDP-7SC pump test showed progressive plugging during the test. Preliminary analysis indicated a transmissivity of 720 ft^2/d (67 m^2/d), corresponding to an average permeability of 3.3×10^{-12} m^2 (3.3 darcy). The nearby offset well NC-EWDP-7S showed a classic interference response. NC-EWDP-7S was completed from 28 to 53 ft (8.5 to 16.2 m) depth, and is 28 ft (8.5 m) from NC-EWDP-7SC. The preliminary interference analysis indicated a transmissivity of 1,560 ft^2/d (140 m^2/d), corresponding to an average permeability of 7×10^{-12} m^2 (7 darcy), and a storativity of 0.026.

NC-EWDP-9SX was tested from January 15 to 18, 1999 (QEC, 1999c). The first test was a pump-spinner test to determine relative contributions of various zones. Approximately 60 percent of the flow was from the deepest volcanic zone from 330 to 340 ft (100.6 to 103.7 m) depth, 20 percent from the middle zone consisting primarily of valley-fill deposits from 250 to 290 ft (76.2 to 88.4 m), and 20 percent from the upper two valley-fill zones from 90 to 120 ft (27.4 to 36.6 m) and 140 to 160 ft (42.7 to 48.8 m). The pump-spinner test was followed with a 48-hr. pump test to determine total transmissivity. The well had 6.6 ft (2.0 m) maximum drawdown from pumping at an average rate of 175 gpm (0.0110 m^3/s). A 1 ft (0.3 m) head drop 26 hr. into the test was attributed to partial plugging of the screen. The recovery when the pump was turned off was extremely rapid, with the head building to within 0.11 ft (0.034 m) of the initial water level within 0.25 hr. The rapid recovery is indicative of high transmissivity. The test was interpreted using a model consisting of three non-communicating layers based on the pump-spinner test results. Because multiple layers were present, it was not possible to obtain a unique solution for the aquifer parameters. Acceptable matches were obtained using a variety of average permeabilities between 4×10^{-11} and 7.5×10^{-11} m^2 (40 and 75 darcy). In all cases examined, the permeability of the deepest zone exceeded 1×10^{-10} m^2 (100 darcy). The individual zones all displayed low wellbore efficiencies (high positive skin). Flow boundaries were inferred to exist at 2,000 to 3,000 ft (about 600 to 900 m) from the well, based on a positive half slope (+½) on the derivative response.

Aeropark AD-2 in Amargosa Valley was tested from June 10 to 12, 1999 (QEC, 2000a). The test included a 48-hr. pump test and a 20-hr. recovery. Head levels in five other wells (the Garlic well, the Washburn 1-X, Well M92, NC-EWDP-5S, and the Shum well) were monitored during the test. The well had 135 ft (41.1 m) maximum drawdown from pumping at an average rate of 1,330 gpm (0.0840 m^3/s). The alluvial floodplain and playa deposits producing in the Aeropark well had a transmissivity of 266 m^2/d (2,860 ft^2/d) based on the drawdown analysis with a leaky aquifer model. Permeability was not computed because the productive interval thickness was not known. The recovery response was complicated by water falling from the tubing back into the well when the pump was shut down (there was no check valve below the pump). A new analysis procedure was developed to account for this fluid redistribution. The Garlic well, located 1,975 ft (602 m) from the Aeropark well, responded to the Aeropark pumping. Analysis using new leaky aquifer type curves indicated a transmissivity of 2,110 ft^2/d (196 m^2/d) and storativity of 2.2×10^{-4}. The extremely low storativity may indicate the presence of "fast pathways" (possibly faults or fractures) between the Aeropark and Garlic wells. No response was seen at the other wells, which are located farther from the Aeropark well than the Garlic well.

BGMW-13 was tested from July 17 to 20, 1999, with a 53-hr. pump test and a 19-hr. recovery (QEC, 2000b). Head levels in three other boreholes (BGMW-5, BGMW-6, and BGMW-8) were also monitored. The well was completed in fractured quartzite, and had 32 ft (9.8 m) maximum drawdown from pumping at an average rate of 111 gpm (0.0070 m^3/s). The BGMW-13 transmissivity was 3,300 ft^2/day (310 m^2/d) based on the drawdown analysis. Permeability was not computed because the productive interval thickness was not known. The head response indicated significant flow restriction or convergence near the wellbore (+20 skin), leading to a well efficiency of only 37 percent. Flow boundaries were inferred to exist at 100 to 200 ft (about 30 to 60 m) from the well, based on a positive half slope (+½) on the derivative response. The recovery response was complicated by water falling from the tubing back into the well when the pump was shut down (there was no check valve below the pump). There was no detected response to the pump test at any of the observation wells. This is not surprising, because the nearest well is more than 14,000 ft (about 4,300 m) from BGMW-13.

4.1.5 Water Chemistry Sampling and Analysis

Nye County initiated EWDP groundwater sampling and analysis in 1998. Previous Nye County analyses were conducted on water samples collected during NWRPO drilling and preliminary development of UE-25 ONC#1 in 1995 (Stellavato, 1996). Samples were collected during EWDP Phases I and II in accordance with Nye County QA Program TP-8.1, *Field Collection and Handling of Water Samples*. Testing laboratories and chemical analytical methods are summarized in Table 4.1-5.

Groundwater samples were collected at different times during drilling, completion, development, or purging activities at EWDP Phase I and II wells. Bailing or air-lifting was used while drilling to collect samples from the first water encountered in potential perched zones in 12 wells. Following drilling, but prior to well development and/or purging, samples were collected from four wells by bailing or submersible pumping. Samples were collected after development and purging by pumping from isolated screens in five multiple screen wells and from single screens in nine piezometer wells. Samples were also collected from four other wells in the Amargosa Valley.

The results of groundwater analyses, with the exception of first water samples, will be presented on Nye County's web page (Nye County, 2001) after NWRPO QA verification requirements are completed. First-water-encountered samples turned out to have little value, because no perched water was encountered in the EWDP boreholes. The first-water samples exhibited elevated dissolved sulfate concentrations compared to water samples collected after well development and/or purging. These higher sulfate levels probably resulted from drilling fluids dissolving gypsum crystals in the vadose zone (Shettel et al., 1998).

Groundwater samples collected by pumping after well development are considered to be more representative of in situ conditions than other samples. At least three borehole volumes were pumped prior to sampling. Trends observed from these data are described below.

Groundwater geochemical facies in different wells are illustrated in Piper diagrams (Figures 4.1-15a and -15b). Data on these figures and Figures 4.1-16a, -16b, and -17 are from all sampling intervals and sampling events (post-well development purging only). Figure 4.1-15a shows that for the majority of wells, the dominant cation type is Na+K (sodium and potassium). The exceptions are NC-EWDP-1S, -12PC, -7S, and BGMW-13, indicating different water sources for those wells. It should be noted that this diagram shows only the relative proportions of the cations and does not show absolute amounts.

For the same samples, Figure 4.1-15b shows that most of the water samples were typical of meteoric water containing HCO_3 + CO_3 (bicarbonate and carbonate) ions. The McCracken well had no predominant anion type and the BGMW-13 well contained SO_4 (sulfate) water.

Dissolved sulfate concentrations versus stable sulfur isotopic values (Del ^{34}S or $\delta^{34}S$) of dissolved sulfate are shown in Figure 4.1-16a. Also included in Figure 4.1-16a for comparison are data from Perfect et al. (1995) for water samples in the vicinity of Yucca Mountain. There is a general trend of increasing dissolved sulfate with increasing Del ^{34}S. The range of Del ^{34}S appears to indicate three distinct sources of sulfate (Faure, 1986; Hoefs, 1980) in these waters:

1. Paleozoic marine sulfates where Del ^{34}S is greater than +20 per mil with respect to the Canyon Diablo troilite (CDT) standard. BGMW-13 and NC-EWDP-1DX exhibit this type.

2. Sulfate dissolved from gypsum and other evaporite minerals in the vadose zone where Del ^{34}S falls in the range of +10.5 to +14.5 per mil CDT.

3. A mixture of oxidized sulfides and sulfates from the previous group where the Del ^{34}S is less than about +10.5 per mil CDT. It should be noted that sulfides have been found in cuttings from NC-EWDP-3D (see Section 4.1.7.1).

Dissolved bicarbonate concentrations versus stable carbon isotope values (Del ^{13}C or $\delta^{13}C$ per mil PDB [Pee Dee Bolemnite]) of dissolved carbonate are shown in Figure 4.1-16b. This plot shows a general trend of increasing dissolved bicarbonate with increasing Del ^{13}C. Samples from NC-EWDP-1DX, which plot in the upper right portion of the graph, represent water from the Paleozoic carbonate aquifer (similar to deep water from UE-25-P1, which is in the Paleozoic carbonate aquifer [Perfect et al., 1995]). Samples from NC-EWDP-4PB, which plot in the lower left portion of the graph, contain carbon predominantly derived from the atmosphere (Hoefs, 1980). Other than samples from NC-EWDP-5SB, which is east of Fortymile Wash, Figure 4.1-16b shows an approximately linear trend in decreasing dissolved bicarbonate and Del ^{13}C with increasing distance from NC-EWDP-1DX. This may represent a mixing trend with decreasing proportions of water from the carbonate aquifer found in wells further from NC-EWDP-1DX. Water from the carbonate aquifer is most likely upwelling along faults in the vicinity of NC-EWDP-1DX (see Section 4.1.2).

Concentrations of selected constituents from the shallowest screened depth intervals of selected EWDP wells are presented in Table 4.1-6 to illustrate ranges in data and trends, including the following:

- Highest fluoride concentrations often occur in waters derived from volcanic rocks and volcaniclastic sediments (e.g., NC-EWDP-3S, -12PA, -12PB, and -15P). Waters flowing through valley-fill sediments are generally diluted and therefore lower in fluoride concentration.

- High dissolved strontium concentrations were observed along the western edge of the EWDP (e.g., NC-EWDP-1S, -7S, and -12P), probably as a result of upwelling of carbonate aquifer water in this area.

- The highest percent modern carbon values (and therefore the youngest waters) are found in NC-EWDP-3S, -19P, and -4PA. The lowest percent modern carbon (oldest shallow water) is found in NC-EWDP-5SB. NC-EWDP-19P, -4PA, and -5SB are all located in Fortymile Wash, but -5SB is located on the eastern margin of the wash where thicker sequences of fine-grained sediments dominate the stratigraphy.

- Measured chlorine isotopic ratios were below values considered to be indicative of atmospheric nuclear testing (more than 1,202 x 10^{-15} $^{36}Cl/Cl$; Fabryka-Martin et al., 1997), and probably represent natural variations in the atmospheric production input into recharge areas.

Figure 4.1-17 shows the variation in the stable isotopes of water (oxygen and hydrogen) for EWDP wells, BGMW-13, and UE-25 J-13 (Perfect et al., 1995). The near vertical black lines separate sample clusters for discussion purposes. Clustering (or lack thereof) may be related to faulting and/or the sample depth. For example, at the same surface location, NC-EWDP-1DX and -1S show the largest separation on the graph. These wells are located on opposite sides of a major fault (Carrara or Highway 95 fault), and samples collected from NC-EWDP-1DX were at least 1,890 ft (576.1 m) deeper than samples from NC-EWDP-1S. Results from NC-EWDP-4PA and -4PB (connected by dotted line) also suggest that screen depth beneath the water table affects the composition of oxygen and hydrogen stable isotopes. The top of the sand pack in piezometer hole NC-EWDP-4PB is more than 200 ft (61.0 m) further below the water table than the bottom of the sand pack in piezometer hole NC-EWDP-4PA (Table 4.1-1). Finally, the middle cluster of results was generated primarily from water samples from NC-EWDP-3S and NC-EWDP-9SX, which are apparently in the same fault block at similar depths.

4.1.6 Water Level Monitoring

Monitoring water levels in EWDP wells and the Yucca Mountain region provides baseline data on water level trends and the response of water levels to factors, such as climate, water well pumping, and tectonic activity. The water level monitoring being performed by Nye County is an improvement over existing data in many areas of Amargosa Desert, in terms of both coverage and frequency. The data collected during EWDP Phases I and II will be expanded in subsequent phases as more wells are completed.

Almost continuous water level measurements are made at multiple zones using transducers and data loggers in EWDP wells instrumented with Westbay® equipment. Other EWDP wells and piezometers are monitored manually, typically on a weekly basis for a period after completion and monthly thereafter. As many as 2 years of water level data are now available for some locations.

Table 4.1-7 summarizes the methods, frequencies, and durations for the NWRPO's water level monitoring. The frequency of measurements, in part, depends on other EWDP activities, particularly during drilling operations. The NWRPO's water level monitoring results, after QA review and approval, are posted on Nye County's web page (Nye County, 2001). Nye County is examining these records to determine the natural temporal variability in water levels to aid in determining long-term monitoring needs.

Vertical hydraulic gradients are present in a number of EWDP wells. Vertical gradients are observed at three types of EWDP well completions: 1) multiple piezometer completions (e.g., NC-EWDP-1DX); 2) multiple screened interval completions equipped with Westbay® instrumentation (e.g., NC-EWDP-1S, -3S, and -9SX); and 3) piezometers located closely together but completed at different depths (e.g., NC-EWDP-4PA and -4PB, and NC-EWDP-12PA, -12PB, and -12PC). A strong downward hydraulic gradient is observed between the shallow and deep piezometers nested in NC-EWDP-1DX. An apparent downward gradient has been observed between NC-EWDP-3D and the adjacent well at NC-EWDP-3S; however, NC-EWDP-3D is an open borehole and the water level measurements may not be accurate. Strong upward vertical gradients are observed between two piezometers (NC-EWDP-4PA and -4PB), between NC-EWDP-19D1 and the adjacent piezometer (NC-EWDP-19P), and between the shallow piezometer at NC-EWDP-12PA and the two deeper piezometers. Lesser upward hydraulic gradients are observed between two zones at NC-EWDP-1S, -3S, and the upper three zones at -9SX. Specific water level measurements are available on the Nye County web site (Nye County, 2001). Vertical upward gradients are attributed to upward leakage of water from the underlying carbonate aquifer. Downward gradients at paleospring sites are likely due to the presence of unique structural and hydraulic controls.

Figure 4.1-18 shows measured water levels for the uppermost screen (Westbay® Probe 1) in NC-EWDP-9SX to illustrate the variability in water levels. The four plots on this figure show semi-continuous measurements for a 3-day period, averaged daily measurements for a 3-month period, averaged weekly measurements from well completion through November 2000, and averaged monthly measurements for this same period. These averages were based upon the semi-continuous data set for each time interval.

The semi-continuous water level measurements are recorded at 10- to 20-min. intervals, thus the semi-continuous record for a well for 1 year may be comprised of several tens-of-thousands of recorded water levels. These records clearly show the effects of barometric changes, typically about 0.05 to 0.3 ft/day (0.02 to 0.09 m/day) at the EWDP wells. Averaging these records over longer periods of time incorporates these diurnal fluctuations into the data; however, it does not mask longer-term trends in the measurements.

The data shown in Figure 4.1-18 demonstrate that single water level measurements taken at NC-EWDP-9SX on any given day in a month are within $\pm$0.15 ft ($\pm$0.05 m) of the average daily value for semi-continuous measurements (compare the upper two plots in Figure 4.1-18). Depending on the end use of the water level data, these results suggest the frequency of measurement may be reduced significantly in some cases without a significant loss of useful data. Since the collection of semi-continuous data is quite expensive, in terms of instrumentation, calibration, and data processing requirements, the NWRPO plans to continue to evaluate usefulness of semi-continuous water level monitoring and, where appropriate, reallocate Westbay® transducers and data loggers to new EWDP wells. If semi-continuous monitoring equipment is removed from a particular well, monthly measurements will replace semi-continuous measurements.

4.1.7 Petrographic and Geochemical Analyses

Petrographic and geochemical analyses were conducted on drill cuttings from EWDP boreholes NC-EWDP-3D and -19D. Drill cuttings from NC-EWDP-3D were analyzed to determine the origin of anomalously high gamma radiation at 500 to 505 ft (152.4 to 153.9 m) depth below ground surface (see Section 4.1.2 and Figure 4.1-2). Drill cuttings from NC-EWDP-19D were analyzed to characterize the distribution of major and trace elements and authigenic minerals that may play a role in transport and sorption processes.

4.1.7.1 NC-EWDP-3D Uranium Mineralization

Fifty-six drill cuttings samples from NC-EWDP-3D ranging in depth from 95 to 2,495 ft (29.0 to 760.5 m) below ground surface were selected for geochemical and petrographic laboratory analyses. These samples were analyzed using SEM with energy dispersive X-ray, spectrometry, and neutron activation analysis. These data will be posted on the Nye County web site (Nye County, 2001) after NWRPO QA verification requirements are completed.

Neutron activation results for cuttings from 500 to 505 ft (152.4 to 153.9 m) showed elevated levels of uranium and molybdenum compared to the rest of the borehole. Peak concentrations of uranium and molybdenum in this depth interval were nearly 175 and 120 parts per million (ppm), respectively. In contrast, levels of uranium and molybdenum in the rest of the well were typically less than 5 and 20 ppm, respectively. The concentrations of zinc, cerium, arsenic, gold, and neodymium were also higher at this depth. The concentrations of uranium, molybdenum, and other constituents are not considered high enough to be minable. The age of the uranium mineralization is 182 +/- 7 Ky (late-middle Pleistocene), based on uranium-series isochron age dating.

Petrographic studies indicate that the uranium is present as coffinite, a silicate mineral. Other metals in the 500 to 505 ft (152.4 to 153.9 m) interval typically occur as small sulfide crystals (pyrites) less than 15 microns in diameter.

The coffinite grains occur on a matrix of pre-existing zeolites (clinoptilolite–analcite) that contain potassium, sodium, and cesium in their super-cages. There is no evidence of zeolite sorption of radionuclides during the mineralization process at 182 +/- 7 Ky. It appears that the zeolite super-cages were satisfied with exchange cations (e.g., strontium and cesium) that are favored over transported radionuclides (e.g., uranium).

These deposits were likely formed by enrichment with epithermal fluids. They have the classic sulfide mineral-textural associations common in both epithermal gold and uranium deposits (Castor et al., 1996; Zielinski, 1982). The source of these epithermal fluids is unknown but may be related to Quaternary volcanism in Crater Flat, just north of the deposit. The confinement of mineralization to an approximately 5-ft (1.5-m) thick interval suggests that flow pathways from the source to the borehole focused flow and minimized dispersion. Additional characterization work beyond the scope of the EWDP is required to verify, refine, and/or revise the above preliminary hypotheses regarding mineralization and transport mechanisms.

4.1.7.2 NC-EWDP-19D Geochemistry and Petrography

Trace and major element geochemistry and supporting petrographic analysis of 41 drill cuttings samples ranging from 400 to 1,380 ft (121.9 to 420.6 m) depth below ground surface were used to assess the sedimentary lithofacies in NC-EWDP-19D. Geochemical analyses were also conducted on a vitric tuff zone at 890 to 1,190 ft (271.3 to 362.7 m) depth, located between intervals of overlying alluvium and underlying lacustrine sediments.

Geochemical analyses included X-ray fluorescence analyses of major oxides, inductively coupled plasma analyses of trace elements, and coulometry methods to determine organic carbon. These analytical data will be posted on the Nye County web site (Nye County, 2001) after NWRPO QA verification requirements are completed. Preliminary data and interpretations are presented below. The results and interpretations presented here are based on analysis of drill cuttings from a single well, and may not be representative of larger-scale samples or other locations at Yucca Mountain. Fine-grained cuttings that did not rapidly settle out of samples containing free water were decanted off and discarded.

Concentrations of major oxides showed no evidence of trends with depth or lithostratigraphy. In contrast, several trends were observed in the distribution of 12 selected trace elements with depth (Figure 4.1-19). The alluvial section from 485 to 490 ft (147.8 to 149.4 m) showed slightly elevated levels of iron, magnesium, mercury, and lithium; and the section from 715 to 720 ft (217.9 to 219.5 m) showed slightly elevated levels of iron, calcium, magnesium, barium, and zirconium. These elevated levels suggest a greater degree of authigenic mineralization in those intervals. Geologic logging and particle size distribution analyses also indicated higher clay contents from 485 to 490 ft (147.8 to 149.4 m).

Cuttings samples from 12 intervals in the vitric tuff zone were also chemically analyzed. These data are reported as average values over the tuff zone in Figure 4.1-19 and indicate no remarkable trace element concentrations in the tuff. The vitric tuff is poorly welded, containing few phenocrysts and some incipient devitrification. Most of the ash fragments showed fairly extensive zeolitic mineralization under petrographic examination. The chemical analysis of the tuff therefore represents rock that has been altered by groundwater flow.

The lacustrine section contains high concentrations of calcium, barium, strontium, and manganese (Figure 4.1-19), possibly representing carbonate and sulfate deposition associated with lacustrine mineral diagenesis. Lithium also spikes in the lacustrine horizon. Authigenic dendritic manganese oxyhydroxides occur in non-carbonate zones in the lake sediments. The lacustrine sediments below the tuff are petrographically characterized by extensive diagenesis, resulting in zeolitic and clay mineral replacements.

Organic carbon levels were very low in all regions of the borehole and ranged from the detection limit (0.01 percent) to 0.13 percent (Figure 4.1-19).

In summary, the solid phase geochemistry in NC-EWDP-19D is considerably different between the shallow alluvium and the deeper lacustrine sediments. The sedimentary section is extremely complex and exhibits significant textural, geochemical, and mineralogical heterogeneity that should be incorporated in flow and retardation models.

4.1.8 Preliminary Hydrogeologic Conceptual Model for Early Warning Drilling Program Area

Although Yucca Mountain and the Nevada Test Site have been extensively studied over the last half-century, there are still many uncertainties about the hydrology of the area. During his tenure as Nevada State Engineer, R. Michael Turnipseed (now the Director of the Nevada Department of Conservation and Natural Resources), stated that while this region is one of the most studied areas on Earth, it remains one of the most poorly understood. This uncertainty results from the incredible geologic complexity of the region, and the costs associated with characterizing and evaluating that complexity.

Studies of Yucca Mountain started with detailed investigation of the mountain block itself, and were expanded to include site-scale and regional-scale evaluations to support the DOE's Total System Performance Assessment. The site-scale evaluation is limited to a 1,350-km^2 region (40-km long and 30-km wide) encompassing portions of Crater Flat, Jackass Flats, and Amargosa Desert, and the regional-scale evaluation includes almost all of the Death Valley regional groundwater flow system (DVRFS). The emphasis in recent years has been on improving the geologic (and hydrogeologic) framework and numerical models at these scales. The EWDP results are helping to refine these models; however, problems of scale and data availability remain. The site-scale model does not cover certain areas of concern to Nye County, for example:

- The community of Amargosa Valley, especially the Amargosa Farms area
- The communities of Beatty and Crystal
- The area east of the Lathrop Wells intersection where development is underway
- Devils Hole and the Ash Meadows National Wildlife Refuge
- The state line area.

The regional-scale model, while including these areas, encompasses areas well beyond Nye County's boundaries. Because of the complexity of the hydrogeologic conditions and poor understanding of some key hydrologic parameters, the regional evaluation is too general to address Nye County's concerns. This does not imply that Nye County believes that these evaluations are not achieving their intended purposes and scopes. Rather, the model boundaries do not coincide with the area of key concern to Nye County.

Nye County's concerns and interests are best addressed by focusing on an area of intermediate scale: Amargosa Desert and its primary tributary groundwater basins, Oasis Valley, Crater Flat, Jackass Flats, Buckboard Mesa, Rock Valley, Mercury Valley, and Pahrump Valley. At this scale, Nye County's data collection efforts can be focused on the specific areas where more information and evaluation are needed. This section presents pertinent conceptual model background information and a preliminary conceptual model of the area of interest to Nye County, and identifies additional information needs.

4.1.8.1 Pertinent Background Information and Model Components

Figure 4.1-20 shows the boundaries of the watershed-scale conceptual model, which generally coincide with hydrographic basins in Nye County. This area has limited precipitation and small, but important, recharge from precipitation. Most of the recharge is from groundwater flow from upgradient basins. Water discharges at locations where groundwater is shallow, such as the spring complex at Ash Meadows, southern Amargosa Valley, Franklin Playa in Inyo County, and, potentially, via subsurface flow into Death Valley. Another important (and growing) component of discharge is consumptive water use for municipal, domestic, mining and milling, and agricultural purposes. Figure 4.1-21 shows conceptual recharge and discharge relationships for the area.

USGS studies have more accurately defined evapotranspiration in Oasis Valley, the Ash Meadows area, Inyo County (Laczniak et al., 1999), and more recently at Mesquite Flat and Gold Valley in Death Valley (Section 5.2). Work by Savard (1998) and others has led to an increased understanding of recharge over the watershed. However, little progress has been made regarding recharge over mountainous areas, and subsurface flowpaths and fluxes under a given area or across a boundary. The DOE's approach in regional-scale modeling will likely result in a better understanding of recharge over the Spring Mountains, the Sheep Range, and the Panamint Range. Therefore, Nye County's focus is on addressing uncertainties in the understanding of subsurface flows, direction, rates, and significance with respect to Yucca Mountain.

Although groundwater fluxes through the region are a critical parameter, they are not well defined. Most of the inter-basin flow values available today are 30-year-old estimates that were based on imbalances in water budgets. Additional information is needed to better define groundwater fluxes from basement rocks into valley-fill sediments. Nye County's future data collection efforts take into account available site-scale and regional-scale information, augment this information with results from the EWDP, and assess additional data needs.

A conceptual hydrogeological model is a representation of the hydrologic processes at work in the subsurface under a given area. Figure 4.1-22 shows the conceptual model's main components: (1) the basement of consolidated rock that underlies the region; (2) the valley-fill sediments, which are discontinuous but linked via the basement rocks; and (3) the areas of surface and groundwater interaction.

4.1.8.2 Importance of Basement Rock

The regional pre-Tertiary basement is the underpinning of the conceptual model. The current basement representation is based on the recent geophysical interpretation by Blakely et al. (2000b), and is shown in Figure 2.1-4. Features shown on this graphic include outcropping mountains and intervening basins (shown as depressions in the surface). The excellent resolution in the latest geophysical survey readily shows key structural elements, such as the Rock Valley fault zone, which is one of the two largest conduits for groundwater flow in the region.

Most of these deep basins correspond to Pleistocene lakes. Direct evidence from the EWDP deep drilling at NC-EWDP-1DX, -2DB, and -3D suggests that there was a large Tertiary lake in Amargosa Desert where no Pleistocene lake was present. It is likely that the Amargosa Desert Tertiary lake was filled by volcanic deposition during the late Tertiary. The ancestral Amargosa River drained to Death Valley during the Pleistocene, preventing a lake from forming in the central Amargosa Desert at that time. Only a small lake was present in the Crystal area, separated from the central portion of the basin by a basement high. No lakes were present in

Jackass Flats, Rock Valley, Buckboard Mesa, or Rock Valley during the Pleistocene, but drilling results indicate that Tertiary sediments underlie volcanic deposits in the Yucca Mountain area.

Detailed information on the Tertiary tectonic history of the Yucca Mountain region is presented in Section 2.2. Extensive post-Paleozoic deformation resulted in the complex geologic framework of the region. The tectonic activity disrupted basement rocks, and also disrupted overlying valley-fill sediments in some areas. The geologic history of the area is summarized in Figure 4.1-23, which illustrates the timing and degree of structural activity that led to the complex conditions present today.

Areas where basement rocks are in direct hydraulic communication with overlying valley-fill sediments are of key concern. In the eastern tributary basins (Rock Valley, Mercury Valley, and Pahrump Valley), groundwater fluxes through the basement rock are largely horizontal, contributing underflow to Amargosa Desert. These fluxes are possibly the largest component of recharge to the area within the conceptual model (Rush et al., 1971).

4.1.8.3 Basement Rock/Valley Fill Interaction

Vertical leakage from basement rocks upward into valley-fill deposits is probably the second largest source of recharge to the valley-fill sediments. An upward vertical gradient exists at Yucca Mountain at UE-25e-P1 and at several EWDP locations. The magnitude of groundwater flux is not accurately known, but could be appreciable. Upward leakage is probably greatest via faults through valley-fill deposits.

Contact relationships between basement rocks and valley-fill sediments can have a pronounced effect on groundwater levels. Most valley-fill sediments are fine-grained, and act as "plugs" in the regional flow regime. In some areas, groundwater flow that once discharged from Paleozoic rocks into vast lakes during early Tertiary time is now impeded by clay-rich valley-fill sediments. This water now rises to the surface at locations such as Ash Meadows and Devils Hole, upgradient of the boundary between the thick sequences of Paleozoic and the thick "plug" of Tertiary sediments in the Amargosa Trough.

4.1.8.4 Role of Volcanics near Yucca Mountain

From Nye County's perspective, the most important part of the conceptual model is the area between the proposed repository at Yucca Mountain and existing groundwater users downgradient in the community of Amargosa Valley. The most important aquifers are the alluvium, the volcanic aquifers, and the uppermost Tertiary sediments. From north to south, the thick sequence of volcanic rocks found at Yucca Mountain transitions into volcaniclastic sediments that were transported from the caldera complexes into a Tertiary lake environment. The sequence of volcanic rocks at Yucca Mountain is well stratified, and more than 50 individual volcanic units have been identified. South of the mountain, along Highway 95 where the EWDP Phase I and II wells are located, this volcanic package is far less stratified.

Some units were not deposited as far south as Highway 95, while other units thin dramatically to the south. Still others were chemically altered from deposition into a lacustrine environment, or were physically altered during aeolian and fluvial transport from the upland deposition areas to the lower Tertiary lake bottom or later marshlands. Even within these lake and marsh sediments, basaltic volcanism resulted in discontinuous lava interbeds in the upper part of the Tertiary valley-fill sequence. It was only in the late Quaternary that tectonic activity died down, allowing relatively thin alluvium to cover the underlying sediments and volcanic units.

The drilling results at NC-EWDP-2DB and -19D demonstrate the variability of volcanic units over only a few kilometers. Because of the nature of the volcanic units, their attitude, and the structural regime, it has not yet been possible to definitively correlate subsurface geology between these wells, although they are only 6,000 ft (1,800 m) apart. Discussions with USGS scientists indicate that the Topopah Spring Tuff, the Bullfrog Tuff, and the Tram Tuff are present in NC-EWDP-2DB, but are not clearly present at NC-EWDP-19D, where a 440-ft (134-m) thick "homogenous" tuff is present. This tuff may represent a different unit that is poorly exposed near Yucca Mountain, or it may be a lacustrine facies of the Topopah Spring Tuff.

4.1.8.5 Compartmentalization

The volcanic units have been faulted and tilted, breaking these units and the basement rocks into compartments, as discussed in Section 2.2. The results of a deep seismic survey by Brocher et al. (1993) show this compartmentalization in Amargosa Desert, but the nature of the boundaries and compartments has not been well defined.

Compartments within the rock aquifers can be hydrologically significant. Compartments and boundaries between compartments can either serve as groundwater flow pathways or as flow barriers. For example, the transmissivity of the Rock Valley compartment is probably on the order of 1 million gal./day/ft (about 12,000 m^2/day), and an estimated 17,000 a.-ft/yr. (21×10^6 m^3/yr.) are transmitted through this compartment into the Amargosa Desert hydrographic basin (Rush et al., 1971). Conversely, the fault bounding the southern boundary of the Crater Flat compartment appears to act as a barrier impeding the flow of water into Amargosa Desert through this area (estimated by Rush et al. [1971] at 2,000 a.-ft/yr. [2.47×10^6 m^3/yr.]).

Fluxes across compartment boundaries are important in Amargosa Desert, since most recharge to the basin is derived from subsurface flow from upgradient basins. Water movement through individual compartments is poorly understood because of the lack of observation wells and aquifer tests throughout most of the region. The original inter-basin flow estimates were based on water budget imbalances. To obtain better estimates of fluxes, aquifer tests are needed in each compartment, along with observation wells to establish groundwater gradients and flow directions.

Another poorly understood aspect of compartmentalization is the interaction between compartments. Aquifer testing in the Devils Hole region suggests that the impacts of water withdrawals in some compartments do not extend beyond the boundaries of that compartment (e.g., see Dudley and Larson [1976]). If so, water withdrawals in the Amargosa Desert compartment would not be likely to impact water levels or spring discharge rates in the Amargosa Flat, Devils Hole, or Ash Meadows compartments. In other instances, hydraulic effects may cross compartment boundaries, but this has not yet been documented in the region.

4.1.8.6 Additional Work Required

While Phases I and II of the EWDP have contributed a great deal of new information for the data gap area, additional work is needed. More water level data are needed between key areas to determine hydraulic gradients and the response of the groundwater system to stresses, both natural and man-made. More aquifer tests are needed for transmissive properties of the aquifers and compartment boundaries. Additional water analyses are needed to further refine source areas, flowpaths, and discharge areas. More exploratory borings and wells, additional geophysical surveys, and a better-distributed network of monitoring wells are needed to better understand the complex geologic and hydrologic systems between Yucca Mountain and the potentially-affected environments of Nye County.

Phase III of the EWDP, to be completed in calendar year 2001, will partially address these needs by completing a north-south transect of boreholes and wells along Fortymile Wash between Yucca Mountain and Highway 95. Additional data are needed to define the volcanic-alluvium contact relationship, groundwater heads and flowpaths, and aquifer properties immediately downgradient of Yucca Mountain, along the boundaries of Amargosa Desert and Jackass Flats with Yucca Flat, Rock Valley, Mercury Valley, Pahrump Valley, and Death Valley. The NWRPO has planned additional phases for the EWDP that, if funded, will address many of these data deficiencies.

4.2 ALLUVIAL TESTING COMPLEX

The ATC was designed to improve understanding of groundwater flow and radionuclide transport through saturated alluvium downgradient from Yucca Mountain. The ATC presently includes NC-EWDP-19D and -19P, and is located to the south of Yucca Mountain, along a potential groundwater flowpath parallel to Fortymile Wash, as illustrated in Figure 4.2-1. The objectives of planned hydraulic and tracer tests of saturated alluvium in boreholes at the ATC are summarized below:

- Conduct geophysical logging to estimate in situ temperature, density, moisture, resistivity, natural gamma, sonic velocity, and borehole diameter and deviation. In addition, borehole gravity meter surveys will be conducted on selected wells.

- Quantify flow parameters, including saturated thickness, transmissivity, hydraulic conductivity, and storativity.

- Quantify transport parameters, including effective porosity, longitudinal dispersivity, and sorption parameters, for diffusion between flowing and stagnant water and for colloid transport.

- Measure sorption coefficients in the laboratory using materials from the ATC borehole(s). Compare lab data to field test results.

- Determine Eh-pH conditions at the ATC and EWDP wells.

- Determine natural colloid concentrations in the alluvium at the ATC and EWDP wells.

- Develop a conceptual model of groundwater flow and radionuclide transport in saturated alluvium south of Yucca Mountain to the Amargosa Desert. Evaluate the extent of mass transfer between flowing and stagnant water.

The USGS, Sandia National Laboratories, and Los Alamos National Laboratory are responsible for conducting and analyzing borehole hydraulic and tracer tests at the ATC. The University of Nevada-Las Vegas Harry Reid Center for Environmental Studies Laboratory is responsible for laboratory analytical services associated with the ATC. The DOE is responsible for obtaining permits from the State of Nevada for water discharge and Underground Injection Control related to the tracer testing. The DOE Test Coordination Office provides the interface between the NWRPO and the above participants.

The NWRPO is responsible for the majority of the operations at the ATC. This includes drilling, completing, developing, and purchasing equipment for the boreholes and surface facilities. Following well development and prior to instrumenting wells with packer systems, Nye County will conduct open-hole spinner logs and aquifer pump tests (see Section 4.2.2). After the packer systems are installed, Nye County will provide groundwater samples to other ATC organizations for chemical analysis. In addition, the NWRPO is also responsible for operational logistics, including site security, sanitation, electricity, fuel, road maintenance, Westbay® monitoring equipment, and support, as needed. Finally, as with the EWDP wells, the NWRPO is responsible for the drilling and Right of Way access permits, environment assessments, archeological surveys, and reclamation.

The saturated zone is one of the natural barriers that will contribute to the overall long-term safety of the repository. By providing important information about the ability of the saturated zone to adsorb radionuclides and retard their movement, the results of the ATC will be instrumental in helping to determine the saturated zone's contribution to the multiple barrier safety strategy proposed by the DOE YMP.

4.2.1 Alluvial Testing Complex Well Completion and Layout

Two boreholes (NC-EWDP-19P and -19D) were constructed during the spring of 2000. These wells were drilled as part of the EWDP Phase II drilling program. In early March 2000, NC-EWDP-19P was drilled to a total depth of 499 ft (152.1 m) to determine the depth to first water in the area and to obtain initial water samples. NC-EWDP-19D was then drilled in late March and early April 2000 to a total depth of 1,456 ft (443.8 m). NC-EWDP-19P is located approximately 25 m northeast of NC-EWDP-19D. A simplified well completion log of the two boreholes is shown in Figure 4.2-2. A plan view of these wells in relation to ATC fence lines is presented in Figure 4.2-3.

NC-EWDP-19P was completed as a piezometer hole with a single slotted screen set just into the water table from 359 to 459 ft (109.5 to 139.8 m). The casing is 2.875 in. (0.073 m) steel casing. The borehole adjacent to the screen was packed with 8-12 mesh sand and sealed above with approximately 8 ft (2.4 m) of bentonite chips and 60 mesh sand. The annulus between the casing and the borehole above the sand and bentonite chips was cemented to the surface.

NC-EWDP-19D was completed with 7 in. (0.178 m) steel casing in seven intervals. The upper four zones are in alluvial or valley-fill sediments, the fifth and sixth zones are in tuffs, and the bottom zone is in an interbedded sandstone, gravel, siltstone, and claystone interval. The completion intervals were selected by the principal investigators and Nye County personnel based on sample cuttings, geophysical logs, water production rates while drilling, and temperature logs. In general, the lengths of slotted pipe were determined from the estimated productive interval thickness with allowances for logistics. As with the piezometer hole, the wellbore adjacent to the screens was packed with 8-12 mesh sand, and isolation between zones was achieved with bentonite grout and cement.

4.2.2 Alluvial Testing Complex Pump Testing

Aquifer pump testing was conducted in NC-EWDP-19D by Nye County from May 10 to 15, 2000. Spinner testing was conducted first under both static and pumping conditions to determine the relative flow contribution from the seven screened zones in this well (Figure 4.2-2) (QEC, 2000c). The upper four zones are in alluvial or valley-fill sediments, the fifth and sixth zones are in tuffs, and the bottom zone is in a sand/clay interval. An analysis of spinner logs indicated that the upper two zones contributed less than 5 percent of the flow on the spinner runs, and the bottom two zones accounted for 2 percent or less of the flow. The third zone from 568 to 691 ft (173.2 to 210.7 m) provided about 50 percent of the flow, followed by the fourth zone (25 percent of the flow) from 717 to 795 ft (218.6 to 242.4 m), and the fifth zone (18 percent of the flow) from 834 to 1,061 ft (254.3 to 323.5 m). The tuff zone (Screen 5) always flowed into the well during the test, indicating it had a higher head than the alluvial zones. A significant portion of the total transmissivity in the tuff appears to be associated with a fracture encountered at 955 ft (291.2 m) depth.

Following the spinner tests, the well was not pumped for 15 hr. to allow head transients from the pump-spinner test to dissipate. A 48-hr. pump test and 24-hr. recovery were then initiated (Figure 4.2-4). Additional spinner runs were made during the pump test to monitor zonal production rates. The well had 18 ft (5.5 m) maximum drawdown from pumping at an average rate of 156 gpm (0.0098 m^3/s).

The test analysis was complicated by the presence of seven completion intervals and at least three different static head levels within various zones completed. The latter head differences caused measurable cross flow to occur between several intervals even under static conditions. A generalized multi-layer model with barriers was developed to interpret test data from this well. This model allows the incorporation of different initial heads in each layer and thus accommodates the observed head differences in this test.

The combined transmissivity of all zones open in the well was 4,000 ft^2/d (372 m^2/d) based on drawdown analysis and modeling of the entire test. The average permeability computed using the net thickness of the upper five zones was 2.3 x 10^{-12} m^2 (2.3 darcy). The influence of boundaries was inferred from a positive half slope (+½) on the derivative response on the log-log diagnostic plot (Figure 4.2-5). The interpretation of the slope of the derivative of the log-log diagnostic plot is discussed in more detail in Section 4.1.4. The estimated distance to the boundaries is approximately 700 ft (about 200 m). It was not possible to determine whether the boundaries occurred in all layers, or whether they were present in only one of the more permeable zones.

Heads were monitored in other wells during the NC-EWDP-19D testing. While the influence of pumping was observed in NC-EWDP-19P located 81 ft (25 m) away, preliminary analysis indicated the data were not suitable for determining aquifer properties. No response was detected at the Washburn well, which is located 6,300 ft (1,920 m) away.

In summary, Nye County's testing of NC-EWDP-19D demonstrated that permeable beds are present in the alluvial zones and in an underlying tuff bed. However, permeability is not evenly distributed through the various zones. Additional testing has been conducted by the USGS to evaluate the transmissivity and flow capacity of each alluvial interval to facilitate selection of appropriate intervals for tracer testing.

4.2.3 Alluvial Testing Complex Tracer Testing

The primary objectives of the ATC are to evaluate and refine the conceptual transport models used in the site-scale saturated zone model for dissolved radionuclides and colloids and to obtain field-scale parameters for use in transport model simulations. The primary tools for achieving these objectives are single-well and cross-hole tracer tests. This suite of tests will augment the testing carried out in the C-wells Complex, which examined transport through the fractured volcanic tuffs. The ATC tracer tests will play a similar role for transport through the alluvium.

Single-well tracer tests generally involve injecting a tracer solution into the formation through a selected well screen, pushing the tracer out into the formation with chase water previously obtained from the formation, an optional rest period where pumping is stopped for a period of time, and then pumping (pulling) the solution back from the formation into the selected well screen. To date, there have been three single-well tracer tests performed in NC-EWDP-19D, all within the uppermost screened depth interval. Tracers and rest periods used in these tests were:

- 2,4 difluorobenzoic acid and microspheres with zero rest period
- 2,6 difluorobenzoic acid and iodide with a 2-day rest period
- Pentafluorobenzoic acid and bromide with a 30-day rest period.

Analysis of the tracer recovery data is still ongoing. A preliminary plot of the percentage tracer recovered for the three tests versus the volume of water pumped is shown in Figure 4.2-6.

Cross-hole tests are more suitable for deriving field-scale transport parameters. Following the drilling of at least two more wells, planned cross-hole tracer tests will involve injecting tracers into two of the new wells shown in Figure 4.2-7. NC-EWDP-IM1 and -IM2 will be used for injection and monitoring, and NC-EWDP-19D will be pumped. NC-EWDP-IM3 and -IM4 will be constructed if funding is available and will be initially used as monitor wells.

The depth interval selected for cross-hole testing will be isolated from the remaining screens in NC-EWDP-19D and -IM2 by custom straddle packer/pump assemblies. The same test interval, as well as all other screened intervals in NC-EWDP-IM1, will be isolated with Westbay® packer systems. Screen intervals in NC-EWDP-IM3 and -IM4 may also be isolated with Westbay®

packer systems if funding permits. Alternatively, these boreholes may be completed as permanent piezometers.

Cross-hole testing will begin by pumping the selected test interval in NC-EWDP-19D while recirculating a portion of the pumped water into NC-EWDP-IM1 or -IM2. After pressures stabilize, a mixture of conservative (a halide and a fluorobenzoic acid [FBA]) and reactive (lithium) tracers, including microspheres, will be injected into the injection well (NC-EWDP-IM1 or -IM2). Pumping and recirculation will continue for approximately 2 months after injection.

Conservative tracers will be injected into both NC-EWDP-IM1 and -IM2 within 1 or 2 weeks of each other. Each tracer injection will be pushed into the aquifer with a measured volume of chase water. A single tracer (probably an FBA) will be injected into one injection well, and an FBA and a halide will be injected into the other injection well. These tests will continue until the rate of tracer recovery becomes insignificant for the tracers tested, or until the expiration of the discharge permit.

4.3 AMARGOSA VALLEY/YUCCA MOUNTAIN NUMERICAL MODEL

This section presents an evaluation of the steady-state boundary condition assumption and the conceptualization of the alluvial aquifer in preliminary DOE regional-scale groundwater flow modeling (D'Agnese et al., 1997) that encompasses the AVYM area, as shown on Figure 4.3-1. The NWRPO developed the AVYM model by extracting that portion of the original DVRFS model pertaining to the AVYM area (NWRPO, 2001b). The MODFLOWP numerical code (Hill, 1992) was used in both the DVRFS and AVYM simulations.

The appropriateness of assuming a steady-state boundary condition in DOE's preliminary DVRFS modeling was evaluated by averaging and interpolating groundwater level observations in the AVYM area over four 10-year periods and one 7-year period between 1950 and 1997. A comparison of the average water levels over these five time periods suggests a general trend of increasing water levels between 1947 and 1997 (NWRPO, 2001b). Figure 4.3-2 shows this trend for the 2,200 and 2,300 ft (671 and 701 m) contour levels for two decades. This trend suggests that the AVYM saturated region has been under transient conditions, rather than steady-state conditions, during this relatively short time interval.

Historical groundwater level data described above are contained in the Nye County geological database (Section 2.4). Since QA review and verification of data in this database have not yet been completed by the NWRPO, the water level trends presented above and in the following section should be considered preliminary and subject to revision.

Following the extraction of the AVYM model from the larger DVRFS model, steps were taken to verify the AVYM model and to modify the AVYM model boundary conditions to support the evaluation of DOE modeling assumptions.

Transient and steady-state modeling were conducted with the AVYM model to evaluate the sensitivity of simulated hydraulic head outputs to both the contrast in the hydraulic conductivity between alluvial channels and surrounding sediments and to the width of the alluvial channel.

Conclusions and recommendations based on water level analyses and modeling results include the following:

- Since an analysis of AVYM area groundwater level data suggests that transient flow conditions may have occurred over the past 50 years, it may be more appropriate to calibrate the AVYM model to these transient flow conditions than to assumed steady-state conditions.

- The greater the contrast in hydraulic conductivities between alluvium and surrounding sediments, the greater the concavity of simulated heads along the main axis of alluvial channels.

- Small differences were observed between transient simulation head results for different alluvial channel widths. These simulated heads also differed from average measured water levels, which may, in part, be due to possible errors in average water level data and/or to errors in calibrated apparent transmissivity values assigned to major aquifer layers.

- The sensitivity of the AVYM saturated zone model to alluvial channel width and to contrasts in hydraulic conductivities between alluvium and surrounding sediments demonstrates the need to modify the conceptual model of the alluvial deposits in future versions of the regional DVRFS model.

- Finally, prior to any future groundwater modeling efforts, additional work is recommended to develop a more comprehensive geologic conceptual model of the area, refine the flow system boundary between the Amargosa Desert area and Death Valley, determine the impacts of warmer water moving up through fault zones on the shallow flow system, and incorporate additional known recharge and discharge areas into the observed data set to improve the results of future calibration efforts.

4.3.1 Sensitivity Analyses

Steady-state simulations of hydraulic heads were conducted with 3,000-m-wide alluvial channels for scenarios where the contrast in the hydraulic conductivity between alluvial channels and surrounding sediments was varied over several orders of magnitude. An example of these simulations is presented in Figure 4.3-3. In these simulations, alluvial channel hydraulic conductivity (K_{river}) was set at 21.2 m/day. In Scenario 1 (shown in Figure 4.3-3a), the DVRFS hydraulic conductivities of surrounding sediments greater than 1 m/day (K_u) were set equal to 1 m/day; and in Scenario 2 (shown in Figure 4.3-3b), the DVRFS hydraulic conductivities of surrounding sediments greater than 0.01 m/day (K_u) were set equal to 0.01 m/day. Comparison of Figure 4.3-3a with -3b shows that simulated hydraulic head contours exhibited a greater concavity along the alluvial channels in Fortymile Wash and Amargosa River in Scenario 2 than in Scenario 1. That is, the greater the contrast in hydraulic conductivities between alluvium and surrounding sediments, the greater the concavity of simulated heads along the main axis of alluvial channels.

Transient and steady-state simulations of hydraulic heads by the AVYM model containing 3,000-m-wide alluvial channels were also compared to each other and to measured water levels averaged over 50 years (Figure 4.3-4). The hydraulic conductivity of the alluvial channel sediments (K_{river}) was set at 21.2 m/day and the hydraulic conductivities of the surrounding sediments were unchanged from the original DVRFS model. The simulated hydraulic head contours were noticeably different for transient and steady-state conditions, and both simulations differed significantly from average measured water levels. The transient simulation results agreed with average measured values slightly better than the steady-state simulation results.

Transient simulation results for 3,000-m-wide alluvial channels and for 15,000-m-wide alluvial channels were compared to each other and to measured water levels averaged over 50 years (Figures 4.3-4b and 4.3-5, respectively). The hydraulic conductivity of the alluvial channel sediments (K_{river}) was set at 21.2 m/day and the original DVRFS hydraulic conductivity values in surrounding sediments remained unchanged. The simulated head contours for the 3,000- and 15,000-m-wide alluvial channel scenarios differed noticeably; however, simulated contours for the 15,000-m-wide alluvial channel were in slightly better agreement with average measured water levels than simulated contours for the 3,000-m-wide alluvial channel. For example, the 15,000-m-wide channel simulation (Figure 4.3-5) shows greater concavity of the 800-m contour north of the EWDP Phase I wells than the 3,000-m-wide alluvial channel simulation (Figure 4.3-4b).

Reasons for the overall relatively poor agreement between transient simulation hydraulic head results and averaged measured values, as well as the slightly better agreement for the 15,000-m-wide channel simulation, are unknown and may be related to possible errors in average water level data and/or to errors in calibrated apparent transmissivity values assigned to major aquifer layers.

4.3.2 Transient Results versus Steady-State Results and Measured Water Levels

At the Devils Hole Workshops in 1998 and 1999, the issue of steady-state versus transient conditions was brought up by Nye County. Some of the early groundwater flow models for the area assumed steady-state conditions over the model domain. This assumption may be in error in periods when climatic conditions or groundwater developments significantly changed the hydrologic flow regime. Such periods represent transient rather than steady-state conditions, and errors in calibrating formation hydraulic conductivities to observed groundwater levels can occur if a system is assumed to be in steady state when transient conditions actually apply.

With the aid of new information obtained from the EWDP wells, future simulations may lead to a better understanding of the hydraulic behavior of the system. The geologic modeling described in Section 2.4 will also support more detailed conceptualization and more realistic models of the alluvial valleys in both Fortymile Wash and Amargosa Valley.

5.0 OTHER STUDIES

This section presents an overview of the geothermal resource potential of Nye County in light of EWDP findings and a summary of the results of regional studies performed by Inyo County.

5.1 GEOTHERMAL RESOURCE EVALUATION

In the *Yucca Mountain Site Description* document, the DOE reported on evaluations of geothermal resources of the Yucca Mountain region and concluded that there are no economically viable resources in the vicinity of the proposed repository (DOE, 2000d, pp. 4.9-13 to -14). This conclusion is based on the reported lack of geothermal discoveries, the lack of potential users, the lack of systematic structural evidence for a thermal anomaly, and non-thermal geochemical signatures of the groundwater in the region. However, recent results of the low-level magnetic survey and preliminary results from Nye County's EWDP suggest that the geothermal resource potential may be greater than originally thought.

Several known geothermal resource areas occur in northern Nye County. Geothermal resource areas include 52 springs and 20 wells with reported warm or hot water (exclusive of Nye County's EWDP wells). Statewide geothermal resource assessments were completed by Garside and Schilling (1979), and Garside (1994). Figure 5.1-1 shows the locations of known geothermal resources of Nye County, and Table 5.1-1 provides summary information about these resources. Only low-temperature geothermal resources (less than 90 °C) have been identified within the county.

The lack of significant geothermal resources over much of eastern and central Nye County is due to the presence of the Eureka heat flow low, a regional hydrologic feature in which colder water recharges the regional aquifer system. Thermal springs within the Eureka heat flow low tend to have lower temperatures than those located in northwestern and southern Nye County.

Except for data from a few springs and deep wells, little is known about the geothermal resource potential of the Amargosa Desert hydrographic basin. Kilroy (1991) noted that cool water areas (less than 20 °C) coincide with probable surface water recharge to the aquifers (Fortymile Wash, Amargosa River channel, etc.). The warmest area (greater than 30 °C) was along the Pahrump Hills (eastern Ash Meadows), where numerous springs discharge from Paleozoic carbonate rocks. Farmers and other well owners in the community of Amargosa Valley have reported distinct temperature variations over short distances between wells, but these observations have not yet been confirmed.

In the Yucca Mountain region, minor geothermal resources are known to occur in the Beatty, Crater Flat, and Ash Meadows areas, as well as at Test Well F in Rock Valley on the Nevada Test Site (Table 5.1-1). The highest reported temperature was at Test Well F (64 °C). Groundwater temperatures in the Ash Meadows area were reported to range from 27 °C at Longstreet, Fairbanks, and Rodgers springs, to 33 °C at Devils Hole. Two wells in Yucca Flat had reported temperatures of 37 to 42 °C. PM-2, situated in the northwesternmost portion of the Nevada Test Site, had a reported temperature of 66 °C at a depth of about 1,969 ft (600 m).

Nye County's EWDP also encountered thermal waters at three locations in north-central Amargosa Desert (NC-EWDP-1DX, -2DB, and -3D) (Nye County, 2001). Temperature logging at NC-EWDP-1DX measured a maximum temperature of 52 °C at a depth of 2,500 ft (762 m), 67 °C at the same depth at NC-EWDP-3D, and 62 °C at a depth of 1,900 ft (579 m) at NC-EWDP-2DB. NC-EWDP-2DB will be relogged at a future date following final clean-out and well completion.

The wells with the highest temperature profiles and the thermal springs are situated along major geologic structures, including the Rock Valley fault zone (Test Well F), Winograd's gravity fault (the springs at Ash Meadows) as defined by Winograd and Thordarson (1975), and the Highway 95-Carrara fault zone (NC-EWDP-1DX, -2DB, and -3D). These findings are consistent with the conclusion in the *Yucca Mountain Site Description* document (DOE, 2000d) that thermal fluids, where they exist, are restricted to faults, fractures, breccia zones, and the deep Paleozoic aquifers.

Also of note is the occurrence of probable buried volcanic features at locations where these structures intersect. These features appear on the magnetic anomaly maps prepared by Blakely et al. (2000a) as sharp magnetic anomalies that range in size from a few square kilometers to more than 20 km^2. Crustal thinning may provide an avenue for conductive rise of heat from depth at the intersect. Alternately, breaching of the carbonate aquifer system by these features may allow hot water upwelling near these now-buried volcanoes.

Historically, the geothermal resources of Nye County have had almost no development. With the exception of a few recreational facilities, hot well or spring water is usually regarded as a nuisance, and the water must be cooled for domestic or irrigation use. In the near future, the proposed Gate 510 and Desert Rock industrial parks might have a use for low-temperature geothermal resources for heating and process water.

5.2 INYO COUNTY REGIONAL STUDIES

The overall goal of Inyo County's studies was to evaluate several important hydrogeologic issues in the vicinity of Death Valley that are related to potential groundwater flow and transport from beneath Yucca Mountain to Death Valley. Ultimately, Inyo County is concerned with the impact of this potential groundwater connection or linkage on human health, safety, and the environment in Death Valley.

5.2.1 Statement of Problem and Approach

Preliminary data collected by Inyo County and other investigators suggest a possible relationship between the carbonate spring waters in Death Valley and the lower carbonate aquifer in the vicinity of Yucca Mountain. This evidence includes geochemical analyses of spring and groundwater samples and structural geology mapping of the southern Funeral Mountains.

The USGS's DVRFS model (D'Agnese et al., 1997) has incorporated some of this evidence and currently includes a potential pathway for inter-basin groundwater flow from Amargosa Desert to Death Valley through the lower carbonate aquifer. However, numerous major data gaps exist in this flow model, including evapotranspiration values for Death Valley, inflow into Death

Valley from the Amargosa River, infiltration into the Death Valley mountain ranges, the source of spring waters in Death Valley, groundwater level data, aquifer hydraulic properties, and hydraulic boundary conditions in Death Valley.

Inyo County fully supports the development of a technically defensible and realistic DVRFS model for use in predicting possible travel times of groundwater and contaminants from Yucca Mountain to Death Valley, and for helping to manage limited groundwater resources. Toward this end, Inyo County, in several cases in cooperation with the USGS, has designed and implemented the following studies to help fill data gaps in the DVRFS model: geochemical analysis of spring water associated with the Death Valley basin to better characterize the source of these waters; measurement of evapotranspiration rates in the saltpan and upland areas of Death Valley to improve previous estimates of groundwater discharge; installation and monitoring of stream gauges on the Amargosa River at Tecopa and Dumont Dunes to estimate surface flows to Death Valley; determination of infiltration rates into mountain blocks at Gold Valley to establish reference infiltration rates for estimating recharge into the Death Valley mountain ranges and to evaluate the applicability of the USGS's Yucca Mountain method of determining infiltration; conduction of time domain electromagnetic and seismic refraction soundings along the eastern edge of Death Valley to better understand the role of faults in the connection of major springs with the underlying aquifer; and modeling of the water balance for the Amargosa River to gain insight into recharge and discharge processes.

5.2.2 Summary of Activities and Results of Spring Water Sampling and Analysis

5.2.2.1 Spring Water Sampling and Analysis

Thirteen water samples from Death Valley springs and two from Amargosa River were collected, preserved, and shipped to designated laboratories in accordance with USGS YMP groundwater sampling protocols. Samples were analyzed for strontium isotopes, uranium-234 and uranium-238 isotopes, and oxygen/deuterium by the USGS and for major anions and cations by a commercial testing laboratory. Preliminary results indicate water sampled and analyzed from small-local springs in mountain ranges in the vicinity of Death Valley have a major ion signature that groups the waters by mountain range. This grouping of water chemistry by mountain range is significant in determining the source of spring waters in the Death Valley region.

5.2.2.2 Death Valley Evapotranspiration Studies

This research was a continuation of the USGS's evapotranspiration studies in Death Valley. The USGS installed and monitored evapotranspiration measurement stations at two locations where remote sensing data indicated that evaporative discharge was likely to be significant: one in Gold Valley and another in the Mesquite Flats area. The Gold Valley station is located at an approximate elevation of 3,400 ft (1,036.6 m) above mean sea level, and the Mesquite Flat station is at approximately sea level. Data collected at each evapotranspiration station beginning in January 1999 and ending in May 2001 included air temperature, wind speed, relative humidity, surface and subsurface soil temperatures, vegetation temperature, soil heat flux, and net radiation.

Evapotranspiration rates were determined from these data using the Bowen Ratio-Energy Budget method (Bowen, 1926). Evapotranspiration values measured for this study are provided in Figure 5.2-1. The maximum daily evapotranspiration rate for the Mesquite Flat station for January to May 2001 was 5.4 mm/day, and for the same period in 2000 was 5.1 mm/day. The maximum evapotranspiration rate for the Gold Valley station for January to May 2001 was 1.0 mm/day. Evapotranspiration rates for Mesquite Flat during the summer of 2000 are in many cases more than 10 times higher than in Gold Valley. The elevation difference between stations is most likely responsible for the large differences in evapotranspiration rates.

5.2.2.3 Installation and Monitoring of Stream Gauging Stations

The USGS installed stream-gauging stations in September 1999 on the Amargosa River at Tecopa and Dumont Dunes, California. Gauging station data were recorded on a data logger and collected by the USGS once a month for approximately 2.5 years. A summary of stream flow rates at each station is posted on the USGS web site http://nevada.usgs.gov (Station ID's 10251300 and 10251375) (USGS, 2001b). Measured base stream flows for the Dumont Dunes and Tecopa stations from January 2000 to May 2001 were approximately 2.5 and 1 ft^3/s (0.071 and 0.028 m^3/s), respectively. Peak storm flow at both stations ranged from 25 to 45 ft^3/s (0.71 to 1.28 m^3/s). Stream flow data indicate high discharge events are due to severe thunderstorms over relatively small portions of the Amargosa River drainage basin.

5.2.2.4 Gold Valley Infiltration Study

Gold Valley, located in the approximate north-south center of the Black Mountain Range, was selected for the infiltration study because it appeared to be hydraulically isolated from adjacent drainage basins. The basin is a pie-shaped bowl defined by relatively steep bedrock valley walls that extend below a broad colluvium/alluvium-filled valley. The average elevation of the valley floor is approximately 1,200 m above sea level, and the drainage basin surface area is approximately 9.6 km^2 (Figure 5.2-2). The water-bearing bedrock materials are fractured metamorphic rocks with negligible matrix permeability. Therefore, the movement and storage of groundwater is controlled by secondary fracture permeability. Finally, surface water discharges from the valley are through Willow Creek into Death Valley. The perennial Willow Spring, located at the headwater of Willow Creek, is the discharge point for drainage from Gold Valley.

Discharge from this spring was monitored for about a 2-year period beginning in August 1999. Net infiltration rates were calculated from these discharge data together with rainfall and evapotranspiration data (collected as described in Section 5.2.2.2) using the water budget modeling code HYMET, an unpublished numerical code developed by Hydrometrics.

Preliminary results of the infiltration study include:

- Precipitation at Gold Valley during 1999 and 2000 was 23 and 61 percent below normal, respectively, based on the 1950 to 2000 precipitation records at Death Valley, Wildrose, Shoshone, and Trona.

- Simulated Willow Creek hourly discharge rates using the HYMET model, based on temperature and precipitation observations, are in reasonable agreement with measured discharges. The mean R-squared (coefficient of determination) calculated from a regression of hourly simulated and observed flows is about 0.45, and of daily flows about 0.55.

- The dominant water-loss factor in this watershed is evapotranspiration of groundwater released from storage. Most precipitation, at least during the past 2 years, appears to be absorbed by the moisture-deficient soil, then immediately lost to evaporation.
- Model results indicate that recharge to the Gold Valley drainage basin is approximately 93 percent of the measured precipitation (Figure 5.2-3). However, the last effective recharge period was probably in 1998, when regional precipitation was more than 200 percent of normal. Therefore, the current discharge of Willow Creek is likely to be from groundwater that was stored in 1998 and in previous years.
- It is not possible at this time to state whether the discharge of Willow Creek is partly derived from a water source outside of the Gold Valley drainage divides.

5.2.2.5 Geophysical Investigation of the Western Flank of the South Funeral Mountains

A series of time domain electromagnetic and seismic refraction soundings were conducted at the Travertine, Texas, and Nevares springs along the eastern edge of Death Valley, and at the Grapevine Spring in Death Valley. The data suggest that regional faulting controls the position of the springs that discharge in this area, as schematically illustrated in Figure 5.2-4. This interpretation is consistent with the results of independent seismic reflection and airborne magnetic surveys conducted by the USGS (Machette et al., 2000). Taken together, these surveys indicate that structural features play an important role in the groundwater flow system of the area.

5.2.2.6 Amargosa River Water Balance Modeling

The hydraulic model of the Amargosa River system suggests that there may be significant transfer of groundwater inflow into the basin through the lower carbonate aquifer in adjacent areas (Bredehoeft et al., 1996) Measured stream flows exceed what would be expected for published evapotranspiration rates and precipitation. Annual groundwater inflow may be on the order of 0.5 cm of water averaged over a drainage area of about 33,000 a. (1.33×10^8 m^2).

6.0 SUMMARY OF MAJOR FINDINGS AND RECOMMENDATIONS

Major findings from ISIP studies described in this report that potentially affect human health, safety, and the environment in Nye and Inyo Counties are summarized below. In addition, recommendations for additional work needed and/or DOE action are also summarized.

6.1 REGIONAL GEOLOGIC STUDIES

Major findings:

- A high-resolution aeromagnetic survey was obtained over the Amargosa Desert and Pahrump Valley region. The analysis of the survey data indicated numerous magnetic anomalies (lineaments). These lineaments may coincide with faults that offset relatively shallow volcanic units, or with the presence of strongly magnetic basement rocks.

- Some of the major trends in these lineaments appear to define boundaries of groundwater basins that may act as groundwater compartments. Other lineaments associated with the State Line fault appear to connect Pahrump Valley, Stewart Valley, and Devils Hole, and terminate near the Rock Valley fault zone, possibly indicating a hydraulic connection between these areas.

- New and existing gravity data from this same region have been analyzed and interpreted to develop a three-dimensional representation of the contact between valley-fill sediments and basement rock (i.e., the basement rock surface).

- A major feature in the basement surface is the deep and relatively narrow basin (Amargosa Trough) that extends from beneath Yucca Mountain to south of Shoshone, California. This basin is divided into sub-basins by ridges in the basement rock corresponding to the Rock Valley, State Line, and Furnace Creek fault systems.

Recommendations:

- Reprocess existing aeromagnetic data to determine if numerous subtle magnetic features that align with springs or spring deposits correspond to faults, buried channels, or other subsurface features that may affect groundwater flow or spring discharge.

- Continue the study of structural relationships and kinematic analysis of fault patterns to improve understanding of the role fault systems play in defining basin and sub-basin (compartment) boundaries.

- Continue surface geologic mapping of quadrangles in the Pahrump and Amargosa Desert hydrographic basins to improve understanding of regional recharge and discharge, and the effect of structures on groundwater flowpaths. This work will also support land and water use planning and water management in local communities.

- Incorporate new ISIP surface geophysics and borehole data into the geologic framework database and model.

6.2 UNSATURATED ZONE STUDIES

6.2.1 Borehole Investigations

Major findings:

- Dual-wall reverse circulation drilling methods can produce minimally disturbed drill cuttings suitable for petrographic and chemical analysis. Wells drilled using these techniques can be successfully instrumented with retrievable Westbay® equipment for unsaturated zone monitoring.

- Pneumatic pressure monitoring in unsaturated zone borehole USW NRG-4 before and after the excavation of the ESF through the PTn unit demonstrated that this unit slows the downward movement of gases from overlying units to the repository horizon and vice versa.

- Significant CFC concentrations more than 1,000 ft (304.8 m) below ground surface suggest that the Yucca Mountain unsaturated zone is a pneumatically open system in direct communication with atmospheric air.

- Petrographic analysis of drill cuttings from welded tuffs in UE-25 ONC#1 suggests that much of the past fluid flow in the unsaturated zone has been through fractures.

Recommendation:

- Continue borehole unsaturated zone monitoring to monitor potential impacts from the ESF and possible future repository construction.

6.2.2 Tunnel Ventilation-Related Studies

Major findings:

- Nye County successfully installed instruments to monitor temperature, pressure, humidity, and wind speed in the ESF and ECRB tunnels. Data obtained during construction and post-construction activities demonstrate that air movement in the repository tunnels is an effective method for removing heat and moisture from the repository.

- Numerical simulations indicate that natural ventilation has potential to keep the repository cool and dry for thousands of years, assuming the repository can be kept open during this time period and potential tunnel stability problems can be avoided.

Recommendations:

- Design and conduct an in situ ventilation experiment to collect tunnel and rock data to calibrate the Nye County and the DOE/YMP ventilation models.

- Use the calibrated Nye County ventilation model to evaluate alternative design factors that impact important host rock and repository conditions (e.g., temperature, humidity, and moisture). These factors in turn affect waste package degradation, contaminant transport, and the health and safety of Nye County residents.

6.2.3 Infiltration/Percolation Conceptual Model Evaluation

Major finding:

- Preliminary order-of-magnitude calculations indicate that the DOE/YMP approach to calculating net infiltration may result in unreasonably high percolation rates for present and future climates.

Recommendation:

- Continue to evaluate DOE/YMP infiltration and percolation models by modeling infiltration into soil and fractured rock with a code that couples the atmosphere with the soil (A-TOUGH©). This code should provide a more realistic estimate of net infiltration.

6.3 SATURATED ZONE STUDIES

6.3.1 Early Warning Drilling Program Borehole Drilling/Logging/Monitoring

Major findings:

- Nye County successfully drilled and completed more than two dozen holes with more than 20,000 ft (6,096 m) drilled in this program. Rock and fluid samples were obtained to help improve understanding and reduce uncertainty regarding the geology and hydrology of the Yucca Mountain and Amargosa Desert area.

- Valley-fill deposits have been shown to be very complex. Seven valley-fill units were identified: alluvial deposits, fluvial deposits, marsh deposits, basalts, volcanic deposits, undivided Tertiary sediments, and lower valley-fill deposits.

- Volcanic sediments appear to be finer grained near the margins of major washes than near the center.

- Nye County interprets the top of the Paleozoic rocks in NC-EWDP-2DB to appear much higher in the hydrostratigraphic columns than proposed by USGS geologists.

- Nye County further believes that geologic materials interpreted in several cases to be volcanic tuffs by the USGS, are instead volcanic sediments.

- Temperature logs in deep boreholes suggest that warm water is upwelling from carbonate basement rocks into overlying valley fill via faults and fractures.

- Water level monitoring in EWDP wells demonstrates an upward gradient from underlying carbonate basement rocks into the overlying valley-fill sediments. Downward gradients are observed locally in wells at paleospring sites.

Recommendations:

- Construct and test additional wells and conduct additional surface geophysical surveys between Yucca Mountain and potentially affected areas of Nye County to fill data gaps in these complex geologic and hydrologic systems.

- In addition to providing adequate spatial coverage, locate wells (where possible) to characterize aquifer properties within compartments and boundaries between compartments.

- Design and carry out geophysical surveys, including seismic reflection and square array resistivity surveys, to improve the delineation of compartment boundaries.

- Continue water level monitoring in wells to better characterize hydraulic gradients within and between compartments.

- Conduct additional lab and field tests to resolve differences in hydrogeologic unit interpretations between the USGS and Nye County.

6.3.2 Early Warning Drilling Program and Alluvial Testing Complex Aquifer and Tracer Testing

Major findings:

- Nye County successfully tested eight wells in these programs.

- With one exception, the aquifer tests demonstrated high permeabilities in valley-fill sediments and volcanic units ranging from 2.3×10^{-12} to 3×10^{-10} m^2. Different alluvial beds and volcanic rock units exhibited significantly different permeabilities.

- Different flow regimes were identified in these tests and modeled accordingly. Multiple flow barriers were interpreted to be present near some of the wells, at distances ranging from approximately 30 to 900 m from the wells.

- Aquifer testing of well NC-EWDP-19D, located at the ATC, showed an average permeability of 2.3×10^{-12} m^2 in alluvial beds and an underlying tuff zone. However, permeability is not evenly distributed between zones and some screen plugging was observed. Flow was interpreted to be linear between flow boundaries estimated to be approximately 700 ft (about 200 m) from the well.

- Pump-spinner tests were shown to be an effective tool for identifying permeable zones and determining their properties.

- Based on the aquifer test results, a preliminary conceptual compartment-like flow model was developed, which involves a series of fast flow pathways separated by lower permeability connections.

Recommendations:

- Continue to conduct aquifer tests (on the largest scale possible) to better define aquifer properties within compartments and the location and properties of flow barriers (i.e., boundaries between compartments or sub-compartments).

- Conduct additional single and cross-hole aquifer and tracer tests at locations between the ATC site and Yucca Mountain to better understand radionuclide transport and groundwater flow through saturated alluvium downgradient of Yucca Mountain.

6.3.3 Analysis of Early Warning Drilling Program Drill Cuttings and Water Samples

Major findings:

- Petrographic and chemical analyses of drill cuttings from NC-EWDP-3D found that naturally occurring low-grade uranium mineralization observed on a borehole gamma log is limited to a narrow depth interval of approximately 5 ft (1.5 m).

- Chemical analyses of drill cuttings from sediments in NC-EWDP-19D indicated significant differences in solid phase geochemistry between upper alluvial and lower valley-fill lacustrine sediments.

- Groundwater chemical analyses indicated that in most EWDP wells, the dominant cation type is sodium/potassium, and the dominant anion type is bicarbonate/carbonate.

- Dissolved bicarbonate concentrations in the water decreased with increasing distance from NC-EWDP-1DX, while Del ^{13}C was found to increase. These trends suggest decreasing proportions of water from the carbonate aquifer with increasing distance from NC-EWDP-1DX.

- Younger waters (highest percent of modern carbon) are found near the center of Fortymile Wash and older water near the margin of the wash.

- Trends in stable isotopes of water suggest possible relations with depth in the aquifer and with faulting. The latter trend supports aquifer compartmentalization hypotheses.

Recommendations:

- Continue water chemistry sampling and analysis to develop baseline water quality conditions and to support the delineation of flow compartments.

- Conduct additional systematic in-depth analyses of chemical data to determine additional trends within and between hydrostratigraphic units.

6.3.4 Conceptual Early Warning Drilling Program Hydrogeologic Model

Major findings:

- Hydrologic processes in the area include interbasin flow in the basement rock, upward leakage from the basement rock into the valley-fill sediments within basins, and interaction between surface waters and groundwater in areas where lower permeability sediments abut more permeable basement rocks.

- Basins and rock regions between basins are divided into aquifer compartments by faulting in volcanic and basement rocks. Since groundwater flow in the Amargosa Desert is derived primarily through subsurface flow from upgradient basins, a good understanding of flow within compartments or across compartment boundaries is necessary for accurate modeling and analysis of groundwater flow in this area. However, with several exceptions, the number and location of compartments and boundaries have not yet been well defined.

- Compartments and boundaries between compartments can either serve as groundwater flow pathways or as flow barriers. For example, the Rock Valley fault system compartment appears to be a highly transmissive flow pathway to Amargosa Desert, but the fault system at the southern boundary of the Crater Flat compartment appears to act as a flow barrier.

Recommendation:

- Continue to incorporate new ISIP hydrogeologic data into the conceptual model.

6.3.5 Amargosa Valley/Yucca Mountain Numerical Model

Major findings:

- An analysis of the AVYM area groundwater level data suggests that transient flow conditions may have occurred over the past 50 years. Therefore, it may be more appropriate to calibrate groundwater flow models of this area to transient flow conditions, rather than to assumed steady-state conditions.

- The AVYM model was found to be sensitive to contrasts in hydraulic conductivities between alluvium and surrounding sediments and, to a lesser extent, to alluvial channel width.

Recommendation:

- Modify the conceptual model of alluvial deposits in future versions of the regional DVRFS model to include new data regarding contrasts in hydraulic conductivity between alluvial channels and surrounding sediments.

6.4 OTHER STUDIES

6.4.1 Nye County Geothermal Resource Evaluation

Major findings:

- Elevated water temperatures ranging from 52 to 62 °C were observed in EWDP boreholes NC-EWDP-1D, -2DB, and -3D located along the Highway 95-Carrara fault zone.

- Although no commercially exploitable geothermal resources have yet been found, these findings suggest that the geothermal resource potential in this area may be greater than originally thought.

- The association of elevated water temperatures with a fault system penetrating the Paleozoic aquifer is consistent with the findings of previous workers investigating geothermal waters in Nye County.

Recommendation:

- Continue to measure temperature profiles in new ISIP boreholes to further characterize the geothermal potential of the Amargosa Valley area.

6.4.2 Inyo County Regional Studies

Major findings:

- Evapotranspiration studies in Death Valley found that evapotranspiration rates for Mesquite Flat were approximately five times those for Gold Valley in the winter and 10 times those for Gold Valley in the summer. These differences were attributed to elevation differences.

- Sampling and chemical analysis of small local springs in Death Valley identified major ion signatures that groups springs by mountain range.

- Peak flows measured along perennial flowing sections of the Amargosa River for a 2.5-year period beginning in 1999 ranged from 25 to 45 ft^3/s. These flows resulted from severe thunderstorms over relatively small portions of the drainage basin.

- Analysis of discharge measurements from Gold Valley over a two-year period from 1999 to 2000 showed that most of the precipitation was absorbed by the soil, and subsequently evaporated very quickly. Almost all of the surface water discharge can be accounted for as released groundwater that had been stored up during recent and past precipitation events.

- Surface geophysical studies at springs along the western flank of Death Valley suggest that regional faulting controls the position of the springs in this area.

- Hydraulic modeling of the Amargosa River suggests that there may be significant inflow of water into the Amargosa Desert basin via the lower carbonate aquifer.

Recommendation:

- Continue Inyo County studies to better delineate carbonate aquifer pathways (if any) between Yucca Mountain and Death Valley.

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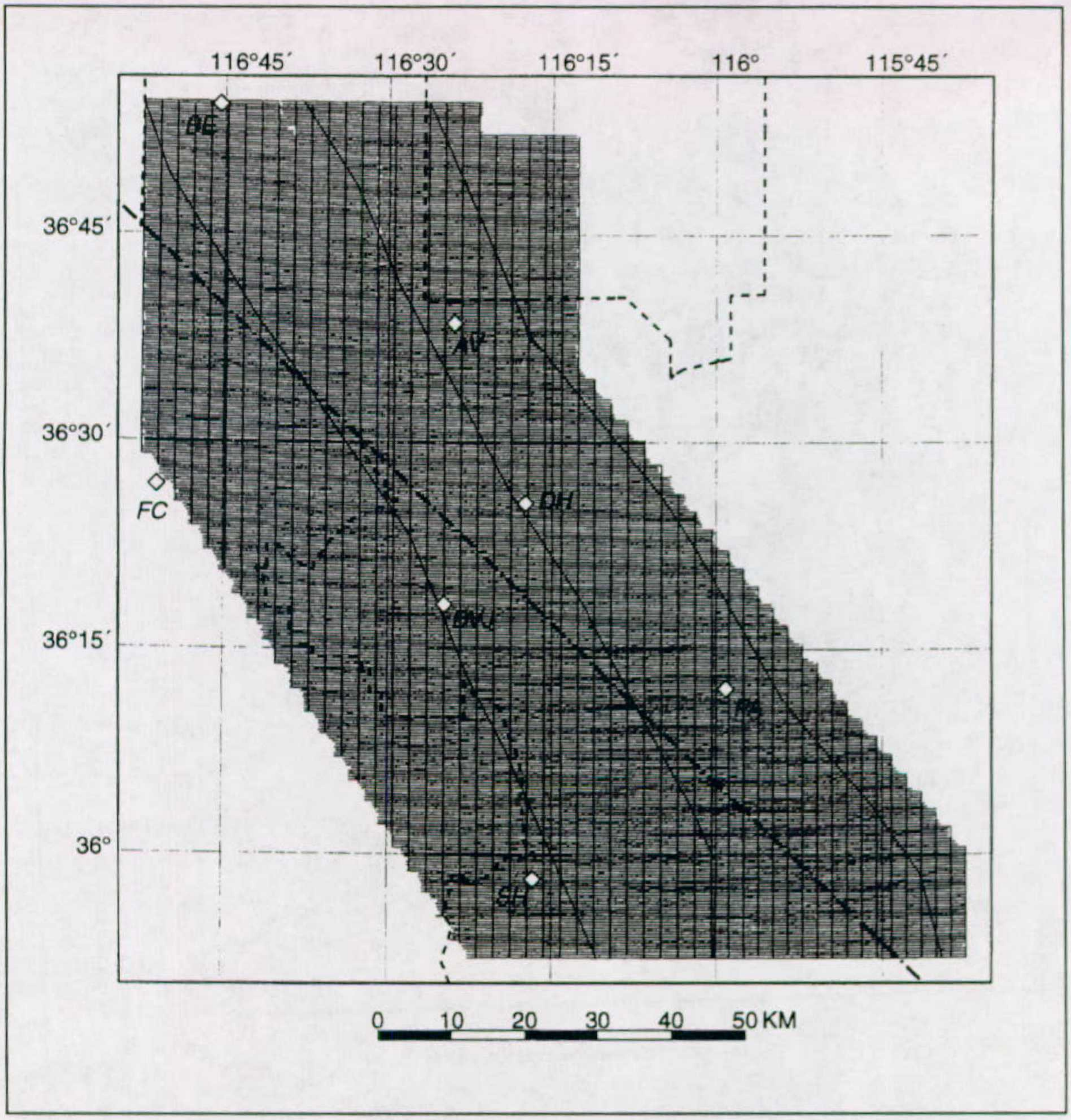


NOTE: AV = Lathrop Wells Intersection; BE = Beatty; DH = Devils Hole; DVJ = Death Valley junction; FC = Furnace Creek; PA = Pahrump Valley; SH = Shoshone Mountain

Figure 2.1-1
Location of Flight Lines for Magnetic Survey

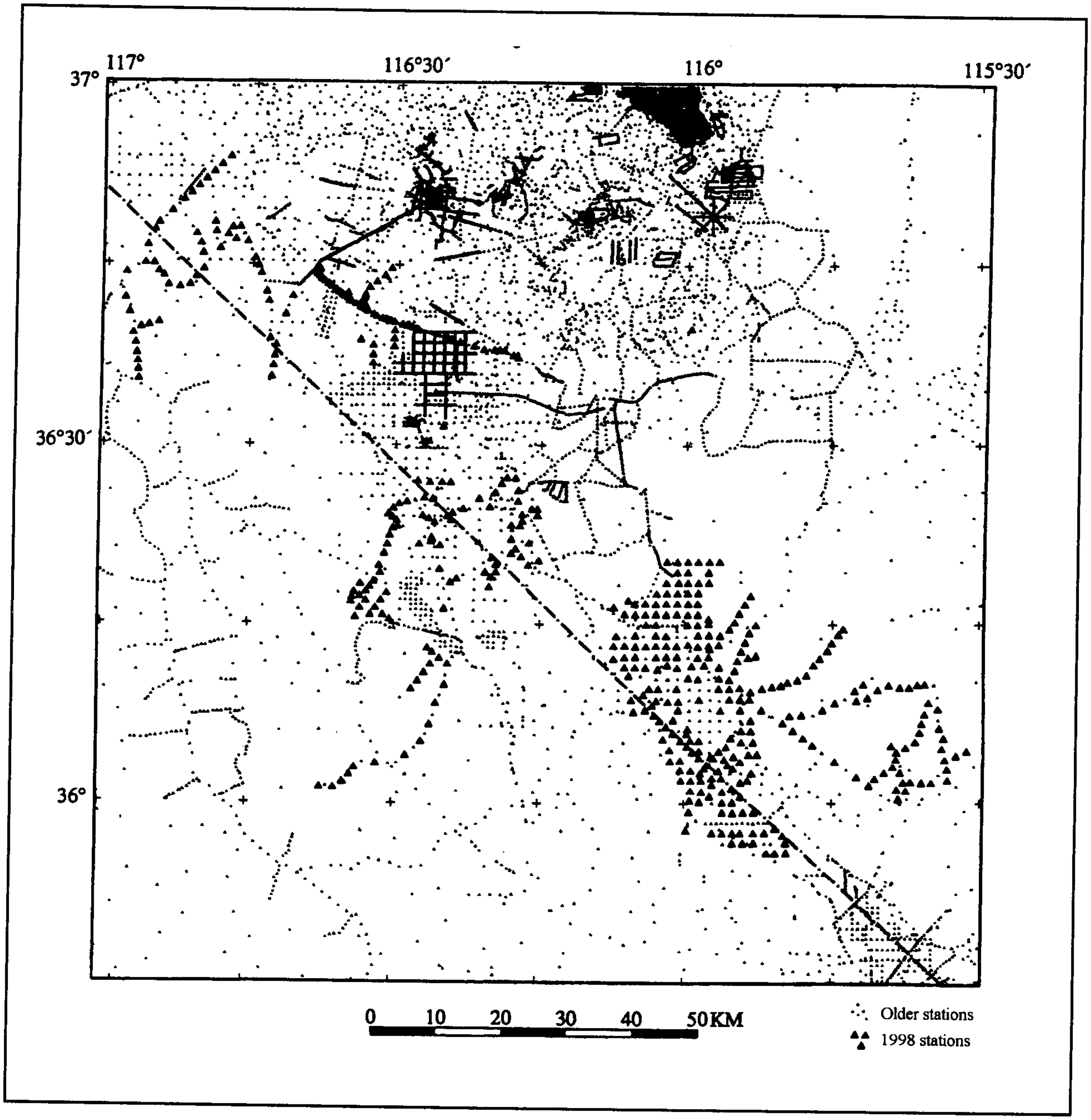
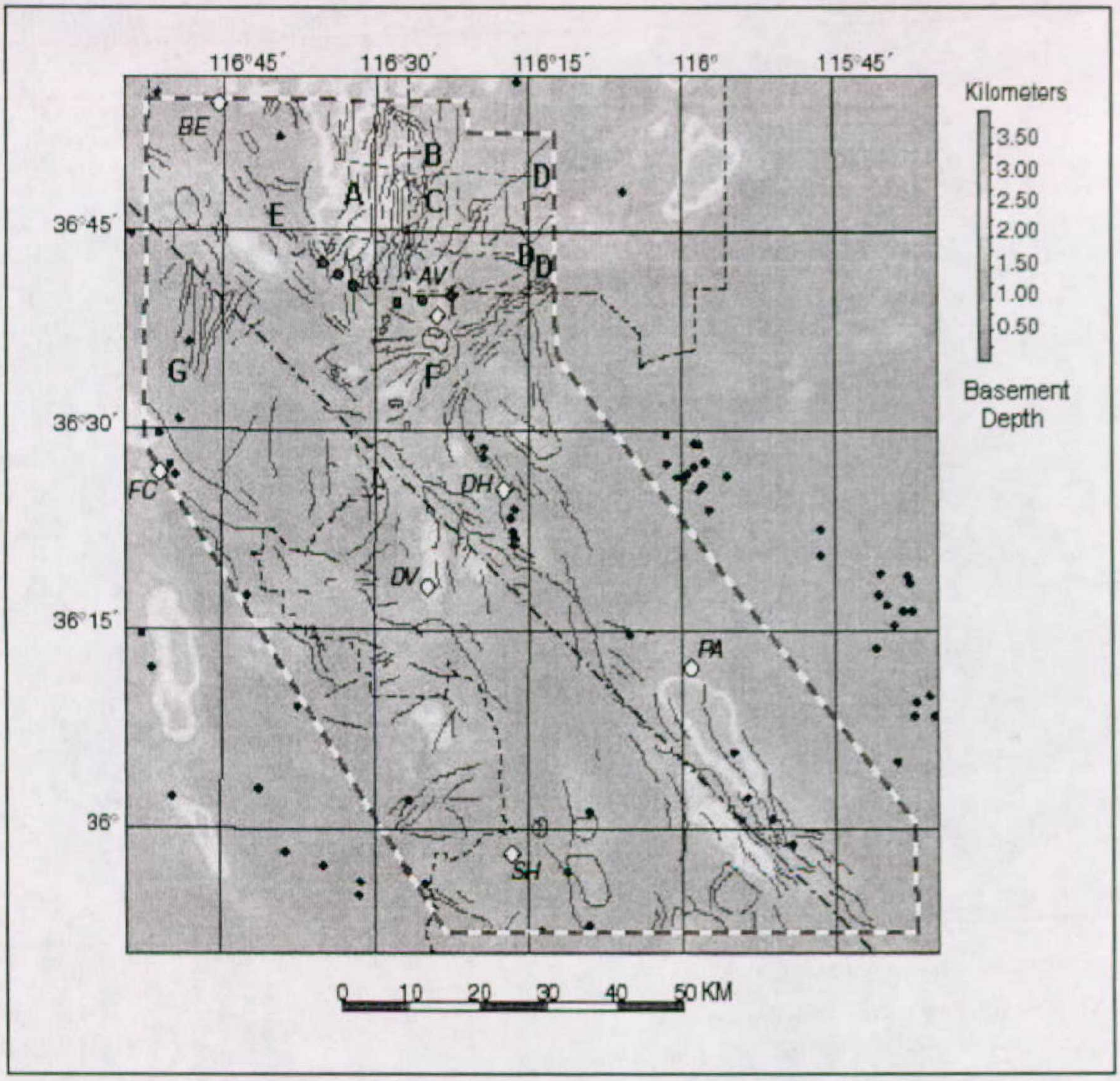


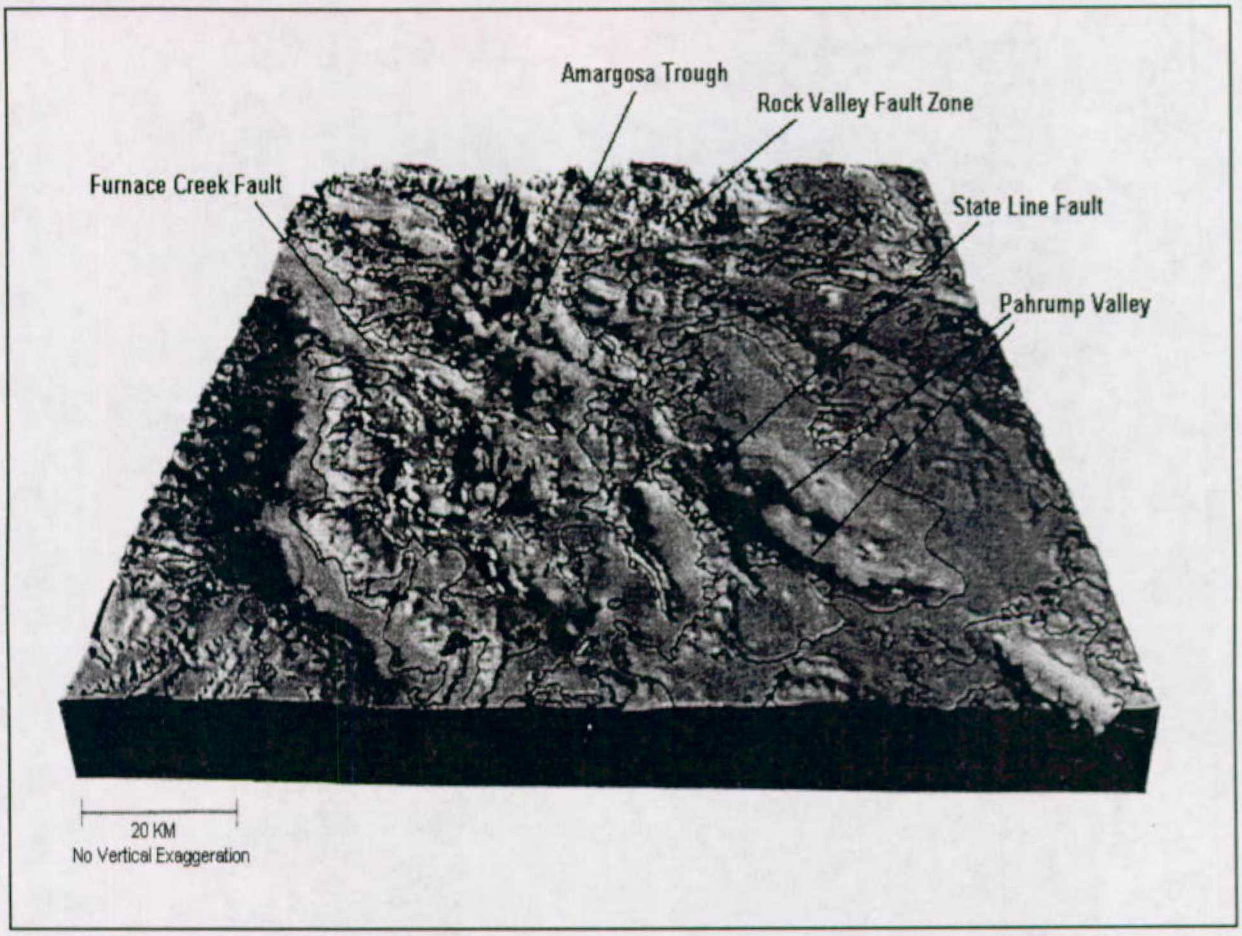
Figure 2.1-2
Location of Gravity Stations



Source: Modified from Blakely et al. (2000a)

NOTES: AV = Lathrop Wells Intersection; BE = Beatty; DH = Devils Hole; DV = Death Valley; FC = Furnace Creek; PA = Pahrump Valley; SH = Shoshone Mountain; See text for explanation of annotations A to G; black-filled diamonds are spring locations; white unfilled diamonds are the geographic locations noted above; gray-filled circles and squares are Early Warning Drilling Program well locations.

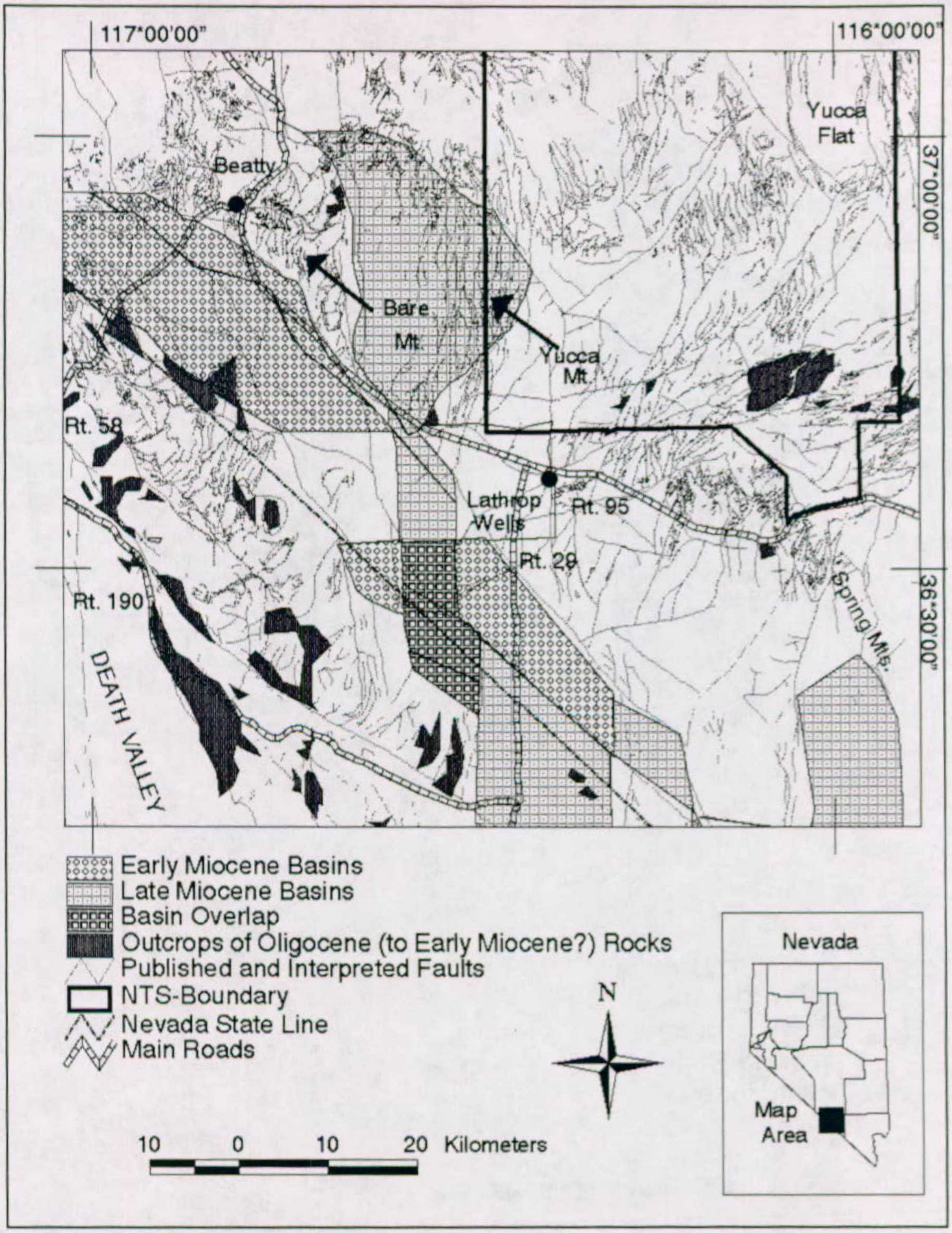
Figure 2.1-3
Magnetic Lineations on Basement Surface



Source: Modified from Blakely et al. (2000b)

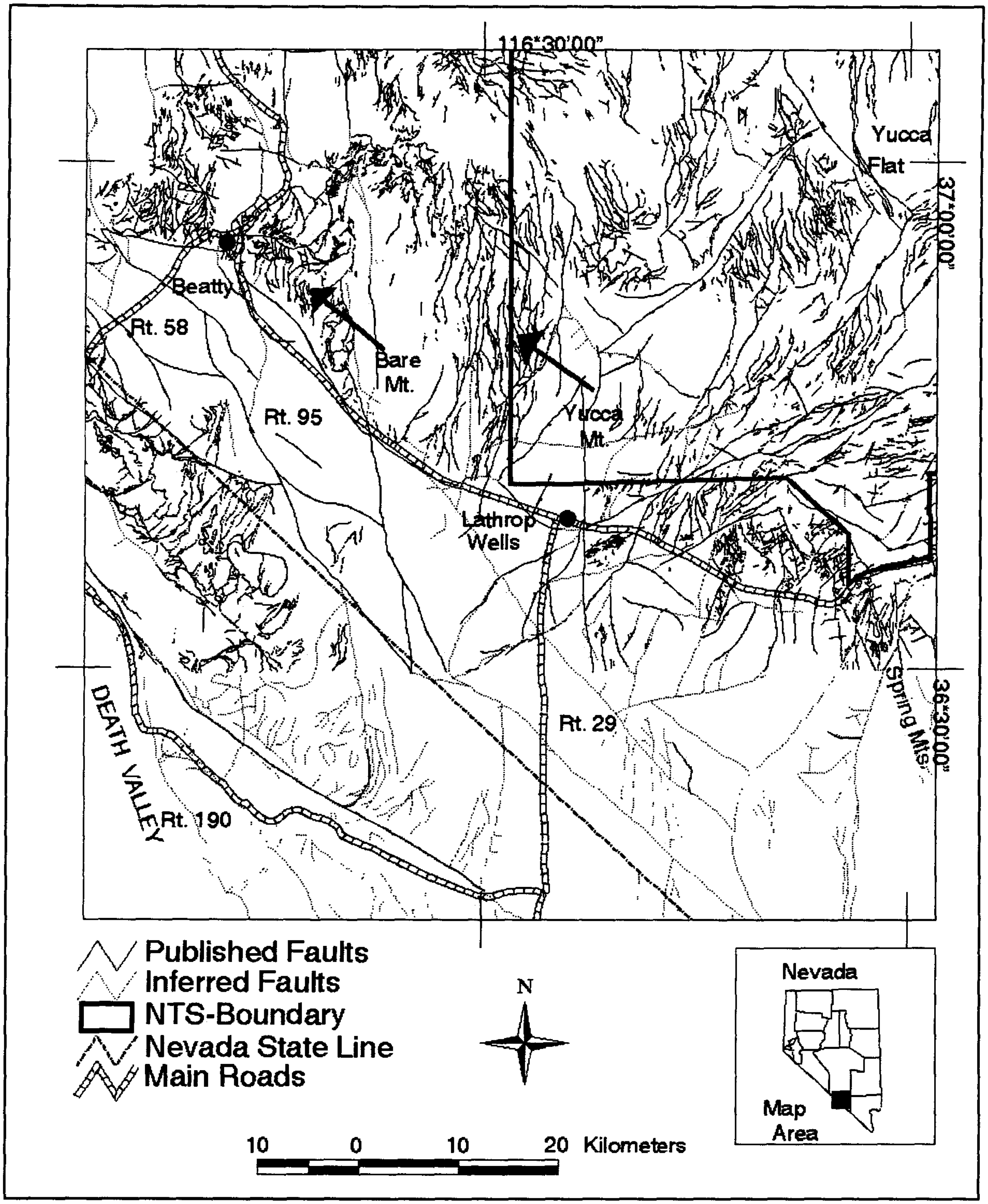
NOTE: Labeled features are discussed in the text.

Figure 2.1-4
Three-Dimensional Representation of the Basement under the Yucca Mountain Region



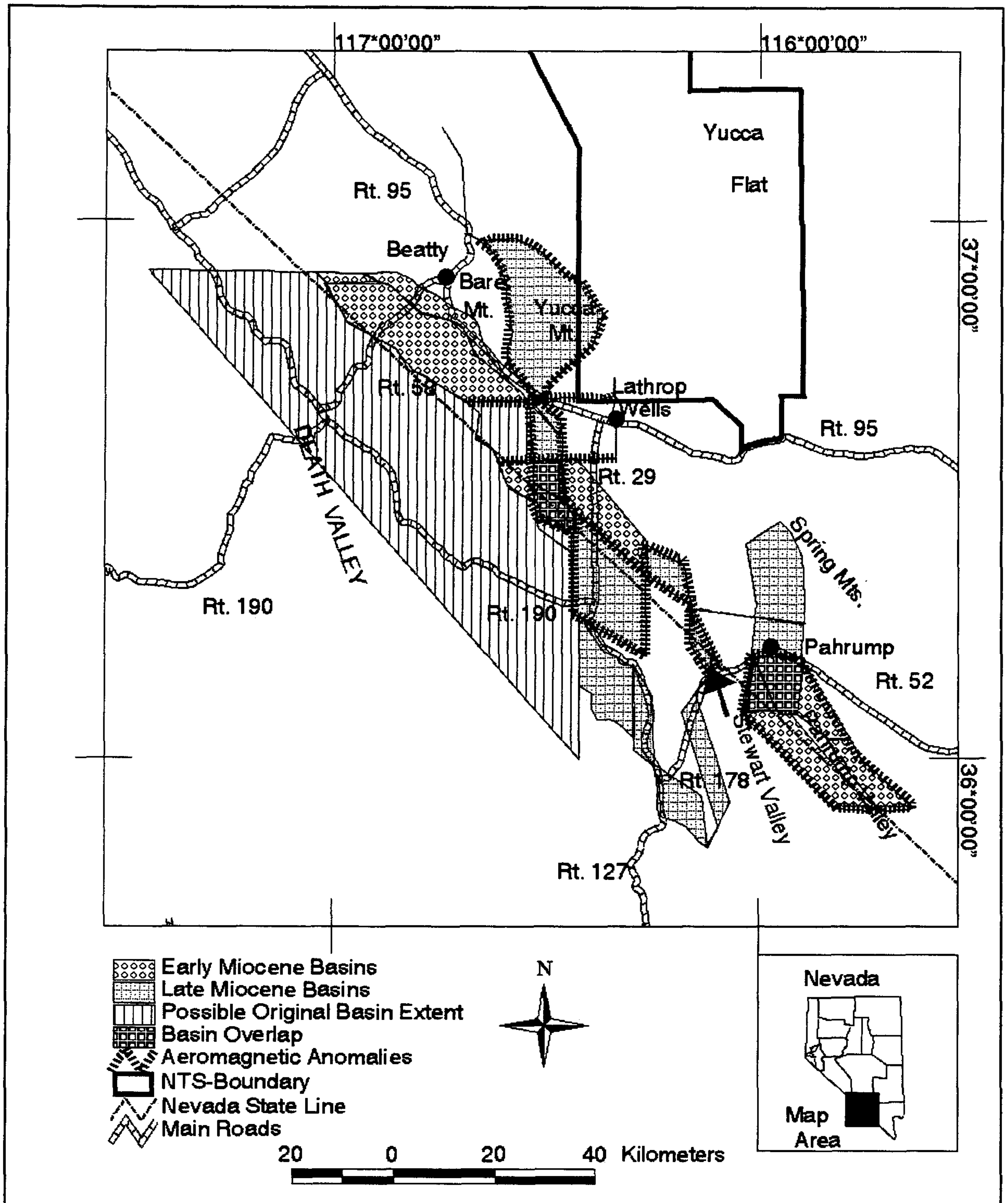
NOTE: NTS = Nevada Test Site

Figure 2.2-1
Structural Basins in the Yucca Mountain Region



NOTE: NTS = Nevada Test Site

Figure 2.2-2
Map of Known and Inferred Faults in the Yucca Mountain Region



NOTE: Some basins are bounded by aeromagnetic anomalies. Each basin or structural compartment contains possible groundwater-bearing strata, underlying recent alluvium. NTS = Nevada Test Site.

Figure 2.2-3
Map of Known and Inferred Basins in the Yucca Mountain Region

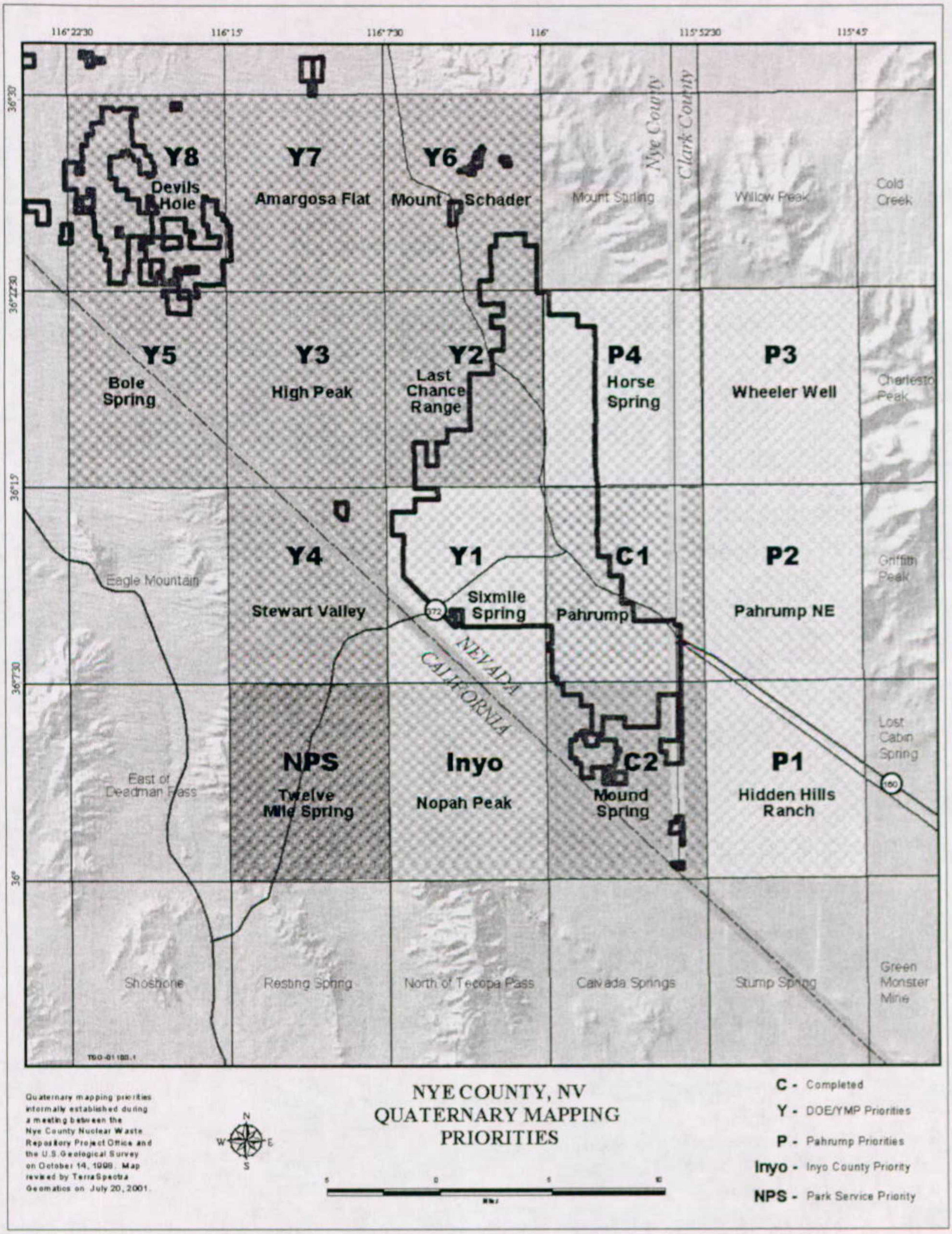
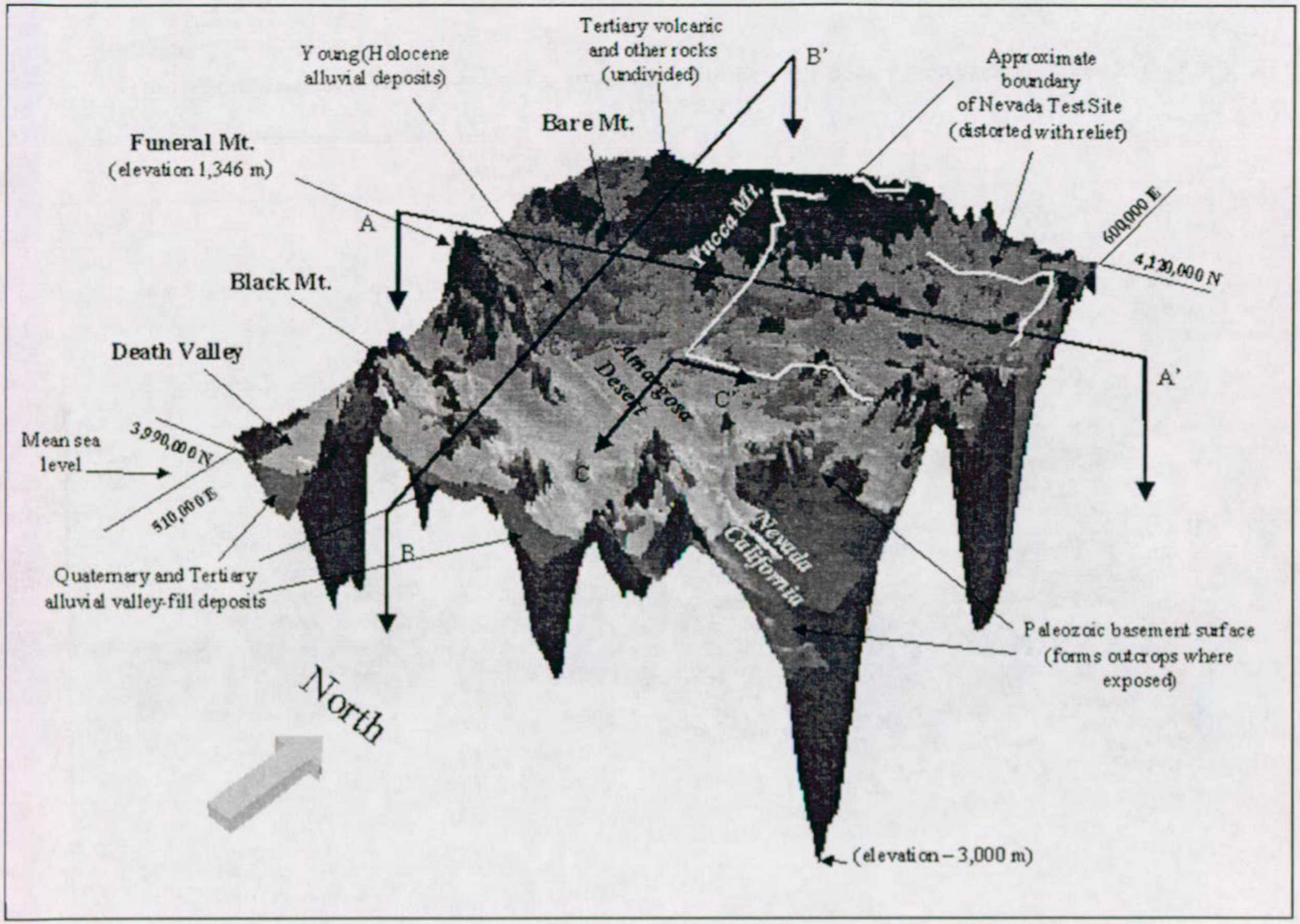
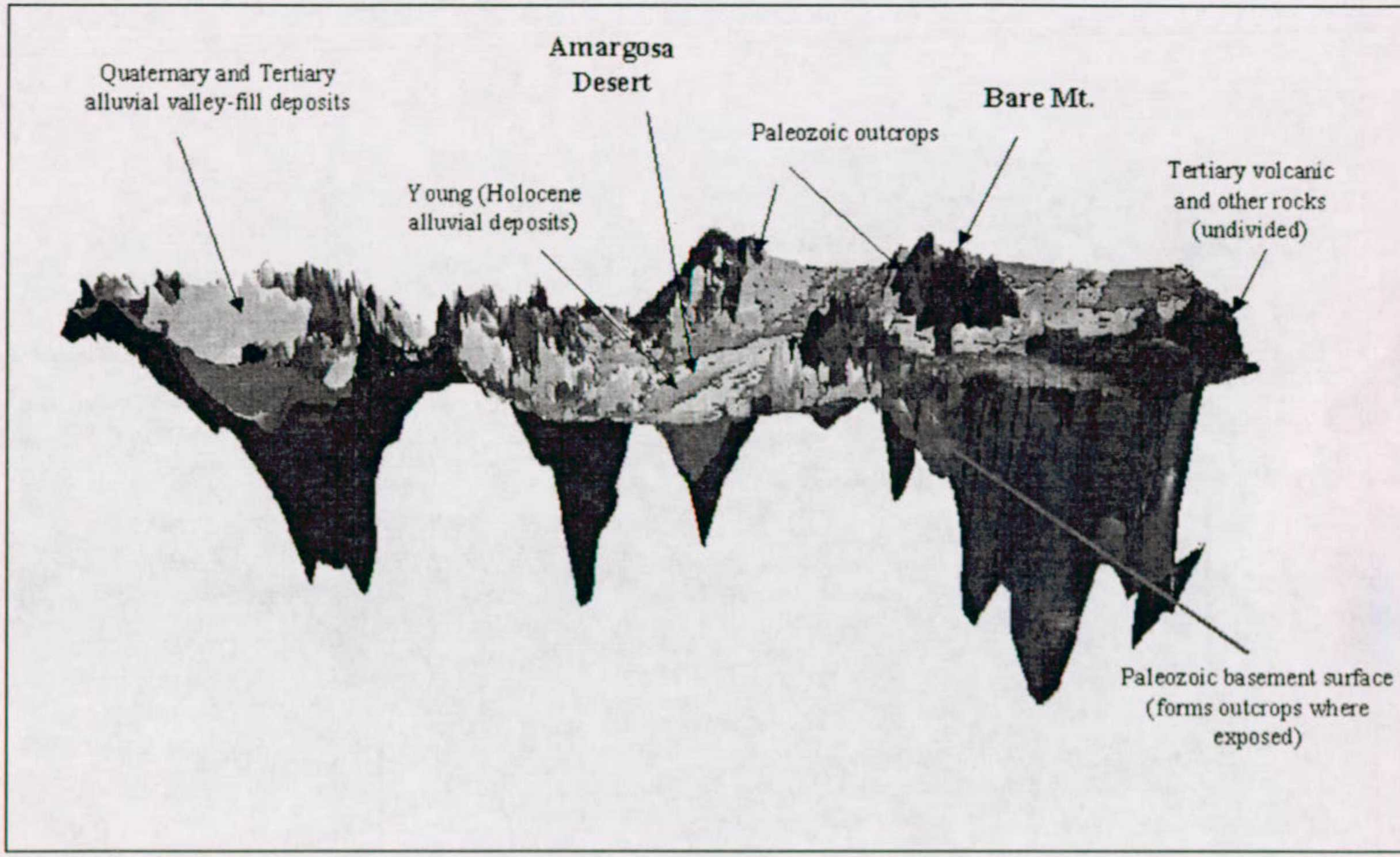


Figure 2.3-1
Status of Geologic Mapping Activities



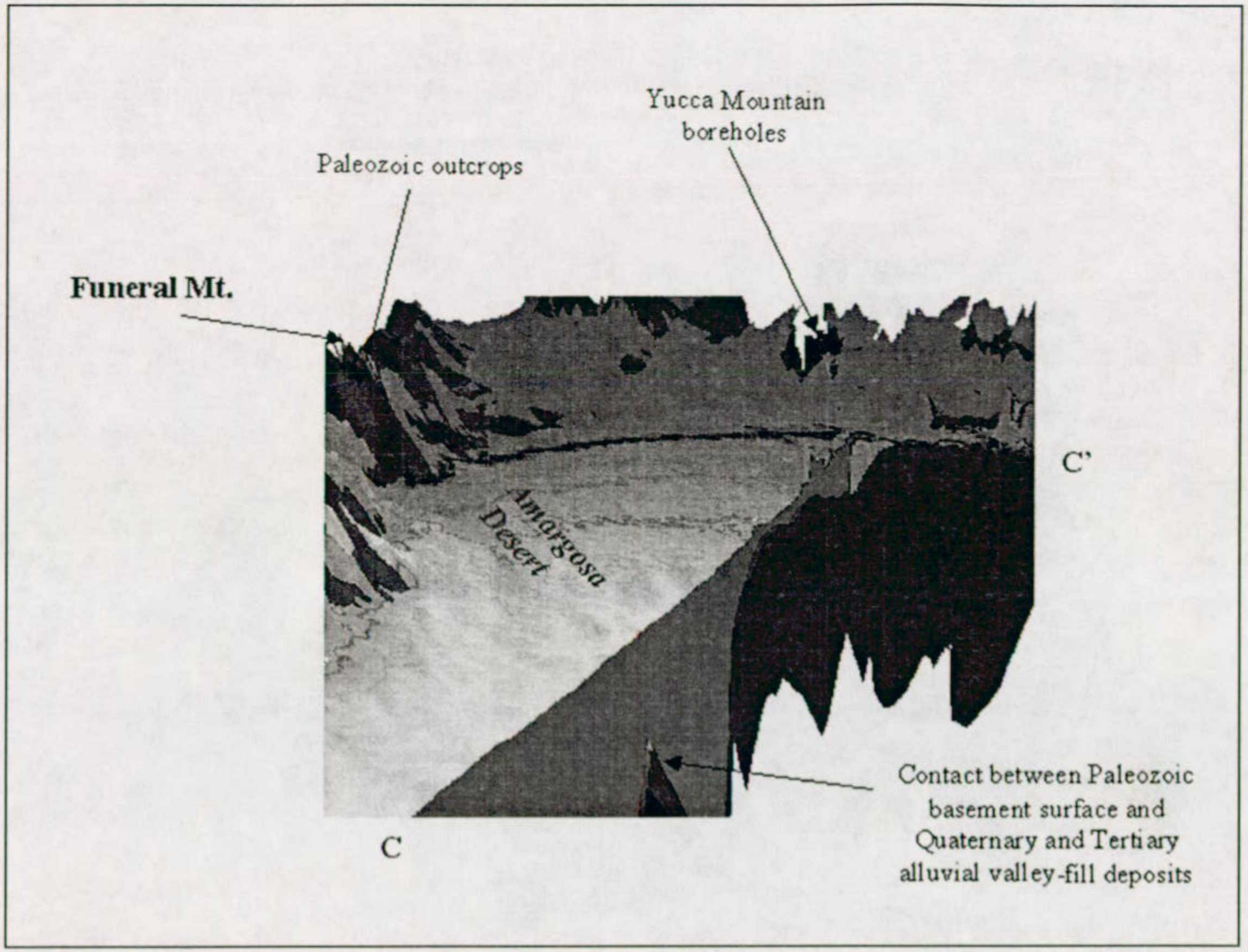
NOTE: UTM coordinates given in the corners of the model are in meters NAD 27. Vertical exaggeration = approximately 10X.

Figure 2.4-1
Simplified Three-Dimensional Geologic Model of the Amargosa Desert/Yucca Mountain Area



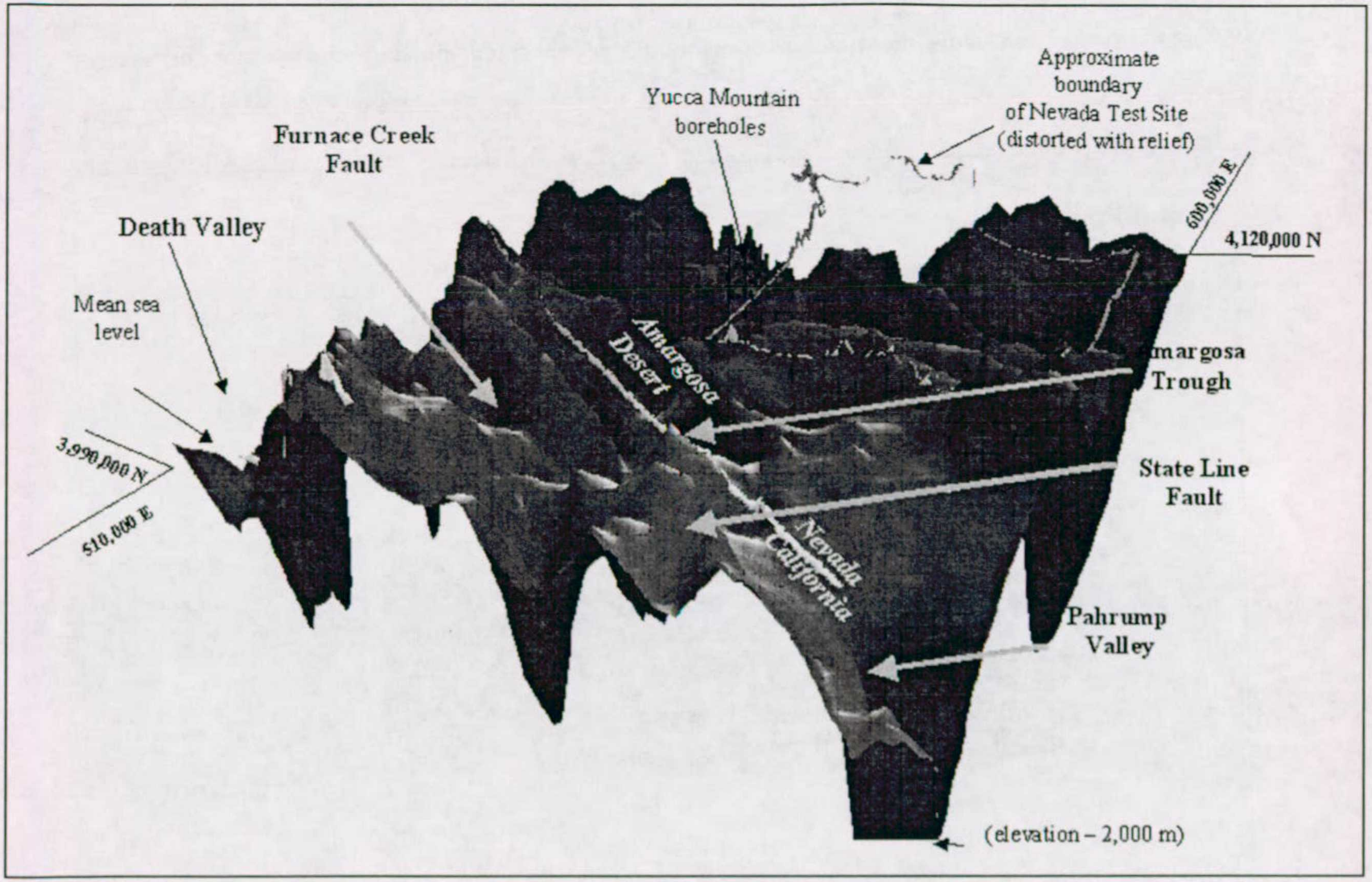
NOTE: Vertical exaggeration = approximately 10X

Figure 2.4-2
Three-Dimensional Geologic Cutout Model of the Upper Amargosa Desert Looking along Line BB' in Figure 2.4-1



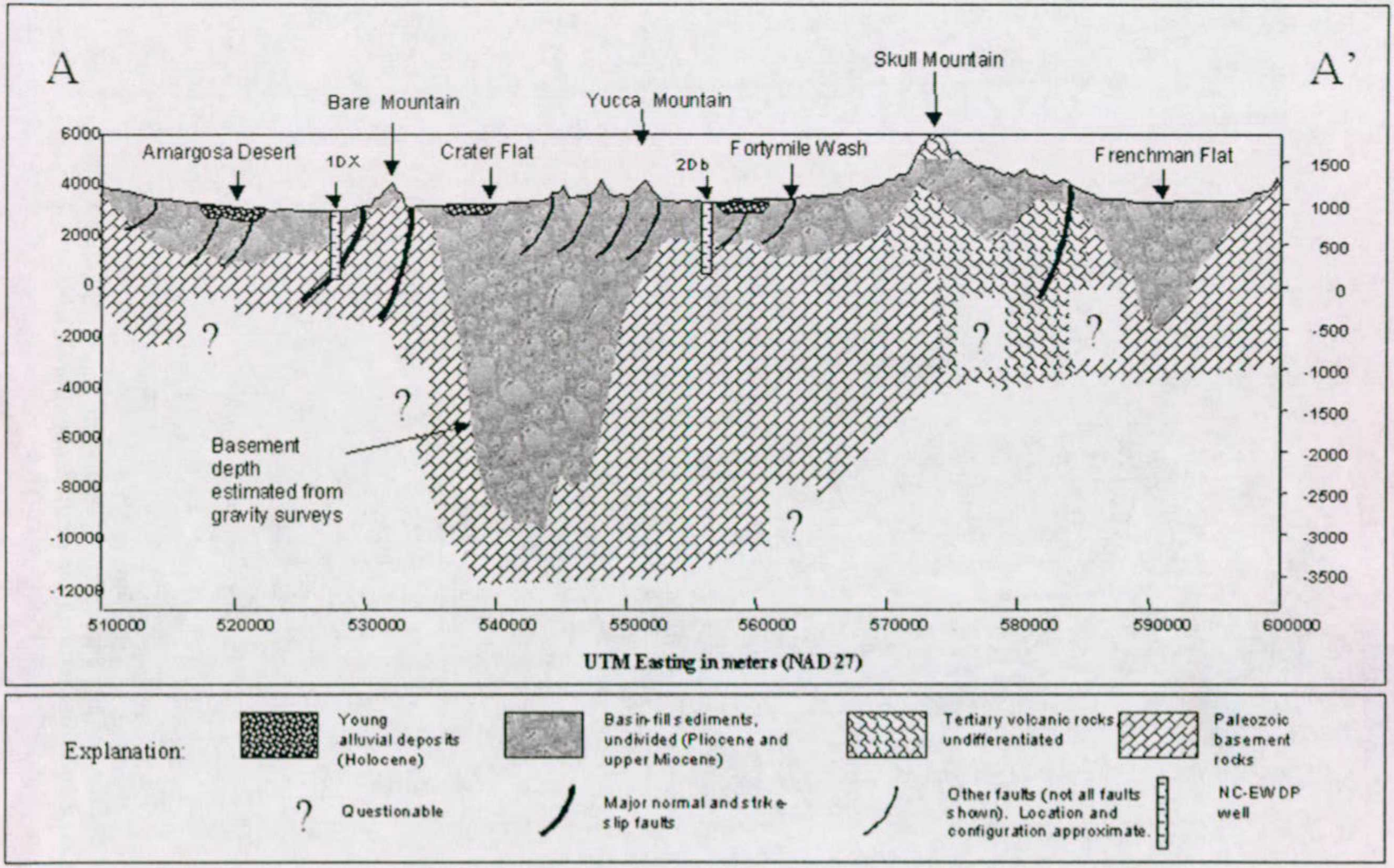
NOTE: Vertical exaggeration = approximately 10X

Figure 2.4-3
Close-Up View of Three-Dimensional Geologic Cutout Model of the Upper Amargosa Desert Looking along Line CC' in Figure 2.4-1



NOTE: View is northwest. Vertical exaggeration = approximately 10X.

Figure 2.4-4
Three-Dimensional Geologic Model of the Paleozoic Basement Surface Stripped of Overlying Deposits in the Amargosa Desert/Yucca Mountain Area



NOTE: The NC-EWDP wells are projected. AMSL = above mean sea level.

Figure 2.4-5
Conceptual East-West Geologic Cross-Section along Line AA' in Figure 2.4-1 Showing Some Major Structural Features and the Extent of the Basin Deposits

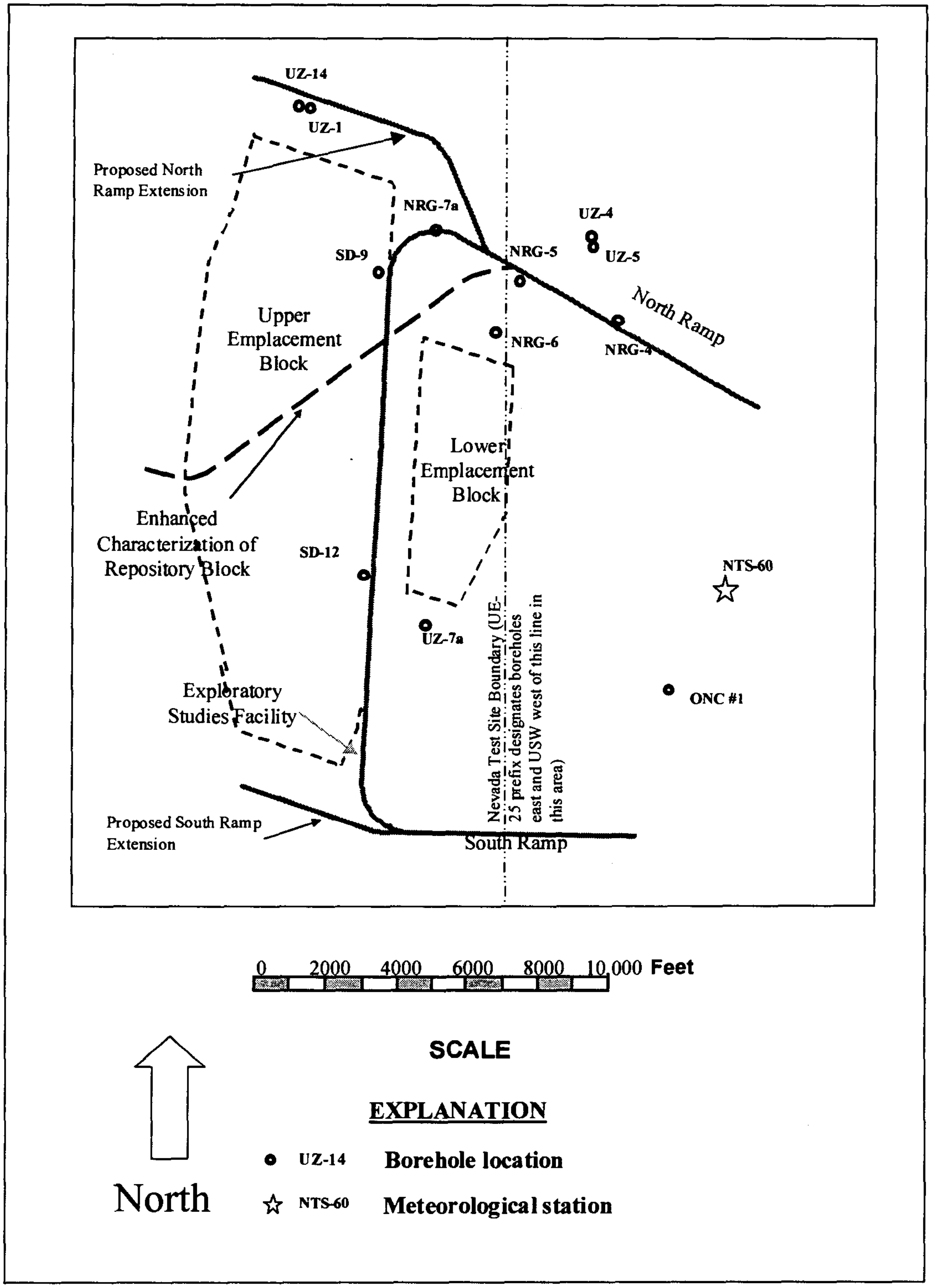
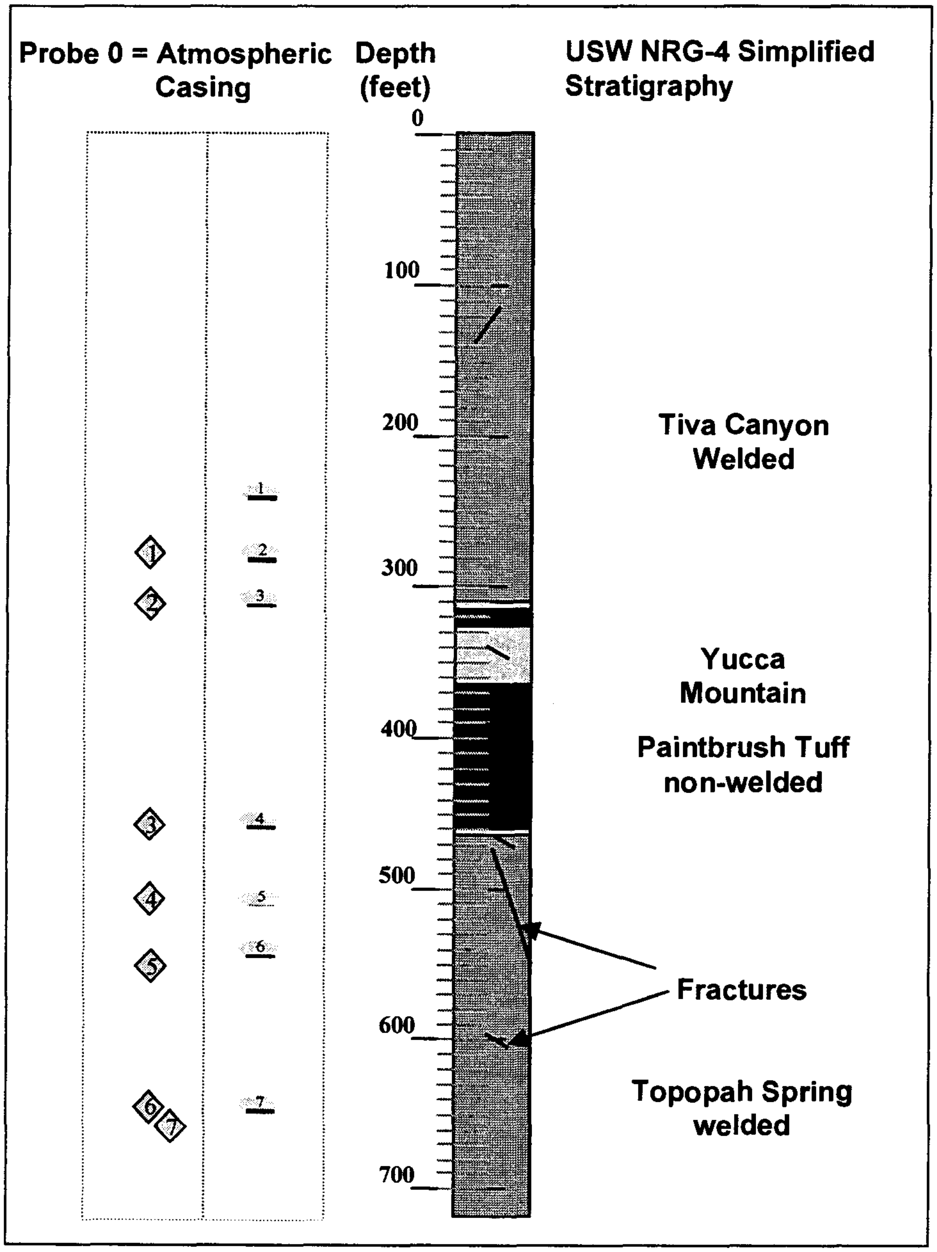


Figure 3.1-1
Location of Selected Boreholes, the Exploratory Studies Facility, and the Enhanced Characterization of the Repository Block at the Yucca Mountain Site



3 Temperature and Pressure Probe — 9 1-m-long Packer

Figure 3.1-2
Schematic Diagram of the Instrumentation and Simplified Stratigraphy in USW NRG-4

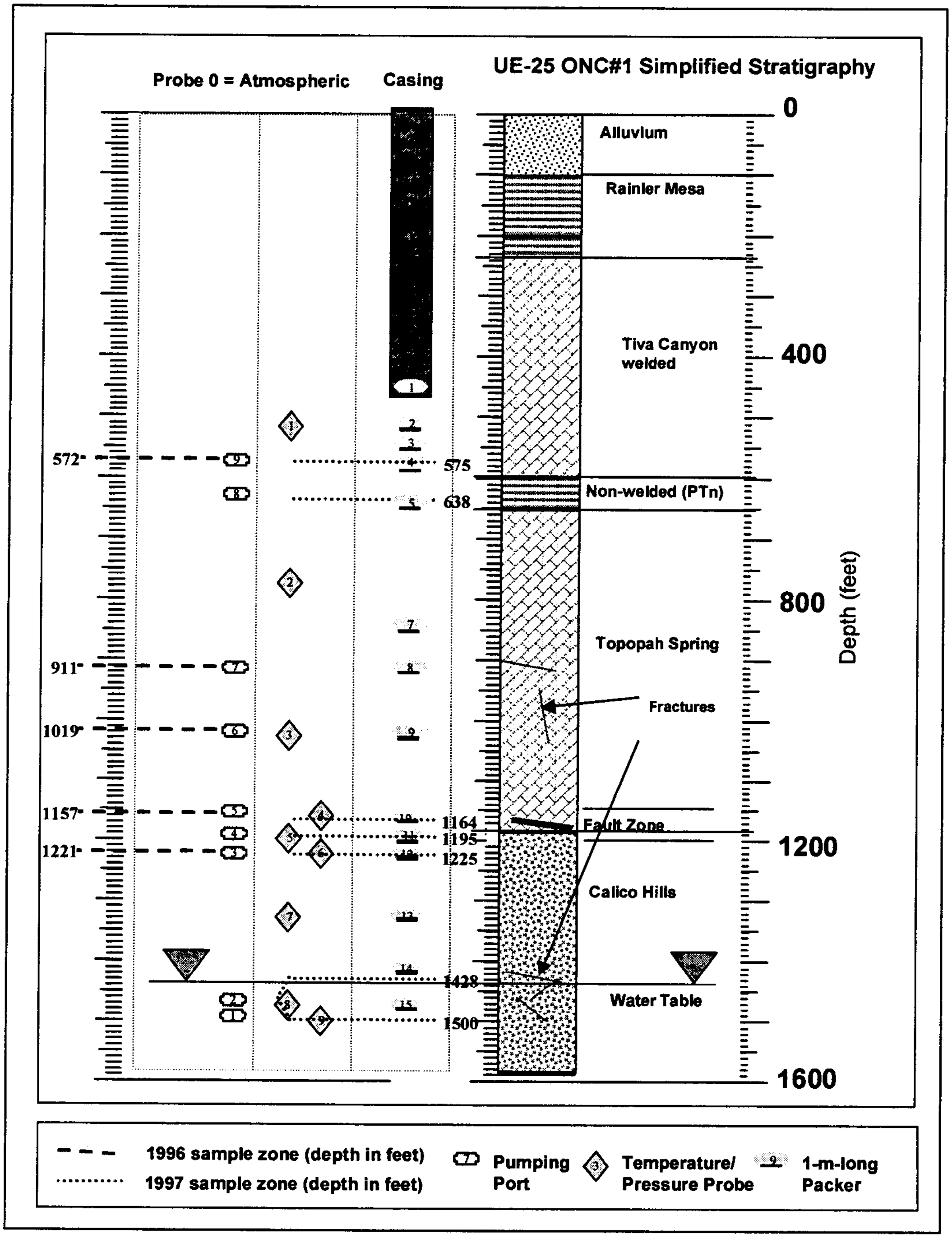


Figure 3.1-3
Schematic Diagram of the Instrumentation and Simplified Stratigraphy in UE-25 ONC#1

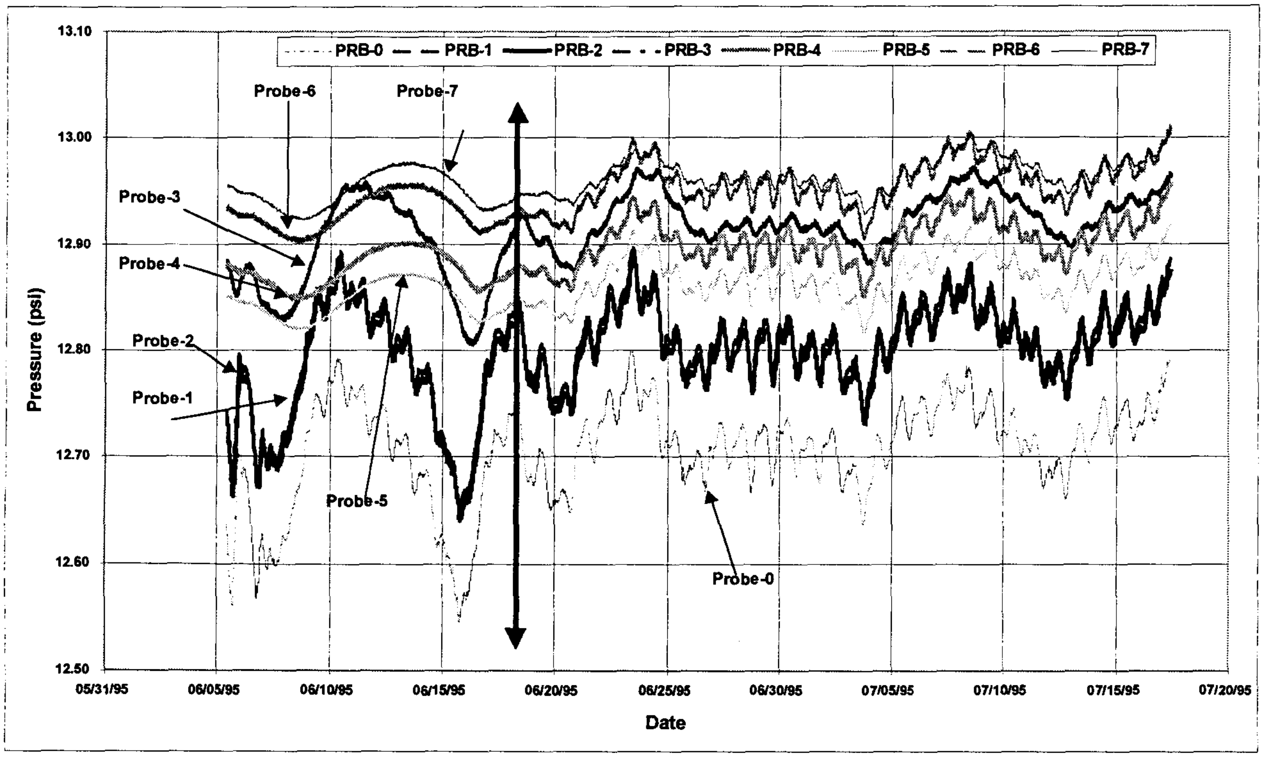
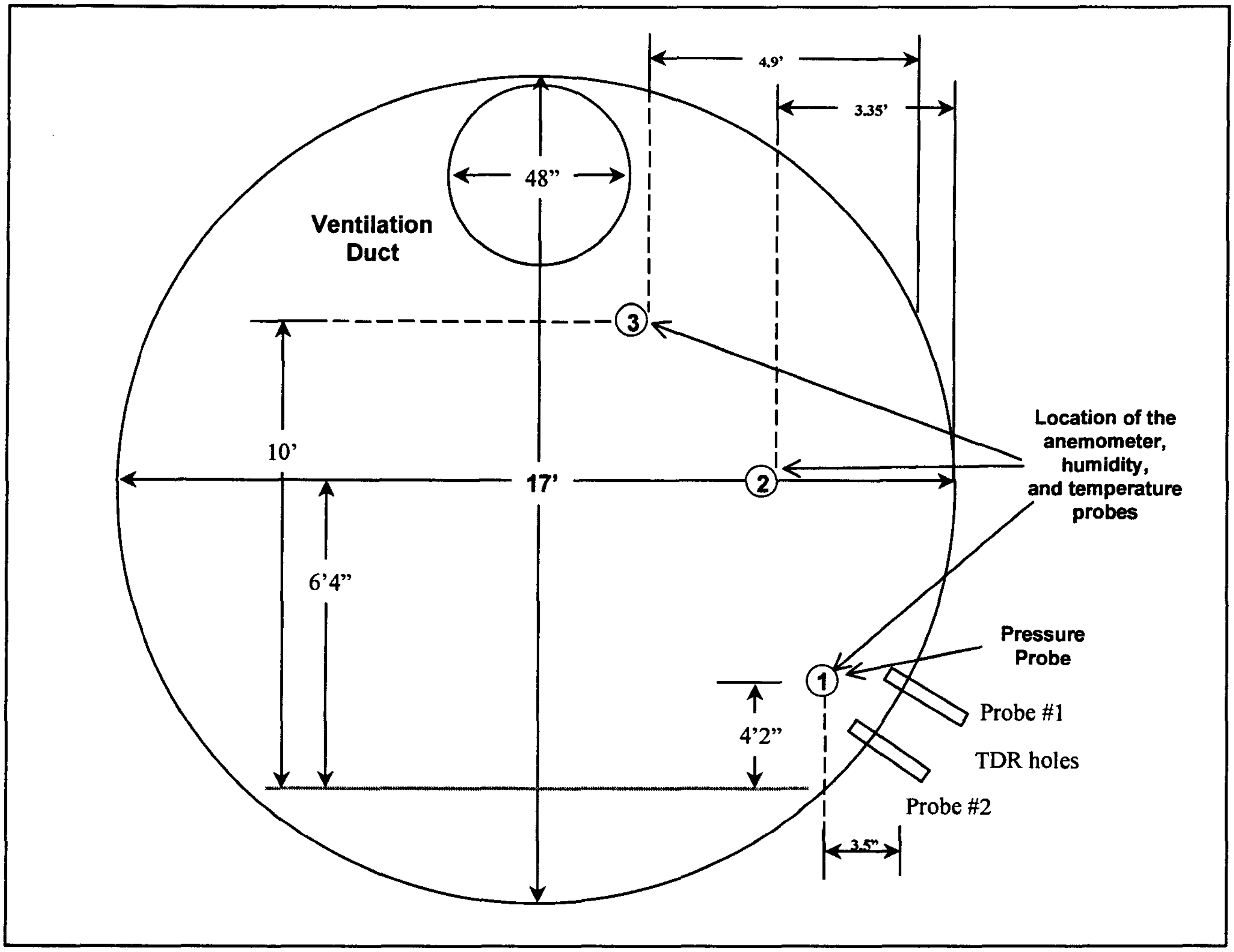
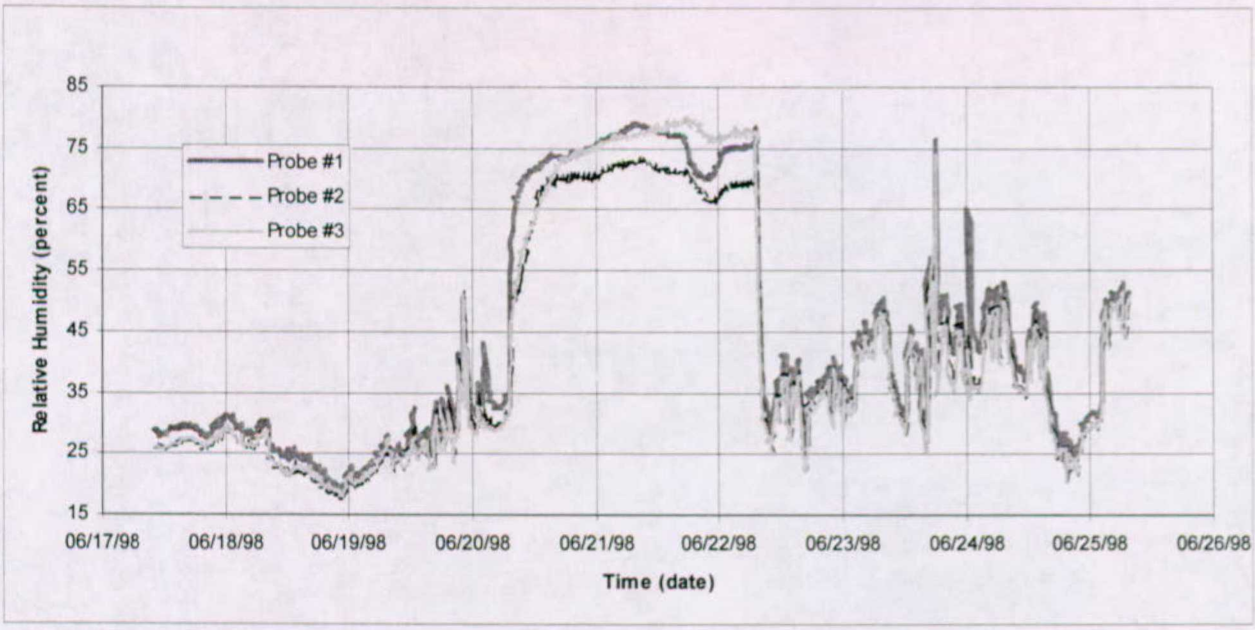


Figure 3.1-4
Pneumatic Pressure Heads in Seven Probes Located in the Unsaturated Zone in USW NRG-4 prior to and Immediately after the Exploratory Studies Facility Broke through the Paintbrush Tuff Non-Welded Unit around June 15, 1995 (shown by double arrow)



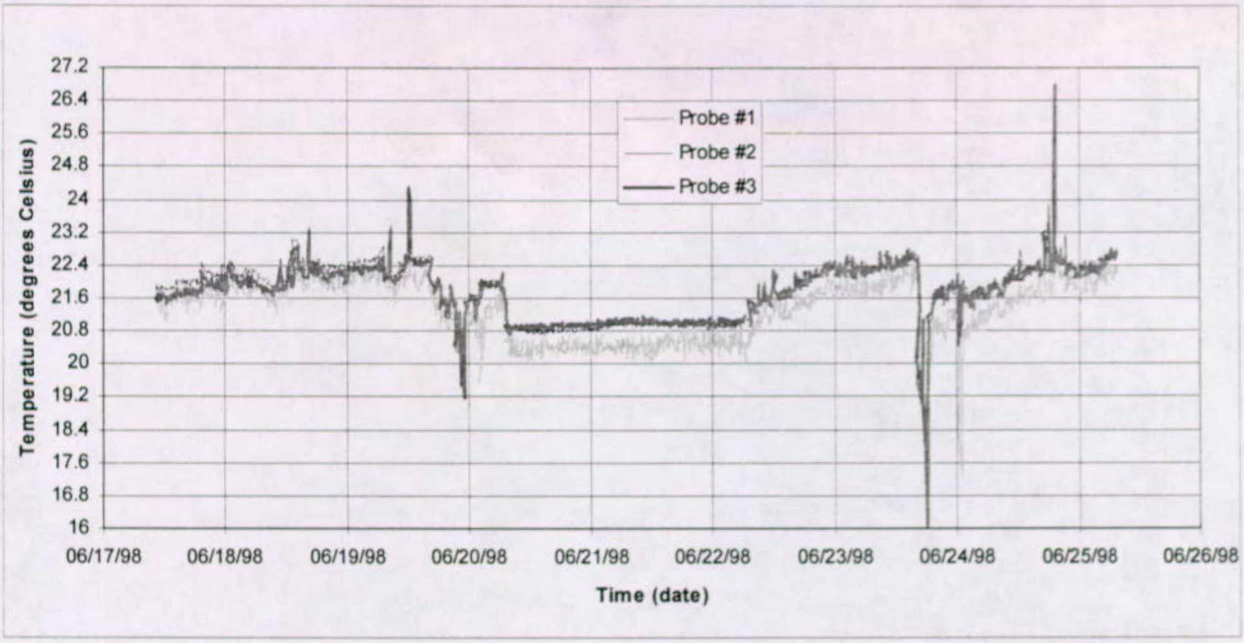
NOTE: TDR = time-domain reflectometry

Figure 3.1-5
Location of Temperature, Pressure, Humidity, Anemometer, and Time-Domain Reflectometry Probes in the Enhanced Characterization of the Repository Block



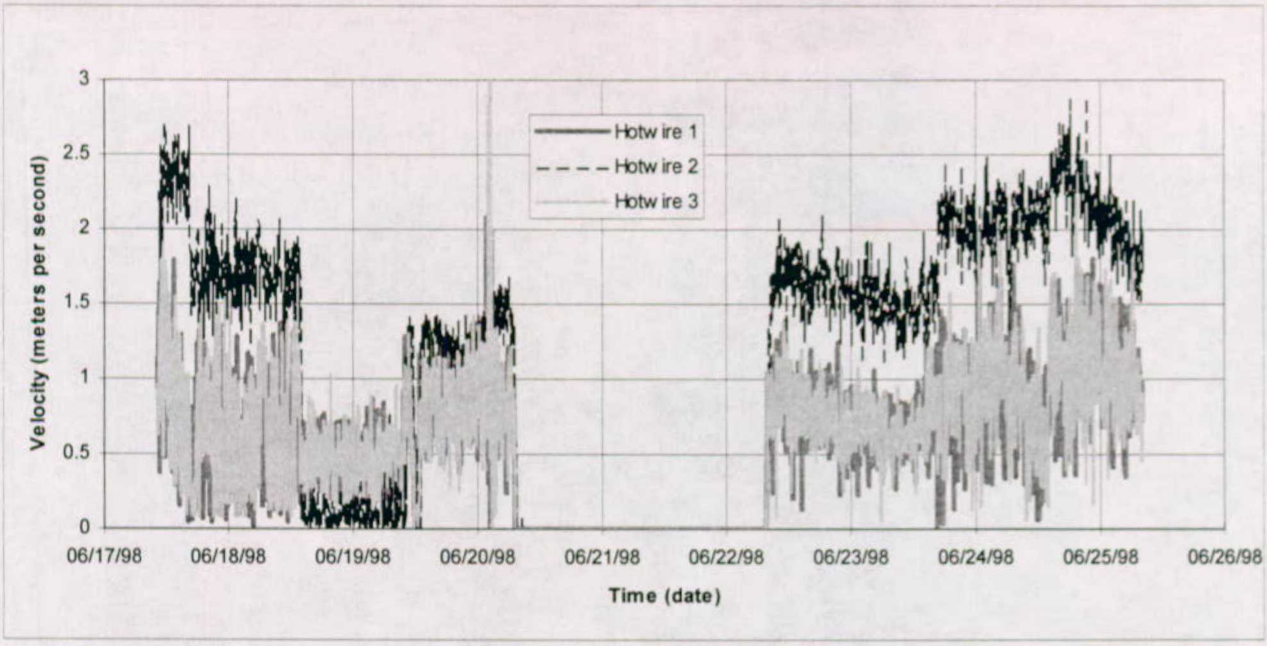
NOTE: See Figure 3.1-5 for location of the probes.

Figure 3.1-6a
Relative Humidity at Three Cross-Sectional Points in the Enhanced Characterization of the Repository Block



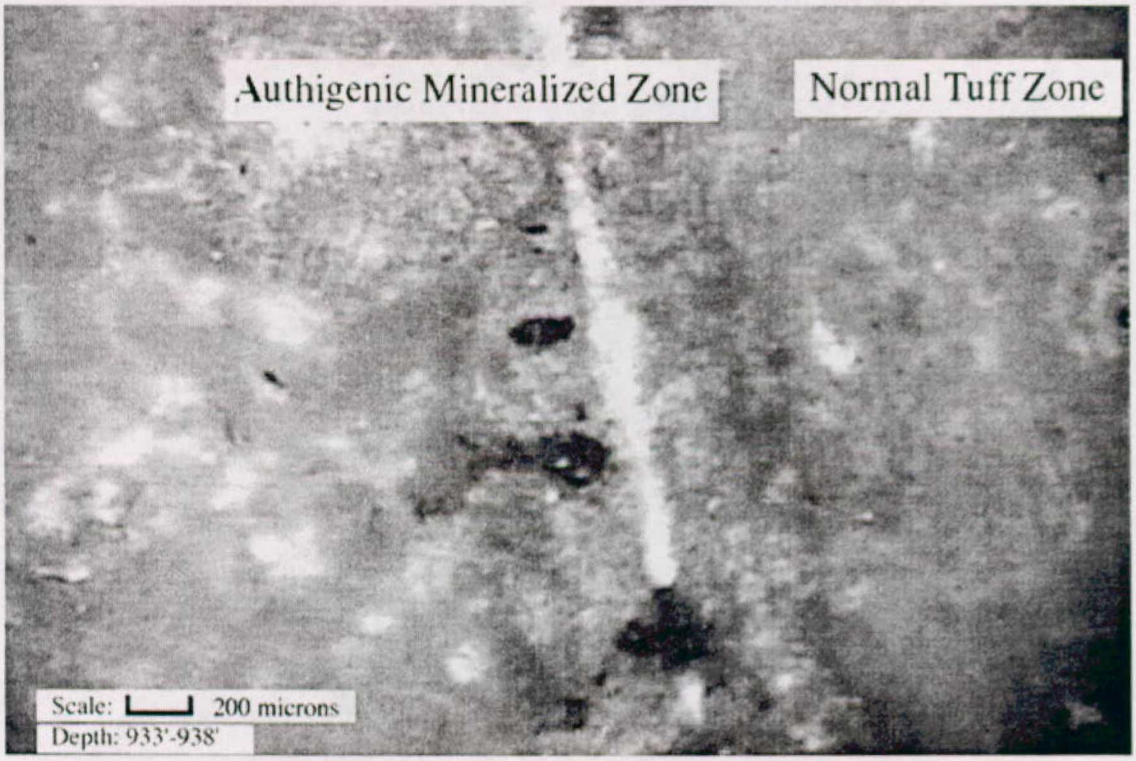
NOTE: See Figure 3.1-5 for location of the probes.

Figure 3.1-6b
Temperature at Three Cross-Sectional Points in the Enhanced Characterization of the Repository Block



NOTE: See Figure 3.1-5 for location of the probes.

Figure 3.1-6c
Relative Air Velocity Measured at Three Cross-Sectional Points in the Enhanced Characterization of the Repository Block



NOTE: The bleached zone is about 500 microns wide on either side of the fracture. It contains authigenic zeolites, some clay, manganese oxides, and quartz polymorphs. There is direct interconnectivity between the bleached zone and the fracture, which is still open. The bleached zone has sorption capabilities.

Figure 3.1-7
Bleached Zone Fracture with Quartz Fracture Filling from the Topopah Spring Tuff (933 to 938 ft depth)

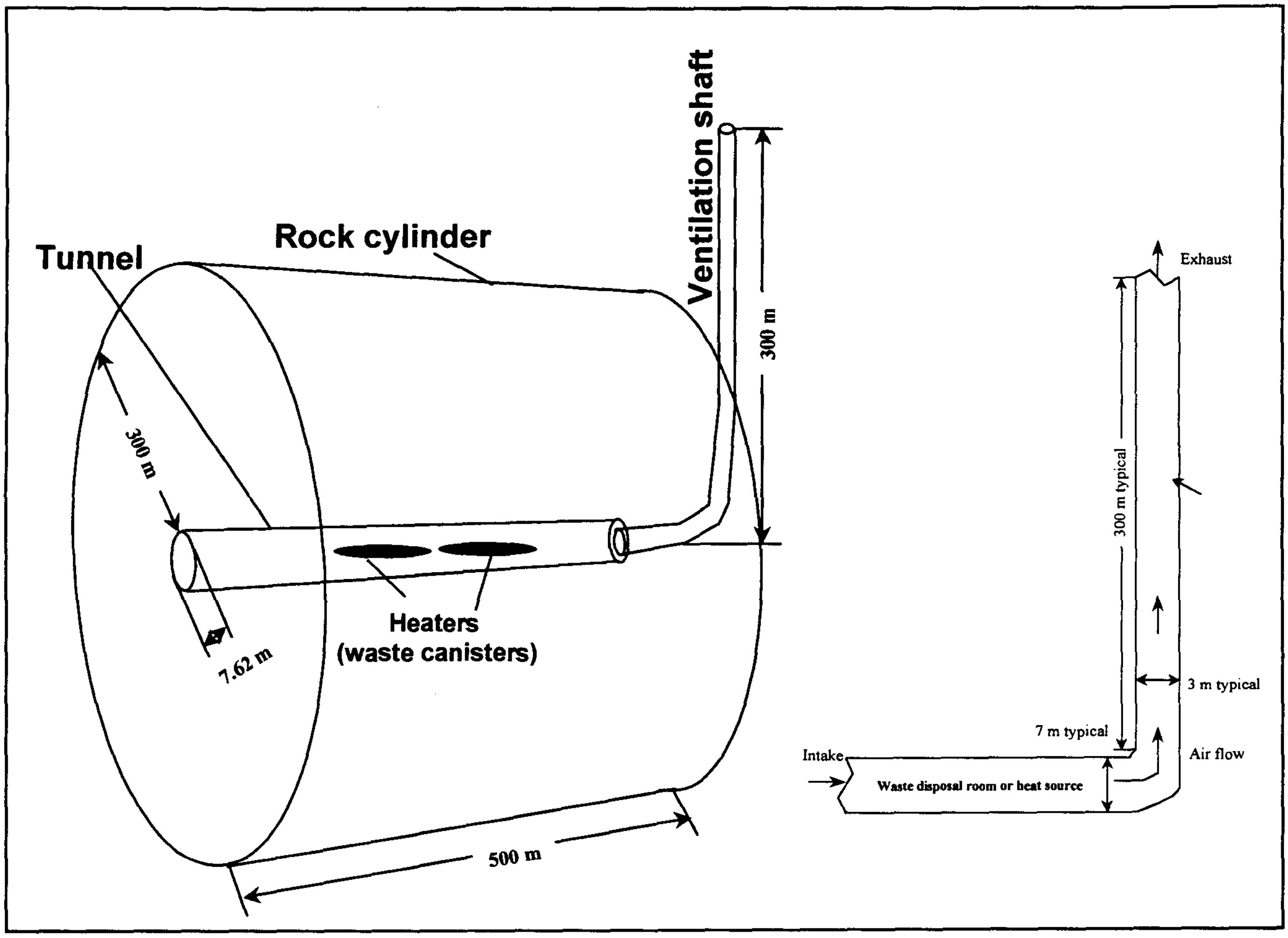
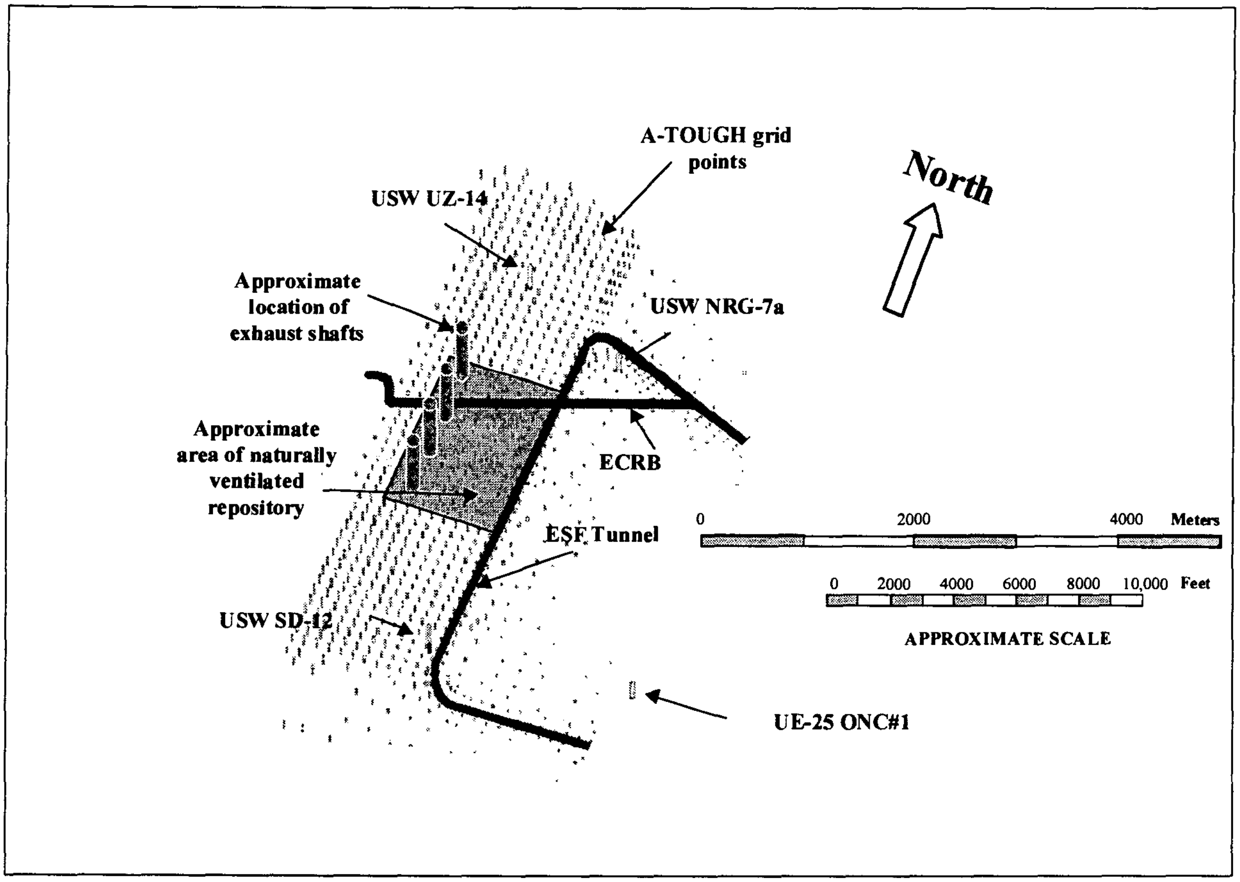
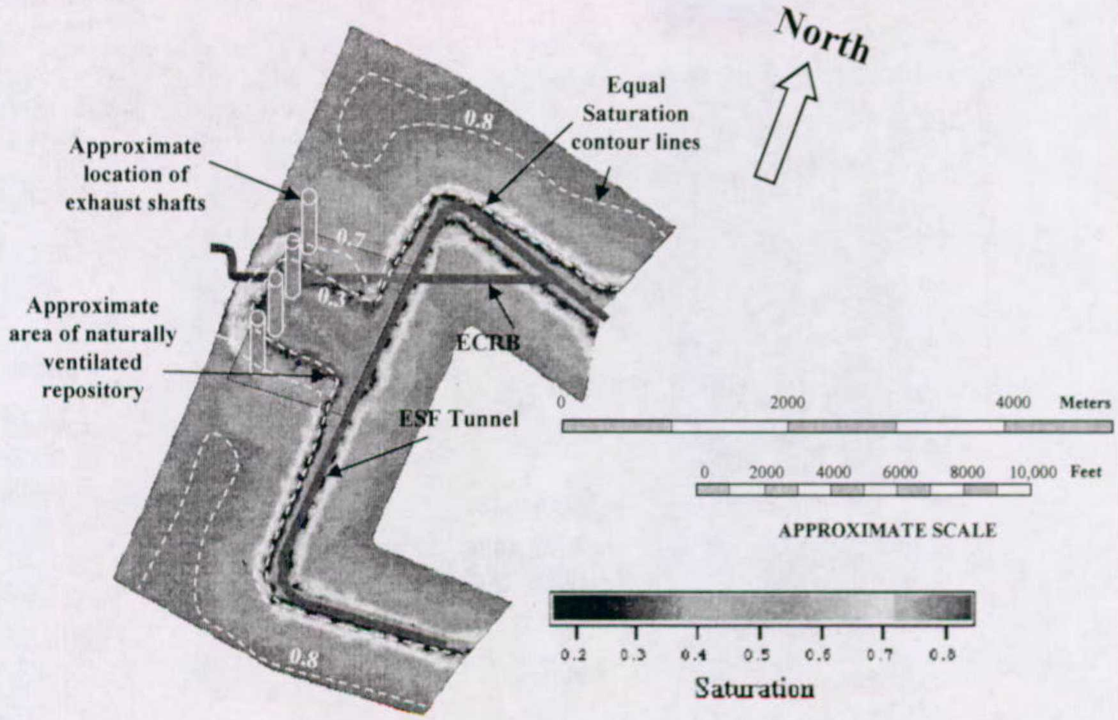


Figure 3.2-1
Three-Dimensional and Cross-Sectional View of the Axisymmetric Tunnel Model



NOTE: ECRB = enhanced characterization of the repository block; ESF = Exploratory Studies Facility

Figure 3.2-2
Oblique View of Modified Site-Scale Unsaturated Zone Model



NOTE: ECRB = enhanced characterization of the repository block; ESF = Exploratory Studies Facility

Figure 3.2-3
Reduction in Water Saturation at the Repository Horizon after 1,000 Years of Ventilation, Assuming an Eddy Diffusivity Value of 0.01 and an Infiltration Rate of 4 mm/yr.

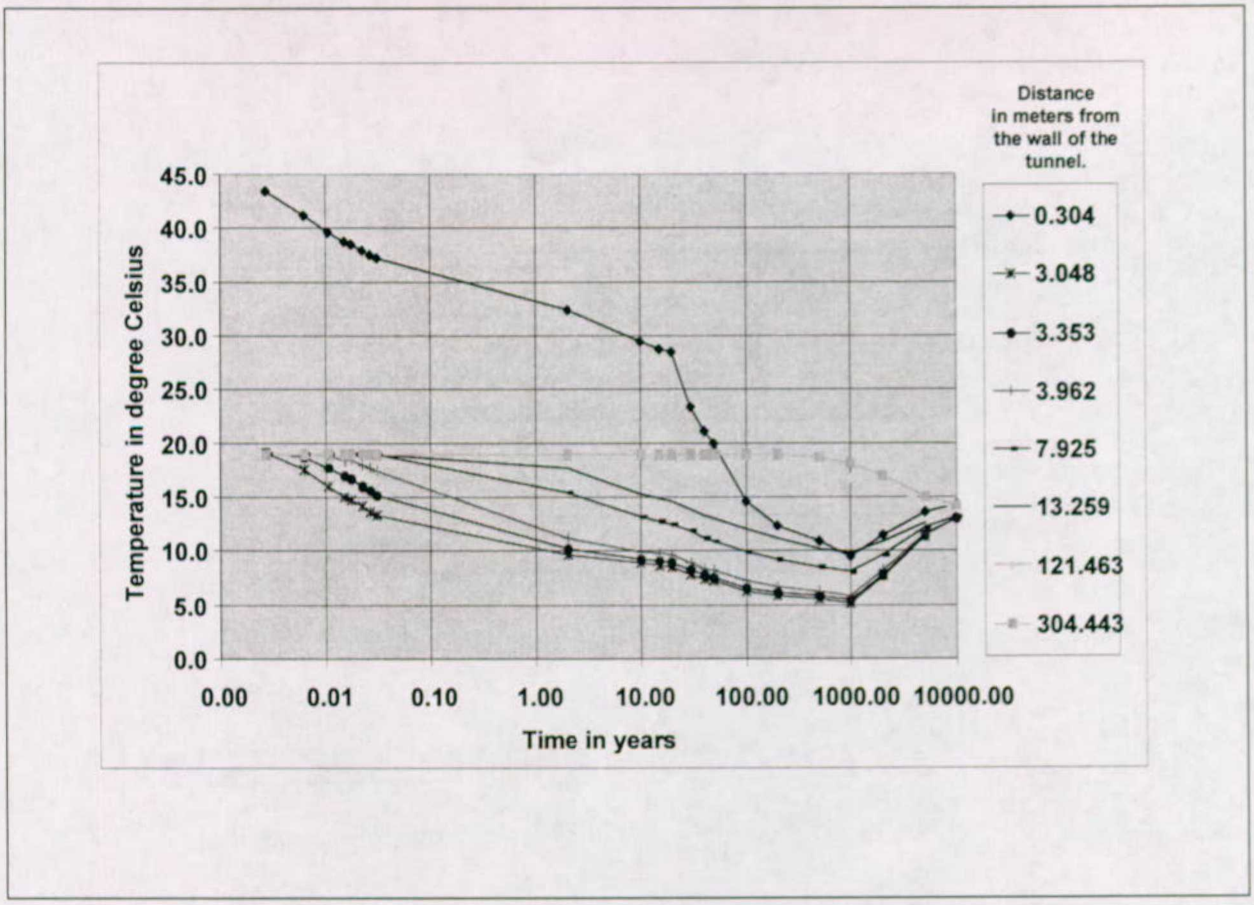


Figure 3.2-4
Reduction in Temperature versus Time and Distance from Tunnel Wall with a Decayed Heat Load, Assuming an Eddy Diffusivity Value of 0.01 and an Infiltration Rate of 4 mm/yr.

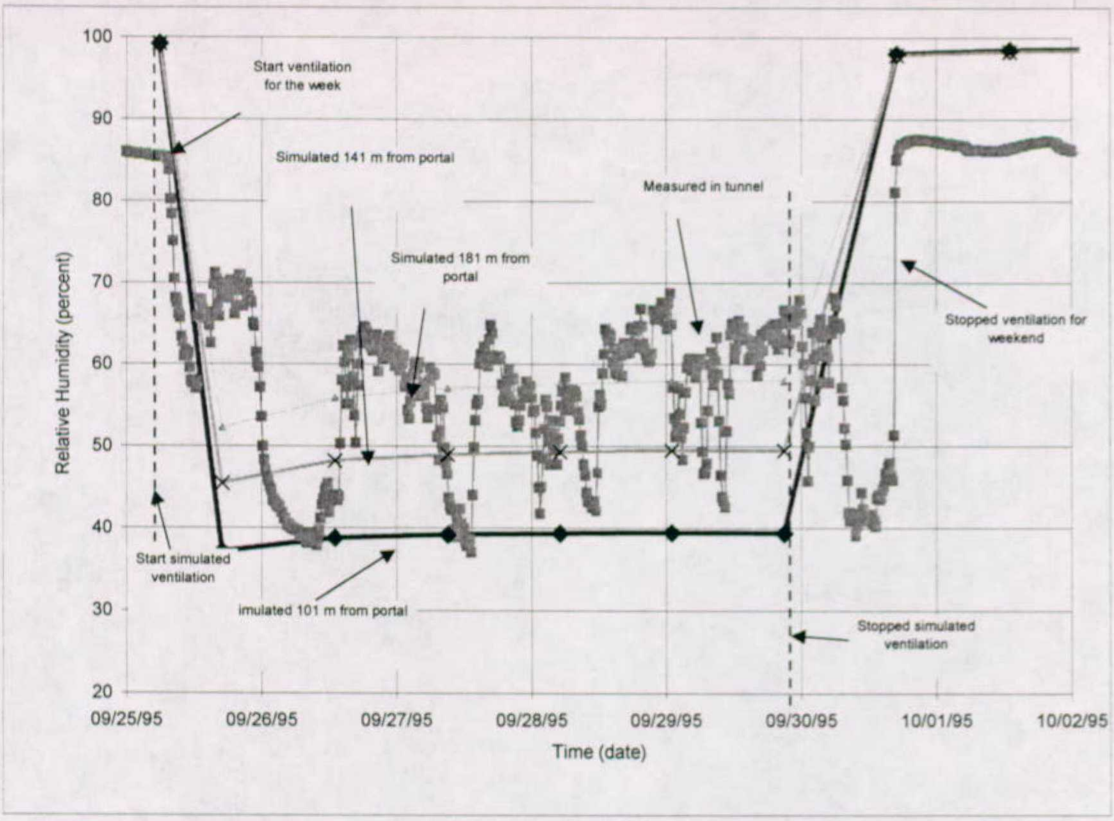


Figure 3.2-5
Comparison between Measured and Simulated Relative Humidity in the Exploratory Studies Facility Tunnel during Construction, Assuming an Eddy Diffusivity Value of 0.01

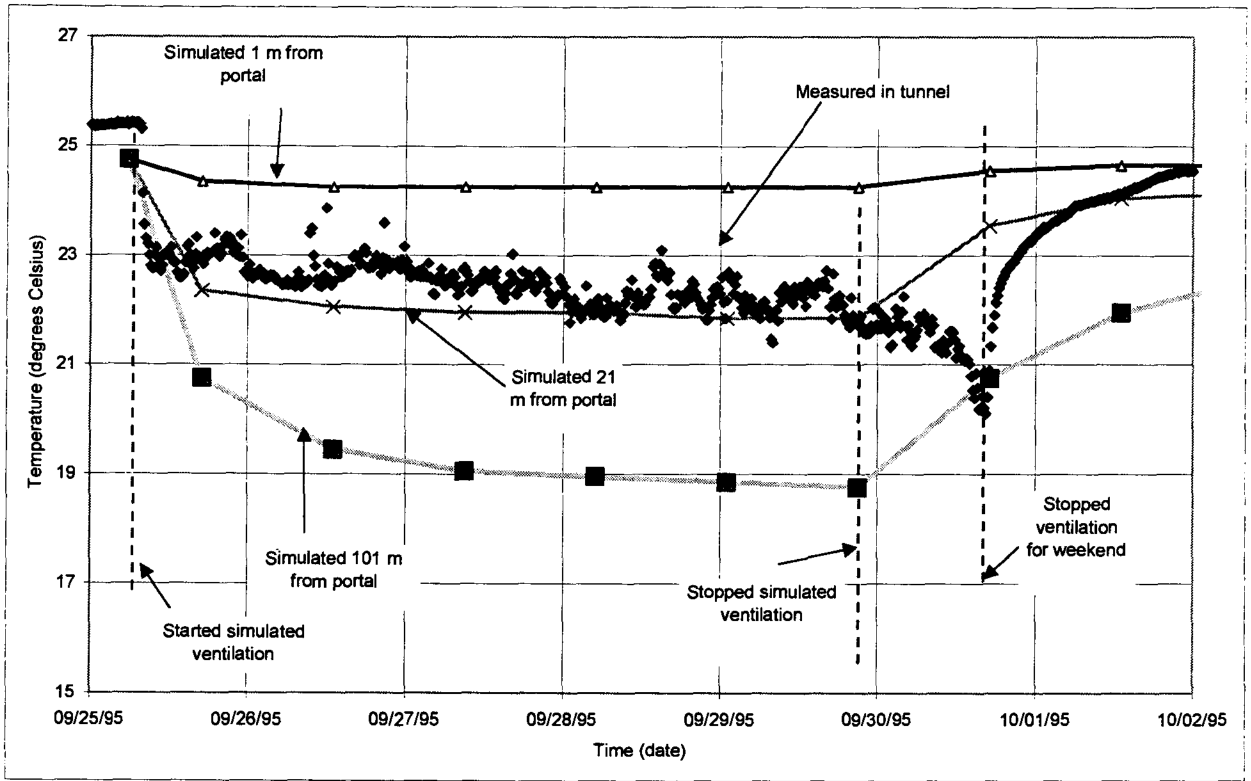


Figure 3.2-6
Comparison between Measured and Simulated Temperature in the Exploratory Studies Facility during Construction, Assuming an Eddy Diffusivity Value of 0.01

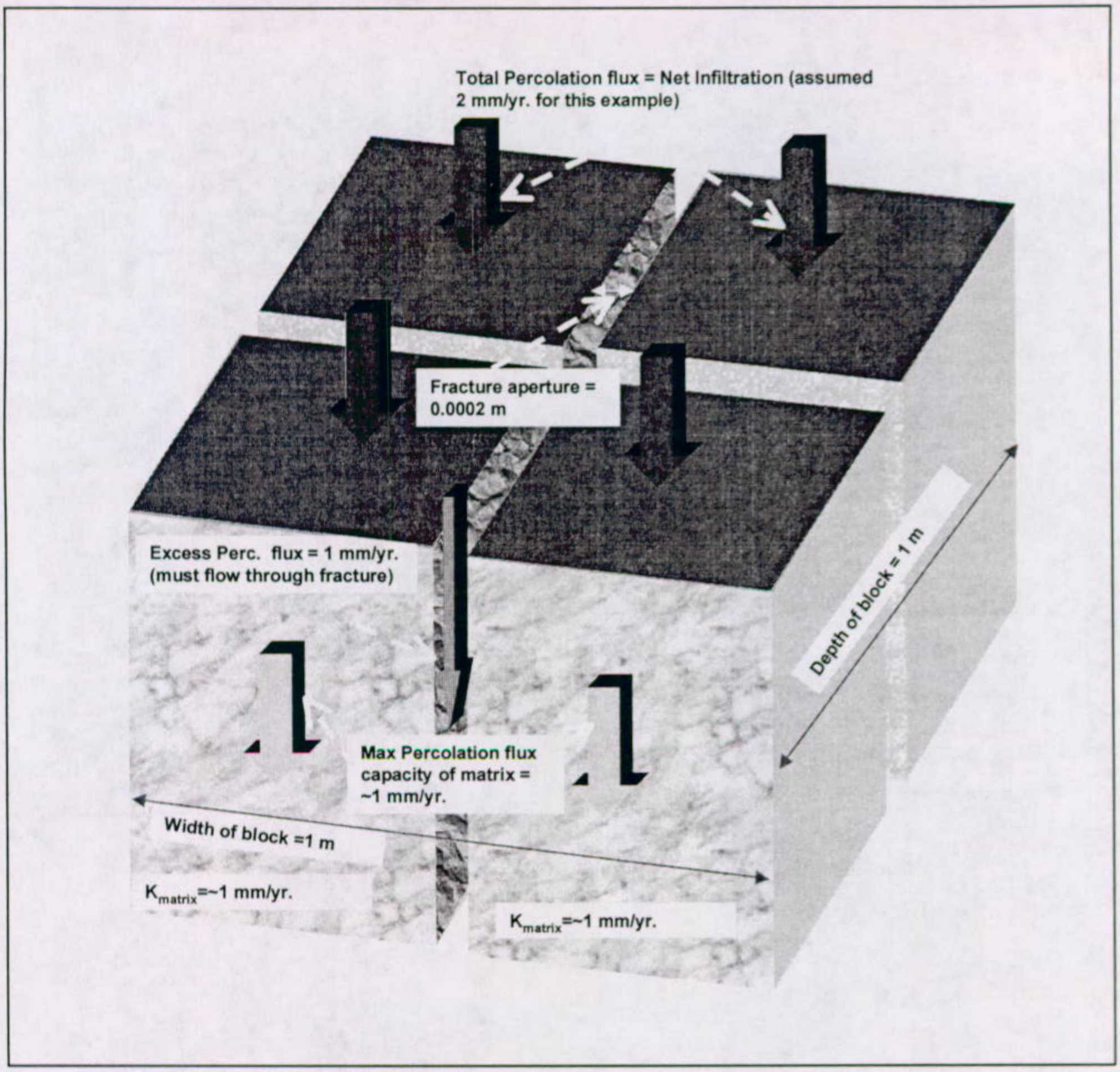


Figure 3.3-1
Conceptual Example Illustrating Assumptions Used for Calculating Percolation through a Fractured Tuff

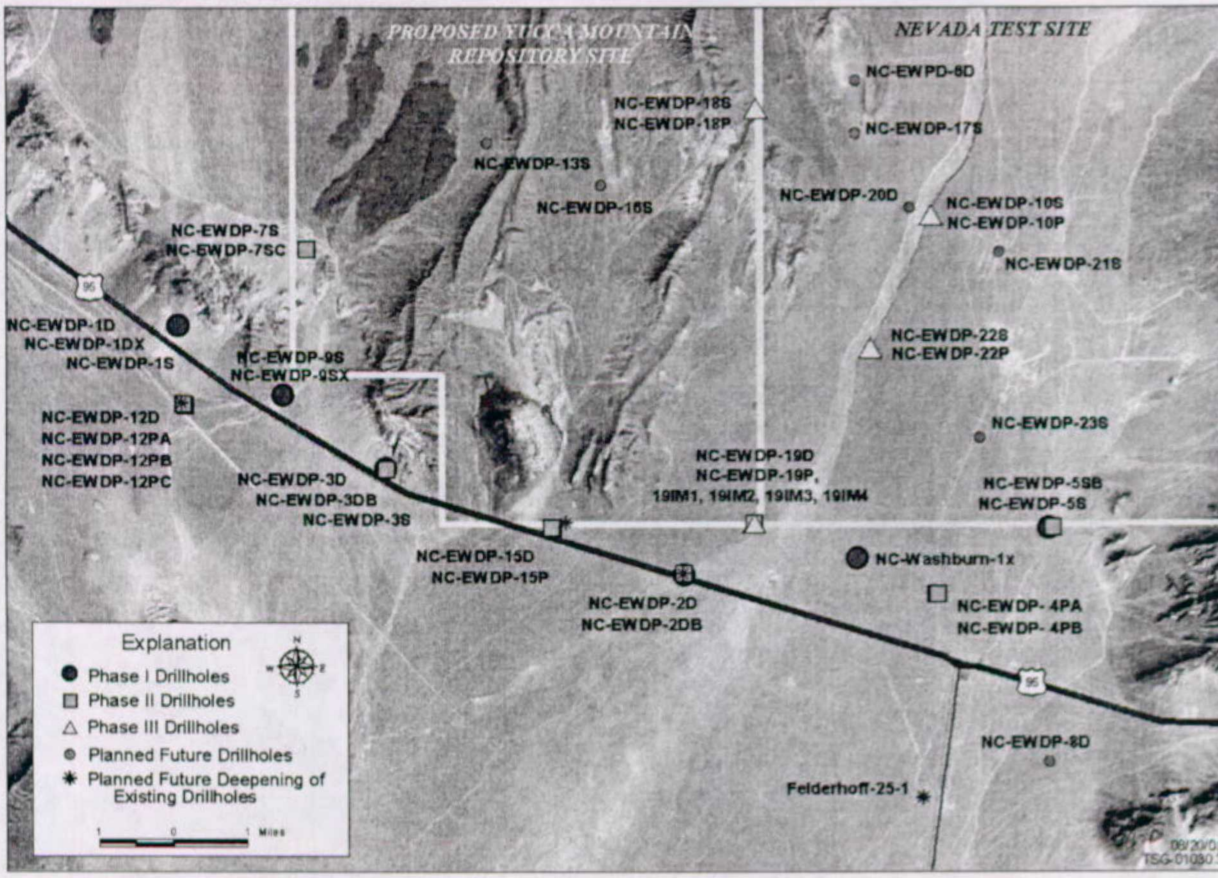
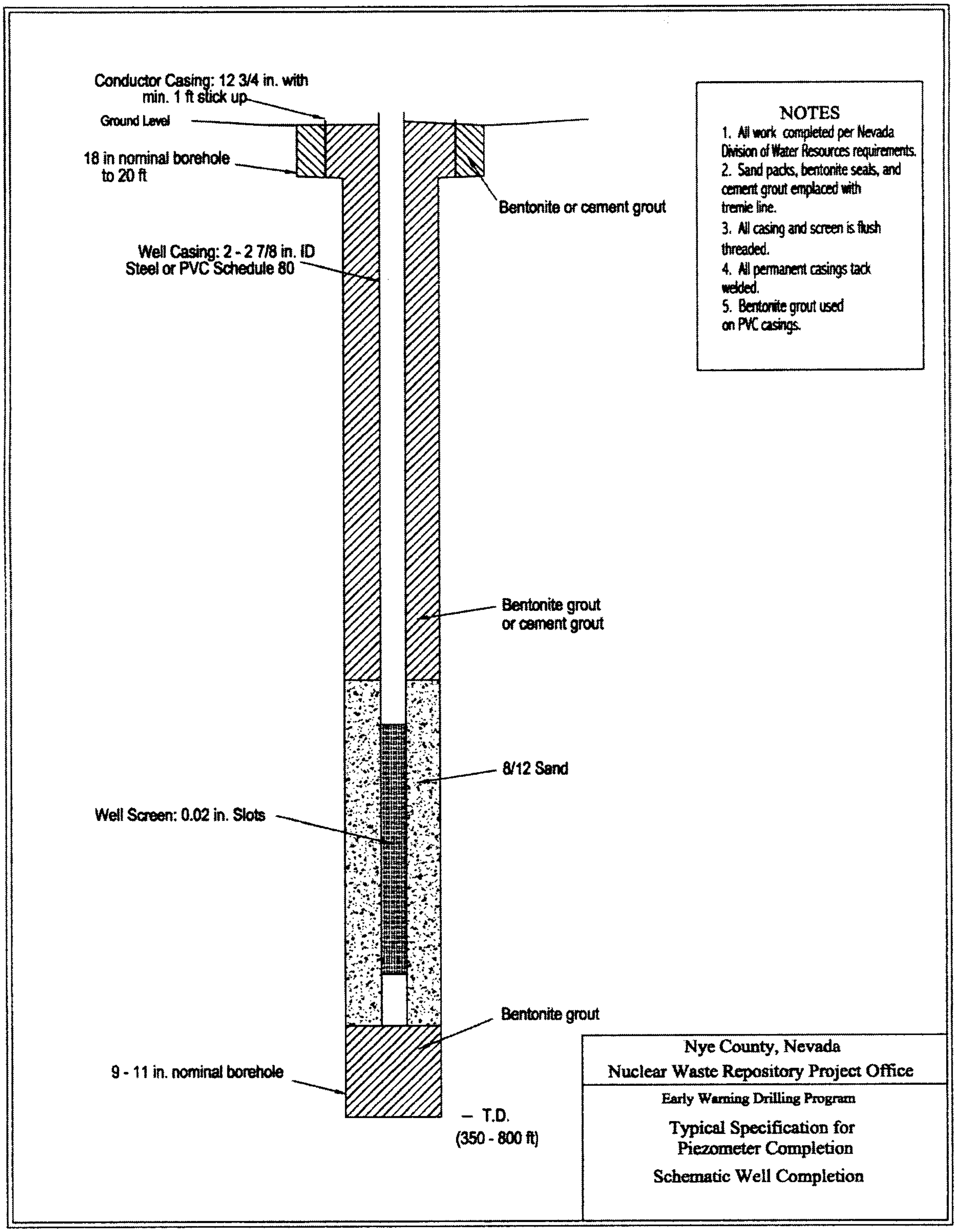
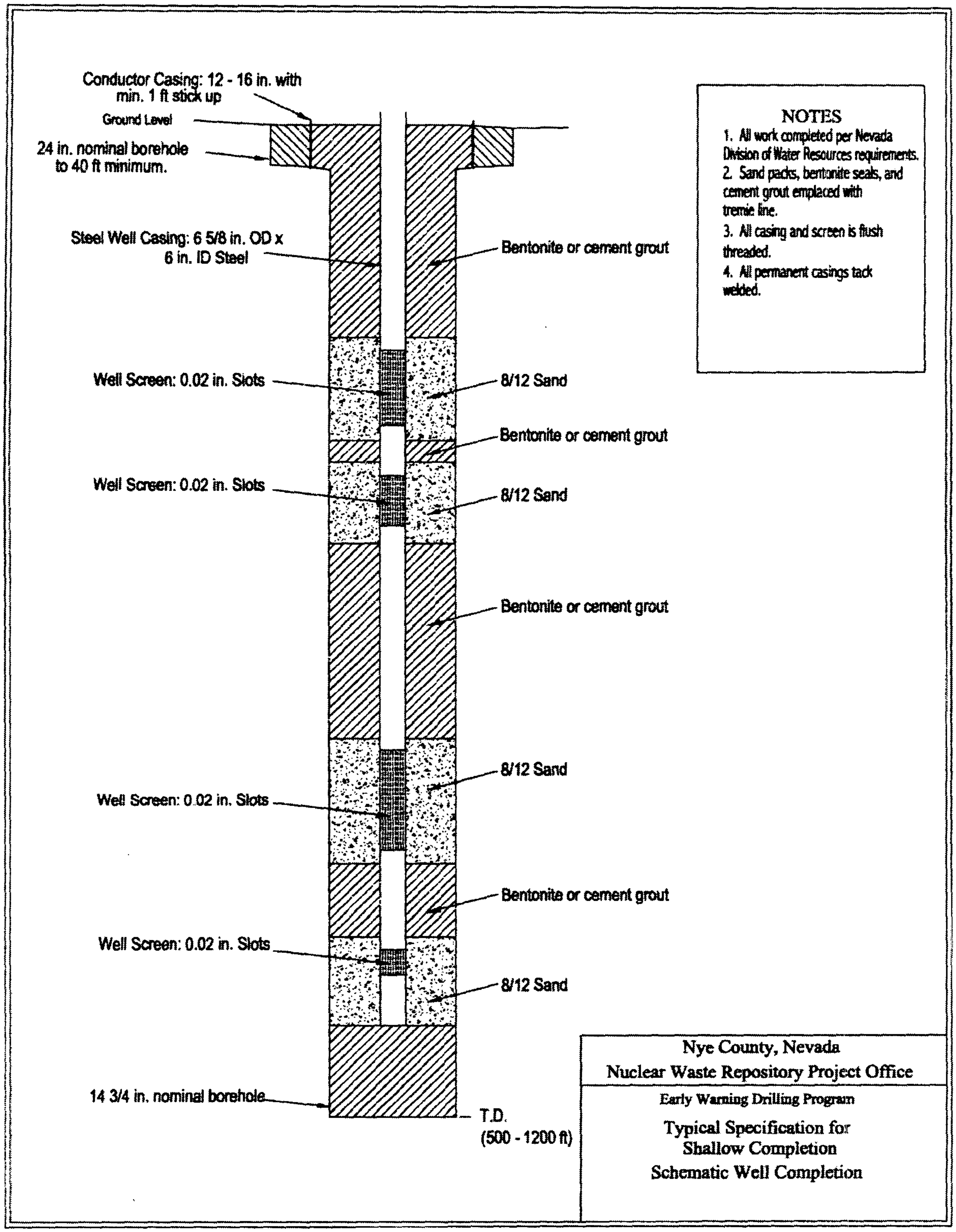


Figure 4.1-1
Location of Early Warning Drilling Program Drillholes



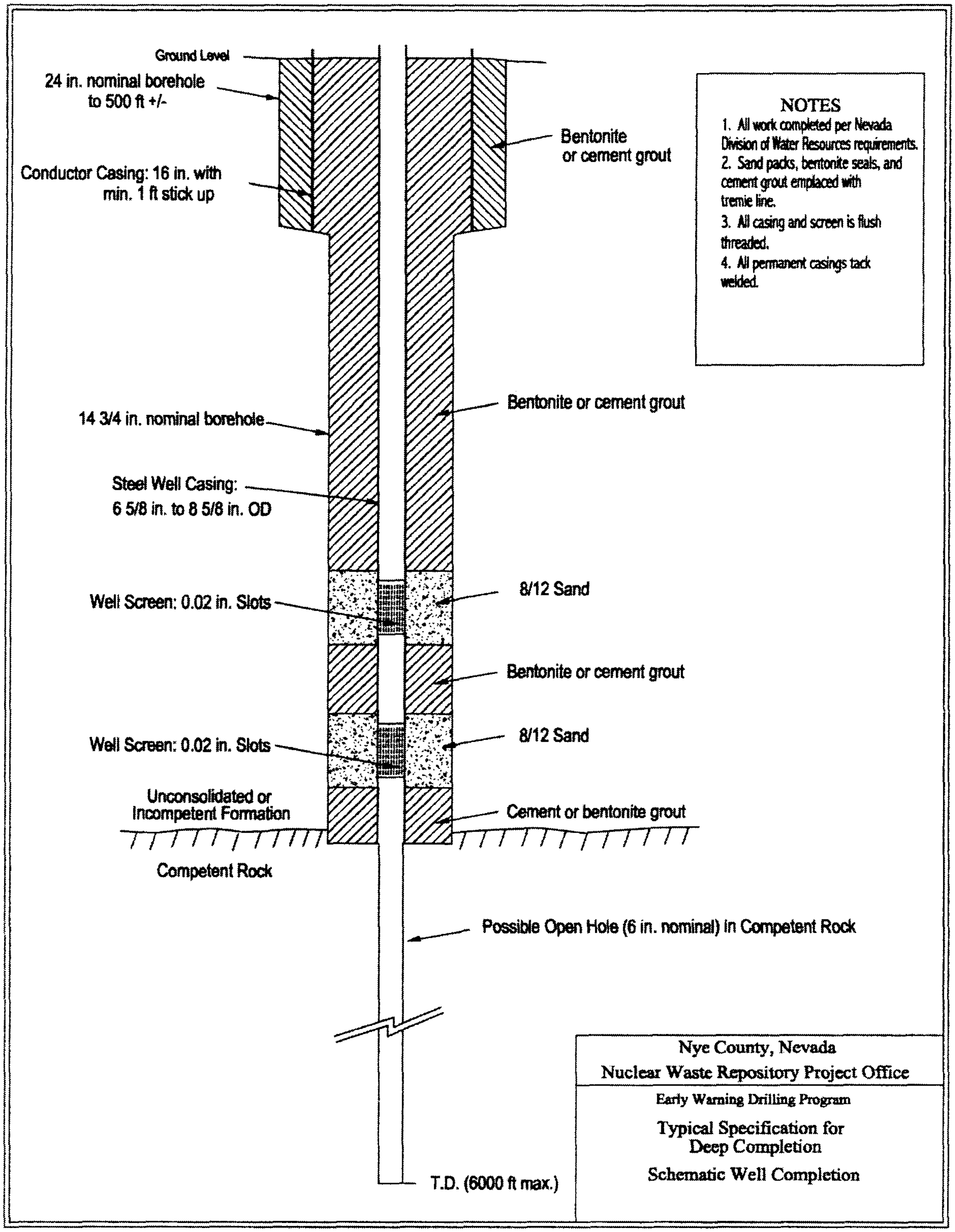
NOTE: ID = inner diameter; PVC = polyvinyl chloride; TD = total depth

Figure 4.1-2
Typical Specification for Piezometer Completion, Schematic Well Completion



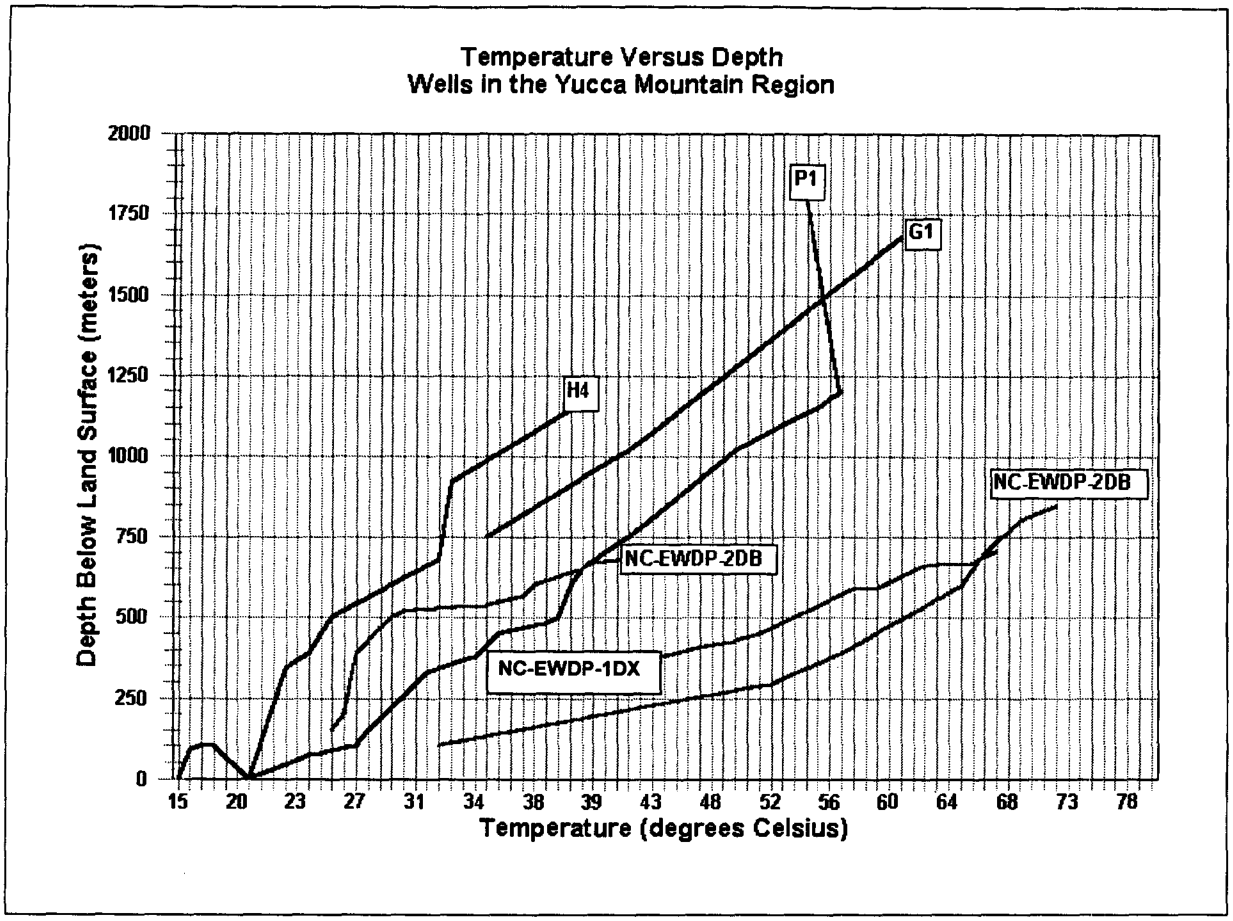
NOTE: OD = outer diameter; ID = inner diameter; TD = total depth

Figure 4.1-3
Typical Specification for Shallow Completion, Schematic Well Completion



NOTE: OD = outer diameter; TD = total depth

Figure 4.1-4
Typical Specification for Deep Completion, Schematic Well Completion



Source: Modified from Sass et al. (1988)

Figure 4.1-5
Temperature Logs for Selected Early Warning Drilling Program and Yucca Mountain Project Boreholes

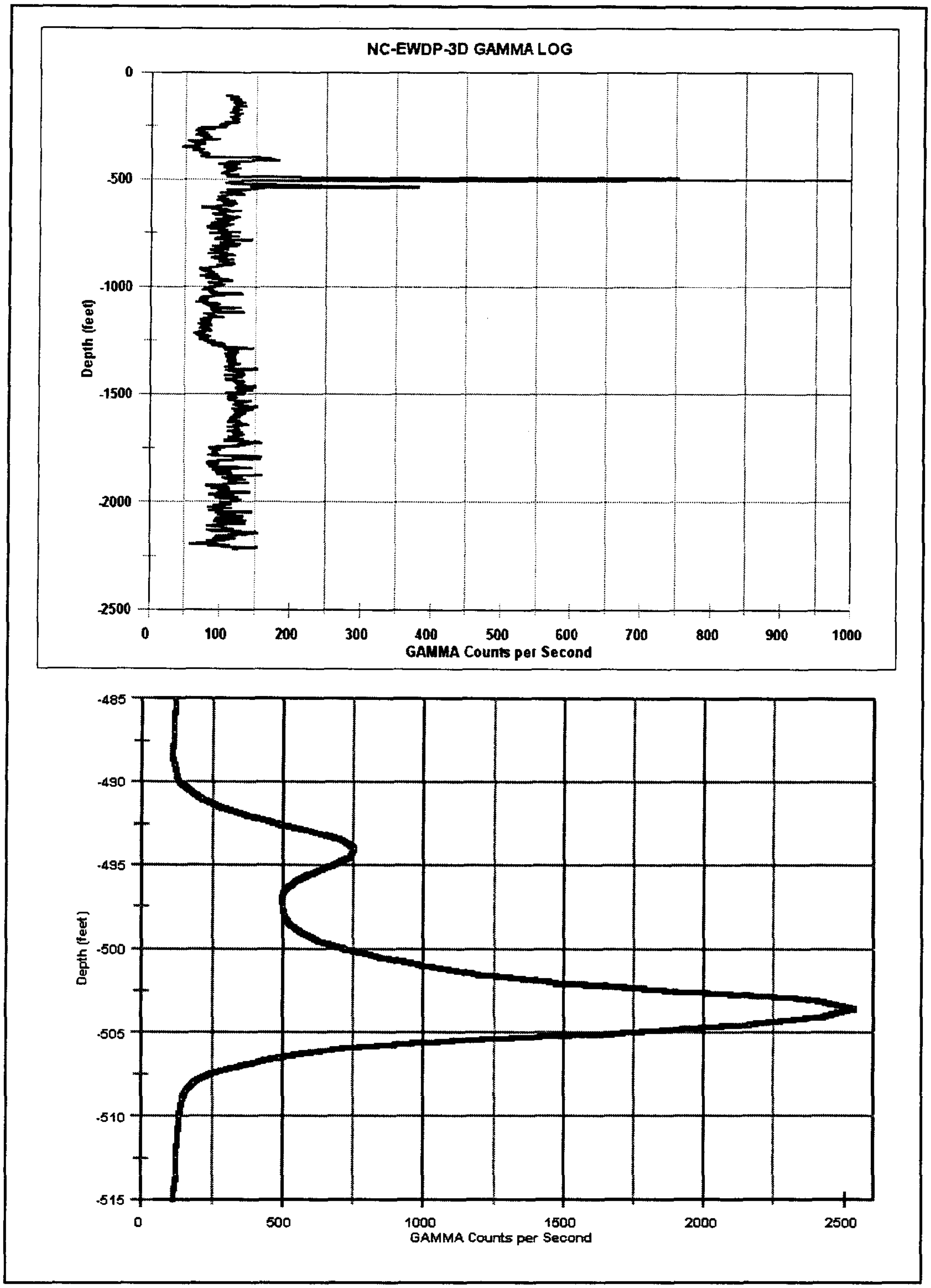
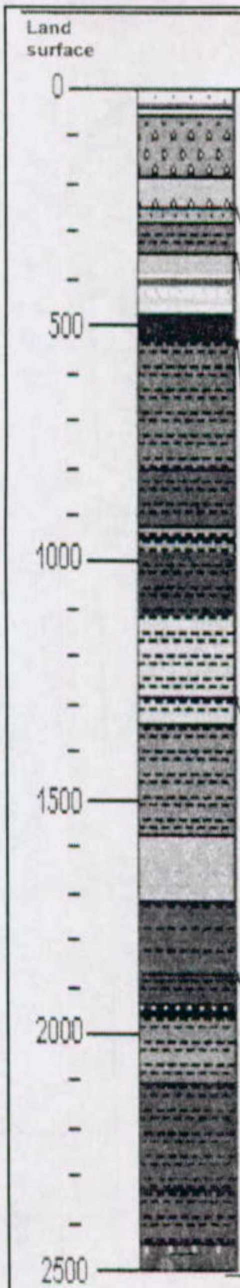


Figure 4.1-6
Natural Gamma Log for NC-EWDP-3D Showing the Gamma Spike



0-251' Valley-fill - Alluvium - 0-185' Alluvium, poorly sorted, coarse gravels and sand, fan-deposits; 0-25' pale orange (10YR 8/2 dry), caliche covered clasts; 25-30' no sample; 30-40' grayish red (10R 4/2) to light brown (5YR 6/4); 40-45' no sample; 45-55' alluvium, as 30-40'; 55-65' no sample, 65-185' alluvium, gravel and sand, grayish red (10R 4/2) to light brown (5YR 6/4), poorly sorted; 185-200' alluvial sand, pale yellowish brown (10YR 6/2), poorly sorted; 200-205' alluvium, gravel and sand, caliche covered, pale orange (10YR 8/2); 205-210' no sample; 210-220' alluvium, gravel and sand, light brown (5YR 6/4); 220-225' no sample; 225-251' alluvial sand, pale yellowish brown (10YR 6/2), poorly sorted

251-343' Tertiary Sedimentary Rocks - 251-278' sandstone, lacustrine/fluvial, pale red (10YR 6/2), 10-20% mafics, tr. FeOx, poss. weathering surface; 278-295' sandstone, as 251-278', grayish orange (10YR 7/4), 1% volc. clasts; 295-343' siltstone, lacustrine, med. dark gray (N4), weakly calcareous, locally clayey

343-533 Tertiary Volcanics - 343-400' Ash Tuff, reworked, grayish orange pink (5YR 7/2) to pale orange (10YR 8/2), up to 5% qtz/sanidine phenos, 1% mafics, up to 20% volc. clasts, becomes yellowish-gray beyond 390'; 400-412'Ash Tuff, ash flow, med. dark gray (N4), 5% qtz/sanidine phenos, 1% mafics, up to 10% pumice, light gray (N7), unflattened; 412-419' Ash Tuff, ash flow, grayish orange (10YR 7/4), 5% biotite and mafics, 1% qtz/sanidine; 419-477' Tuff, ash, reworked, pale orange (10YR 8/2), 5-10% abraded biotite and mafics, 1-5%qtz/sanidine phenos, up to 20% volc. clasts, becomes grayish yellow green (5GY 7/2) 445-460', yellowish gray (5Y 7/2) 460-478'; 478-533' tuff, ash flow, black (N1), 20-30% pumice (pale orange (10YR 8/2)),0-50% qtz/sanidine phenos, 0-10% mafics, unflattened pumice, pumice color becomes greenish yellow (10Y 8/2) beyond 505'

533-1285' Tertiary Sedimentary Rocks - 533-945' siltstones, calcareous, homogeneous, brownish gray (5YR 4/1) to med. dark gray (N4), locally clay-rich esp. 705-805', 805-920' color is darker, dusky brown (5YR 2/2) to med. dark gray (N4), some grayish olive (5Y 4/2); 945-1105' siltstones, lacustrine, noncalcareous, light olive gray (5Y 5/2) to grayish black (N2), locally clay beds to 1055', locally and tuff beds (light gray N8) beyond 980', fine sandstone beds beyond 1210'

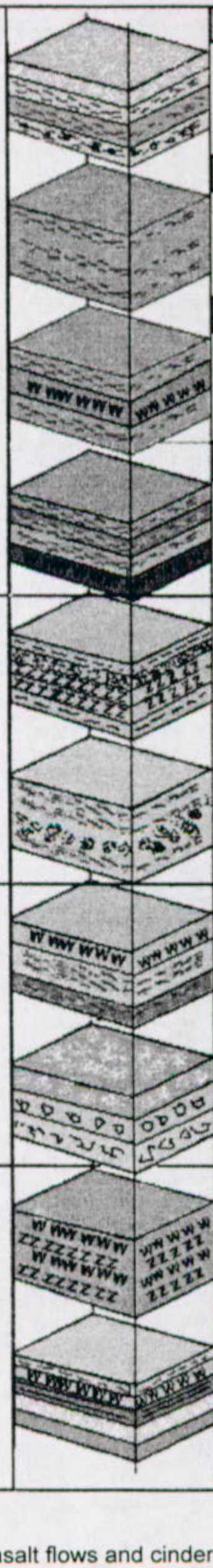
1285-1870' Tertiary Mixed Sedimentary and Volcanic sequence - 1285-1340' siltstone/crystal tuff reworked, dk. gray to grayish-black (N3-N2), 2% white pumice and qtz frags. decreasing downhole, tr. vfg pyrite; 1340-1565' siltstone/sandstone, poss. reworked tuff, med gray (N5-N4), qtz. and fsp. crystals, tr. vfg pyrite, grain size is vfg sand to silt, local gray-black (N2) fragments to 1390', local grayish-yellow (5Y 8/4) tuff frags. beyond 1540' and cherty siltstone beds (N3) beyond 1520'
1565-1714' tuff, ash flow, light gray (N7), fine aphyric, local cherty beds? (N2), blebs of vfg pyrite
1714-1870' siltstone/tuff interbedded, yellowish brown(10YR 2/2) to brownish black (5YR 2/1) siltstones (1714-1739', 1785-1802', 1835-1839', 1854-1864'), laminated, locally 1% pyrite interbedded with crystal tuffs (1739-1785', 1802-1835', 1839-1854', 1864-1870'), medium gray (N5), 10-50% qtz/sanidine crystals, 5-10% hornblende/biotite crystals, local black (N1) lithic fragments

1870-2500' Tertiary Sedimentary Rocks - 1870-1925' siltstone, sandy, lacustrine, brownish black (5YR 2/1) to yellow brown (10YR 5/4); 1925-1932' silstone as 1870-1925', clay-rich, light gray (N8); 1932-1945' siltstone, black (N1) to yell-brn (10YR 5/2);1950-2000' siltstones, fine dark yell-brn (10YR 3/2) mixed with coarser pale yell-brn, becomes gray-brn (5R 3/2) beyond 1990', lt. gray tuff bed 1997-2000'; 2000-2085'sandy siltstone, pale brown (5YR 5/2) to gray and olive gray (5Y 6/1), partly calcareous; 2085-2100' siltstone w/ grey clay beds (N4);2100-2320' siltstone and marl interbedded, lacustrine, brn-blk siltstone (5YR 2/1) ~60%, pale brown silty marl (5YR 5/2) ~40%, beyond 2235, color is dark grey (N3) and olive-gray (5Y 4/2); 2320-2430' siltstone, lacustrine, dark

Figure 4.1-7
NC-EWDP-3D Summary Lithologic Log

NOTE: NTS = Nevada Test Site

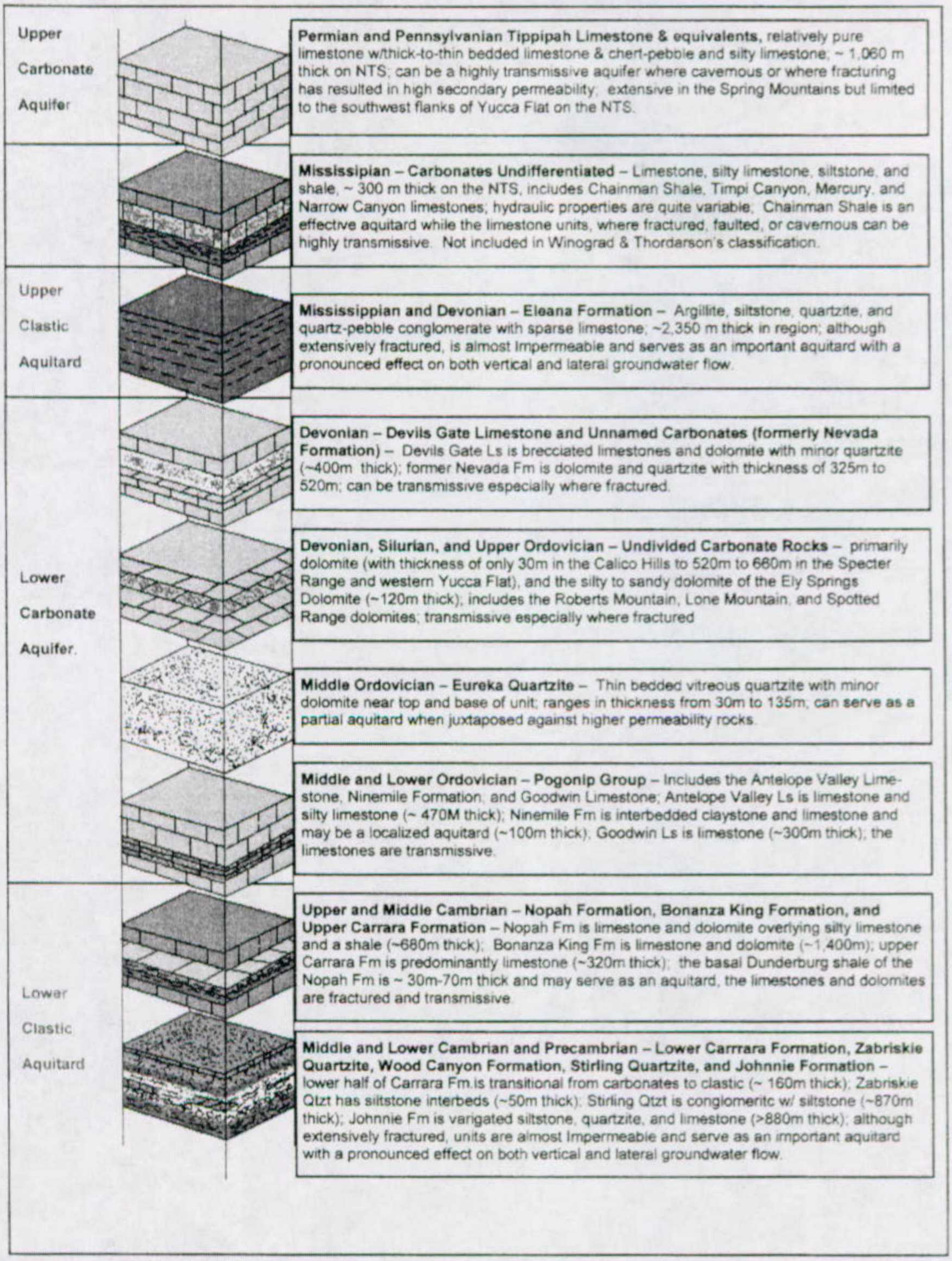
Figure 4.1-8
Major Valley-Fill and Older Units of the Yucca Mountain Region



Hydrogeologic Unit	Rock Units	Description
Upper Volcanic Aquifer	**Thirsty Canyon Group** Gold Flat Tuff Trail Ridge Tuff Pahute Mesa Tuff Rocket Wash Tuff **Fortymile Canyon Assemblage** Beatty Wash Formation **Timber Mountain Group** Ammonia Tanks Tuff Rainier Mesa Tuff Rhyolite of Fluorspar Canyon **Paintbrush Group** Tiva Canyon Tuff Yucca Mountain Tuff Pah Canyon Tuff Topopah Spring Tuff	Rocks of the Timber Mountain group, where saturated, are aquifers and are included within the upper volcanic aquifer classified by Winograd and Thordarson (1975) as the welded-tuff aquifer, and by Luckey et al (1996) as the Upper Volcanic Aquifer. This group may be greater than 260 m in some locations. The welded tuffs have low porosity and negligible porosity and, depending upon the degree of primary and secondary fracturing, low to high transmissivity. The fractured, bedded tuff portions of the Topopah Spring Tuff have a much higher porosity and moderate permeability. The Topopah Spring Tuff averages about 210 m in thickness but the upper 15 m and lower 9 m have low permeability. The Topopah Spring Tuff is the aquifer that supplies water to wells J-12 and J-13, which are each capable of producing several hundred gallons per minute.
Upper Volcanic Confining Unit	Calico Hills Formation Wahmonie Formation Salyer Formation	This unit also includes the unfractured basal part of the Topopah Spring Tuff. The Calico Hills Formation thins from more than 460 m to 15 m over a distance of only a few kilometers under Yucca Mountain. The Wahmonie Formation has an upper lava-flow and ash-fall tuff, tuffaceous sandstone, and tuff breccia and is about 1,200 m thick. The Salyer Formation is primarily breccias interbedded with sandstone, siltstone, and claystone with a total thickness of about 520 m. Both units have high porosity, negligible permeability, and low transmissivity.
Lower Volcanic Aquifer	**Crater Flat Group** Prow Pass Tuff Bullfrog Tuff Rhyolite of Prospector Pass Tram Tuff **Belted Range Group** Dead Horse Tuff Grouse Canyon Tuff Split Range Comendite	The Lower Volcanic Aquifer comprises ash-flow tuffs with varying degrees of welding, and rhyolite lavas. The upper part of the Prow Pass Tuff, where unfractured, is considered part of the Upper Volcanic Confining Unit. This aquifer is less fractured and more altered than the upper aquifer and is thus less permeable. The maximum thickness of this aquifer is probably more than 1,080 m.
Lower Volcanic Confining Unit	Lithic Ridge Tuff **Older Tuffs** Lava of Tram Ridge Tunnel Formation Tub Spring Tuff Tuff of Yucca Flat Redrock Valley Tuff	The Lower Volcanic Confining Unit includes the Lithic Ridge Tuff and the older tuffs and flows. The Lithic Ridge Tuff ranges from 185 to 304 m in thickness and the underlying units may be more than 350 m. Some of the older tuffs may be fractured and and capable of transmitting groundwater. Czarnecki et al. (1997) identified a lowermost volcanic aquifer within this unit, correlative with the Tub Spring Tuff.

NOTE: Basalt flows and cinder cones are included in valley-fill deposits.

Figure 4.1-9
Major Volcanic Rock Units of the Yucca Mountain Region



NOTE: NTS = Nevada Test Site

Figure 4.1-10
Major Paleozoic and Precambrian Rock Units of the Yucca Mountain Region

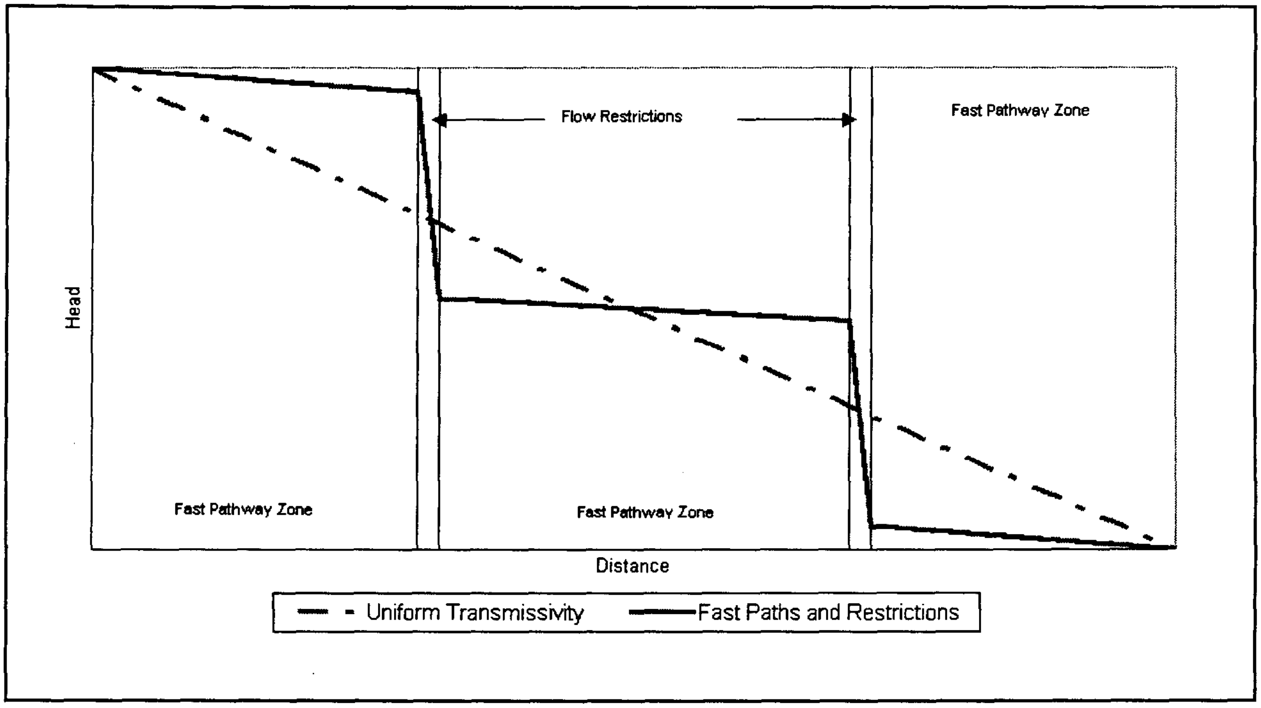


Figure 4.1-11
Conceptual Head Changes along a Flow Pathline

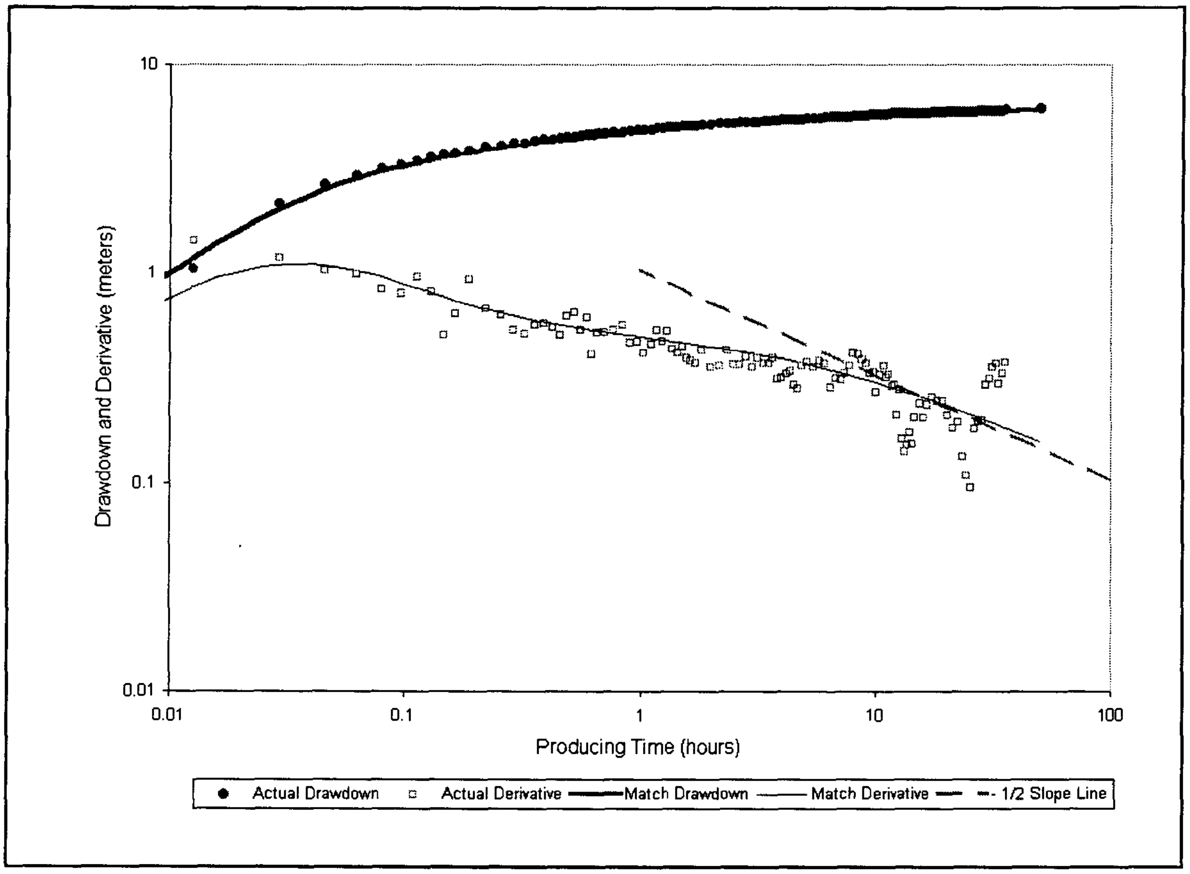


Figure 4.1-12
Log-Log Diagnostic Plot for NC-EWDP-3D
Showing –½ Slope in Derivative Characteristic of Spherical Flow

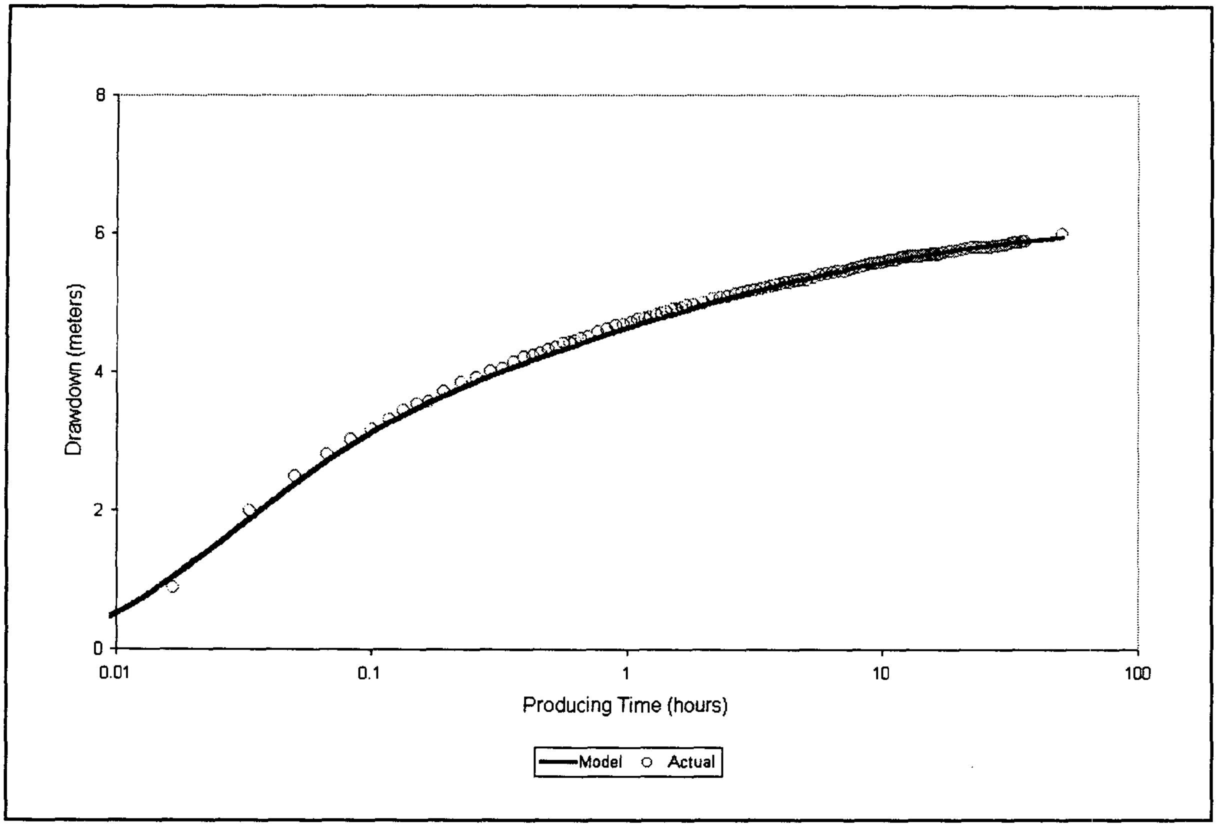


Figure 4.1-13
Semilog Cooper-Jacob Plot for NC-EWDP-3D

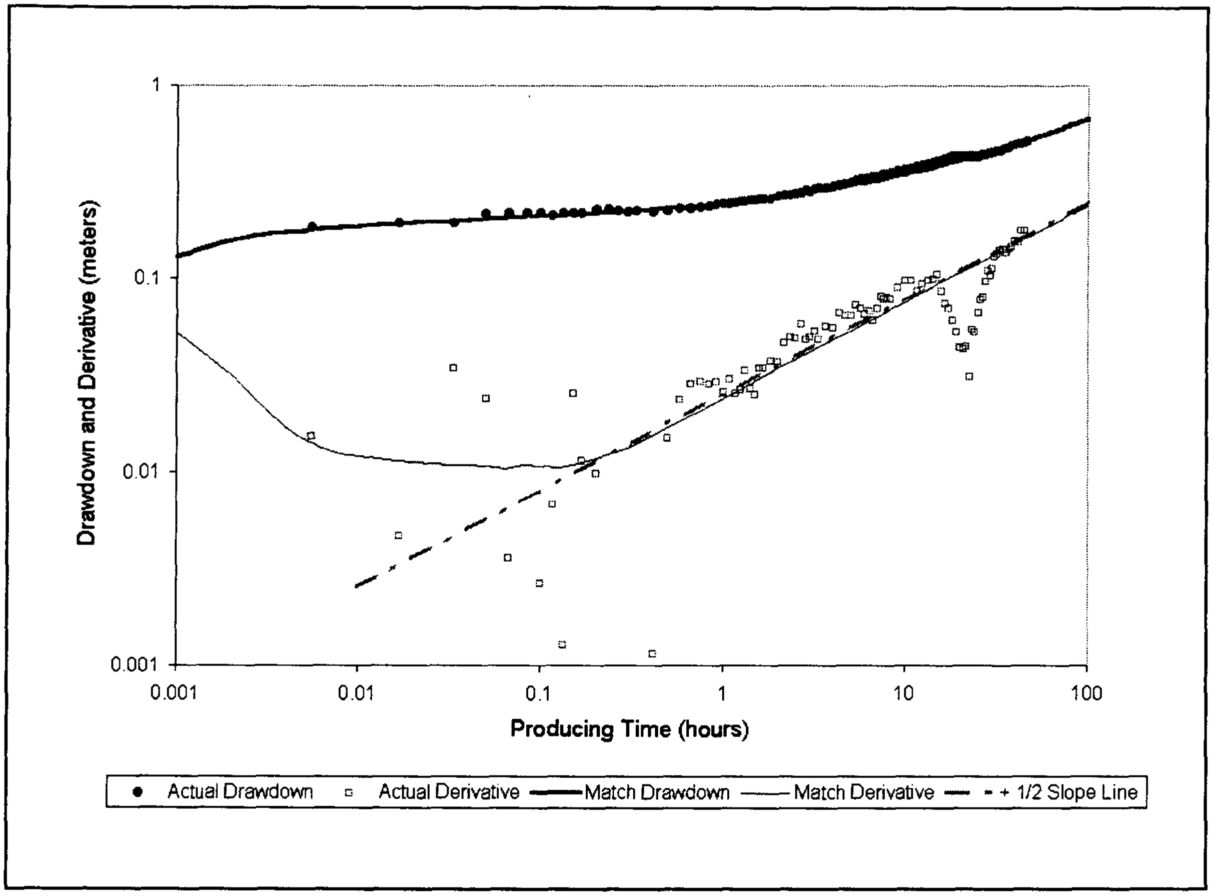


Figure 4.1-14
Log-Log Diagnostic Plot for NC-EWDP-1S
Showing +½ Slope in Derivative Characteristic of Parallel Boundaries

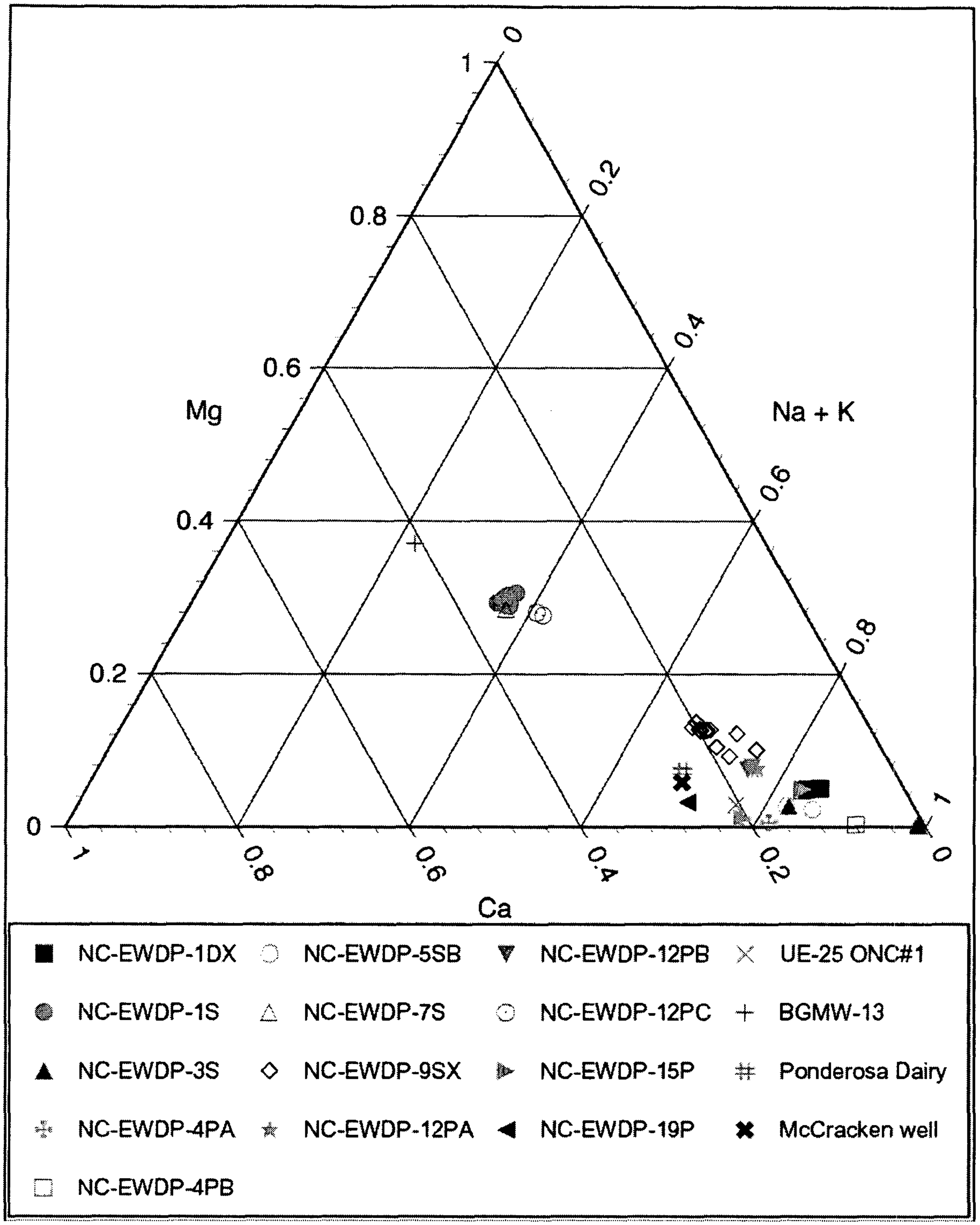


Figure 4.1-15a
Cation Ternary Piper Diagram for Early Warning Drilling Program Water Samples

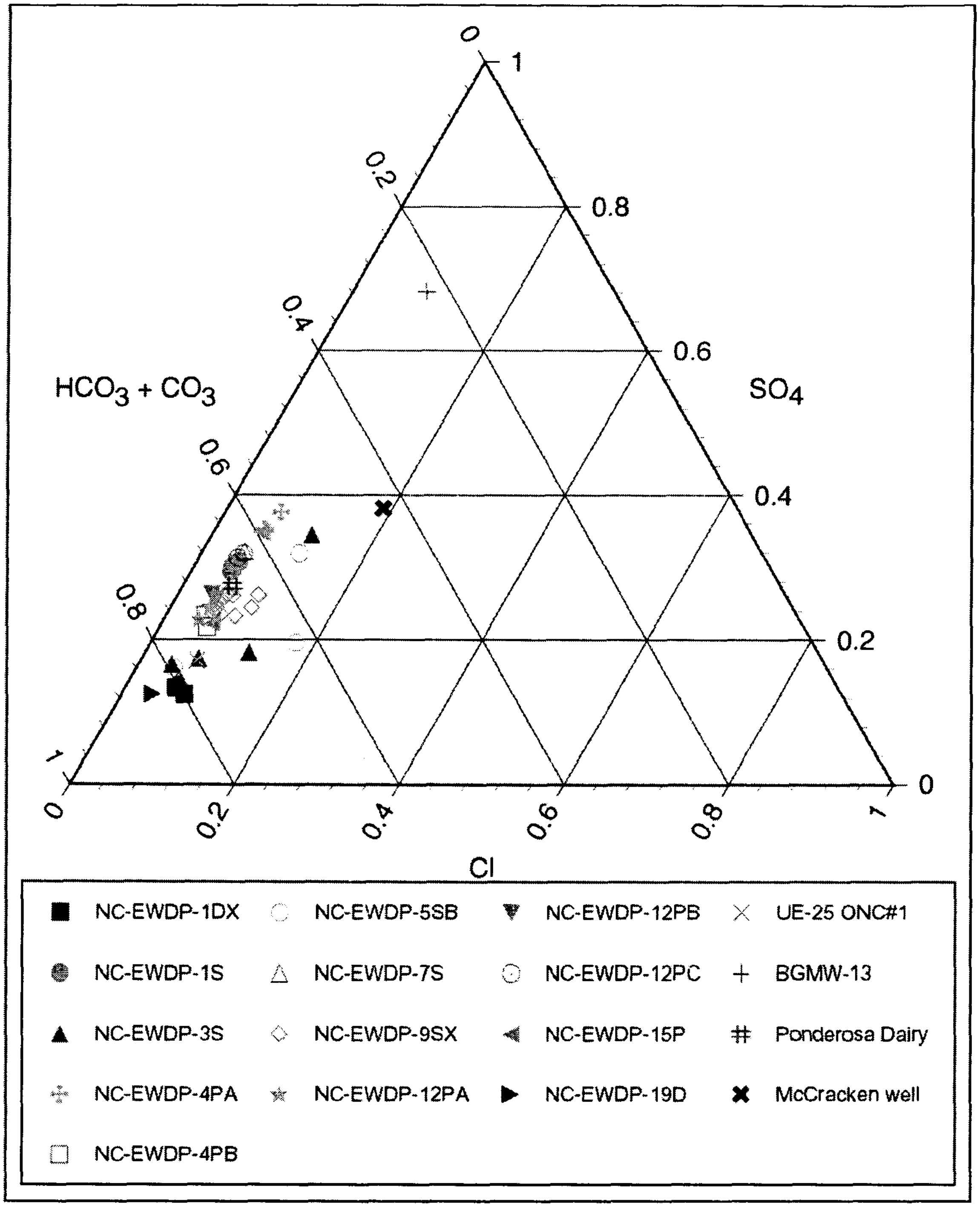


Figure 4.1-15b
Anion Ternary Piper Diagram for Early Warning Drilling Program Water Samples

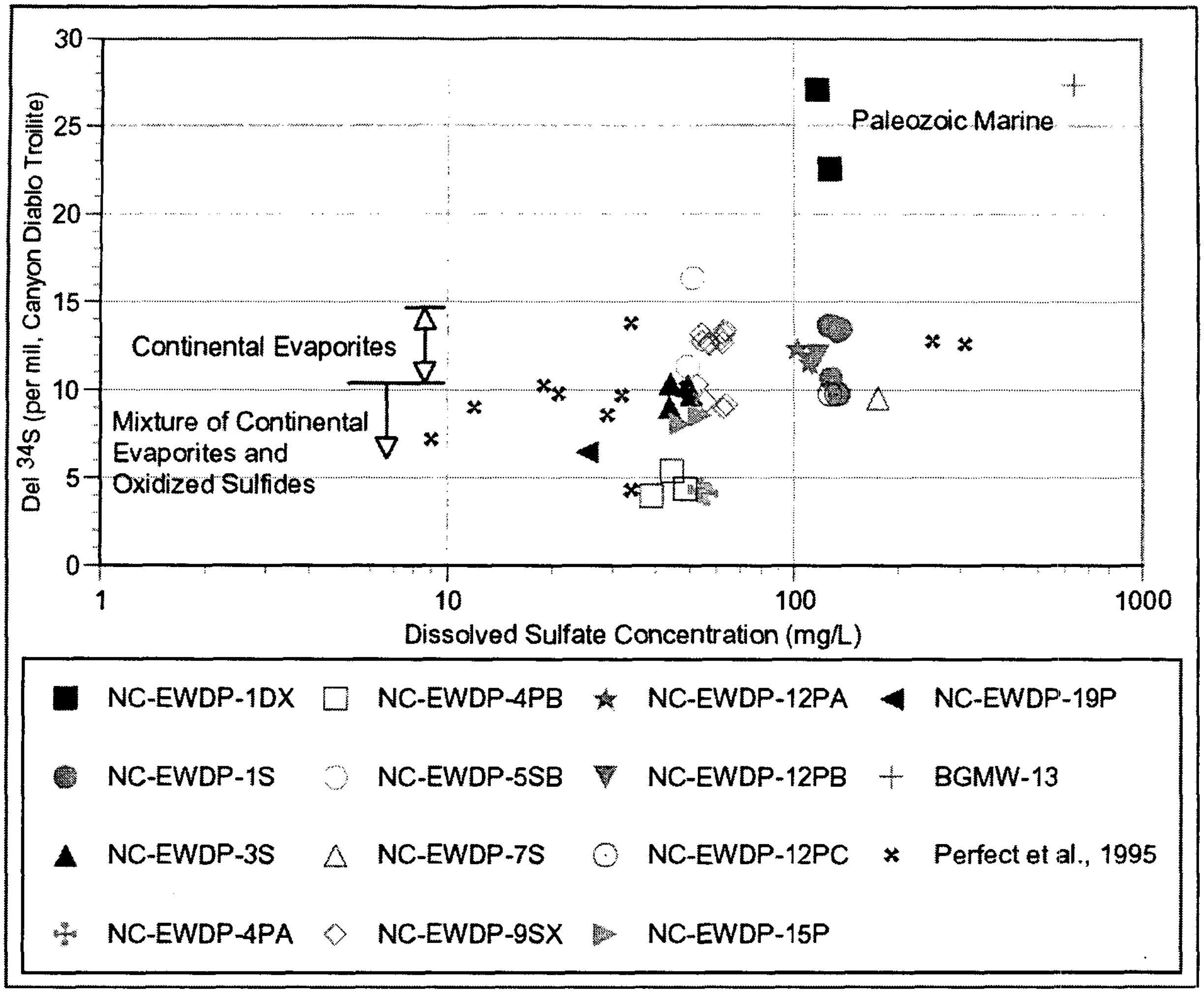
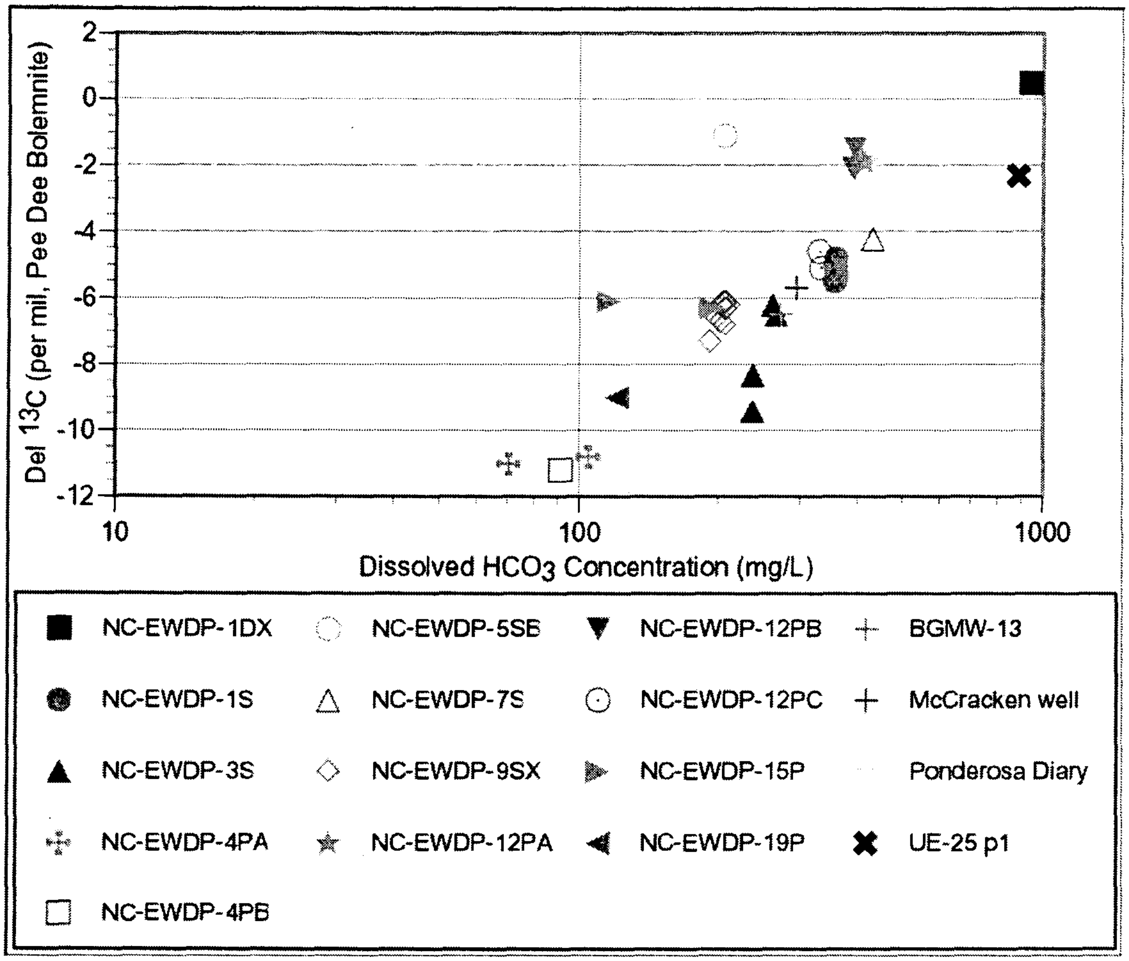


Figure 4.1-16a
Sulfur Isotopes of Sulfate and Dissolved Sulfate Concentration for Selected Early Warning Drilling Program and Other Water Samples



NOTE: Legend is the same as in Figure 4.1-16a.

Figure 4.1-16b
Stable Carbon Isotopes of Bicarbonate and Dissolved Bicarbonate Concentration for Selected Early Warning Drilling Program Water Samples

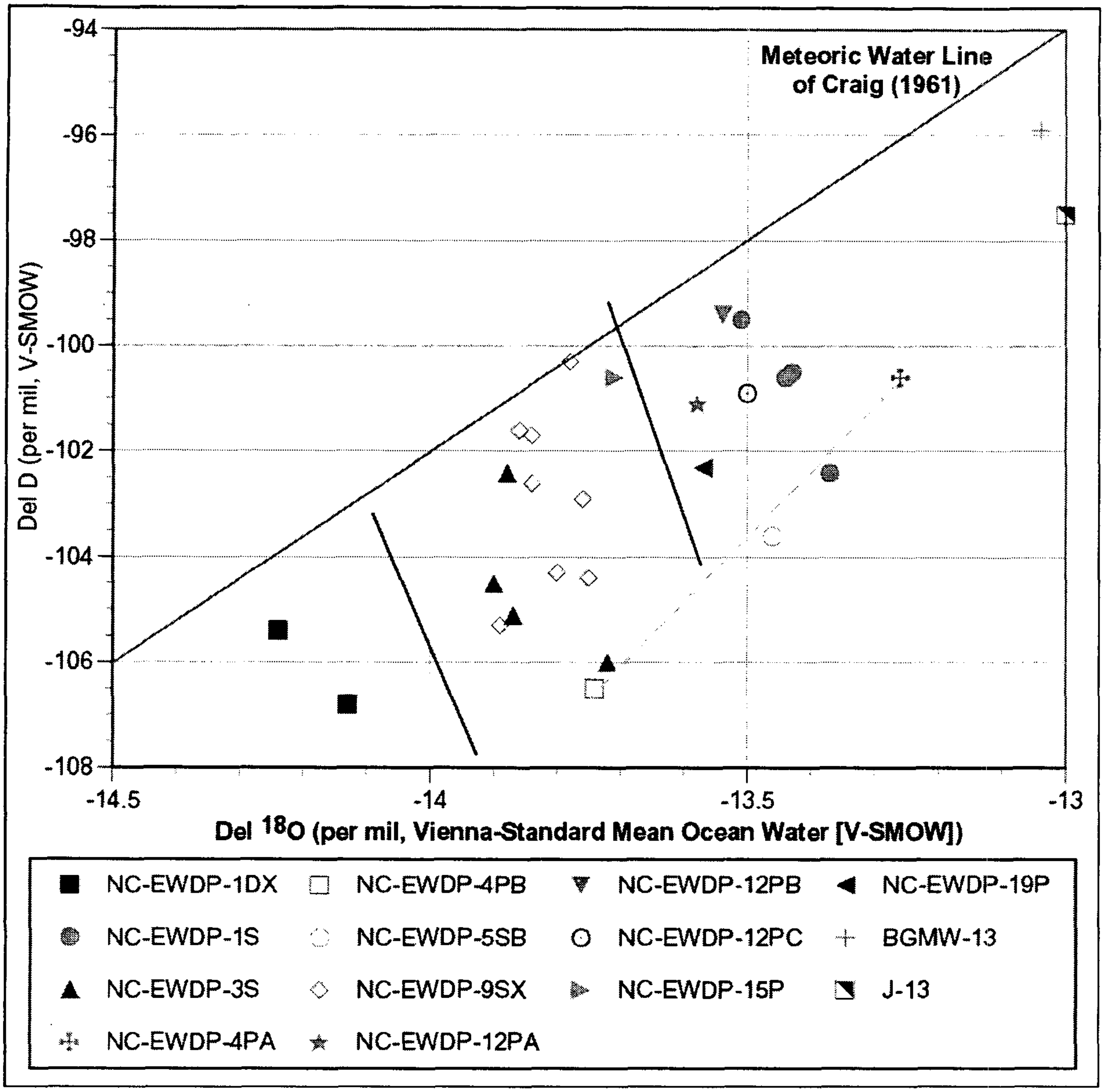
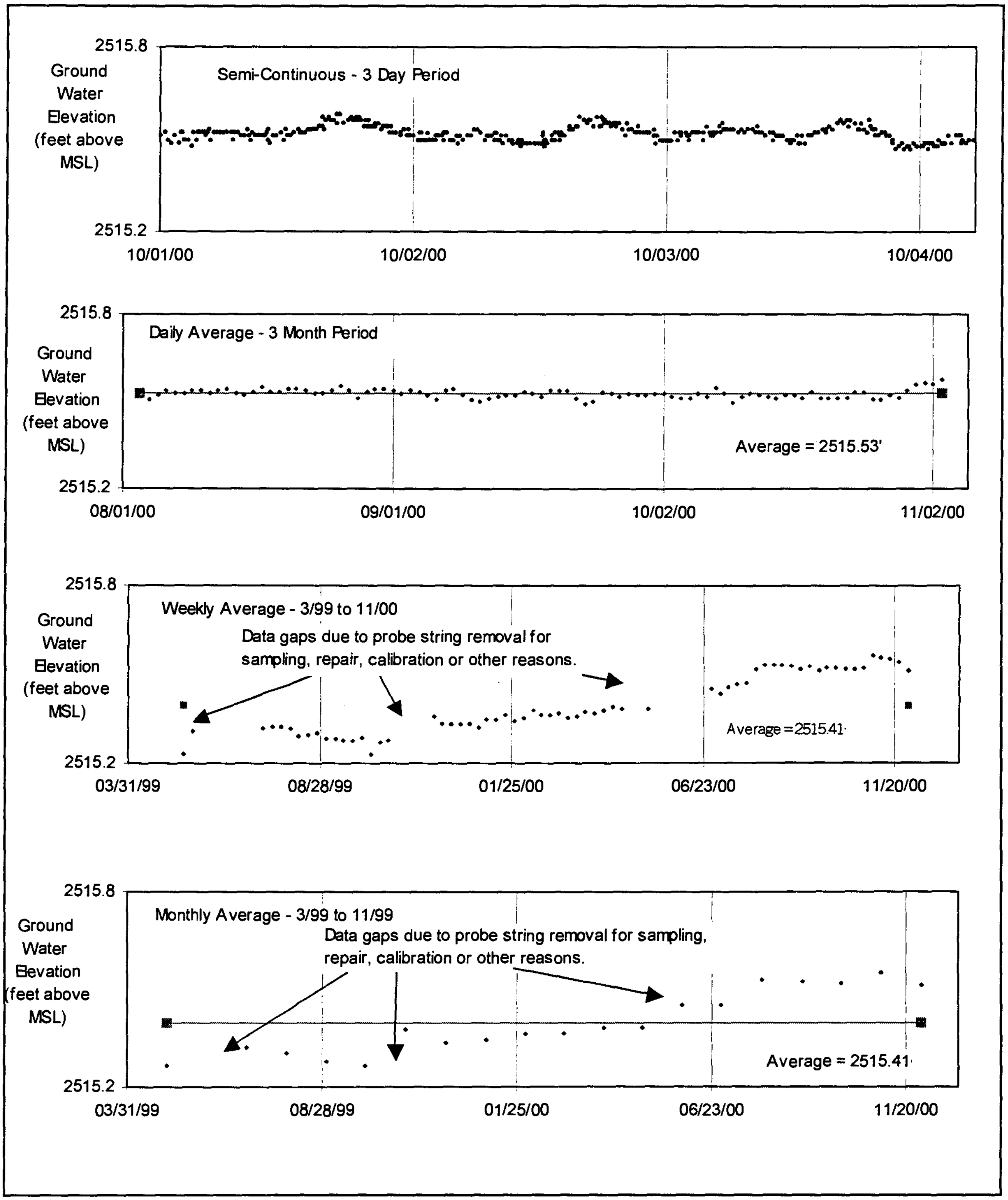


Figure 4.1-17
Stable Isotopes of Water for Selected Early Warning Drilling Program and Other Water Samples



NOTE: MSL = mean sea level

Figure 4.1-18
Water Level Variations in NC-EWDP-9SX for Various Time Periods

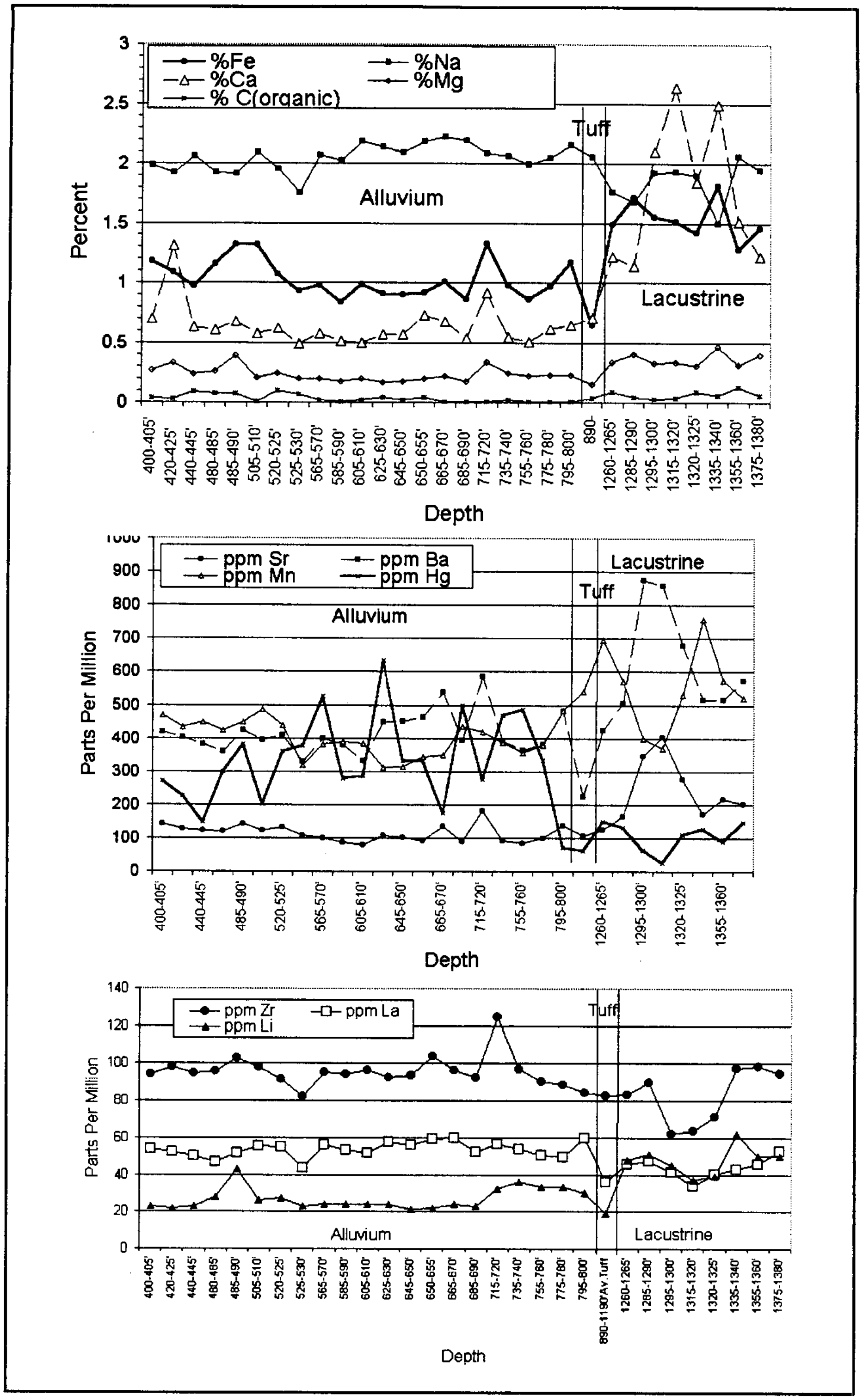


Figure 4.1-19
Trace Element Distribution, NC-EWDP-19D

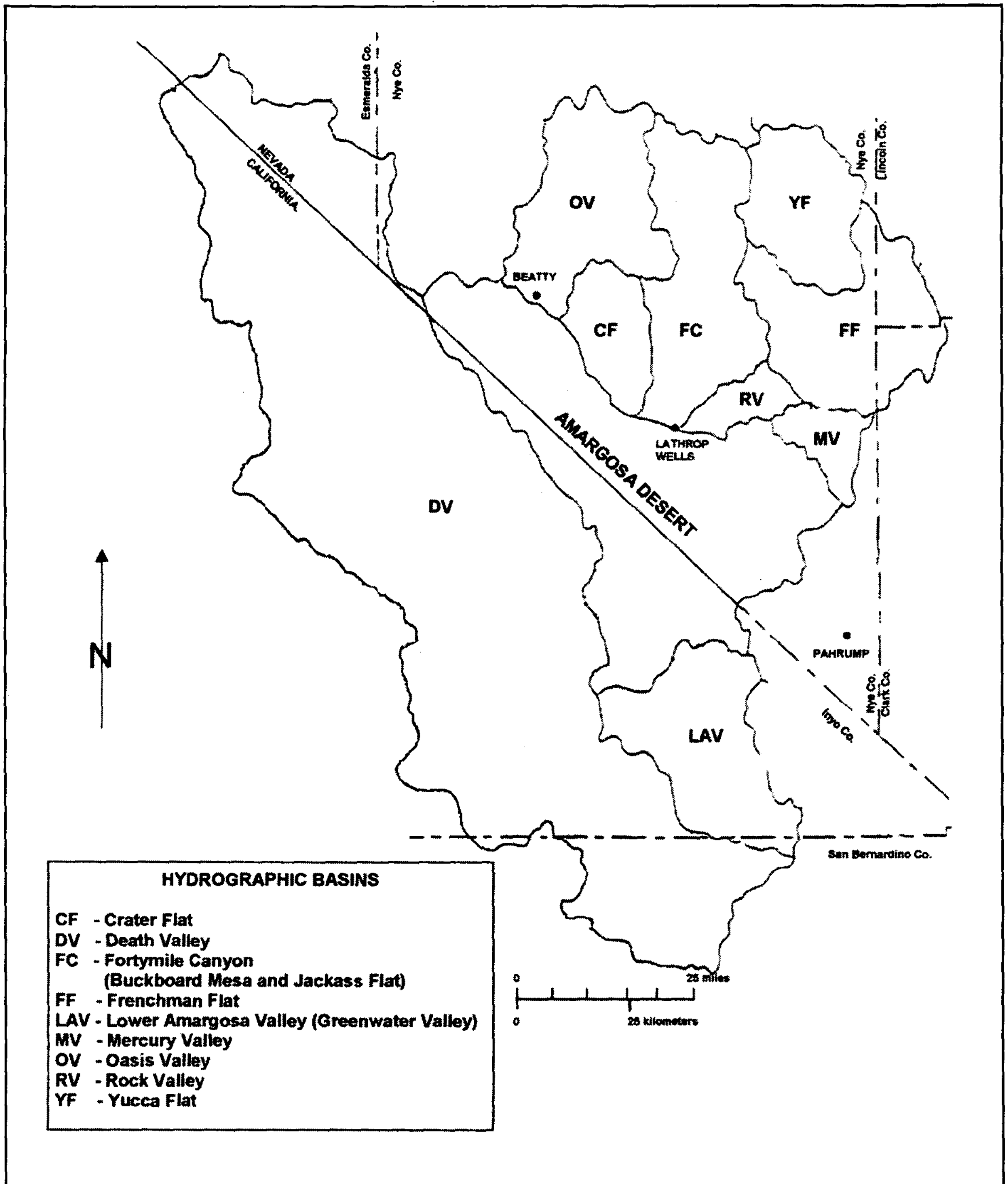


Figure 4.1-20
Watershed/Hydrographic Basin Boundaries

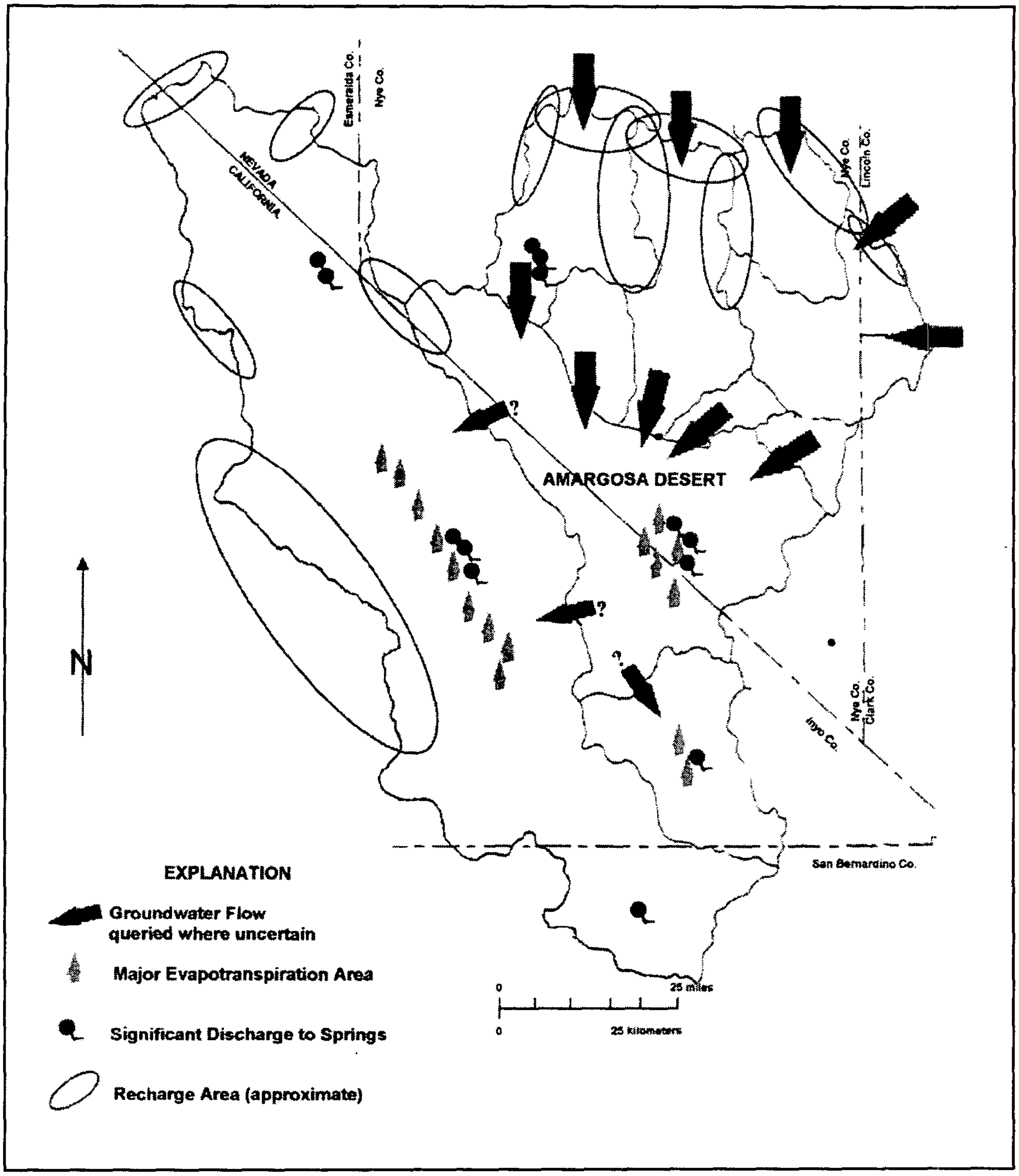
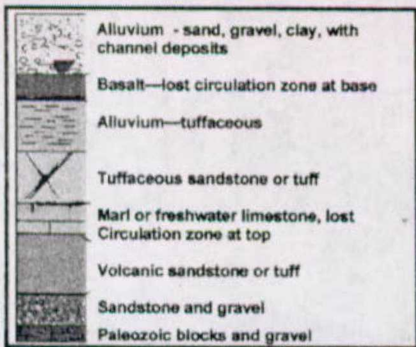


Figure 4.1-21
Recharge to and Discharge from Amargosa Desert

VALLEY FILL DEPOSITS

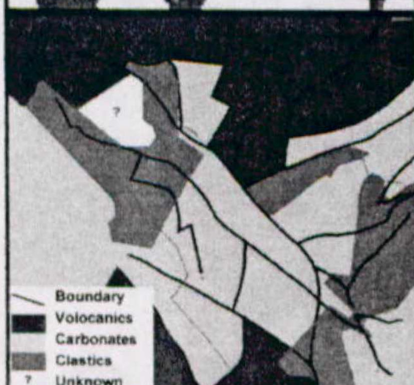


The valley-fill deposits comprise a number of geologic materials with contrasting hydraulic characteristics. Preferential pathways for flow include channel deposits in otherwise fine grained sediments, intercalated volcanic units, freshwater limestone, fractured conglomerate, and, at the top of the sequence, alluvium. Groundwater flows through the valley-fill deposits from the recharge sources toward the central valley floor and then into the southern part of the basin where it is either lost to evapotranspiration or discharge to downgradient areas. Most groundwater used in Amargosa Desert for agriculture, mining, and domestic purposes is pumped from wells that penetrate the alluvium and upper most portions of the Tertiary valley-fill deposits.

In the Ash Meadows area, ground water derived from the east and northeast flows through the permeable carbonate basement rocks and rises to the surface near the fault contact with the thick valley-fill sediments to the west. Significant spring discharge occurs in this area. Some leakage across this contact may be occurring. In the geologic past, this discharge of this nature occurred elsewhere in the basin. Since that time, the climate has dramatically changed resulting in a lowering of the water table and leaving fine-grained deposits at the locations where groundwater once flowed at the surface.

Between the mountainous areas, the basement is overlain by thick sequences of Tertiary volcanic rocks and/or valley-fill deposits. The valley-fill deposits are recharged primarily by lateral flow from the volcanic rocks and basement rocks along the mountain fronts and by upward leakage along geologic structures. Limited recharge occurs over reaches of Fortymile Wash and from precipitation over discharge areas.

BASEMENT



The basement rocks have been disrupted by a complex history of tectonic activity. Some geologic structures provide avenues for significant quantities of groundwater flow. Other structures juxtapose the basement rocks against fine-grained sediments resulting in shallow groundwater conditions upgradient of the contact, such as at NC-EWDP-1DX. These structures divide the basement into sub-areas or compartments. Clastic rocks serve as barriers in some areas of the basement rocks, resulting in further compartmentalization. North of Amargosa Desert, the basement rocks are buried under thick volcanic sequences and are probably not significant aquifers. It is inferred that many of the structures that serve as compartment boundaries also act as conduits for the leakage of groundwater from the basement rocks into the valley-fill deposits. The magnitude of this leakage is not known but could be appreciable.

The pre-Cenozoic basement rocks underlying Amargosa Desert receive large quantities of groundwater recharge from the Springs Mountains and Sheep Range, and lesser quantities of recharge from the upland areas north of the Nevada Test Site, the Bullfrog Hills, the Funeral Mountains, and portions of Crater Flat. Deep basins within the basement surface, such as the Amargosa Trough, were probably filled with lakes during early Tertiary time. Discharge from the basement rocks occurs as springs, leakage into overlying volcanic rocks and valley-fill sediments, and possibly via deep underflow into downgradient areas such as Death Valley. The quantities of recharge, discharge, and underflow are not well defined.

Figure 4.1-22
Preliminary Hydrogeologic Conceptual Model of Amargosa Desert

Holocene (10,000 bp to present) Continued alluvial deposition.
Pleistocene (1.6 MA to 10,000 bp) Alluvium and marsh sediments deposited in central Amargosa Desert. Basaltic volcanism northwest of Lathrop Wells. Six mi^2 Ash Meadows Lake in Amargosa Flat area (Crystal). Amargosa Desert, Jackass Flats, and western Crater Flat become quiescent.

Pliocene (1.6 to 5.3 MA) Deposition of alluvium, colluvium, gravel, limestone, and the Basalt of Crater Flat.

Miocene (5.3 to 23.7 MA) Ash flow and bedded tuff volcanics deposited as Thirsty Canyon Group, Fortymile Canyon assemblage, Timber Mountain Group, Paintbrush Group, Calico Hills Formation, Wahmonie Formation, Crater Flat Group, Belted Range Group, and older tuffs. Quartz-latite dikes at Bare Mountain. Sedimentary rocks deposited as Rocks of Joshua Hollow. Volcaniclastic lacustrine sediments deposited that may be equivalent to Rocks of Pavits Spring. Conglomerate, sandstone, limestone, ash deposited in some areas as Amargosa Valley Formation. Basin and Range faulting resulting in uplift of Bare Mountain and Funeral Mountains, Spotted Range-Mine Mountain Structure. Funeral Mountains detachment (9 to 7.5 MA). Death Valley detachment system (12.7 to 7 MA). Begin basaltic volcanism (11 MA). Development of southwestern Nevada volcanic field results in volcanic pile from five major episodes of eruptions, followed by possible post-eruption deflation (15 to 7.5 MA). Development of north-south trending basins or troughs (by 15 MA). Pre basin and range extension, crustal thinning, continued shear (Oligocene to Middle Miocene). Shear with associated dextral and sinistral faulting along the Walker Lane, Rock Valley, and Las Vegas Valley shear zones and the Furnace Creek Fault Zone (Early Miocene). Basins develop in northwest and southern Amargosa Desert (26 to 18 MA).

Oligocene (23.7 to 36.6 MA) Volcaniclastic lacustrine sediments deposited that may be equivalent to Rocks of Pavits Spring, lacustrine limestone that may be equivalent to Horse Spring Formation in Mercury Valley, and landslide breccias. Diorite dikes at Bare Mountain. Volcanic eruptions east and north of Yucca Mountain (Late Oligocene). Extensional faulting forming basins in Paleozoic surface.

No Eocene (36.6 to 57.8 MA) or Paleocene (57.8 to 66.4 MA) units have been identified in the Amargosa Desert basin.

No Cretaceous (66.4 to 144 MA) or Jurassic (144 to 208 MA) deposition except megabreccia. Triassic (208 to 245 MA) plutonic rocks intruded on the Nevada Test Site outside of Amargosa Desert basin. Granite sills at Bare Mountain. Sevier Orogeny – North to Northeast trending fold-thrust system with associated folding. Belted Range, CP, and Spotted Range thrusts and possible synclinorial basin.

Permian-Pennsylvanian (245 to 330 MA) Carbonate province rocks deposited as the Tippipah Limestone.

Mississippian (330 to 360 MA) Terrigenous detrital province rocks deposited as the Eleana Formation and unnamed units. Antler Orogeny – Deep water deposition of clastics in a foreland basin east of the Antler orogenic belt. Resulted in deposition of Eleana Formation and equivalents that comprise the upper clastic aquitard.

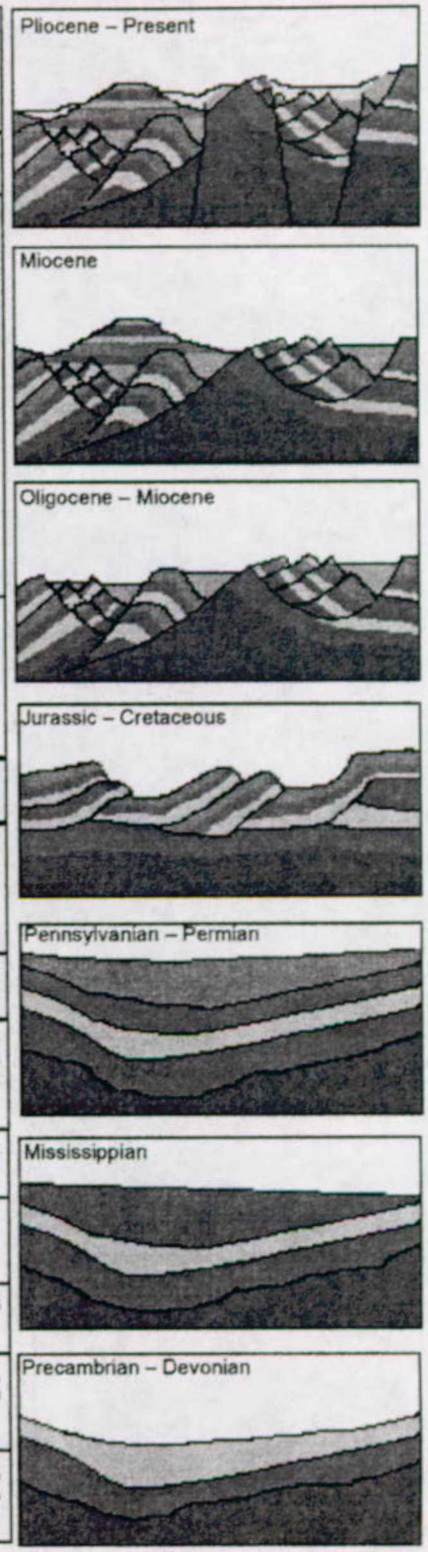
Devonian (360 to 408 MA) Carbonate and quartzite province rocks deposited as Devils Gate Limestone, Nevada and Fluorspar Formations, and unnamed units.

Silurian (408 to 438 MA) Dolomite province rocks deposited as Roberts Mountain Formation and Lone Mountain Dolomite.

Ordovician (438 to 505 MA) Carbonate and quartzite province deposited as Ely Springs dolomite, Eureka Quartzite, and Pogonip Group.

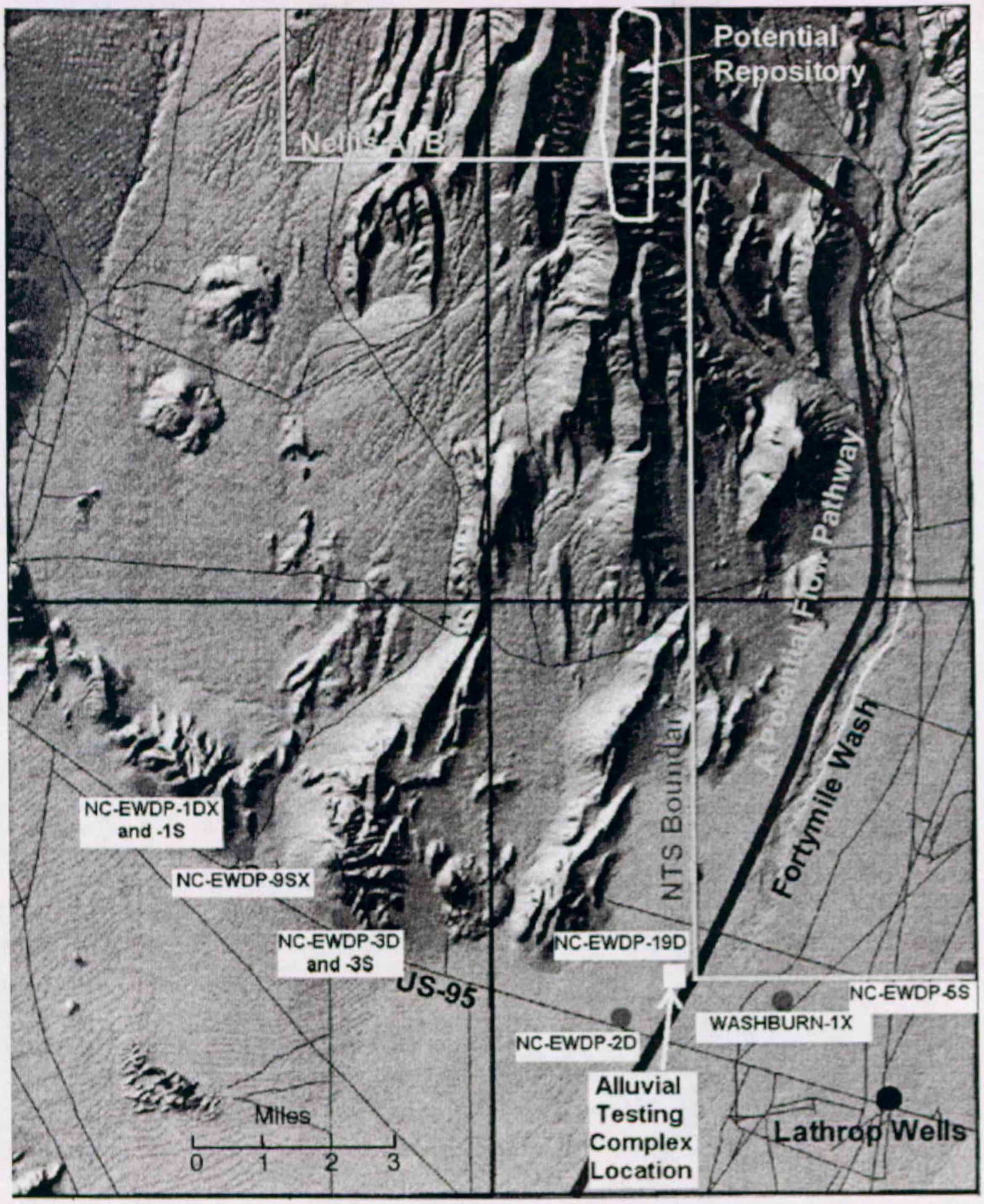
Mid to Upper Cambrian (505 to 540 MA) Carbonate province rocks deposited as Nopah, Bonanza King, and Carrara Formations underlain by siltstone, carbonate and quartzite province rocks deposited as Zabriskie Quartzite and upper Wood Canyon Formation.

Late Precambrian to Lower Cambrian (540 to 900 MA) Phyllitic siltstone, conglomerate, limestone, and dolomite deposited as lower Wood Canyon Formation, Stirling Quartzite, and Johnnie Formation.



Source: Based primarily on Burbey (1997), Stewart (1980), and DOE (1998)

Figure 4.1-23
Summary Geologic History of the Evolution of Hydrostratigraphic Units of the Amargosa Desert



NOTE: NTS = Nevada Test Site, AFB = Air Force Base

Figure 4.2-1
Location of Alluvial Testing Complex

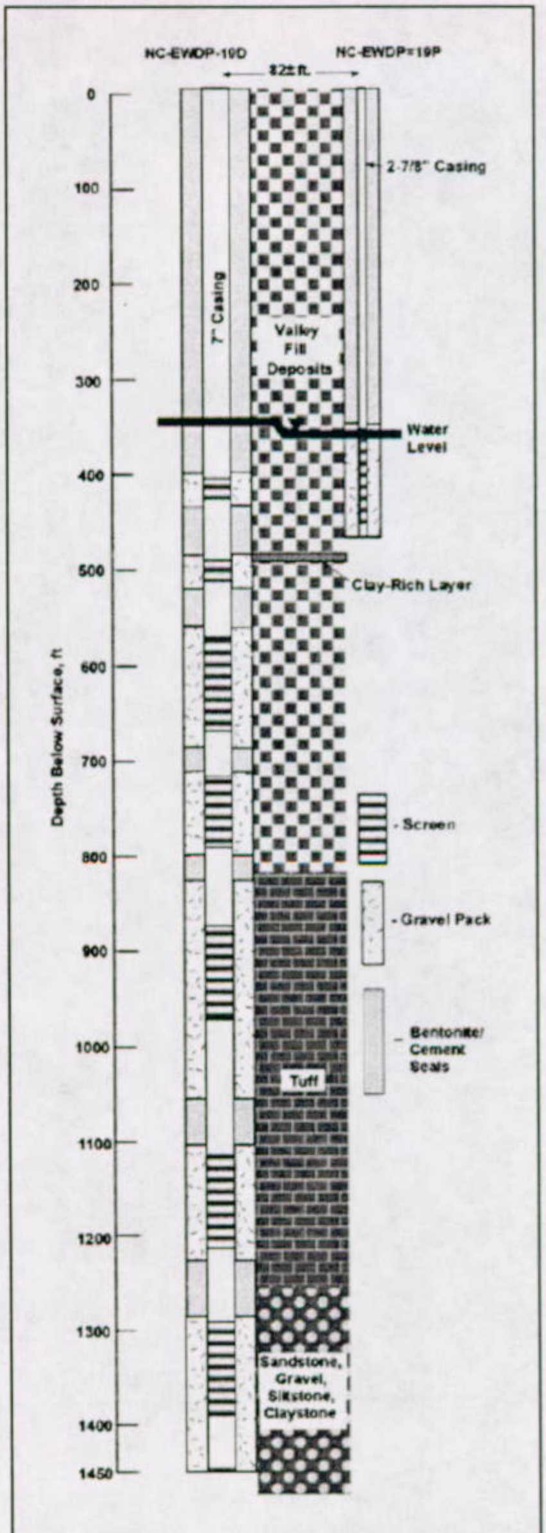
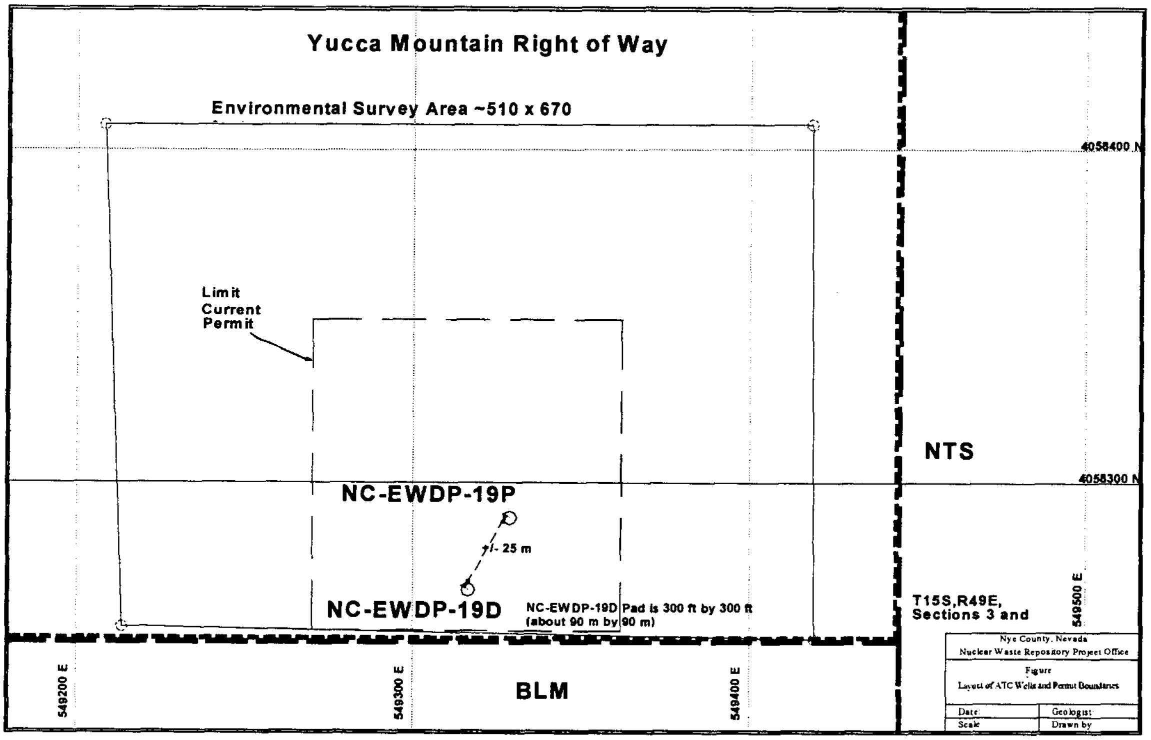


Figure 4.2-2
Wellbore Completion Diagram for NC-EWDP-19D and -19P



NOTE: BLM = Bureau of Land Management; NTS = Nevada Test Site

Figure 4.2-3
Current Alluvial Testing Complex Configuration with Permit Boundaries

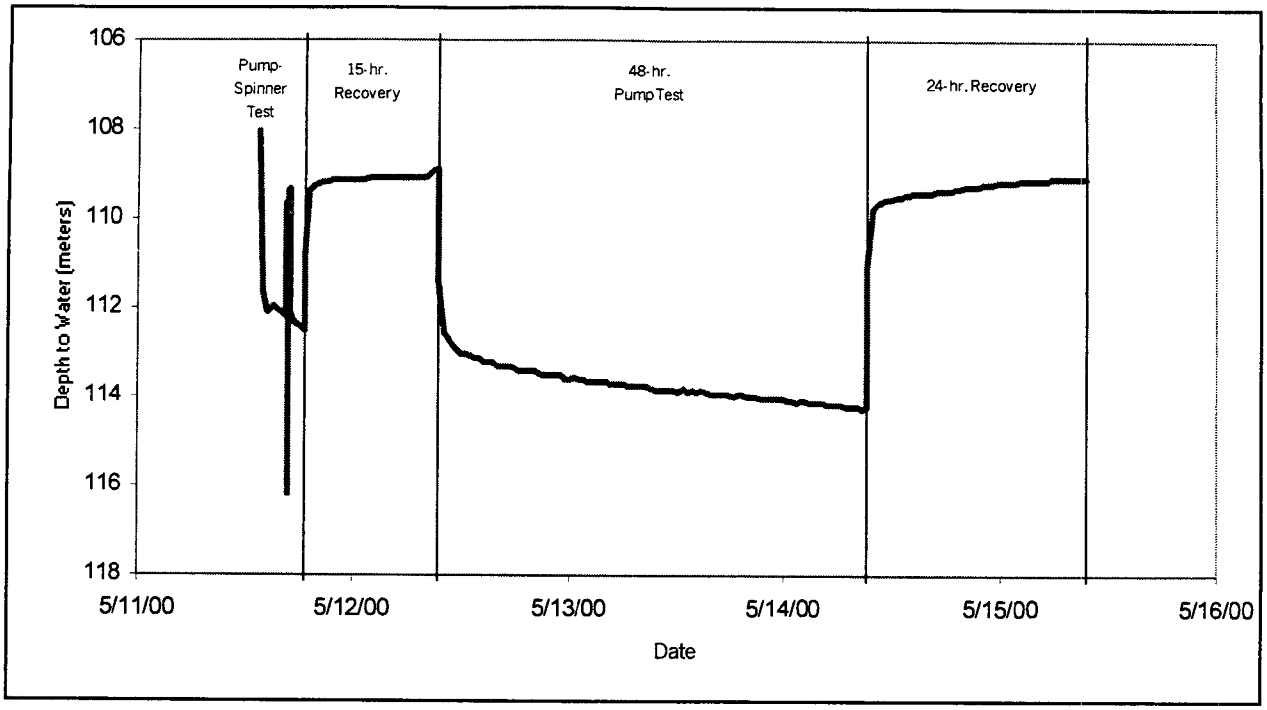


Figure 4.2-4
NC-EWDP-19D Test Response

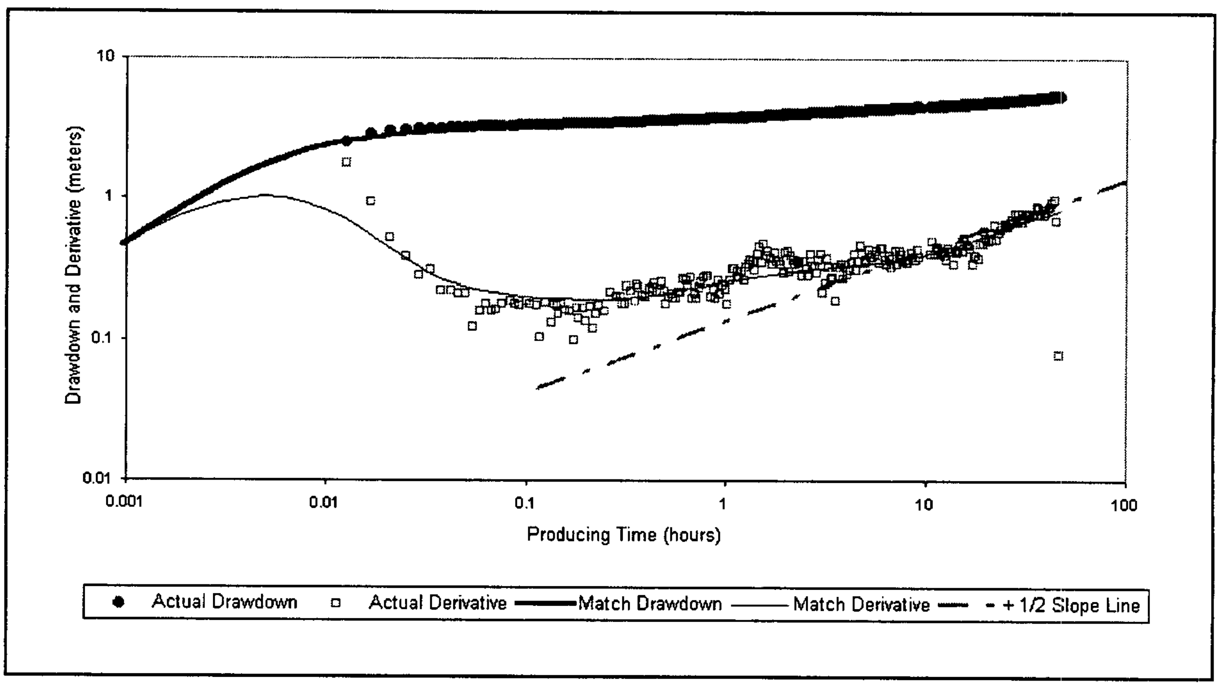
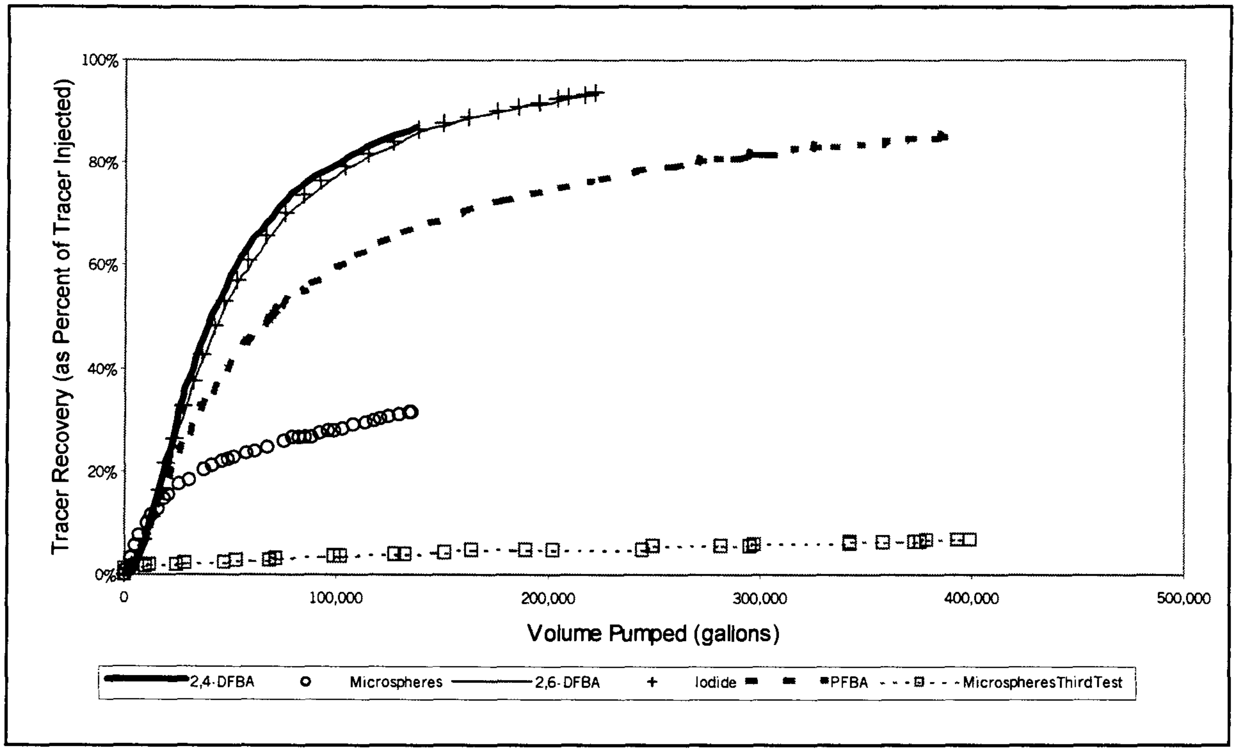
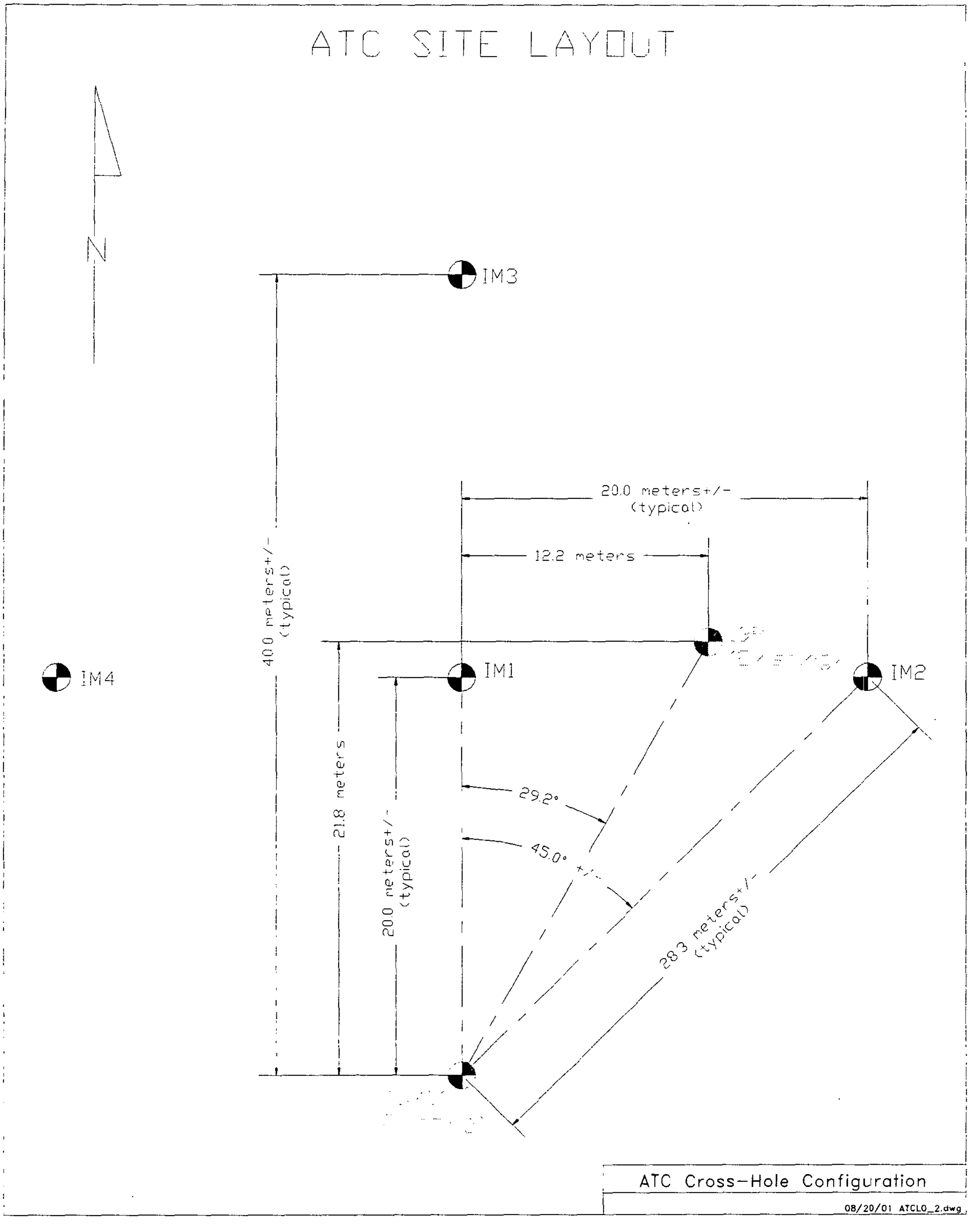


Figure 4.2-5
Log-Log Diagnostic Plot for NC-EWDP-19D Showing +½ Slope in Derivative at Late Times Characteristic of Parallel Boundaries



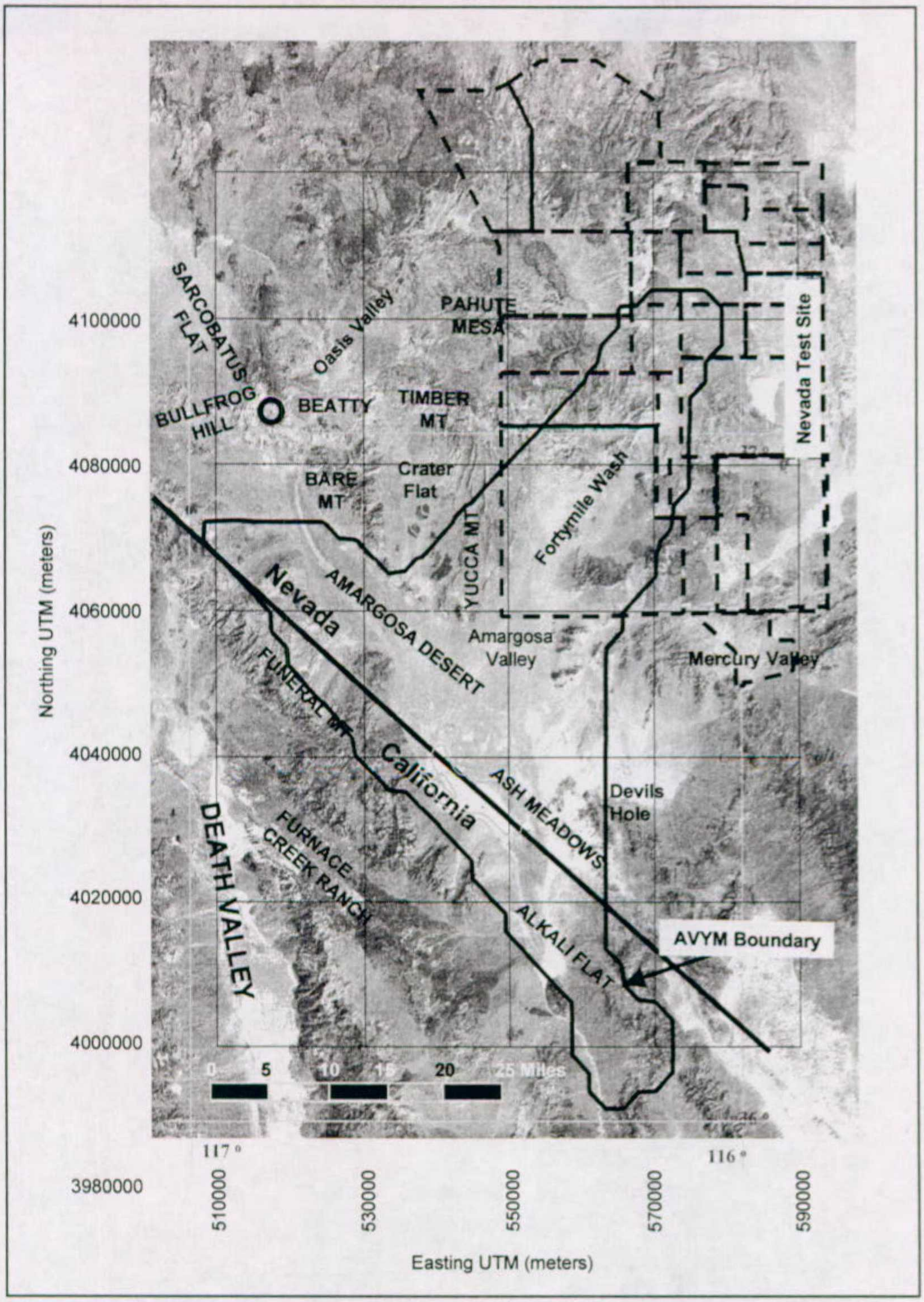
NOTE: DFBA = difluorobenzoic acid; PFBA = pentafluorobenzoic acid

Figure 4.2-6
Preliminary Tracer Recovery Curves, Alluvial Testing Complex Single-Well Tracer Tests



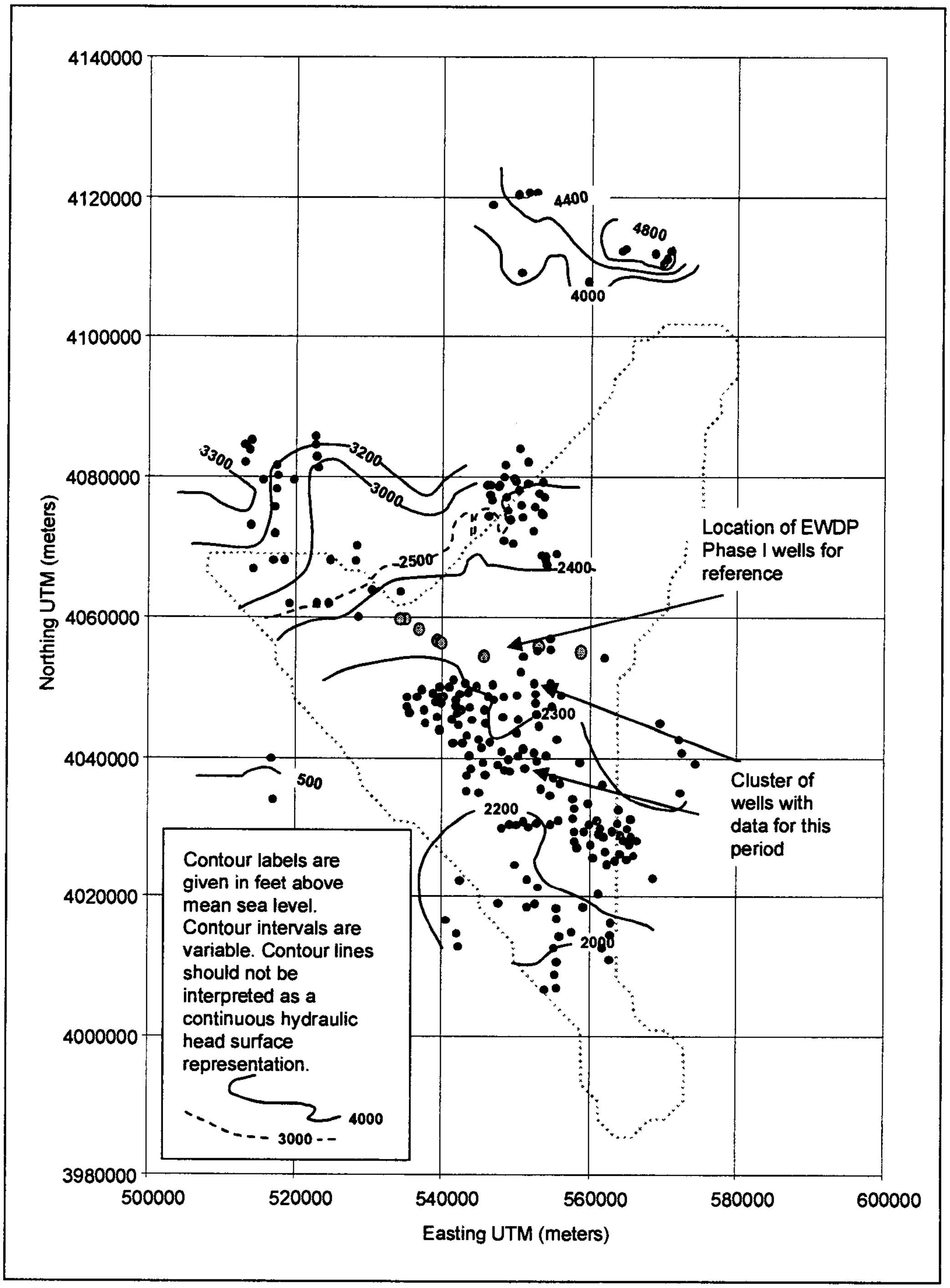
NOTES: ATC = Alluvial Testing Complex. The official prefix for the wells shown on this figure is NC-EWDP-.

Figure 4.2-7
Proposed Alluvial Testing Complex Configuration for Cross-Hole Testing



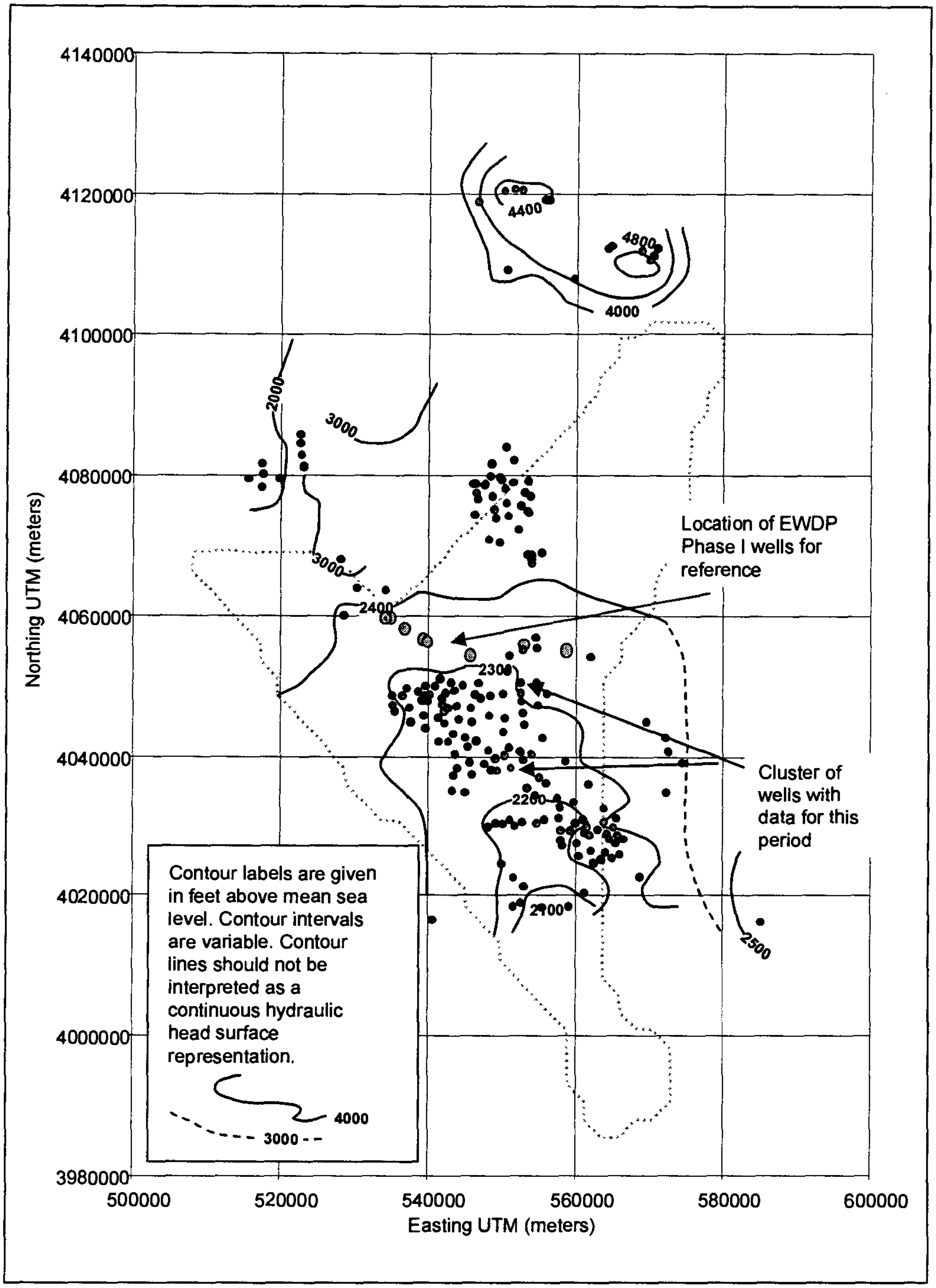
NOTE: AVYM = Amargosa Valley/Yucca Mountain

Figure 4.3-1
Simplified Physiographic Features of the Amargosa Valley/ Yucca Mountain Model Region



NOTE: EWDP = Early Warning Drilling Program

Figure 4.3-2a
Water Level Elevations in Feet Averaged for the Period 1980 to 1989 (11,310 water level measurements at 503 locations)



NOTE: EWDP = Early Warning Drilling Program

Figure 4.3-2b
Water Level Elevations in Feet Averaged for the Period 1990 to 1997
(5,651 water level measurements at 325 locations)

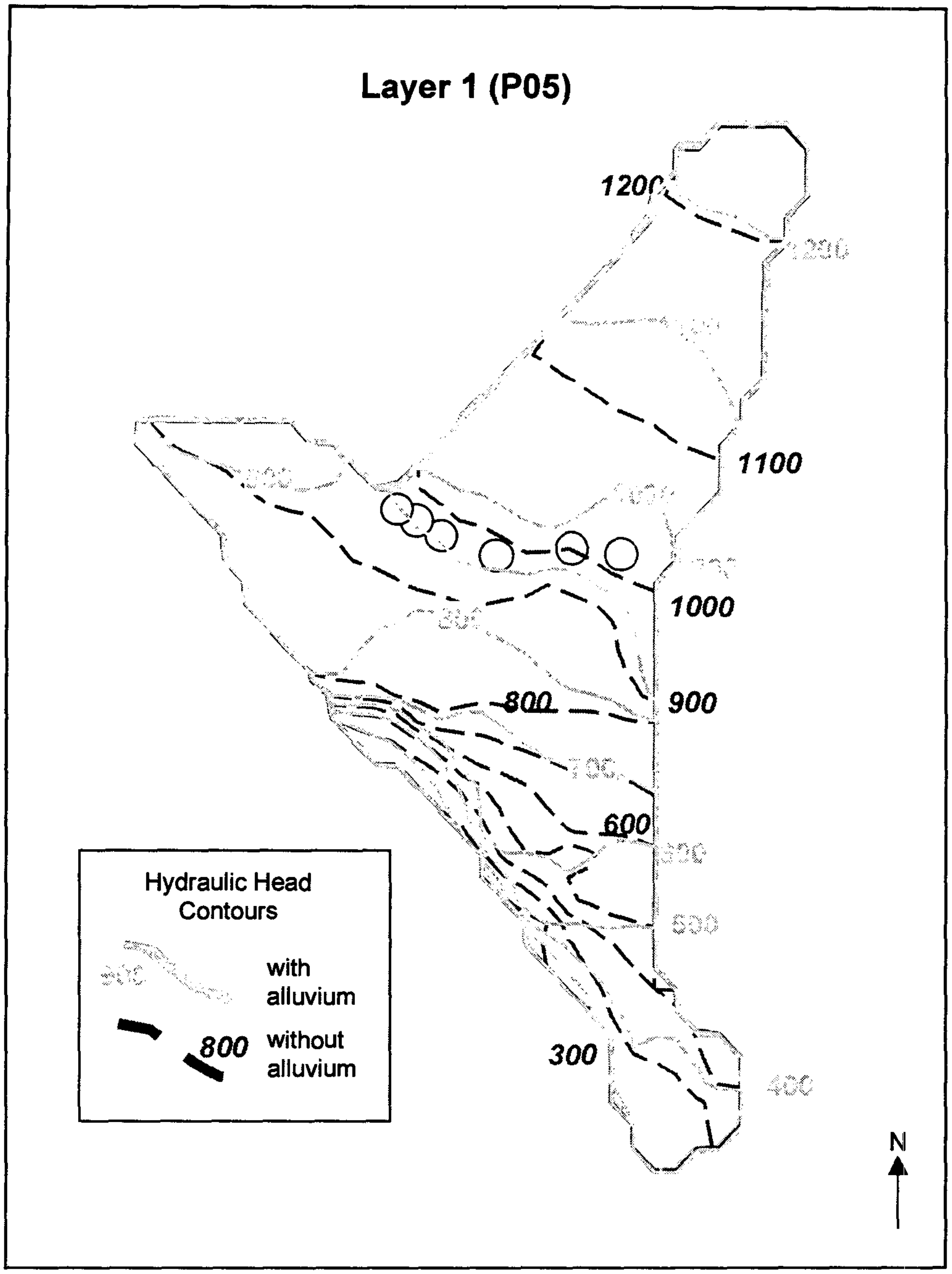


Figure 4.3-3a
Layer 1 Results of Amargosa Valley/Yucca Mountain Model Steady-State Simulations with and without Alluvium (K_u or Upper K_a restriction applied to all layers [K_u = 1 m/day, K_{river} = 21.2 m/day])

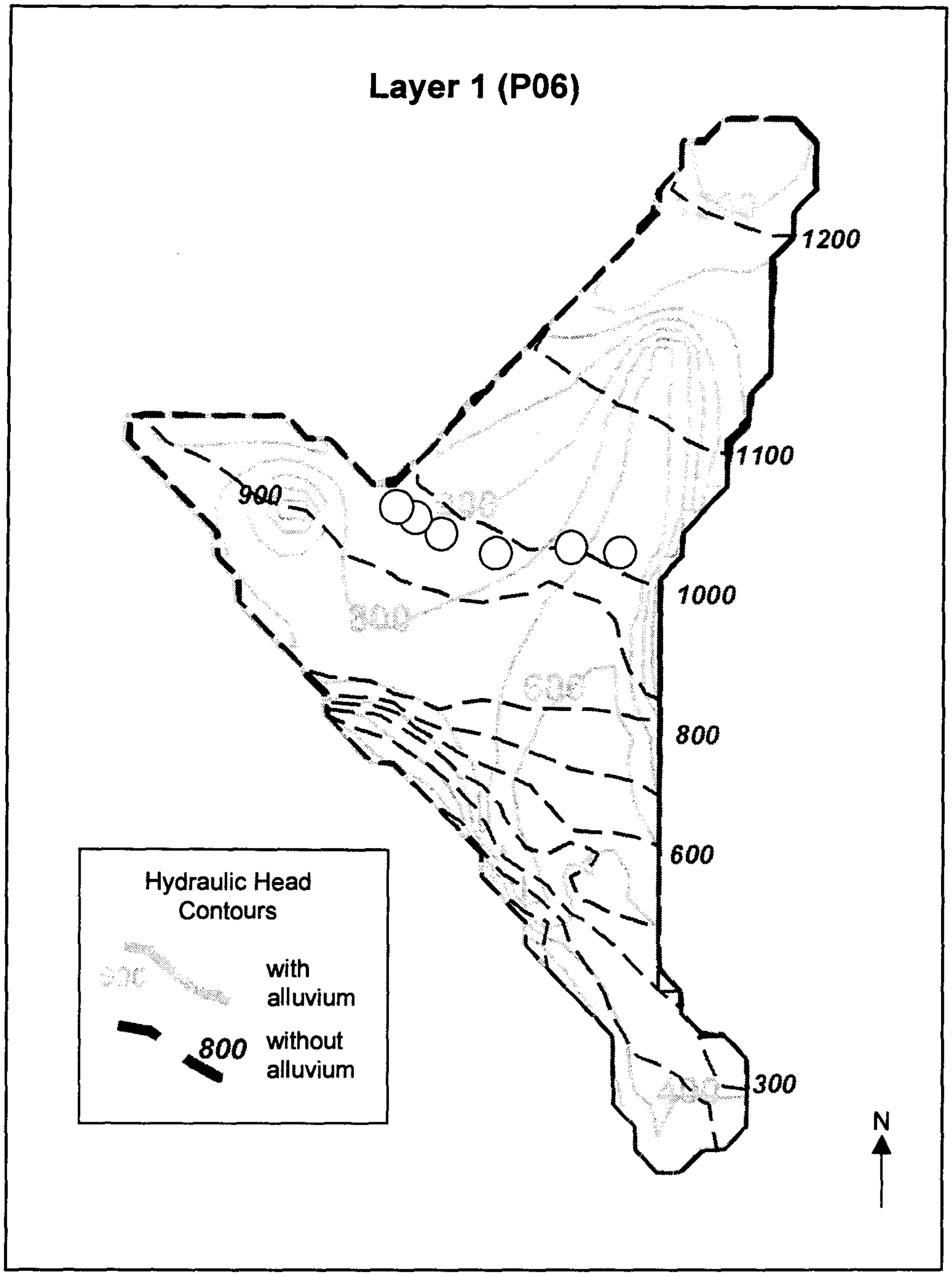


Figure 4.3-3b
Layer 1 Results of Amargosa Valley/Yucca Mountain Model Steady-State Simulations with and without Alluvium (K_u or upper K_a restriction applied to all layers [K_u* = 0.01 m/day, K_{river} = 21.2 m/day])

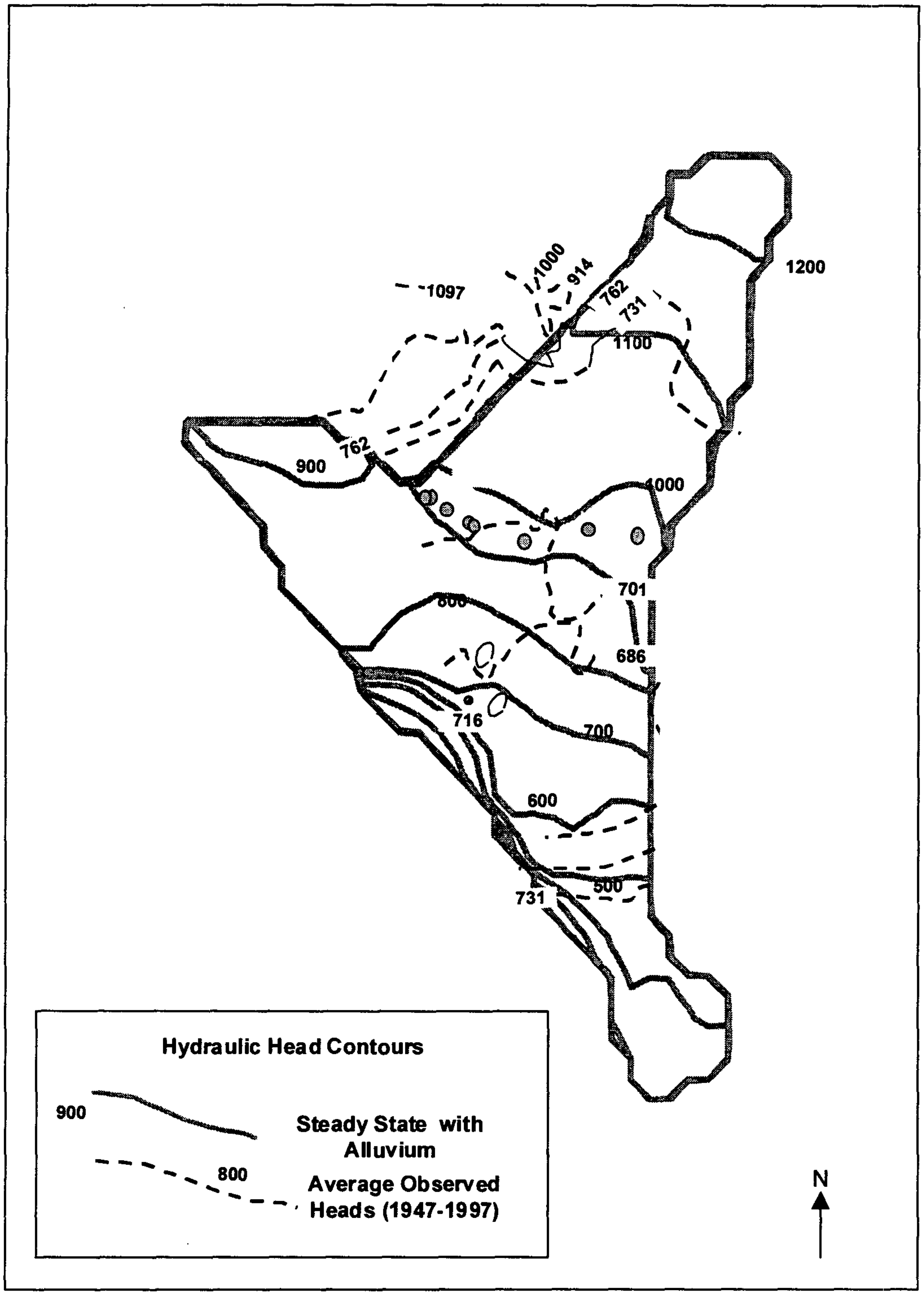


Figure 4.3-4a
Steady-State Hydraulic Heads for 3,000-Meter-Wide Alluvial Channels, where Surrounding Sediment Hydraulic Conductivities Were Equal to Original Death Valley Regional Groundwater Flow System Values, Compared to Measured Hydraulic Head Data Averaged between 1947 and 1997

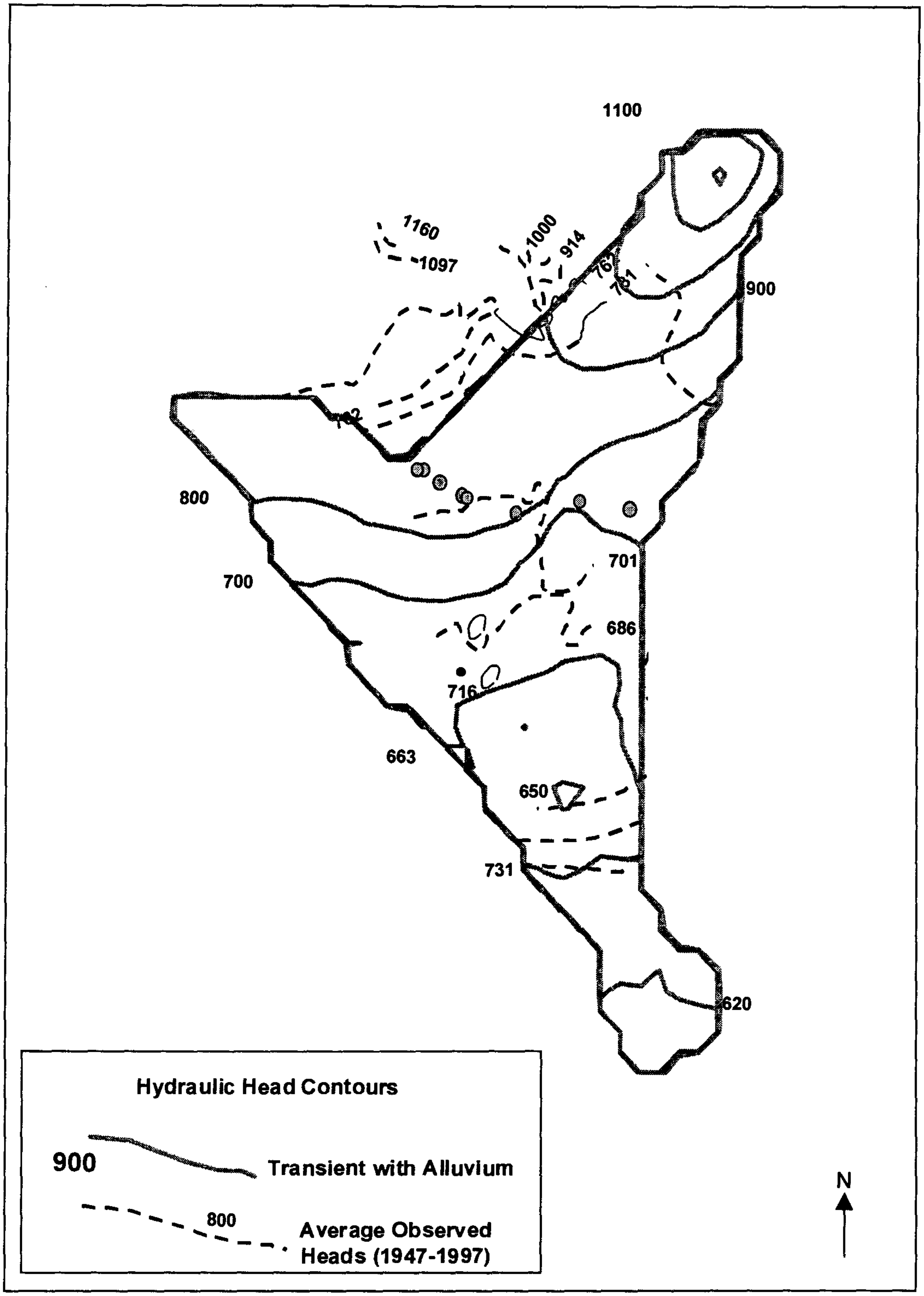
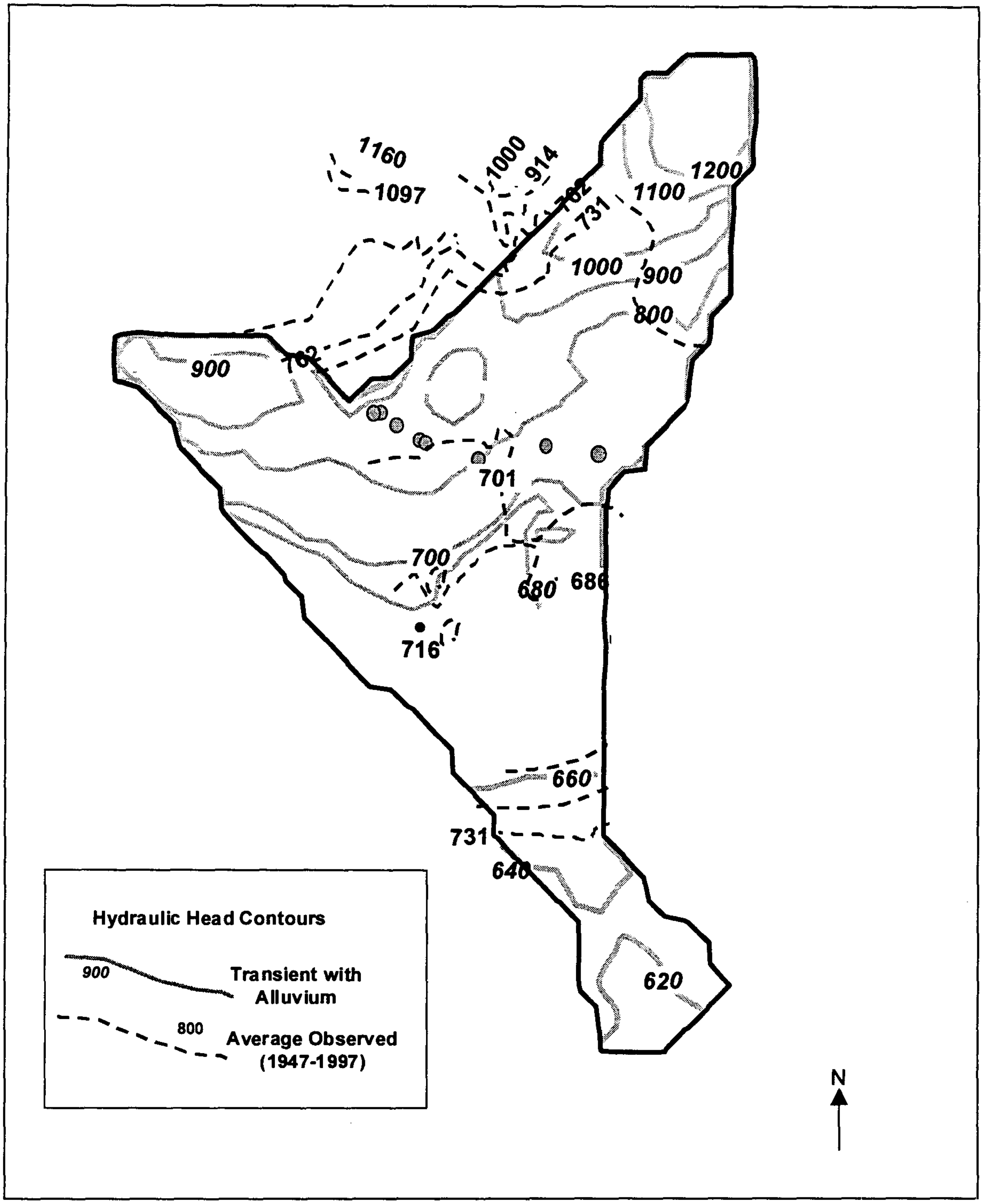
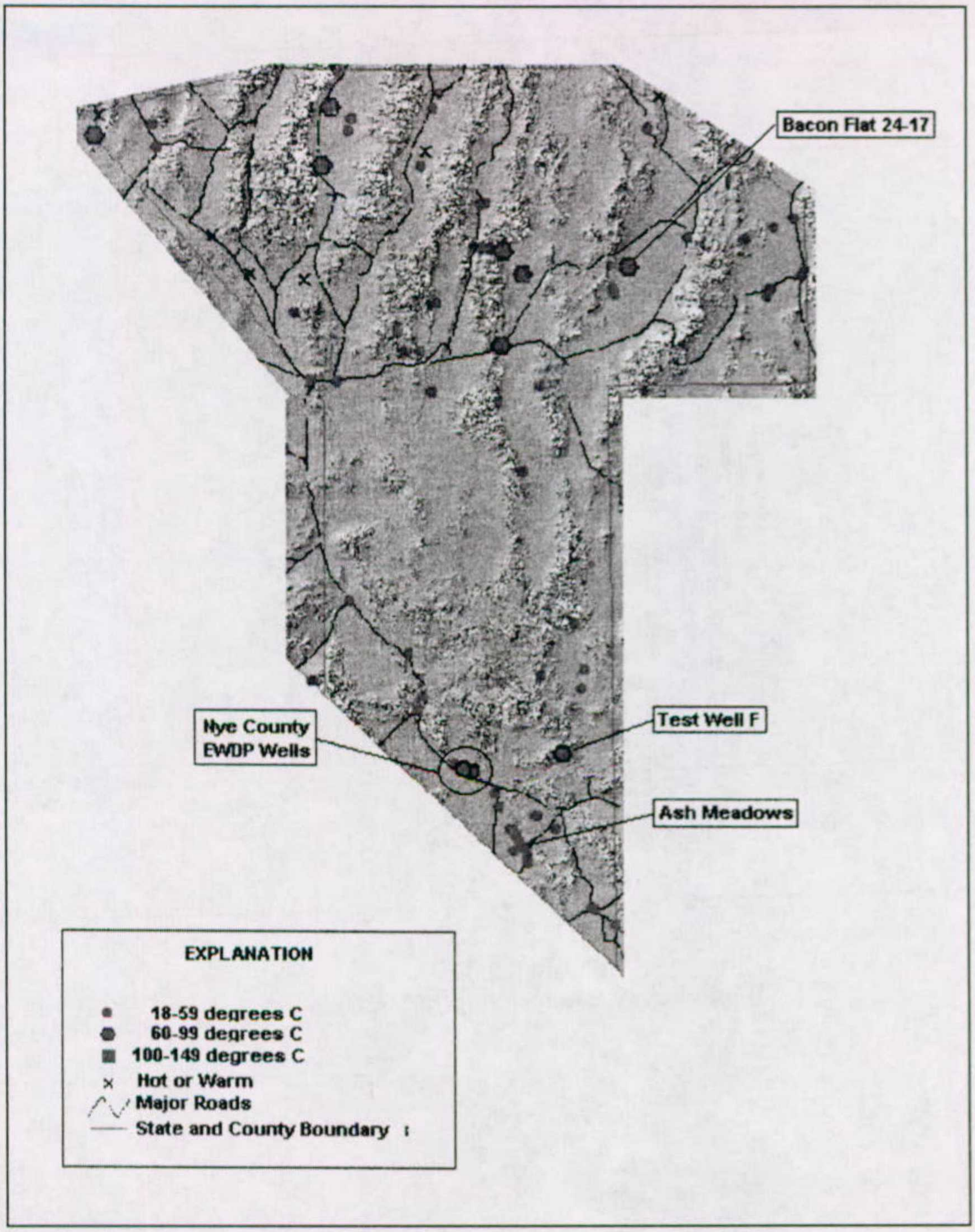


Figure 4.3-4b
Transient Hydraulic Heads for 3,000-Meter-Wide Alluvial Channels, where Surrounding Sediment Hydraulic Conductivities Were Equal to Original Death Valley Regional Groundwater Flow System Values, Compared to Measured Hydraulic Head Data Averaged between 1947 and 1997



NOTE: EWDP = Early Warning Drilling Program

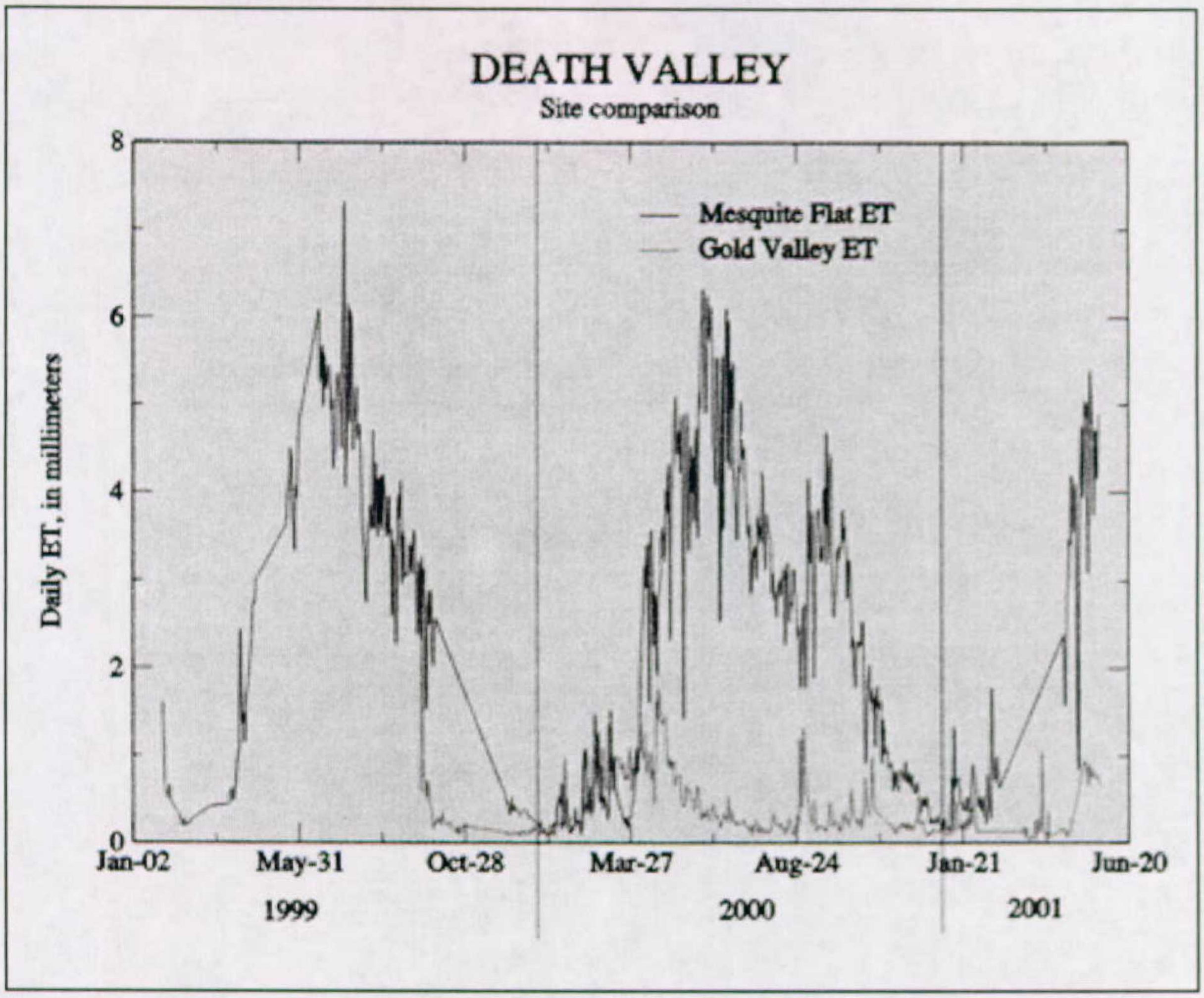
Figure 4.3-5
Transient-State Simulated Hydraulic Heads for 15,000-Meter-Wide Alluvial Channels, where Surrounding Sediment Hydraulic Conductivities Were Equal to Original Death Valley Regional Groundwater Flow System Values, Compared to Measured Hydraulic Head Data Averaged between 1947 and 1997



Source: Modified from Garside (1994)

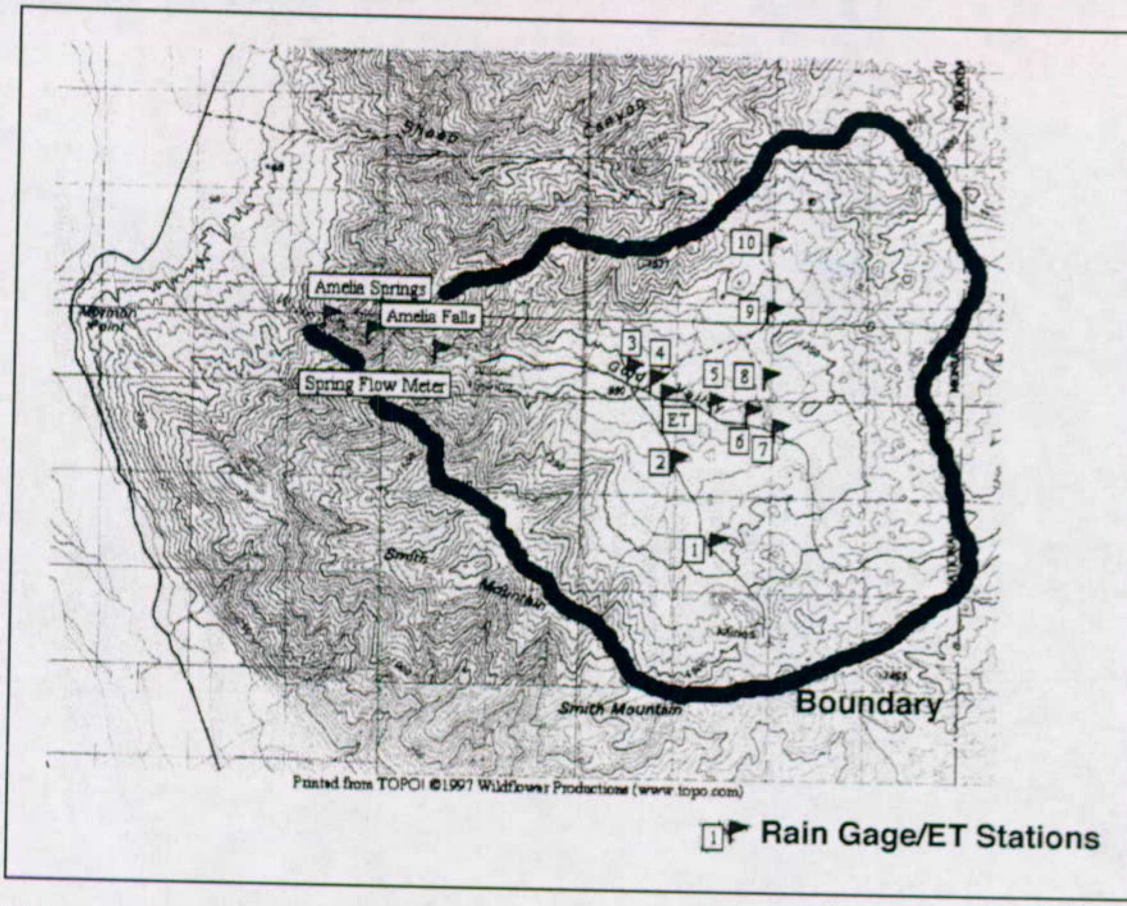
NOTE: EWDP = Early Warning Drilling Program

Figure 5.1-1
Geothermal Resources of Nye County



NOTE: ET = evapotranspiration

Figure 5.2-1
Death Valley Evapotranspiration Data



NOTE: ET = evapotranspiration

Figure 5.2-2
Gold Valley Infiltration Study Area

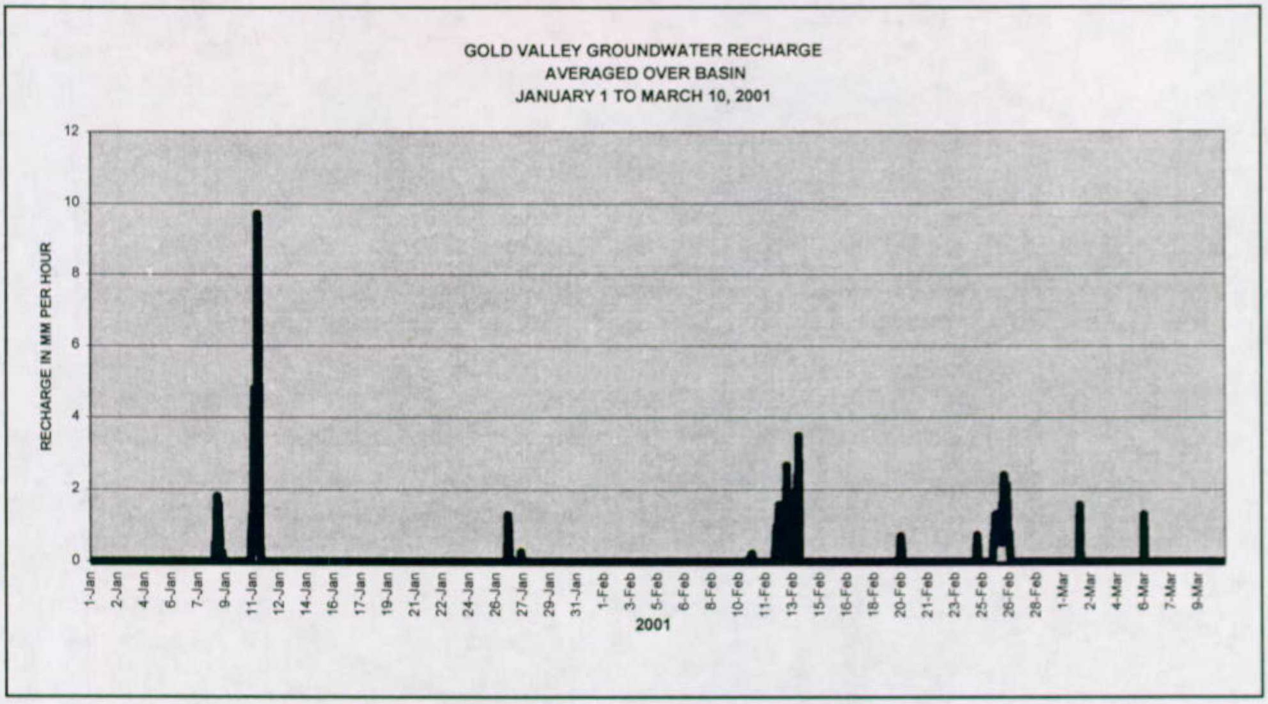


Figure 5.2-3
Gold Valley Recharge Data

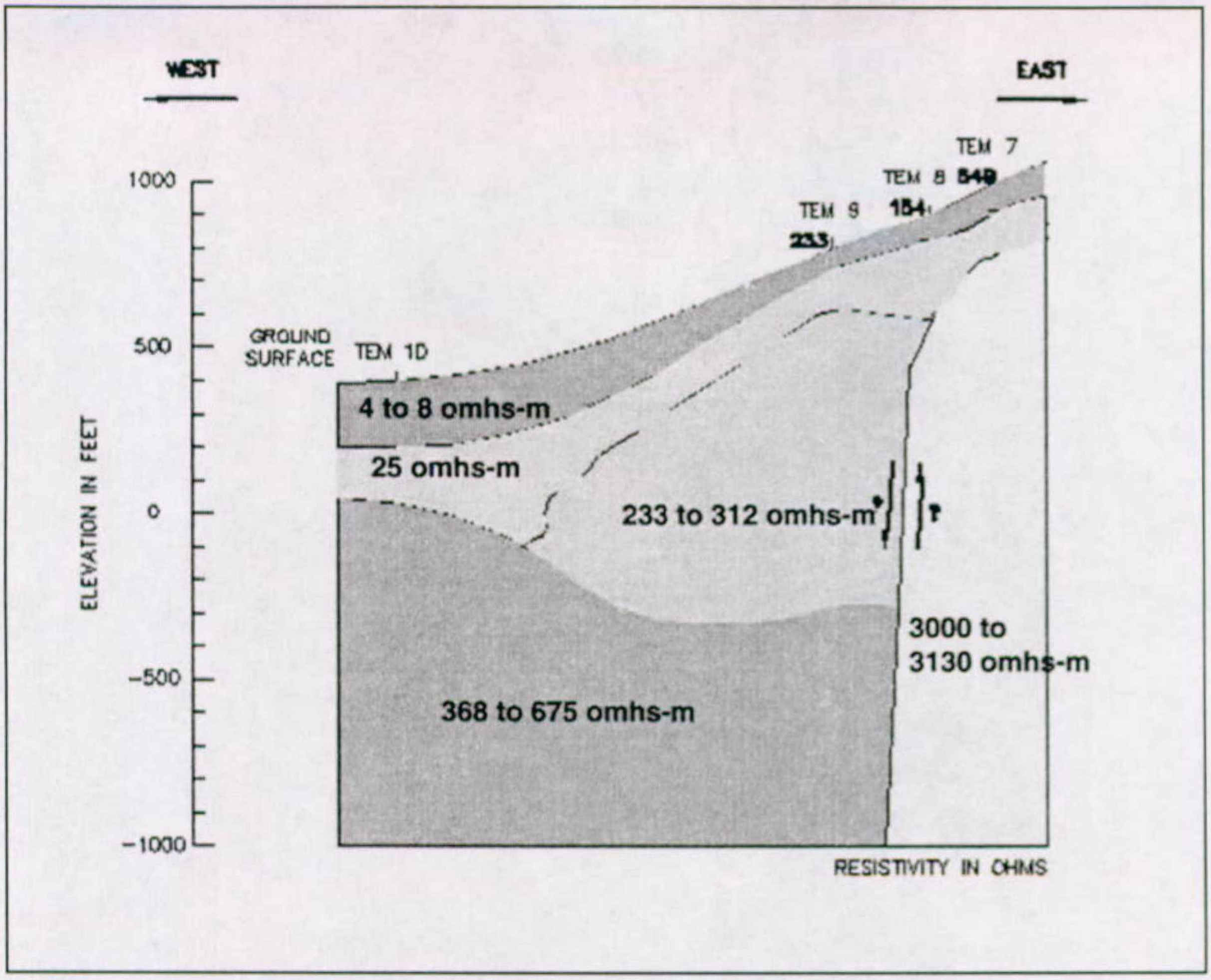


Figure 5.2-4
Nevares Springs Time Domain Electromagnetic Profile

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TABLES

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Table 2.4-1
Summary of Contents of Geologic Database

Tables in Geologic Database	Primary (P) or Secondary (S) Tables[a]	Type of Data and Information in Table
BoreholeData	P	This table includes name, identification, and coordinates of boreholes in UTM NAD 27, and completion information, if available.
Borehole LoggerData	P	If borehole logger was used to enter data, this table contains details of borehole logs.
CAS[c] Index	P	This table includes names used to describe data, such as peak flow, or chemical names. Also elevation of sample and range of spatial coordinates for the specific data type are provided in this table.
Category	P	This table provides further specific data identification, such as precipitation or water level, historical streamflow, volatile organic compounds, carbonates, etc. It can be used to group data types.
FLDIndex	P	This table includes sample type, such as water, air, rock, or soil samples.
Image	P	This table references a directory structure where scanned or html images are stored. This table is used to direct the data in the LabData table to a specific source for quality assurance or detailed explanation purposes.
LabData	P	The major types of data are incorporated in this table. Every record identifies the location identification, borehole identification, image identification, and date of the list of sample information, including depth of the sample, sample identification, category identification, measurement units, amount, measurement type, CAS index, and source identification. CAS identification can be used to specify a mixture of various data in one field.
Lithologic Description	S	This is an optional table used to keep track of lithological naming conventions and is a supplement to the soil detail table. The contents of this table are not used in queries.
Location	P	This table identifies and classifies locations for the data. The geographical area of interest is organized into 13 different locations corresponding to the hydrologic basins.
Measure Type	P	This table specifies the level of reliability of the information.
Soil Type Table	P	Lithologic descriptions with their geologic symbols and colors to be used for maps are identified here.
Soil Detail Table	P	In this table, the top and bottom of each geologic or hydrologic unit encountered in the borehole are defined.
References	S	References are listed in this table.
Selected Boreholes	S	This temporary table is generated during database querying for borehole geology. Queries can be saved as permanent tables by renaming this table.
LabData Archive	S	This table is an exact duplicate of LabData and is user-maintained for quality assurance purposes.

NOTES: [a]Primary tables are required.

[b]Secondary tables are informational.

[c]CAS = chemical abstract system. Originally, CAS was designed to keep track of chemical names using an indexing system. CAS has been expanded to include other types of data, such as temperature, pressure, humidity, water table elevation, or any other user-defined data type.

Table 3.1-1a
Results of Inverse Simulation of Barometric Response in UE-25 ONC#1 Pressure Probes

Probe	Hydrogeologic Unit	Depth to Bottom of Layer (ft)	Depth to Bottom of Layer (m)	Pneumatic Diffusivity[a] (cm/sec)
1	Tiva Canyon	600.00	182.88	1.43E-01
2	Paintbrush Tuff non-welded	934.38	284.80	2.61E+01
	Topopah Spring			
3		1,034.38	315.28	1.63E+01
4		1,198.36	365.26	3.27E+00
5	Fault	1,206.56	367.76	4.90E+03
6	Calico Hills non-welded	1,239.37	377.76	4.90E+02
7		1,403.35	427.74	4.90E+02
8	Prow Pass	1,485.37	452.74	Saturated
9		1,613.65	491.84	

NOTE: [a]Pneumatic diffusivity is the ratio of pneumatic conductivity to porosity at standard temperature and pressure conditions.

Table 3.1-1b
Results of Inverse Simulation of Barometric Response in USW NRG-4 Pressure Probes

Probe	Hydrogeologic Unit	Depth to Bottom of Layer (ft)	Depth to Bottom of Layer (m)	Pneumatic Diffusivity[a] (cm/sec)
1	Tiva Canyon	315.00	96.01	2.87E-01
2	Paintbrush Tuff non-welded	466.00	142.04	6.86E-03
3				
4	Topopah Spring	514.00	156.67	4.90E-03
5		544.00	165.81	4.90E+01
6		653.00	199.03	2.25E+03
7		719.00	219.15	2.25E+03

NOTE: [a]Pneumatic diffusivity is the ratio of pneumatic conductivity to porosity at standard temperature and pressure conditions.

Table 3.1-1c
UE-25 ONC#1 Vacuum Test Results

Depth of Pumping Port		Hydrogeologic Unit	Permeability	
(ft)	(m)		(m^2)	(darcy)
638.00	194.46	Topopah Spring	2.17E-13	0.22
1,164.00	354.79		3.06E-13	0.31
1,195.00	364.24	Calico Hills non-welded	5.13E-12	5.2
1,225.00	373.38		2.96E-12	3.0

Table 3.1-2
Concentrations of Chemical Constituents in Gas Samples from the Atmosphere, the Exploratory Studies Facility, and UE-25 ONC#1 for June 1997

Depth (feet) or Sample Location	Lithostratigraphic Unit	Methane (pptv)	Carbon monoxide (pptv)	Carbon dioxide (ppmv)	Nitrous Oxide (ppbv)	Chlorinated Fluorocarbon F12 (pptv)	Chlorinated Fluorocarbon F11 (pptv)	Chlorinated Fluorocarbon F113 (pptv)	Trichloroethane (pptv)	Carbon tetrachloride (pptv)	Tetrachloroethylene (pptv)	Oxygen (%)	Nitrogen (%)	Deuterium (delta D)
Atmosphere	–	1,994	104	316	431	668	290	62	95	111	0	–	–	–
ESF	Topopah Spring	1,847	260	503	411	653	310	63	1,267	192	–	–	–	–
ESF	Topopah Spring	1,857	482	505	403	634	288	61	976	144	–	–	–	–
1,150	Topopah Spring (Fault)	385	32	799	572	316	149	29	0	56	0	–	–	-160
1,195	Topopah Spring (Fault)	234	28	894	612	237	99	18	0	34	0	–	–	-146
1,225	Calico Hills	0	0	2,064	586	249	110	22	0	35	–	–	–	-150

NOTE: ESF = Exploratory Studies Facility; % = parts per 100 by volume; ppmv = parts per million by volume; ppbv = parts per billion by volume; pptv = parts per trillion by volume

Table 3.1-3
Results of Gas Sampling in UE-25 ONC#1 for June 1997 (carbon isotopes)

Depth (ft)	Lithostrati-graphic Unit	Delta Carbon-13 (per mil)	% Modern Carbon	Carbon-14 Corrected Apparent Age (years BP)
575	Tiva Canyon	-11.8	51.83	5280
638	Topopah Spring	-11.3	36.38	8120
1,164	Topopah Spring	-6	44.54	6495
1,195	Topopah Spring	-5.7	38.27	7715
1,225	Calico Hills	-10.3	35.97	8215
1,428	Prow Pass	-7.4	15.85	14800
1,501	Prow Pass	-8.8	16.91	14275

NOTE: BP = before present

Table 3.1-4
Diagenetic Events Observed in UE-25 ONC#1

Lithology	Diagenetic Events and Paragenesis
Welded Tuff	Fractures and pores filled with quartz and other silica polymorphs.
	Fractures filled with quartz and manganese oxide; some fractures open and close several times through various events. The fact that quartz fills the fracture does not preclude the fracture from opening and becoming reactive as a conduit.
	Fractures and pores filled with iron and/or manganese oxide-oxyhydroxides.
	Fractures and pores filled with carbonates or carbonates and opal-CT.
	Fractures and pores filled with zeolites and/or clays.
	Fractures that have coatings of the above minerals on the fracture walls but are not in the classical sense ""filled"' with these minerals.
	Fractures filled or partially filled with authigenics that have extensive weathering on and in the fracture walls. These are fractures with bleach zones (Figure 3.1-7). Bleach zones develop as weathering fronts in fracture conduits that are actively transporting fluids. They are compelling evidence of past flow in fractures flow. Tuff minerals and glass are dissolved, and phyllosilicates dominated by clinoptilolite and smectites are deposited. The matrix porosity in the bleach zone is greater than the porosity in the fresh unweathered tuff away from the fracture. This is due to volume changes caused by hydration of primary minerals and obsidian, the conversion of obsidian to perlite, and the conversion of the perlite to open phyllosilicates. In addition, new splay fractures in the bleached zones were formed due to differential stresses caused by hydration. These splay fractures generally are connected to the main fracture conduit. Neominerals created during this hydration process have significant capabilities for sorption and filtration of cations and complex aqueous species. Bleach zones are commonly seven to ten times the diameter of the original fracture on each wall-side of the fracture. They provide a very significant area of potential retardation along past and presently active paths of transport. The bleach zones clearly pre-date the fracture fillings (mostly quartz), and, since most of the quartz-filled fractures in the bleached zones were re-fractured at later times, the bleach zones increase the active porosity along the transport pathway by providing hydration (base exchange) reactions at the boundary between the bleached zone authigenics and the unaltered matrix. These reactions extend the alteration front into the matrix on a grain-by-grain basis, in addition to the creation of new microfracture pathways from the bleach zone into the fresh matrix. The net overall result is an increase in the overall porosity and potential sorption capacity along the bleach zone fracture pathway with time.
Poorly Welded Tuff	Diagenesis in poorly welded tuffs occurs both in the tuff matrix and in the fracture pathways. Both locations fill with authigenic minerals, thereby retarding fluid transport in the vadose zone. The minerals that fill pore space are mostly manganese oxyhydroxides, carbonates, clays, and zeolites. In some cases, quartz and quartz polymorphs were observed. Some of the fractures reopen, similar to the welded tuffs. Fracture fillings tend to be mostly carbonates and manganese oxyhydroxides with minor amounts of zeolites, quartz, and quartz polymorphs. Matrix pores on fracture walls tend to fill with authigenics earlier than pores that are located deeper in the matrix. In many cases, fracture flow dominates.

Table 3.3-1
Estimated Fluid Particle Velocity through Fractures in Various Percolation/ Infiltration Scenarios

		Average Particle Velocity through Fractures at Repository Level (Topopah Spring welded unit) (mm/yr.)[a]				
		Present-Day Climate Infiltration/Percolation Rate			Extreme Climate Infiltration/ Percolation Rate	
		Lower Bound	Mean	Upper Bound	Monsoon	Glacial Transition
Effective Porosity	Matrix K (mm/yr.)	2 mm/yr.	7 mm/yr.	12 mm/yr.	20 mm/yr.	30 mm/yr.
0.001154	0.0263	1,711	6,044	10,378	17,311	25,978
0.000536	0.0263	3,685	13,022	22,358	37,296	55,968
0.001154	2.63	full matrix flow	3,789	8,123	15,056	23,723
0.000536	2.63	full matrix flow	8,164	17,500	32,438	51,110

NOTE: [a]Percolation was estimated from maps (DOE [2000c, Figures 6-12, 6-13, 6-14, 6-43, 6-44]). Full matrix flow is assumed to occur when percolation rate is smaller than matrix K.

Table 4.1-1
Drilling Methods, Well Types, Casing Sizes, and Screened Intervals

Well/ Borehole ID[a]	Well Type[b]	Drilling Method[c]	Total Depth (feet below ground surface)	Screened Interval(s) (feet[d] below ground surface)	Sand Pack or Open Hole Intervals (feet[d] below ground surface)	Well Casing Depth (feet[d] below ground surface)	Well Casing Outside Diameter (inches[e])
1DX[f]	W	ARC	2,500	72.1-52.4 NA 2,160-2,240	39.5-72.5 NA 2,160-2,240[g]	72.5 1,375.9 2,294.7	2.375 2.375 2.375
1S	W	AH/ARC	310	160-180 210-270	151.8-189.3 203.7-321.0	290.5	6.625
2DB	W	FR	3,075	NA	2,685-3,075	2,685	8.625
3S	W	AH/ARC	550.0	249.8-269.8	238.5-274.1 295.6-550.0	294.8	6.625
4PA	P	AH	499.7	405.3-485.2	394.7-499.7	495.2	2.875
4PB	P	AH	849.5	739.5-839.2	718-849.5	849.2	2.875
5S	P	AH/ARC	1,200.0	601.4-779.9	597.6-1,200.0	790	2.375
5SB	P	AH	499.4	379.3-489.0	366.0-499.4	499.4	2.875
7S	P	ARC	53.2	28.0-40.0	26.0-53.2	45.0	2.875
7SC	W	ARC	778.5	80.0-90.0; 180.0-210.0; 270.0-370.0; 429.8-449.8	75.9-99.8; 164.7-220; 262.9-379.3; 422.4-470.0	459.7	6.625
9SX[f]	W	DC/AH	397	90.0-120.0; 140.1-160.1; 250.1-290.1; 330.1-340.1	85.0-126.1; 134.1-167.1; 245.5-295.6; 325.0-360.5	360.5	6.625
12PA	P	AH	389.5	324.7-384.4	317.5-389.5	389.5	2.875
12PB	P	AH	399.8	325.0-384.7	316.2-399.8	399.75	2.875
12PC	P	AH	249.6	170.1-229.6	160.4-249.6	249.6	2.875
15P	P	AH	289.6	200.1-259.9	191.0-274.5	270	2.875
19D1[f]	W	FR	1,456.3	413.0-431.2; 498.0-516.1; 577.8-675.7; 722.6-795.2; 882.2-980.3; 1,122.2-1,219.6; 1,296.7-1,379.7	405.0-437.0; 487.0-519.0; 563.0-691.0; 711.0-795.0; 831.0-1,060.0; 1,109.0-1,220.0; 1,252.0-1,456.3	1,421.9	7
19D	X	ARC	1,438.3	NA	NA	NA	NA
19P	P	AH	499.2	359.2-468.6	351.5-474.5	468.6	2.875
Washburn-1X	P	ARC	658.0	333.0-353.0; 420.0-480.0	310.0-353.0; 399.5-658.0	353; 510	1.9
3DB	C	FR	505	NA	NA	NA	NA
12D	C	FR	68	NA	NA	NA	NA
15D	C	FR	607	NA	NA	NA	NA
1D[h]	X	DC	57.7	NA	NA	NA	NA
2D	X	ARC	1,618.4	NA	NA	NA	NA
3D	X	ARC	2,500	NA	NA	521.7	7

Well/ Borehole ID[a]	Well Type[b]	Drilling Method[c]	Total Depth (feet below ground surface)	Screened Interval(s) (feet[d] below ground surface)	Sand Pack or Open Hole Intervals (feet[d] below ground surface)	Well Casing Depth (feet[d] below ground surface)	Well Casing Outside Diameter (inches[e])
9S[h]	X	DC	100	NA	NA	NA	NA
7SB	X	ARC	102.5	NA	NA	NA	16

NOTES: [a]"NC-EWDP-" is the official prefix of all new Nye County wells.
[b]W = single or multiple screen well; P = piezometer (single or multiple string); C = conductor casing only; X = exploratory borehole
[c]DC = diamond drill coring; AH = dual wall air hammer; ARC = dual wall air reverse circulation; FR = flooded mud reverse circulation
[d]Conversion for feet to meters: 1 ft = 0.3048 m
[e]Conversion for inches to centimeters: 1 in. = 2.54 cm
[f] X-designation only refers to samples sent to the Yucca Mountain Sample Management Facility
[g]Fractured cement grout
[h]Original cored borehole
NA = not applicable.

Table 4.1-2
Geophysical Logging Conducted in Phase I Boreholes/Wells

Hole/Well ID[a]	Date	Log Type	Borehole Depth at time of Logging (feet)	Logged Interval (feet)	Comments
Washburn-1X	12/6/98	1[b]	657	0-657	None
		2[c]	657	340-511	None
1D					Not logged
1DX/1D	1/10/99	1,2[d]	2,040	0-1,600	Caliper log to 228 ft
	1/14/99	2[d]	2,320	0-1,155	Single run to 1,155 ft; unstable hole
	1/23/99	1	2,500	0-2,470	Run inside HX drill rod
	1/23/99	2[d]	2,500	1,147-2,425[d]	Resistivity, fluid resistivity, temperature, spontaneous potential, and natural gamma in pieces: 2,425-2,292 ft; 2,300-2,086 ft; 2,100-1,886 ft; 1,900-1,686 ft; 1,700-1,486 ft; 1,500-1,227 ft; 1,160-1,147 ft
	1/24/99	2[d]	2,500	0-2,488	Temperature log only
	4/26/99	3[e]	2,500	0-1,133	Density and casing collar locator logs
				0-1,152	None
1S	2/3/99	2	309	0-309	None
9S					Not logged
9SX/9S	12/14/98	1	397	0-397	None
	1/15/99	4	397	0-397	None
3S	3/11/99	2[d] &3	550	0-530	Well was cased to 294.8 ft
	3/30/01	2[d]	550	0-515	Caliper only
3D	1/22/99	1	1,275	0-1,250	Spontaneous potential, natural gamma, temperature, fluid resistivity. Logging was conducted in drill pipe.
	2/3/99	2	2,229	0-2,260	None
	2/5/99	2	2,500	0-2,500	None
	2/17/99	3[d]	2,500	0-975	Spinner logs only
	5/17/99	3[d]	2,500	60-815	Idronaut[f] hydrochemistry tool.
5S	2/21/99	1	1,200	0-1,160	None
		2[d]	1,200	500-950	Caliper log for 500-690 ft only
2D	2/22/99	1	1,618	0-428	None

NOTES: [a]"NC-EWDP-" is the official prefix of all new Nye County wells.
[b]Logged inside drill pipe or casing (cased log) generally includes natural gamma, density (gamma/gamma), neutron moisture, temperature, and deviation logs.
[c]Logged in open borehole (open hole logs) generally includes logs in footnote b and normal, lateral, and single point resistivity, natural gamma, spontaneous potential, temperature, fluid resistivity, and caliper logs.
[d]Not a complete suite of logs for type; see comments column.
[e]Logged inside well casing (completion log) generally includes natural gamma, density (gamma/gamma), and temperature logs.
[f]Idronaut hydrochemistry tool includes: salinity, conductivity, pressure, oxygen saturation, redox, oxygen concentration, pH, temperature.

Table 4.1-3
Geophysical Logging Conducted in Phase II Boreholes/Wells

Hole/Well ID[a]	Date	Log Type	Borehole Depth at time of Logging (feet)	Logged Interval (feet)	Comments
4PA	1/10/00	1[b]	500	0-500	None
4PB	1/23/00	1	850	0-850	None
2DB	1/23/00	2[c]	503	0-503	None
	8/14/00	2	2142	0-1910	Borehole cased to 500 ft
	8/24/00 to 8/25/00	2	2723	0-2723	None
	8/31/00	2	3075	0-2495	Hole bridged
	9/24/00	2[d]	3075	0-2635	Caliper log only; pre-casing
	10/19/00	2[d]	3075	2655-2814	Caliper log only; post-casing
5SB	2/7/00	1	500	0-500	None
7S	2/28/00	2	53	0-49	Surface casing to 25 ft
15P	2/28/00	1	290	0-290	None
19P	3/10/00	1	500	0-500	None
12PA	3/23/00	1	390	0-390	None
	3/24/00	2	390	205-390	Logged in segments
12PB	3/30/00	1	400	0-400	None
	3/30/00 to 3/31/00	2	400	230-385	None
12PC	4/11/00	1	250	0-242	None
19D	3/26/00	2	350	0-350	None
	3/30/00	1[d]	657	0-654	Deviation log only
	4/2/00	1	1437	0-1418	None
19D1/19D	4/14/00	1[d]	846	0-800	Deviation log only
	4/16/00	2	1448	0-1448	None
	4/24/00	2[d]	1448	0-1432	Temperature, density, and caliper logs only
	5/3/00	3[d,e]	1456	0-1430	Temperature and density logs only
	5/10/00	3	1456	0-1420	Includes spinner logs
	5/11/00 to 5/12/00	3[d]	1456	0-1400	Various spinner logs only
15D	4/3/00	2	607	0-600	None
7SC	4/15/00	1	779	0-779	None
	1/16/01	2	779	0-418	Hole cleaned out to 468 ft only
	3/26/01 to 3/27/01	3[d]	779	0-450	Spinner logging only
	3/30/01	3	779	0-459	Includes Idronaut hydrochemistry tool[f]

NOTES: [a]"NC-EWDP-" is the official prefix of all new Nye County wells.
[b]Logged inside drill pipe or casing (cased log) generally includes natural gamma, density (gamma/gamma), neutron moisture, temperature, and deviation logs.

[c] Logged in open borehole (open hole logs) generally includes logs in footnote b and normal, lateral, and single point resistivity, natural gamma, spontaneous potential, temperature, fluid resistivity, and caliper logs.
[d] Not a complete suite of logs for type; see comments column.
[e] Logged inside well casing (completion log) generally includes natural gamma, density (gamma/gamma), and temperature logs.
[f] Idronaut hydrochemistry tool includes: salinity, conductivity, pressure, oxygen saturation, redox, oxygen concentration, pH, temperature.

Table 4.1-4
Summary of Early Warning Drilling Program Well Test Interpretations

Well	Horizontal Permeability (m^2)	Transmissivity (m^2/d)	Storativity	No. of Boundaries Inferred	Distance to Boundaries (m)
NC-EWDP-1S	3×10^{-10}	7,330	N/A	2	30
NC-EWDP-3D	1.34×10^{-11}	900	N/A	0	N/A
NC-EWDP-3S	4.3×10^{-14}	4.2	N/A	0	N/A
NC-EWDP-3D Interference	6.2×10^{-14}	6.0	13	0	N/A
NC-EWDP-7SC	3.3×10^{-12}	67	N/A	0	N/A
NC-EWDP-7S Interference	7×10^{-12}	145	0.026	0	N/A
NC-EWDP-9SX	4×10^{-11} to 7.5×10^{-11}	1,860 to 3,600	N/A	2 or 3	600 to 900
NC-EWDP-19D	2.3×10^{-12}	372	N/A	2	200
Aeropark AD-2	N/A	266	N/A	0	N/A
Garlic Interference	N/A	196	0.00022	0	N/A
BGMW #13	N/A	307	N/A	2	30 to 60

NOTE: N/A = not applicable

Table 4.1-5
List of Analytes Measured in Water Samples, Laboratories Used, and Methods Used

Analyte	Laboratory	Method
Gross chemistry: chloride, sulfate, bromide, calcium, magnesium, sodium, potassium, bicarbonate, nitrate, phosphate, dissolved silica	Desert Research Institute--Water Resource Center	Greenberg et al. (1992)
Electrode/probe measurements: iodide, fluoride, pH, specific conductivity	Desert Research Institute--Water Resource Center	Skougstad et al. (1985)
Trace elements	Desert Research Institute--Water Resource Center	EPA (1994)
Tritium	Desert Research Institute--Water Resource Center	Krieger and Whitaker (1980)
Gross alpha	Barringer Laboratories (Golden, Colorado)	EPA method 900.0 (Krieger and Whitaker, 1980)
Gross beta	Barringer Laboratories (Golden, Colorado)	EPA method 900.0 (Krieger and Whitaker, 1980)
Uranium activities	Barringer Laboratories (Golden, Colorado)	EPA method 908.0M (Krieger and Whitaker, 1980)
Thorium activities	Barringer Laboratories (Golden, Colorado)	USAEC RMO 3008, unpublished Barringer Laboratories internal procedure
Tritium	Barringer Laboratories (Golden, Colorado)	EPA method 906.0 (Krieger and Whitaker, 1980)
Radium-222	Barringer Laboratories (Golden, Colorado)	SM7500Ra-BM (Clesceri et al., 1996)
Radiocarbon	Institute of Geological and Nuclear Sciences (New Zealand)	Taylor, C.B.; Trompetter, V.J.; Brown, L.J.; and G. Bekesi. In press. "Hydrogeology of the Manawatu aquifers, North Island, New Zealand: clarification using a multi-disciplinary environmental tracer approach." *J. Hydrology.*
Tritium	Institute of Geological and Nuclear Sciences (New Zealand)	Wolf et al. (1981)
Total dissolved inorganic carbon	Institute of Geological and Nuclear Sciences (New Zealand)	Taylor and Fox (1996)
Stable isotopic ratio analyses (SIRA): carbon (del 13C), oxygen (del 18O), hydrogen (del D)	Institute of Geological and Nuclear Sciences (New Zealand) and Geochron Laboratories (Cambridge, Massachusetts)	McCrea (1950); O'Neil and Epstein (1966); Craig (1961)
Stable isotopic ratio analyses (SIRA): nitrogen (del 15N)	Geochron Laboratories (Cambridge, Massachusetts)	Pang and Nriagu (1977)
Stable isotopic ratio analyses (SIRA): sulfur (del 34S)	Geochron Laboratories (Cambridge, Massachusetts)	Thode et al. (1961)
Unstable isotopic ratios: strontium isotopic ratios, uranium isotopic ratios, lead isotopic ratios	Geochron Laboratories (Cambridge, Massachusetts)/Massachusetts Institute of Technology	Bowring, unpublished internal laboratory procedures; Huh et al. (1998); Sherrell et al. (2000)
Chlorine-36 isotopic ratio	University of Arizona/Purdue Rare Isotope Measurement Facility	Bentley et al. (1986)

Table 4.1-6
Average Concentrations of Selected Constituents from Shallowest Zones (well screens) in Boreholes Aligned along an Approximately East-West Transect from NC-EWDP-5SB in the East to NC-EWDP-1S in the West

Well ID	Rock Type	Average Concentration of Constituent			
		Fluoride (mg/L)	Strontium (μg/L)	Percent Modern Carbon	Cl-36/Cl (x $1X10^{15}$)
NC-EWDP-5SB	Valley-fill alluvium	1.0	284	1.58	244
NC-EWDP-4PB	Valley-fill alluvium	1.9	38	12.55	654
NC-EWDP-4PA	Valley-fill alluvium	1.2	50	17.70	605
NC-EWDP-19P	Valley-fill alluvium	1.8	64	17.77	425
NC-EWDP-15P	Valley-fill alluvium	1.8	57	8.19	493
NC-EWDP-3S	Tertiary volcanics	2.6	4	17.00	245
NC-EWDP-7S	Valley-fill alluvium	0.8	683	6.50	nd
NC-EWDP-9SX	Valley-fill alluvium	1.8	143	9.36	313
NC-EWDP-12PA	Mud flow tuff and ash, tuffaceous sandstones, pyroclastic flows	3.3	346	2.60	343
NC-EWDP-12PB	Tuffaceous sandstones, conglomerate, tuff	3.2	320	2.87	314
NC-EWDP-12PC	Valley-fill alluvium	1.0	506	5.43	370
NC-EWDP-1S	Tertiary volcanics	0.5	594	5.21	349

NOTE: nd = not determined yet

Table 4.1-7
Summary of Water Level Monitoring in Early Warning Drilling Program Wells and Boreholes

Well No. (NC-EWDP-)[a]	Methods	Frequency	Duration
1DX	Manual	Weekly/Monthly	5/99 to Present
1S	Transducers/Datalogger	Semi-continuous	3/99 to Present
2D	Manual	N/A[b]	1/99
3D	Manual	Weekly/Monthly	1/99 to Present
3S	Transducers/Datalogger	Semi-continuous	3/99 to Present
5S[c]	Manual	Weekly/Monthly	3/99 to 4/99
9SX	Transducers/Datalogger	Semi-continuous	1/99 to Present
Washburn-1X	Manual	Weekly/Monthly[d]	12/98 to Present
2DB	Manual	Weekly/Monthly	10/00 to Present
4PA	Manual	Weekly/Monthly[d]	1/00 to Present
4PB	Manual	Weekly/Monthly[d]	1/00 to Present
5SB	Manual	Weekly/Monthly	2/00 to Present
7S	Manual	Weekly/Monthly	2/00 to Present
7SC	Transducers/Datalogger	Semi-continuous	4/01 to Present
12PA	Manual	Weekly/Monthly	3/00 to Present
12PB	Manual	Weekly/Monthly	3/00 to Present
12PC	Manual	Weekly/Monthly	4/00 to Present
15P	Manual	Weekly/Monthly[d]	3/00 to Present
19P	Manual	Weekly/Monthly[d]	3/00 to Present
19D	Manual	Periodic[d]	4/00 to Present
3DB, 12D, 15D[e]			

NOTES: [a] Prefix for all Early Warning Drilling Program wells.

[b] Borehole cannot be sounded; no depth to water is available; N/A = not applicable.

[c] Well plugged; data valid through 4/99.

[d] Ancillary digital transducer/datalogger data available with U.S. Geological Survey Alluvial Testing Complex work.

[e] Wells are not complete.

Table 5.1-1
Low and Moderate Temperature Springs and Wells in Nye County

Name	Type	Temperature (° C)	Flow (L/min.)	Depth (m)
McLeod 88 Spring	Spring	87.9	–	–
Pott's Ranch Hot Spring	Spring	45	125	–
Diana's Punch Bowl	Spring	59	–	–
Hot Well	Well	hot	–	–
Gene Sawyer Well	Well	54	–	84.0
Gabbs Area	Well	47.8	–	66.0
Charnock (Big Blue) Springs	Spring	26.7	1,03	–
Big-Blue, Charnock Spring	Spring	32	–	–
Darrough's Well	Well	90.5	–	244.0
Darrough's North Spring	Spring	71.2	–	–
Warm Spring	Spring	warm	–	–
Stanley A. Tanner Well	Well	warm	–	–
Indian Springs	Spring	warm	–	–
Hall Mine Well (Anaconda)	Spring	27.7	–	–
Well	Well	28	–	–
Wells	Well	hot	–	–
Belmont Mine, 1,500 ft level	Well	37.2	–	457.0
Mosquito Ranch Springs	Spring	31.6	–	–
Spring	Spring	40	–	–
Test Hole UCE-10	Well	48	–	903.1
Spring	Spring	35	–	–
Old Dugan Place Hot Spring	Spring	36.1	–	–
Hot Creek Ranch Spring	Spring	62.8	2,888	–
Hot Creek Valley Spring	Spring	61.1	–	–
Warm Spring	Spring	26.1	19	–
Salisbury Spring	Spring	30	–	–
Spring	Spring	21	–	–
Upper? Mud Spring	Spring	25.5	–	–
Spring	Spring	25	–	–
Spring	Spring	29	–	–
Warm Springs	Spring	63	170	–
Spring	Spring	22	–	–
Spring	Spring	25	–	–
Duckwater Area	Spring	33.9	–	–
Big Spring	Spring	38	–	–
Blue Eagle Springs	Spring	29	7,030	–

Name	Type	Temperature (° C)	Flow (L/min.)	Depth (m)
Moorman Spring	Spring	37	1,294	–
Flag Spring No. 3	Spring	22.8	–	–
Butterfield (Flag, Sunnyside) Springs	Spring	23.9	7,571	–
Hot Creek Ranch Springs	Spring	26.7	–	–
Moon River Springs	Spring	32.5	–	–
Bacon Flat 24-17 Oil Well	Well	113	–	1,653
Chimney Hot Springs	Spring	60	–	–
Spring	Spring	45	–	–
Spring	Spring	46	–	–
Cedar Spring	Spring	25	9	–
Climax Seep	Well	41.5	–	–
Tippipah Spring No. 2	Spring	22	–	–
Yucca Flat Test Well 84-69, TW-E	Well	42.2	–	572
Yucca Flat Well 79-69A, TW-C	Well	37.2	–	519
Sarcobatus Flat-Beatty Area	Well	22.2	–	–
Spring	Spring	21	–	–
Hicks (Burrell) Hot Springs	Spring	38	19	–
Beatty Mineral Springs	Spring	24.4	379	–
TW- F Well	Well	64	882.96	1,036
Well	Well	46	–	32
Cooks East Well	Well	32	–	91
Fairbanks Spring	Spring	27.2	–	–
Rodgers Springs	Spring	27.8	–	–
Longstreet Spring	Spring	27.8	–	–
Unnamed Spring	Spring	27	–	–
Scruggs Spring	Spring	30	–	–
Devils Hole	Spring	33	–	–
Point of Rock (King) Spring	Spring	32	4,399	–
Jack Rabbit Spring	Spring	28	–	–
Big, Ash Meadows, and Deep Springs	Spring	28	–	–
Crystal Spring	Spring	30	–	–
U.S. Geological Survey Tracer Well 2	Well	30.6	–	–
Cherry Patch Well	Well	27.5	–	66
Manse Ranch Springs	Spring	25	4,542	–
Pahrump Springs	Spring	25	1,840	–
Pahrump Community Church Well	Well	27	–	–

Source: Garside (1994)

NOTE: – = not applicable or not measured